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EFFICIENCY AND EFFECTIVENESS OF CIRCUIT ARRANGEMENT AND PLACEMENT OF THERMOELECTRIC FOR THE DESIGN OF UTILIZING ZINC ROOF AS AN ELECTRICAL SOURCE

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ABSTRACT

The problem related to electrical power sources commonly encountered in society is the frequent occurrence of rotating power outages or sudden blackouts, which disrupt activities for both communities and industries as they heavily rely on electrical power to meet their needs, both collectively and individually. In order to meet the needs of society and industry, Indonesia requires a sufficiently large energy supply. One renewable energy source that can be utilized is solar energy due to its easy availability, cleanliness, and cost-effectiveness. In this study, an experimental method is employed, which utilizes the heat from zinc roofs and converts it into electrical energy using thermoelectric generators. Testing is conducted by varying the circuit arrangements, including series, parallel, and combined configurations, as well as the number of thermoelectric modules (20, 30, and 42 modules), and placement locations on zinc roofs and house ceilings, to observe the output results in terms of voltage and electrical current. As observed from the test results presented in the graphs, the output voltage and current vary for each type of circuit. Based on the use of various circuit arrangements, it can be concluded that combining thermoelectric generators results in higher current and voltage values. The greater the number of thermoelectric modules, the larger the output value. There is a difference in output values between placement on zinc roofs and ceilings, with higher output values observed when installed on zinc roofs. This is due to direct contact between the hot side of the thermoelectric generator and the inner part of the zinc roof. All data obtained from these variations depend on the temperature difference between the hot and cold sides of the thermoelectric generator. The greater the temperature difference produced, the larger the voltage and current output from the circuit. This temperature difference affects the overall performance of the circuit.

Keywords: Thermoelectric Generator; Zinc Roof; Voltage; Current; Temperature Difference;

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INTRODUCTION

One significant issue that profoundly impacts the welfare of society is related to the existing and available electrical power sources. The problem associated with electrical power sources frequently encountered in society is the occurrence of rotating power outages or sudden blackouts, which hinder community activities. These outages have significant impacts on both industries and ordinary society, as all forms of activity rely on electrical power to support the needs of both groups and individuals.

Indonesia, in order to meet the needs of society and industry, requires a significant energy supply. Currently, Indonesia's energy consumption is still heavily dependent on non-renewable energy sources such as crude oil, coal, and natural gas. According to data from the National Energy Council, Indonesia's national energy demand reaches around 300-350 gigawatts per year. However, the majority of this energy supply is still derived from non-renewable fossil fuel sources, as mentioned earlier. Empirical data can provide a more concrete understanding of actual energy consumption, growth trends, and the potential transition to renewable energy sources. Integrating this data will assist in formulating more sustainable energy policies for Indonesia's future. These non-renewable energy sources are utilized by converting them into fuel for power plants, which convert the heat energy from combustion into mechanical energy with turbines and then into electricity using generators [1]. The utilization of fossil energy also has environmental implications, as a source of environmental pollution that contributes to greenhouse effects, ultimately leading to increased global warming and acid rain, thereby triggering various diseases that can threaten human life [2]. Hence, there is a need to utilize alternative or renewable energy sources abundantly available in nature as an energy source because they are continuously available, not quickly depleted, and can be renewed [2].

Solar energy, as one of the renewable sources of electricity, has been widely utilized by previous researchers using various methods and principles, one of which is the thermoelectric principle. Thermoelectricity is a direct conversion process from temperature difference (gradient) to electrical potential difference or vice versa [3]. A thermoelectric generator (TEG) is a device that converts heat energy (in this case, temperature difference) directly into electrical energy using the Seebeck effect [4]. Mostly, thermoelectric generators are used to harness waste thermal energy from an industrial process, which can then be reused as a power source [5]. Thermoelectric generators are environmentally friendly as they do not contain chemical products [6].

