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Solar Thermoelectric Generator (STEG) for Lighting System

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Abstract: The Covid-19 pandemic has dramatically affected the B40 household in Malaysia. One effective method to lessen the burden of this is to conduct an optimal electrical energy consumption to minimize everyday expenses such as a thermoelectric generator. However, around 2.8 million B40 communities were estimated to have lost their jobs as a result of the Covid-19 outbreak in March 2020, resulting in financial difficulties. Therefore, this project discussed developing a prototype solar thermoelectric generator (STEG) for a lighting system using renewable energy. The significant parts of this project consist of the Peltier plate module, LED, wire, heat sink, fan, and battery. The Peltier plate module which is known as thermoelectric plate absorbs the sunlight, which will later cause a temperature differential that produces electricity through the Seebeck effect. The efficiency of a STEG is thus determined by both the efficiency with which sunlight is transformed to heat and the device's thermoelectric efficiency. Its efficiency depends on the temperature difference between the sides of the thermoelectric generator plates.

Keywords: Solar Thermoelectric Generator, Lighting System, Electrical Energy

1. Introduction

The Covid-19 outbreak that struck Malaysia in 2019 has disproportionately impacted low-income households, including the B40 household. The B40 section relates to the country's lowest incomes, which account for roughly 40% of the country's overall income. Around 2.8 million B40 communities were estimated to have lost their jobs as a result of the Covid-19 outbreak in March 2020, resulting in financial difficulties. A way to reduce each household's spending is to conduct an optimal electrical energy consumption to minimize everyday expenses such as a thermoelectric generator. Thermoelectric have commonly been used for deep-space research and waste heat recovery. The research is to

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investigate the ability of thermoelectric with solar energy for electricity generation using a solar thermoelectric generator (STEG) that can help to solve the socioeconomic issue of the affected B40 household.

Solar thermal is the conversion of solar radiation into thermal energy or electrical energy for industrial, commercial or residential purposes [1]. Solar collectors are used to collect the solar radiation thereafter; the radiations can be stored or directly used for warming the air or water for domestic, industrial or commercial use [2]. Thermoelectric generators are used in a wide-areas of applications like recovery of waste heat for automobiles [3]-[5], wearable sensors [6], micropower generation [7], wireless sensor network [8], space power [9] and buildings [10]. Thermoelectric coolers are used in cooling electronic devices [11] refrigerators and air conditioners [12] and for specific applications in military, aerospace, instrument, biology, medicine and industrial products [13].

This project is aim to develop solar collector which is called a parabolic reflector. As the solar collector absorbs the intense sunlight, the heated area of a thermoelectric generator mounted at this location produces heat. A selective area on the hot side of the material has a good absorbance which is more than 90 percent from 300 nm to 1000 nm. As a result, the hot side absorbs the majority of the solar energy. The majority of the solar energy incident on the generator tends to increase the temperature on the hot side area as suitable selective areas are used. The thermoelectric module converts a portion of this thermal energy to electrical energy through the Seebeck effect [14].

2. Materials and Methods

2.1 Steg working principle

STEGs work by absorbing sunlight, which will later cause a temperature differential that produces electricity through the Seebeck effect [15]. Once a temperature gradient (ΔT) is applied to a thermoelectric couple consisting of p-type and n-type semiconductor materials, the mobile charging carriers located at the hot end (heat source) diffuse to the cold end (heat sink) thus producing an electrostatic potential (ΔV). The process of producing potential difference due temperature gradient is known as the Seebeck effect. Thomas Seekbeck. The Seebeck coefficient is an intrinsic thermoelectric material property expressed as in Eq. 1 [16],

$$\alpha = \frac{\Delta V}{\Delta T} \qquad Eq. 1$$

Conversely, applying a current through the two junctions to a thermoelectric couple creates a temperature difference.

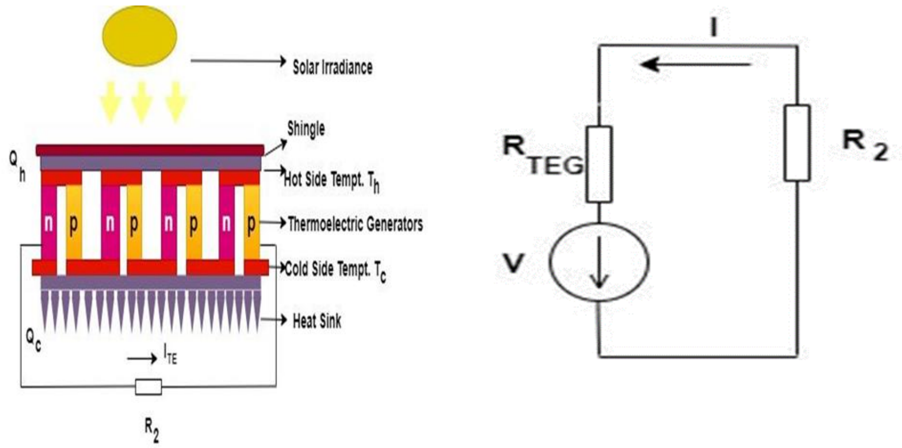
The efficiency of a STEG is thus determined by both the efficiency with which sunlight is transformed to heat and the device's thermoelectric efficiency [2]. Its efficiency depends on the temperature difference between the sides of the thermoelectric generator plates. Thermoelectric Generators Power output and efficiency [17] in Eq. 2, 3 and 4:

