Section II: Methodology

Role of Student vs. Mentor

My mentors included my uncle and my mother. They provided a deeper knowledge of electricity, electronics, and batteries and were able to provide insight and teaching of different techniques. They contributed to my skill development, especially with electronic components, as well as problem solving when I ran into roadblocks. I created the design, researched available materials that would work for my project, constructed the devices, built the electronic components, interfaced and programmed the Arduino processor, conducted tests, and performed calculations. I spent XXX hours on this project.

Equipment and Materials

The following are the major subsystems which comprised my thermal battery project.

The input electricity measurements were taken using a 150A RC Watt Meter High Precision Power Analyzer. This was used to measure voltage, current, and watthours during the charging phases of the project. Temperature measurement and control was done using an ELEGOO UNO R3 Board ATmega328P Arduino-Compatible processor connected to a laptop using a USB cable. Input power (24VDC) to the project was provided using an Acopian A24H1200M Regulated DC Power Supply.

The cooling portion used TEC1-12715 Peltier Semiconductor refrigeration tablets attached to an aluminum heatsink left over from a Dell R710 Server. Cooling used two (2) 4500 RPM 80mm x 80mm x 25mm 12VDC fans and one (1) 3500 RPM 80mm x 80mm x 25 mm 24 VDC fan. Gennel G109 Thermal Conductive Glue was used to glue the four (4) Peltier modules to the heat sink. To hold the water as it cooled, a Steel Spice Tin was used which held .7 liters of liquid. This tin was wrapped with Foil-Backed Fiberglass insulation, 3” wide x 1” thick.

The temperature of the water was measured using a HiLetgo DC 3-5V MAX6675 Module Type K thermocouple temperature sensor and amplifier connected to the Arduino processor. A custom board was developed for cooler control, consisting of an orange LED (to show +5VDC present), a blue LED (to show 24 VDC sent to heater), a micro relay (5 VDC relay 1A coil, DPDT) and a high-power relay (24 VDC relay 6A coil, DPDT). This board interfaced to a digital output (DO) from the Arduino processor to be able to turn the cooler on and off again once the desired temperature was reached.

The heating portion consisted of a heating coil salvaged from a discarded room heater. This was adapted to run on the 24VDC power supply available. To hold the paraffin wax, another Steel Spice Tin was used. This tin was wrapped with insulation. The paraffin wax was sourced from Sigmaldrich as SKU 411663 (1KG) which had a melting temperature of 65 ^{o}C. The temperature of the paraffin was measured using a HiLetgo DC 3-5V MAX6675 Module Type K thermocouple temperature sensor and amplifier connected to the Arduino processor. A custom board was developed for heater control, consisting of the same components as the cooler board. It interfaced to a digital output (DO) from the Arduino processor to be able to turn the heater on and off again once the desired temperature was reached.

The Thermoelectric Generator (TEG) portion of the project used six (6) 1 watt TEG modules from TEGMART, rated with output voltage of 2 VDC, each 80mm x 80mm in size. These are connected to a custom-built board that takes an input from the six modules and connects to a XINGYHENG DC-DC Buck Voltage Converter Module 4.5-40V 12 to 5V for use with USB power supply.

Technique 1: Cooling

To freeze water, designated aluminum heat sinks with Peltier modules and fans were attached to a steel spice tin. Insulation was wrapped around the setup to prevent loss in efficiency of cooling. Temperature and power used were measured every thirty minutes.

Technique 2: Heating

To melt paraffin wax, a heating coil was placed underneath a steel spice tin filled with .7 liters of paraffin. Insulation was wrapped around the setup to prevent heat loss. Temperature and power were measured every thirty minutes.

Technique 3: TEG

Six (6) TEG modules were placed between hot and cold spice tins with a strap to hold them in place. Voltage generated was measured every five (5) minutes.

Statistical Tests

Several statistical tests were used to evaluate the performance of the thermal battery. These tests included:

- **Time Series Analysis** – The performance of the battery during charging cycles and discharging cycles were measured, including the voltage, current, watt Hours, and temperature differentials of the battery components.
- **Correlation Analysis** – The correlation of the delta temperature between the cold and hot temperature tanks were measured and compared to the output voltage produced by the battery to develop the correlation between those parameters.
- **Hypothesis Testing** – The hypothesis of the battery performance using theoretical parameters of the two materials used (water and paraffin wax), the number of joules that are absorbed by each, and the predicted output of the battery were compared to the actual results.
- **Data Visualization** – Trend charts were prepared to interpret trends in the battery performance data.
- **T-Tests** – a two-tailed T-Test was used to determine whether different measured sets of data were different from each other.

