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Performance Evaluation of a Thermoelectric Generator (TEG) Integrated Closed Waste-to-Energy Incineration System

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Abstract

Household waste management and renewable energy generation have become increasingly critical issues due to rising waste production and environmental pollution. This study presents the development of a Closed Incineration Mini House Waste-to-Energy System utilizing Thermoelectric Generator (TEG) technology to convert waste heat into electrical energy. The system comprises a closed combustion chamber constructed from mild steel with refractory brick insulation, fueled by garden waste. Experimental trials were conducted using 300 g and 600 g biomass loads, with transient temperature profiles monitored across the chamber surfaces to determine the optimal TEG placement. Results revealed that the top surface consistently produced the highest thermal intensity, reaching a maximum of 108.0 °C at the 3-minute mark, thereby establishing it as the most effective location for TEG installation. Further evaluation of thermal management strategies demonstrated that ice-block cooling generated the strongest temperature gradient (ΔT), producing peak electrical outputs of 8.4 V and 0.5 A for Series 1 and 5.7 V and 0.45 A for Series 2. However, performance declined rapidly as the ice melted and the hot side cooled, underscoring the need for a sustained heat source and long-lasting cooling medium to ensure stable power generation. Overall, the developed system successfully converted waste heat into usable electricity while simultaneously reducing household waste, highlighting its potential as a low-cost, environmentally friendly, and scalable waste-to-energy solution for small-scale applications.

1. Introduction

The increasing amount of household waste has become a major environmental issue due to rapid population growth and urban development [1]. Improper waste disposal methods, such as open burning, release harmful gases and contribute to air pollution and climate change. Incineration is an extensively implemented methodology for achieving substantial solid waste volume reduction [2]. Therefore, there is a growing need for sustainable waste management systems that can reduce waste while producing useful energy. Waste-to-energy (WTE) technology is one of the promising solutions for managing waste while generating useful energy. When integrated with thermoelectric generator (TEG) technology, waste thermal energy can be converted into

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electrical energy, providing a potential decentralized waste-to-energy solution for localized electricity generation.

The operation of a thermoelectric generator is based on the Seebeck effect, which occurs when a temperature difference is maintained between the hot and cold surfaces of the thermoelectric module. This temperature gradient causes charge carriers within the semiconductor material to move, resulting in the generation of electrical voltage. When TEG technology is integrated with an incineration system, the thermal energy produced during combustion can be converted into useful electrical energy. Waste thermal energy conversion using TEG technology therefore provides a potential decentralized waste-to-energy alternative capable of localized electricity generation. Thermoelectric generator modules possess several engineering advantages, including solid-state construction, low maintenance requirements, and quiet operation. This configuration allows low-grade waste heat from controlled combustion chambers, cooking stoves, or exhaust systems to be directly converted into usable electrical energy [3].

Thermoelectric generators (TEGs) are attractive among waste heat recovery technologies because they can convert heat directly into electricity through the Seebeck effect without requiring moving mechanical parts [4]. Although thermoelectric generator technology has been widely studied for industrial waste heat recovery and vehicle exhaust systems, its application in small-scale household waste management remains relatively limited. Furthermore, the electrical output of a TEG depends greatly on the temperature difference between its hot and cold surfaces. Therefore, improving heat transfer and selecting an effective cooling method are important factors in increasing the performance of the system. By scaling down the principles used in industrial waste heat recovery, small-scale waste-to-energy incinerators equipped with TEG arrays and power-conditioning circuits can provide a practical approach to reducing domestic waste volume while generating low-voltage electrical power for localized domestic loads [3,4].

TEG systems are compact, reliable, require little maintenance, and can recover waste heat from combustion processes. Due to these advantages, thermoelectric generators are considered a high-potential energy generation technology suitable for waste heat recovery applications [5]. Thermoelectric generators also stand out from other energy-generating devices because of their simple structure, small size, ability to utilize abundant heat sources, and low pollution and noise characteristics. Thermoelectric generator technology can convert heat directly into electrical energy and is suitable for recovering energy from waste heat sources such as engines, cooking stoves, and waste incineration systems [6]. In addition, this technology can contribute to small-scale renewable energy generation while offering potential benefits in reducing landfill dependency, minimizing open burning practices, and supporting sustainable energy initiatives.