$$\alpha = (\alpha_p - \alpha_n)n \qquad Eq. 2$$
$$R = \left(\frac{\rho_p \text{l}_p}{S_p} + \frac{\rho_n \text{l}_n}{S_n}\right)n \qquad Eq. 3$$
$$K = \left(\frac{K_p S_p}{\text{l}_p} + \frac{K_n S_n}{\text{l}_n}\right) \qquad Eq. 4$$

Where α, ρ, and K are the Seebeck coefficient, electrical resistivity and the thermal conductivity of the semiconductor material of the TEG. Also n is the quantity of the TEG, ꞁ and S are the length and cross-sectional area of the semiconductor element while subscripts n and p represent the n- and p-type element in Eq. 5 and 6:

$$Q_h = \alpha T_h I_{TE} + K(T_h - T_c) - \frac{1}{2} I_{TE}^2 R \quad Eq.5$$
$$Q_c = \alpha T_c I_{TE} + K(T_h - T_c) - \frac{1}{2} I_{TE}^2 R \quad Eq.6$$

Where Q_h, Q_c are the thermal energy from the PV to the TEG and from the TEG to the heat sink, I_{TE} is the operating current of the TEG. The PV and the TEG are electrically isolated but thermally connected as shown on Figure 1 [18].



(a) Schematic Diagram of STEG System (b) The Equivalent Circuit of STEG
Figure 1. Basic Diagram of STEG System

To raise the temperature differential in a STEG, there are two suggested methods which are by using optical concentration and thermal concentration. Optical concentration focuses on the concentration of sunlight to increase the heat flux at the absorber surface while a thermal concentration focuses on allowing the rise of heat flux through the thermoelectric legs by having a highly thermally conducting absorber is greater than the area of the thermoelectric legs [3].

2.2 Materials

This project consists of only hardware tools. Below is the item that has been used in the project for the STEG. Figure 2 shows the block diagram of the prototype.

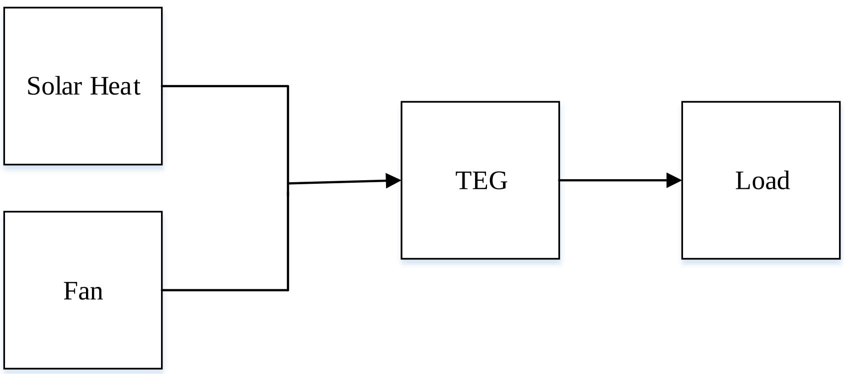


Figure 2: Block diagram of the project

The main components of the project are: peltier module, heat sink, module fan adan LED as the load of system.

i. Peltier module

There are four Peltier module TEC1-12705 that has been used in this project. The Peltier module has two sides which is a hot and cool side. The hot side will be receiving from the sunlight and the cool side of the module fan will be used. The module is the solid-state semiconductor device that transforms a temperature differential and heat flow into a practical direct current (DC) power source. The module will produce a voltage by the Seebeck effect. Figure 3 shows the peltier module used in this prototype.

Figure 3: Peltier module

ii. Heat sink

The heat sink is used to control the temperature of the module. It is important to the total system performance and must be emphasized [17]. Figure 4 shows heat sink used in this project.

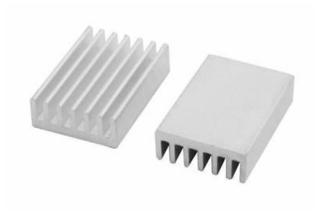


Figure 4: Heat Sink

iii. Module fan

The fan will be one medium to cool the cooling side of the Peltier module. So it can generate more energy with the hot side of the module. The fan will be activated with an external source which is a battery. Figure 5 shows the module fan used in the project.

