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Research Original Article

Heat Energy Conversion System into Electric Energy Using Peltier Technology

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Abstract
This paper explains about to design and test a system for converting heat energy into electrical energy using a Peltier thermoelectric module. The Peltier module utilizes the temperature difference between the hot and cold sides to generate electricity through the Seebeck effect. The use of this technology is relevant in efforts to utilize renewable energy, especially in utilizing waste heat from engines or other unused heat sources. The designed system consists of a Peltier module, heat source, and supporting electronic circuits to optimize energy conversion. Tests are carried out at various temperature levels to measure the voltage and electrical power produced. The research results show that the system is capable of producing electrical power of up to several watts. Factors that influence system performance, such as temperature differences and module quality, are analyzed to provide suggestions for further development. This research shows the potential application of Peltier modules in small-scale thermal energy utilization systems, although increased efficiency and design optimization are needed for wider use.
Keywords: Heat Energy Conversion; Peltier Module; Seebeck Effect; Thermoelectric; Renewable Energy

Introduction
Utilization of renewable energy is one of the main focuses in global efforts to reduce dependence on fossil fuels and their negative impact on the environment. Thermal energy, which is produced from various natural sources such as sunlight, geothermal heat and industrial waste heat, has great potential to be converted into electrical energy [1]. However, without the right technology, this heat energy is often wasted. Converting heat energy into electricity is an innovative solution that can increase energy efficiency and reduce carbon emissions. By utilizing available heat, both from natural sources and industrial by-products, we can create a more sustainable and environmentally friendly energy system.

One technology that allows the direct conversion of heat energy into electricity is thermoelectric technology. This technology works based on the thermoelectric effect, where the temperature difference between two materials can produce an electric current. In recent decades, significant progress has been made in the development of increasingly efficient and affordable thermoelectric devices. One of the most famous devices in this category is the Peltier module [2]. This module is increasingly in demand because it does not require moving parts, so it is more durable, easy to maintain, and can be integrated into various applications [3].

The role of Peltier modules in energy efficiency is increasingly important because they can utilize heat that is often wasted, such as in machines or electronic devices. By converting this heat into reusable electrical energy, these systems can increase the overall efficiency of a process or machine. Peltier modules also offer flexibility at various scales, from small devices such as electronics coolers to larger applications in power generation systems. Thus, this thermoelectric technology has the potential to become an integral part of future renewable energy strategies, providing efficient and environmentally friendly solutions in the utilization of thermal energy [4].

The main problem to be resolved with a system for converting heat energy into electrical energy using Peltier technology is the efficient use of heat energy which is often wasted, both from natural sources and industrial waste products. A lot of heat energy released by machines, electronic devices or industrial processes is not utilized optimally. [5], [6] This system aims to optimize the conversion of energy into electricity, so as to reduce energy waste and increase overall energy efficiency. The challenge faced is how to increase the performance and efficiency of the Peltier module in capturing temperature differences and converting them into significant electricity [7]. Apart from that, innovation is also needed to reduce heat losses that occur during the conversion process and ensure that the system it can be widely applied with affordable cost and high durability.

The main objective of this research is to design and test a system for converting heat energy into electrical energy using Peltier technology. This research focuses on developing a device that is able to efficiently convert temperature differences into electricity, so that it can utilize waste heat that has previously been wasted. In addition, this research aims to evaluate the performance of the Peltier module in various temperature conditions and different heat sources, as well as identifying factors affecting energy conversion efficiency. Thus, it is hoped that the results of this research can provide practical solutions in increasing energy efficiency, as well as reducing dependence on fossil energy resources through more optimal use of renewable energy [8], [9].

