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Study of Placement and Design of Thermoelectric Generator at Outdoor Air Conditioner Harvesting Energy for Closed-Circuit Television (CCTV) Application

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Abstract

In today's world, harnessing energy through recycling provides a viable option to promote a greener environment. Air conditioning systems are among the largest energy consumers in the world, primarily used to control the indoor temperature of buildings. In Malaysia, split unit air conditioning systems are popular for small spaces. However, the heat emitted by the outdoor unit is often wasted. This issue can be overcome by using Peltier devices as thermoelectric generator (TEG) modules. The aim of this project is to design a thermoelectric generator (TEG) that is capable of capturing the waste heat from the outdoor unit and converting it into electricity, while determining the optimal location for maximum electricity generation. The TEG uses a Peltier device, which is sandwiched between copper plates measuring 40 mm x 40 mm x 2 mm. One side of the copper plate is placed in an area with high heat, while the other side is mounted on a heat sink with a lower temperature to facilitate efficient heat transfer. Five Peltier modules are arranged in series or parallel between the iron plates to differentiate outputs such as voltage and current. Two differently placed locations were monitored based on the temperature difference (ΔT) between the compressor and the condenser, as well as between the compressor tank and the condenser copper pipe. The highest ΔT was recorded between the heat tank and the condenser copper pipe, in addition to simultaneous voltage output measurements for each Peltier module. A maximum voltage of 1.0 V and 230mW was generated from the compressor tank and the condenser copper pipe of the split unit air conditioner after 60 minutes of operation, with a ΔT of approximately 35-40 °C. The application of TEG technology for heat recovery offers a promising solution for converting waste heat into electricity, providing a valuable alternative to meet the energy needs of small-scale households. To enhance its performance, the TEG is integrated with a power management system that ensures stable and reliable power output. The generated power is then used to power CCTV equipment, such as cameras and monitors, reducing the need for external power sources. The results will also provide valuable insights into the potential of thermoelectric technology for energy harvesting and the possibility of integrating it with existing infrastructure.

1. Introduction

The utilization of thermal energy harvesters from waste heat air conditioners for Closed-circuit Television (CCTV) appliances presents an innovative approach towards sustainable energy solutions [1]. Harvesting waste heat from air conditioners to aligns with the growing emphasis on energy efficiency and renewable sources [2]. By converting thermal energy into electricity, these systems can enhance the sustainability of surveillance operations while reducing environmental impact [3]. Thermal energy harvesting technology, particularly from waste heat sources like air conditioners, offers a promising electrical for powering CCTV appliances [4]. This approach taps into the untapped potential of waste heat, transforming it into a valuable energy source. The integration of thermal energy harvesters with CCTV systems can lead to enhanced operational efficiency and reduced reliance on traditional power sources [5]. The concept of re-purposing waste heat from air conditioners for CCTV appliances underscores the importance of sustainable energy practices in modern technological applications [6]. By harnessing this wasted energy, organizations can achieve greater energy autonomy and reduce their carbon footprint. This innovative approach exemplifies the convergence of energy efficiency and technological advancements in the realm of surveillance systems [7]. The integration of thermal energy harvesters from waste heat air conditioners for CCTV appliances represents a forward-thinking solution that combines sustainability with technological innovation. This approach not only enhances the operational efficiency of CCTV systems but also contributes to a greener and more sustainable future.

This project aims to harness waste heat from household air conditioning systems, specifically focusing on utilizing thermoelectricity as the primary method of energy conversion. The objective is to develop a thermoelectric generator system (TEG) that extracts heat released by the compressor of the air conditioner to generate electricity. Experimental data from the air conditioner compressor, including hot and cold side temperatures will be used as input for the TEG system [8]. The harvested energy from the air conditioning system will be used to power closed circuit television (CCTV), thereby offsetting energy consumption from conventional power sources [9]. Additionally, the TEG system can serve as an alternative energy source for distributed energy generation (DEG) applications, contributing to energy sustainability [10]. By strategically placing TEGs on the air conditioner units, the system will generate electricity to power CCTV appliances, enhancing their operational efficiency and reducing their environmental impact. Waste heat generated by air conditioners, which is often released into the environment, represents an untapped energy source that can be harnessed to power CCTV appliances [11]. By utilizing thermoelectric generators (TEGs) to convert this waste heat into electricity, the energy efficiency of CCTV systems can be improved, reducing their reliance on traditional power sources [11]. The development of a thermal energy harvester system for CCTV appliances involves several key components. Firstly, the TEGs must be strategically placed on the air conditioner's compressor or discharge pipe to maximize the temperature difference and optimize energy generation [12]. The generated electricity can then be stored in batteries or directly supplied to the CCTV system, ensuring a reliable power source even during periods of high demand or grid instability [12].

1.1 Problem Statement

The integration of thermal energy harvesters from waste heat air conditioners for Closed-circuit Television (CCTV) appliances presents a promising solution to address the growing energy demands and environmental concerns associated with surveillance systems [13]. CCTV appliances, which are essential for security and monitoring purposes, require a reliable and continuous power supply [14]. CCTV is usually installed outside the house and will operate in 24 hours. This causes the cost of electricity to increase from the installation of CCTV. So in order to save on the use of CCTV, CCTV can be installed using renewable energy source technology, which is energy harvested from air conditioners. However, the successful implementation of this system requires overcoming several challenges. The efficiency of TEGs can be affected by factors such as temperature fluctuations, thermal resistance, and the stability of the cold side [15]. Additionally, the integration of the harvester with the CCTV system must be seamless and cost-effective to ensure widespread adoption [15]. The development of a thermal energy harvester from waste heat air conditioners for CCTV appliances presents a significant opportunity to enhance the sustainability and efficiency of surveillance systems. By harnessing the untapped potential of waste heat, this innovative approach can contribute to a more energy- efficient and environmentally friendly future for CCTV technology.

1.2 Objective

The purpose of this project is as listed below:

1. To investigate the potential of heat energy that can be harvested from outdoor unit of air conditioner systems.
2. To design and develop a thermoelectric generator system (TEG) based on heat release from air conditioning compressor.
3. To evaluate the performance and effectiveness of energy harvesting for air conditioners.

1.3 Project Scope

The scope of this project revolves around addressing the often-overlooked potential of thermal energy emitted by air conditioner outdoor units. A thermal energy harvesting system utilizing a thermoelectric generator (TEG) with specifications TEC1-12706, rated at 12V and 90W, is being designed to effectively capture waste heat from the compressor of a York 1Hp air conditioning unit. This system will be tested in both series and parallel configurations to determine the most efficient setup. Furthermore, the performance of the TEG will be evaluated by placing it in two different locations within the outdoor unit, allowing for a comparison of voltage outputs to identify the optimal position for maximum energy production.

