Active Roof System

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Team 06

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Document

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Contents

1.0 Brief Project Description

The amount of power needed to maintain a constant comfortable temperature inside of large warehouse like buildings is too high. In order to investigate possible solutions to this problem, our team will design and build prototypes of active and passive roof systems that are designed to reduce the amount of energy required to maintain a cool, comfortable temperature.

2.0 Finalized Testing Methods

The team will conduct several trials of each of the various roof systems. The roof prototypes will be tested using a condensed time schedule of two hours and the simulated sun. The simulated sun will be placed on a frame that is 6 feet tall, 4 feet wide and 6 feet long which will allow for easy movement of the simulated sun, and the simulated sun consists of incandescent light bulbs that will produce equivalent heat flux values as the sun. More information on the simulated sun is included in section 6 of this report.

The control, passive, and active roof prototypes will each be tested three times (for a total of 9 tests) to obtain accurate results and remove any possible errors that might have occurred while testing. Each test will be two hours long and during that time, the sun position will change every 5 minutes to make sure that the panels are exposed to a simulation of the sun's rotation. Each move of the simulated sun will be a linear distance of 6 inches, which will replicate the various angles of the sun throughout the day.

Originally testing was going to take place in building 98C (NAU's fabrication shop), but do to issues with the amount of heat produced and the power required by the simulated sun, a new testing facility must be secured. After meeting with the managers of the fabrication shop, our team has come up with two possible options for testing locations: The back covered patio of the fabrication shop or the waste water treatment facility (nicknamed "Trotta's Farm"). Trotta's farm would be a more ideal testing location because there is an enclosed area which can protect the prototype from the effects of the wind while testing. Neither testing location will be able to have a constant temperature for all tests, but these are the only two locations where testing can occur sense the power required by the simulated sun is so great that a portable generator must be used.

3.0 Team Job Assignments

On order to work most efficiently on the construction of the prototypes, each team member was assigned two specific projects which are shown in Table 1 on the following page.

Table 1: Team Job Assignments

Team Member	Job Assignment 1	Job Assignment 2
Mohammed	Temperature Measurement System	Power Usage Programming (Audriuno Board)
Coy	Construction of Prototype Building	Construction of Simulated Sun
Donovan	Construction of Prototype Building	A/C System Design & Construction
Marissa	Construction of Prototype Building	Construction of Roof Panels
Krysten	Active Roof Rotation Design & Construction	Forming a Hypothesis (Heat Transfer Analysis)

In the table above, the title "Job Assignment 1" implies that the project is either that team member's main focus or that it must be started before "Job Assignment 2" due to construction priorities.

4.0 Temperature Measurement System

In order for the A/C system to be able to function as designed, a temperature measurement system will be used to read the interior temperature of the prototype building. A TMP36 thermistor and an Arduino board will be the two main components of this system.

The TMP36 thermistor was chosen because it is accurate, sensitive and has a high temperature range. It is capable of reading temperature between −40°C to +125°C. The thermistor has three wires as shown in Figure 1. The left wire is for the power supply.

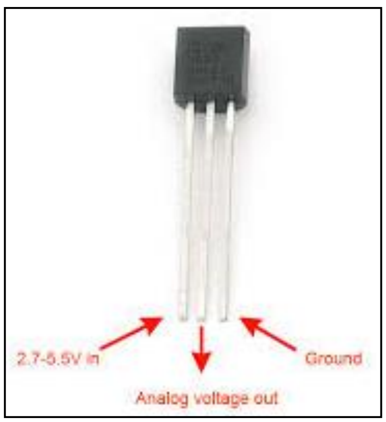

Figure 1: TMO36 Thermistor

The required power for this thermistor is between 2.7-5.5Volts (V). Since the Arduino being used is can only supply 3.3V or 5V, the thermistor must be connected to a power supply with 3.3V output.

The middle wire is for the analog reading. It is going to be connected to the analog pin in the Arduino to read the current temperature. The wire on the right is the ground wire.

Four thermistors will be used to monitor the internal temperature of the prototype building, and they are placed in different locations within the prototype. The locations for the thermistors are shown in Figure 2 below.

