Jurnal Kejuruteraan 37(6) 2025: 3055-3062
https://doi.org/10.17576/jkukm-2025-37(6)-39

Investigation of Power Generation from Air Conditioning Waste Heat Towards Sustainable Cooling Solution

Nur Hasalli Ibrahim*, Saad Najir Ahmed Cheplin, Zainon Sharmila Shamsuddin & Azizul Rahman Abd Aziz

School of Engineering, University of Wollongong Malaysia

Corresponding author: hasalli.i@uow.edu.my

Received 4 December 2024, Received in revised form 14 May 2025
Accepted 14 June 2025, Available online 30 September 2025

ABSTRACT

Air conditioning systems release significant waste heat that can reach up to 90°C during operation presenting an opportunity for energy recovery. Thermoelectric generators (TEGs), leveraging the Seebeck effect potentially to convert the heat into electricity with efficiency enhanced by maintaining a large temperature gradient. This research explores the potential of generating electricity from the waste heat of air-conditioners, addressing the growing demand for sustainable energy solutions. Utilizing thermoelectric generators (TEGs), the study evaluates the feasibility of converting waste heat into electricity using Seebeck effect. An experimental setup was developed to measure waste heat output, with simulations validating the concept. Two prototypes were constructed which is air-cooled model and water-cooled model and equipped with commercial Bi_2Te_3-based TEG modules. The water-cooled prototype based on water pump circulation demonstrated superior performance, generating a net power output of 1.45 W, compared to 0.05 W for the air-cooled prototyped that made of DC fan and supplied with the exhaust air temperature ranges 85 – 90° C on the hot side and maintained at 20 – 23° C on the cold side. The net power generation was calculated by accounting for the energy consumed by the cooling systems. Scaling the water-cooled design to the dimensions of a typical household air-conditioner resulted in an estimated efficiency improvement of 2.8%, significantly reducing the electricity consumption and promoting environmental sustainability. This study highlights the potential of integrating waste heat recovery into air-conditioning systems, offering a promising pathway toward energy-efficient and eco-friendly solutions.

Keywords: Thermoelectric generator; seebeck effect; waste heat recovery system; air conditioning unit

INTRODUCTION

Air-conditioning systems are crucial in modern buildings, contributing significantly to overall energy consumption. Furthermore, the large supply of hot and humid outdoor fresh air for diluting indoor carbon dioxide also contributes more than 30% of the energy consumption (Aridi, et al., 2021). However, a significant portion of the energy used by air conditioners is released as waste heat, which is often overlooked as a potential energy source and opportunity to improve overall energy efficiency (Chen & Yang, 2023) (Kaidir, Mulyanef, & Burmawi, 2018). The heavy use of air conditioning systems in any type of building generates a significant amount of waste heat which is regularly vented into the atmosphere. This heat waste is a valuable resource that might be used to create electricity and reduce the energy produced by main resource of power and the amount of gas released into the atmosphere (Gómez-Charris, Umaña-Ibáñez, Silva-Ortega, Caicedo-Ortiz, & Camargo-Acuña, 2020) (Wiriyasart & Kaewluan, 2024).

Based on the standard operating conditions, the refrigerant temperature from condenser should be in the ranges between 50 – 60°CZhou, Zhang, Li, Yang, & Shen, 2023). This temperature ranges can be higher when exhaust out to the environment which able to goes up to 95°C. These typical values make the use of thermoelectric generators (TEGs) is promising as a small-scale electricity generation and for sustainable energy recovery system in HVAC applications where in recent studies shows the conversion efficiency by TEGs improved up to 20% (Li, et al., 2017) (Lamrani, Marbet, Rehman, & Kousksou, 2024) (Xie, He, Zhao, & Vulin, 2025). Thermoelectric generator (TEG) is a solid-state device, compact and offers unique advantages. This device functioning based on the Seebeck effect that directly converts the waste heat into electricity without moving parts, ease for installation and low maintenance (Hewawasam, Jayasena, Afnan, Ranasinghe, & Wijewardane, 2020) (Albatati & Attar, 2021).

