

Heat Energy Harnessing via Seebeck Generators

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Abstract

Energy is what drives many aspects of everyday life. Humans use the energy from food, cars use energy from fuel and the multiple electronic devices that we use every day all use energy in the form of electricity. To produce this energy, there are numerous natural and artificially induced processes that take place. As in, our body naturally processes the food we consume to provide us with energy, cars rely on artificially aided combustion and in the mix, we also have renewable sources of energy. While all these sources of energy production and consumption are effective and highly useful, they are not entirely efficient. If we were to go running, our body would use energy to help move our muscles in the required manner, but at the same time our body would produce heat, not all of which is useful. Another interpretation to such a situation is a firepit on a cold night. It might provide warmth to those around it, but the energy lost to the pit itself and the environment in general is quite large.

Inspired to find a solution that can help harness this excess heat energy, this project attempts to build a Heat Energy Harnessing Seebeck Generator to address the fire pit situation. The uses of such a concept are vast and can be expanded to a wide range of applications. The prototype is built in such a fashion that one can start a fire in the pan attached to the top of our device and if it is relatively colder towards the bottom of the device, as in if it were placed in snow or if elevated in a manner that cold air would pass from underneath, then from the change in temperature it would be able to generate a voltage using the Seebeck effect from the help of 18 thermoelectric generator (TEG) pads sandwiched within the device. The prototype would be able to harness excess heat energy and produce approx. 16 volts at 100 °c, which can then be used for purposes such as charging a phone or powering a moderately sized lightbar. This can be a very practical tool for purposes such as camping and the applications of such a concept are endless.

This paper discusses the process of mind storming the approach towards the solution, followed by the design, material choices, construction choices and the construction itself of the prototype. While also presenting the results of testing that the prototype has undergone and further applications of such technology.

Introduction

In the modern world, we realize the importance of renewable energy and as a global community; we are all committed to transition towards a world where most of our energy comes from 'green' sources. While generation of energy using clean methods is essential, another important aspect with respect to a world where energy is clean is 'efficiency'. In the case of a coal fired powered plant, even the most efficient plants produce only about 50% usable power, whereas the rest is lost to the environment in the form of heat [1]-[3].

On a smaller scale, there are many households that have wood fireplaces. While the heat from the fireplace is useful, there is still a large amount of excessive heat that is lost to the environment. This brings rise to the problem statement: ‘There are multiple activities and processes that take place on a day-to-day basis which result in heat energy production as a byproduct or in unusable excessive amounts and this energy is lost to the environment’.

Having understood the problem of inefficiency and having looked at the multiple ways in which energy is lost in the form of heat, one is very likely to wonder if this energy can be harnessed and be put to better use. To address this problem at hand, there are a limited number of solutions and one of the better options is the Seebeck generator based on the Seebeck effect. A Seebeck generator would help harness heat energy and provide usable energy in the form of electricity.

A Seebeck generator is unlikely to be a replacement for any existing sources of power, but one to improve the energy efficiency of multiple existing systems and to be used in tandem with other sources of energy.

Seebeck Effect

In the year 1821, a physicist named Thomas Seebeck discovered the Seebeck Effect (Figure 1). He found that when he placed two dissimilar metal wires in a loop and when their junctions were maintained at different temperatures, an electric current would be produced [4].

When one of the conductors or semiconductors in the loop is heated up, the valence electrons from the hotter side would travel towards the colder side of the loop. This happens as electrons tend to move towards the direction of lower energy. As a result, when this loop is connected to an electrical circuit, a direct current (DC) flow can be observed. When Thomas Seebeck discovered the effect, he used Copper and Bismuth, but today the metals commonly used to facilitate for the Seebeck effect are Constantan with either Copper, Iron, Chromel or Alumel.