To contextualize the performance of thermoelectric generators in waste heat recovery applications, alternative thermodynamic cycle systems such as the Organic Rankine Cycle (ORC) [7], Stirling Engine Systems, and the Kalina Cycle are also frequently evaluated in the literature. However, these technologies generally involve more complex mechanical configurations, working fluids, and specialized maintenance infrastructure compared with solid-state thermoelectric generators [8]. The simple structure and absence of moving mechanical components make TEG technology particularly attractive for small-scale and decentralized energy recovery applications.

2. Methodology

This section outlines the systematic engineering methodology, design criteria, and empirical protocols adopted to construct and evaluate the Closed Incineration Mini House Waste-to-Energy system. Controlled biomass combustion was investigated in conjunction with specialized thermoelectric generator arrays to assess the efficiency of capturing and converting discarded heat into low-voltage electricity via the Seebeck effect. By integrating combustion engineering with thermoelectric conversion, the study provides a replicable design pathway for small-scale renewable energy systems, while simultaneously addressing household waste management challenges in a sustainable manner.

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2.1 TEG Surface Placement Optimized Test

The thermoelectric generators Surface Placement Optimization Test was carried out to identify the optimal outer surface on the cube-shaped incinerator housing for installing the thermoelectric generator modules. This test evaluated the thermal profiles of the Top, Right, Left, and Rear walls to determine which surface produced the highest and most stable temperatures during biomass combustion. To maximize thermal absorption within the burning chamber and ensure efficient radiative heat transfer to the outer walls, the entire exterior of the housing was coated in a matte black finish. Dried garden waste was utilized as the standard biomass fuel source. To evaluate the influence of varying fuel amounts on surface temperature distribution, two distinct loads of 300 g and 600 g were prepared using a calibrated digital weighing scale. High-temperature thermocouples connected to a multi-channel digital thermometer were attached securely to the geometric center of each test surface. For each test run, the designated fuel load was placed inside the chamber, ignited, and the door was immediately sealed to maintain a closed combustion environment. Temperature readings (°C) from all four surfaces were recorded at one minute intervals from the onset of ignition until the fuel was completely consumed and the temperatures began to decline. The system was allowed to cool to room temperature between subsequent trials. All collected data were compiled into tables to identify the best mounting location based on peak thermal output and structural temperature stability.

2.2 Experimental Setup and Testing Procedure for TEG Cooling Methods

The primary objective of this experiment was to evaluate the effectiveness of phase-change material cooling in maintaining a low temperature on the cold side of the thermoelectric generator. Since a thermoelectric generators relies on a substantial temperature differential (ΔT) between its hot and cold surfaces to generate electricity via the Seebeck effect, preventing the cold side from overheating is critical to maximizing voltage and current output. To achieve a high temperature gradient, the cold side of the thermoelectric generators assembly was regulated using ice blocks as a phase change thermal management medium. During the experimental trials, a digital thermometer was used to continuously monitor the temperature of the cooling block at regular intervals, while a digital multimeter was integrated into the circuit to measure the generated electrical voltage and current as shown in Fig. 1. The resulting thermal and electrical data were compiled to evaluate the performance and suitability of this phase change cooling configuration for the wast to energy system.