The wasted heat contributes to energy inefficiency and elevated greenhouse gas emissions, resulting in a loss of opportunity for power generation. Studies shows that around two-thirds of global waste heat is released in the low-temperature range which less than 200°C and unutilized due to the limitations of the system (Jouhara, et al., 2018) (Lamrani, Marbet, Rehman, & Kousksou, 2024). Thus, implementation of TEGs in the air condition system specifically in the exhaust area could overcome the overflow of heat waste to environment and reduce greenhouse gas emissions. Although the potential benefits of capturing waste heat from air conditioning systems are evident, there have been limitations that need further investigation. Research and advancement in this field indicate that the current technologies have not yet reached their optimal practical application for widespread use. The challenge lies in the efficient and cost-effective recovery of waste heat generated by air conditioning systems and its conversion into usable electrical power, while also considering the practical challenges of integrating waste heat recovery technologies into existing air conditioning systems. Furthermore, the inefficiencies in current air conditioning systems have been linked to a decrease in the coefficient of performance (COP) caused by the increased of temperature during condensation process which leads to an increase of energy consumption and emissions (Rady, Albatati, Hegab, Abuhabaya, & Attar, 2021) (Jouhara, et al., 2018).

Many studies have explored different methodologies and systems to harness this waste heat effectively, which contributes a unique insight into the potential of this technology. Cheng et.al (2024) has used a concept of cascade systems integrates with absorption refrigeration and liquid desiccant dehumidification subsystems to utilize waste heat effectively and this system can achieve a COP of 0.77, demonstrating efficient heat utilization and potential for low-cost applications (Cheng, et al., 2024). While Bishal et al (2023) was integrated cooling and power systems with supercritical carbon dioxide cycles, gas turbines, and organic Rankine cycles to recover waste heat and these systems can achieve a COP of 0.72 and an energy utilization factor of 49.09% (Bishal, Faysal, Ehsan, & Salehin, 2023). Zhou et al (2023) also suggest that the integration of vapor compression refrigeration with desalination and organic Rankine cycles, multi-generation systems can simultaneously provide cooling, freshwater, and power to optimize the use of low-grade waste heat (Zhou, Zhang, Li, Yang, & Shen, 2023). Simple modifications to traditional air conditioning systems can enable the recycling of waste heat for power generation, reducing energy consumption and enhancing environmental sustainability.

While the potential for power generation from air conditioning waste heat is significant, challenges remain in optimizing system efficiency and cost-effectiveness. Future research should focus on integrating these systems with renewable energy sources and exploring new materials and technologies to enhance performance. Additionally, lifecycle analyses are crucial to fully understanding the environmental impacts and benefits of these technologies. In contrast, some studies emphasize the importance of optimizing existing systems rather than developing new ones. As an example, enhancing the efficiency of current air conditioning units through better design and materials can also contribute to sustainability without the need for complex additional systems (Ohenhen, et al., 2024) (Slamet, Zambri, & Salim, 2020).

This paper purposely investigates the potential thermodynamic systems that can regenerate power from waste heat. Thermoelectric generator (TEG) was used to regenerate power at two different conditions which are air- and water-cooled models. The use of elementary mechanisms into air-conditioning systems will facilitate developing a cost-effective device that can decrease energy consumption and costs while fostering environmental sustainability.

METHODOLOGY

THERMOELECTRIC GENERATORS (TEG)

A thermoelectric generator is a device that has the capability to generate electricity from the transfer of heat. The work principles of this device are based on the Seebeck effect where the heat is added to a junction of a circuit made with two different wire materials which created the current flow through the circuit (Molki, 2010). Figure 1 shows the energy flow process in a system with integration of the TEG to recover the waste heat. The energy comes from primary energy such as electrical energy to produce cooling effects and the dissipated heat energy that escapes into the environment. The waste of heat is then redirected to the TEG for conversion process through Seebeck effect and during the conversion process, there is the portion of energy that is lost and causes inefficiencies in the systems.