In the previous study [7], waste heat from zinc roof was utilized as a source of renewable electrical energy using a thermoelectric generator, where the heat from the zinc roof originated from solar heat energy. An advantage of the study was the addition of a fan with a constant speed of 5 m/s, which was used to maintain the temperature on the cold side of the thermoelectric, thereby influencing the output voltage generated. This is because the greater the temperature difference between the two sides of the thermoelectric, the greater the voltage produced. However, a limitation of the study was the use of only one method, which was the placement of the thermoelectric parallel to the ceiling, and employing only one circuit in the testing. Thus, it cannot be concluded that this method is efficient enough to be used and implemented in society.

With the existing advantages and disadvantages, this study intends to add another method to serve as a comparison for more efficient and effective results. This will be achieved by introducing an additional method of placing the thermoelectric generator directly on the zinc roof. Circuit variations will be implemented for each test, including series, parallel, and combined series-parallel configurations, with the number of thermoelectric generators varied for each circuit in every test. The variations conducted in this study aim to determine the design of the thermoelectric generator to be used, understand the relationship between the number of thermoelectric module units, investigate the impact of circuit arrangement on the generated voltage and current, and evaluate the efficiency of thermoelectric generator utilization by harnessing heat energy from both zinc roof and ceiling.

METHOD

Experimental method is a research method aimed at investigating or determining the possibility of a cause-and-effect relationship conducted under controlled conditions [8]. The experimental research method employed in this study involves converting heat energy from the zinc roof into electrical energy using a thermoelectric generator (TEG).

This research was conducted in various stages, involving variations in both circuit configurations and the number of thermoelectric modules at each placement location. The thermoelectric circuitry was based on the types of circuits to be used, including series, parallel, and combined series-parallel circuits, utilizing cables as connections between the thermoelectric modules. The variations in quantity involved using 20, 30, and 42 thermoelectric modules, each placed on both the zinc roof and the house ceiling.

(a) (b)

Figure 1. Circuit Placement (a) on Metal Roofing (b) on Ceiling

This study conducts preparatory work prior to data collection by testing the performance of a thermoelectric generator (TEG) circuit. This is done to ascertain whether the thermoelectric module, intended for use as its primary device, functions properly or not. The thermoelectric generator circuit is attached to a heatsink using thermal paste on the cold side of the thermoelectric generator, which adheres to the heatsink surface. The thermoelectric generator circuit is affixed to the inner side of a metal roof with the hot side of the thermoelectric module adhering to the metal roof, and to the ceiling of the house, installed parallel to the ceiling. Ensuring that all components are properly and securely installed, ready for testing.

Data collection in this study involves measuring the temperature of the metal roof as the hot side (high temperature) and the room temperature around the cold side of the thermoelectric generator (low temperature) on the heatsink using a thermometer. Voltage and current generated are measured using a multimeter. Measurements are taken simultaneously on the same circuit for the thermoelectric generator directly attached to the metal roof and the one parallel to the ceiling. Measurements are taken every 10 minutes from 06:00 to 18:00 local time. The measurement results are recorded. The same measurements are conducted for parallel circuits and series-parallel combined circuits. Testing is conducted for 2 days for each test on the same circuit with different placements. For each circuit, the testing process is conducted gradually. All circuits for testing on the metal roof and on the ceiling begin with 20 thermoelectric modules, then 30 modules, and finally 42 modules.

The data collected in each test will be computed, and the results of these calculations will be analyzed to draw conclusions. The data analysis calculation used in this study involves calculating the power (W) generated by the circuit using the following equation [9].

$$P = V \times I \tag{1}$$

Where V and I represent the voltage and current values obtained from the output of the thermoelectric generator circuit. From the obtained power values, the electrical energy of the circuit can be calculated using the following equation [10].

$$P = \frac{\mathrm{W}}{t} \tag{2}$$

Additionally, the performance efficiency of the thermoelectric generator system in each test is calculated using equation [11].

$$\eta = \frac{P_o}{P_i} \times 100\% \tag{3}$$

In this context, P_o represents the output power of the system (W), and P_i represents the input power of the system (W). Meanwhile, effectiveness is the relationship between the output and the intended goal or objective. The greater the output achieved relative to the specified goals and objectives, the more effective the functioning of an organizational unit [12].