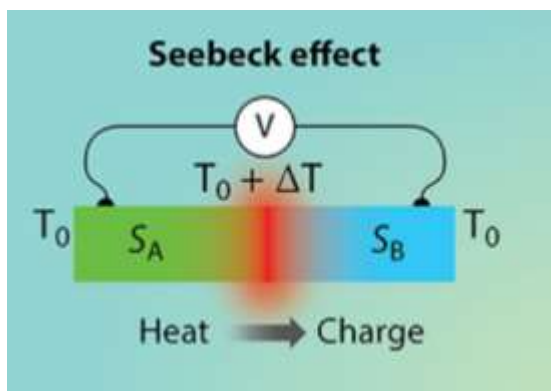


Figure 1– Seebeck Effect [5]

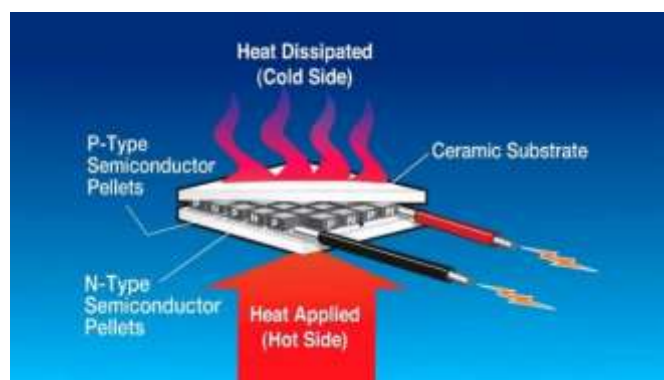


Figure 2 – Thermoelectric Generator Module [6]

Thermoelectric Generator

A thermoelectric generator, also known as the Seebeck generator [7]-[8] is a device capable of converting heat flux (ΔT) into electrical energy using the principles of the Seebeck effect. Figure 2 is an image of a thermoelectric generator module. If this device is exposed to cold temperature on one side and heat on the other, it can produce an electric current output.

Method and Approach

The concept of this prototype is to create a device that has a pan like structure on the top where in one can start a fire and use it for cooking or heating purposes. The pan would then sandwich thermoelectric generator pads with another piece of metal beneath it. Following which, when the contraption is either propped up on a stand or when placed in snow, the temperature difference between the inside of the pan and towards the other side of the generator would help produce a temperature gradient and thus electricity that can then be used for other purposes.

The designing of the prototype was based on the aforementioned requirements and three major factors were considered. The first being that the prototype shall be able to harness heat energy using the concept of a thermoelectric generator. Second, the prototype shall be possible to build with easily accessible resources that are moderately affordable at the same time. The third factor being that the prototype shall be able to function as a proof of concept under indoor testing conditions (due to university restrictions).

Given the set factors, an attempt was made to find the resources available for prototyping. Finally, a local hardware store and 'amazon.com' were decided as convenient sources of procurement. Having understood the resources available for use, the design was based on the same.

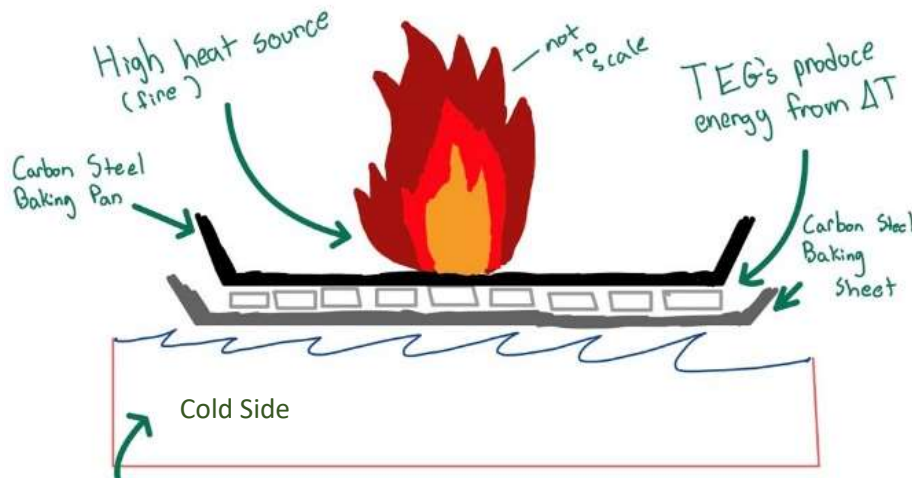


Figure 3 – Hand Drawn Design Sketch

Figure 3 is a brief representation of what the prototype was to be built like. The design also accounts for the situation that aluminum sheets were not available and hence the prototype had to be built using a baking purposed carbon-steel pan and tray.