The benefits of this research are very significant, both in terms of energy savings and increasing the efficiency of thermoelectric technology. By optimizing the conversion of heat energy into electricity, this research has the potential to reduce energy waste, especially from industrial waste heat, machines or electronic devices, which have not been utilized effectively. In addition, this research will encourage the development of thermoelectric technology, especially Peltier modules, by improving its efficiency and opening up wider application opportunities. The applications of this technology can be utilized in various sectors, such as the manufacturing, automotive and power generation industries, as well as in more energy efficient electronic or household cooling systems [10], [11]. On a larger scale, the use of this technology can support the transition towards renewable energy sources and a more sustainable energy system, thereby contributing to global efforts to reduce carbon emissions and maintain environmental sustainability.

Literature Review

Thermoelectric energy is energy produced through the direct conversion process of temperature differences into electricity, without the need for moving mechanical components. The basic principle behind this technology is the thermoelectric effect, which involves two main phenomena: the Seebeck effect and the Peltier effect. The Seebeck effect occurs when the temperature difference between two conductive materials causes electrons to move from the hotter side to the cooler side, creating an electric current as shown in figure 1 [12]. This process allows the conversion of heat energy into electrical energy directly [13]. Thermoelectric technology offers various advantages, such as the ability to work in extreme conditions, without noise, and with minimal maintenance, because it does not involve moving parts [4]. In practical applications, heat energy generated from various sources, such as waste heat from engines or solar energy, can be harnessed with thermoelectric devices to generate electricity, [14] thereby potentially increasing overall energy efficiency and reducing dependence on fossil energy sources.

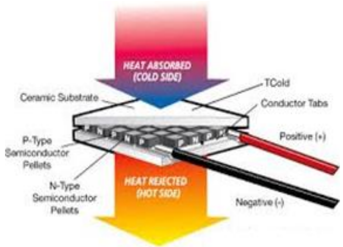

Figure 1. Electron flow from point P to N

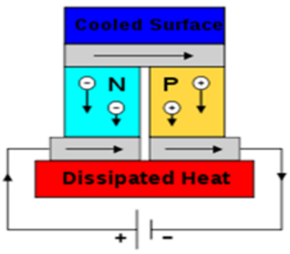

Figure 2. Illustration of the Seebeek Effect

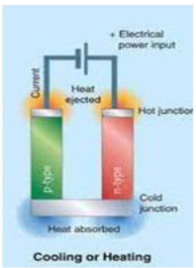

Figure 3. Illustration of the Peltier Effect

The Peltier module is a thermoelectric device that works based on two main principles, namely the Seebeck effect as shown in figure 2 and the Peltier effect shown in figure 3 which allows the conversion between heat and electrical energy. The Seebeck effect occurs when the temperature difference between two sides of the module creates a flow of electrons from the hot side to the cold side, producing an electric current as in figure 4. In contrast, the Peltier effect occurs when an electric current flows through the module, causing one side of the module gets hot and the other side gets cold. These Peltier modules are often used in cooling applications, such as in processor coolers or portable mini refrigerators, where electricity is used to create a cooling effect. Additionally, in thermoelectric systems, Peltier modules can be used to convert waste heat into useful electricity, such as in the automotive industry, power generating machines, or electronic devices that produce heat [15].

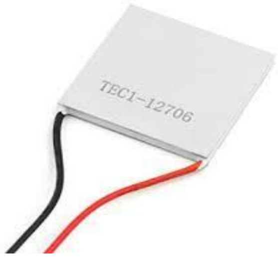

Figure 4. The Peltier

Previous research on the conversion of heat energy into electricity using Peltier technology has shown great potential in increasing the efficiency of using wasted energy. Several studies have tested the capabilities of Peltier modules in various applications, such as converting waste heat from vehicle engines or generators into electricity [16]. For example, research in the automotive field shows that Peltier-based thermoelectric systems can utilize heat from the exhaust to produce additional power, which indirectly increases the vehicle's fuel efficiency. Peltier converts heat generated by devices such as processors or servers into reusable electrical energy, while also helping in thermal management. However, many studies also note challenges, such as low conversion efficiency and relatively high Peltier module production costs, wider and more economical on an industrial scale [17].

