Deliverable G

Luke Beausoleil 0300244213
Nicholas Martins 0300306097
Harrison Meeds 0300306567
Michael Mekalopolos 0300239862

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Table of Contents

1. Introduction

The purpose of this deliverable is to determine the best material and size for the casing and insulation of our prototype. This deliverable will also include the client feedback, updates design to modify the information founded, and as well task plan updates. In the previous deliverable, we stated that we would be testing the functionality of the load sensor with our code, but unfortunately the materials needed we did not have, so we had to change it to finding the best materials for our prototype.

2. Client Feedback

The client meeting indicated that the general design concept is functional and should be continued with development.

However, the design was updated to accommodate certain feedback from the client. First, it was indicated that the ground area below the silo is roughly 10 square feet. Second, it was also indicated that the height from the vacuum's extraction point to the ground is smaller than expected. Therefore, these two pieces of information have updated the design to accommodate for the spacing requirements.

3. Prototype 2

3.1. Test Plan

Prototype 2 was an analytical model focused on the performance of different materials for the casing and insulation. These materials were chosen based on their availability in local stores, making them easy to obtain. Each material will be discussed in depth in section 3.2 of this report.

All of the materials are potential insulators or casings that are readily available. This means they have known parameters with which calculations can be conducted. Because six different materials need to be tested in a variety of conditions, an analytical model is best in this circumstance.

The tests will be done in two parts: casing and insulation. For the casing, the materials' load bearing capabilities will be investigated. This will be done by calculating force values from known maximum wind and snow conditions. These are assumed based on the worst conditions Ottawa normally encounters. For the insulators, each one's performance in different temperatures will be carried out. The three results will be graphed showing max and min conditional lines to demonstrate if each material is capable of withstanding Ottawa's warmest and coldest months.

Lastly, a review of the results will occur where the casings and insulators will be examined to determine the best material to use. Cost will also play a role in this determination as no matter the quality, the cost must be reasonable to accommodate large scale budgets.,

3.2. Analysis

3.2.1. Casing

The focus of testing the casing was to compare the yield strength of numerous materials, and see if this strength would hold up against possible extreme weather conditions. The yield strength measured for each material is the force that would be required to permanently deform the material in any way. The materials chosen for prototyping were ¼ " galvanized steel, 0.019" Aluminium, and ½" Polyvinyl chloride (PVC). The important specifications of these materials are shown in table 1 and were used to evaluate the capabilities of each material. These specifications included testing to see if the material could survive the force caused by 50 cm of snow, and 124 km/h winds (both local extremes).

Table 1 Casing Materials' Specifications

Material	**Yield Strength (MPa)**	**Survives Snow ($4.17x10^{-4}$ MPa)**	**Survives Wind ($7.26x10^{-4}$ MPa)**	**Cost ($/m^2)**
Galvanized Steel	520	Yes	Yes	28.58
Aluminium	270	Yes	Yes	41.23
Polyvinyl chloride (PVC)	55.2	Yes	Yes	53.77

The force produced by snow ($4.17x10^{-4}$ MPa) was calculated by finding the weight of the maximum amount of snow on one square meter by using the most extreme possible values. First the snow load was found by multiplying the thickness of the snow (0.5 m) with the density of the snow (750 kg/m^3 for very wet snow). Then snow weight = length x width / cos(pitch(°)) x snow load. Using one square meter and a pitch of 26° the weight of the snow could be found in kg/m^2 which was easily transferred to MPa by adding time as a factor. The final value $4.17x10^{-4}$ MPa could then be compared with the materials yield strength and if yield strength > snow force then we know the material will survive the pressure.

The force produced by wind ($7.26 x10^{-4}$ MPa) was calculated by using a wind load calculator. This calculator gathered values for wind velocity (124 km/h) and air density (1.225 kg/m^3) and calculated the dynamic pressure applied on an inputted 90° m^2 object. Just like the snow load, the final value $7.26 x10^{-4}$ MPa could then be compared with the materials yield strength and if yield strength > wind force then we know the material will survive the pressure.

3.2.2. Insulation

The focus of testing the insulation was to determine the best material to maintain the load sensor temperature within its operating range of approximately -10–80ºC. Three insulating materials were chosen for prototyping: EDPM rubber, Silicone rubber, and QEP cork plus. The important specifications for these materials are given in table 2 and were used to evaluate the capabilities of each material.