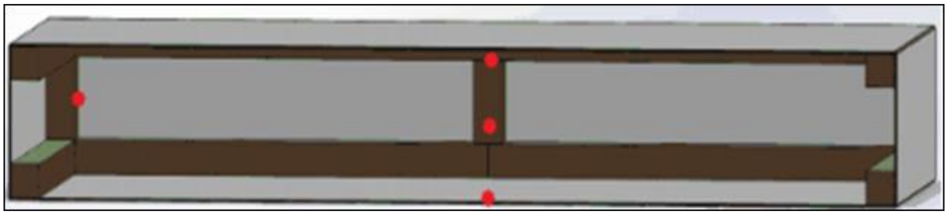

Figure 2: Locations of Thermistors inside the Prototype

The first one is placed at one of the corners of the prototype. Another is placed at the center of the prototype attached to the roof, and the third thermistor is placed at the center of the prototype at mid height. The last thermistor is placed at the center of the prototype attached to the ground.

The type of the Arduino board that will be used is an UNO R2. The power supply wire of the thermistor is connected to the 3.3V pin in the Arduino. The ground wire is connected to the ground pin in the Arduino. Each analog wire of the four thermistors is connected to a different analog pin in the Arduino. The way in which the thermistors are connected to the Arduino board is shown in Figure 3.

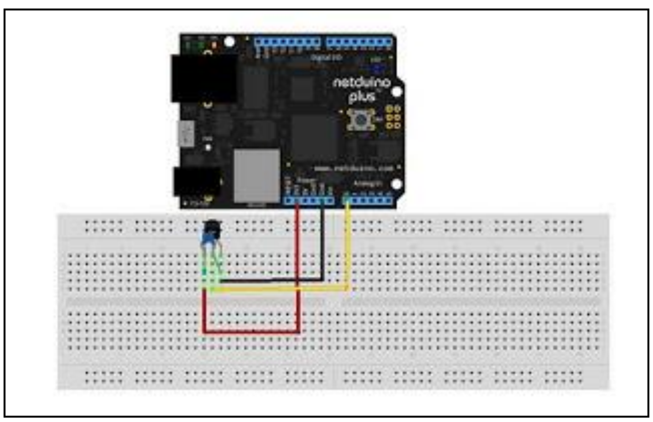

Figure 3: Arduino connection to a thermistor

The Arduino is programmed to read temperature of the prototype. If the temperature is above 70˚F, the Arduino will send a signal to the cooling system to turn on and turn off when the temperature is less than 70˚F. The Arduino is also programmed to calculate the total time which A/C system is running during each 2 hour test, and then this time measurement will be used to calculate the amount of power used by the A/C system. Figure 4 on the following page is a picture of the thermistors and Ardiuno board which make up the main two components of this temperature measurement system.

Figure 4: The Components of the Temperature Measurement System

In order to record data from the Arduino, the Parallax Data Acquisition tool (PLX-DAQ) software is used. The software is able to retrieve the data from the Arduino and save them in an Excel file. The data from each thermistor will be written in a separate column in the Excel file. This will provide an easy to read spread sheet which can be used for any necessary analysis after testing.

5.0 Prototype Building Construction

The construction of the prototype building consists of three main sections: the internal frame of the prototype, the walls of the prototype, and the interior support beams.

The first part of the construction process was the construction of the internal wooden frame of the prototype. First, the 1inch square wooden dowels were cut to specific lengths corresponding to the bottom, top, and the wall dimensions required of the prototype. Each joint the wooden dowels were connected using 2in x 4in metal truss plates, and the corners of the frame were assembled together with corner brackets (see Figure 5 below).