Materials & Methods

The design and configuration of the system for converting heat energy into electricity using Peltier technology will consist of several main components that interact with each other to achieve maximum efficiency. First, a heat energy source in the form of a candle will be prepared, which produces heat from combustion [18]. Near the heat source, a Peltier module will be installed, with one side connected directly to the heat source and the other side cooled using ambient air. The system is equipped with a light load to optimize the electric current produced. In addition, a monitoring system is implemented to monitor the temperature on both sides of the Peltier module and measure electricity output in real-time as shown in Figure 5. With this design, it is hoped that the system can operate effectively in using wasted heat energy and producing electricity with high power and affordable costs.

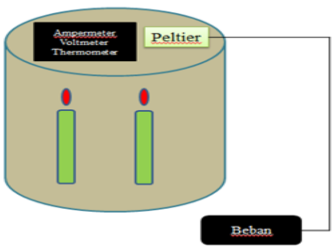

Figure 5. The circuit schematic

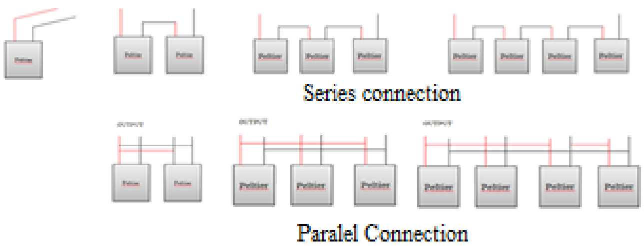

Figure 6. The Peltier modules connected in series and parallel

The main components used in this heat to electricity energy conversion system include several important elements that work synergistically to achieve optimal efficiency. First, the Peltier module functions as the core of the system, responsible for converting temperature differences into electrical current as shown in figure 6. This module must be selected based on the power specifications appropriate to the heat source used. Furthermore, on the cold side the Peltier module is directly cooled to the surrounding air maintaining the temperature difference needed to generate electricity. The heat source is a candle [19]. Apart from that, this system also requires supporting electronic circuits aimed at monitoring temperature, voltage and current in real time. All of these components are designed to work together to create a system that is effective in converting heat energy into electrical energy. The specifications of the components used are shown in table 1.

Table 1. Materials and Tools

Component	Specification	Unit
Peltier	TEC1-12706	4
Cable Socket	26AWG	10
Conductor	Aluminium	1
Ampere meter	5 A	1
Voltmeter	0-100V	1
Resistive load	Bulb	1
Thermometer	-20 – 100°C	1

The steps in designing and assembling a heat to electricity energy conversion system as shown in Figure 7 begin with an analysis of system requirements and specifications, including determining the heat source to be used and the amount of electrical energy desired. After that, the next stage is to choose the right components, such as Peltier modules and electronic circuits, based on the expected technical specifications. Once the components are selected, a mechanical design process is carried out to design a supporting structure that can accommodate all components firmly and safely. Once the design is complete, the next step is to assemble the components, where the Peltier module is installed between the heat sources and ensures good contact to maximize heat transfer. Then, an electronic circuit is connected to monitor temperature, voltage and current readings as well as lamp load. Once all components are installed, initial testing is performed to ensure the system is functioning properly, followed by performance measurements to evaluate energy conversion and make adjustments if necessary. By systematically following these steps, an energy conversion system can be built and optimized to provide the desired results.

Figure 7. The actual circuit

The method used to measure the efficiency and performance of the system in converting heat energy into electricity involves several structured testing and analysis stages [20]. First, temperature measurements on the hot side and cold side of the Peltier module This is done using a digital temperature sensor to determine the resulting temperature difference. Next, the electrical output produced by the Peltier module, in the form of voltage and current, is measured using a multimeter, so that the electrical power produced can be calculated. In addition, performance measurement data during various operational conditions, such as variations in heat source temperature and cooling intensity, are also analyzed to understand how these changes affect electrical output. The results of this testing will provide insight into overall system efficiency and areas that may require further improvement or optimization.

