Investigation of Peltier Devices for Refrigeration

A Senior Project by

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Abstract:

The purpose of our project was to characterize Peltier devices and determine if they were good candidates toward inexpensive off-grid solar powered refrigeration in poor countries. We measured the rate of cooling with a constant temperature thermal sink for different current inputs. Through numerous experiments we calculated the coefficient of performance for two different thermoelectric coolers (TECs) through a range of temperature differentials. In addition, we found the lowest temperature these Peltier chips could reach so that we could test the accuracy of the information provided by the manufacturers spec sheets. Overall the data gathered through our research is compelling toward the creation of TEC-driven refrigeration.

Introduction:

The motivation for this area of research is how people in third world countries can make use of innovative technologies. Thermoelectric coolers were the technology our group was tasked with. The long term vision of this group is to implement a solar powered refrigerator in Ghana. The average annual temperature there is about 79^0F and in that heat, produce, meat, and dairy spoil incredibly quickly. By providing a method of refrigeration, less food will go to waste. They also won't have to buy or gather produce as often and meat and dairy will not have to be consumed as quickly. Another relevant statistic is that the current percent of children under 5 who suffer from malnutrition is estimated to be 3.5%, which is significantly higher than first world countries like the US. With an average yearly income of $4100, our project must also be economically designed. Though there are other groups around the world addressing the problem of medication storage in these areas, a TEC refrigerator could serve that purpose as well.

Many factors contributed to our desire to research the efficiency and practicality of a TEC refrigerator. First, Peltier devices are cheap, solid state, environmentally friendly, run on DC, and have a lifetime of around 20 years. Each chip costs approximately $2, while a compressor, which is the normal cooling unit of a refrigerator, costs close to 100 times that. Additionally, compressors usually run on AC so one would also need to invest in an inverter as photovoltaics (PVs) output DC. AC motors also require a surge power to get started, usually 5x what it normally runs on, which is especially difficult when the power source is a PV. Although buying a brushless DC motor would address some of these problems, it would simultaneously considerably increase the cost. A TEC with no moving parts increases simplicity while decreasing likelihood of malfunction.

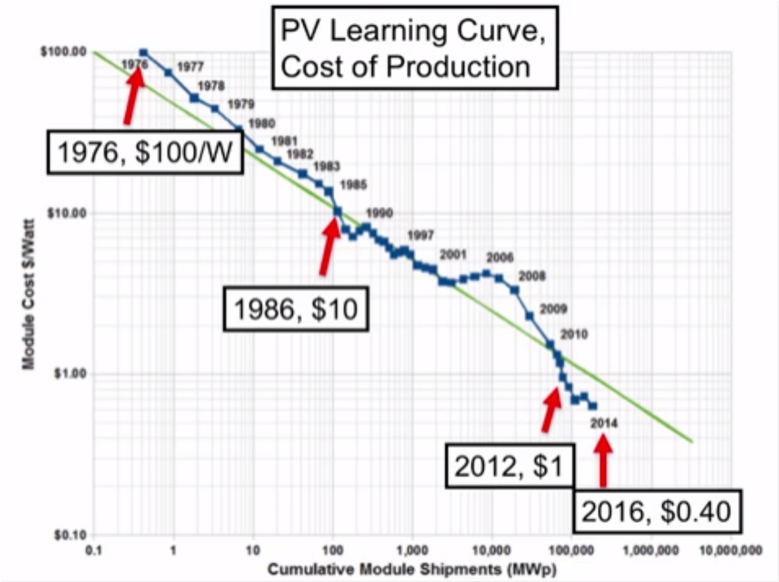

Figure 1

Figure 1 illustrates the ever declining price of photovoltaics. TEC technology becomes more practical with decreased PV cost. It allows the inefficiency of Peltier modules to become less relevant since we can just utilize more PVs and TECs to get the same result. This, along with the trend in TEC improvement since its inception, makes it clear that Peltier chips will win in the long run.