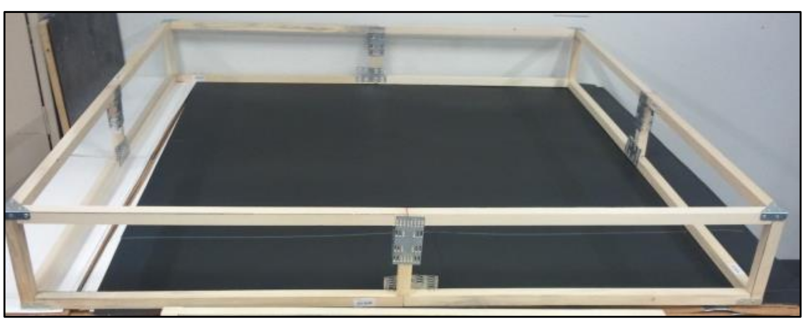

Figure 5: Internal Frame of the Prototype Building

The next step of the construction process was attaching the insulation and poster board walls and floor to the outside frame of the prototype. Each wall/floor was constructed of two layers of poster board with a layer of cork between. As designed, the walls of the prototype have one layer of insulation while the floor has two layers and the ceiling will have three layers. The last step in attaching these walls was to seal the prototype at all corners and intersections by using hot glue. Hot glue was used instead of caulking because it is cheaper and can just as effectively block air from escaping from the inside of the prototype during testing. Figure 6 below shows the prototype building with the walls and floor attached:

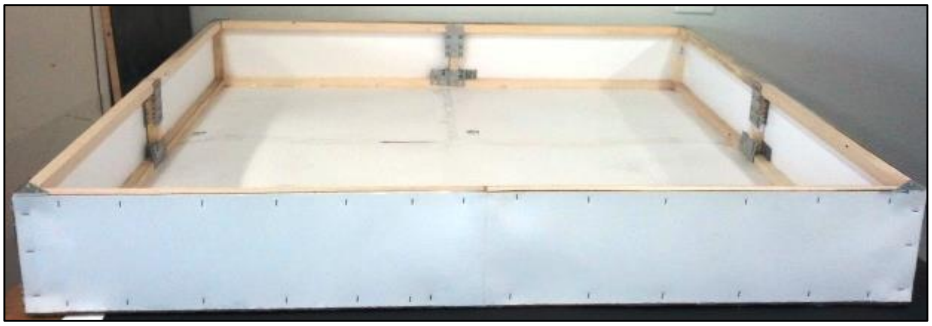

Figure 6: Prototype Building with the Walls and Floor Attached

The last part of the construction of the prototype building was adding additional support beams to the inside of the building. Four support beams were added to help the prototype building to support the weight of the active and passive roof systems which will be placed on top of the building during testing. These support beams were constructed out of 1inch square wooden dowels just like the frame, and were connected using metal T-brackets and 2in x 4in metal truss plates (see Figure 7 below).

Figure 7: Interior Support Beams within the Prototype Building

6.0 Simulated Sun

The purpose of the simulated sun is to output power through conduction and convection heat transfer into the prototype building at different angles with respect to the prototype's location. There are three main components of the simulated sun system, and they are the framing the structure and the electrical system

The framing structure was built out of 2x4's, and is currently 6 feet tall, 4 feet wide and 12 feet long. However, due to size restrictions of the fabrication shop this large framing structure will be reduced to only 6 feet long. The framing structure itself looks like a very large table with no top. On the top there is a built in ledge where the panel of lights can securely sit. This allows the panels of lights to be removed between testing for transportation reasons.

This change in length only slightly changes how the prototypes will be tested because now the entire simulated sun structure will be moved 6 inches every 5 minutes, and to ensure that every test is consistent the floor will have markers showing how far the structure should each time and where the prototype should be placed.

The lighting system of the simulated sun consists of 16-200 Watts incandescent light bulbs. The 16 lights are aligned on a four by four grid on a 4 foot by 4 foot square piece of plywood. In order to set the light sockets into the plywood, 16 holes were drilled into the plywood. Figure 8 below shows a picture of the underside of the light panel and the type of light socks used:

Figure 8: Lighting Panel and Light Sockets Used for the Simulated Sun

The second of the part lighting system is the electrical connections of the lighting system (simulated sun). Recall that each light bulb produces 200 watts of power, so for 16 light bulbs the whole lighting system cohesively produces 3,200 watts of power. The problem that was encountered in the electrical system was that the building's electrical system could not handle that amount of power without blowing a fuse. Therefore, the simulated sun will have to be powered by a gas powered generator that is able of supplying the required 3,200 watts of power for 2 hours during each test.