Table 2. Insulation Materials' Specifications

Material	Thermal Conductivity Coefficient 'k' (W/m/K)	Thickness 'L' (mm)	Cost
EDPM Rubber	0.465	6.35	$5.44/sq.ft
Silicone Rubber	0.165	3.175	$10.27/sq.ft
QEP Cork Plus	0.38	6	$65.00

These materials, along with galvanized steel selected from the casing analysis, were analyzed in a heat transfer resistance model, as per figure 1. Additionally, it was discovered that a heater (80ºC output) would need to be attached to the wall of the casing because the lowest operating temperature of the load cell is -10ºC, and Toronto winters have temperatures as low as -35ºC. However, if a different, industrial load sensor is used that can operate below -35ºC, the heater would not be needed.

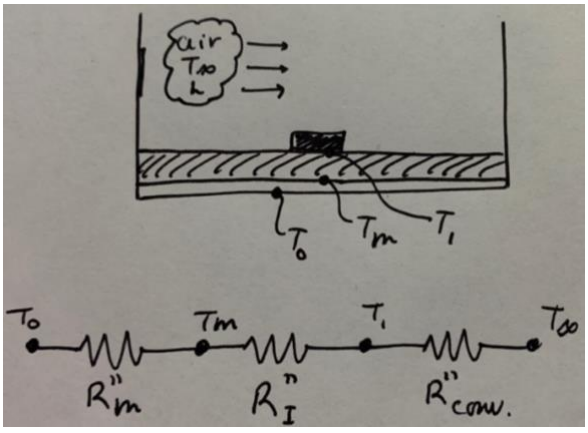

Figure 1. Heat Transfer Resistance Model

This model makes certain assumptions to be able to calculate the effectiveness of each model which should be mentioned.

First, it is assumed steady state heat transfer. This is a valid assumption since the system will be continuously working, thus it will reach steady state at some point during the process.

Second, it is assumed that there are no edge effects on the insulation or casing, and that each material is homogeneous and isotropic. Since the thickness of the materials is much smaller than the length and width, the edge effects only affect a small portion of the insulation and are very negligible. Furthermore, the materials can be assumed homogenous and isotropic because they are not composite materials, thus they should have the same properties regardless of location and direction in the material. These characteristics allow a 1-dimensional heat transfer model to be applied, thus greatly simplify all calculations.

Third, it is assumed that the load cell will not generate any heat. This assumption is reasonable since the load cell is not designed to emit heat, and thus any heat it does emit will be negligible. Furthermore, since the heater is attached to the wall of the casing, it is far enough away from the load cell that it can act as a source of ambient temperature rather than a source of heat generation.

Last, it is assumed that the heater will only be turned on when the ambient air temperature is at or below -10ºC. This assumption is valid because the load cell is operable between -10 and 80ºC, therefore, it only requires additional heating when the temperature is below -10ºC.

Using the assumptions and operating conditions, an analytical model was constructed to emulate the heat transfer and load cell temperature when the ambient air temperature is between -35 and -10ºC. It should be mentioned that a model for temperatures above -10ºC was not constructed because the load cell is operable up to 80ºC, and thus it is never at risk of failing, even when during hot summer days.

Using equations 1 and 2, the resistivities (R") of each material can be calculated. Then, using equation 3, the heat flux can also be calculated. This allows for the calculation of load cell temperature using equation 3 as well.

$$R''_{conduction} = L/k \tag{1}$$

$$R''_{convection} = 1/h \tag{2}$$

$$q'' = \frac{\Delta T}{\sum_i R''_i} \tag{3}$$

$$\text{R" = thermal resistivity; L = thickness;}$$
$$\text{k = thermal conduction coefficient; h = thermal convection coefficient;}$$
$$\text{q" = heat flux; T = temperature}$$

A range of temperatures from -35 to -10ºC was created, and at each temperature, the corresponding load cell temperature was calculated. This process was performed for each insulator material. However, it should be mentioned that the thickness of each material was changed to be as close to 1" as possible by adding multiple layers. This was done to ensure better heat resistivity of each material. As well, the thickness was never set to be greater than 1" because of the limited space available for the insulation.

Lastly, it should be mentioned that the coefficient of convective heat transfer for air can vary from 2.5–25 W/m^2/K. Therefore, the prototype model included a trial for both values of 2.5 and 25 W/m^2/K. These were the only two convective heat transfer coefficients tested because they yield either the lowest or highest load cell temperatures, respectively, thus they test the extreme conditions, which will show whether the insulator will work or not.