2. Methodology

2.1 System Flowchart

The flow chart of the project starts with the initial step where the process begins as shown in Figure 1. The flowchart describes the process of using a thermoelectric generator (TEG) to convert heat from an air conditioner into electricity. The process starts with the air conditioner being turned on, which causes the outdoor unit to operate and the compressor to release heat. This heat is then absorbed by the TEG, which converts it into electricity. The electricity is then boosted by a DC-DC converter and stored in a battery. The battery then supplies power to a power inverter, which converts it into AC power. The AC power is then used to power a CCTV camera.

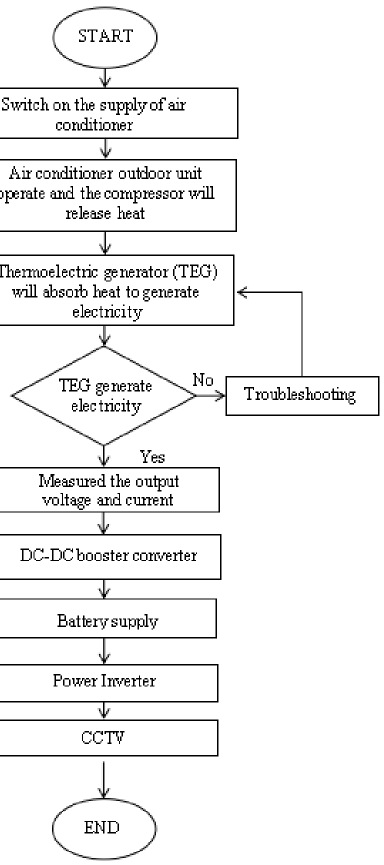
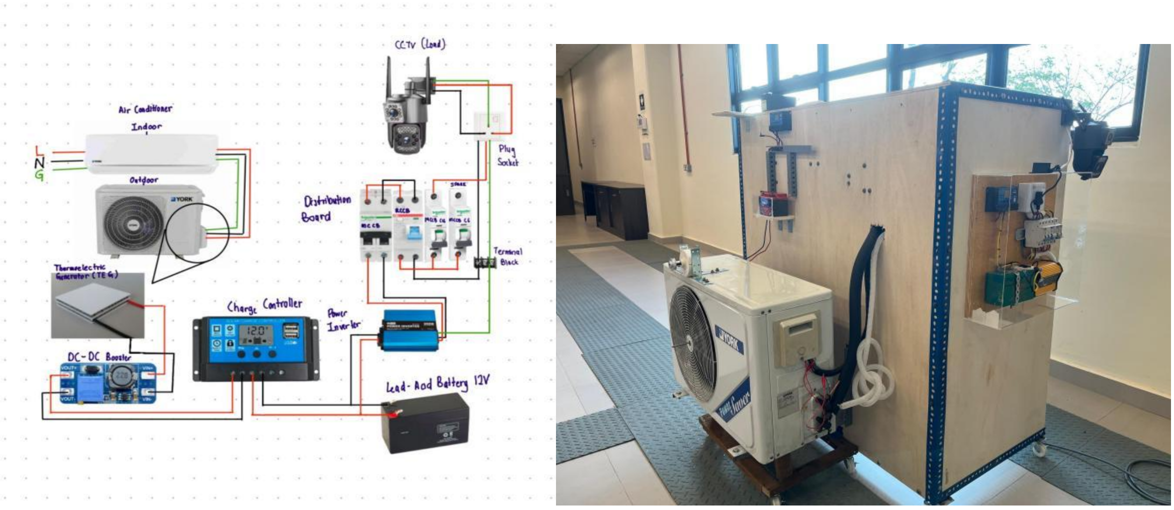


Fig. 1: System Flowchart

2.2 Project Circuit Diagram and Project Development

Develop a thermal energy harvesting system to power Closed-Circuit Television (CCTV) appliances using waste heat from air conditioners. The initial steps include defining project objectives, conducting feasibility studies, and allocating the required resources. Component selection is crucial, including choosing suitable Thermoelectric Generators (TEGs), assessing air conditioner waste heat output, selecting a power management system, and ensuring compatibility with the CCTV system. Figure 2 (c) system design entails strategically placing TEGs for optimal temperature differentials, designing electrical circuits, and incorporating heat dissipation mechanisms. Prototype development follows, involving assembly, integration, and testing to ensure proper functionality. Data collection and analysis focus on monitoring temperatures, measuring power output, and evaluating system performance. Optimization includes adjustments for efficiency improvement, leading to full-scale implementation, monitoring, and maintenance. Evaluation and reporting assess system performance, environmental impact, and provide documentation for future enhancements, ultimately contributing to energy sustainability and operational efficiency in surveillance systems. Figure 2 (b) shows the project development of air conditioner harvesting energy using thermoelectric for closed-circuit television (CCTV) generator application.



(a) Project Cicuit Diagram **(b)** Project Development

Fig. 2: Circuit diagram of the project

2.3 Placing of Thermoelectric Generator

The study involved measuring temperatures at various parts of the air conditioning system to identify optimal heat sources for TEG placement. Figure 3 shows the different location to place the TEG system compressor outdoor air conditioner.

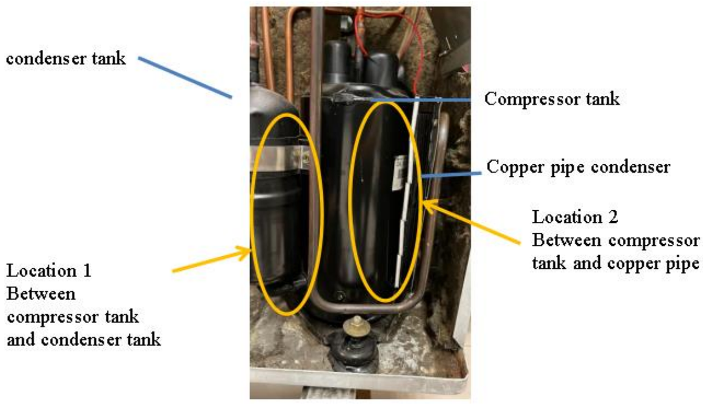


Fig. 3: Thermoelectric generator placement at different location

Figure 4 illustrates the physical placement of the thermoelectric generator (TEG) modules between the compressor tank and condenser tank. The design will make the heat differential between these components to optimize energy harvesting. The compressor is the primary heat source, while the condenser serves as a heat sink. The aluminium plate are placed for quickly absorbs and transfers heat, making it ideal for distributing thermal energy evenly. This placement ensures consistent exposure to significant temperature gradients, critical for thermoelectric conversion. The choice of this location emphasizes maximizing heat availability while maintaining thermal stability, which impacts the system's ability to generate reliable electrical output.