RESULTS AND DISCUSSION

The thermoelectric generator is a device that operates according to the Seebeck effect principle, which can directly convert heat energy into electrical energy [13]. The heat energy converted into electrical energy in this study originates from the heat of the metal roof. In this case, the heat source from the metal roof comes from solar energy, which is one of the renewable energy sources and is freely available on the Earth's surface.

In the placement on the metal roof, the positioning of the device is divided into two sides to adapt to the model of the metal roof used in the house. This approach aims to maximize heat absorption on the hot side of the thermoelectric generator from the heat source, namely the metal roof. The use of the heatsink surface area in this study is determined by considering the size of the device to be hung on the metal roof and ceiling. The size of 30 cm x 30 cm is ideal for installing the device by hanging because it is neither too small nor too large, which could cause the device to fall to the floor due to excessive weight. Given various limitations, this device only utilizes the ceiling, wooden frame, and nails to secure the device to prevent it from falling. The heatsink is employed to assist in enhancing heat dissipation on the cold side of the thermoelectric generator, thereby increasing the efficiency of the module. Thermal paste serves as an adhesive, which also aids in maximizing the heat transfer process from the cold side of the thermoelectric generator to the heatsink [14].

The output of the thermoelectric generator circuit in the testing phase consists of current and voltage. The greater the output voltage generated, the higher the power value of a circuit [15]. Additional data obtained during the testing includes temperature and the intensity value of sunlight. Below are the average output data for each circuit presented in graphical form.

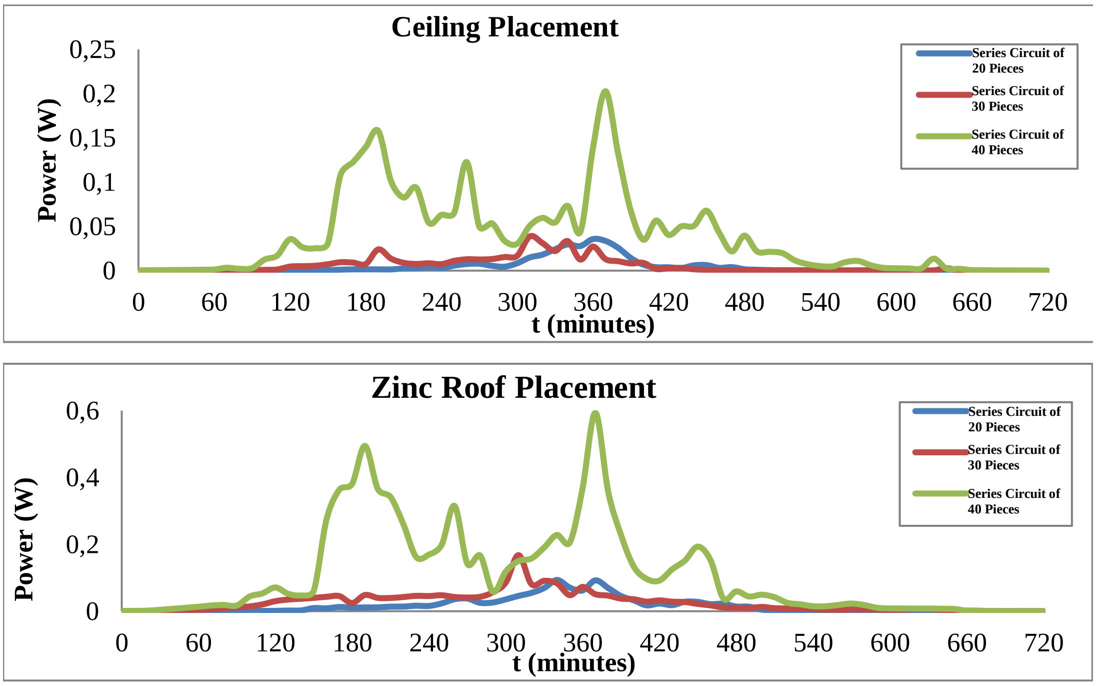


Figure 2. The Relationship between Time and Power of Series Circuit Placement on Metal Roof and Ceiling Placement from 06:00 AM to 06:00 PM WITA