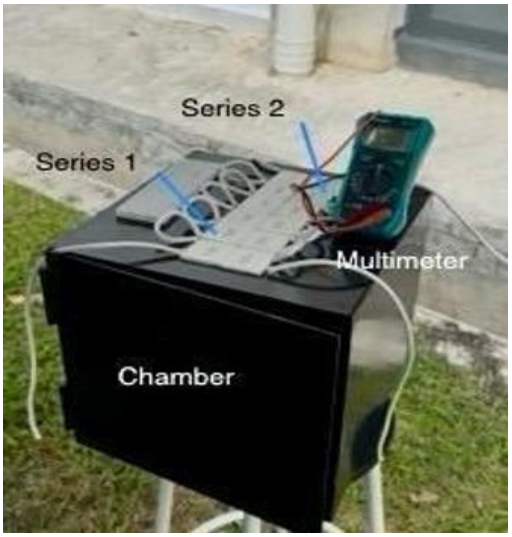


Fig. 1 *Passive Shading under a tree canopy*



Fig. 2 *Air Convection Using a Fan to Create Wind*

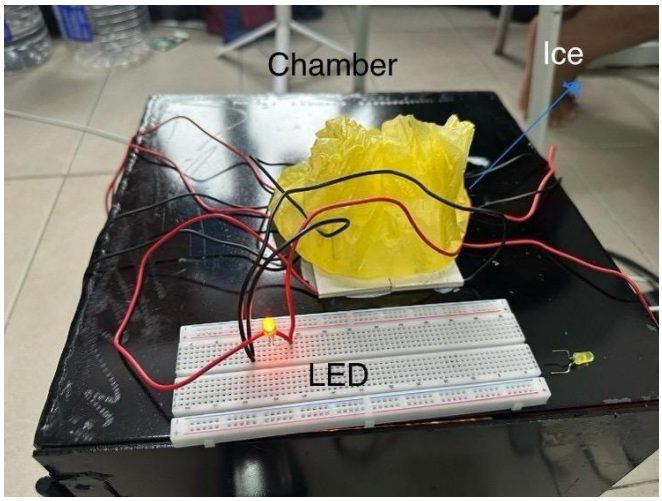


Fig. 3 *Phase Change Material Cooling Using Ice Blocks*

3. Results and Discussion

This section presents and analyzes the experimental findings from the two primary evaluation phases of the waste to energy system: the surface temperature distribution of the incinerator housing and the electrical power generation performance of the thermoelectric Generator module.

3.1 Surface Temperature Measurement for TEG Placement

To establish the optimal physical location for mounting the Thermoelectric generators modules, transient temperature profiles of the top, right, left, and rear housing surfaces were continuously monitored under standard operational chamber conditions. The thermal accumulation behavior was evaluated across two distinct dry biomass fuel loads (300 g and 600 g) over extended burning durations to identify peak heat generation zones and surface stability. The analysis focused on surface heat distribution to determine localized hot spots suitable for TEG placement, temporal variation of temperature to capture dynamic changes during combustion cycles and also comparative assessment of fuel loads to evaluate scalability and performance under different waste input conditions. Tables 1 and 2 present the surface temperature distributions for 300 g and 600 g biomass loads, respectively. These datasets provide insight into the thermal gradient formation, which is critical

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for maximizing the Seebeck effect. In addition, the study incorporated cold-side cooling strategies which are forced air as shown in Fig. 2 and phase change materials as shown in Fig. 3 to enhance ΔT across the thermoelectrical generator modules, thereby improving conversion efficiency. By combining thermal mapping with empirical cooling trials, the experimental design ensures that the most effective mounting positions are identified, balancing both thermal stability and electrical output potential.

