Active Room System

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Team 06

Concept Generation and Selection

Document

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1.0 Brief Description of the Problem

The basic problem which drives this project is that power usage to keep the interior of large buildings at a comfortable, cool temperature is too high.

2.0 Brief Description of the Project

For this project our team will be investigating different roof designs which could lower this power usage, and then design, construct and test these roof designs by using scale model prototypes representing a large building [1].

3.0 Design Requirements for All Three Prototypes

There are three main design requirements which all three prototypes must satisfy: 1) Prototypes must be scaled to a real, large building; 2) Prototypes must have an interior heating and cooling system; 3) There has to be a way to measure the internal temperature of the prototypes.

3.1 Scaling the Prototypes

For our prototypes, we have decided to construct a scale model of a Wal-Mart store, because these are rather large buildings and there are hundreds of them across the country. Originally, our team wanted to scale our prototypes to a small Wal-Mart Supercenter, but Wal-Mart Supercenters can range in size from 78,000 to 26,000 square feet [2], so naturally the 26,000 square feet building was selected.

In order to properly scale the prototypes it became necessary to know the thermal resistance value (R-value) and thickness of the type of insulation which a large building, such as a Wal-Mart, would use. Insulation's R-value is a measurement of the insulation's ability to reduce the heat flow through an object [3]. The U.S Department of Energy there are different insulation thermal resistance values recommended for different regions of the United State, and this is displayed in Figure 1 to the right:

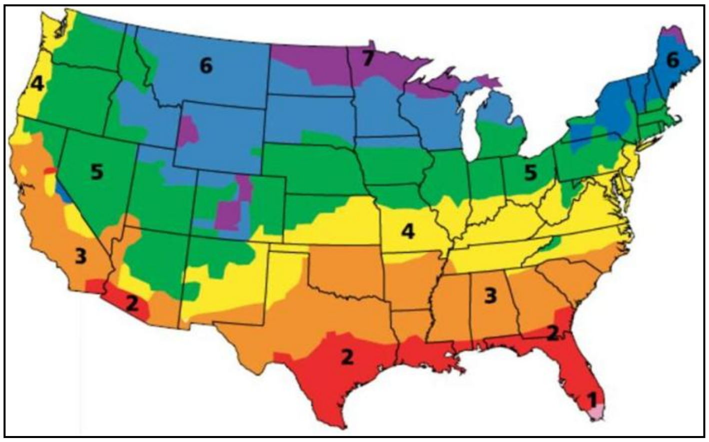

Figure 1: Insulation Type Zone Map [4]

Since our prototype's will be tested in Flagstaff, Arizona and is suppose to represent a real, large building, our team will be using the zone 5 insulation requirements shown in Table 1 below:

Table 1: Insulation Type Based on Zone [4]

Zone	Heating System	Attic	Cathedral Ceiling	Wall		Floor
				Cavity	Insulation Sheathing	
1	All	R30 to R49	R22 to R15	R13 to R15	None	R13
2	Gas, oil, heat pump Electric furnace	R30 to R60	R22 to R38	R13 to R15	None	R13 R19-R25
3	Gas, oil, heat pump Electric furnace	R30 to R60	R22 to R38	R13 to R15	None R2.5 to R5	R25
4	Gas, oil, heat pump Electric furnace	R38 to R60	R30 to R38	R13 to R15	R2.5 to R6 R5 to R6	R25 to R30
5	Gas, oil, heat pump Electric furnace	R38 to R60	R30 to R38 R30 to R60	R13 to R15 R13 to R21	R2.5 to R6 R5 to R6	R25 to R30
6	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
7	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30
8	All	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 to R30

Although the table above mainly applied to homes using roll, fiberglass insulation and not large buildings, the thermal resistance values may still be used because they are approximately the same to the R-values of the sprayed polyurethane foam used in large metal buildings [5], such as a Wal-Mart. So based off of Table 1 above and using the values for a "Gas, oil, heat pump" heating system for Zone 5, our team can estimate the insulation used in an average Wal-Mart Building in Flagstaff. For our prototypes our team will use the following R-values: R14 for the walls, R34 for the ceiling and R27 for the floors.