Based on the testing of the series circuit as shown in Figure 2, it is evident that the highest output value is observed with 42 pieces of thermoelectric generators. Meanwhile, the lowest output value is observed with 20 pieces of thermoelectric generators, regardless of whether they are placed on the metal roof or ceiling. However, for the metal roof placement, the output value is higher compared to the ceiling placement.

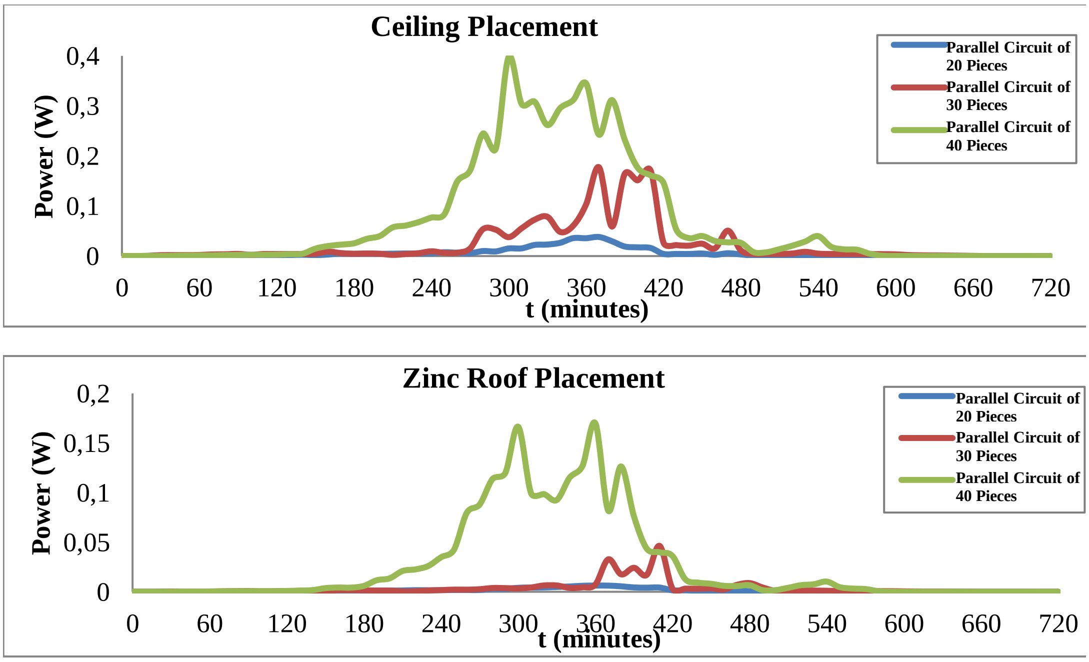


Figure 3. The Relationship between Time and Power of Parallel Circuit Placement on Metal Roof and Ceiling Placement from 06:00 AM to 06:00 PM WITA.

Testing on the parallel circuit yielded similar results to the series circuit testing, whereby the variation with 42 pieces of thermoelectric generators had a higher output value compared to variations with 30 and 20 pieces of thermoelectric generators. However, the output value in the parallel circuit was not greater than that in the series circuit. This can be observed from the maximum output value achieved by the parallel circuit, reaching only 0.4 W, while the series circuit reached 0.6 W for the metal roof placement. Similarly, for the ceiling placement, although there was a small difference, the output value of the series circuit was higher by 0.2 W compared to the parallel circuit, which was 0.16 W.