Figures 2, 3, and 4 show the resulting load cell temperatures for insulation of EDPM rubber, silicone rubber, and QEP cork, respectively.

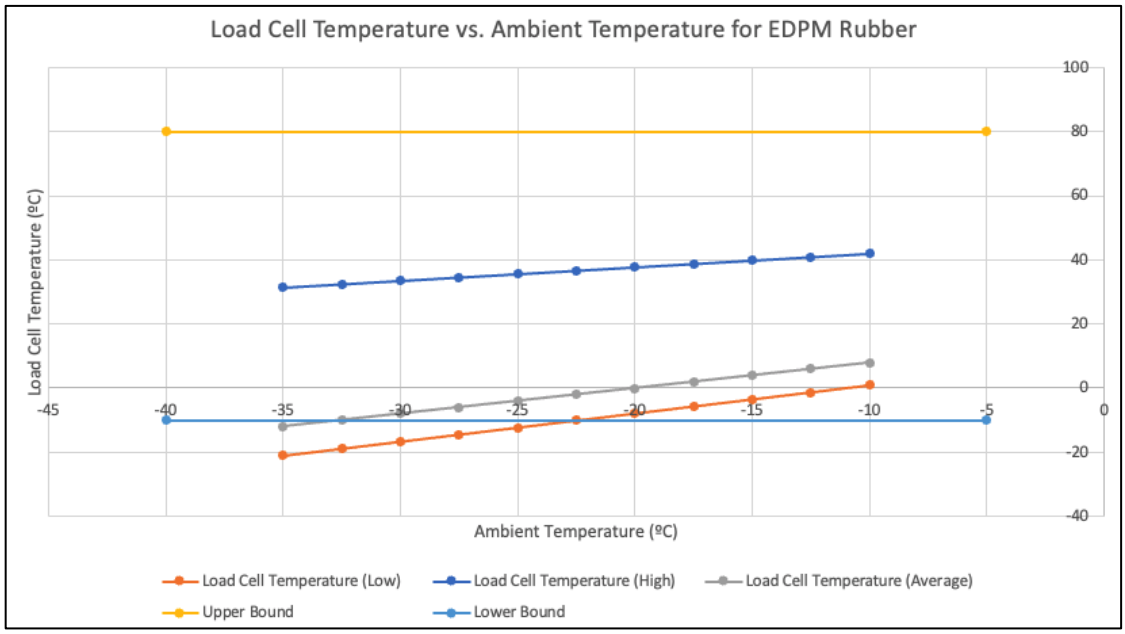

Figure 2. Load Cell Temperature vs. Ambient Temperature for EDPM Rubber

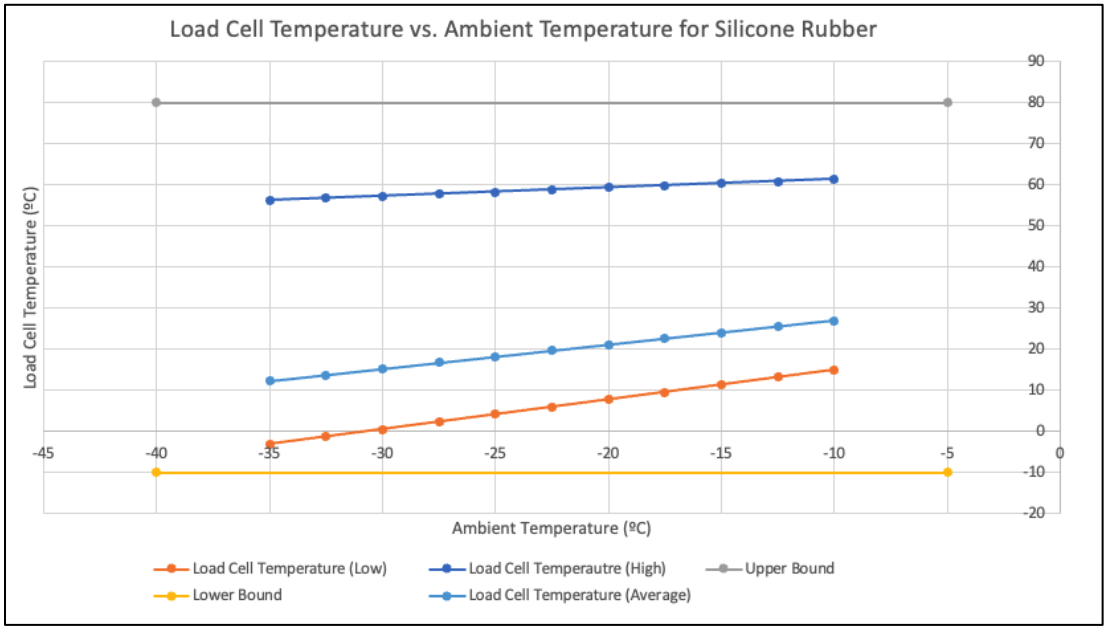

Figure 3. Load Cell Temperature vs. Ambient Temperature for Silicone Rubber

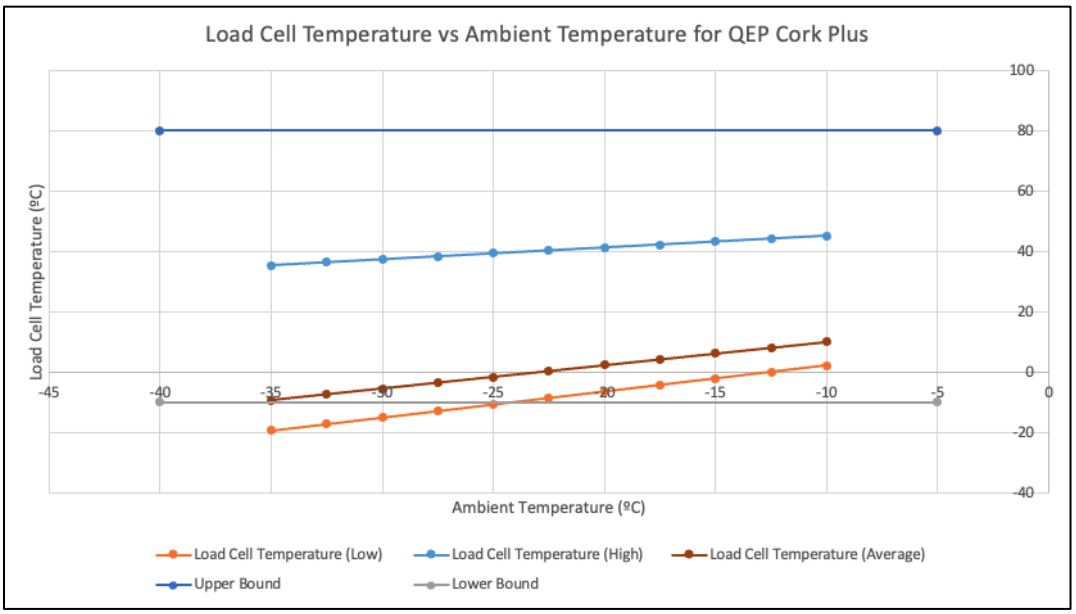

Figure 4. Load Cell Temperature vs. Ambient Temperature for QEP Cork Plus

As seen in Figures 2 and 4, EDPM rubber and QEP cork plus fail to insulate the heat provided from the heater at low temperatures and low convective heat transfer since they yield load cell temperatures below the lower bound. Therefore, these two materials are not functional for the design. However, as per figure 3, silicone rubber kept the load cell temperature within the temperature bounds at both extremes tested. Therefore, the final design will include a 1" thick silicone rubber insulation beneath the load sensor.

3.3. Results

After careful consideration, ¼" galvanized steel will be used for the casing. The price for ¼" galvanized steel at Home Depot is $28.58/m^2. According to the current design, approximately 3.14 m^2 of galvanized steel will be needed to complete the casing. Therefore, it would cost approximately $89.75 to complete the casing. This number is high, however it is not completely out of range for our final prototype, so the material usage of our final prototype will be dependent on our remaining budget by that time. For our client however, $89.75 is very well within the price range. Presenting this cost for the final design should bring no issues and if anything, entice due to its very low nature.

Regarding the insulation, silicone rubber will be used. This can be purchased from Home Deport for $10.27/sq.ft. However, this product comes in 1/8" thick sheets, but the design requires 1" thick sheets. Therefore, 8 layers of the silicone rubber will be used as insulation, making the price $82.16/sq.ft. The design will require 6.146 sq.ft of insulation, making the total cost of using silicone rubber $504.96. This price is beyond the budget for prototyping, and thus this much insulation will not be used for the final prototype. However, this will not be a problem because the final prototype will be a scaled down version of the final design, which should only

require approximately 1 sq.ft of insulation that is 1/8" thick. Furthermore, the $504.96 is well within the price range of the client for the final design and thus should not be an issue.

