THERMAGEN

A Mobile Thermoelectric Generator

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Acknowledgements

I would like to thank the many mentors that have been there every step of the way in the progression of this project. Without their assistance, this project would not have been what it is. I'd like to begin by thanking Mr. Pavel Loven. Mr. Loven is the parent of an alumni of Mass Academy and has no direct affiliation with the school otherwise. However, he elects to help students with their STEM projects every year. I learned a lot about the field of thermoelectrics and electrical systems in general from Mr. Loven. I would also like to thank my STEM advisors Ms. Siobhan Curran and Mr. Andrew Barnes. Ms. Curran guided me in my first true experience of STEM research and development, by explaining the fundamentals of the field. Mr. Barnes specifically advised me on aspects of my actual project, helping me focus my efforts in key areas of development. Lastly, I would like to thank my parents, for enabling me to experiment and develop my product, as well as helping to keep me motivated and active throughout this project.

Abstract

According to data from Statista, approximately 62.9 percent of the people in this world owned a mobile phone in 2016. For many, it is important to keep these devices charged regularly. However, individuals may find themselves in situations where they do not have access to an outlet. The goal of this project was to develop an inexpensive, portable, and easy-to-use device which can convert an abundant form of energy into electricity that can be used for the charging of mobile devices. A device known as a Peltier Tile was used as the means of converting thermal energy from the environment into the electricity needed to charge a mobile device. Thermal energy is an abundant and practical source of energy. The apparatus was developed by placing the Peltier Tiles in a series array. The product was tested using simple heating and cooling items (candles/small fires and ice packs respectively), to simulate simplistic and practical applications of the device. The electrical output results were: 4.311 DC volts, 143.10 milliamps, 642.79 milliwatts. This product shows promise as an efficient emergency charger.

Literature Review

Introduction

Earth is suffering from an energy crisis, a dual-fronted issue that involves the imminent lack of energy resources and the ongoing climate change dilemma. This crisis is growing exponentially as there is still a continued reliance on fossil fuels. These substances such as coal, oil, and gas are burned to generate electricity, especially in electric power plants. These resources are beneficial for energy production, but they have one major drawback: their consumption is detrimental to the environment. The combustion or burning of fossil fuels leads to the production of greenhouse gases. The scientific community has attributed rising global temperatures to increases in these gases such as carbon dioxide due to its characteristic of trapping some of the heat radiating off the Earth's surface. Furthermore, the Earth only has a finite amount of non-renewable energy resources. Because 80 percent of energy generation derives from fossil fuel combustion, a failure to meet consumer energy demands will occur in the near future. Earth will eventually need an alternate source of energy, one which is renewable (sustainable). By implementing renewable energy in electric generation, the dependence of fossil fuels will falter and ultimately improve the current status of the global climate change crisis. Although renewable energy is the ultimate solution to the crisis, the technology behind it will need to be developed small-scale first and then implemented over time for more demanding applications. [1]

Renewable Energy

Untapped renewable energy can be found in the environment every single day. The many forms of energy that people encounter in everyday settings include thermal, solar/light, sound, mechanical, and chemical. An abundance of three particular energy forms (thermal, solar, and mechanical) is underutilized. The solar variant is derived from the Sun itself. It consistently provides immense amounts of both thermal and light energy without any signs of notable degradation in the foreseeable future. Although solar energy is used for a variety of power needs, ranging from simple calculators to homes, electric-grid connected solar panels need to be large to function efficiently. [2] Mechanical energy, the energy of motion (sum of kinetic and potential energy), is present all around. Human body movement generates mechanical energy and it is also generated at the atomic level, as atoms are constantly in motion (kinetic energy). Thermal energy, a form of kinetic energy (energy of moving particles) can be found abundantly in nature as well as in common habitable environments for humans. Daily electronics is a common source of thermal energy. An excess of thermal energy is emitted while devices such as mobile phones or laptops are in use, however this energy is simply allowed to flow through the air without being utilized. [3]

Purpose

If even one of these forms of excess renewable energy can be harnessed more efficiently, it could ultimately lead to reducing electricity demands from generation plants and making consumer use devices even more convenient. Although a permanent solution to the energy crisis is far from complete, modern gradual improvements toward renewable energy technology need to be developed to reach that goal.

In particular, thermal energy in the form of heat, constantly flows throughout human environments. Sources of thermal energy can be found in moving objects, kitchen cookware and appliances, lights, the Sun, heating systems, electronic devices, and organic materials in most living things including plants and animals. [3] This form of energy is found often as a byproduct of a reaction. Thermal energy goes quite underutilized by humans and the environment in general, not having any particular use. However, if proper methods and technology are applied, thermal energy has the potential for use in the generation of electricity. [4]

Thermoelectric Generation

Thermoelectric generation is the process of generating electricity using a temperature differential, prompting a flow of electrons.

Peltier Effect

The Peltier Effect, which is an important discovery for the field of thermoelectric generation, was developed by a French watchmaker Jean Charles Athanase Peltier in 1834. He discovered that when an electrical current was applied to the system, heating and/or cooling would occur at the junction point of two dissimilar metals. Later in 1838, further research was conducted by a scientist of the name Emil Lenz, who helped to confirm and support the work and research of Jean Charles Peltier. One of Emil Lenz's contributions to the field of thermoelectrics relates heavily to Peltier's findings. Lenz suggested that the direction of current flow, when applied to the system, would determine whether the system would heat up or cool down. For example, by adjusting the direction of the current flow, the junction could freeze water and turn it to ice. However, by adjusting the direction in an opposite fashion, the same junction could melt the ice it has just formed. The Peltier Effect dictates that the amount of heat created or lost at a junction is proportional to the electrical current applied to it. This proportion is known as the Peltier coefficient. [4]

Seebeck Effect

Between the years of 1821 and 1823, Thomas Johaan Seebeck discovered that a circuit, when connected to two dissimilar metals of different temperatures, would deflect the compass magnet. Originally, he believed it was the temperature difference which had some connection to

Earth’s magnetic field. However, later, Seebeck realized that the circuit with the temperature difference actually generated a “Thermoelectric Force” which was responsible for the magnetic disruption. The temperature difference in a closed circuit actually generates an electrical potential energy, commonly referred to as voltage (the potential difference of charge in a circuit). [4]

The proportion between the voltage produced by this temperature differential, and the difference between the sides of the junction is known as the Seebeck coefficient. This proportion coefficient is generally referred to as “thermopower.” In reality, the coefficient is more closely related to the potential of electrical energy, due to its relation to voltage, rather than the power of energy. Sb_2Te_3, Bi_2Te_3, $Bi_{0.9}Sb_{0.1}$, SnTe, Cu-Ni are alloys deemed to be good thermoelectric materials, as researched by Werner Maken in 1910, and they are effective in demonstrating the Seebeck Effect. [4]

In summary, the Seebeck Effect is often related to the generation of electricity, more specifically generating voltage, which increases the electrical potential energy of a system or junction which can provide an electrical current. The Peltier Effect refers more to the generation of a temperature differential across the two sides of a junction, using the application of a directional current. The following figure visualizes the differences and similarities between the Seebeck Effect and Peltier Effect. [5]