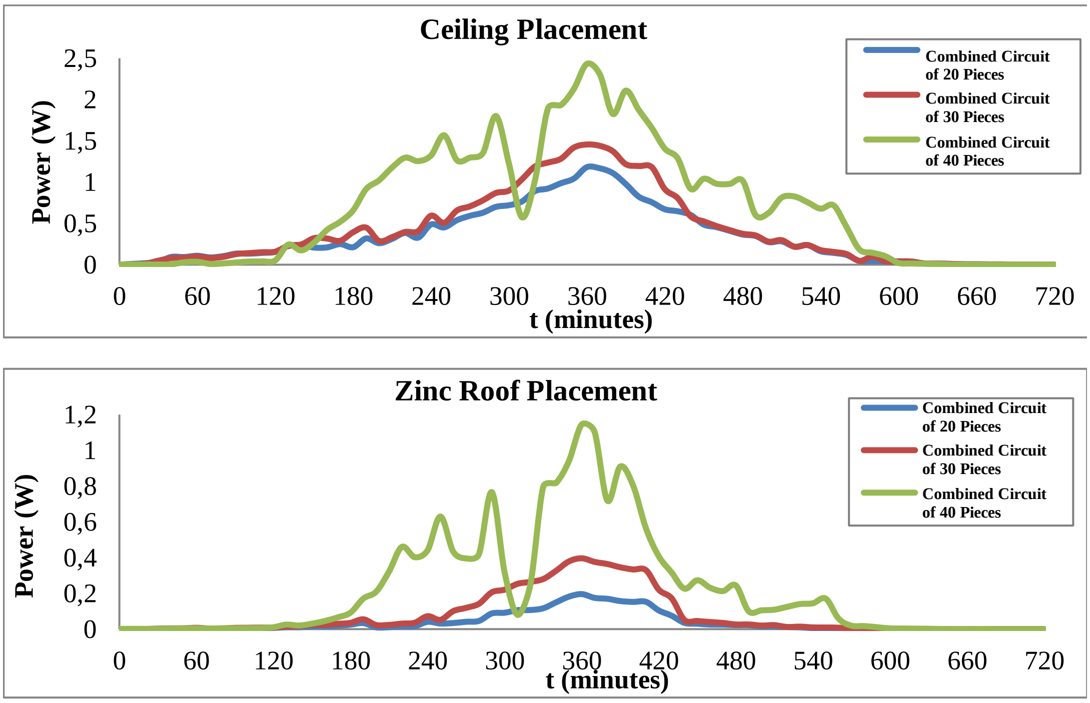


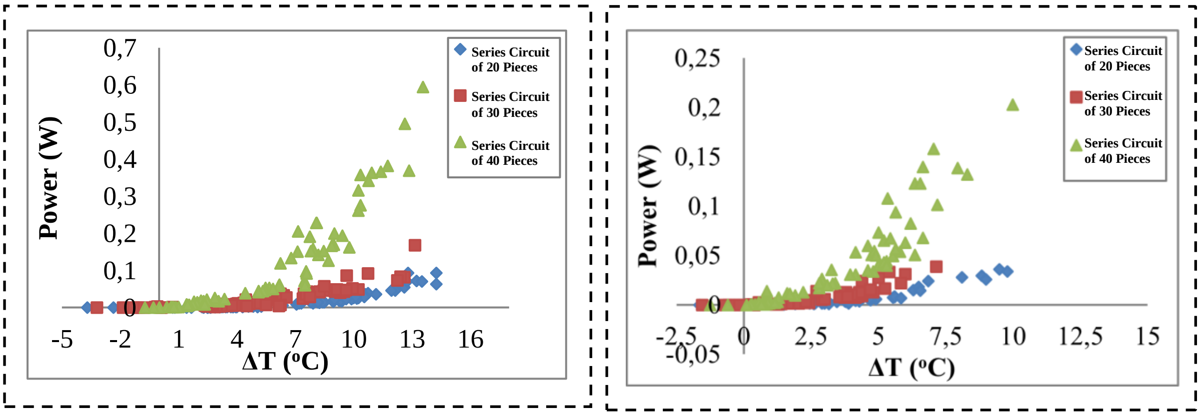
Figure 4. The Relationship between Time and Power of Combined Circuit: Zinc Roof and Ceiling Placement from 06:00 WITA to 18:00 WITA