Connecting wires to the light socket wires required a bit of electrical wiring knowledge. Since that the lighting system's consists of 16 incandescent light bulbs aligned equally in a four by four grid. In order to limit the power load on the wires, four sockets are connected in series to one extension cord. Since there are a total of four rows of four light sockets, four extension cords were needed. The purpose of connecting the light sockets in this way is for the purpose to avoid any potential electrical hazards such as overheating the extension cord wires. At each wiring junction electrical nuts have been used to safely secure the two wires together and then an electrical junction box was installed for each connection in order to follow basic electrical safety codes and regulations. Figure 9 below shows these junction connections for the lighting panel:

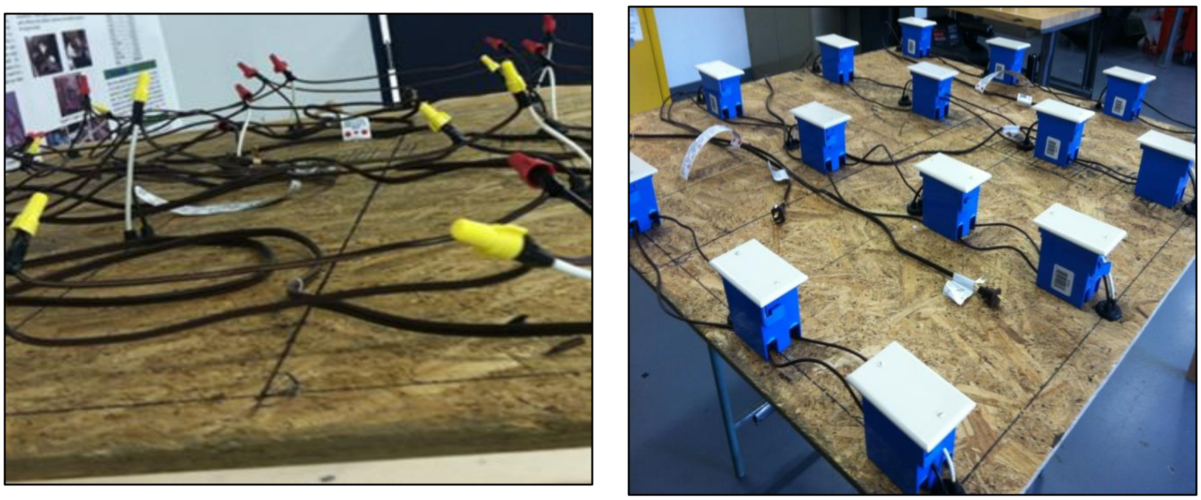

Figure 9: Lighting Panel Wiring with Electrical Nuts and Junction Boxes

7.0 A/C System

The A/C system is a very basic cooling set-up, a serpentine copper piping layout connected to a small water pump that will pump ice water that is approximately 40˚F. The copper piping will radiate cool air and slowly lower the temperature of the inside of the prototype building. This is possible because of the centralized location of the piping unit (see Figure 10 below).

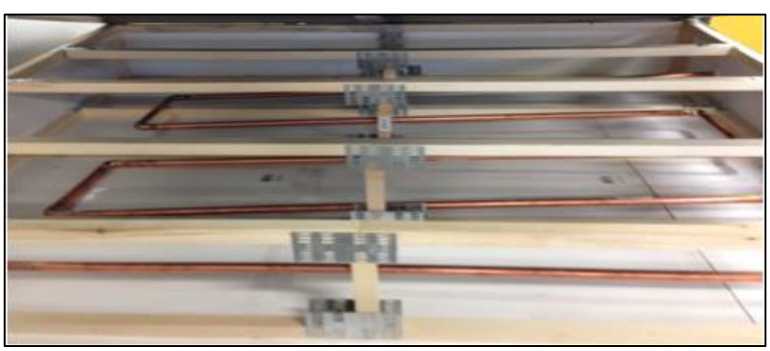

Figure 10: Copper Piping of A/C system Inside the Prototype

It has been brought to attention that fans may be needed to increase the cooling effect of the A/C system. However, it has been decided that the current system will be tested to see if it can cool down the interior of the prototype enough, and if this test shows that the current A/C set up is not effective enough then two to four fans will be installed on the walls of the prototype. These fans will be placed in the corners of the prototype, much like they were in the initial design of the first semester, in order to remove possible hot spots.