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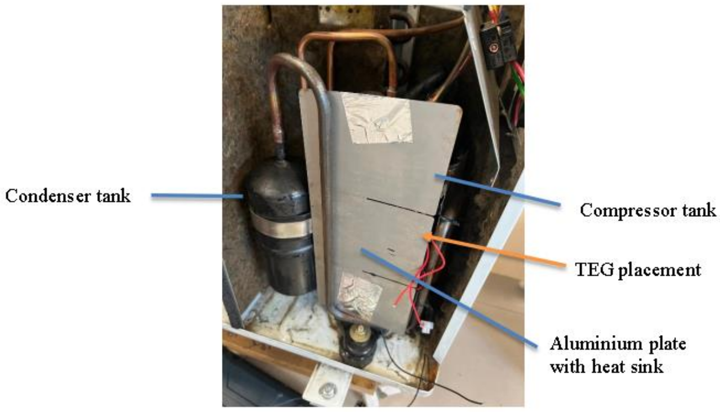


Fig. 4: Design placement of TEG between compressor tank and condenser tank

TEG placement compressor tank and condenser copper pipe which is can produce electricity is shown on Figure 5. This figure illustrates the physical placement of the thermoelectric generator (TEG) modules between the compressor tank and condenser copper pipe. The design leverages the heat differential between these components to optimize energy harvesting. The compressor is the primary heat source, while the condenser serves as a heat sink. This placement ensures consistent exposure to significant temperature gradients, critical for thermoelectric conversion. The choice of this location emphasizes maximizing heat availability while maintaining thermal stability, which impacts the system's ability to generate reliable electrical output. The figure reflects the importance of strategic placement for achieving effective thermal management and maximizing performance.

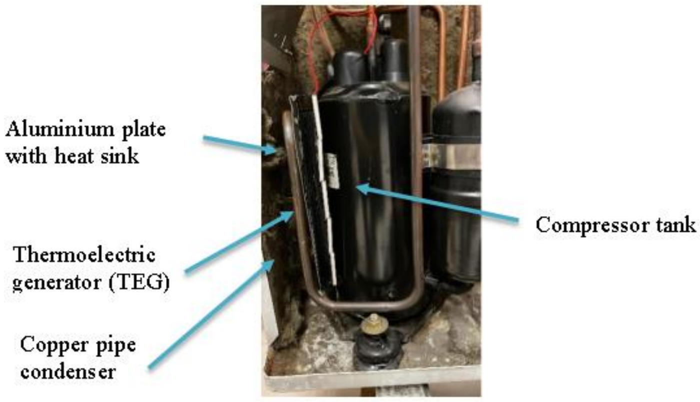
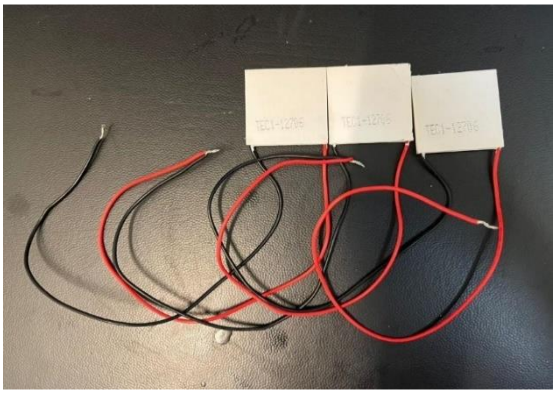


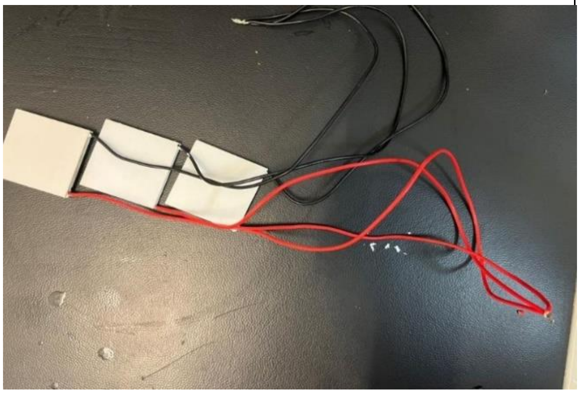
Fig. 5: Placement of TEG between compressor tank and condenser copper pipe

2.4 Thermoelectric Module Design

The project begins by making the connection of thermoelectric generator (TEG) modules. The connection method used to link these modules is crucial in determining the output power. Two common configurations are series and parallel connections. In a series connection, the TEG modules are linked end-to-end, forming a continuous chain, as depicted in Figure 6(a). This arrangement allows the modules to operate at higher voltages while maintaining the same heat pumping capacity. Conversely, in a parallel connection, each TEG module has its own dedicated path to the battery, as shown in Figure 6(b). For this configuration, two wire connectors are employed to combine the positive and negative terminals of the modules. For both the series and parallel connections, the combined terminals are then connected to the generator's terminals. The choice between series or parallel configuration depends on the specific requirements of the project, such as voltage and current needs. Series connections are suitable when higher voltages are required, while parallel connections are preferred when higher currents are necessary. For the project, it used three TEG to generate the electricity.



(a) Series connection



(b) Parallel Connection

Fig. 6: TEG connection

3. Result and Discussion

Testing the placement and design of a Thermoelectric Generator (TEG) module on the outdoor unit of an air conditioner aims to find the best location to use heat from the air conditioner to generate electricity. The goal is to test the TEG works in different outdoor conditions, such as varying temperatures and humidity. This test also need to figure out the best location to place the TEG for maximum power generation without affecting the performance of the air conditioner. This test shows how much electricity the TEG can produce when exposed to heat from the air conditioner's compressor or condenser, and how much cooling is needed on the cold side of the TEG. The TEG should be placed where there is enough heat but not too much to harm the system. During testing, the TEG's placement need to know that have an affects the airflow and cooling ability of the air conditioner or not.