Currently TECs are employed for a variety of applications, but not popularly used as the cooling unit in refrigerators. Thus, this research is strategically timed to develop tomorrows technology.

TECs and Refrigeration:

This project revolved around Peltier devices that take advantage of the thermoelectric effect. The thermoelectric effect occurs when there is a junction between two dissimilar metals. If there is a temperature gradient across this junction a voltage is generated. This is known as the Seebeck effect. The Peltier effect has the reverse relationship. When a current is driven through the junction, a temperature gradient will develop across the device. This effect is most prominent in semiconductors.

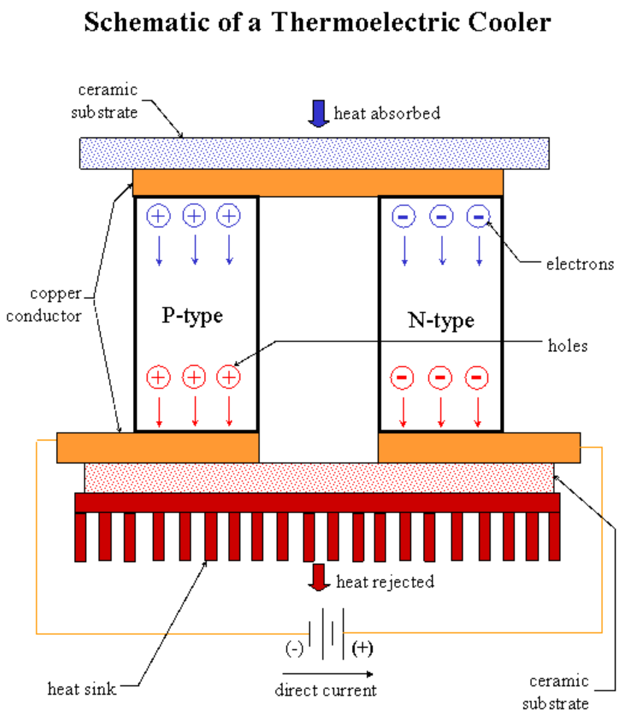

Figure 2

A typical TEC is composed of n and p type semiconductor pairs that are in series, compressed between two thermally conductive and electrically insulated plates (Figure 2). The heat carriers are the electrons and holes in the n and p type semiconductors. This heat is removed from one of the semiconductor junctions and deposited at the other when current flows through the two electrical junctions. The heat moved by a single semiconductor pair is determined by the Seebeck coefficient, resistivity, and thermal conductance of each material.

Experimenting:

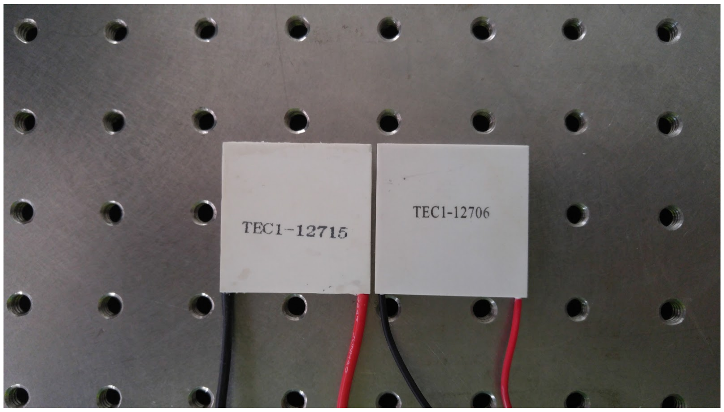

Figure 3

We designed an experiment that would accurately test the desired parameters of the Peltier. We tested two devices, the TEC1-12706 and TEC1-12715 (Figure 3). The "127" indicates each one has 127 n and p type semiconductor pairs while the "06" and "15" correspond to their maximum current (6 and 15 amps). Their size (40 mm x 40mm x 3.9 mm) corresponds to a current density of ~ 0.01 A/mm^2.