Figure 5: Module fan

iv. Load

The LED will be medium of load for the project. The LED may be a benefit for increased energy efficiency, longer bulb life, and safer light source. The LED needs to be light up at the end of the process of this project from the source of the peltier module. Figure 6 shows the LED as a load used in the project.

Figure 6: LED

v. House Model

The house will be a prototype for the LED as a lighting system in the house. The house can give a proper look if the project builds in a real project. Figure 7 and Figure 8 shows the connection of the system and full prototype with house in this project.

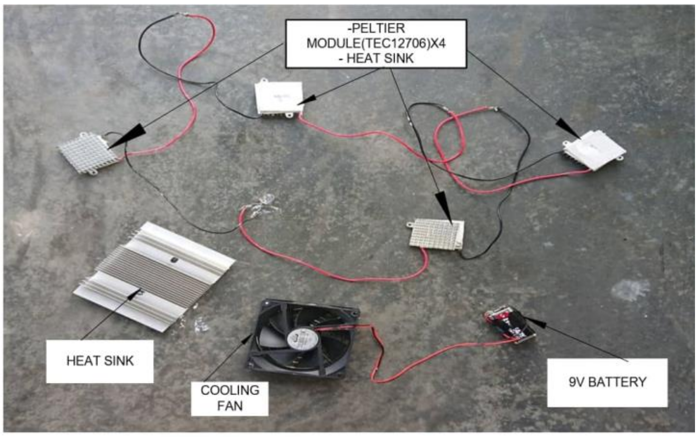


Figure 7: Connection of system

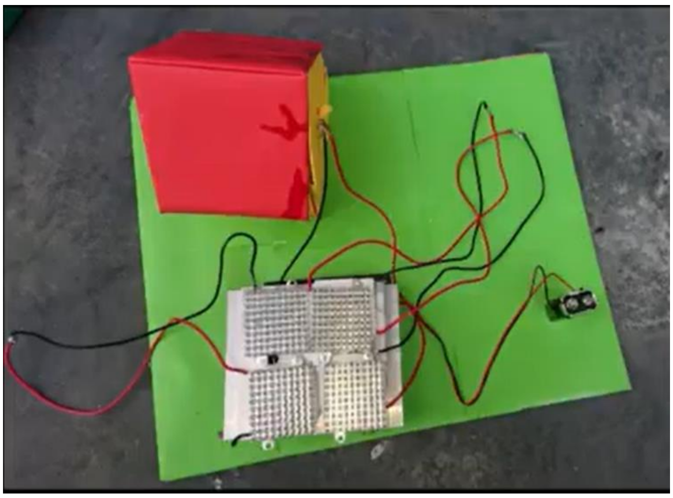


Figure 8: Full prototype with house

3. Results and Discussion

To testing the project prototype, two experimental setups have been executed as follows:

a) The voltage output of the project
b) The voltage output to turn on the lighting system

3.1 The voltage output of the project

To develop a prototype that can supply energy for the lighting system, the testing regarding the potential difference between two sides of the peltier module, the cool side and hot side is important to ensure the voltage generated can be implemented in this project.

This testing was conducted by developing two sides of the Peltier module, cool side, and hot side hardware setup. The cool side is controlled by the module fan to maintain a low temperature and the hot side is controlled by the variation of the sunlight (by increasing the time, the temperature goes higher).

The temperature of the cool side that controlled by the module fan maintained at 20 °C. The variation of the temperature for the hot side and the voltage generated is shown in Table 1.

Table 1: The variation of the temperature for the hot side and the voltage generated

Heat Temperature (°C)	Voltage Generated (V)	Voltage Reading by The Multimeter
28.9	0.96	
31.3	1.23	
33.7	1.42	
36.0	2.04	

The experiment shows that if the differential of temperature maintains the temperature of the cool side and varies the temperature of the hot side, it gives the variation of the generated voltage into a practical direct current (DC) power source.

3.2 The voltage output to turn on the lighting system

After the voltage generated by the prototype was tested, it is ready to connect to the lighting system of this prototype in which the LED. It is enough to supply 2 V to turn-on of the LED as the minimum voltage required by the LED is 1.5 V. Figure 9 shows the LED turned on after it was supplied by practical direct current (DC) power source of the prototype that has 2 V.

Figure 9: Lighting system supplied by the DC power system of the prototype

4. Conclusion

Many people, especially those in the B40 community, are currently affected by the economic downturn. They struggle to earn a living. This project's main objective is to reduce their burden of paying power bills by using renewable energy as the primary source of energy, which would undoubtedly reduce the costs. By utilizing a combination of solar and thermal energy, the savings regarding the electrical system will be optimal for the users. In the future, there will be an addition of features to make the product more reliable in terms of user friendly. For example, send data to the user about heat stored in the thermal itself by installing Internet of Things (IoT) technology into the product to make sure that the product is always monitored.

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