3.1 Testing of Series Connection TEG placement between compressor tank and condenser tank (with thermal paste and heat sink)

The experiment results indicate the placement of a thermoelectric generator (TEG) between the compressor tank and condenser tank. Figure 7 highlights the temperature measurement at the compressor of the air conditioner. Higher-temperature areas, such as the compressor, are ideal for thermoelectric energy harvesting as they can generate more electricity. The temperature reading recorded on the thermometer is 55.6°C

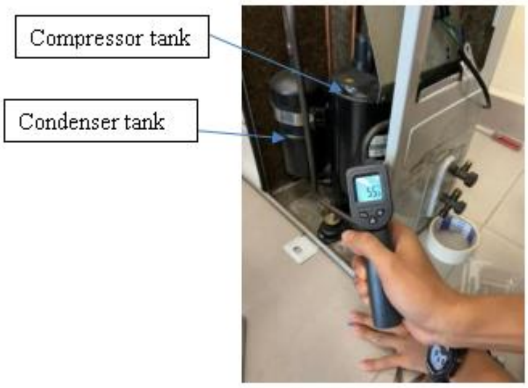
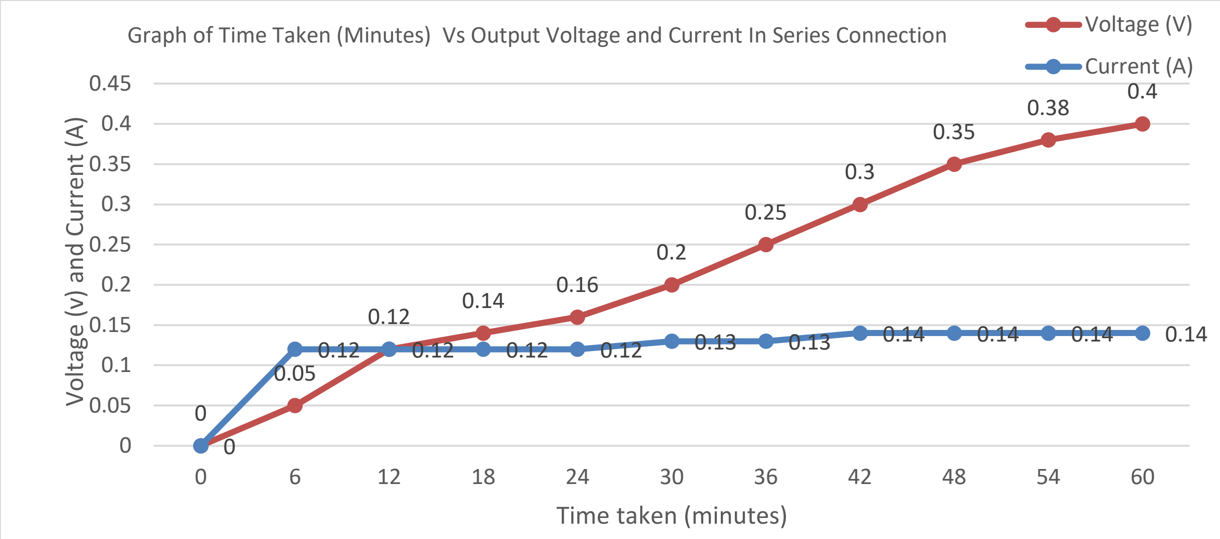


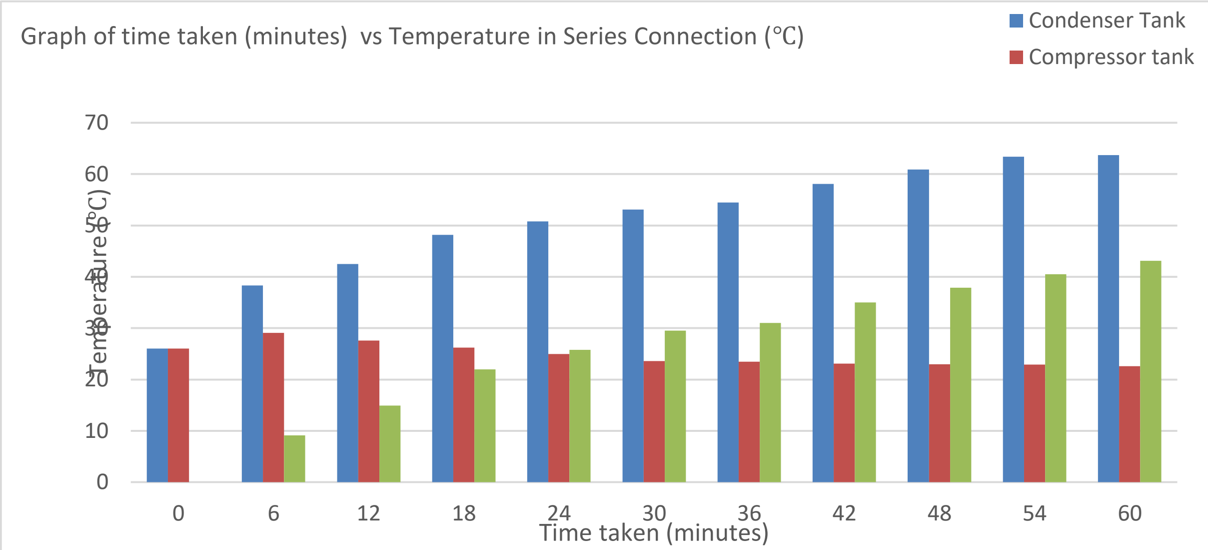
Fig. 7: Measured temperature at compressor and condenser tank

3.1.1 Testing of Series Connection TEG placement between compressor tank and condenser tank (with thermal paste and heat sink)

Figures 8 (a) & (b) illustrate the thermal and electrical performance of a series-configured thermoelectric generator (TEG). The compressor side shows a steady temperature increase, while the condenser remains cooler, enabling effective energy harvesting. Voltage output steadily rises, peaking at 0.40 V after 60 minutes, highlighting consistent energy conversion and system stability. Similarly, the current output increases linearly, reaching 0.14 A, emphasizing the trade-off between current and voltage in the series setup. Thermal paste and heat sinks enhance heat transfer, ensuring stable performance. These results demonstrate the configuration’s suitability for applications requiring reliable voltage and efficient thermal management.