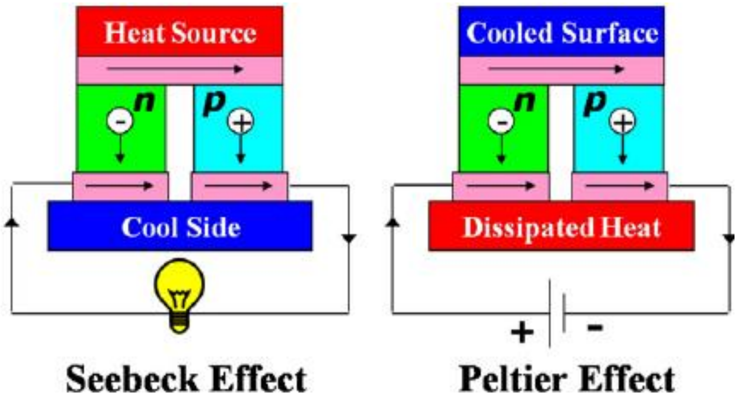

Figure 1. Seebeck Effect and Peltier Effect visualized [5]

Peltier Tile Functionality/Applications

A Peltier tile is the common system or apparatus used for Thermoelectrical Generation (TEG) as well as Thermoelectrical Cooling (TEC). The components of one Peltier Module, as well as some of its functions can be visualized through the diagram below. [6]

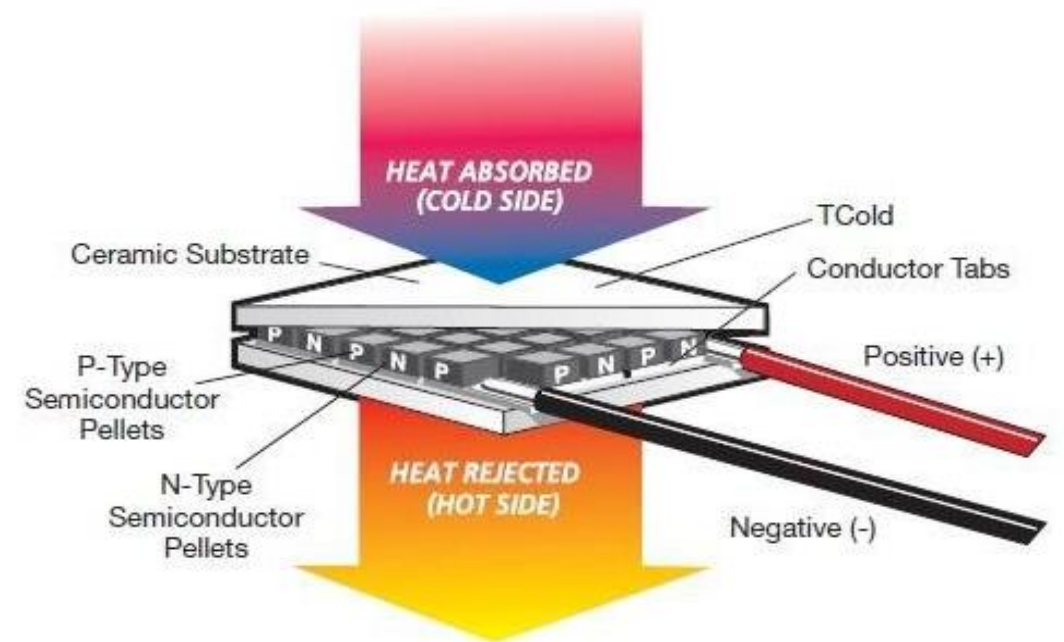

Figure 2. Peltier Tile Deconstructed and Explained Component by Component [6]

Applications of Peltier tiles, the Peltier Effect, and the Seebeck Effect can be found in many areas. Common applications include refrigeration and cooling technology. It was once believed that thermoelectric technologies such as Peltier tiles would replace heating and cooling agents/mechanisms of our time; however, that has not completely happened. Peltier tiles can be found in some refrigerators as well as climate control in vehicles, particularly in seating temperature control. Another application is in the space industry. TEGs are being installed to generate electricity for long – term space missions (when the sun cannot be used), with the use of radioisotopes. This form of energy generation is highly effective, particularly in these missions, as the lack of moving parts in the TEGs decrease the likelihood that any maintenance will be required, furthering the sustainability of the mission. [4]

Existing Peltier Devices

Power Watch – Matrix Industries

The PowerWatch is a smartwatch powered by the thermal heat emitted from the human body, particularly from the wrist. After many iterations, the team at Matrix Industries developed a system which used the Seebeck Effect to generate electricity to power the watch, using only the thermal energy from the user's wrist and a ventilation system to stimulate the temperature differential. [7] It has shown promising results as a startup product, fulfilling many criteria of the modern smartwatches such as: slim profile, attractive, and useful.

Figure 3. Peltier Tile Deconstructed and Explained Component by Component [7]

Hollow Flashlight

The Hollow Flashlight is a first-place Google Science Fair project for 2013, by a 15-year-old girl from Canada named Ann Makosinski, which converts thermal energy from your hand into electricity to power an LED flashlight. Ann discovered that humans had the potential energy to emit enough heat for “100 watts’ worth of lightbulbs.” [8] This product was designed in response to the challenge to develop a cheap method of producing light, potentially for use in nations with electricity shortages. The apparatus consists of an aluminum cylinder lined with Peltier tiles on the exterior. The interior is hollow to provide air flow for the cool side of the Peltier tile. [9]

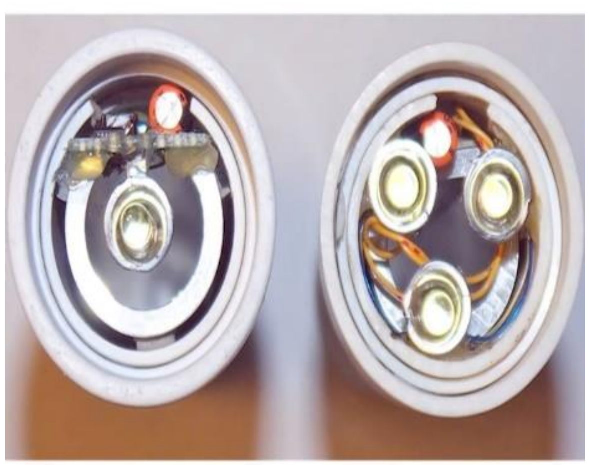

Figure 4A. Internal View of Makosinski's Product [8]

Figure 4B. External View of Makosinski's Product [9]

Conclusion

Ultimately, a new source of energy, optimally renewable will be needed in the future to sustain consumer demands as well as to resolve the global warming crisis. However, there are currently plenty of methods of implementing small-scale green renewable energy sources into the daily lives of many. [1] These small actions of change could lead to reduced greenhouse gas concentrations in the atmosphere. Many advancements have been made in finding a new alternative renewable energy source. Solar energy is one major field being advanced extensively, however it retains many drawbacks (costly, inefficient, large-scale). [2] The field of thermal energy has also shown some promise. Effects such as the Peltier and Seebeck demonstrate the opportunities of thermal manipulation, most notably thermoelectric generation. Small-scale and potentially large-scale electrical generation can result from the use of a Peltier tile, which consists of two ceramic substrates that allows for an electron gradient between them from a temperature differential. [4] There has not been much advancement in this field as of now, barring products like the PowerWatch, [7] yet there is still a lot of opportunity for development and expansion.

Engineering Plan

Engineering Problem Statement

There is no effective, efficient product for consumers of mobile products to generate electricity for their devices in emergency situations without access to standard electrical outlets.

Engineering Goals

The goal of this project is to engineer an accessory which captures, converts, and stores energy from the environment as electricity for personal use in situations of need.

General Procedure

Internal Setup

1. Place six Peltier Tiles in a series array
2. Cut and strip positive (red) and negative (black) wires of each Peltier Tile
3. Solder red wires to adjacent black wire
4. Apply thermapaste to both sides of tiles.