The pump of this system will be controlled using the Arduino connected to the temperature measurement system, and it will turn on when the internal temperature is greater than 75˚F and turn off when it has reached 70˚F. The copper piping will be placed so that there is at least one pipe in each chamber; the building is divided into five chambers by the interior support beams of the model.

8.0 Active Roof System

Since the Progress Check on 01/27/2014, there have been some major changes to the active roof system due to the planned system being too heavy and possible complications with aligning the gears with the chain. The active roof system now is manually controlled and the reflective panels pivot up to 180˚. Figure 11 below shows the construction of the new active roof system:

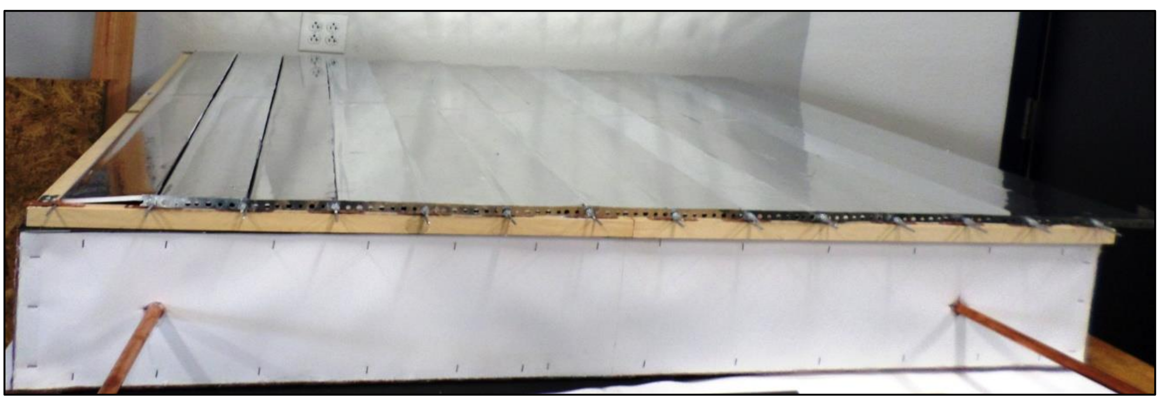

Figure 11: Active Roof System with Panels Laying Flat at 180˚

The panels will be moved to a new angle to reflect away the radiation from the simulated sun every 5 minutes using the level arm system. The panels of this system are made of foam board wrapped in Mylar with 1/8 in diameter aluminum rods attached to the top and bottom faces (see Figure 12 on the following page).

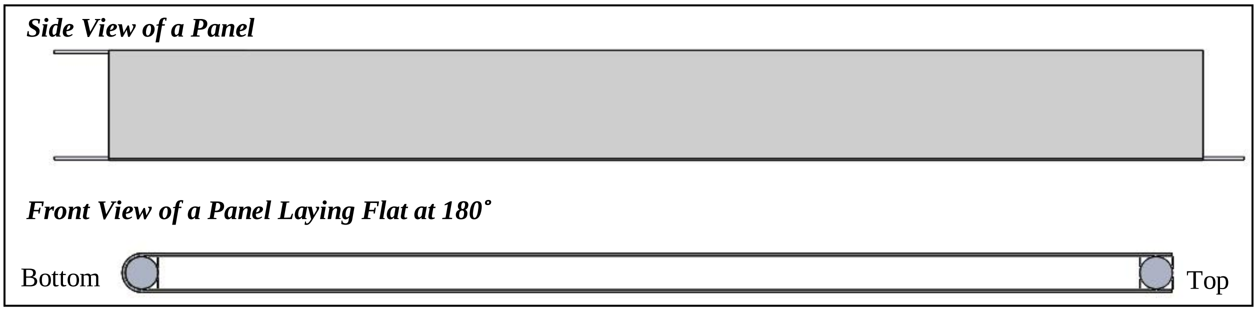

Figure 12: Schematic of the Reflective Panels of the Active Roof System

This lever system allows all the panels to move in unison and the approximately the same angle. For the panels to lay flat the lever arm either has to be pulled all the way to the right or the left. Figure 13 below, shows how moving one of the ends of this lever system caused the panels to all pivot to the same angle:

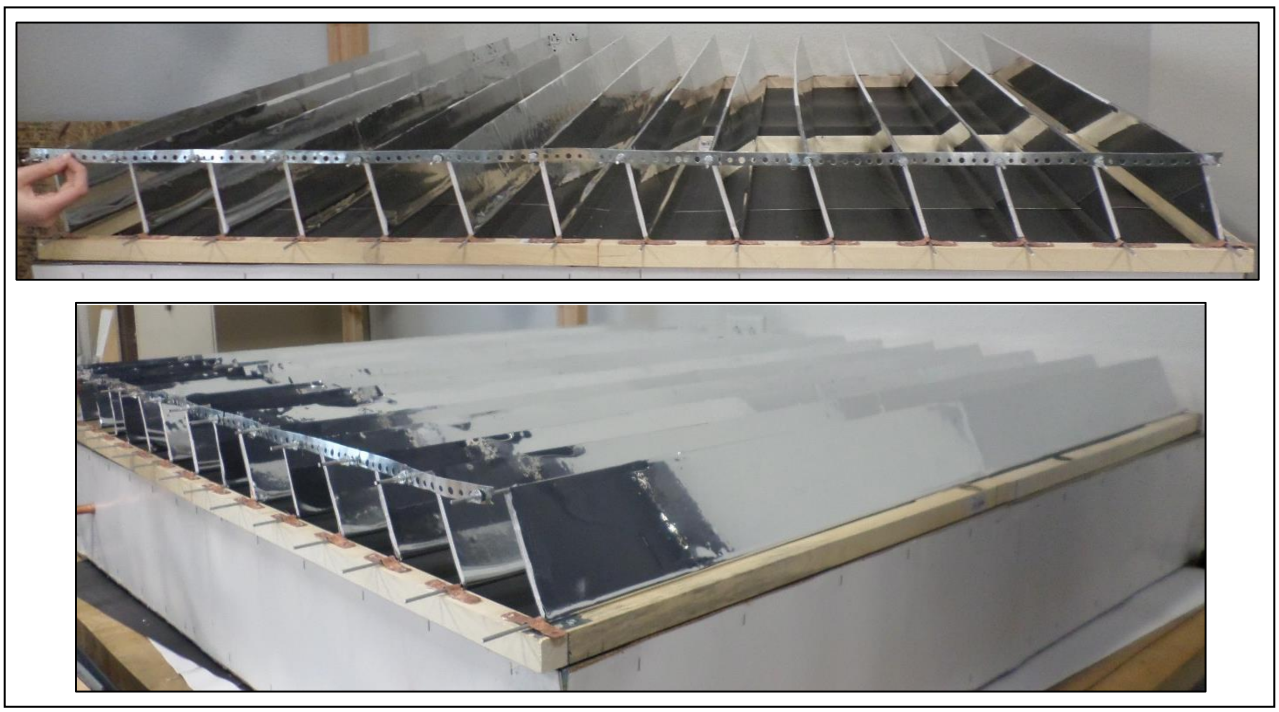

Figure 13: Active Roof System with the Panels at an Angle

The figure above acts as an example of how pulling on one of the end links connecting all the panels together can cause the panels to simultaneous rotate to the same angle. The aluminum rods attached to the bottom of the panels is held down to a square wooden frame using copper U-brackets which have been customized to fit the 1/8in rods.

14 of these 6 foot long Aluminum rods were ordered, and after the rod was attached to the bottom face the excess material hanging off the end of the panel was cut off. This small

section of left over rod was then attached to the top of each of the panels, so that there was a way to connect all the panels together using links. These links are held in place on the rod by gluing small washers on either side of the link.