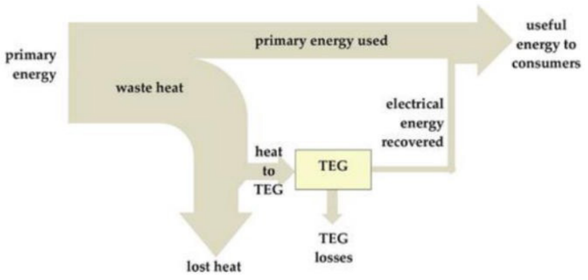

FIGURE 1. TEG mechanism (Meisner, 2010)

Thermoelectric generators have two main functions. First, TEG is able to create a heat transfer when a current or potential difference resistance is applied across the TEG. This is useful to implement in cooling devices such as electronic components. Second, the use of TEG can generate the current when there is a heat difference applied across the plates of the thermoelectric generator. The second function of TEG will give significant advantage in this study. One side of the TEG needs to heat, and the other side of TEG is cooled down. The hot air from the condenser in the air-conditioner will be used to heat up the hot side of the TEG. As for the cool side, the two methods are used which are air-cooling and water-cooling. In the air-cooled model, a small DC fan was used while for the water-cooled model, a small pump was utilized. In order to power the devices, electricity is generated, and the required electricity should be considered to ensure the smoothness of the system operation.

SYSTEM DESIGN

SOLIDWORKS software was used to design air-cooled and water-cooled models. Figure 2 shows the design of the air-cooled model which consists of two heat sinks. The large heat sinks located at the bottom are designed to flow the hot air from the condenser of the air-conditioner, whilst the small heat sink at the top side is for cool air flow. The TEG is placed in between these two heats sinks and is surrounded by thermal insulation to ensure minimal heat loss. Then, air will enter from the bottom heat sink, heating it up, which in turn heats up the hot side of the TEG.

The other heat sink is attached to the DC fan, which provides cooling for the cool side of the TEG. The greater the temperature difference between the two sides, the greater the amount of energy being produced. Figure 3 shows a detailed explode view of the design for water-cooled model where this model was attached to the pump and supplied water to cool the cool side of the TEG.

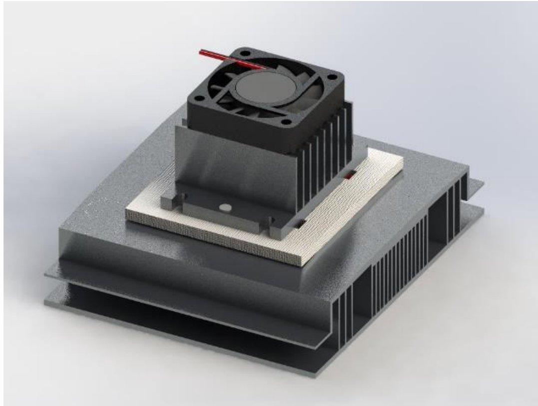

FIGURE 2. Air-cooled model

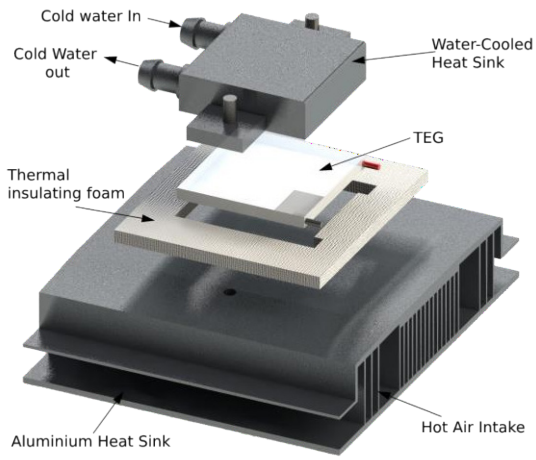

FIGURE 3. Water-cooled model

Both designs are made from Aluminum. Most of the heat exchangers in the market are made from copper since copper is able to easily absorb the heat, but it also simply releases the heat easily. On the contrary, aluminum absorbs the heat at a slightly slower rate but has the ability to retain the heat for a prolonged period of time as compared to a copper heat sink (Tohid, et al., 2018) (Beaton, 2016). This is advantageous for the prototypes as the temperature difference is directly correlated to the electricity generated by the TEG.