Having roughly designed as to how the prototype was to be built, a 3D model was developed for the prototype using Solidworks (Figure 4). The 3D model had further refinements made to it and is more representative of the final prototype as when compared to the initial sketch.

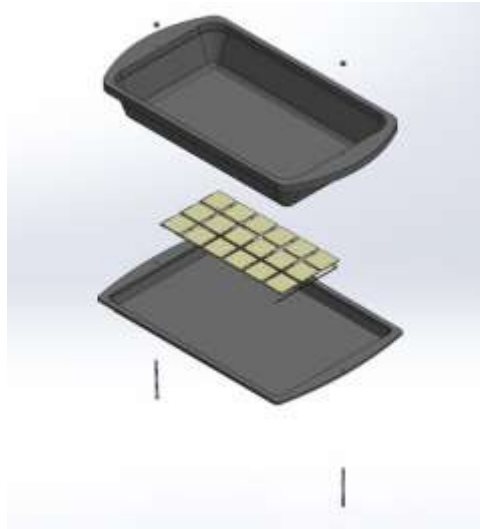


Figure 4 – Solidworks Based Design Drawing of Prototype (in 3D)

With the design finished and having briefly planned the assembly of the prototype, all required material was procured and the prototype was constructed. The construction took place in a university maker’s space where there was access to a soldering iron and certain other basic tools and resources.

Table 1 - Resource List

Resource Name	Qty.	Place of Procurement	Specification
Thermoelectric Generator Pads (TEG Pads)	18	Amazon.com	The Seebeck effect-based generators that will be used to produce electricity (sandwiched between pan and tray)
Carbon Steel Pan	1	Hardware Store	Top part of prototype to hold fire
Carbon Steel Tray	1	Hardware Store	Bottom side of the contraption
Nut and Bolt Set	2	Hardware Store	To hold pan and tray together
Electric Tape	1	Hardware Store	To cover the wires of the TEGs
Heat Shrinks	20	University Makerspace	To protect the soldered TEG wires
Gorilla Glue	1	University Makerspace	To stick the TEGs to the contraption
Thermal Compound	1	Amazon.com	To make the TEGs conduct heat better
Duct Tape	1	University Makerspace	To seal the open gap between the pan and the tray

Assembly

The first step of the assembly process was to solder the TEGs together in a series circuit using the soldering iron at the university makerspace (Figure 5a). After having soldered the TEGs together, the exposed wire was wrapped in heat shrink. Then this circuit was placed on the carbon steel tray (Figure 5b), where a very small amount of gorilla glue was applied to the corner of each TEG and a substantial amount of thermal compound was applied to the rest of the TEG (Figure 5c). This process ensured that the TEG stuck to the tray in a secure manner while having substantial thermal conductivity.



Figure 5a



Figure 5b

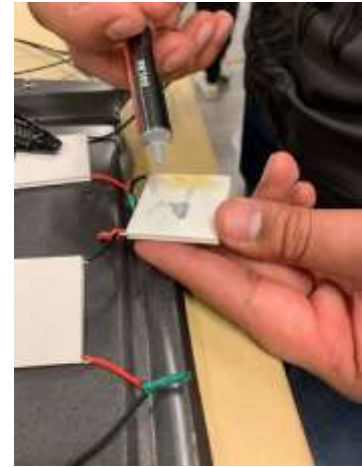


Figure 5c

Post these steps, the carbon steel pan was placed on top of the TEGs to create an almost sandwich like situation (as shown in the 3D drawing -Figure 6) and then the tray and pan were held together using a set of nuts and bolts. The positive and negative leads were then drawn out of the contraption for access and the remaining gap was sealed using duct tape to complete the assembly of the prototype (Figure 7).



Figure 6



Figure 7

Testing

To test the function and efficiency of the prototype, testing was conducted in two cases.

Table 2 – Testing Case 1	
Independent Variable	Temperature of the Carbon Steel Pan - The temperature of the pan will be changed gradually.
Dependent Variable	Voltage Produced – At each different notable temperature that the pan is risen to, the production of voltage by the TEG will be measured.
Controlled Variable	Temperature of the Carbon Steel Tray – The prototype will be placed in ice all throughout the testing and the bottom side of the prototype will be maintained at 0°C.