Table 1 *Surface Temperature Distribution for 300 g Waste*

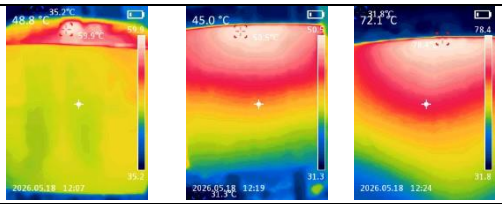
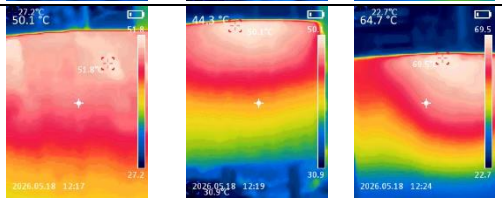
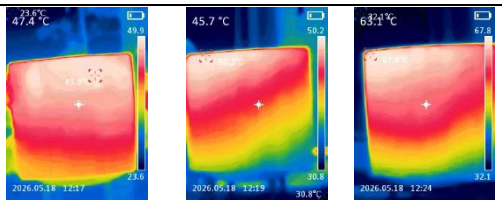
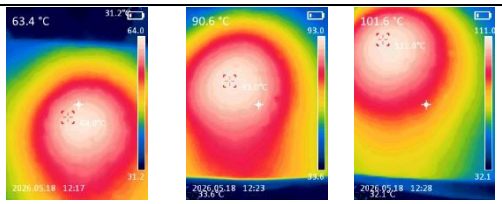
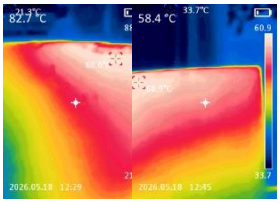
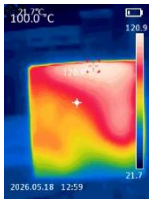
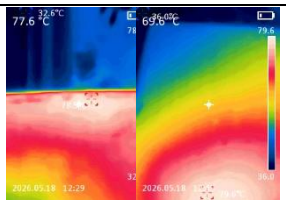
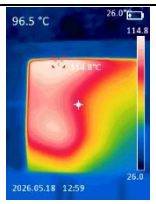
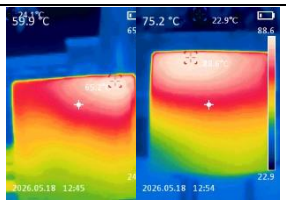
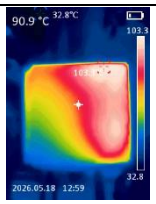
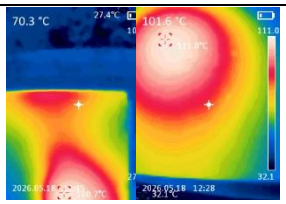
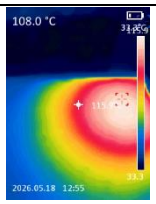
No	Surface Location	Combustion Time (Min)			Average Temprerate (℃)	Reference
		1	2	3		
1.	Rear Surface	48.8 ℃	45.0 ℃	72.1 ℃	55.3 ℃	
2.	Rigth Surface	50.1 ℃	45.0 ℃	64.7 ℃	53.0 ℃	
3.	Left Surface	50.1 ℃	44.3 ℃	64.7 ℃	52.1 ℃	
4.	Top Top	63.4 ℃	90.6 ℃	101.6 ℃	85.2 ℃	

Table 2 *Surface Temperature Distribution for 600 g Waste*

No	Surface Location	Combustion Time (Min)			Average Temprerate (℃)	Reference	
		1	2	3			
1.	Rear Surface	82.7℃	58.4 ℃	100.0℃	80.37℃		
2.	Rigth Surface	77.6 ℃	69.6 ℃	96.5 ℃	81.23 ℃		
3.	Left Surface	59.9 ℃	75.2 ℃	90.9 ℃	75.33 ℃		
4.	Top Top	70.3 ℃	101.6 ℃	108.0 ℃	93.30 ℃		

Based on the comparison between Table 1 and Table 2 for Surface Temperature Measurement for thermoelectric generators placement before ventilation modification, increasing the biomass load from 300 g to 600 g resulted in significantly higher surface temperatures across all sides of the enclosure. This outcome is expected, as a larger fuel mass produces more sustained combustion and greater heat release. The average temperatures for the rear, right, and left surfaces rose from 55.3 °C, 53.0 °C, and 52.1 °C with 300 g of waste to 80.37 °C, 81.23 °C, and 75.33 °C with 600 g of waste, respectively. Most importantly, the top surface consistently exhibited the highest thermal intensity, recording an average of 85.2 °C with 300 g of waste and increasing to 93.30 °C with 600 g of waste. At the 3-minute mark, the top surface even reached a maximum of 108.0 °C, indicating strong and stable heat accumulation. This consistent thermal dominance of the top surface highlights its suitability as the optimal mounting location for TEG modules. The high and steady heat flux ensures a larger and more reliable temperature gradient across the hot and cold junctions, thereby maximizing the Seebeck effect and improving electrical output efficiency. In conclusion, the top surface is the most effective placement site for TEG installation, as it provides both the highest average temperatures and stable thermal behavior under varying fuel loads. This finding establishes a clear design criterion for subsequent system optimization, ensuring that thermoelectric conversion is harnessed at its most efficient point.