Since R14 is the thinnest of the three different insulation types with an average thickness of only 3.5 inches [6], it will be the main factor used to figure out the scaling factors for the prototypes. How the two different scaling factors were calculated is shown below:

$$\text{Scale Factor}_{\text{R-value}} = (R_{\text{Prototype Insulation}} / R_{\text{Actual Building Insulation}})$$

$$\text{Scale Factor}_{\text{Thickness}} = (t_{\text{Prototype Insulation}} / t_{\text{Actual Builing Insulation}})$$

In the case of the 26,000 square foot Wal-Mart Super center it can be broken down that the building's interior dimensions can be simplified to 426.6 feet by 426.6 feet with a standard ceiling of 25 feet tall. Our team's first, initial guess at what type of insulation to use in the scaled prototypes was the smallest foam insulation boards we could find, and they had an R-value of 3.2 and a thickness of 0.5 inch [7]. Unfortunately, this insulation type proved to be too thick when the scaling factors were calculated as shown below:

$$\text{Scale Factor}_{R\text{-value}} = (3.2/14) = 0.23 \quad \& \quad \text{Scale Factor}_{Thickness} = (0.5/3.5) = 0.14$$

The first issue with these scaling values is that they are not close enough to each other and the other issue is that when the Thickness Scale Factor is applied to the 426.6 feet by 426.6 feet building, the prototypes would have to have dimensions of about 59 feet by 59 feet. Building three prototypes that size is unfeasible, and is directly due to the calculated Thickness Scale Factor is simply too high.

The next step was to find a thinner and lower R-value insulation which would produce low scale factors. What our team found was a cork roll with a thickness of 3/32 inch [8], and since cork has an R-value of 3.6 per inch [9] that means that this thickness of cork has an R-value of approximately 0.3375.

The second step was to lower the size of Wal-Mart building we were going to scale, because even the smallest Wal-Mart Supercenter was too large to build a scale model out of under our insulation thickness scale constraint. So instead our team decided to base our scale prototypes off the one of the smallest Wal-Mart stores, which still has an interior of 30,000 square feet [2]. This new store dimension's can be simplified to a building that is 173.2 feet by 173.2 feet with 25 foot tall ceilings.

Using this newly selected building size and cork insulation the scaling factors were calculated as shown below:

$$\text{Scale Factor}_{R\text{-value}} = (0.3375/14) = 0.024 \quad \& \quad \text{Scale Factor}_{Thickness} = ((3/32)/3.5) = 0.026$$

Since both of the scaling factors are reasonably small and relatively close to each other, the 3/32 inch cork was selected as the insulation for the scaled prototypes. The prototype scaled interior dimensions are calculated below:

$$\text{Wall lengths} = 173.2\text{ft} * 0.026 = 4.5\text{ft} \quad \& \text{ Ceiling Height} = 25\text{ft} * 0.026 = 0.65\text{ft}$$

The insulation R-values for the prototype are calculated below:

$$R_{ceiling} = 34 * 0.024 = 0.816 \quad \& \ R_{floor} = 27 * 0.024 = 0.648$$

Since R-values of insulation add together if they are stacked together [3], the walls of the prototype will have one layer of the cork insulation while to get approximately the calculated, scaled R-values the ceiling will have 3 layers and the floor will have 2 layers.

3.2 Basic Requirements of the Interior Heating/Cooling System

In order to properly model our prototypes after an actual Wal-Mart building, they will each have to include some sort of interior temperature controlling system. This system will be used to maintain a constant interior temperature of 70^{o}F for the prototypes, and this system will have to have a measurable power usage. Having a measurable power usage is crucial for this heating/cooling system because the point of the project is the compare the power usage needed to keep each of the three prototypes, with the different types of roof designs, at this comfortable temperature of 70^{o}F. So by comparing the power usage of each of the three prototypes we can then find out how effective each roof system.

3.3 Basic Requirements of the Interior Temperature Measurements

In order for the heating/cooling system to function it will need to have some sort of interior temperature read out. By using periodic measurements of the each of the prototype's interior temperatures the heating/cooling will know when to switch on and off the heating or cooling element. This temperature measurement system should record the temperature of each of the prototypes interiors every ten minutes without opening up the prototype, that way the temperature measurements will be as accurate as possible without the outside ambient air temperature interfering.

4.0 Design Requirements for Only the Passive Roof Prototype

The passive roof prototype will have no mechanical or electrical parts at all, but will instead consist of several stationary panels oriented at an angle to allowing sunlight to be absorbed in during the winter and reflected away during the summer. These panels will be made of a reflective material, such as glass and will be oriented at a 43° angle from horizontal.