Insulation and Heat Managament

1. Apply and secure the two heat sinks with four screws and appropriate nuts.
2. Insert carbon fiber sheets as barrier between Peltier Tile wires and hot heat sink.
3. Cover the base of the output wires with silicon sleeve to alleviate bend tension.
4. Seal all components and side of device and tiles with Kapton tape.

Output Managament

1 Solder extension wires to the output wires
2. Take the ends of the two extension wires and solder them on to the DC to USB Convertor unit.
3. Seal the DC to USB convertor unit by wrapping the solder points with the Kapton tape.

Methodology

Materials

The following materials were collected and utilized for the development of the generator.

Table 1: A Full Table of Materials Used for the Construction of the Generator

Materials		
Item Name	Quantity	Source
DC to USB Convertor	1	Amazon (Solu)
Peltier Tile	6	Amazon (Laqiya)
Flir One Infrared Camera	1	MAMS
Extension Wires	2	Mr. Pavel Loven
Flathead Screwdriver	1	Mr. Pavel Loven
Heat Shrink Seals	2	Mr. Pavel Loven
Heavy Hex Nuts	4	Mr. Pavel Loven
Intel Pentium 2 Heat Sink	1	Mr. Pavel Loven
Intel Pentium 3 Heat Sink	1	Mr. Pavel Loven
Internal Tooth Lock Washers	4	Mr. Pavel Loven
Machine Phillips-head Screws	4	Mr. Pavel Loven
Multimeter	1	Mr. Pavel Loven
Phillips-head Screwdriver	1	Mr. Pavel Loven
Roll of Kapton Tape	1	Mr. Pavel Loven
Scissors	1	Mr. Pavel Loven
Sheet of Carbon Fiber	1	Mr. Pavel Loven
Silicon Sleeve	1	Mr. Pavel Loven
Soldering Equipment	1	Mr. Pavel Loven
Tub of Thermapaste	1	Mr. Pavel Loven
Wire Stripper	1	Mr. Pavel Loven
Zip Ties	1	Mr. Pavel Loven

Methods

Construction of Device

In preparation for the final product assembly, six Peltier tiles were placed on one of the two heat sinks, numbers side up. This was done in such a fashion, so that a series circuit could be formed, around the edge of the heat sink. The red (positive) and black (negative) wires of each Peltier Tile were cut and shortened, with the ends stripped a half-inch, to be soldered together. Leaving one black and one red wire from two adjacent Peltier Tiles alone (to be used as output wires), each red wire of a Peltier Tile was soldered to the black wire of the adjacent Peltier Tile, so the series circuit was formed. Once all necessary wires were soldered, Kapton tape was used to seal the soldering points and to protect it from heat.

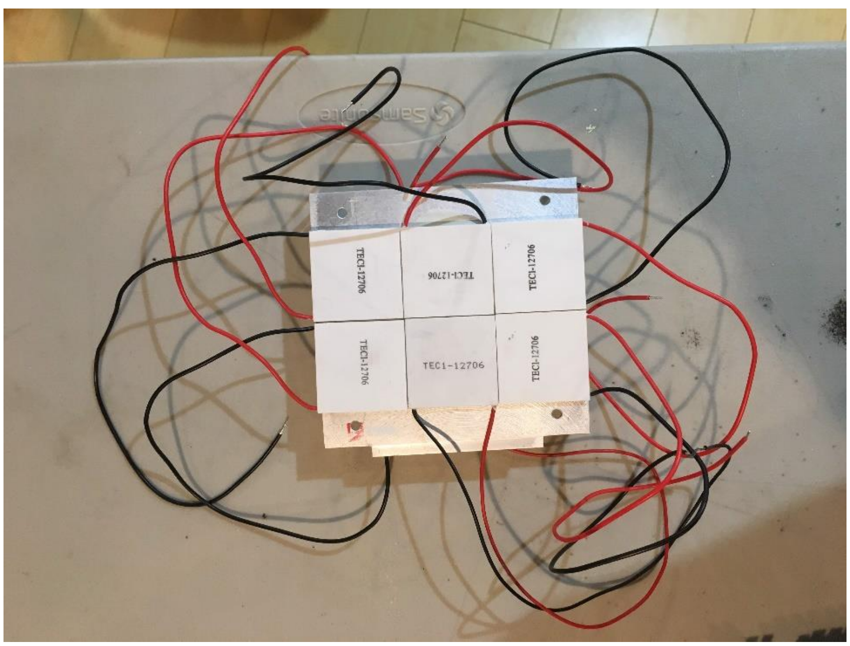

Figure 5. Overhead view of Peltier Tiles on heat sink prior to being soldered together

Figure 6. Closeup view of a soldering point between two Peltier Tiles, wrapped in Kapton Tape

Light amounts of thermapaste were applied to both the top and bottom sides of each of the six Peltier Tiles, using the flathead screwdriver. The other unused heat sink was then placed on top of the thermapaste-coated Peltier Tiles. Pressure was applied to both heat sinks to smooth out the thermapaste on the Peltier Tiles. The two heat sinks were placed on the tiles, so the machined screw holes of the two heat sinks were aligned. This assortment of Peltier Tiles and heat sinks was secured and fastened together by screwing 4 screws through the machined screw holes and using the heavy hex nuts and internal tooth lock washers to tighten the screws. One heat sink was designated as the heat sink for use with the heat source and the other heat sink would serve as the heat sink reserved for heat dissipation.

Carbon fiber sheets were cut and fitted under any exposed wires using the flathead screwdriver to prevent any heat-induced wire damage. A silicon sleeve was placed around the base of the two designated output wires to prevent any tension due to bending. This sleeve was stabilized and attached to the device using a zip tie. Kapton tape was wrapped around the sides of the device, covering the exposed internal Peltier Tiles and wires.

Using the wire stripper, half inch cuts were made on each end of the extension wires. The green extension wire was soldered on to the end of the black output wire, and the white extension wire was soldered on to the red output wire. To seal the soldering points, heat shrink seals were applied. The appropriate output wires were soldered on to the appropriate ends of the DC to USB Convertor unit. To seal the DC to USB convertor unit, the Kapton tape was used once again and wrapped specifically around the soldering points on the unit.

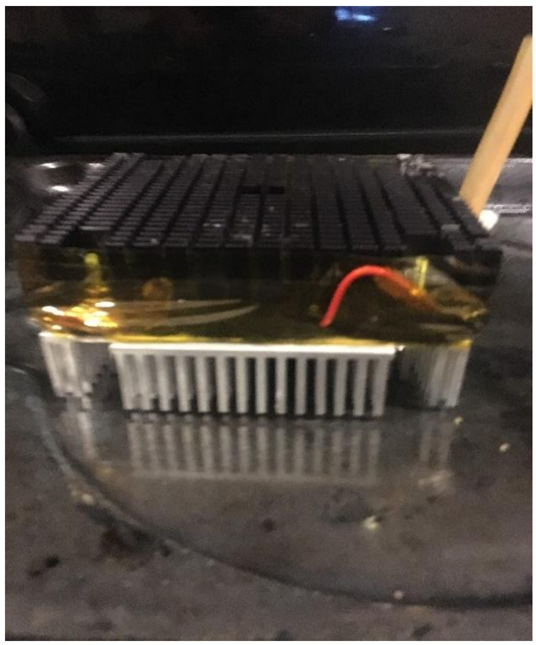

Figure 7. First Iteration of Product Development

Method of Testing Functionality of Device

A multimeter was the primary tool used to test the functionality of the device and collect data. As a heat source was applied (primarily fires ranging from candles to campfires) to the hot heat sink, and a multimeter was used to collect current and voltage data. To test for temperature data, thermal images with temperature readings in Celsius were taken using the Flir One infrared camera.

