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# Design of Heat exchanger and smart Thermoelectric Power Generation with IoT

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**ABSTRACT**:In today's world, the rising energy demand and depletion of non-renewable resources highlight the need for alternative energy solutions. A significant amount of industrial waste heat is lost, contributing to energy inefficiency and global warming. This project develops a Thermoelectric Generator (TEG) that converts waste heat into electricity using the Seebeck effect. A Peltier module, assisted by a heat element and DC fans, facilitates thermal-to-electrical conversion. An ESP8266 NodeMCU enables real-time monitoring, while a DHT11 sensor measures temperature variations for efficiency optimization. The L298 motor driver controls the DC fans, and a 12V battery stores the generated power for future use. A multi meter analyzes the electrical output. This system supports industrial waste heat recovery, automotive applications, and remote power generation. Future advancements in thermoelectric materials and energy storage can enhance efficiency and scalability. This project demonstrates a promising approach to sustainable energy generation

**Keywords:** Thermoelectric power generation, Heat exchanger, IoT integration, Peltier, Waste heat recovery, Electricity.

## INTRODUCTION

In today's era, electricity generation heavily depends on fossil fuels, including coal, oil, and natural gas. However, the depletion of these resources, along with rising costs and environmental concerns, has driven the search for alternative and sustainable energy solutions. Renewable energy sources such as solar, wind, hydro, and geothermal have gained attention, but each has its own limitations, including high initial investment, location dependency, and efficiency challenges. Among these, thermoelectric generators (TEGs) have emerged as a promising technology for converting waste heat into electrical energy using the See-beck effect.

Thermoelectric power generation offers several advantages, including reliability, compact size, low maintenance, and environmental friendliness. Unlike traditional power generation methods, TEGs can harness low-grade heat sources such as industrial waste heat, vehicle exhaust heat, or solar thermal energy to produce electricity. Despite their relatively low conversion efficiency (typically around 5-10%), TEGs are highly effective in applications where waste heat is readily available and otherwise unused.

This project aims to develop a thermoelectric generator system utilizing components such as the ESP8266 Node MCU, L298 motor driver, 12V battery, Peltier module, heating element, DC fans, DHT11 temperature sensor, and a multimeter. The Peltier module plays a crucial role in the system by converting thermal energy into electrical power, while DC fans regulate the temperature gradient across the module. The L298 motor driver manages the operation of the fans, and the ESP8266 Node MCU facilitates real-time data monitoring and control, enabling remote access. The DHT11 sensor helps optimize the system by providing temperature and humidity measurements.

By integrating smart control and monitoring features, this project demonstrates the feasibility of thermoelectric energy harvesting for self-powered systems, waste heat recovery, and off-grid applications. The proposed system not only explores the potential of TEGs in renewable energy but also contributes to advancing efficient and sustainable power generation solutions.

## 1.2 WASTE HEAT IN INDUSTRIES

As we talk about the waste heat, lots of heat is simply exhausted into the sink i.e., the atmosphere which can be utilized in many ways.

Industrial waste heat refers to energy that is generated in industrial processes without being put to practical use. Sources of waste heat include hot combustion gases discharged to the atmosphere, heated products exiting industrial processes, and heat transfer from hot equipment surfaces. The exact quantity of industrial waste heat is poorly quantified, but various studies have estimated that as much as 20 to 50% of industrial energy consumption is ultimately discharged as waste heat. While some waste heat losses from Industrial processes are inevitable; facilities can reduce these losses by improving equipment efficiency or installing waste heat recovery technologies. Waste heat recovery entails capturing and reusing the waste heat in industrial processes for heating or for generating mechanical or electrical work. Example uses for waste heat include generating electricity, preheating combustion air, preheating furnace loads, absorption cooling, and space heating. A heat exchanger is a device which is used to transfer heat from a hot body to a cold body.

Heat recovery technologies frequently reduce the operating costs for facilities by increasing their energy productivity. Many recovery technologies are already well developed and technically proven; however, there are numerous applications where heat is not recovered due to a combination of market and technical barriers. As discussed below, various sources indicate that there may be significant opportunities for improving industrial energy efficiency through waste heat recovery. A comprehensive investigation of waste heat losses, recovery practices, and barriers is required in order to better identify heat recovery opportunities and technology needs. Such an analysis can aid decision makers in identifying research priorities for promoting industrial energy efficiency.