The resulting electrical power can be obtained using the formula:

$$P = V \times I \quad (1)$$

Where
P is in Watts
V is the voltage measured in Volts
I is the current measured in A units

Results and Discussion

The test results of the heat to electrical energy conversion system using the Peltier module show variations in the voltage and electrical power produced depending on the applied temperature difference. The measurement results can be seen in Figure 8.

The measurement results are shown in figures 9, 10, and 11. In the initial test, when in the first 5 minutes the heat source reached a temperature of around 30°C, the Peltier module produced maximum voltage for the connection of 1 peltier, 2 peltier series, 2 peltier parallel, 3 peltier series, 3 peltier parallel, 4 peltier series, and 4 peltier parallel respectively around 2.18, 3.47, 0.11, 6., 0.22, 8.75, and 0.45 volts and an electric current of around 0.003A on 4 Peltier connected in series for other peltier modules not There is a current reading so that the electrical power produced is around 0.02625 watts. When the temperature increases to 42°C, the electrical output increases significantly, for connections of 1 peltier, 2 peltier series, 2 peltier parallel, 3 peltier series, 3 peltier parallel, 4 peltier series, and 4 peltier parallel each voltage reaches 4.37, 8.75, 0.22, 13, 0.45, 17, 5 and 0.9 volts and an electric current of around 0.005A on 4 Peltiers connected in series. For the other Peltier modules there is no reading current so the electric power produced is around 0.0875 watts. Further testing at a temperature of 64°C showed further improvement, for connections of 1 peltier, 2 peltier series, 2 peltier parallel, 3 peltier series, 3 peltier parallel, 4 peltier series, and 4 peltier parallel respectively the voltage reached 6.56, 13.12 , 0.33, 19.5, 0.67, 26, and 1.35 volts and an electric current of around 0.007A on 4 Peltiers connected in series. For the other Peltier modules there is no reading current so the electric power produced is around 0.182 watts. The last test at a temperature of 85°C showed an increase, for connections of 1 peltier, 2 peltier series, 2 peltier parallel, 3 peltier series, 3 peltier parallel, 4 peltier series, and 4 peltier parallel respectively the voltage reached 8.75, 17.5, 0.45, 26, 0.9, 35, and 1.8 volts and electric currents of around 0.003, 0.005, 0.007, and 0.15 A respectively at 1 Peltier, 2 Peltier series, 3 Peltier series and 4 Peltier series for other Peltier modules there is no readable current so the power The electricity produced in 1 Peltier, 2 Peltier series, 3 Peltier series and 4 Peltier series is around 0.02625, 0.875, 0.182 and 0.525 watts.

These results indicate that there is a positive linear relationship between the temperature difference and electrical output, where the higher the temperature of the heat source, the greater the voltage and power produced by the Peltier module and this shows the Seebeck effect and Peltier effect and is clearly visible in series connected Peltiers. . By increasing the peltier components in series connected modules, the power will also increase significantly. While the Peltier is connected in parallel, the voltage value is very small and the current is not visible at all. These data provide important insights for further developments in the design of more efficient and effective energy conversion systems.

Analysis of the power produced in the heat to electricity energy conversion system using Peltier technology shows varying results, depending on the configuration used. In this study, the average power conversion achieved was around 0.2 Watt which can be considered low compared to other thermal energy conversion technologies, such as steam turbines or thermoelectric generators based on more advanced semiconductor materials, which can achieve efficiencies of up to 20% or more. For example, in research by Huang et al. (2014), the use of a bismuth telluride-based thermoelectric generator produces an efficiency of around 8-12% when utilizing heat from a car engine. In this comparison, although the Peltier system has lower power, its advantages lie in its ease of installation and compact size, as well as its ability to function without moving parts, which reduces maintenance requirements. Additionally, Peltier systems also demonstrate stable performance under different environmental conditions, which can be an advantage in certain applications. Therefore, although the conversion of heat energy into electricity using Peltier modules still needs to be improved, this system remains promising as a practical solution for utilizing wasted energy on a small scale and in specific applications.

