Energy Harvesting using Thermoelectric Generator Applied to Food Stand

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***Abstract*—Thermoelectric generators (TEGs) are solid state device that works similar to solar panels. This study is done to design a system that will harness the thermal energy from the food stand and convert it into electrical energy to charge lithium-ion batteries and power up a 2 watt LED bulb. A microcontroller-based data logger is used to read and store the hot and cold temperature as well as the voltage and current produced by the TEGs in a SD card. The study proves that the installed TEG system does not affects the consumption of kerosene and ice. Furthermore, the study showed that there is a significant difference in the voltage produced when ambient temperature is used as the cold source of the TEGs when compared to the voltage produced when a cold source was used. Using a DC-DC step up boost converter, the produced voltage of the TEGs are step up to 5V which is needed to charge a Lithium-ion battery with a capacity of 2200 mAh. Having an average current of 360mA, the charging time is 6 hours for the battery to be fully charge. Charged batteries can power up a 2 watt LED bulb which can last up to 10 hours of usage.**

***Index Terms*—Energy Harvesting; Thermoelectric Generator; Food Stand; Microcontroller; Renewable Energy.**

I. INTRODUCTION

Fossil fuel causes environmental concerns and it will someday deplete [1]. Civilization is very dependent on fossil fuel to power up our cars, appliances, and other gadgets. However, using fuel causes environmental concerns and it will someday deplete. That is why many scientists and engineers have been discovering and developing systems that are capable of ambient energy scavenging to produce energy which is environment friendly and also came from renewable sources. Ambient energy scavenging or energy harvesting is the process of obtaining usable energy from nature and man-made sources that can be found in our environment and everyday lives. Mechanical vibration, heat, solar, and wind energies are some energy that are naturally occurring and can be harvested. These said energies can be gathered by using devices that converts these energies to electrical energy which are called transducers. Currently, scientists and engineers are still discovering new source of energy and developing existing energy harvesting technology to be more efficient [2].

Renewable energy sources can be: solar, thermal, acoustic, mechanical and others. One of the renewable energy currently under study is the thermal energy which is harvested using a thermoelectric generator (TEGs). These generator is a solid-state device that works similar to solar panels but converts heat, rather than sunlight, directly into electricity [2,3].

Using thermoelectric generators is an interesting way to retrieve heat that is otherwise wasted in the form of exhaust or mechanical waste. They also recover heat that occurs naturally, such as the heat that geothermal vents, volcanoes, or hot springs. However, their efficiencies are limited due to their thermal and electrical properties being dependent on each other.

Gas stoves have been used extensively around the world for indoor and outdoor cooking. Such as food stand which is a stationary kitchen that is set up on the streets to facilitate the sale and marketing of street food to people from the local pedestrian traffic, in which case in this country most food stands cook *fishball, kikiam* and *qwek-qwek* and also offer homemade beverages. Thermoelectric modules have been commercially available for about 30 years [4-9] ranging from various type of application for power generation.

The main objective of the study is to build and design a prototype that will harness thermal energy from food stand by using Thermoelectric Generator (TEG). The specific objectives are (a) to create a microcontroller-based data logger that will be used to measure and record the hot and cold temperature, voltage, and current during the time of operation; (b) to determine if the installed TEG prototype will affect the cost and consumption of the kerosene and ice; and (c) to determine if the TEG prototype can charge a 3.7 V Lithium-ion battery and power up a 2-Watt LED bulb.

The study is made to pursue the development of energy harvesting technology which is environmental friendly and uses renewable sources. The system is designed to provide electrical energy for the vendor to use. This can be used to power up LED bulbs. The prototype maybe used to stationary or mobile carts.

The system will mainly focus on harnessing the thermal energy produced by the stove and the beverage container. Researchers are planning to use thermoelectric generators (TEGs) and thermally conductive materials such as copper metal to help transfer and concentrate the heat which came from the stove into one of the faces of the TEG. The TEG is attached in the food stand wherein the concentrated heat from the stove and the concentrated cold temperature from the beverage container will be separately gathered. The ice block that is used in the beverage was made using a plastic ice bag with a dimension of 4 in by 12 in. A microcontroller-based data logger is used to measure the hot and cold temperature, voltage, and current. Using an SD card module, the microcontroller will save the data on an SD memory card. The system is designed to charge a 3.7 V lithium-ion battery and a power up a 2-Watt LED bulb.

II. Material and Methods

The entire system is composed of two main parts, the thermoelectric generator setup and the data logger which is responsible for measuring the temperature of the hot and cold side of the TEGs as well as the output voltage and current of the TEGs. It also stores the gathered data in a SD card.