### 1.3 THERMOELECTRIC GENERATOR THEORY

A Thermoelectric generator (TEG) is a device that converts heat directly into electrical energy through a phenomenon called the Seebeck effect. Thermoelectric generators could be used in power plants in order to convert waste heat into additional electrical power. Another application is radioisotope thermoelectric generators which are used in space probes, which has the same mechanism but use radioisotopes to generate the required heat difference. They are primarily used as remote and off-grid power generators for unmanned sites. They are the most reliable power generator in such situations as they do not have moving parts, work day and night, perform under all weather conditions, and can work without battery backup

Thermoelectric power generators consist of three major components: thermoelectric materials, thermoelectric modules and thermoelectric systems that interface with the heat source.

Thermoelectric materials generate power directly from heat by converting temperature differences into electric voltage. These materials must have both high electrical conductivity (σ) and low thermal conductivity (κ) to be good thermoelectric materials. Having low thermal conductivity ensures that when one side is made hot, the other side stays cold, which helps to generate a large voltage while in a temperature gradient. The measure of the magnitude of electrons flow in response to a temperature difference across that material is given by the Seebeck coefficient (S).

## 2. WORKING PRINCIPLE

A thermoelectric generator is typically composed of multiple thermocouples connected electrically in series or parallel, creating what is known as a **thermoelectric module**. The hot side of the thermocouple is placed at a heat source (e.g., a furnace, engine exhaust, or solar concentrator), and the cold side is maintained at a lower temperature, often using a heat sink. The heat causes the electrons in the materials to move, generating a voltage. This voltage can be harnessed and used to power electronic devices or stored in a battery.

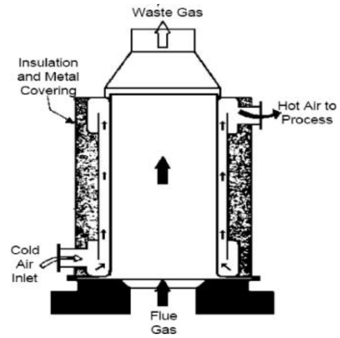
### 2.1 HEAT EXCHANGER

Heat exchangers are most commonly used to transfer heat from combustion exhaust gases to combustion air entering the furnace. Since preheated combustion air enters the furnace at a higher temperature, less energy must be supplied by the fuel. Typical technologies used for air preheating include recuperators, furnace regenerators, burner regenerators, rotary regenerators, and passive air preheaters.

### 2.2 RECUPERATOR

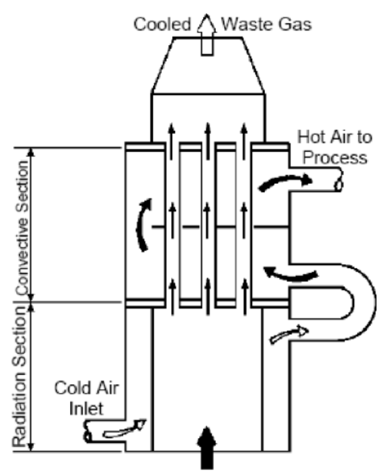
Recuperators recover exhaust gas waste heat in medium to high temperature applications such as soaking or annealing ovens, melting furnaces, afterburners, gas incinerators, radiant tube burners, and reheat furnaces. Recuperators can be based on radiation, convection, or combinations: A simple radiation recuperator consists of two concentric lengths of ductwork. Hot waste gases pass through the inner duct and heat transfer is primarily radiated to the wall and to the cold incoming air in the outer shell. The preheated shell air then travels to the furnace burners. The convective or tube type recuperator (heat exchanger) passes the hot gases through relatively small diameter tubes contained in a larger shell. The incoming combustion air enters the shell and is baffled around the tubes, picking up heat from the waste gas. Another alternative is the combined radiation/convection recuperator. The system includes a radiation section followed by a convection section in order to maximize heat transfer effectiveness.

Recuperators are constructed out of either metallic or ceramic materials. Metallic recuperators are used in applications with temperatures below 2,000oF [1,093$^0$C], while heat recovery at higher temperatures is better suited to ceramic tube recuperators. These can operate with hot side temperatures as high as 800 $^0$ F [1,538 $^0$C] and cold side temperatures of about 1,800°F [982 $^0$C].




a) Metallic Radiation Recuperator Design

b) Radiation Recuperator Installed at Glass Cutter




c) Convection Recuperator Fig 1.1 Recuperators

## 2.5 EXISTING SYSTEM

The current thermoelectric generator (TEG) systems utilize thermoelectric materials to convert heat into electricity based on the See-beck effect. These systems are widely used for waste heat recovery, remote power generation, and industrial applications. However, they still face several limitations in terms of efficiency, cost, and scalability.

