Experimental study of cascaded thermoelectric generators with differences in focal length using LED lights energy radiation

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Abstract. The length of concentration focus to the cascaded thermoelectric generator (TEG) module determines the power of the output along the entire surface of the heated side receiving the thermal radiation. LED-type (Lighting Emitting Diode) bulb with low power 10, 15, and 20 Watt shown that the emitted lights also contain the thermal that can generate electricity on the TEG. The experiment results show that the 20 Watt lamp with a concentration focus of 110 mm has the highest power and efficiency (2.5%), while the efficiency of 15 and 10 Watt bulbs is 1.2 and 1.6%, respectively. The significant amount of bulb power used by consumers today has the potential to be the source of new and renewable energy to produce electricity. Although the amount of power still small, it can be used to charge mobile phones and power banks.

1. Introduction
Discourse over clean and renewable energy becomes the topic that many people hold as one of the solutions to anticipate the fossil energy crises, which diminishes over time. One of the less-researched sources of thermal energy is indoor bulb radiation. The bulb known to people as energy-efficient lighting is LED (Lighting Emitting Diode). LED’s primary function is as the source of lighting, but the bulb also produces thermal radiation. The heat can be utilized by a thermoelectric generator (TEG). In general, research on TEG focused on the calefaction was sourced from the heat dissipated from the engine’s combustion chambers, radiator chamber, and other combustion mechanisms, for example, the heat from the organic and inorganic waste incineration. TEG module as the technological tool working under the Seebeck effect can utilize exhaust heat as the thermal input to generate electric current due to the voltage difference in the type p and n semiconductor materials TEG pin. TEG has many advantages, among others, direct energy conversion, absence of moving parts, and operating without noise and environmentally friendly. Despite its low-efficiency value, it does not prevent the researchers from losing their motivation to continue the investigation and modification in different applications. Some experimental investigations related to the use of exhaust heat, such as Hsiao et al.,[1] have put TEG at the exhaust pipe and radiators chambers of the vehicle engine. The result showed a better TEG performance in the exhaust pipe. A group of researchers from Komatsu company has made a large-scale development on this exhaust heat, like Snyder [2], who utilized the exhaust heat in the vehicles. He
installed the BiTe/Silicide cascade-type module, which produced DC electricity power as the power charger to the automotive battery that can reduce and even replace the alternator functions in the cars.

Kaibe et al., [3-4] have developed 16 parallel and serial Bi-Te cascade-type TEG modules. Four batteries with 12V-65Ah capacity stores the generated power. Mahmud et al. [5] developed the model and prototype of thermal electric modular utilization for TEG from various types of materials; Bi$_2$Te$_3$ (Bismuth Telluride), PbTe-Bite, CMO and CMO Cascade-32-62S-32-62S [Calcium Mangan oxide]. The output powers of the TEG produced 0.091 Watt, enough to charge a mobile phone.

Concerning the utilization of bulb heat radiation, Mustofa et al. [6] performed an early investigation using halogen, incandescent, and xenon light bulbs with power on a single hybrid of mini PV and TEG. Their research merely described the light radiation and wavelength without explaining the characteristics of PV and TEG. Meanwhile, Piarah et al. [7], in his research, used a 50-Watt Halogen light bulb with hot mirror spectrum separator. The source of the radiation spectrum of the Halogen light bulb did not reflect the reality on the ground, and that type of light bulb was used merely for experiments, not reflect the daily usage needs. Therefore, the utilization of LED light bulb type, dubbed in electronic media as an energy-efficient light bulb, as the source of energy provides an exciting option to test the utilization of TEG in the household, particularly at night. Therefore, the purpose of this research is to optimize the LED light leading to reduce the wasting energy. Moreover, the length of the Fresnel lens focus will be varied to obtain optimum TEG output power.

2. Materials and Methods
2.1 Experimental set-up
This experiment uses the Peltier module made from ceramic material/Bismuth Telluride with TEC1 12706 model with dimensions of 40x40x3.4 mm and an operating temperature of 29-50°C. Meanwhile, to focus the LED light radiation used Fresnel lens from Polymethyl methacrylate (PMMA) material with the dimension of 112x73 mm and 110 mm focal length, 2 mm thick lens with 92% light transmittance. As displayed in Fig 1, a thermoelectric module is placed under the Fresnel (Fl) lens, while the LED light bulb is positioned at the top and covered. Its light beam is focused on the FL and further transmitted to the TEG. The TEG module is stacked and connected in series. The focus length of the FL and TEG module is placed in three positions (110, 120, and 130) mm. The objective of the placement is to find out the parameters affecting the performance of the Peltier module with the radiation of the low intensity LED light bulbs.

During the observation, a rotary potentiometer is used to regulate the R load of the electricity produced by the TEG. As for the commercial power of the LED light bulbs, variations of 20, 15, and 10 Watt with different bulb diameters were used (Fig 2). The selection of the power is made based on the intensity that people generally use so that the bulb will have a double function mainly in the peak-hours if further development is aimed to conserve household electricity consumption supplied by the state electricity company (PLN).
2.2 Model equation
The calculation of TEG ($P_{TEG}$) power refers to the output power resulted from the calculation of the current flows through the resistor in the circuit. The following equation defines the output power:

$$P_{TEG} = I_{TEG}^2 R_{Load}$$  \hspace{1cm} (1.1)

with,

$$I_{TEG} = \frac{\alpha(T_{hot} - T_{cold})}{R_{TEG} + R_{Load}}$$  \hspace{1cm} (1.2)

because 2 TEG modules are connected in series, therefore $R_{TEG} = R_1 + R_2$
while $\alpha$ is the Seebeck coefficient obtained from the following equation:

$$\alpha = \frac{\Delta V}{T_{hot} - T_{cold}} \quad \text{(V/°C)}$$

(1.3)

and,

$$R_{TEG} = \text{integral load of TEG (3.96 } \Omega)$$

$$R_{Load} = \text{circuit load (} \Omega)$$

The electricity current is calculated with the following equation

$$I = \frac{\alpha(T_{hot} - T_{cold})}{R_{TEG} + R_{LOAD}}$$

(1.4)