4. Potential Client/User Feedback

Mr. Steve White, who works with vacuuming and air conditioning units was generally in agreement with this focused prototype. He indicated that it was wise to investigate both the weight bearing capabilities of the protective casing as well as temperature range data. In conversation, he emphasized cost as being an important factor too in deciding the selected material. He performed a brief verbal evaluation of the six materials (three for each component) and provided the following feedback in table 3.

Table 3. Potential Client/User Feedback

Material	Feedback
Galvanized Steel	- Fairly inexpensive and readily available - Very sturdy - Used in industry considerably often
Aluminum	- Moderately expensive - Less rigid and firm than steel - Also used often in industry
PVC	- Quite expensive - Poor strength capacity (generally) - Rarely used
EDPM Rubber	- Moderately expensive (unknown availability) - Quite resistant to loads - Used when appropriate (case dependant)
Silicone Rubber	- Expensive in comparison to other 2 insulators - Fairly elastic and has good molding properties - Used usually in tight areas, such as corners
QEP Cork Plus	- Quite inexpensive - Difficult to cut and can easily break apart - Seldom used

All the above feedback was coming from Mr. White's personal experience after thirty years in industry. He suggested that, for this project, Galvanized steel (low corrosivity) for the casing and silicone rubber are the best choices for price and reliability purposes. In his view, it is especially important that the actual product be fully functional, rather than aesthetically pleasing. He indicated that he felt we were following through on that aspect.

5. Updated Design

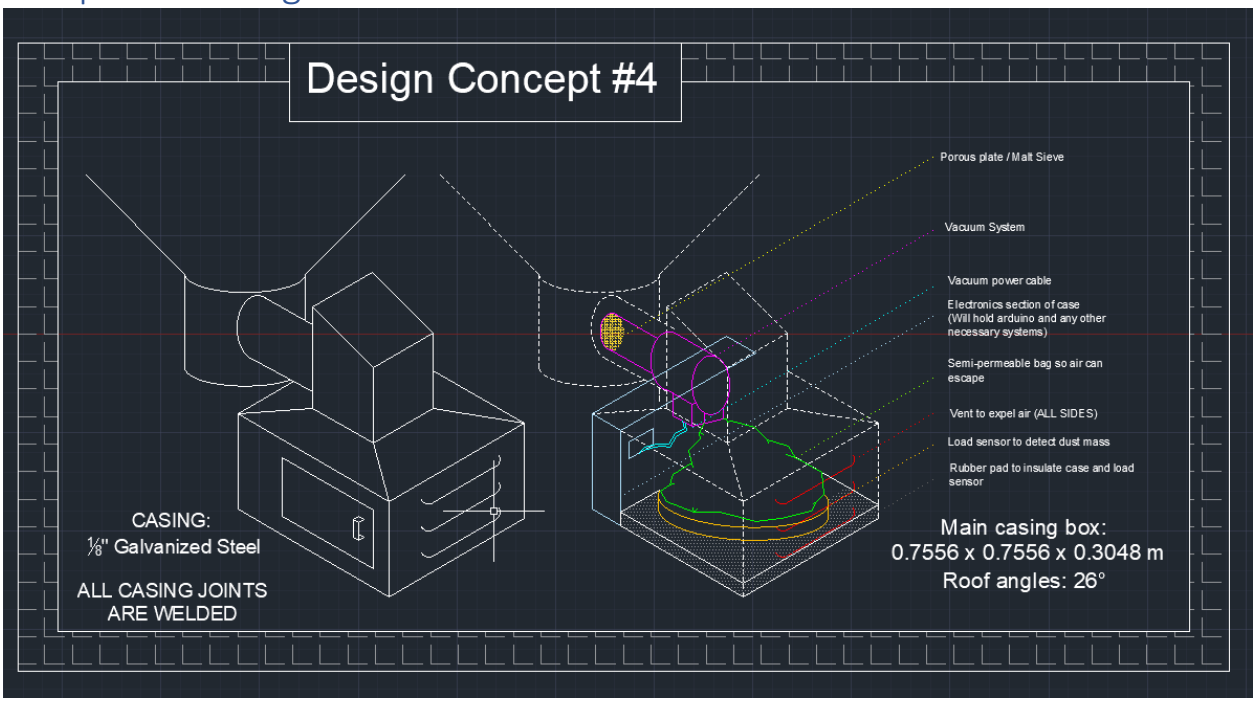

Figure 5. Updated Design

6. Updated Bill of Materials

Due to the change in schedule for this prototype, the DC to AC step-up converter was not found, and thus the price of it is still unknown. However, during the next team meeting, finding the needed device will be the highest importance item, and thus the price will be found and included in the next update of the bill of materials.