(a) Graph time taken again output voltage and current in series connection

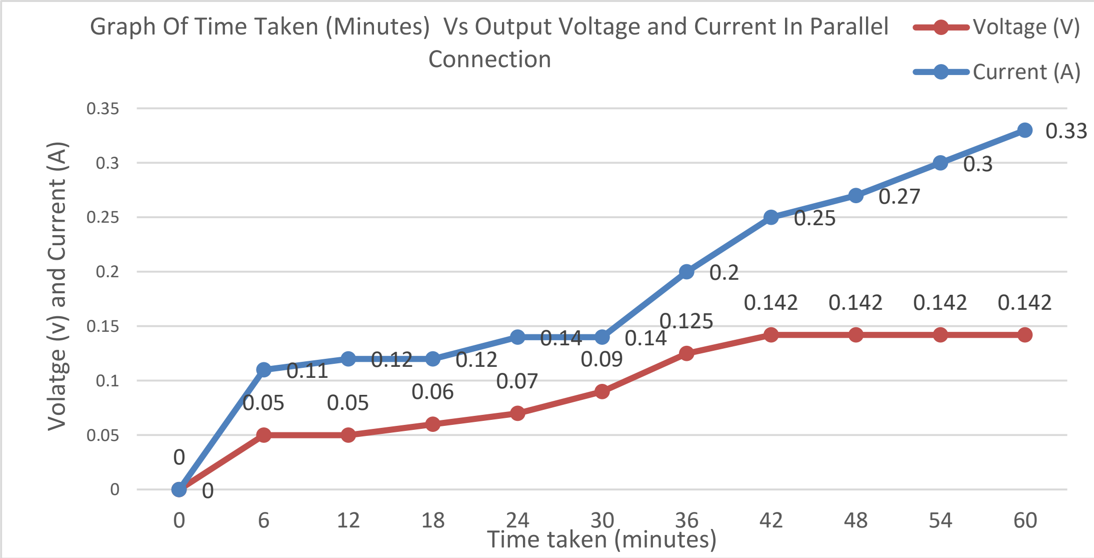


(b) Graph time taken again temperature in series connection

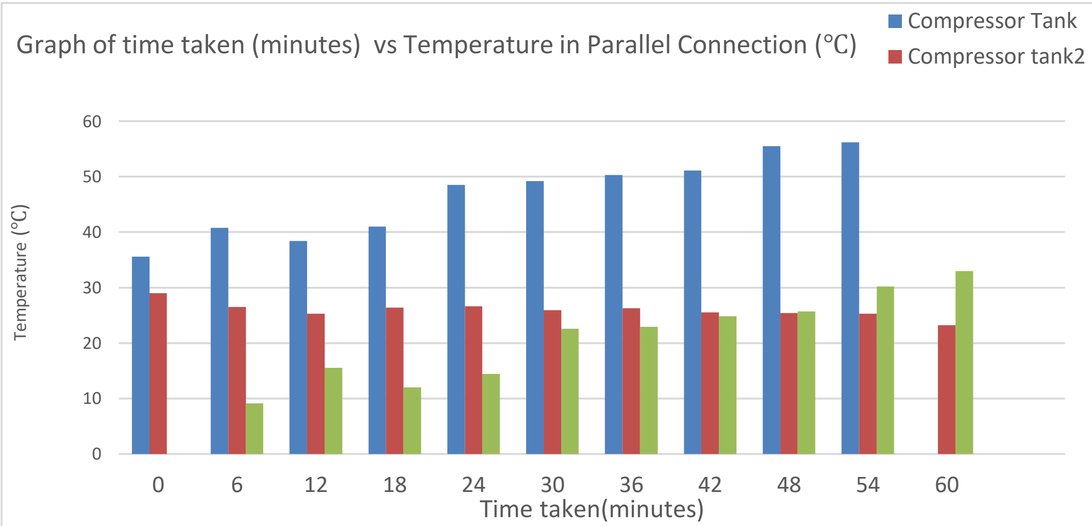
Fig. 8: Result testing of Series Connection TEG placement between compressor tank and condenser tank (with thermal paste and heat sink)

3.1.2 Testing of Parallel Connection for TEG placement between compressor tank and condenser tank (with thermal paste and heatsink)

Figures 9 (a) & (b) illustrate the performance of the parallel configuration of TEG modules. The temperature graph in Figure 9 (b) shows a steady rise in the compressor's temperature with minor fluctuations at the condenser, highlighting the role of thermal paste and heat sinks in maintaining a stable gradient for efficient thermoelectric conversion. The output voltage graph in Figure 9 (a) demonstrates a gradual increase, reaching 0.142 V at 60 minutes, indicating stable energy harvesting suitable for high-current applications like CCTV cameras. The current graph in Figure 9 (a) shows a sharp increase, peaking at 0.33 A after 60 minutes, emphasizing the parallel configuration's ability to support substantial and dynamic current demands, making it ideal for powering multiple devices.



(a) Graph time taken again output voltage and current in parallel connection



(b) Graph time taken again temperature in parallel connection

Fig. 9: Result testing of Parallel Connection TEG placement between compressor tank and condenser tank (with thermal paste and heat sink)

3.1.3 Comparison of Series and Parallel Configurations between Compressor and condenser for TEG placement

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. This highlights their suitability for devices with higher current demands, such as multiple CCTV cameras or motors. 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. Figure 10 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 Figure 10, 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.

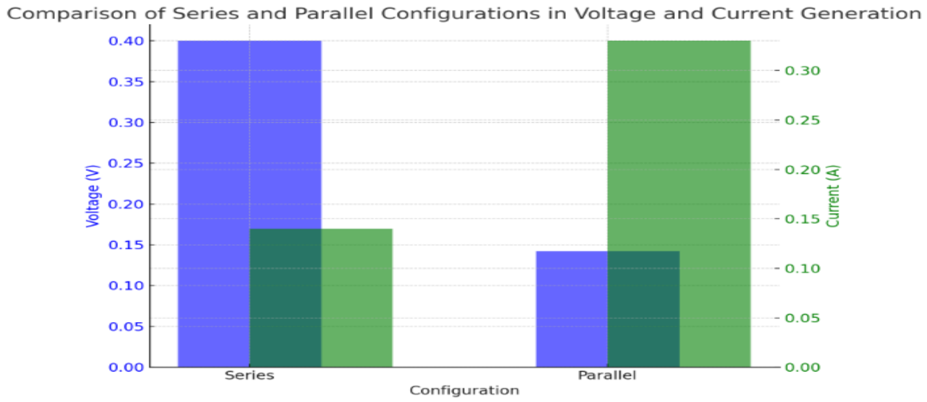


Fig. 10: Comparison Series and Parallel Configuration Output

3.2 Testing on the Thermoelectric Generator between compressor tank and condenser copper pipe.

The experiment results indicate the placement of a thermoelectric generator (TEG) between the compressor tank and the condenser copper pipe. Figure 11 focuses on measuring the temperature at the compressor of the air conditioner. Higher-temperature areas, such as the compressor, are ideal for thermoelectric energy harvesting, as they can generate more electricity. The temperature reading displayed on the thermometer is 27°C.