While for the absorbed heat ($Q_h$) is determined from the below equation

$$Q_h = \alpha I T_h + K(T_{hot} - T_{cold}) - 0.5 I^2 R_{TEG}$$

(1.5)

where $k$ is the module’s thermal conductivity, $T_{hot}$ means the temperature of the heated side, $T_{cold}$ is the temperature of cold side, $I$ means the TEG current, $\alpha$ is the Seebeck coefficient, $R_{TEG}$ refers to the internal resistance, $A_{TEG}$ size of the TEG surface and $t$ is TEG. For efficiency calculation ($\eta$), the TEG modules can be calculated with the equation below::

$$\eta_{TEG} = \frac{P_{TEG}}{Q_h} \times 100$$

(1.7)

3. Results and Discussion

3.1. The size of LED light area and characteristics of TEG power

3.1.1 Focus length with TEG module (110 mm)

Fig. 3 showed the diameter of the LED light size transmitted by Fl to the heated side of the TEG stacked and connected in series. The diameter of the light is located at the optimum focal point based on the dimension of the heated side of the module’s surface. It shows that the thermal radiation is within the optimum intensity that the bulb can emit.

![Figure 3. The diameter of LED lights to TEG, 110mm](image)

Subsequently, the thermal radiation of LED light bulb with 10, 15, and 20 Watt of power generates the characteristics of power-voltage P-V and current-voltage I-V of the TEG, as shown in Fig 4. It is
noticeable that the maximum output power of TEG is generated by using a 20 Watt light bulb by $10 \times 10^{-3}$ $\mu$Watt at 2.5 Volt (Fig 4c). The result also shows that the higher the radiation power of the LED, the bigger the output power of the TEG at a focal length of 110 mm from the Fresnel lens.

(a)

(b)
Figure 4. Characteristics of P-V and I-V in cascaded TEG, 110 mm(a) 10, (b) 15, and (c) 20 Watt

3.1.2 Focal length with TEG module (120 mm)
Unlike the Fig 3, the LED light bulb’s diameter transmitted by Fl to the heated side of the TEG is somewhat higher with the lens distance and the heated side of the module’s surface of 120 mm. The explanation is because since it moves away from the focus area of the lens, diminishing the intensity and thermals.

Figure 5. The Diameter of LED light to TEG, 120 mm

The characteristics of the current, the voltage of TEG module electricity show a similar trend with the focal length of the Fresnel lens of 110 mm and 120 mm, respectively. Although the 20-Watt bulb has higher maximum power compared to the 15-Watt bulb, the value is almost similar by 3.5 with $3 \times 10^{-3}$ µWatt or 0.5 difference.
Figure 6. Characteristics of P-V and I-V in cascaded TEG, 120 mm; (a) 10, (b) 15, and (c) 20 Watt
3.1.3 Focal length with TEG module (130 mm)

It is evident in Fig 7 that the light emitted by the LED as transmitted by Fl to the heated side of the TEG expands to the edges of the TEG and shows a diminishing thermal intensity and radiation. It is consistent with the amount of electric power released because of the Seebeck effect of the TEG modules. Interestingly, the maximum power at the farthest focal length from the Fresnel lens is produced by thermal radiation of 15-Watt light bulb and not 20-Watt (Fig 8). It is different in a focal length of 110 and 120 mm, where both produce the optimum power in 20-Watt light bulbs. One of the causes is the variations in the bulb diameter of 10, 15, and 20-Watt in 50, 54 and 57 mm, respectively affecting the thermal radiation transmitted by the Fresnel lens.

**Figure 7.** The diameter of LED lights to TEG, 130 mm
3.2 TEG Efficiency

The experiment results and calculation analysis show that the value most efficient (2.5%) is obtained at the focal length, the distance between the Fresnel lens with TEG modules, of 110 mm, using 20-Watt light bulbs. The next most efficient is a 120 mm focal length with the same light bulb power. At a focal length of 130 mm, the efficiency value is almost the same for the three light bulb powers (10, 15, and 20) Watt (Fig 9).

Figure 9. The efficiency of cascaded TEG series
4. Conclusions
The heat energy emitted by the LED light bulb is not significant enough to produce a temperature difference between the hot and cold sides of the thermoelectric generator module, consequently the resulting voltage is less than 1 Watt. Furthermore, the amount of power and efficiency produced by the TEG is determined by the focal length of thermal radiation size received by the heated surface of the TEG and the thermal radiation power of the light bulbs. The bigger the light bulb power, the bigger the thermal radiation emitted, as reported by Piarah [8] research. It is interesting to conduct a further investigation to find out the spectral power of the light spectrum transmitted to the TEG [7] and its implication against the additional heat absorbers on the TEG. More LED light bulb radiation is also needed for a further research.

Acknowledgments
The authors acknowledge the Faculty of Engineering of the University of Tadulako for supporting this research. We also feel indebted and want to express our appreciation to Haslan and Rahim Ma'ruf who helped collect this research data.

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