Figure 4 shows the flow chart of the entire proposed design. The waste heat from air conditioners consisting of high temperature is directed to the TEG where it is converted into electrical energy using the Seebeck effect. To maintain the necessary temperature gradient, a cold source from air- or water-cooled mechanism is utilized. The generated electrical energy is then regulated and stabilized by a DC-DC converter to ensure compatibility with the connected load. Any excess energy is stored in a supercapacitor or battery, providing a reliable power source for later use. This setup optimizes the utilization of waste heat, promoting energy efficiency and sustainability in air conditioning systems.

The generated electricity is stored in the battery or supercapacitor for later use or alternatively will be fed back to the compressor that is powering the air-conditioning system. This will make the system use less electricity during operation and at the same time increase efficiency. Then, the simulation was also conducted to evaluate the flow performance in two different mechanisms by focusing on the initial column where the TEG is heated up. The summary of the TEG properties and boundary conditions that applied in this research are shown in Table 1 where the data was taken based on the manufacturing datasheet, literature, experimental and simulation data.

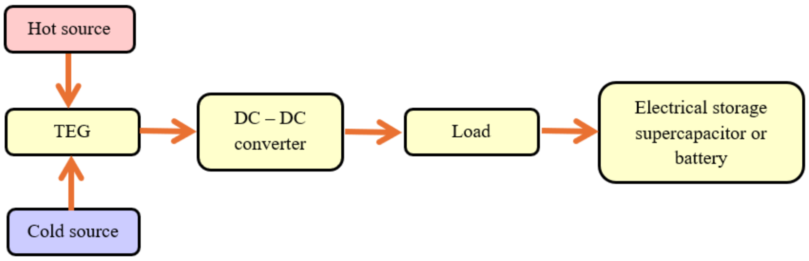

FIGURE 4. Entire process using TEG in air-conditioning system

TABLE 1. Summary of the TEG properties and simulation boundary conditions

Parameter	Condition	Remarks
TEG module	TEC1-12706, Bi_2Te_3-based	(Al-Rubaye, Al-Farhany, & Al-Chlaihawi, 2018); (MFR, 2023)
Seebeck efficiency ()	2 – 5%	(Molki, 2010)
Maximum temperature gradient (	94 °C(hot side); 20°C (cold	Experiment data (prototype)
Expected output (datasheet)	side) 1.7 – 1.8 W at ΔT ≈ 60°C	(MFR, 2023)
Hot-side temperature	85 – 90°C	Solidworks Flow simulation
Cold-side temperature (air cooling)	20°C	Fan cooling
Cold-side temperature (water cooling)	20 – 23°C	Water-cooled with pump
Hot air velocity	1.33 m/s	Simulation input
Ambient temperature	20.05°C	Experiment data

RESULT AND DISCUSSION

The simulation was run with a hot air speed of approximately 1.33 m/s. Ambient temperature of the surroundings was set to 20.05°C. A flow simulation within SOLIDWORKS was run with the heat transfer option selected. Both models were tested similarly, and the results are shown in Figure 5 and Figure 6, respectively.

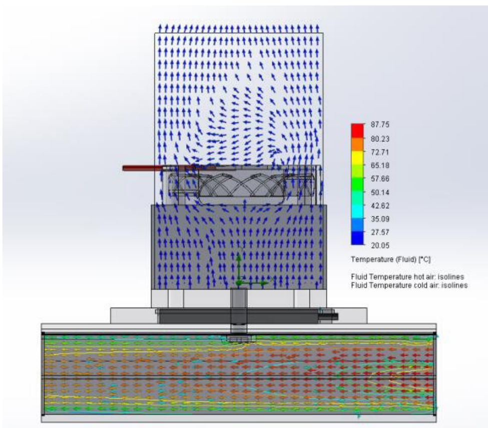

FIGURE 5. Air-cooled flow simulation model

The air-cooled flow simulation results show that most of the hot air from the condenser of the air conditioning system approximately occurred at 85°C, whilst the cold air from the fan on the cooling side is around 20.05°C. Similar parameters and boundary conditions were used for the water-cooled model. Preliminary measurements were conducted during prototype testing in order to ensure the input data can be used in the simulation.