1. **Heat Source:** A heat element (such as an engine, exhaust, or industrial heat source) provides the required thermal energy.
2. **Thermoelectric Module (Peltier Module):** The heat flows through the Peltier module, generating an electrical output due to the temperature difference between the hot and cold sides.
3. **Heat Dissipation:** DC fans or heat sinks are used to cool the cold side, ensuring a consistent temperature gradient.
4. **Power Storage & Utilization:** The generated electricity is either directly used or stored in a battery for later use.
5. **Monitoring & Control:** Multi-meters and microcontrollers (e.g., ESP8266 Node MCU) are used for voltage, current, and temperature monitoring.

## 2.6 PROBLEM STATEMENT

In today's world, a significant amount of heat energy is wasted in various industries, automobiles, and household appliances. This waste heat is typically dissipated into the environment without being utilized effectively. At the same time, conventional power generation methods rely heavily on fossil fuels, leading to environmental pollution, depletion of resources, and increased energy costs.

## 2.7 PROPOSED SYSTEM

The proposed system aims to develop an efficient, IoT-enabled thermoelectric generator that converts waste heat into electrical energy while overcoming the limitations of existing TEG systems. This system will use Peltier modules, a heat element, cooling fans, a 12V battery, and an ESP8266 Node MCU for real-time monitoring. The integration of a smart control mechanism ensures better efficiency, optimization, and usability in practical applications.

1. Waste Heat Recovery in Industries (e.g., steel plants, refineries, manufacturing units).
2. Automobile Exhaust Heat Utilization for increasing fuel efficiency.
3. Remote & Off-Grid Power Generation in rural and isolated areas.
4. Renewable Energy Systems as a hybrid backup to solar or wind power.
5. IoT-Based Smart Energy Solutions for real-time power management.

## 2.8 MATERIALS USED

The materials used in this project include an L298 Motor Driver for controlling the 12V DC Fan, ensuring efficient heat dissipation. An ESP8266 NodeMCU is integrated for real-time monitoring and data analysis, while a DHT11 Module measures temperature variations to optimize performance. A Peltier Module is used to convert waste heat into electrical energy, supported by a Heat Element as the primary heat source. A 12V LiPo Battery stores the generated power for further applications, and a Multimeter is used to analyze the electrical output. Jumper Wires facilitate connections between components, ensuring smooth operation. A Thermoelectric Peltier Refrigeration Cooling System is incorporated to enhance cooling efficiency. Lastly, a Rocker Switch is included for easy system control and operation.

### 2.9 SOFTWARE DETAILS

The software implementation of this project involves **Arduino IDE**, which is used for programming and uploading code to the **ESP8266 NodeMCU**. The coding is done using **Embedded C**, ensuring efficient control and communication between the hardware components. Additionally, **Blynk** is integrated for IoT-based real-time monitoring, enabling remote access and data visualization of temperature variations and power output. This combination of software tools ensures smooth operation, automation, and optimization of the thermoelectric power generation system.

## 3 WORKING

This circuit demonstrates a smart thermoelectric generator that can efficiently convert heat into electrical power while monitoring system performance using IoT technology. It is useful for applications like waste heat recovery, renewable energy systems, and remote power generation.

**1. Power Supply & Control:**

The system is powered by a 12V LiPo battery that supplies energy to different components.
Three switches control different sections of the circuit, allowing manual activation of cooling fans and other elements.

**2. Heat Generation & Thermoelectric Conversion:**

The heat element generates thermal energy, providing the hot side for the Peltier module (TEC1-12706).
The Peltier module works on the See-beck effect, converting the temperature difference into electrical voltage.

**3. Cooling Mechanism & Temperature Control:**

Two 12V DC fans help cool the cold side of the Peltier module, ensuring a stable temperature gradient.
The L298 motor driver is used to regulate and control the fan speed based on real-time temperature readings

**4. Data Monitoring & IoT Connectivity:**

The DHT11 temperature and humidity sensor collects environmental data to monitor system efficiency.

The ESP8266 Node MCU processes this data and can send it wirelessly to a cloud platform or IoT dashboard for remote monitoring.