Results

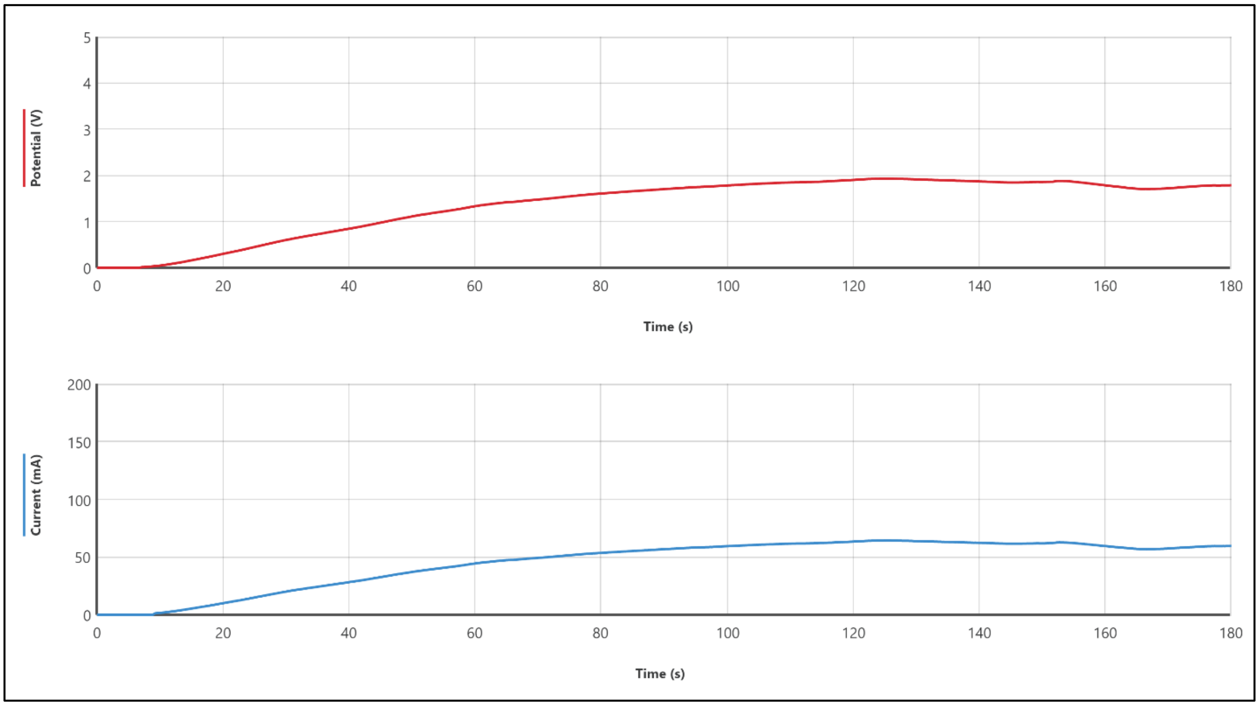

Figure 8. Single Peltier Tile Trial V1 - Voltage and Current Graph

The above figure displays two graphs of electrical data, voltage and current as listed, from the single-tile prototype over a 180 second time period. The graph and the raw data confirm that the maximum voltage was 1.931 DC volts, with an average of 1.37 DC volts. The graph and the raw data confirm that the maximum current was 64.4 milliamps, with an average of 45.54 milliamps. From the raw data collection and graph, the maximum power was determined to be 124.30 milliwatts, averaging 74.87 milliwatts. Data was collected using Vernier Go Direct Energy Sensor, with the prototype over an active gas stove.

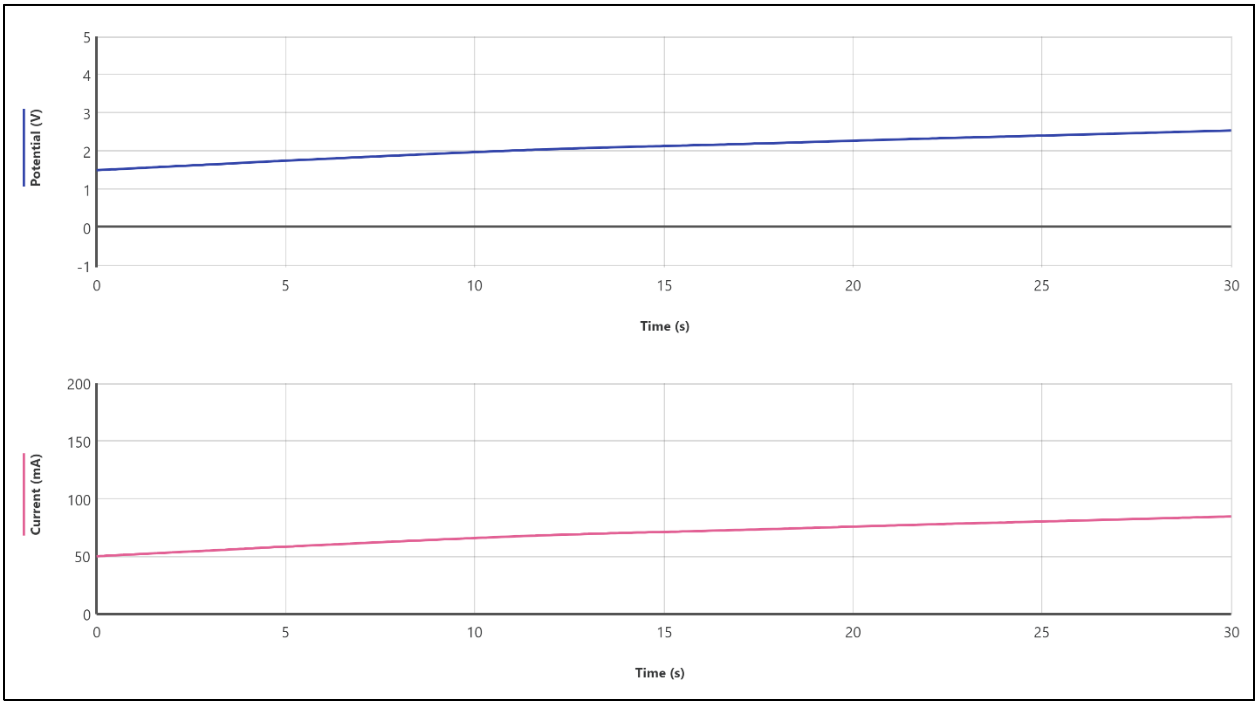

Figure 9. Six-Tile Series Prototype Trial 1 - Voltage and Current Graph

The above figure displays two graphs of electrical data, voltage and current as listed, from the six-tile final prototype over a 30 second time period. The graph and the raw data confirm that the maximum voltage was 2.543 DC volts, with an average of 2.097 DC volts. The graph and the raw data confirm that the maximum current was 84.7 milliamps, with an average of 69.899 milliamps. From the raw data collection and graph, the maximum power was determined to be 215.4 milliwatts, averaging 149.40 milliwatts. Data was collected using Vernier Go Direct Energy Sensor, with the prototype over an active gas stove.