This orientation angle was determined based on the latitude of Flagstaff, Arizona, which is 35.1992°N [10]. The summer and winter equinox sunlight angles are based on complimentary angles. Starting with 90°, the summer equinox solar angle can be found by subtracting the latitude of the city and then adding the tilt of the earth (23.5°), and to find the winter equinox angle it is the same process but instead subtracting the tilt of the earth [11]. For Flagstaff the calculated summer and winter solstice angles come out to be 78.3° and 31.3°, respectively. This same equation can be used to determine the spring and fall equinoxes, except the tilt of the earth is not a factor. The calculated spring and fall equinox angles both come out to be 54.8°. The chosen 43° angle is between the lowest winter angle and the spring equinox angle.

During the winter, the sun follows a path closer to the southern horizon [12]. The panels for the passive roof prototype will need to be tilted toward the southeast in order to get as much sunlight in as possible during the morning and evening hours (see Figure 3 below). However, during the summer months, the sun follows a path that up higher, and this will cause the sun rays to point down at a straighter angle onto the building (see Figure 2 below).

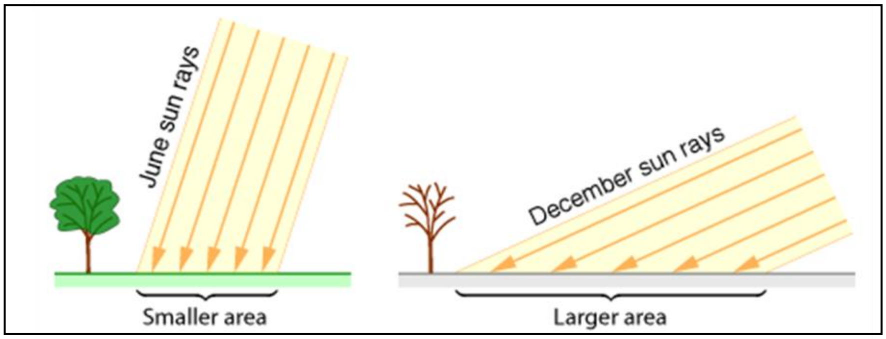

Figure 2: Basic angle of Sun Rays for Summer and Winter [12]

With the chosen angle of 43°, the sun will be blocked during the majority of the day. The morning and evening hours will be the only time of day where sun rays will get through to warm the roof.

5.0 Design Requirements for Only Active Prototype

The active roof prototype will have reflective panels that are all attached to a single shaft or mechanism which can be rotated by a motor. These reflective panels will continually rotate throughout a day to certain angles that will allow sunlight to be absorbed by the roof during winter months and reflect the sunlight away from the roof during the summer months. This motor will be controlled by a computer system that has been programmed to tell the motor when and how much to rotate. As is well known, the sun position continually changes during the day as well during the different seasons.

Writing a thorough program for the real, full scale active roof system would either use a solar tracker or have a program of all the sun angles throughout every day of the year based on the building's location on the globe, but since programming that is simply not possible given the timeline of this project, our team has come up with a simpler model that will be implemented for the prototype of the active roof. This simpler model is based on Flagstaff and consists of the average sunrise and sunset times for the summer, fall, spring and winter, and also the sunrise angle and the sunset angle. The average sunrise and sunset times [13] are shown in Table 2 below:

Table 2: Average Sunrise and Sunset Times for Flagstaff, AZ

Season	Average Sunrise Time	Average Sunset Time
Winter	7:45 AM	5:15 PM
Spring	6:45 AM	6:30 PM
Summer	5:20 AM	7:30 PM
Fall	6:20 AM	6:20 PM

Then, using these sunrise and sunset times our program will rotate the panels by a certain degree every ten minutes, and the angle which it rotates every ten minutes will be based on how long the sun is up and how many degrees the sun rotates throughout the day. Since sunrises and sunsets in Flagstaff are both at approximately 1^{o} [14] the amount the sun rotates throughout a day is calculated by $180^{o}-2(1^{o})=178^{o}$ (see Figure 3 below).