**5. Output Measurement & Regulation:**

The generated voltage and current are measured using a multimeter to analyse power efficiency. A diode is placed in the circuit to ensure proper current flow and prevent reverse voltage damage.

### 3.1 Block Diagram:

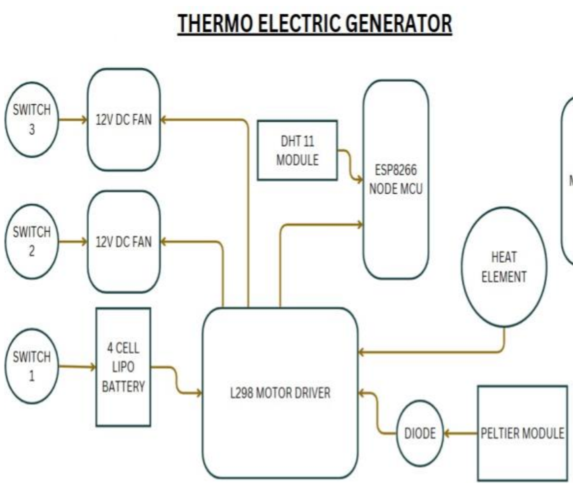



Fig.3.1 Block Diagram of Thermo Electric Generator

The Thermoelectric Generator (TEG) System efficiently converts waste heat into electrical energy using the Seebeck effect, integrating various components for power generation, regulation, and monitoring. A heat element creates a temperature gradient across the Peltier module, generating electricity, while 12V DC fans maintain optimal cooling. The L298 motor driver regulates power distribution, and a diode ensures unidirectional current flow for system protection. A 4-cell LiPo battery supplies initial power, controlled by switches for selective operation. The ESP8266 NodeMCU and DHT11 sensor enable real-time data monitoring and automation, enhancing system efficiency. A multimeter measures output voltage and current, validating performance. This system demonstrates an effective waste heat recovery approach, with potential advancements in smart energy management and improved thermoelectric materials for greater efficiency and sustainability.

### 3.2 Circuit Diagram:

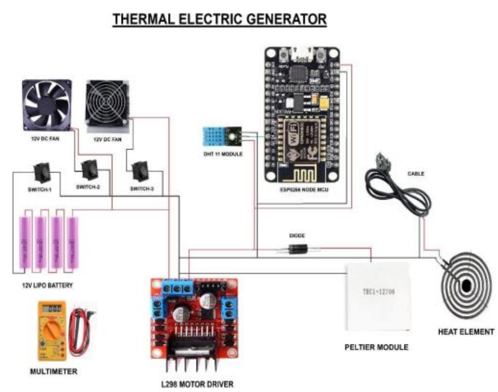



Fig.3.2 Circuit Diagram

## 4 PERFORMANCE ANALYSIS

The thermodynamics of open systems has been developed which provides an entirely new theoretical framework based on novel concepts without any recourse to statistical mechanics. The standard chemical potential is replaced by a convective potential itself derived from a new concept referred to as the “thermo baric potential”. Entropy convicted by addition of masses into an open system is obtained using only classical concepts without leading to Gibb's paradox. A generalized Gibbs-Duhem theorem is derived. Application to chemical systems leads to new expressions for the affinity and an "intrinsic" heat of reaction which excludes the heat of mixing and is more representative of the true chemical energy. These expressions involve only mechanical and calorimetric concepts. They are much more general than the standard formulas which are restricted to temperature variations. The van't Hoff-le Chatelier principle is extended to open systems in terms of the new convective potential.

The convergence of heat exchangers, thermoelectric power generation (TEG), and the Internet of Things (IoT) provides an auspicious answer for energy recovery, sustainability, and optimization of smart technology. Heat exchangers, used to transfer thermal energy between fluids, are pivotal in creating the temperature gradients that are needed by TEG systems. Thermoelectric generators transform this temperature gradient into electricity through the Seebeck effect, enabling the recovery of waste heat that would otherwise be lost. Although TEG efficiency is low in general, this technology is useful in applications where waste heat can be used to generate energy, for example, in industrial processes or in automotive systems. The addition of IoT to TEG systems improves their efficiency by providing real-time tracking of the most important parameters such as temperature and power. IoT sensors monitor for faults such as temperature drift or system inefficiency, which allows for optimization of energy generation and predictive maintenance. The addition of IoT also provides remote control and data processing, making it possible for smart energy management and system optimization. The integration of these technologies can result in greater energy efficiency, lower environmental footprint, and the creation of smart energy systems that lower costs while enhancing performance.Yet, obstacles are present in the guise of TEG's inefficient conversion, high thermoelectric material costs, and requirements for secure IoT infrastructure to shield against possible cybersecurity threats. Regardless of these challenges, the combination of heat exchangers, TEG, and IoT has much potential in the areas of industrial waste heat recovery, off-grid power, and automotive energy systems, all to help make a more sustainable and energy-efficient world.