Table 3 – Testing Case 2	
Independent Variable	Temperature of the Carbon Steel Pan - The temperature of the pan will be changed gradually.
Dependent Variable	Amperage Produced – At each different notable temperature that the pan is risen to, the production of amperage by the TEG will be measured.
Controlled Variable	Temperature of the Carbon Steel Tray – The prototype will be placed in ice all throughout the testing and the bottom side of the prototype will be maintained at 0°C.

Considering that the Seebeck Effect works based on the change in temperature gradient (ΔT) that the thermoelectric generators are exposed to the change in the temperature of the pan will facilitate to produce electricity. A point to be noted here is that, since the bottom of the prototype is maintained at 0°C, the absolute change in the temperature gradient experienced by the prototype is equal to the change in temperature of the pan on the top.

Table 4 – Apparatus for testing

Apparatus	Significance
Laser Thermometer	To measure the temperature of the pan
Multimeter	To measure the voltage and amperage produced
Tub	To hold the ice on which the prototype shall be placed
Ice	To maintain tray at 0°C
Heat Gun	To heat the pan

Testing Setup



Figure 8 – Testing Setup

Figure 8 is a pictorial representation of the prototype being tested with the help of the testing apparatus listed above.

Results and Analysis

From the testing that was conducted, data was obtained for both the pre-determined testing cases.

S. No	Temperature (°C)	Voltage (V)
1	35.4	4.50
2	45.3	5.50
3	62.7	8.20
4	71.2	11.5
5	80.8	13.9
6	93.3	14.7
7	102	16.3

Table 5 - Data for Testing Case 1

S. No	Temperature (°C)	Amperage (A)
1	35.4	0.05
2	45.3	0.10
3	62.7	0.12
4	71.2	0.17
5	80.8	0.20
6	93.3	0.21
7	102	0.22

Table 6 – Data for Testing Case 2

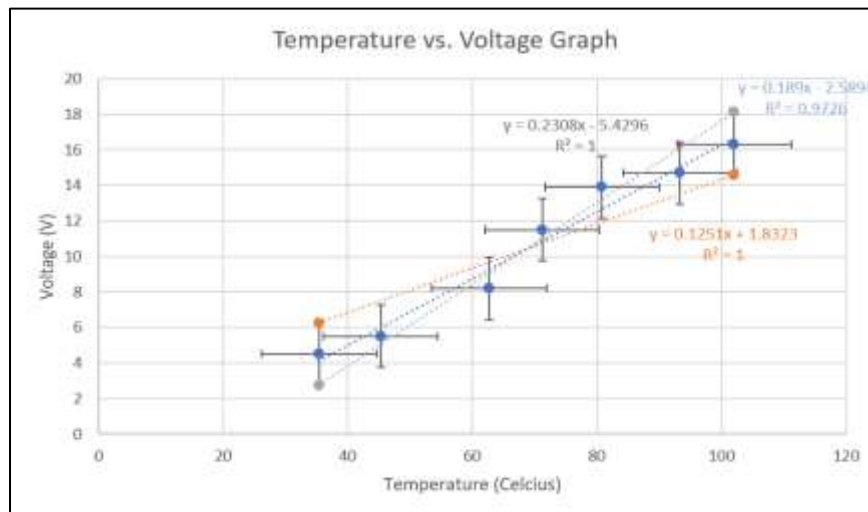
Calculating Uncertainties

For this project, it was decided that the uncertainties for the data would be calculated using the standard derivation based standard error method. Calculation for uncertainties is shown in appendix 1.

Data	Standard Deviation	Standard Error
Temperature	24.3	9.18
Voltage	4.66	1.76
Amperage	0.06	0.02