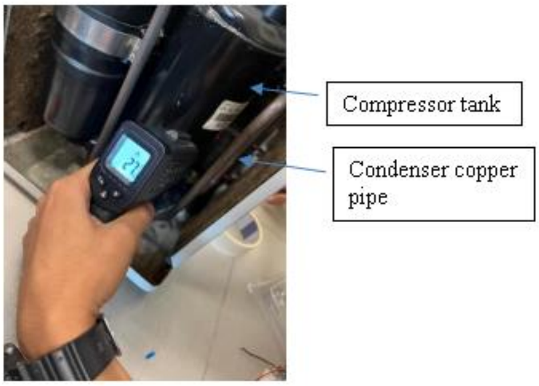
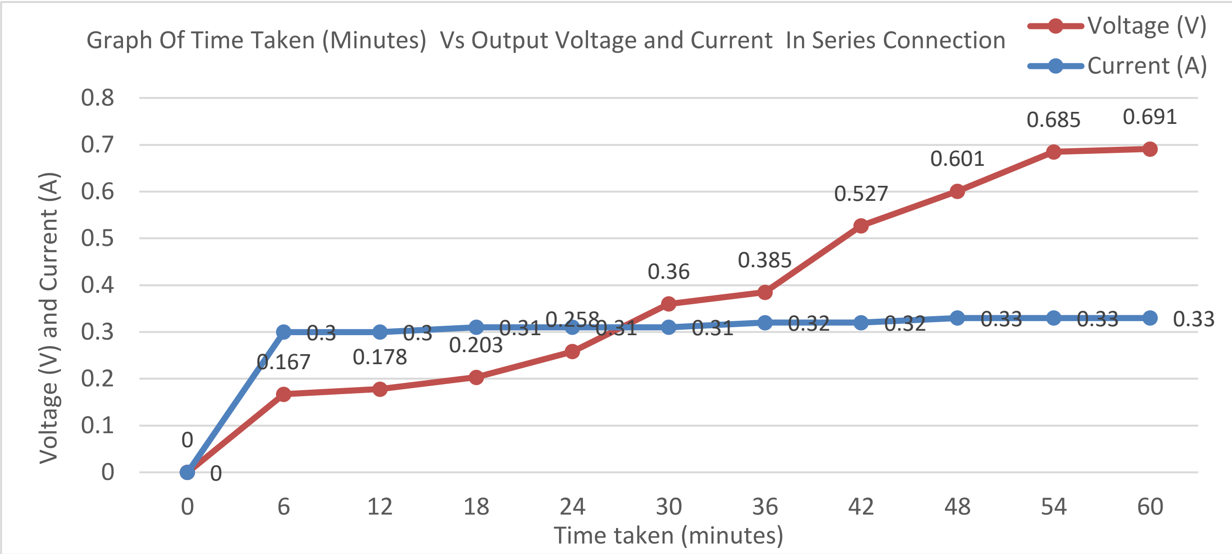


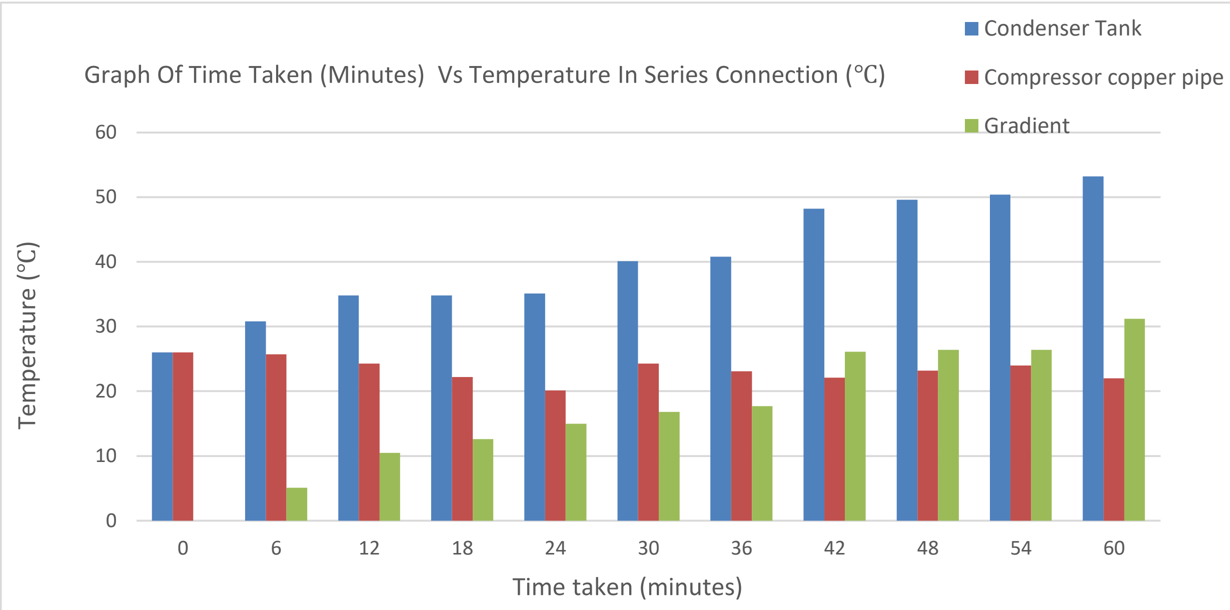
Fig. 11: Measured temperature at compressor and condenser copper pipe

3.2.1 Testing of Series Connection for TEG placement between compressor tank and condenser copper pipe (with thermal paste and heatsink)

Figures 12 (a) & (b) illustrate the performance of the series configuration with thermal paste and heat sinks. The temperature graph in Figure 12 (b) shows a steady rise in the compressor tank's temperature and stable cooling at the condenser copper pipe, enabled by reduced thermal resistance and improved heat transfer, which ensures an efficient thermal gradient for energy harvesting. The voltage graph in Figure 12 (a) reveals a significant increase over time, showcasing the series configuration's strength in generating high and stable voltage outputs, ideal for voltage-dependent applications. The current graph in Figure 12 (a) indicates a gradual and consistent rise in current, supported by enhanced thermal conductivity, highlighting the system's capability to maintain sufficient current for low-current applications. Overall, the thermal enhancements play a critical role in optimizing energy conversion efficiency, making the series configuration versatile for powering devices requiring reliable and stable voltage.