Figure 4 illustrates that the variation with 42 pieces of thermoelectric generators, whether placed on the metal roof or on the ceiling, resulted in higher values. The output of this combined circuit is also greater than that of both the series and parallel circuits. It can be observed that the highest achieved value by the combined circuit reaches 2.5 W for the metal roof placement and 1.2 W for the ceiling placement.

The utilization of various circuit arrangements, the number of thermoelectric modules, and their placements in this study aim to observe the magnitude of the thermoelectric output. As seen from the test results presented in the graphs, the power output for each type of circuit varies. The use of different circuit arrangements concludes that thermoelectric generators combined (series-parallel) yield higher output values, and the greater the number of thermoelectric modules, the higher the output value generated by the circuit. Similar to previous research [16], an increase in the number of thermoelectric modules connected in series, followed by connecting them in parallel, can result in an increase in the output voltage.

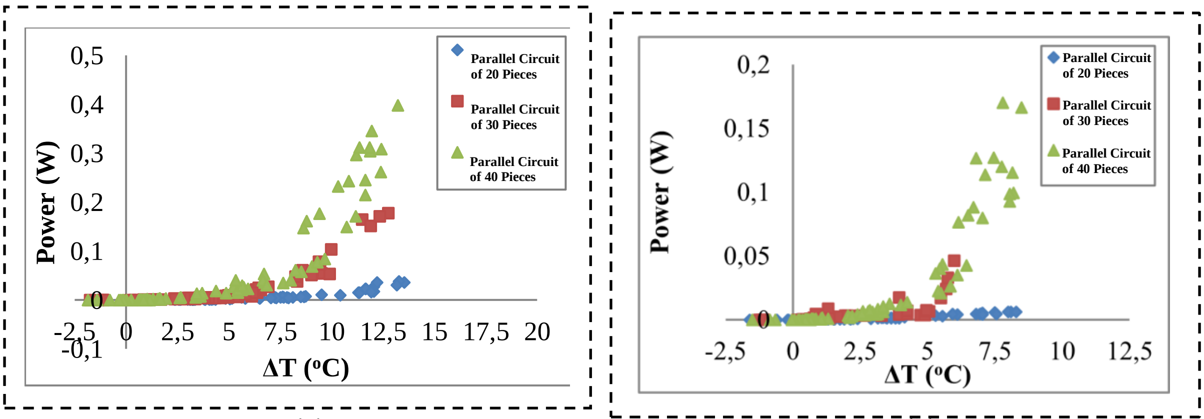
The utilization of metal roofs as a heat source in this study is because the majority of the population uses metal roofs as roofing or house covering material. The researchers intended to utilize an available heat source that is present in almost every household, allowing for daily utilization during sunlight exposure periods as one of the energy sources. Data collection per day was conducted to observe the output of the circuit and the value of solar radiation intensity each day.

The entirety of the data obtained using the provided variations depends on the temperature difference between the hot and cold sides of the thermoelectric generator. The greater the temperature difference generated, the higher the voltage and current output from the circuit. For instance, research [17] resulted in a voltage of 5 V greater with a large temperature difference of 70°C. The output value of the circuit in the metal roof placement is higher because the hot side of the thermoelectric generator is in direct contact with the inner side of the metal roof. Therefore, the heat transfer in the thermoelectric generator from the metal roof is faster compared to those placed on the ceiling. This phenomenon of heat transfer is commonly known as conduction heat transfer. Meanwhile, on the ceiling, heat from the metal roof does not directly transfer to the surface or hot side of the thermoelectric generator. This is because the circuit in the ceiling placement does not have direct contact with the metal roof. The heat transfer that occurs in the circuit with ceiling placement is typically referred to as convective heat transfer, where heat is conveyed through a fluid medium.