### 4.2 READINGS OBTAINED FROM PRACTICAL CALCULATIONS

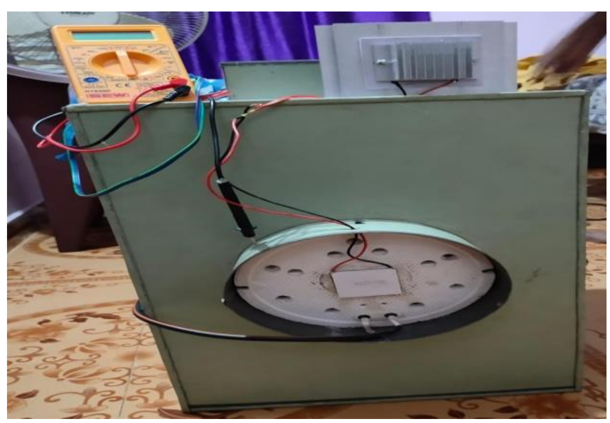


Fig.4.1 Fabricated Heat Exchanger

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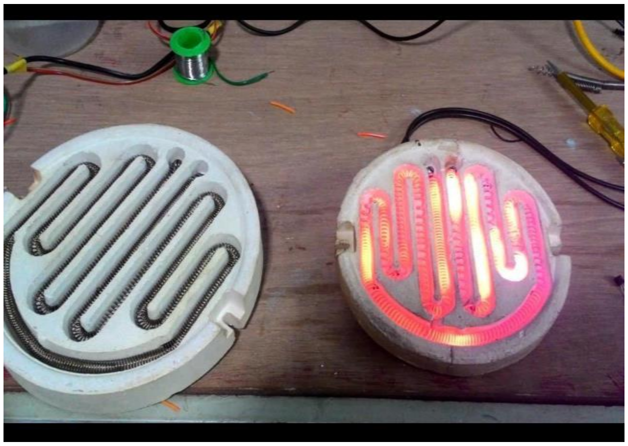
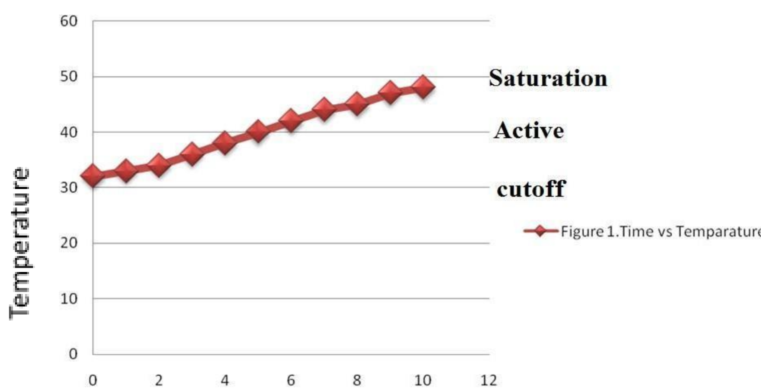


Fig.4.2 Testing and Placing of Heat Exchanger


Fig.4.4 Voltage Reading from Multimeter

| S.No | Time (in seconds) | Temperature (°C) |
|---|---|---|
| 1 | 0 | 32 |
| 2 | 1 | 33 |
| 3 | 2 | 34 |
| 4 | 3 | 36 |
| 5 | 4 | 38 |
| 6 | 5 | 40 |
| 7 | 6 | 42 |