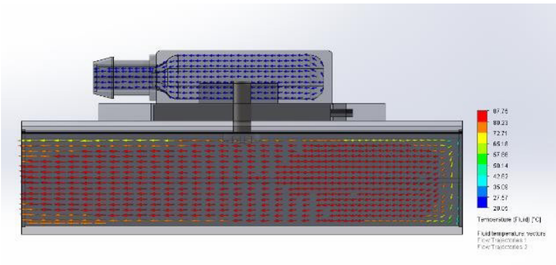

FIGURE 6. Water-cooled flow simulation model

Figure 7 shows the temperature of the solid, in this case, the heat sinks when the simulation was run. Theoretically, the solids reached the same temperature as the fluids flowing through them. This is true for both the air-cooled model, and the water-cooled model. The most probable reason is that since the simulation is independent of time, given enough time, the hot air will heat up the bottom heat sink to the same temperatures, whilst the air/water will cool down the top heat sink to the same temperature. However, practical results are likely to show differences as air has a different thermal conductivity as compared to water. The hot side of the TEG reaches a temperature of about 85°C - 90°C, whilst the top side (cold side) of the TEG reaches around 20°C. Using this temperature data and the TEG datasheet, the expected or ideal electricity generated can be found.

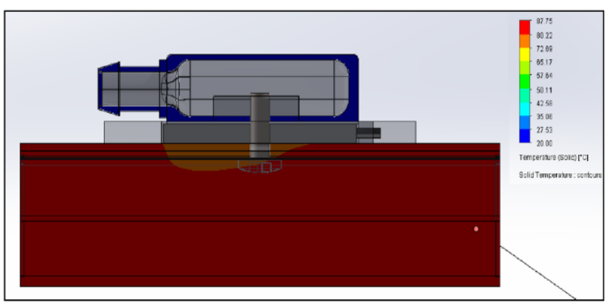

FIGURE 7. Temperature of solid after the flow simulation

Based on the commercial types of TEG module, TEC1-12706 used in this research, the module can generate around 1 – 3 W within 80 - 100℃ at hot-side region and maintained at 20 - 30℃ at the cold-side region (MFR, 2023) (Al-Rubaye, Al-Farhany, & Al-Chlaihawi, 2018). These references were used to approximate the expected power output and validate the results. When the hot side has a temperature of about 90°C and the cool side has a temperature of 30°C, the expected power output is approximately 1.7 – 1.8 W. A part of the actual prototype created is shown in Figure 9. The temperature source from the waste heat was set at 90°C based on the actual measurement from thermocouple placed in the outside air conditioning environment. The ambient reference temperature during testing was 20.05°C and the temperature recorded at the range of 85 – 90℃ which aligns with the other research studies that confirmed the regeneration of waste heat are effective in the range of 80 - 100℃ support the validity of using 90℃ for this study (Raveendran & Sekhar, 2020) (Heidinger, M.Nascimento, D.Gaspar, & D.Silva, 2018) (Valenti, Valenti, & Staboli, 2019).

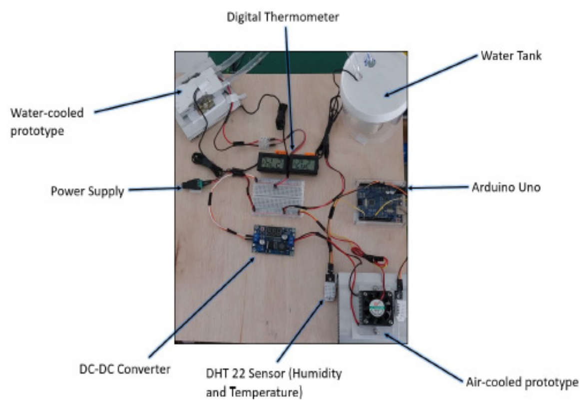

FIGURE 9. Prototype

Figure 10 shows the variation of voltage, current, and power output at different temperature values for water-cooled thermoelectric generator models. The results show a clear and strong positive correlation between the temperature gradient and electrical performance where the temperature difference is directly proportional to the voltage, current and power output. These indicate the significant enhancement in the Seebeck voltage generated across the thermoelectric module. Furthermore, the maximum temperature difference achieved approximately occurred at 70°C highlights the importance of maintaining a sufficient thermal gradient for efficient energy conversion. The effectiveness of the water-cooling system to maintain the low cold-side temperature is evident from this trend as it enables a consistent high temperature difference and enhance thermoelectric performance.