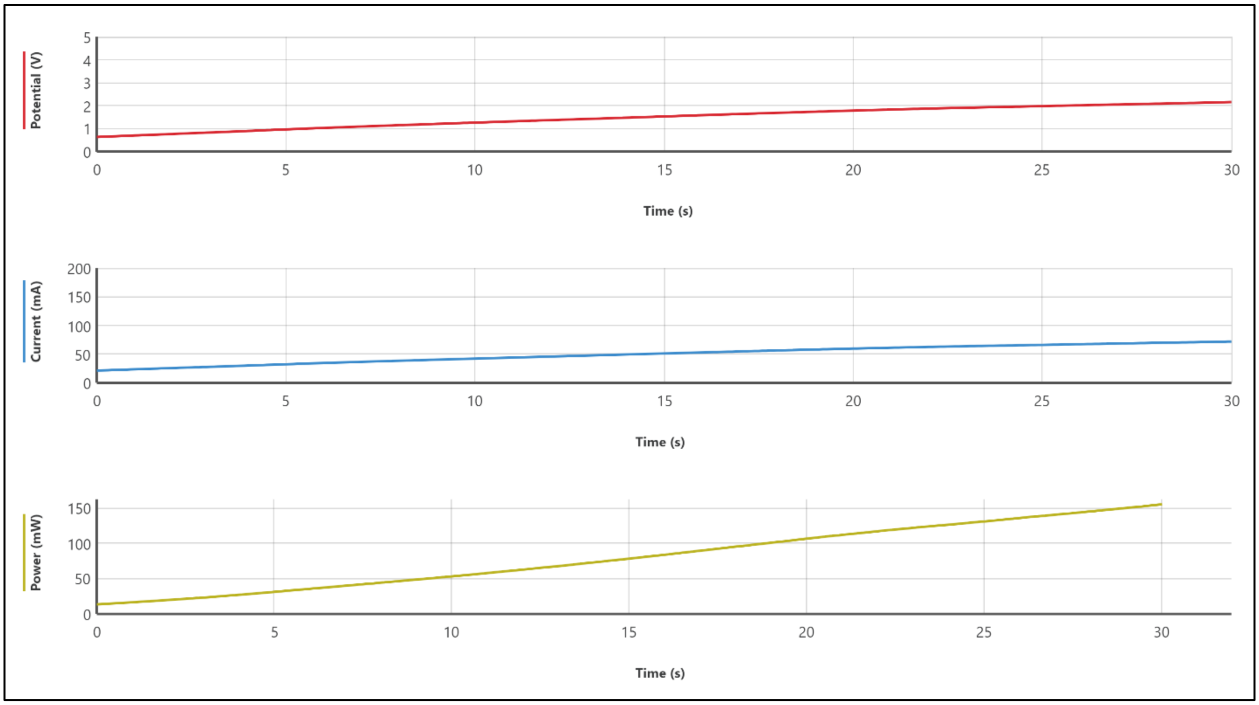

Figure 10. Six-Tile Series Prototype Trial 2 - Voltage, Current, Power Graph

The above figure displays three graphs of electrical data (Voltage/Potential, Current, Power) from the six-tile final prototype over a 30 second time period. The graph and the raw data confirm that the maximum voltage was 2.158 DC volts, with an average of 1.49 DC volts. The graph and the raw data confirm that the maximum current was 71.9 milliamps, with an average of 49.68 milliamps. From the raw data collection and graph, the maximum power was determined to be 155.2 milliwatts, averaging 80.623 milliwatts. Data was collected using Vernier Go Direct Energy Sensor, with the prototype over an active gas stove.

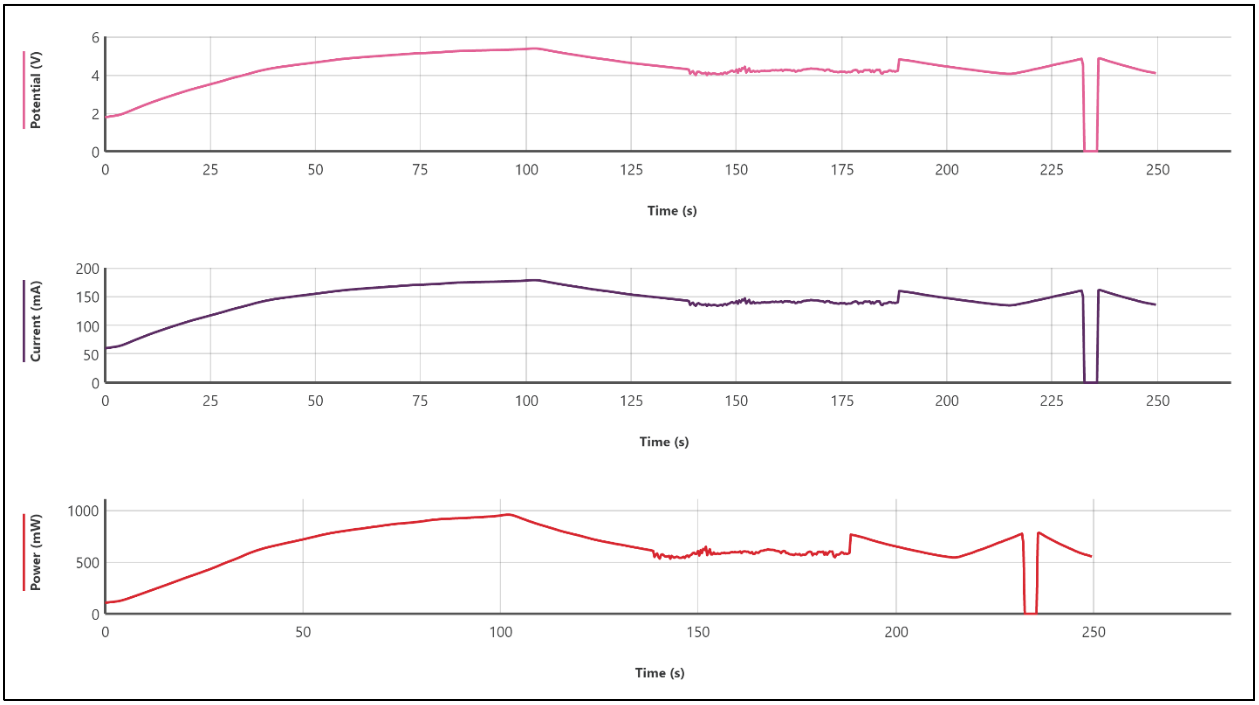

Figure 11. Six-Tile Series Prototype Trial 3 - Voltage, Current, Power Graph

The above figure displays three graphs of electrical data (Voltage/Potential, Current, Power) from the six-tile final prototype over a 250 second time period. The graph and the raw data confirm that the maximum voltage was 5.381 DC volts, with an average of 4.311 DC volts. The graph and the raw data confirm that the maximum current was 178.5 milliamps, with an average of 143.10 milliamps. From the raw data collection and graph, the maximum power was determined to be 960.6 milliwatts, averaging 642.79 milliwatts. Data was collected using Vernier Go Direct Energy Sensor, with the prototype over an active gas stove.

Analysis of Results

The simultaneously collected electrical output data included the following: voltage (in volts), current (in milliamps), power (in milliwatts). The average voltage, which was recorded in DC, resulted in 4.311 DC volts. The maximum voltage through multiple trials was consistently reaching six DC volts, with periods of rapid increase reaching up to eight volts. The high voltage was acclimated to rapid temperature differences occurring when the product was initially placed over heat sources. The average current recorded was 143.10 milliamps. The maximum consistent amperage was 178.5 milliamps with values nearing two amps at moments of rapid temperature differentiation, similar with what was occurring with the voltage.