(a) (b)

Figure 5. The Relationship between Temperature Difference and Power of Series Circuit: (a) Zinc Roof Placement (b) Ceiling Placement



(a) (b)

Figure 6. The Relationship between Temperature Difference and Power of Parallel Circuit: (a) Zinc Roof Placement (b) Ceiling Placement

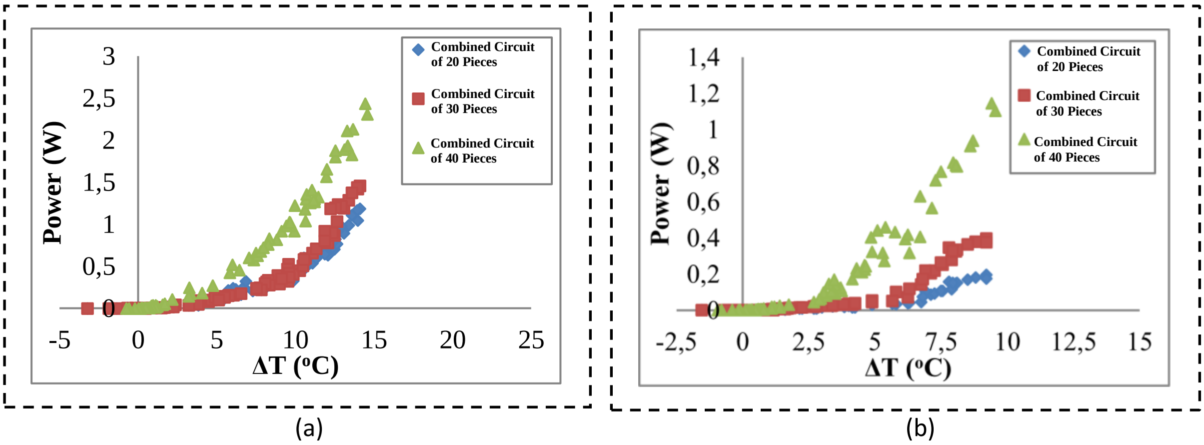


Figure 7. The Relationship between Temperature Difference and Power of Combined Circuit: (a) Zinc Roof Placement (b) Ceiling Placement

The relationship between temperature difference and the output power of a thermoelectric generator in series, parallel, and combined circuits is illustrated in Figures 5, 6, and 7. It is observed that the temperature difference occurring in both placements is not the same. Placement on the zinc roof shows a greater temperature difference compared to placement on the ceiling. It can be seen that the greater the temperature difference between the hot and cold sides of the thermoelectric generator, the larger the output value generated.

Indirectly, there are several factors that influence the magnitude of the temperature difference between the two sides of the thermoelectric generator and subsequently affect the output value of the circuit. The thickness of the thermoelectric plates is one of the influencing factors because it is only 3.6 mm thick, which means the distance between the hot and cold sides of the thermoelectric generator is very close, causing the air temperature around the cold side of the thermoelectric generator to rise rapidly. The absence of cooling machinery such as fans or similar devices results in the temperature on the cold side of the thermoelectric generator having only a small difference compared to the temperature on the hot side.

The weather conditions during the data collection varied constantly. This is evident from the recorded values of sunlight intensity (Lux) observed each day of testing, ranging from 06:00 AM Wita to 06:00 PM Wita. Due to these changing weather factors, the temperatures on the zinc roof and in the room also fluctuated, leading to fluctuations in the output values of the thermoelectric generator circuit, including both current and voltage. Therefore, in each graph, the output values of the circuit displayed fluctuations or were characterized as fluctuating.

The efficiency of the thermoelectric generator design in the placement on the zinc roof and on the ceiling can be observed in the following table.