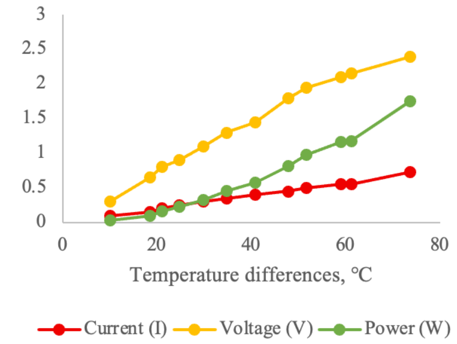

FIGURE 10. Water-cooled model output electrical data

Figure 11 illustrates the relationship between temperature difference and the electrical data output for air-cooled thermoelectric generator model. As observed, all three output parameters which are voltage, current and power increase progressively with the increment of temperature and the variation in the data does not show any anomalies. The voltage output shows a moderate increment from 0.4 V to 1.25 V in the range of 46°C of temperature difference. Similarly, the current also increases steadily from 0.1 A to 0.41 A, showing a linear trend while the power output reaches up to 0.51 W.

Compared to the water-cooled model, the overall electrical performance of the air-cooled model is considerably lower due to the limited ability of air to dissipate heat efficiently and small temperature changes across the thermoelectric module. In addition, thermal conductivity for water at 0.6 $W.m^{-1}K^{-1}$ is higher than air's which is at 0.024 $W.m^{-1}K^{-1}$. Even at the highest temperature difference, the output remains significantly below the water-cooled counterpart. Similarly, the results from other researchers related to the HVAC waste heat recovery also show the system cooled by liquid perform better than the system cooled by air (Jouhara, et al., 2018) (Aridi, et al., 2021) (Lamrani, Marbet, Rehman, & Kousksou, 2024).

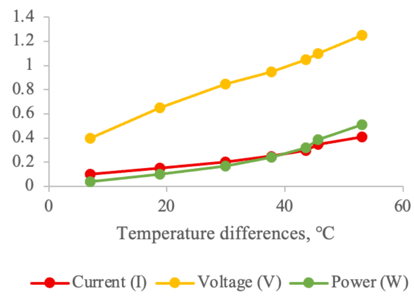

FIGURE 11. Air-cooled model output electrical data

In order to cool the cool side of the model, the fan and pump were used which make the importance measure the total power used and generated in this study. The air-cooled model was powered by a DC fan which was rated at 12V, 0.1A. However, the fan could run 5V, 0.1A while for the water-cooled model, the pump was rated at 3V, 0.1A, yielding a total power consumption of 0.3 W. Both the power from the pump and the fan will be subtracted from the total power output shown in Figure 10 and Figure 11.

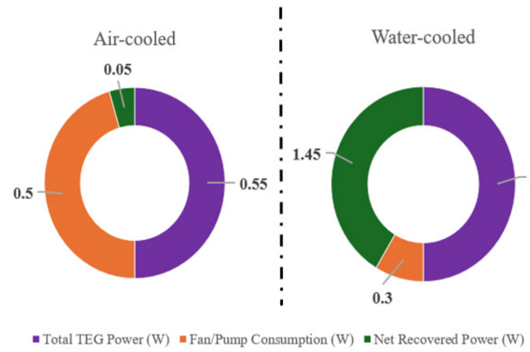

FIGURE 12. Power balances of both prototypes

The comparison of powers in air-cooled and water-cooled prototypes are shown in Figure 12 where the net power output of the air-cooled model is 0.05 W, and the net power output of the water-cooled model is 1.45 W, indicating that the water-cooled model outputs 1.4 W more new power than the air-cooled model. This is because the water-cooled model has a lower power pump combined with the higher thermal conductivity of water. The good performance of water-based compared to air-based cooling system due to the higher thermal conductivity and stable temperature gradient when flowing in the TEG system.