The input of the TEG prototype are the heat which comes from the stove and the cold temperature which comes from the beverage container. The Thermoelectric generators (TEGs) are placed in between the stove and beverage container. Heat and the cold temperature were transferred to the TEGs with the help of the copper rods and plates. The Thermal difference will be converted by TEGs into electrical energy which will be used to charge battery. A microcontroller based data logger will read and store the temperature from both side of the TEGs as well as the voltage and current being delivered to the load for every 10 minutes. Stored electrical energy will be used to power up an LED bulb.

Figure 1 is the system flowchart for the prototype design. Heat from the stove and the cold temperature from the beverage container is concentrated on the thermoelectric generators with the help of the copper metals. The TEGs converts the thermal energy into electrical energy. If the energy gathered is not yet sufficient, researchers physically modified the system set up in order for more heat conduct into the TEG. The microcontroller based data logger automatically measures the temperature of the hot and cold side, the voltage, and current produced in every 10 minutes interval. The system is designed to charge a 3.7V lithium-ion battery and/or light a 2-Watt LED bulb.

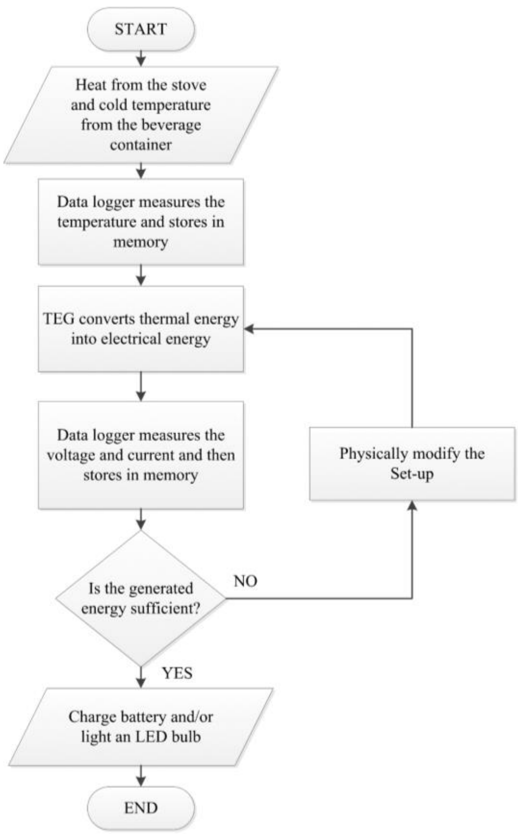

Figure 1: System Flowchart

A. Prototype Set-Up

Researchers used thermoelectric generators (TEGs) and thermally conductive materials to transfer and concentrated the heat into the sides of the TEGs. Heat is transferred using copper rods and copper plate to distribute the heat on one of the faces of the TEG. Also, the beverage container is confined inside a metal box with copper metal to transfer the cold temperature to the cold side of the TEG. Figure 2 shows the dimension of the prototype. A step up boost converter is used to step up the voltage supplied by the TEGs into voltage which is required to charge the lithium-ion batteries. Figure 3 shows the step-up boost converter schematic diagram.

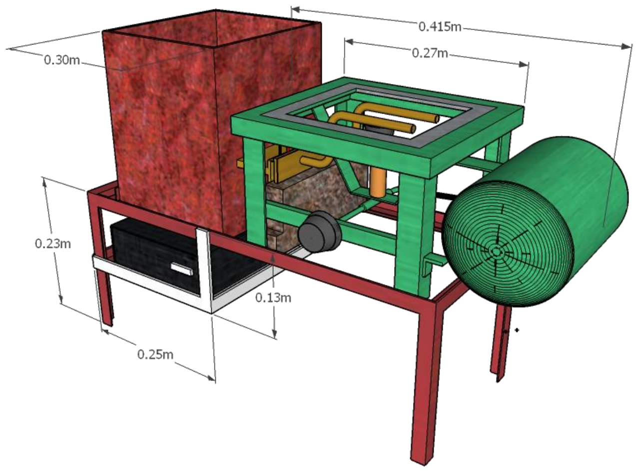

Figure 2: Prototype with Dimensions

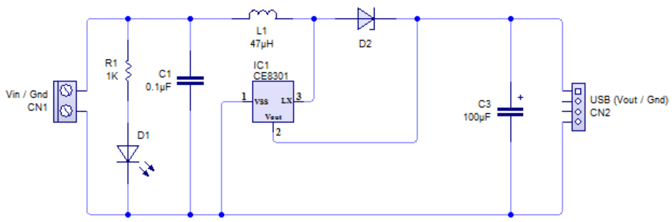

Figure 3: Step-up Boost Converter Schematic Diagram

B. Data Logger

A microcontroller based data logger was used to record the temperatures in both sides of the TEG, voltage and current delivered to the load. The researchers used Arduino as the microcontroller. Temperature sensors, voltage and current sensors are attached to the microcontroller. Temperature sensors are placed on the copper plates of the hot and cold side of the TEGs. The voltage sensor is attached in parallel to the load and the current sensor is installed in series with the step up boost converter and the charging batteries. The Arduino microcontroller is programmed to read all the input data and store it in an SD card using an SD Card Module. The microcontroller stores the read data every 10 minutes.