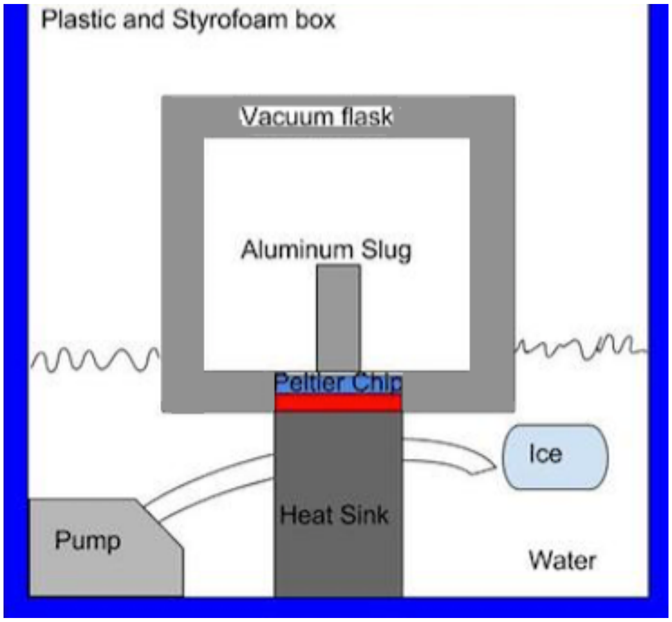

Figure 4

In the experiment (Figure 4) a well insulated aluminum slug is cooled by pumping heat to a constant temperature heat sink. A 462.6g aluminum slug inside a vacuum flask is connected to the cold side of a TEC. The hot side of the TEC is connected an aluminum heat sink immersed in ice water with a circulation pump keeping the heat sink near 0°C.

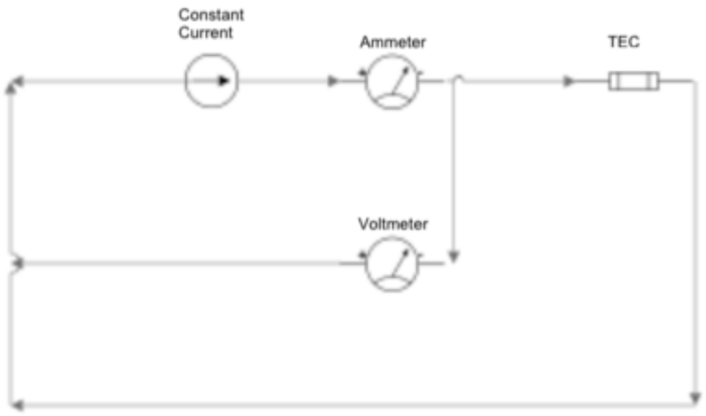

Figure 5

The electrical circuit powering the TEC and measuring the current and voltage can be seen in Figure. 5. It shows what electrical components were involved in our experiment and the how they were wired together to get the data we needed. For each experiment the temperature of the target, the temperature of the heat sink, and time were recorded.

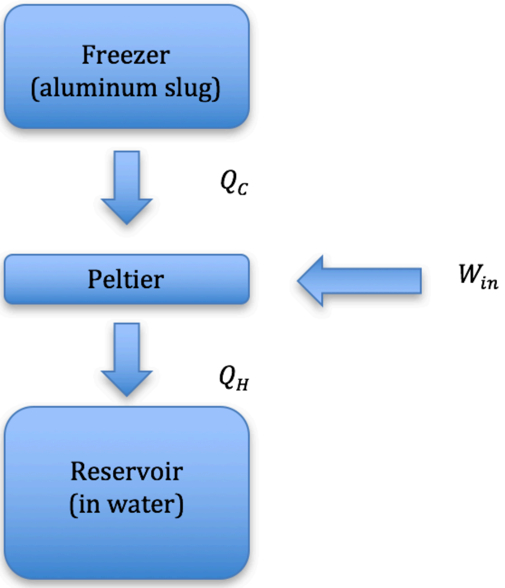

Figure 6

Figure 6 visualizes how heat flowed in our system during operation, while Figure 7 shows the actual experiment. A constant current power supply powers the TEC, and a multimeter measures the voltage across the Peltier chip. The phone captured a photo every 30 seconds recording the voltage and temperature of the hot and cold side of the TEC.