Table 7 - Standard Deviation and Standard Error calculations

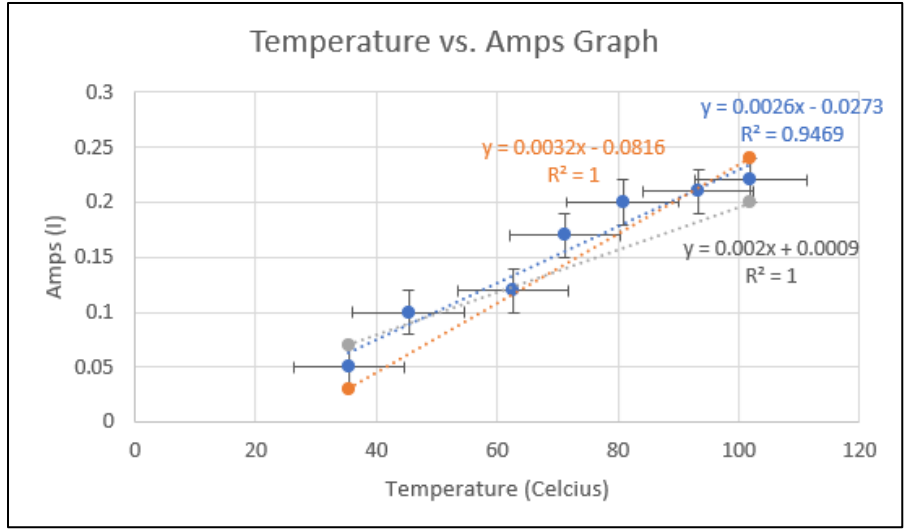
Graphing the Data



Graph 1 - Graph for testing Case 1 data – Temperature vs. Voltage Graph

Equation of best fit line: $y = 0.189x - 2.5894$

Correlation Coefficient of testing data: $R^2 = 0.9726$



Graph 2 - Graph for testing Case 2 data – Temperature vs. Amperage Graph
Equation of best fit line: $y = 0.0026x - 0.0273$
Correlation Coefficient of testing data: $R^2 = 0.9469$

The following analysis can be developed having graphed data for testing cases 1 and 2 .
Testing Case 1:

- The relationship between temperature and voltage is linear
- The data is well correlated as indicated by the R^2 value
- The data is coherent, and no outliers can be observed

Testing Case 2:

- The relationship between temperature and amperage is linear
- The data is well correlated as indicated by the R^2 value
- The data is coherent, and no outliers can be observed

Further data processing

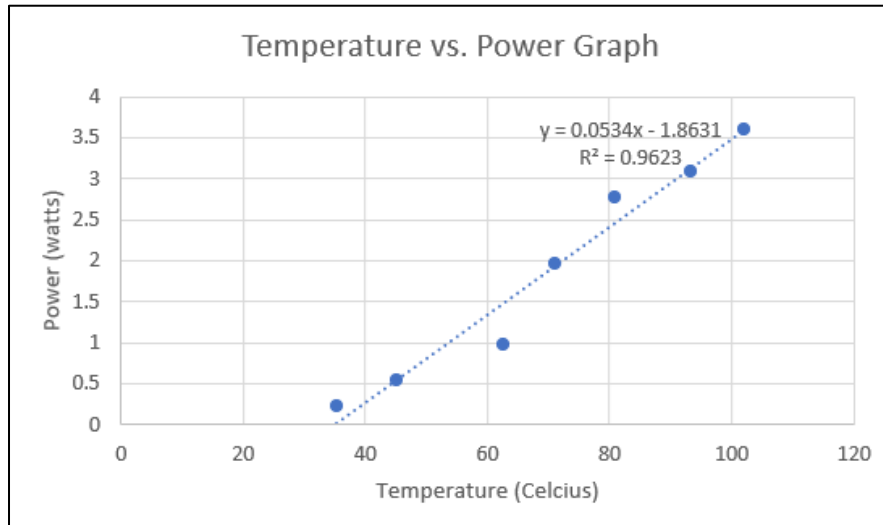
Data values of voltage and amperage can be used to find the power generated by the prototype at each individual temperature value.

$$Power (watts) = Current(A) \times Voltage(V)$$

*Current values measured in amps listed in table 6 carried over.

S. No	Temperature (°C)	Voltage (V)	Current (A)	Power (watts)
1	35.4	4.50	0.05	0.22
2	45.3	5.50	0.10	0.55
3	62.7	8.20	0.12	0.98
4	71.2	11.5	0.17	1.96
5	80.8	13.9	0.20	2.78
6	93.3	14.7	0.21	3.09
7	102	16.3	0.22	3.59

Table 8 – Calculating Power Output



Graph 3 – Temperature vs. Power Graph

The relation between temperature and power is linear as per the function of the prototype. At the peak point of our testing, the instantaneous power output from the prototype was roughly 3.59 watts. Most trends between power and temperature are like those between temperature and amperage, and temperature and voltage. Although that is to be expected considering that the value of power is just a multiplied value of voltage and amperage.