Figure 4 shows the system block diagram. Figure 5 shows data logger wiring diagram.

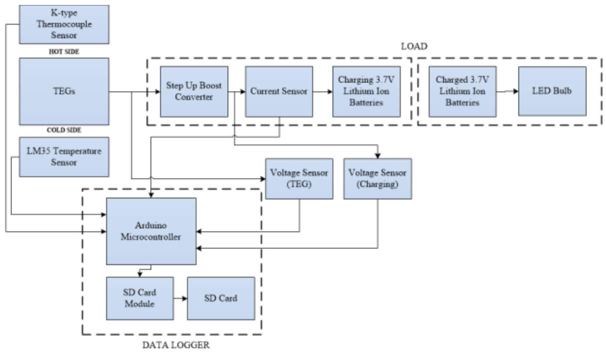

Figure 4: System Block Diagram

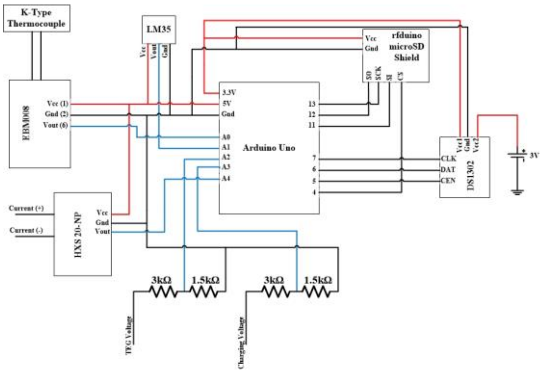

Figure 5: Data logger Wiring Diagram

III. Results and Discussions

Temperature, voltage and current sensors are attached to the TEG Set-up to measure the parameters. These sensors are connected to the microcontroller which will read the input data and store it in an SD card using an SD card module. Test was conducted using cold source and ambient source and the average value for operation was attained. Table 1 shows the averaged value for operation with cold source and Table 2 shows the average value for operation with ambient source.

Table 1
Averaged Value for Operation with Cold Source

Date	Total time of Operation	Temperature Difference (ºC)	Voltage(V)		Current (A)
			TEG	Charging	
11/28/16	5.8	61.29	0.94	4.86	0.36
11/29/16	6.47	62.81	0.94	5.03	0.36
11/30/16	5.65	62.79	0.94	4.87	0.36
12/1/16	5.52	66.26	0.99	4.91	0.36
12/2/16	5.43	65.05	0.97	5.18	0.38

Table 2
Averaged Value for Operation with Ambient Source

Date	Total time of Operation	Temperature Difference (ºC)	Voltage(V)		Current (A)
			TEG	Charging	
12/5/16	5.28	55.39	0.83	4.38	0.31
12/6/16	5.53	55.55	0.83	4.52	0.32
12/7/16	5.13	53.83	0.81	4.27	0.31
12/8/16	5.23	53.72	0.8	4.47	0.32
12/9/16	5.22	47.28	0.71	3.33	0.24

T-test was used to determine if there is a significant difference with the voltage and current produced with a cold source and with ambient as cold source. Using the null hypothesis which state that there is a significant difference between the voltages produced by the TEG when the cold side has a cold source compared to when the TEG only has ambient temperature as the cold source. However, for the current produced, it is proved that the current produced by the TEG with cold source and with only ambient temperature as cold source is significantly similar with 95% level of confidence since the p-value is greater than the level of significance. Results is shown in Table 3 and 4 respectively.

Table 3
Statistical Data for the difference of Voltage Produced

Number of Samples	100
Sample Mean	0.9388
Population Standard Deviation	0.10472
Test Statistics	6.3693
Level of Significance	0.05
Level of Confidence	0.95
p-value	0.0000

Table 4
Statistical Data for the difference of Current Produced

Number of Samples	100
Sample Mean	0.7013
Population Standard Deviation	1.98167
Test Statistics	-0.8881
Level of Significance	0.05
Level of Confidence	0.95
p-value	0.3755

Kerosene and Ice consumption was measured for two consecutive weeks without prototype and another two consecutive weeks with prototype with a cold source and ambient source. Results is shown in Table 5. Kerosene and Ice consumption was measured for two consecutive weeks without prototype and another two consecutive weeks with prototype with a cold source and ambient source. Results is shown in Table 5.