Figure 7

The relationship between the differences in temperature of each important feature in the apparatus can be seen in the equation, $\Delta T_{Peltier} = \Delta T_{data} + \Delta T_C + \Delta T_H$, where $\Delta T_{Peltier}$ is the difference in temperature across the Peltier, ΔT_{data} is the difference in temperature between the sensor readouts, and ΔT_C and ΔT_H are the temperature difference between the target aluminum slug and cold side of the Peltier and the temperature difference between the heat sink and the hot side of the Peltier.

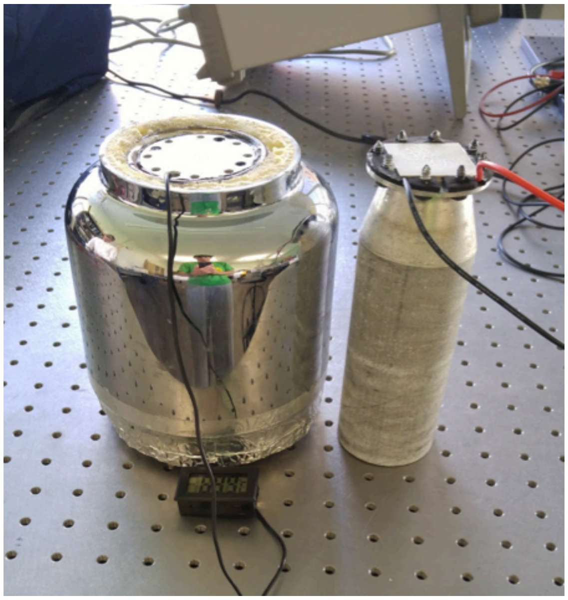

Figure 8

Figure 8 displays the heat sink and vacuum flask not screwed together. In order to reduce heat conduction between the aluminum slug and the thermal reservoir we used plastic screws instead of the more conductive metal screws. Additionally, we surrounded our Peltier chip with rubber foam.

Data:

To characterize the TECs we ran different currents through them and measured ΔT_{data} and time until ΔT_{data} plateaued or "saturated". For clarification, when ΔT is mentioned throughout the remainder of this paper it is referring to ΔT_{data}. We calculated the electrical power using the equation $P_{in} = IV$, while determining the power we pulled out of the system through the $P_{out} = mC\frac{dT}{dt}$ relationship. The heat moved through the TEC was calculated by measuring the change in temperature of the aluminum slug: $E = mc\Delta T$.

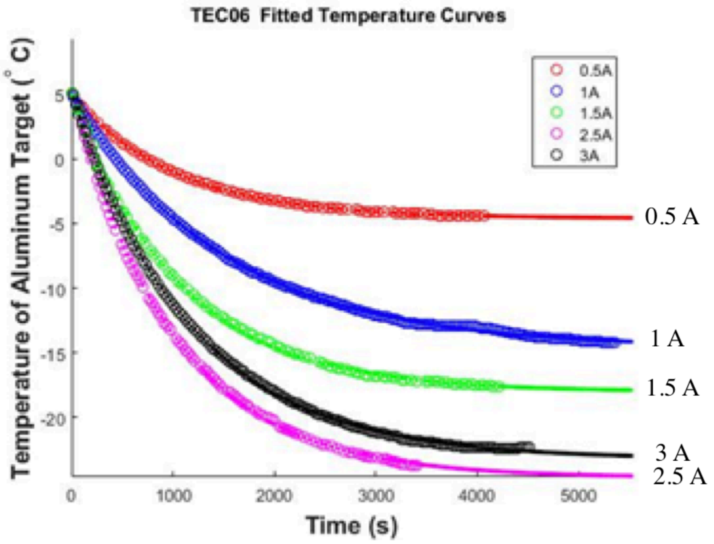

Figure 9

Figure 9 shows a plot of the temperature of the aluminum slug in the vacuum flask as a function of time. Performance is optimized between 1.5 A and 3 A as 2.5 outperforms the 3 A run. It's possible the heat sink wasn't able to pull the extra energy being generated by the Joule heating fast enough at higher currents. The higher the current, the more heat produced by Joule heating will need to be removed. The data of Figure 9 and10 nicely fit to the theoretical curve of Newton's Law of cooling: $\frac{dT}{dt} = -k(T - T_s)$ and $T(t) = T_s + (T_o - T_s)e^{-t/t_0}$.