Conclusion

Having processed the data produced by the testing, it can be concluded that the results of testing prove that the prototype is a valid proof of concept. The prototype can clearly be seen to be producing substantial amounts of voltage and amperage. It was also understood that whenever the temperature is increased, there is a linear and gradual rise in both the voltage, as well as the amperage. The testing was done at 7 different data points and was monitored using electronic devices. This proves the function of the prototype to a great degree of accuracy and adds to the validity of the data. Error still does exist within the testing data as calculated above, but it is within moderate limits and does not compromise the integrity of this investigation.

Overall, the construction and the testing of this prototype can be deemed a success as it functions as a proof of concept, provides an answer to the problem statement and the nature of the resultant data is promising.

Safety Precautions

This project involved working with electricity, a drill, and a soldering iron, all of which could have caused physical injuries. For the same, certain precautions were taken during the construction process. The prototype was to be initially tested using fire to generate heat. Later during the process, it was decided that for the purpose of safety, the testing would be conducted indoors using a heat gun, which is relatively safer.

Future improvements

If work on this prototype were to continue, the following improvements would be greatly beneficial:

- Using aluminum sheets instead of carbon steel for better thermal conductivity
- Improving the seal between the bottom layer and the top pan – using heat resistant foam or rubber instead of duct tape
- Adhesive thermal compound could have been used instead of gorilla glue and thermal compound

Real life application

Thermoelectric generators have been used in the past by space organizations on their rovers to be able to produce usable energy in outer space. At the same time, their application was seen in the medical industry to provide pacemakers with a long battery life, which has now been replaced with lithium battery technology. In a different application, TEG based technology has also been used to provide remote areas with usable power. TEG technology in combination with nuclear based power generation has led to the development of the radioisotope thermoelectric generator (RTG), which is an efficient power source. Despite being highly usable technology, thermoelectric power generation has been limited due to the efficiency issues of normal TEGs and the potential hazards of the RTGs. While their widespread use cannot be observed, there are multiple theoretical energy production concepts that have been developed using TEG technology.

This prototype is a proof of concept and with slight modifications can be used as a camping stove and a garden fire pit. But, in such situations, the use of a capacitor and battery would enable the prototype to provide a non-fluctuating and stable output which can be used by the end user. Effective design and development are essential to improve this prototype further and to make it efficient for everyday use. As mentioned before, the integration of TEGs in everyday life would be to improve the overall efficiency of existing power sources and to be used in tandem with them but not as an absolute replacement to them.

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Appendix 1: Temperature Standard Deviation and Standard Error Calculation

$$\text{Standard Deviation} = \sigma = \sqrt{\frac{\sum_{i=1}^N (xi - \bar{x})^2}{N - 1}}$$

$xi - \bar{x}$	$\bar{x} = 70.1$	$\sum_{i=1}^7 (xi - x)^2$
$33.4 - 70.1 = -34.7$		$(-34.7)^2 = 1204.09$
$45.3 - 70.1 = -24.8$		$(-24.8)^2 = 615.04$
$62.7 - 70.1 = -7.4$		$(-7.4)^2 = 54.76$
$71.2 - 70.1 = 1.1$		$(1.1)^2 = 1.21$
$80.8 - 70.1 = 10.7$		$(10.7)^2 = 114.49$
$93.3 - 70.1 = 23.2$		$(23.2)^2 = 538.24$
$102 - 70.1 = 31.9$		$(31.9)^2 = 1017.61$
		<i>Sum</i> = 3545.44

$$\sigma = \sqrt{\frac{\sum_{i=1}^N (xi - \bar{x})^2}{N - 1}} = \sqrt{\frac{3545.44}{7 - 1}} = 24.3$$

$$\text{Standard Error} = \frac{\sigma}{\sqrt{N}} = \frac{24.3}{\sqrt{7}} = 9.18$$

Similar calculations were done to solve standard deviation and standard error for both voltage and amperage. The values of those calculations are listed and used in the work.