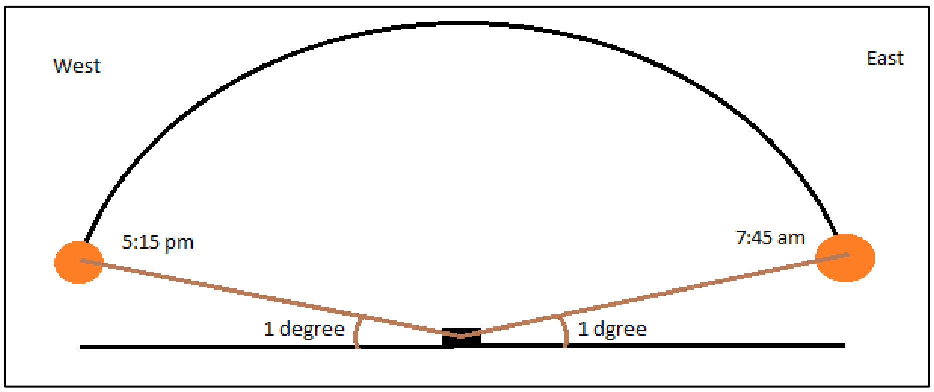

Figure 3: Sun Altitude Angles for Sunset and Sunrise [14]

6.0 Internal Temperature Measurement System

There are three concepts/designs which our team considered for the temperature measurement and recording system. Each one of these designs will be explained individually below:

The first design is the "Manual" reading and recording design, and is basically be a thermometer. The thermometer will be placed in the prototype and there will be a sight glass to allow us to read the current temperature. The temperature sampling over a period of time will be manually recorded. To test our designs a temperature sampling will be recording in 10 minutes increments for a long period of time. The advantage of using thermometer is the low cost of the thermometer. The disadvantages of using thermometer are low accuracy and a high time consumption due to manually recording the temperatures.

The second design is the "Semi-Automatic" system. The semi-automatic is an electronic device that will only measure the internal temperature. The device will consist of an internal or external temperature probe. The current temperature will be digitally displayed on LCD screen, and then the temperature would be manually recorded. The advantages of using semi-automatic are accuracy and low cost. While the disadvantages are that this design will have a high time consumption due to manually recording the temperatures.

The third design is the "Fully Automatic" system, and will consist of a measurement device that will measure and record the internal temperature over a period of time. The current temperature will be displayed on LCD screen on the device, but the device itself can digitally store and even send the temperature data. To access the data, a USB cable will be used to connect the device to a laptop. The advantages of using fully-automatic concept are that it is highly accurate and it has the automatic recording feature which will result in saving time during testing. While the disadvantage of this design is that it comes with a high cost.

Each of these three designs have been rated from 1 to 10 for each of the design criteria described below, with 1 meaning that the design demonstrated poorly within that criteria and 10 means the design demonstrates excellently. The decision matrix and descriptions of the design criteria are shown in Figure 4 below:

Internal Temperature Measurement System Decision Matrix

		Designs		
Criteria	**Weight**	**Manual Data**	**Semi-Automatic**	**Fully Automatic**
Accuracy	9	4x9 = 36	9x9 = 81	10x9 = 90
Ease of Construction	7	7x7 = 49	5x7 = 35	7x7 = 49
Response Time	4	5x4 = 20	7x4 = 28	10x4 = 40
Cost	10	9x10 = 90	6x10 = 60	4x10 = 40
Automatic Data Output	8	0x8 = 0	7x8 = 56	10x8 = 80
	TOTAL	195	260	299

Decision Matrix Design Criteria

Accuracy – This is essential to have an accurate set of temperatures over time.

Ease of Construction – The temperature recorder need to be as simple as it could be to avoid having error on our data.

Response Time – The time it takes to read and record temperature.

Cost – The cost of the device need to be low to fit our budget.

Automatic Data Output – The automatic data output is important to have an accurate

Figure 4: Decision Matrix and Design Criteria Descriptions for Internal Temperature Measurement System

Based on the decision matrix above the fully-automatic temperature measurement and recorder was selected for our project. The fully-automatic is the one that fulfilled our needs. In our project, the temperature monitor will be used to measure and record sampling temperature over a period of time for three prototypes. The data collected need to be very accurate to realize the effectiveness of the active and passive roof system.

To find the perfect temperature data logger, our team came up with a list of features that are necessary in order for the device to be used in our prototypes. Figure 5 below has a list of the temperature data logger devices being considered and their features as well as cost [15].

Features and Cost of Each Device

Device	**Supco SL500XT**	**HOBO Onset**	**Lascar – GFX-DTP**	**Supco DVT4**	**Lascar EL-GFX-1**
Accuracy	± 0.5°C	± 0.21°C	± 0.1°C	± 0.5°C	± 0.1°C
Temperature range	-40°C to 80°C	-20°C to 70°C	-40°C to 125°C	-40°C to 70°C for external -10°C to 65°C for internal	-30°C to 80°C
Response time	1 second to 9 hours	1 second to 18 hours	2 second to 1 hour	1 second to 18 hours	10 second to 12 hours
Memory size	43,344 readings	84,650 readings	252,928 readings	87,000 readings	256,000 readings
Temperature probe	One external	One internal	Two external	One internal Three external	One internal
Cost	$106	$125	$185	$285	$135

Figure 5: Temperature Data Logger Devices and Features

Description of Device Features

Accuracy – The closeness of the temperature measurement to the true temperature is needed to have accurate results.