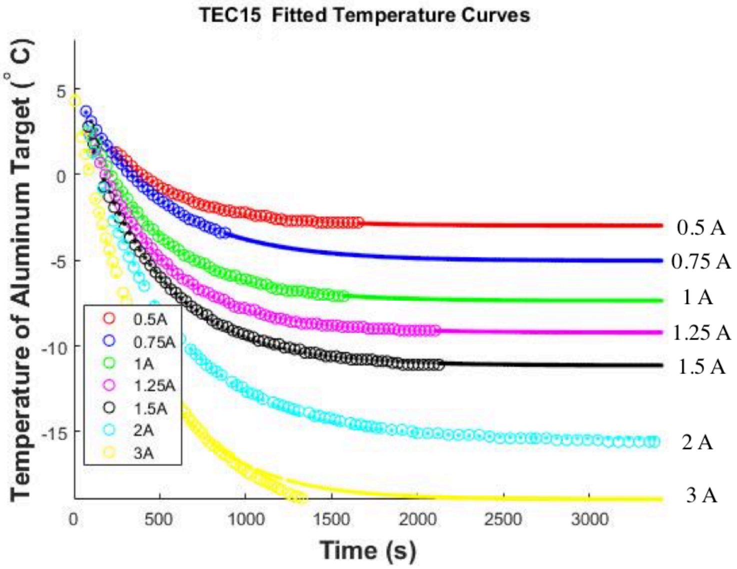

Figure 10

Figure 10 repeats the experiment in Figure 9 for the other TEC. Unlike the TEC06 the performance of the TEC15 continues to increase with increased current.

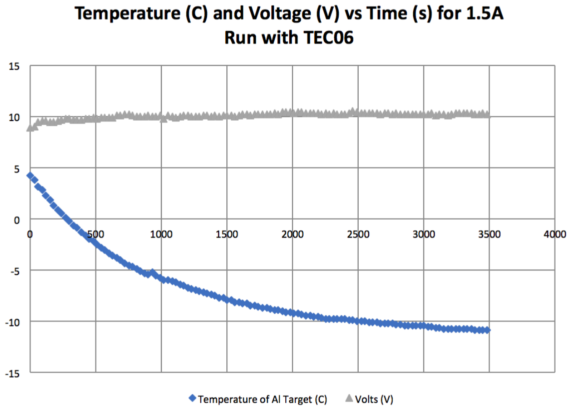

Figure 11

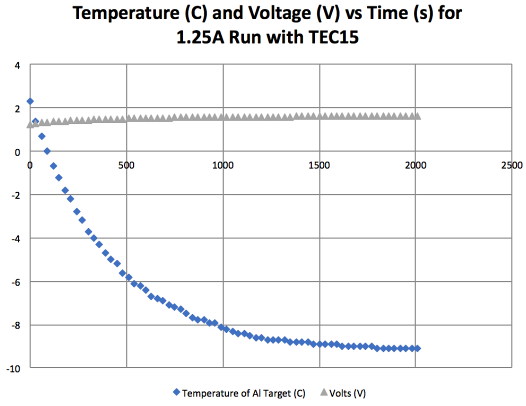

Figure 12

The relationship between the temperature of the target and the voltage needed to keep the current constant throughout the run is shown in Figures 11 and 12. For both devices the voltage increased slightly as the aluminum target got colder.