Time-series Analysis and Data Visualization

Melting the 0.7 liters of paraffin was found to have a linear relationship to the number of watts. This was about until the paraffin reached about 55 ^{o}C, as shown by the first graph of paraffin wax temperature and watt hour usage, with the delta temperature increasing steadily about 7-9 ^{o}C per half hour. At about 13:40, the temperature rate of change increased to about 17 ^{o}C and dropped to 12^{o}C the next half hour.

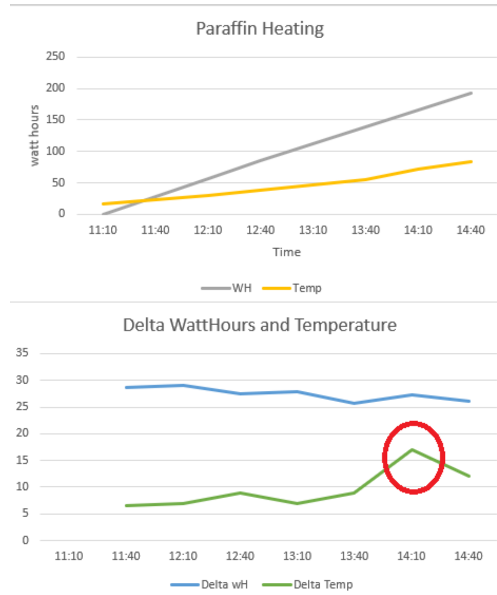

Figure 1: Temperature vs. Watthour graph for paraffin wax in paraffin heating test (top), and change (delta) in temperature and Watthours over time (bottom).

Hypothesis Testing

For the paraffin wax melting test, the total number of joules of heat energy in 0.7 liters of paraffin wax is calculated to be 289,957 J. The measurement of the watt hours used to melt the paraffin wax from the ambient 23.75 ^{o}C to the target temperature of 84 ^{o}C is given by the formula:

1 Watt Hour = 3600 Joules

The measured watt hours were 3600 Joules x 192-watt hours, meaning that the paraffin should have 691,000 Joules. The difference between the theoretical vs. the actual joules gained by the paraffin can be explained by heat losses in the resistance heater, ancillary loads (i.e., meters, LEDs, etc.), and heat loss from the spice tin to the surroundings.

Correlation Analysis

(Test to be performed).

T-Tests

Test to be performed.

Section III: Results

After testing, the results collected are as follows.

Freezing Water:

Four (4) TEC modules were initially used with three (3) fans to cool 0.7 liters of water. This design was not efficient as the delta temperature (temperature drop) was 10 degrees Celsius after a total of four (4) hours. The watthour consumption over this period was 590wH.

Subsequently, the heat sink and TEC configuration were adjusted, showing a drop of sixteen (16) degrees Celsius after 1.2 hours. The Watthour consumption over this period was 226wH.

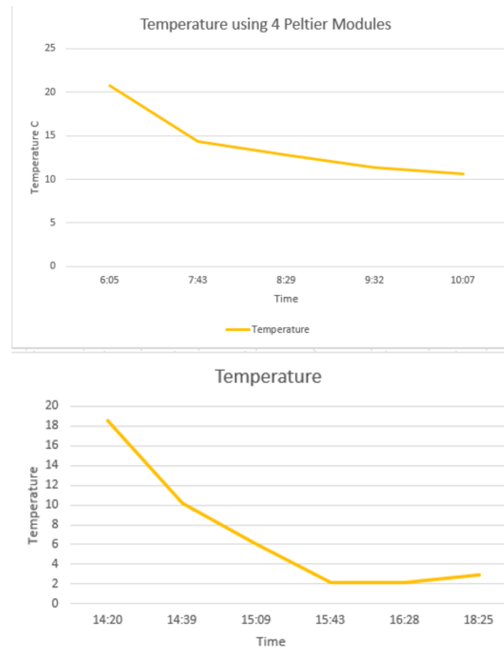

Figure 2: Temperature graph from freezing test using four Peltier modules and 3 fans (top), and temperature graph from freezing test using new stacked configuration (bottom).

Melting Paraffin:

A heating coil was used to melt the paraffin wax. The delta temperature (temperature increase) measured was 54 degrees Celsius over a period of 6.5 hours. Paraffin wax was successfully melted.

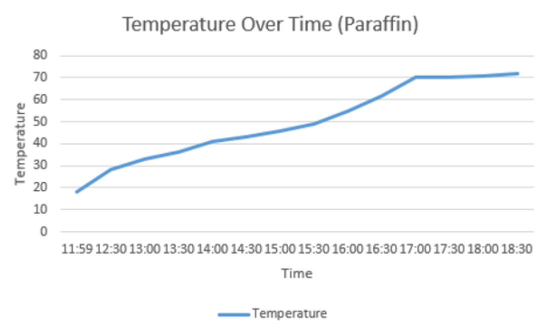

Figure 3: Temperature graph from heating test using heating coil. Delta temperature measured was 54 degrees Celsius.

Thermoelectric Generation:

More work needed.