(a) Graph time taken again output voltage and current in series connection

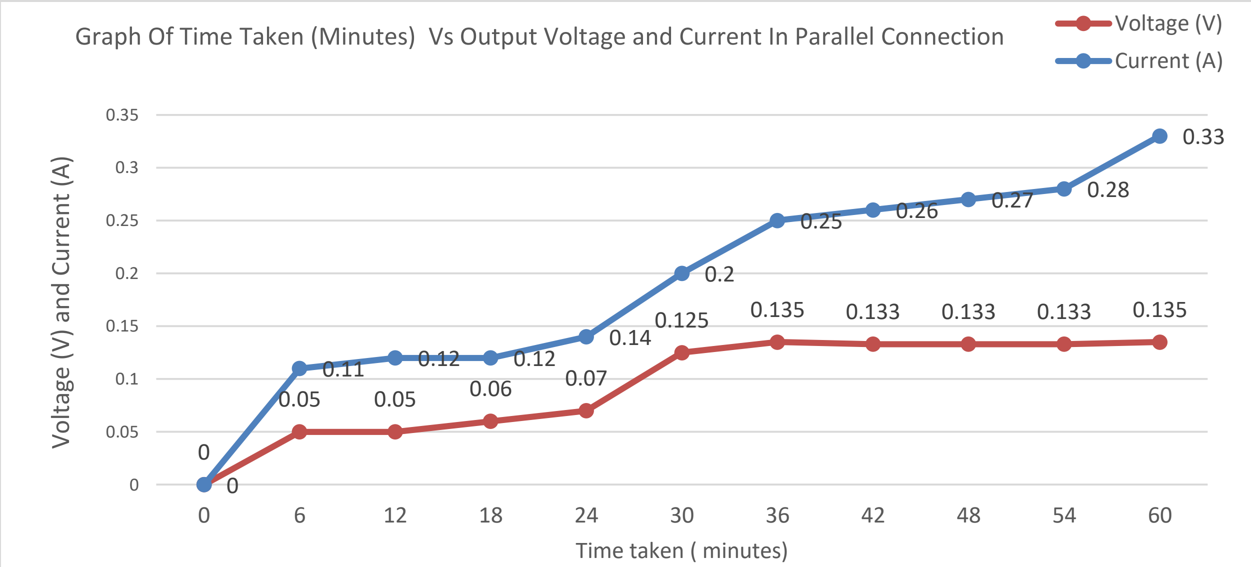


(b) Graph time taken again temperature in series connection

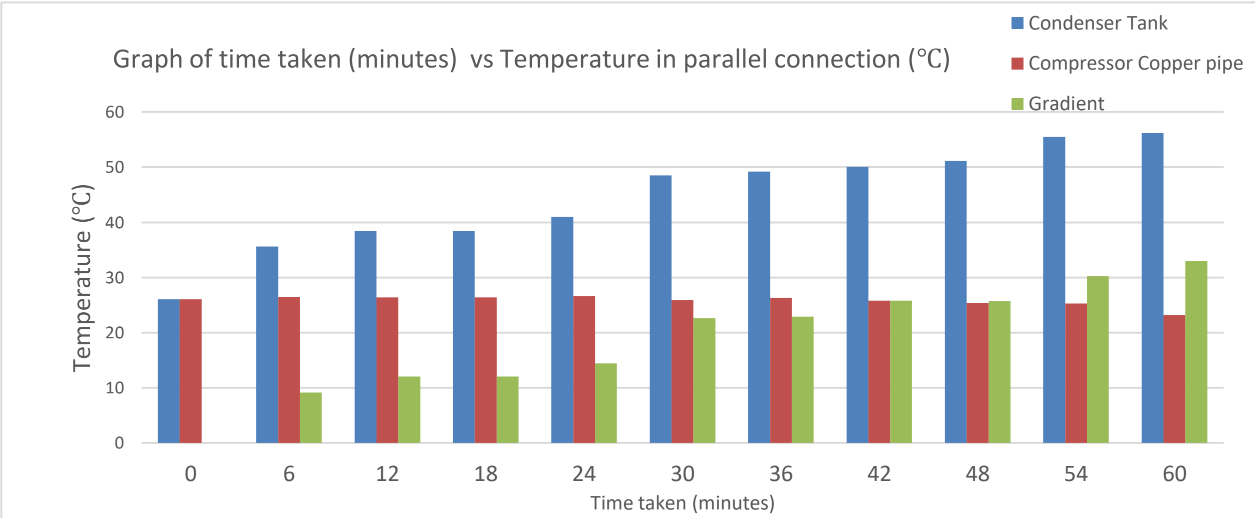
Fig. 12: Result testing of Series Connection TEG placement between compressor tank and condenser copper pipe (with thermal paste and heat sink)

3.2.2 Testing of Parallel Connection for TEG placement between compressor tank and condenser copper pipe (with thermal paste and heatsink)

Figures 13 (a) & (b) highlight the performance of the parallel configuration in a TEG system. The temperature graph in Figure 13 (b) shows a steady increase in the compressor tank's temperature, while the condenser copper pipe remains relatively stable, creating a consistent gradient for efficient thermoelectric generation, aided by thermal paste and heat sinks. The voltage graph in Figure 13(a) demonstrates stable output, peaking at 0.135–0.142 V, reflecting the parallel setup's focus on current generation rather than voltage. The current graph in Figure 13 (a) shows a consistent rise, starting at 0.05 A and peaking at 0.33 A after 60 minutes, showcasing the system's capability to handle high current demands for applications like CCTV systems. Thermal management significantly enhances efficiency, enabling reliable energy conversion and scalability for higher loads.



(a) Graph time taken again output voltage and current in parallel connection



(b) Graph time taken again temperature in parallel connection

Fig. 13: Result testing of Parallel Connection TEG placement between compressor tank and condenser copper pipe (with thermal paste and heat sink)

3.2.3 Comparison of Series and Parallel Configurations between Compressor and condenser for TEG placement

The comparison of series and parallel configurations for thermoelectric generators (TEGs) highlights their distinct performance characteristics. Without thermal paste and heat sinks, the series setup peaked at 0.131 V and 0.16 A, with a power output of 20.96 mW, but suffered from inefficient heat transfer. The parallel configuration, focused on current generation, achieved 0.30 A and 0.135 V, with a power output of 33.6 mW, though inconsistent heat dissipation limited efficiency. With thermal enhancements, the series configuration excelled in voltage output (0.691 V, 228 mW), making it ideal for voltage-dependent applications, while the parallel setup optimized current generation (0.33 A, 44.55 mW), making it suitable for high-load systems like CCTV. Figure 14 illustrates these trends, emphasizing the importance of thermal management in enhancing energy conversion efficiency for both configurations.

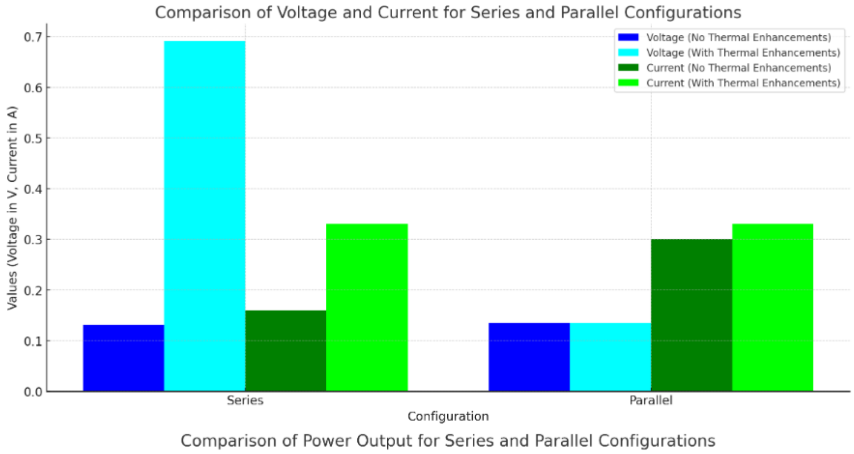


Fig. 14: Graph comparison of voltage and current outputs for series and parallel configurations of the thermoelectric generator (TEG)

3.3 Suggestion the best placement for Thermoelectric Generator for CCTV application

The summary of the result findings highlights varying levels of air pollutants under different environmental conditions. Table 2 shows the result summary findings. For optimal placement of thermoelectric generators (TEGs) in CCTV applications, the area between the compressor tank and the condenser copper pipe is recommended. This placement leverages the stable temperature gradient between these components. The use of thermal paste and heat sinks is crucial to ensure efficient heat transfer and dissipation, thereby maximizing energy conversion.