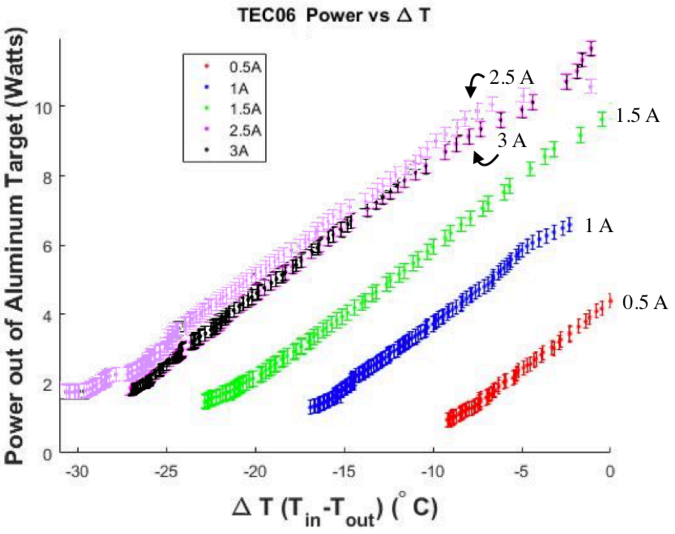

Figure 13

A linear relationship is apparent for each of the data sets with respect to the power being moved out and the total difference in temperature indicating a slope of about 0.4 $W/$□C. Another interesting aspect of Figure 13 is that the power increases at a decreasing rate as the current rises.

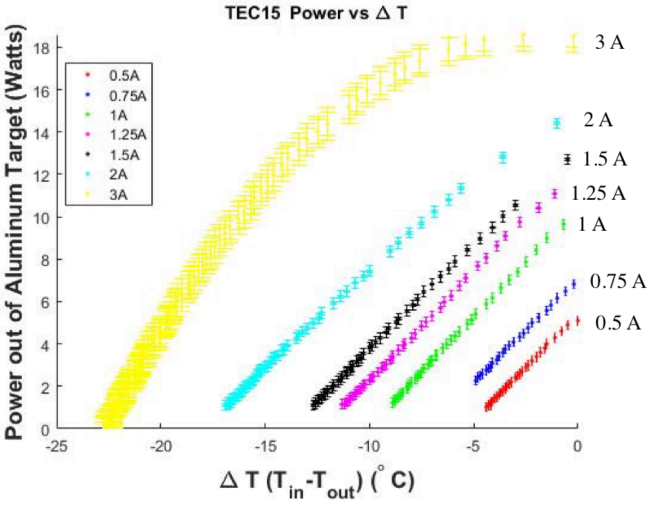

Figure 14

The nonlinear relationship the 12715 Peltier had for the 3A data is displayed in Figure 14.

Figure 15 provides insight into how efficient the 12706 is at removing heat from the target when compared with the power they put into the system. Figures 15 and 16 show that coefficient of performance (COP) decreases as ΔT increases.