See "Data Collection" folder to view complete raw data for each trial

Conclusion

With respect to charging devices, it is not simply voltage or current that is important. Having a balance between the two is most important for an efficient power source. The balance can be determined using the value of power, which is essentially the product of the voltage and current outputs. The maximum power was determined to be 960.6 milliwatts, averaging 642.79 milliwatts. In the case of this project voltage outputs were large enough for many devices, as standard chargers for mobile devices are generally rated at five volts. The current output of the device was approximately 0.2 amps, however that is rather minimal considering standard mobile chargers generally output somewhere between .5 to one amp.

The overall output of the device was plenty to power multiple LEDs and other loads like small batteries (unclear how fast, as it was passed through lithium battery). Theoretically, the outputs achieved were plenty for also charging standard mobile devices (although the low current would result in slower charging rates). [9] However, there was no indication that the tested device (2-year old Apple iPhone 6s) was actually charging, even when hitting the threshold for voltage.

Review of Engineering Goals and Design Criteria

The original goal for the device was to be able to capture, store, and utilize an abundant form of energy to generate electricity, being of use in situations of need. Electricity was clearly outputted, and enough was generated for low-power devices like LEDs, thus fulfilling the goals.

The design criteria for the product was for it to be inexpensive, portable, and easy to use. The device was inexpensive as personal costs were under $30 USD [10], although overall costs are estimated to be around the $50-75 USD [10] range. In terms of portability, the final prototype weighed 3.0 pounds, similar to the weights of many modern laptops, thus being suitable for carrying in a backpack. Lastly, in terms of usability, the device was optimized to be as simple as possible. When the final product assembly was finished, the process of generating electricity simply required placing the device over a heat source and then plugging in a mobile device through the USB port.

Scoring Matrix

Table 2. A Table to Compare Values Across the Prototypes

Single Tile vs Final Six Tile Product Values		
Category	**Single Tile Prototype**	**Final Product**
Portability	1 Lbs.	3 Lbs.
AVG Voltage	1.37 volts	4.311 volts
AVG Current	45.54 milliamps	143.10 milliamps

Table 3. A Table of the Final Scores for Each Category Between the Prototypes

Single Tile vs Final Six Tile Product Final Scores		
Category	**Single Tile Prototype**	**Final Product**
Portability	10	4
AVG Voltage	6	15
AVG Current	3	9
Overall Score	**19**	**28**

See Appendix D for Scoring System Information

Future Extensions

Future extensions include making the design more appealing for the consumer market. Currently, the product looks quite industrial and not user-friendly, so that would be an area of improvement. When testing the product, noticeable damage was beginning to occur due to overheating of components, prompting for an improved heat management and protection system to be developed. Also, the data revealed underwhelming amperage results, so individually analyzing the components, particularly each tile, is important for future development.

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Appendix

Appendix A: Limitations and Assumptions

Limitations:

1. There was no direct and full-time access to electrical equipment such as soldering equipment, electrical measurement devices, and wire management tools
2. Due to many electronic component companies being based internationally, ordering of items was limited
3. Due to safety concerns, there were restrictions on testing using alternative heat sources (large fires)
4. For efficiency, device needs to have a temperature difference of at least 20 degrees Celsius
    a. Prompted a larger design for the product
    b. Also, larger heat sources are required
5. Required by SEFOS to always have supervision of an expert/engineer while experimenting

Assumptions:

1. Heat sources for the device are already confirmed and tested to work efficiently
2. Heat sources used will not be hot enough to damage components of device
3. All Peltier Tiles are made exactly the same and will maintain the same efficiency
4. Wires used in the setup are all equally as efficient
5. Efficiency of components such as Peltier Tiles will not degrade with continued exposure to heat sources

Appendix B: Notes File

Knowledge Gaps

This list provides a brief overview of the major knowledge gaps for my project, how they were resolved, and where to find this information.

Knowledge gap	Resolved by	Information is located
What is involved in surge protection of mobile devices?	Reading	(Armstrong, 1996) Notes page 3
What applications of thermal generation of electricity exist currently	Reading	(Etemadi, Ahmad ; Emdadi, Arash ; AsefAfshar, Orang; Emami, Yunus , 2011) Notes page 3
General information about Peltier Tiles.	Reading	(Kaphungkui, N. K., Phukan, A., Sharma, M., Gogoi, A., & Subhani, M. (2016).)

Literature Search Parameters

These searches were performed between 9/18/18 and 2/12/19

List of the keywords and databases used during this project

Database/search engine	Keywords
Engineering Village	Mobile communication, surge protection, telecommunication standards, voltage, transients Thermal generation of electricity

Source Title	**Surge protection for mobile communications**
Source Citation	Armstrong T. Surge protection for mobile communications. Electronic Design. 1996;44(23):133-4.
Source Type	Journal Article
Keywords	Mobile communication, surge protection, telecommunication standards, voltage, transients
Summary	This article details the regulations put in place for surge protection purposes, especially in the EU
Reason for Interest	To fill a knowledge gap of how electricity flows in a device
Notes	• Lower-voltage devices demand improved transient protection. • Although it is widely available to find surge protection devices, compatibility of parts still plays a huge role
Questions	What is transiency? How does it relate?

Source Title	**Electricity generation by the Ocean Thermal Energy**
Source Citation	Etemadi A, Emdadi A, AsefAfshar O, Emami Y. Electricity generation by the ocean thermal energy. . 2011;12:936-943. http://dx.doi.org.ezproxy.wpi.edu/10.1016/j.egypro.2011.10.123. doi: 10.1016/j.egypro.2011.10.123.
Source Type	Conference Proceeding
Keywords	Thermal generation of electricity
Summary	This source describes the OTEC, Ocean Thermal Energy Conversion, process and how the different temperatures of the water allows for a flow of warmer water in the form of steam, bubbles, and more to turn turbines etc.
Reason for Interest	Discovering common applications
Notes	• Very similar to researched air temperature differential process • Involves the moving of a turbine to generate the electricity • 170,000 TW of solar radiation hit Earth, making it the most plentiful renewable resource at our disposable

	• It is relatively difficult to capture energy from it • Thus, large collection areas are required • The oceans cover 71% of Earth's Surface, making it an optimal location for harvesting sites • Due to rotations of heated and cold water, a large oceanic thermosyphon occurs • The ocean maintains thermal (heat from sun) and mechanic (movement of water and waves) • ***A temperature differential of 20 degrees or more is required for an energy conversion*** • Onshore and Offshore facilities available for development as well as sea cables to transport energy • Manually fluctuating the flow of the hot and cold waters can allow for some forms of crop manipulation, a side benefit • Open-Cycle OTEC, is a process which uses flash evaporation of warmer water in chambers to spin turbines. The evaporated water is then condensed to reinitiate the cycle. • The use of water is beneficial as it is non-toxic as well as being well controllable • Desalination of water leading to freshwater yield is a potential benefit from the evaporation process • A Closed-Cycle OTEC, is a process which uses warm water to heat a controlled fluid. This fluid will then be evaporated, in turn turning the turbine • The several methods of OTEC could be an effective source of renewable energy with zero emissions
Questions	How efficient is this process? Could be efficient if applied. What happens to the desalinated water?