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3.2 Transient Thermal and Electrical Performance of the Installed TEG System

An evaluation was conducted to analyze the performance data of the thermoelectric generators system across four distinct thermal management configurations, as shows in Table 3 (Ice Cooling). This comparative assessment investigated how different heat rejection mechanisms ranging from natural passive convection to forced convection and phase-change cooling affect the temperature difference (ΔT) across the thermoelectric generator array and how these variations subsequently influence electrical power generation over time. The study emphasized the transient behavior of ΔT under each cooling setup, the correlation between cooling efficiency and electrical output, and the sustainability of each method in maintaining effective thermal gradients. The results highlight that while passive convection provides only a baseline ΔT, active cooling strategies such as ice-assisted phase change and forced air circulation significantly enhance thermal gradients, thereby improving voltage, current, and overall power generation. This evaluation underscores the critical role of optimized thermal management in maximizing the efficiency of small scale waste toenergy systems.

Table 3 *Performance Data of TEG using ice blocks*

No	Time	Temperature		Voltage		Current	
	(Min)	Hot Side	Cool Side	Series 1	Series 2	Series 1	Series 2
1.	1	93.6 °C	11.7 °C	3.47V	3.10V	0.15A	0.13A
2.	2	100.6 °C	14.1 °C	8.4V	5.7V	0.5A	0.45A
3.	3	77.3 °C	23.7 °C	4.7V	3.6V	0.34A	0.33A

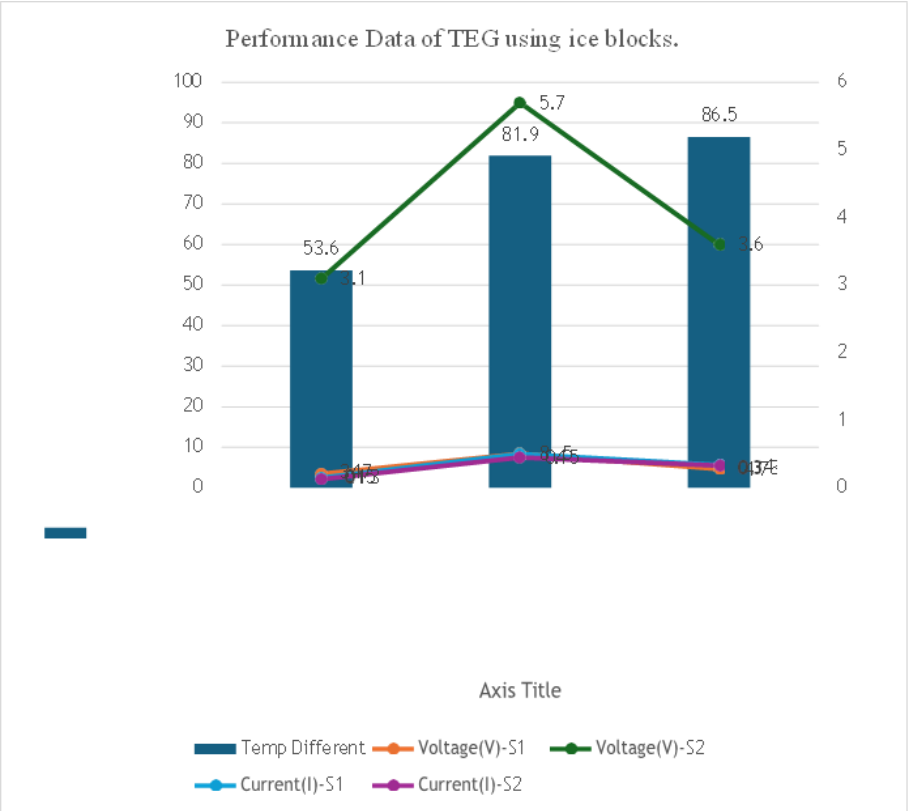


Fig. 4 *Voltage and current performances using ice blocks*

Based on the graph analysis in Fig. 4, the results indicate that ice cooling maintains the cold side at a much lower temperature, thereby enabling the Thermoelectric Generator to produce significantly higher voltage and current compared to soil cooling. At Minute 2, the temperature difference between the hot side at 100.6 °C and the cold side at 14.1 °C reached its maximum, resulting in peak power output of 8.4 V for Series 1 and 5.7 V for Series 2, while the current simultaneously attained its highest values of 0.5 A and 0.45 A, respectively. However, by Minute 3, the hot side temperature dropped rapidly to 77.3 °C, while the melting of the ice caused the cold side to warm to 23.7 °C. This reduction in temperature different led to a sharp decline in both voltage and current during the final stage of the test. In conclusion, ice cooling proves highly effective in creating a strong temperature gradient for maximum electricity generation, but the system's performance diminishes quickly as

the ice melts and the hot side cools. Therefore, a steady heat source and a sustained cold reservoir are essential to ensure stable and continuous power output in practical applications.