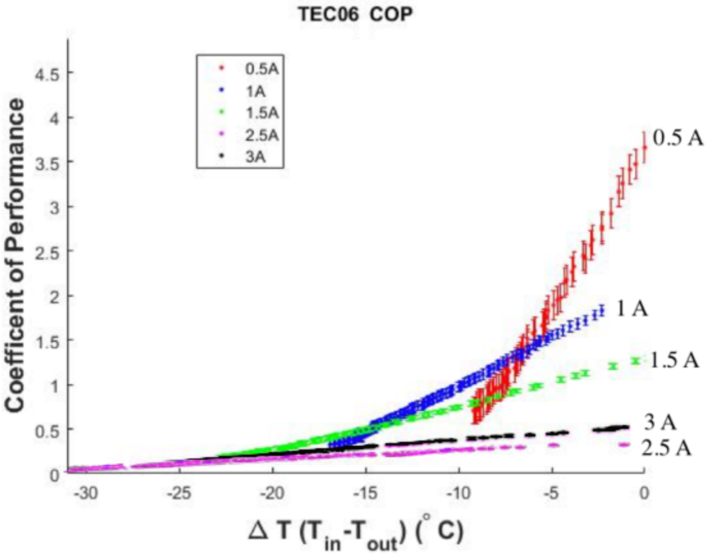

Figure 15

Most importantly these graphs tell us what current we should run given a certain ΔT. For example, the highest COP for the TEC06 at ΔT = -10° is reached when the device is run at 1A. The equation $COP_{cooling} = \frac{E_{removed}}{E_{electrical}} \leq \frac{T_{cold}}{T_{hot} - T_{cold}}$ allowed us to calculate COP for both of the devices at different temperatures throughout our runs.

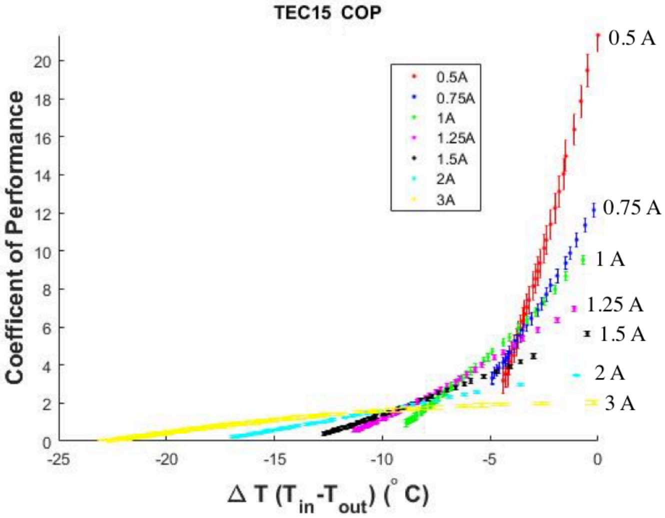

Figure 16

It is apparent that the 12715 has a higher COP, as plotted in Figure 16, but the 12706 reached lower ΔT's for the same input current.

Conclusion:

The greatest finding from our research was that at the same current the 12706 reaches a lower temperature while the 12715 reaches its saturation temperature faster and has a higher coefficient of performance. We believe that TECs show promise in use as a direct solar cooling element and have confidence that these can be used to achieve our original goal. The next steps for a future group working on this project would be to calculate the efficiency of stacking, determine the best Peltier device for a solar powered refrigeration system, and to design and build a prototype. Determining whether stacking is a more effective technique than a single layered system is the next big piece of information needed to move forward with this idea. Stacking could be beneficial as it would allow the TEC chips to be run at lower currents, thus higher COPs, and reach an even lower ΔT than a single layered setup. The trick is to see if that actually requires less power than just running one TEC at a really high current. This also plays a role in deciding which Peltier device to use. It seems that the 12706 could work best in a single layer design, while the 12715 could be better suited for stacking as it would need multiple devices to reach a temperature below freezing, from a hot side at room temperature. When choosing a TEC, one would also benefit from testing if there were other larger sized or higher quality devices that would work better. We looked into locally manufactured Peltier's to see if they would perform at a higher level than ones made abroad. The real balance here lies in whether the improved performance is worth the extra expenses. Finally, constructing a prototype would be the concluding stage in this project. The culmination of all the experimenting and preparation would introduce the last phase of problems before a working model is produced. It would help us see exactly what it would look like to try and implement one in an underdeveloped country and what would need to change before introducing them overseas. Overall Peltier cooled refrigerators seem to be a legitimate possibility and will only become more competitive as the cost decreases and the performance increases for both TECs and solar panels.

References:

Figure 1: Schwartz, Pete. "Solar Electric Cooking and Uganda, Pete Schwartz, Cal Poly Physics" *YouTube*. YouTube, 08 Feb. 2017. Web. 15 June 2017. <https://www.youtube.com/watch?v=lgAXLDsDT7w&t=92s>

Figure 2: "FAQ's & Technical Information - TE Technology. TE Tech Products. N.p., n.d. Web. 15 May 2017. <https://tetech.com/faqs/>.