Table 5
Kerosene and Ice consumption

Without Prototype				With Prototype (with cold and ambient source)			
Date	Total time (h)	Kerosene Consumption (Liter)	Ice Consumption (per ice block)	Date	Total time (h)	Kerosene Consumption (Liter)	Ice Consumption (per ice block)
5/23/2016	5.8	0.55	4	11/28/2016	5.8	0.55	5
5/24/2016	6.47	0.6	6	11/29/2016	5.88	0.6	6
5/25/2016	5.65	0.55	5	11/30/2016	5.48	0.5	6
5/26/2016	5.52	0.5	4	12/1/2016	6.1	0.6	7
5/27/2016	5.43	0.5	4	12/2/2016	5.28	0.5	5
5/30/2016	5.28	0.5	4	12/5/2016	5.37	0.55	4
5/31/2016	5.53	0.55	4	12/6/2016	5.17	0.5	4
6/1/2016	5.13	0.45	5	12/7/2016	5.52	0.5	5
6/2/2016	5.23	0.5	5	12/8/2016	5.92	0.6	4
6/3/2016	5.22	0.5	4	12/9/2016	5.13	0.45	4

T-test was used to determine if there is a significant difference with the consumption of kerosene and ice with and without the prototype. Using the null hypothesis which state that the thermoelectric generator system will not affect the consumption of kerosene and ice, it is proved that the consumption of kerosene with or without the TEG system are significantly similar with 95% level of confidence since the p-value is greater than the level of significance. Results is shown in Table 6 and 7 respectively.

Table 6
Statistical Data for the difference of Kerosene

Number of Samples	10
Sample Mean	0.5275
Population Standard Deviation	0.04757
Test Statistics	-0.7006
Level of Significance	0.05
Level of Confidence	0.95
p-value	0.4925

Table 7
Statistical Data for the difference of Current Produced

Number of Samples	10
Sample Mean	4.85
Population Standard Deviation	1.0328
Test Statistics	-1.7685
Level of Significance	0.05
Level of Confidence	0.95
p-value	0.0939

The cost consumption of the ice and kerosene consumption with and without the prototype is taken into account. The average consumption per hour of the ice and kerosene were calculated by dividing the consumed ice and kerosene to the total time of operation. Table 8, 9 and 10 shows the results.

The total operation time with prototype is 55.65 hours. The increased amount of kerosene and ice consumed when the prototype is installed can be computed by subtracting the average consumption per hour of with prototype with the average consumption per hour of without prototype. Afterwards, the difference will be multiplied by the total time of operation with prototype.

The total cost of increase in kerosene and ice for two consecutive weeks of operation with prototype is PHP 21.43.

Table 8
Cost Computations: (a) Kerosene and Ice Consumption

Test Condition	Without Prototype	With Prototype
Average Kerosene Consumption per Hour (L/hr)	0.092	0.096
Average Ice Consumption per Hour (Ice/hr)	0.814	0.0921

Table 9
Amount Increased

Total Amount increased in Kerosene (Liter)	0.2226
Total Amount increased in Ice (Ice per block)	5.95455

Table 10
Total cost increased

Cost of the amount increased (PhP)	
Kerosene	Ice
6.54	14.89

To determine the actual battery charging time of the lithium ion battery, the researchers charged a single fully drained battery using the TEG prototype and monitor the time the battery reaches its maximum voltage which indicates that it is fully charged. Table 11 shows the battery voltage for every hour of charging. According to the datasheet of 18650 Lithium-ion battery, the discharged (Min.) voltage is equal to 2.7V and full charge (Max.) is 4.2V. After 6 hours of charging, the lithium ion battery has a voltage of 4.12V. The charged battery was used to supply the LED bulb to determine how long it could light it up. Table 12 shows the discharging time and battery voltage. After 4 hours of supply the LED bulb, the battery has still 3.06V. The battery was fully drained after 10 hours of operation.

Table 11
Battery Voltage every 1 hour of charging

Time	Battery Voltage (V)
1:11:00 PM	2.79
2:11:00 PM	3.02
3:11:00 PM	3.27
4:11:00 PM	3.50
5:11:00 PM	3.79
6:11:00 PM	4.05
7:11:00 PM	4.12

Table 12
Discharging time and battery voltage

Time	Battery Voltage
7:12:00PM	4.12
11:12:00PM	3.06
5:12:00PM	2.62

IV. Conclusion

Thermoelectric generator system applied to food stand with stove as the hot side and the beverage container as the cold side can produce an average TEG voltage of 1 V and with an average current of 360 mA. The statistical analysis shows that the TEG system does not affects the consumption of kerosene and ice. Furthermore, it is proved that the voltage produced by the TEGs having a cold source and TEGs having only ambient temperature as cold source has significant difference. However, there is no significant difference with the produced current. With a help of a DC to DC step up boost converter, the system can produce voltage up to 5V charge a Lithium-ion battery with a capacity of 2200 mAh. Having an average current of 360mA, the charging time is 6 hours for the battery to be fully charge. Charged batteries can power up a 2 watt LED bulb, that can last up to 10 hours of usage.

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