Competitor Review		
Product Name/Company	Description	Criteria Review
PowerWatch /Matrix Industries	This company designed and manufactured a premium smart watch. It uses solely thermal heat from your wrist to power the device. Its capabilities include recording health data, sleep tracker, and advanced models even act as notification devices and more.	Cost: ranges from $199-279 USD (quite steep for a relatively new product) Very well designed but lacks customizability It is in a deep market filled with other innovative devices. It is unclear whether it will truly become a big name in the future.
HandEnergy	A Kickstarter funded, apple-sized mobile device which generates sufficient output to charge a phone. It generates energy by shaking it in circular motions. Coupled with the app, it can be used as a fitness app or potentially a fitness tracker or game.	Cost: ~70 euros base price Their website does not list an official price, leading me to believe that it is continuing to be in development. The design is quite unique but if it was able to be powered whilst in a bag or something, it would be less cumbersome. Has a lot of potential in my opinion.
Firebee Power Tower/Hydrobee	A thermoelectric generator that is meant to be used as a mobile device charger. It is designed to be used over a large heat source like a chimney or a stove.	Cost: $159 USD It is a large device that is not very versatile. Requires a large heat source to generate energy for mobile devices. Not very efficient for a device its size.
Skybee/Hydrobee	An all-weather-resistant portable solar pack which is powerful enough to operate in	Cost: ~$250

	the rain. It packs two outputs with USB.	Quite expensive for a mobile device power generator Relatively heavy with models weighing in between 4-6 lbs How practical is carrying around a solar panel kit.
Batterbee/Hydrobee	A unique device; a rechargeable battery charged through a built in USB. It can function normally as a AA battery. Hydrobee boasts that the 4-pack can replace 2000 disposable batteries.	Cost: ~24.95 per 4 batteries Cheap, versatile, efficient This device truly is innovative and could prove to be very big in the future of saving the environement
Window Emergency Solar Power Harvester/XDDesign?	A potential design I found while researching. Mentions a solar powered generator which takes advantage of an adhesive to stick to a window. Essentially plugging a panel on to a window rather than plugging your phone	NA, no official pertinent information as of right now

Source Title	**Wearable Thermoelectric Generator with Copper Foam as the Heat Sink for Body Heat Harvesting**
Source Citation	Shi Y, Wang Y, Mei D, Chen Z. Wearable thermoelectric generator with copper foam as the heat sink for body heat harvesting. Access. 2018;6:43602-43611. https://ieeexplore.ieee.org/document/8425035. doi: 10.1109/ACCESS.2018.2863018.
Source Type	Journal Article
Keywords	Wearable, thermoelectric, heat sink
Summary	This details an application of a thermoelectric generator which is designed using copper foam as a heat sink and is intended to be implemented as a wearable
Reason for Interest	I plan on developing some form of a wearable or usable thermoelectric generator
Notes	• Body heat as potential to heat personal medical sensors

	• The use of copper foam as a heat sink is intended to up the low voltage and power generation as seen with using basic body thermal energy • Utilizes the Seebeck effect • The use of a heat sink allows for better cooling of the designated cool side • Regular copper heat sinks tend to be too rigid, making it less ideal for actual use as a wearable • The conductors are sometimes called thermoelectric legs • The team decided to use an accelerometer as the device to be powered by the wrist TEG • Arduinos were also used as control decks for the accelerometer • Adding motion seemed to add to the output of electricity. • As the accelerometer was tested and functioned normally, it is safe to say that the implementation of Seebeck generators or thermoelectric generators in body parts such as the wrist potentially could power important devices in the future. It is predicted by the team that it could potentially be a constant renewable power supply to power electronics and medical sensors for health monitoring and detection. • The application and efficiency of using the copper foam is still being tested but the signs are looking good.
Questions	How did motion induce a larger output of electricity?

Source Title	**The Hollow Flashlight**
Source Citation	Bowne H. The hollow flashlight. . 2015;24(1):11+. http://link.galegroup.com.ezproxy.wpi.edu/apps/doc/A400414006/SCIC?u=mlin_c_worpoly&sid=SCIC&xid=45000e08.
Source Type	Magazine Article

Keywords	Peltier tile application, thermoelectric generation,
Summary	This article describes a first-place Google Science Fair project from a couple years ago by a 15-year-old girl from Canada named Ann Makosinski, which converts thermal energy from your hand into electricity to power an LED flashlight. This was designed in response to develop a cheap method of producing light.
Reason for Interest	This type of model of a project is very similar to what I hope to accomplish.
Notes	• This battery less flashlight could be beneficial to about 1.3 billion people in this world who lack consistent electricity • The average human radiates enough energy to power a 100-watt lightbulb • Electricity is the movement of electron particles • Amps, volts, and watts are three characteristics of electricity • Amps, are the units used to measure the rate that electrons flow in a current • Volts measure the force of the moving electrons or in other terms, the electrical flow • Watts are the total amount of power produce or the electricity consumed. • According to Ann's calculations, to keep a consistent energy flow for the light, she required a nine-degree temperature difference between the body heat and outside air
Questions	Where did she acquire the necessary materials?

Source Title	**Portable cell phone battery charger using solar energy as the primary source of power**
Source Citation	US6977479B2
Source Type	US Patent
Keywords	Renewable energy, mobile accessory

Summary	This patent details a device that is a portable battery bank, specialized for cell phones, and uses solar energy as a primary power source
Reason for Interest	Very similar to my potential STEM project because it shares the same applications
Notes	• Modular design – retractable solar panels • Multi-use: to directly charge the mobile device, to charge the internal battery of the solar energy case, and to charge mobile devices using the internal battery of the case • Energy generation efficiency is maximized by the ability to rotate the solar panels • It is a unique design in the field of solar panel technology because it does not require direct ambient sunlight to function at a high level • The effectiveness of this device comes from the fact that it has its own internal batteries which it can charge itself
Questions	What is the effectiveness of the modular design?

Source Title	**Thermoelectric Management of Lithium Ion Batteries in Mobile Devices**
Source Citation	E-project-050114-154355
Source Type	MQP of WPI
Keywords	Batteries and thermoelectric activity
Summary	This e-project from a WPI team hopes to make lithium ion batteries, commonly found in mobile devices, much more effective through thermoelectric management.
Reason for Interest	This paper details thermoelectric management in small device sizes, like in mobile devices. This is a very similar scale as in my project
Notes	• As mobile devices are becoming more advanced, they require more power

	• However these products are getting smaller and smaller, thus smaller batteries in some devices • The only option is to make whatever batteries we have more efficient • This can be achieved through thermal management, as battery performance is heavily impacted by thermal conditions of its environment • Potential solutions to thermally manage lithium ion batteries currently exist, such as micro heat pipes, phase change materials, and nanocomposites • A Peltier system in an Arduino board, which is wirelessly connected, was used by the team to control the battery surface temperature • Lithium ion batteries are chosen for mobile devices due to the high CPU power demands of these devices being supported by the high energy density of these batteries as opposed to alternative technologies • These batteries have optimal temperature ranges like many products • If its too cold or too hot, these batteries will not be able to discharge • The objective of this project was to develop characteristics required of a thermal management system for lithium ion batteries for future recommendations of thermal management solutions
Questions	How does the team plan to make a small enough design? **Will be revisited for further notes**

Source Title	**VENTILATION APPARATUS CAPABLE OF RECOVERING THERMAL ENERGY**
Source Citation	EP2679924 (A2) — 2014-01-01
Source Type	European Patent
Keywords	Thermal Energy capture
Summary	This ventilation system is meant to be applied large-scale like in a building. A ventilation

	apparatus essentially cycles the air through the building, in such a fashion which recovers much of the thermal energy is producing
Reason for Interest	This system and related systems could help me create an efficient thermal system, so I can capture the most thermal energy for my project
Notes	• Includes a main body, absorption filter, heat exchanger, blowing fans, a water supply pipe • Exhaust ports through the main body allow for indoor air to exit and outdoor air to enter • The absorption filter essentially cools the flowing air • The heat exchanger is located in such a way so that it can do as its name suggests and can exchange the heat between the supply and exhaust air • The two fans are responsible for cycling the air in and out of the building • The water supply pipe acts as the cooling agent at the absorption filter location as it supplies the water to it • An effective part of this design is how it largely controls the air flow inside and out – restricting any unnecessary heat loss • This invention can help alleviate air conditioning costs, as it can redirect the heat flow as needed by building inhabitants • This apparatus has the added benefit of being a humidifier in the colder, winter months
Questions	How easily can this system be miniaturized? How much can it be miniaturized?