Additionally, the bill of materials is tentative and will be updated when more information is obtained; however, table 4 is the currently updated bill of materials.

Table 4. Bill of Materials

Material/equipment	Quantity	Cost ($)	Purpose	Obtained From
Centrifugal Fan	1		Create partial vacuum	
-----Vacuum Cleaner	1	$ 10.00	Obtain fan	https://www.facebook.com/marketplace
Fan Motor	1		To run the fan	
-----Vacuum Cleaner	1	$ -	Obtain fan motor	https://www.facebook.com/marketplace
Cardboard			Construct fake pipe for testing	
-----old cereal boxes	10	$ -	Obtain cardboard	Garbage
Duct Tape	1 roll	$ -	Fasten Cardboard	House
Old Popcorn	1 Bag	$ -	To emulate malt in first prototype	House
Flour	150 g	$ -	To emulate malt dust in first prototype	House
Garbage Bag	1	$ -	Capture dust in testing	House
MDF Porous Plate	1		Test effect of pores	
-----1/8" MDF Sheet	1	$ 3.00	Create MDF porous plate	https://makerstore.ca/
-----Laser Cutter	1	$ -	Cut MDF sheet	Makerspace
-----Inksacpe		$ -	Design cut for MDF sheet	https://inkscape.org/
Power			Power motor of fan	
-----Wired		$ -	Power motor of fan	Wall outlet
Screwdriver	1 case	$ -	Deconstruct vacuum cleaner	House
Dirt Bag	1	$ -	Collect dust in final product	comes with vacuum cleaner
Arduino Uno	1	$ -	Send code to load sensor for testing	Borrowed from makerspace
Wires	10	$ -	Wire Arduino	Borrowed from makerspace
Load Sensor	1	$ 16.94	Measure dust mass in final product	Amazon
Kitchen Scale	1	$ -	Measure dust mass in testing	House
Arduino Uno IDE	1	$ -	Write code for arduino	https://wiki-content.arduino.cc/en/software
Silicone Rubber sheet	1sq.ft	$ 11.61	Insulate Load sensor	Home Depot
DC to AC Step-up Converter	1	???	Convert DC power from Arduino into AC power to vacuum	Amazon
Galvanized Steel	1.6 sq.m	$ 51.67	Build Casing for final prototype	Home Depot
Heater	1	$ 12.32	Heat interior of casing during winter	Amazon
Total		$ 105.54		

7. Third Prototype Test Plan

Due to not being able to get the materials on time, we will be now officially moving on to the functionality of the load sensor with the use of C++. We replaced the second prototype test plan with testing the thermal resistance of a EDPM rubber, silicone rubber, and QEP cork plus.

This plan will be successful if the load sensor will be connected to an Arduino which will be run a C++ code into an Arduino IDE, which will be able to the display the load sensor is performing and the values. Also, when giving the dust composition, we will determine how long it takes the load sensor to give to the values. We will record the time it takes to retrieve the value.

We will need to make sure while developing this code, that everything runs smoothly and that we do not encounter any errors. If done correctly, we will be given the dust composition in reasonable time. We will be doing several tests making sure that our code is functional and that we are running into no issues. Also making sure that the value we are retrieving from the code is like what we expect from our first test.

8. Task Plan Update

https://www.wrike.com/frontend/ganttchart/index.html?snapshotId=zMxSdBuWTkQGM0MN7KEFAivWlQN9m3YB%7CIE2DSNZVHA2DELSTGIYA

9. Conclusion

To conclude, we have determined the proper materials which is needed to progress further with the prototype. With all the testing made, we have concluded that silicone rubber would be a good insulation material and for the casing of the prototype, we will be choosing galvanized steel. For this part of the prototype plan being successful, we will now begin the third phase of the prototype test plan.