Table 4.1 Analytical Results of Prototype

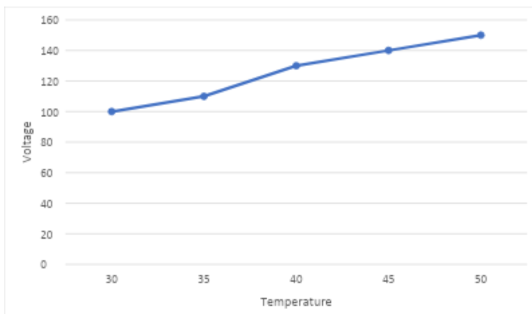



Graph 4.1 Temperature Vs Time

The temperature values that are available from time to time are drawn in a graph in which time in seconds along the x-axis and temperature along the y-axis. On studying the graph, it is noted that the minimum temperature that is noticed is $30^0$c is called the cutoff temperature. The temperature of $40^0$c is called the active temperature and $50^0$c is called the saturation temperature.

| S.no | Temperature (°C) | Voltage (millivolts) |
|---|---|---|
| 1 | 30 | 100 |
| 2 | 35 | 110 |
| 3 | 40 | 130 |
| 4 | 45 | 140 |
| 5 | 50 | 150 |

Table 4.2 Temperature and Voltage readings




Graph 4.2 Temperature vs Voltage

| S.no | Temperature(°C) | Current(mA) | Voltage(mV) | P=V*I(mW) |
|---|---|---|---|---|
| 1 | 30 | 75 | 100 | 7500 |
| 2 | 35 | 75 | 110 | 8250 |
| 3 | 40 | 75 | 130 | 9750 |
| 4 | 45 | 75 | 140 | 10500 |
| 5 | 50 | 75 | 150 | 11250 |

Table 4.3 Power(mV)

**Calculations P=V*I**

**P = Power in milli Watts V = Voltage**
**I = Current**

75*100 = 7500mw

75*110 = 8250mw

75*130 = 9750mw

75*140 = 10500mw

75*150 = 11250mw
so with increase in voltage we get more power

## 4.3 RESULT

The proposed system incorporates a Peltier module (TEC1-12706) to convert heat energy into electrical energy, generating a voltage between 6V and 10V under sufficient temperature gradients. A DHT11 sensor accurately measures the temperature on both sides of the module, ensuring precise thermal monitoring. An ESP8266 NodeMCU processes the data and facilitates real-time remote monitoring through IoT connectivity. To maintain system stability and prevent overheating, cooling fans controlled by an L298 motor driver dynamically adjust their speed based on temperature data.

This system effectively integrates thermoelectric power generation, temperature control, and IoT-based monitoring, demonstrating the feasibility of waste heat recovery for electricity generation. With potential applications in industrial waste heat recovery, automotive energy harvesting, and remote power generation, this technology offers an efficient and sustainable energy solution. Future advancements in thermoelectric materials and energy storage technologies can further enhance the efficiency and scalability of such systems, making them a promising alternative for sustainable energy generation.

## 5 CONCLUSION

The successful implementation of this Thermoelectric Generator (TEG) System utilizing L298 Motor Driver, ESP8266 Node MCU, 12V Battery, DC Fans, Peltier Module, Heat Element, DHT11 Sensor, and a Multi-meter effectively demonstrates the potential of converting waste heat into electrical energy through the Seebeck effect. This project underscores the importance of waste heat recovery in industries, automotive applications, and remote power generation, contributing to sustainable and efficient energy utilization.

By incorporating microcontrollers (ESP8266 Node MCU) and temperature sensors (DHT11), the system enables real-time monitoring and automation, enhancing its operational efficiency. The DC fans play a crucial role in maintaining the necessary temperature gradient, ensuring optimal performance of the Peltier modules. This highlights the significance of proper thermal management in thermoelectric power generation systems.

Despite the conversion efficiency limitations associated with current thermoelectric materials, this project demonstrates the feasibility of TEGs in harnessing waste heat for useful power generation. Future advancements in nanotechnology, material science, and system design are expected to improve the efficiency and commercial viability of thermoelectric generators. By optimizing heat exchange mechanisms and integrating AI-based predictive analytics, these systems can be further enhanced for smart energy recovery applications.

Furthermore, this project serves as a foundation for future research and development, paving the way for innovative energy harvesting solutions. It reinforces the role of thermoelectric technology in energy conservation and environmental sustainability, making it a promising alternative energy source for a wide range of applications, including industrial waste heat recovery, self-powered IoT devices, wearable electronics, and off-grid power solutions.

As the global demand for renewable and sustainable energy sources increases, thermoelectric generators hold great promise in addressing energy efficiency challenges while reducing carbon footprints. This project not only showcases the potential of thermoelectric energy conversion but also encourages further exploration into cost-effective, high-efficiency, and scalable thermoelectric solutions for the future.

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