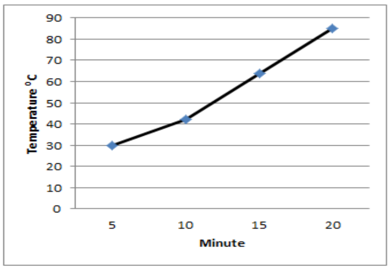

Figure 8. Changes in wax temperature with time

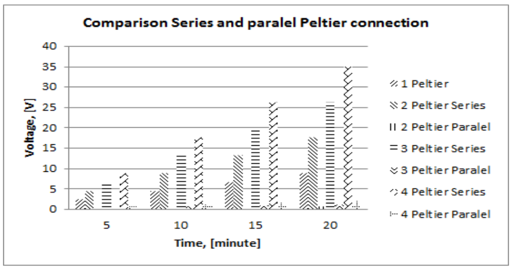

Figure 9. Changes in voltage with time

The performance of a heat to electricity energy conversion system using a Peltier module is influenced by several key factors that need to be considered to increase power. First, the temperature of the heat source plays an important role; The higher the temperature difference between the hot and cold sides of the Peltier module, the greater the voltage generated. However, extreme temperatures can also cause material degradation and affect module lifespan. Second, the quality of the Peltier module itself is crucial; modules with better materials, such as bismuth telluride, usually have higher efficiencies than those with cheaper materials. Third, the cooling system on the cold side of the Peltier module is very vital to maintain optimal temperature differences. In addition, mechanical design and configuration, such as thermal contact between the module and the heat source, also influence the energy transfer efficiency. By understanding and managing these factors, the performance of thermal energy conversion systems can be significantly improved, enabling more efficient and effective utilization of wasted energy.

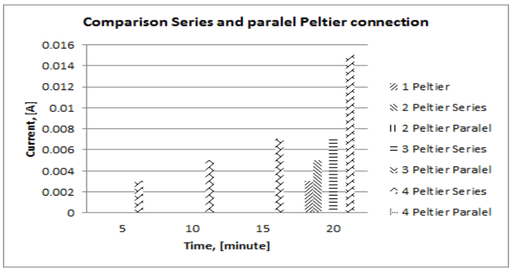

Figure 10. Changes in current over time

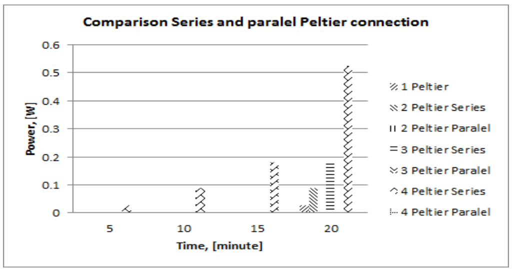

Figure 11. Changes in power over time

Conclusions

The conclusion from the results of this research shows that the system designed to convert heat energy into electrical energy using Peltier technology is quite effective, although its power is still below other energy conversion technologies. With an average power conversion of around 0.2 Watt, this system shows promising potential in utilizing waste heat, especially in small-scale applications and situations where alternative energy sources are difficult to access. Test results show that a significant temperature difference between the hot and cold sides of the Peltier module contributes to increased electrical output, but factors such as module quality and cooling system effectiveness also influence overall performance. This research underlines the importance of further development to improve Peltier module power and system design optimization, as well as providing a better understanding of the practical application of thermoelectric technology in energy conversion. With the right approach, this system can be a useful solution for utilizing wasted energy in various sectors, supporting the transition towards more sustainable and power energy use.

Suggestions for further research and development in the conversion of heat energy to electricity using Peltier technology include several approaches that can be taken to increase system efficiency and applicability. Research into hybrid systems that combine Peltier technology with other renewable energy sources could also provide more sustainable solutions. With this approach, it is hoped that energy conversion of power can be increased, and Peltier technology can be implemented more widely and economically in various sectors.

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