Source Title	High power output from body heat harvesting based on flexible thermoelectric system with low thermal contact resistance
Source Citation	Park, H., Lee, D., Kim, D., Cho, H., Eom, Y., Hwang, J., . . . Kim, W. (2018). High power output from body heat harvesting based on flexible thermoelectric system with low thermal contact resistance. Journal of Physics D: Applied Physics, 51(36), 365501. doi:10.1088/1361-6463/aad270
Source Type	Journal Article
Keywords	Body heat harvesting thermoelectric system
Summary	This paper reports body heat harvesting and refrigeration effects based on a flexible thermoelectric (TE) system made of rigid inorganic bulk materials.
Reason for Interest	My project could potentially involve using the thermal energy from our bodies and convert it to electricity
Notes	• The wearable TE system shows enough flexibility to be used on curved or non-flat surfaces such as human skin • Powered by a portable battery, it performs refrigeration on human skin and is embedded in an arm band • It refrigerates human skin at approximately 4.4K, which is cold enough for humans, based on a theoretical analysis. • A wearable TE system was also attached to human skin for power generation • The TE system shows potential for use as a body heat harvester or human body refrigerator • This is demonstrated on the polarity of a Peltier tile, how it can both cool or capture and convert the heat of something it is applied to • The thermal potential difference directly converts to electrical potential, the so-called Seebeck Effect – (Electricity Generation) • Carriers transfer the heat while current is applied to the TE material, the so-

	called Peltier Effect – (Opposite effect, Transfer of heat thus causing one side to get colder) • For refrigeration purposes, a current can be applied to a tile • To achieve flexibility in TE devices, many researchers have focused on patterning materials with thermoelectricity on flexible substrates, usually of organic materials •
Questions	What are Bakelite holders?

Source Title	**Highly efficient electricity generation with Peltier Module**
Source Citation	Kaphungkui, N. K., Phukan, A., Sharma, M., Gogoi, A., & Subhani, M. (2016). Highly efficient electricity generation with peltier module. *International Journal of Engineering Trends and Technology, 35*(10), 500-503. doi:10.14445/22315381/IJETT-V35P300
Source Type	Journal Article
Keywords	Peltier module, seebeck effect, thermocouple, Fresnel lens, DC amplifier.
Summary	• This work presents the efficient generation of electricity using the principle of Seebeck effect which is a phenomenon in which a temperature difference between two dissimilar semiconductors produces a voltage difference between the two substances. • The higher the temperature differences, the higher the voltage it produces. • Here two innovative ways of harvesting energy is proposed i.e one from direct sunlight using Fresnel lens during daytime and one from simple heat source candle during night time. • Generating electricity with wind energy and solar panel is common nowadays and moreover the cost is high.

	• The aim of this paper is to generate electricity in remote areas where electricity is still irregular and insufficient. • The designed module produces power in small watt for application in low power consumption electronic products even at the absence of wind and sun energy. • The total output voltage of the design module when using candle as heat source and water as coolant, produce DC 7.6 vol and current of 4.3mA with a total power of 31.64 Watt which is enough to light low power LEDs and charging of mobile phone.
Reason for Interest	• Directly relates to materials used in project
Notes	• 7.6 volts and 4.3 mA, resulting in 31.64 watts was achieved from the candle heat source • Utilized similar apparatus
Questions	How was the outputted power efficient enough for mobile device electrical generation?

Appendix C: Experimentation Images

Figure 12. Product Data Collection using Stove Heat Source with Vernier Sensor

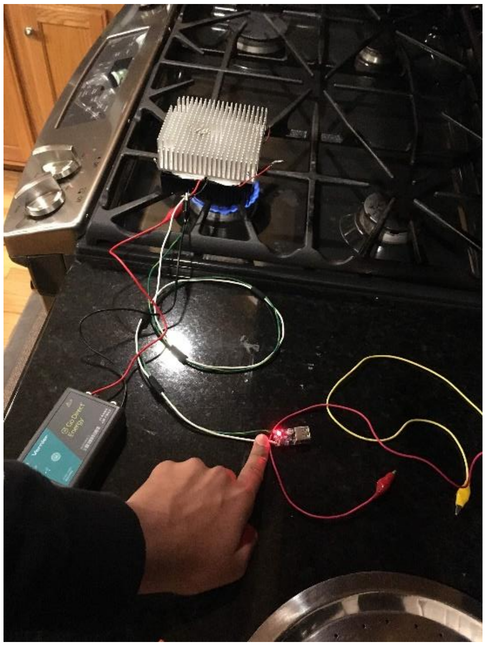

Figure 13. Demonstration of the Lighting of an LED

Figure 14. Construction of Product at the Loven Workspace

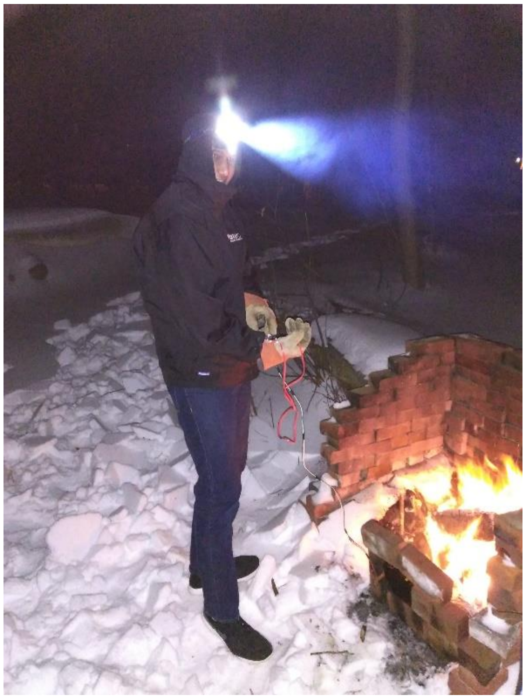

Figure 15.: Field Testing using Campfire

Appendix D: Scoring System Table for Scoring Matrix

Table 4. A Table of the Scoring System for Calculating Scores in the Scoring Matrix

Scoring System						
Category	**Weight**	**Value (1-5)**				
	(1-3)	**1**	**2**	**3**	**4**	**5**
Portability	2	Weight >=5 Lbs	4 Lbs < Weight <= 5 Lbs	3 Lbs < Weight <= 4 Lbs	2 Lbs < Weight <= 3 Lbs	1 Lbs < Weight <= 2 Lbs
AVG Voltage	3	Volts >= 1 volt	1 volt < Volts <= 2 volts	2 volts < Volts <= 3 volts	3 volts < Volts <= 4 volts	Volts > 4 volts
AVG Current	3	.01 amps<Amps <= .05 amps	.05 amps < Amps <= .1 amps	.1 amps < Amps <= .15 amps	.2 amps < Amps <= .25 amps	.25 amps < Amps <= .3 amps