Finally, the wooden frame was permanently attached to one of the black roofs constructed of poster board. That way the entire active system prototype is detachable and can be easily moved.

The last component of the active roof prototype which still needs to be constructed is the control board which will allow the operator to manually rotate the panels to the proper angle every time. The control board will consist of a long, thin piece of aluminum with strategically placed, drilled holes. Attached to the end of the links on either the left of right side of the prototype will be a lever arm with a small cylinder extruding out the back side. This lever arm will be moved every five minutes to the correct hole which corresponds to the angle which the panels need to be at. This control board will be attached to a wooden base so that it can stand perpendicularly on its own next to the prototype during testing.

One of the large issues brought up by changing the active roof system to a manual control rather than having a motor is that now there is no real way to actually measure the amount of energy used in continually rotating the panels to reflect away the radiation of the simulated sun. The purpose of this prototype is to see if the amount of energy saved due to the A/C system running less since less heat is transferring to the interior of the prototype is enough to justify the power used by the motor to continually rotate the power. Then, this total power usage needs to be compared to the power usage of the passive roof system from the A/C unit.

However, since now there is no actual motor being used the theoretical power that would have been used by a motor to rotate the panels needs to be calculated. This can be done by sizing the motor with approximately the right torque which would have been required to rotate all 14 panels. This can be done by using the estimated weight of each of the panels if the originally gears which were originally selected were attached and if the originally designed bike chain was used. From there it can be estimated how much electrical power would have been used to rotate the panels approximately 180˚ which would be a half rotation for the motor.

Although this estimation of power usage does add error into the analysis of this system, the design of the original panel rotation system had to be changed due to the tight timeline of this project and large tolerances on all the dimensions of the handmade pieces.

9.0 Current Budget Spent

Up to this point in the semester the team has already bought most of the supplies that will be needed to construct the prototype roofs and the necessary systems. The amount spent on supplies for each system or type of supplies is shown in Table 2 below:

Table 2: Current Budget Spent on Each Type of Supplies

Category	Supplies	Cost
Wood	1'' Wooden Square Dowels	$233.21
	2' x 4' s	$28.83
Fasteners	Hot Glue & Guns	$45.93
	Brackets & Joining Plates	$74.92
	Screws, Nails, Tape & Staples	$35.78
Cutting Tools	Scissors, Exacto Knife & Drill Bits	$19.75
Prototype Walls	Poster Board	$19.60
	Cork	$249.06
Active Roof	Aluminum Rods &Plate	$81.51
	Foam Board	$5.88
	Metal Ribbon, Arcs & Washers	$10.23
	Spray Adhesive	$7.79
	Mylar	$29.95
Simulated Sun	Light Bulbs	$53.46
	Sockets	$52.32
	Electrical Wiring & Wire Nuts	$46.21
A/C System	Copper Piping	$52.94
	Saudering Supplies	$14.89
	Pump Motor	$83.35
	TOTAL (before tax)	$1,145.61
	TOTAL (after tax)	$1,227.58

As expected, the two largest costs came from the large amount of 1inch square wooden dowels and cork needed to physically construct the building of the prototype. However, some money the team did not expect to spend came from all the supplies needed to construct the simulated sun, but since only one prototype building is required in order to test the three roof designs then the money saved from not buying the extra wood and cork went to buying the supplies needed for the simulated sun. So far the project is within its set budget, and with most of the construction for this project completed, there are only a few more supplies that need to be bought.