4 Conclusion

This research successfully demonstrated the engineering feasibility of a decentralized Closed Incineration Mini House Waste to Energy System utilizing integrated Thermoelectric Generator technology. By offering a safe and controlled alternative to conventional open burning practices, the closed-combustion prototype provides an environmentally responsible pathway for disposing of domestic biomass and garden waste. Empirical testing confirmed that the top surface of the combustion chamber consistently accumulated the highest thermal energy, achieving an average temperature of 93.30 °C and a localized peak of 108.0 °C under a 600 g fuel load, thereby establishing it as the optimal installation zone for TEG modules. The evaluation of cold-side thermal management further verified that phase-change cooling using ice blocks maintained the large temperature gradient (ΔT) necessary across the semiconductor layers. This optimized configuration achieved a maximum electrical output of 8.4 V and 0.5 A, sufficient to power low-consumption domestic electronics or diagnostic units. These findings highlight the system's potential as a low-cost, small-scale renewable energy solution that simultaneously addresses household waste management challenges.

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References

[1] Mukilan, P., Balasubramanian, M., Petrov, J., Sobotík, J., & Narayanamoorthi, R. (2025). Sustainable tiles for renewable energy harvesting using integrated solar PV thermoelectric generator and piezoelectric technologies. *Results in Engineering, 26*, 105478. https://doi.org/10.1016/j.rineng.2025.105478

[2] Chen, H., Li, J., Li, T., Xu, G., Jin, X., Wang, M., & Liu, T. (2022). Performance assessment of a novel medical-waste-to-energy design based on plasma gasification and integrated with a municipal solid waste incineration plant. *Energy, 245*, 123156. https://doi.org/10.1016/j.energy.2022.123156

[3] Anandasabesan, A., Mahamani, S., Soundararajan, H. S., Natarajan, S., Sokkanaravanan, S., & Sathiyanarayanan, M. (2021). Work-in-progress: Smart automatic regeneration of electricity using thermoelectric generator technology. In *Proceedings of the 2021 4th International Conference on Computing and Communications Technologies (ICCCT)* (pp. 484–488). IEEE. https://doi.org/10.1109/ICCCT53315.2021.9711775

[4] Sheikdavood, K., Asokan, R., Thangaraju, D., Vedhashree, S. K., Lakshmi, R., & Arumugam, R. A. (2024). Sustainable power generation from waste: Reducing landfill waste and meeting growing energy demands. In *2024 3rd International Conference on Automation, Computing and Renewable Systems (ICACRS)* (pp. 297–301). IEEE. https://doi.org/10.1109/ICACRS62842.2024.10841770

[5] Gunge, V. S., & Yalagi, P. S. (2016). Smart home automation: A literature review. *National Seminar on Recent Trends in Data Mining (RTDM 2016), 1*, 6–10.

[6] Jouhara, H., Żabnieńska-Góra, A., Khordehgah, N., Doraghi, Q., Ahmad, L., Norman, L., Axcell, B., Wrobel, L., & Dai, S. (2021). Thermoelectric generator (TEG) technologies and applications. *International Journal of Thermofluids, 9*, 100063. https://doi.org/10.1016/j.ijft.2021.100063

[7] Cui, X., Wu, Y., & Chen, X. (2025). Thermoelectric generation: Principles, applications, and prospects. *Renewable and Sustainable Energy Reviews, 224*, 116081. https://doi.org/10.1016/j.rser.2025.116081

[8] Zhao, Y., Liu, G., Li, L., Yang, Q., Tang, B., & Liu, Y. (2019). Expansion devices for organic Rankine cycle (ORC) using in low temperature heat recovery: A review. *Energy Conversion and Management, 199*, 111944. https://doi.org/10.1016/j.enconman.2019.111944