Based on the results and analytical study, the use of TEGs was evaluated for a 1 m^2 household air-conditioning unit with the net electrical power that can covered by the TEGs modules was estimated at 42 W approximately. The electrical input baseline also consider at 1500 W to recovered power corresponds to a 2.8% reduction of electricity consumption by the air-conditioning system. As transparency, this percentage does not directly reflect the efficiency of TEG modules in converting the heat into electricity that originally considered lower. Instead, it can show how much energy can be saved through waste heat recovering system. The relationship can be expressed as:

$$\text{Energy savings, E.S (\%)} = \frac{\text{Power recovered}}{\text{Total power}} \tag{1}$$

$$\text{E.S} = \frac{42}{1500} \times 100 = 2.8\%$$

Thus, the implementation of TEGs in the full scale able to utilize 2.8% less energy compared to the conventional mechanism. Theoretically, if all the air conditioners were retrofitted with the prototype, the total electricity consumption would be reduced to 37.2%. However, the biggest drawback would be the cost associated with retrofitting all air conditioning systems with this technology and further investigation into other organic cycles should be implemented for better performance. The findings highlight the potential of optimized cooling strategies in advancing thermoelectric technology for practical applications, especially in waste heat recovery or low-grade heat harvesting systems.

CONCLUSION

This research has shown the feasibility of generating power from the waste heat of air conditioners using TEG mechanisms. The concept involved harnessing the waste heat from the air conditioner to elevate the temperature on the hot side of the TEG using waste heat which is also obtained from the air conditioner. Two approaches were utilized to cool the cold side of the thermoelectric generator. The first method involved the fan utilizing air as the cooling medium while the second method used the pump to utilize water as the cooling medium. From the fluid flow simulations, the temperature is equivalent when the fluid flows through both models. In the prototype, the hot air temperature applied at 90°C which exhibited a net power of 0.05 W for air-cooled model and 1.45 W power for the water-cooled model. This is close with the theoretical power generated at 1.8 W maximum.

ACKNOWLEDGEMENT

The authors would like to thank University of Wollongong Malaysia for their support throughout this study.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Albatati, F., & Attar, A. 2021. Analytical and experimental study of thermoelectric generator (TEG) system for automotive exhaust waste heat recovery. *Energies* 14: 204.

Al-Rubaye, A. T., Al-Farhany, K., & Al-Chlaihawi, K. 2018. Performance of a portable thermoelectric water cooling system. *International Journal of Mechanical Engineering and Technology* 9(8): 277-285.

Aridi, R., Faraj, J., Ali, S., El-Rab, M. G., Lemenand, T., & Khaled, M. 2021. Energy recover in air conditioning systems: Comprehensive review, classifications, critical analysis and potential recommendations. *Energies* 14: 5869.

Beaton, C. F. 2016. *Thermal and Mechanical Properties of Heat Exchanger Construction Materials.* New York: Begell House Inc. doi:10.1615/hedhme.a.000535

Bishal, S. S., Faysal, D. F., Ehsan, M. M., & Salehin, S. 2023. Performance evaluation of an integrated cooling and power system combining supercritical CO2, gas turbine, absorption refrigeration, and organic rankine cycles for waste energy recuperating system. *Results in Engineering* 17: 100943. doi:https://doi.org/10.1016/j.rineng.2023.100943

Chen, L., & Yang, F. 2023. Experimental investigation of the dehumidification and decarburization performance of metal–organic frameworks in solid adsorption air conditioning. *RSC Advances* 13(2): 808. doi:10.1039/d2ra07209b

Cheng, X., Yin, Y., Che, C.-H., Ji, Q., Cao, B., & Chen, W. 2024. Experimental and simulation study on an air conditioning system cascade driven by waste heat using multicomponent solution. *Building and Environment* 247: 111021. doi:https://doi.org/10.1016/j.buildenv.2023.111021

Gómez-Charris, Y., Umaña-Ibáñez, S., Silva-Ortega, J., Caicedo-Ortiz, J., & Camargo-Acuña, G. 2020. Business model for the optimization of energy consumption by VAC equipment in service sector buildings. *IOP Conference Series: Materials Science and Engineering* 844: 012049. doi:10.1088/1757-899X/844/1/012049

Heidinger, G. G., M.Nascimento, S., D.Gaspar, P., & D.Silva, P. 2018. Experimental evaluation of the thermal performance at different environmental conditions of a low temperature display case with built-in compressor and water-cooled condenser. *Applied Thermal Engineering* 144: 825-835.