Table 1. Calculation Results of the Efficiency of Thermoelectric Generator Design Placement on Zinc Roof

Circuit Arrangement	Number of TEGs	P_o (W)	P_i (W)	η (%)
Series	20	0,0159	3,8619	0,004117
	30	0,0261	3,4875	0,007484
	42	0,1108	3,4379	0,109525
Parallel	20	0,0059	3,5063	0,001683
	30	0,0225	2,9279	0,007685
	42	0,071	3,2288	0,02199
Combined	20	0,3356	4,3806	0,076611
	30	0,4116	4,5237	0,090987
	42	0,7041	3,9711	0,177306

From the table above, it can be observed that the highest efficiency value is in the series circuit and the combined circuit with a variation of 42 plates, with efficiency values of 0.109525% in the series circuit and 0.177306% in the combined circuit. The lowest efficiency value in this study, with variations in zinc roof placement, is in the parallel circuit using 20 thermoelectric plates, which is 0.001683%.

Table 2. Calculation Results of the Efficiency of Thermoelectric Generator Design Placement on the Ceiling

Circuit Arrangement	Number of TEGs	P_o (W)	P_i (W)	η (%)
Series	20	0,00449	1,6657	0,002696
	30	0,00588	1,3352	0,004404
	42	0,03854	2,0753	0,018571
Parallel	20	0,0013	1,6216	0,000802
	30	0,00344	1,0062	0,003419
	42	0,0268	1,9405	0,013811
Combined	20	0,0615	2,0554	0,029921
	30	0,0775	2,0732	0,037382
	42	0,224	2,0452	0,109525

Testing the circuit placement on the ceiling, the highest efficiency value is in the combined circuit with a variation of 42 thermoelectric generator plates, with an efficiency value of 0.109525%. The lowest efficiency is in the parallel circuit with a variation of 20 plates, with a value of 0.000802%. The efficiency values for the ceiling placement are lower compared to the efficiency values obtained from testing on the zinc roof.

Based on the efficiency measurement table of the thermoelectric generator design, both for placement on the zinc roof and on the ceiling, it is evident that the combined circuit, particularly with a variation of 42 plates, yields higher efficiency values compared to circuits with other plate variations. In the zinc roof placement, the efficiency values are higher compared to those in the ceiling placement. Therefore, the combined series-parallel circuit is more effective to use as it produces greater output values compared to both series and parallel circuits. Additionally, the more thermoelectric generator plates used, the larger the output value of the circuit. Furthermore, increasing the temperature gradient between the hot and cold sides by directly placing the thermoelectric plates closer to the heat source, in this case, the zinc roof, enhances the output value of the circuit, making such circuit variations more effective and efficient for future use.

CONCLUSION

For each series in every test, varying the number of thermoelectric chips conducted concludes that the greater the number of thermoelectric generator chips, the greater the output current and voltage or power generated. This can be observed from the average electrical power of the thermoelectric generator. In each series, the smallest value is at a variation of 20 chips, while the largest value is at a variation of 42 chips. The placement on the zinc roof, for series circuits, is 0.01589 W and 0.1108 W, for parallel circuits 0.0059 W and 0.071 W, and for combined circuits 0.3356 W and 0.7041 W. Meanwhile, placement on the ceiling, for series circuits is 0.00449 W and 0.03854 W, for parallel circuits 0.0013 W and 0.0268 W, and for combined circuits 0.0615 W and 0.224 W. The arrangement of thermoelectric generator circuits has a significant effect on the output current and voltage of the circuit. By observing the average electrical power values, combined series and parallel circuits produce greater power values compared to series circuits or parallel circuits for each thermoelectric generator placement. The smallest output is in parallel circuits. The placement of the circuit also affects the output of the circuit. Where the closer the circuit is to the heat source, the greater the temperature of the hot side of the thermoelectric generator, which can cause a greater temperature difference. Then, the greater the temperature difference between the hot side and the cold side of the thermoelectric generator, the greater the output voltage and current or power of the circuit.

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