To meet the power requirements of a typical CCTV system, which operates on 12V DC power, a series configuration is most suitable as it maximizes voltage output. Based on experimental results, approximately 18 TEG modules connected in series, each generating 0.69 V, would be required to achieve the necessary voltage. To further enhance the output, a DC-DC booster can be employed to step up the voltage to meet the system's demands. A CCTV system typically requires 12V DC power. Assuming the system uses a 12V, 7Ah (84 Wh) battery, a series configuration is recommended to maximize voltage output. Based on experimental data, approximately 18 TEG modules in series, each generating 0.69 V, would be needed to achieve the required voltage. To further optimize, a DC-DC booster can be employed to step up voltage for reliability. Table 4.11 show the battery charging time calculation

Table 1: Battery charging time calculation

Battery capacity	12V×7Ah=84
TEG power output	228 mW
Charging time	Charging Time = Battery Capacity (Wh)/Power Output (W) =84/0.228 ≈ 368 hours

To reduce charging time, the system can be optimized by integrating multiple Thermoelectric Generator (TEG) arrays or using higher-capacity DC-DC boosters. The setup includes strategically placing TEGs between the compressor and condenser, ensuring they are connected in series to optimize the voltage output. A DC-DC booster is used to step up the voltage, making it suitable for charging purposes. A 12V, 7Ah battery is incorporated for power storage, allowing the system to store energy for future use. The power is then connected to a CCTV system, ensuring reliable operation and continuous monitoring. For the summarize of discussion, the series configuration with thermal enhancements is best suited for powering CCTV systems due to its high and stable voltage output. The integration of additional TEG arrays or advanced boosters can enhance system efficiency and reduce battery charging times. Further studies can focus on optimizing the number of TEGs and thermal management for practical deployment.

4.0 Conclusion

In conclusion, the study successfully demonstrated the feasibility of utilizing TEGs to harvest waste heat from outdoor air conditioners and convert it into usable electrical energy by finding the best location and design to placing the thermal electric generator. Experimental results revealed that placing TEGs between the compressor tank and condenser copper pipe provided the most significant temperature gradient 30 degree Celcius, enabling higher power output 228mW. Series configurations produced higher voltage suitable for powering devices with steady voltage requirements, while parallel configurations excelled in generating higher current, catering to high-load applications. The integration of thermal paste and heat sinks significantly enhanced the performance of TEGs by improving heat transfer and maintaining efficient thermal gradients. The TEG system, with proper thermal management, achieved a maximum voltage of 0.80 V and a current of 0.33 A under a temperature gradient of approximately 56.2°C. This power output was sufficient to supplement the energy needs of low-power CCTV systems.

Acknowledgement

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References

[1] Hidalgo-Leon R. et al., 2022, "Powering nodes of wireless sensor networks with energy harvesters for intelligent buildings: A review," Energy Reports, vol. 8, pp. 3809–3826, Doi: 10.1016/j.egyr.2022.02.280.

[2] CityU Research, 2021 "Turning Waste Heat from Air-conditioners into Electricity | City University of Hong Kong," City University of Hong Kong, https://www.cityu.edu.hk/research/stories/2021/04/01/turning-waste-heat-air- conditioners-electricity

[3] Fang H., Xia J., Zhu K., Su Y., and Jiang Y., 2020, "Industrial waste heat utilization for low temperature district heating," Energy Policy, vol. 62, pp. 236–246, doi: 10.1016/j.enpol.2013.06.104.

[4] Jacoby M. et al., 2021, "WHISPER: Wireless home Identification and Sensing platform for energy reduction," Journal of Sensor and Actuator Networks, vol. 10, no. 4, p. 71, doi: 10.3390/jsan10040071.

[5] Sandhya Thyagaraj Naidu., 2021, "Energy Harvesting from Human Motion in Smart Cities: An Alternative Renewable Energy Source," Energy and Environmental Engineering, Available:https://www.theseus.fi/bitstream/handle/10024/502763/Thyagaraj%20Naidu_Sandhya.pdf?isAllowed =y&sequence=3

[6] Lee A., "Direct expansion air conditioning systems," Pressbooks, Apr. 06, 2021. https://opentextbc.ca/basichvac/chapter/direct-expansion-air-conditioning-systems/

[7] "Indirect cooling systems," Waterline ControlsTM, May 28, 2020. https://www.waterlinecontrols.com/technical-articles/cooling-towers-use- theory/cooling-tower-types/indirect-cooling-systems/

[8] Rauniyar B. and H. S. Sodhi, "Research on the air conditioning system," ResearchGate,Jan.2018,Available: https://www.researchgate.net/publication/342379040_Research_on_the_Air_ Conditioning_System

[9] Bell, L. E., 2008, Cooling, Heating, Generating Power, and Recovering Waste Heat with Thermoelectric Systems. Science, 321, 1457-1461.

[10] Alaquainc T., "The functions of evaporator and condenser in your air conditioning system," ALAQUA, Mar. 14, 2024. https://www.alaquainc.com/evaporator-and- condenser-in-your-air-conditioning-system/?t

[11] Philip, "What is an Aircon compressor, and how does it work?," Billy Aircon, Dec. 06, 2023. https://www.billyaircon.com.sg/air-conditioner-compressor/

[12] Greener Solutions Heat & AC, "What is a Condenser Unit for AC & What Does it Do?," Greener Solutions Heat & AC, Mar. 09, 2023. https://www.gshomeservices.com/what-is-a-condenser

[13] Sun D. et al., Apr. 2020, "Modeling and analysis of the influence of Thomson effect on micro-thermoelectric coolers considering interfacial and size effects," Energy, vol. 196, p. 117116, Doi: 10.1016/j.energy.2020.117116.

[14] Wu Y., H. Zhang, and L. Zuo, Feb. 2018, "Thermoelectric energy harvesting for the gas turbine sensing and monitoring system," Energy Conversion and Management, vol. 157, pp. 215–223, Doi: 10.1016/j.enconman.2017.12.009.

[15] Kim T. Y., J. Kwak, and B.-W. Kim, Mar. 2018, "Energy harvesting performance of hexagonal shaped thermoelectric generator for passenger vehicle applications: An experimental approach," Energy Conversion and Management, vol. 160, pp. 14–21, Doi: 10.1016/j.enconman.2018.01.032.