Hewawasam, L., Jayasena, A., Afnan, M., Ranasinghe, R., & Wijewardane, M. 2020. Waste heat recovery from thermo-electric generators (TEGs). *The 6th International Conference on Power and Energy Systems Engineering (CPESE 2019)* (pp. 474-479). Okinawa, Japan: Elsevier.

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. 2018. Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress* 6: 268-289. doi:https://doi.org/10.1016/j.tsep.2018.04.017

Kaidir, Mulyanef, & Burmawi. 2018. Performance study on solar hybrid air-conditioning system for residential water heating. *MATEC Web of Conferences* 248: 1003. doi:https://doi.org/10.1051/matecconf/201824801003

Lamrani, B., Marbet, S. E., Rehman, T.-u., & Kousksou, T. 2024. Comprehensive analysis of waste heat recovery and thermal energy storage integration in air conditioning systems. *Energy Conversion and Management: X* 24: 100708.

Li, Y., Wu, Z., Xie, H., Xing, J., Mao, J., Wang, Y., & Li, Z. 2017. Study on the performance of TEG with heat transfer enhancement using graphene-water nanofluid for a TEG cooling system. *Science China Technological Sciences* 60: 1168-1174.

Meisner, G. P. 2010. *Thermoelectric Generator Development for Automotive Waste Heat Recovery*. Detroit, Michigan: U.S. Department of Energy.

MFR, T. (2023, October 25). Thermoelectric power generators in both air cooled and liquid cooled. Retrieved from Thermoelectric Gencell Technology (TEC): https://thermoelectric-generator.com

Molki, A. 2010. Simple Demonstration of the Seebeck Effect. *Science Education Review* 9(3): 103-107.

Ohenhen, P. E., Chidolue, O., Umoh, A. A., Fafure, A. V., Ilojianya, V., & Ibekwe, K. 2024. Sustainable cooling solutions for electronics: A comprehensive review: Investigating the latest techniques and materials, their effectiveness in mechanical applications, and associated environmental benefits. *World Journal of Advanced Research and Reviews* 21(1): 957-972. doi:http://dx.doi.org/10.30574/wjarr.2024.21.1.0111

Rady, M., Albatati, F., Hegab, A., Abuhabaya, A., & Attar, A. 2021. Design and analysis of waste heat recovery from residential air conditioning units for cooling and pure water production. *International Journal of Low-Carbon Technologies* 16(3): 1018-1032. doi:https://doi.org/10.1093/ijlct/ctab033

Raveendran, P. S., & Sekhar, S. J. 2020. Experimental studies on the performance improvement of household refrigerator connected to domestic water system with a water-cooled condenser in tropical regions. *Applied Thermal Engineering* 179: 115684.

Slamet, M. F., Zambri, N. A., & Salim, N. 2020. Air-conditioning unit harvesting energy using DC generator. *Progress in Engineering Application and Technology* 1(1): 166-172. doi: https://doi.org/10.30880/peat.2020.01.01.019

Tohid, M. Z., Baharin, T. M., Yatim, H. M., Kang, C. C., Suhaimi, F. A., & Azmi, M. 2018. Energy harvester from waste heat using thermoelectricity. *Chemical Engineering Transactions* 63: 781-786. doi: 10.3303/CET1863131

Valenti, G., Valenti, A., & Staboli, S. 2019. Proposal of a thermally-driven air compressor for waste heat recovery. *Energy Conversion and Management* 196: 1113-1125.

Wiriyasart, S., & Kaewluan, S. 2024. Waste heat recovery of air conditioning on thermal efficiency enhancement of water heater. *Thermal Science and Engineering Progress* 47: 102296. doi:https://doi.org/10.1016/j.tsep.2023.102296

Xie, L., He, Z., Zhao, Y., & Vulin, D. 2025. Research of structure and performance on passive cooling heat sink in TEG waste heat recovery system based on topology optimization. *International Journal of Heat and Mass Transfer* 242: 126795.

Zhou, S., Zhang, K., Li, M., Yang, W., & Shen, S. 2023. Thermodynamic and exergoeconomic analysis of a combined cooling, desalination and power system for low-grade waste heat utilization. *Thermal Science and Engineering Progress* 45: 102079. doi:https://doi.org/10.1016/j.tsep.2023.102079