10.0 Current Spring Timeline

A timeline was created to help in aiding our team to keep on track with the completion of tasks. It also helps us to understand which tasks can be worked on simultaneously, and that will cause us to work more efficiently. Our team's current spring 2014 timeline is shown in Figure 14 below:

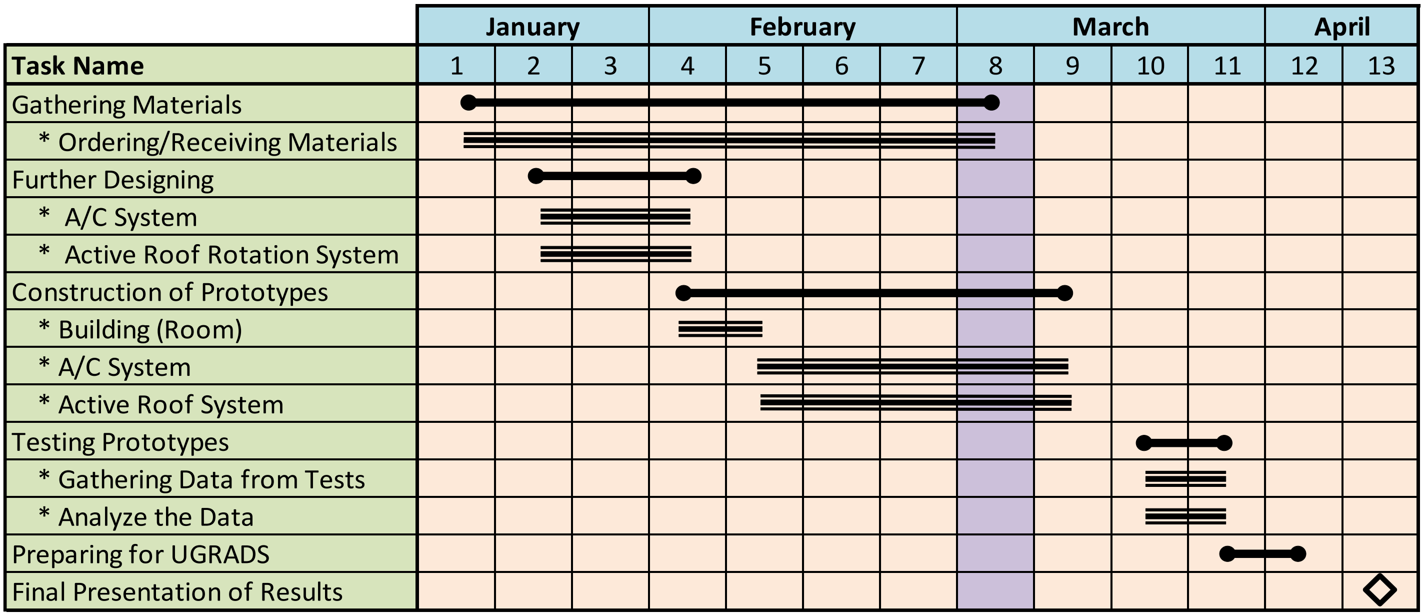

Figure 14: Current Spring 2014 Timeline

Currently, it is the end of the eighth week of the spring semester and this is shown in the figure above by the purple column. Any final materials that are required for the prototype construction will be purchased within the next week, and construction will continue throughout this upcoming week.

Our remaining tasks are to test the different systems to ensure functionality, test the roof prototypes, and preparing for the UGRADS presentation by analyzing our test results. Testing will take place during the tenth and eleventh weeks, while the UGRADS preparation will take place during the eleventh and twelfth weeks. This preparation will include creating a poster which describes every aspect of our project as well as prepare an oral presentation. Then, final presentation of our results will be during the thirteenth (and final) week.

11.0 Conclusions

Each roof prototype will be tested a total of three times over a two hour period. A simulated sun consisting of sixteen incandescent light bulbs will be used during each test, and this simulated sun will be moved every five minutes in equal increments. Also, the panels of the active roof system will be rotated at the same rate as the simulated sun. The internal temperature of the prototype will be measured using four thermocouples placed in strategic points within the prototype. These temperature readings will then be used to control the A/C system pump using an Arduino board. The A/C system consists of ice water being pumped through copper piping assembled in a serpentine design inside the prototype building. If the A/C system with just the copper piping alone is not strong enough to keep the interior of the prototype type at 70˚F, then small fans may be added to move the air over the piping and thus increasing the effectiveness of the A/C system by switching the heat transfer from natural to forced convection. Our current budget spent stands at $1227.58 with only few purchases remaining. Currently, our project is on schedule to finish building by the ninth week and begin testing on the tenth or eleventh week.