Temperature Range – The device need to be able to measure and record low and high temperature.

Response Time – The rate of time that the device can take a temperature sampling.

Memory Size – The amount of data that can be stored.

Temperature Probe – Number of internal and external temperature sensor that the device has.

Cost – The cost of the device need to be appropriate with our budget.

7.0 Heating and Cooling System

With the prototypes' interior dimensions being relatively small, there are three designs that we have come up that will work as a heating and cooling system within those small interiors, and they are each described below:

The first design is the "Hand Pump". This design involves hand pumping hot or cold water through small pipes running through each of the three prototypes. This design seems very inefficient but with the size of the prototypes being relatively small, it could be done. However, this design is dependent upon the fact that someone would have to be standing by to monitor the temperatures and make the heating or cooling system act accordingly.

The second design is the "Water Pump". This design still involves using water hot or cold water to cool/heat the prototypes, but instead of a manual pumping system it will consist of an automated pumping system controlled by an electronic device (that will be discussed later in section 8). This electronic device will be programmed to turn on and off the water pump as well as switch between hot and cold water based on the data send from the internal temperature measurement system.

The third design is the "Air Flow", and this design will regulate the internal temperature of the prototypes by either blowing hot or cold air into the model. This design will be controlled by an electronic device in the same way as the "Water Pump" design.

Each of these three designs have been rated from 1 to 10 for each of the design criteria described below, with 1 meaning that the design demonstrated poorly within that criteria and 10 means the design demonstrates excellently. The decision matrix and descriptions of the design criteria are shown in Figure 6 and the following page:

Internal Heating/Cooling System Decision Matrix

Criteria	Weight	Designs: Hand Pump	Water Pump	Air Flow
Accuracy	7	4x7 = 28	9x7 = 63	10x7 = 70
Ease of Use	6	6x6 = 36	8x6 = 48	8x6 = 48
Efficiency	6	3x6 = 18	8x6 = 48	10x6 = 60
Cost	10	3x10 = 30	6x10 = 60	8x10 = 80
Data Collections	8	0x8 = 0	7x8 = 56	9x8 = 72
	TOTAL	112	275	330

Decision Matrix Design Criteria

Accuracy – How close to maintaining 70^{o}F can the system get.

Ease of Use – How easy is the system to use.

Efficiency – An estimate on how well the design will be able to heat/cool.

Cost – The cost of the device need to be low to fit our budget.

Data Collections – How well can the designs take the temperature inputs of the internal temperature measurement system and use them

Figure 6: Decision Matrix and Design Criteria Descriptions for Heating/Cooling System

Based on the decision matrix above, the way that has been chosen to regulate the internal temperatures of the prototypes is by using the "Air Flow" heating/cooling system. Our team also chose this design because after speaking with our project client, we believe that it will give us a better idea of what the companies are facing when heating and cooling their buildings because most of the large Wal-Mart buildings depend on flowing warm or cold air to regulate their internal temperatures.

8.0 Control Systems

There are two systems within our prototypes which will need to be controlled via an electronic device: the motor controlling the reflective panels on the active roof prototype and the communication between the internal temperature measurement system and the heating and cooling system.

The plan is to incorporate an arduino board electronic device system to operate the motors of the active roof prototype. This arduino board system will operate based on the program that will be developed using the information presented in section 5.

Another arduino board will be in charge of turning on and off the "Air Flow" heating/cooling system as well as switch the system from blowing hot or cold air when on. This arduino board will receive the temperature reading from the "Fully Automated" temperature measurement system every 10 minutes and use its programmed logic act accordingly.

Using these arduino boards will have the following advantages:

1. Inexpensive control devices
   - The arduino boards are relatively inexpensive to purchase [16].
2. Easy to Program
   - The arduino board systems will only require some basic computer programming.
3. Easy to Connect
   - The arduino boards have the ability to connect to all of the systems we need it to control as well as a laptop so the code can be debugged easily.

9.0 Changes to the Previous Project Timeline

The only change that has been made to the entire project timeline is that during the fall semester a task was added. This task is called "Experimental Construction" and is highlighted in yellow in Figure 7 below:

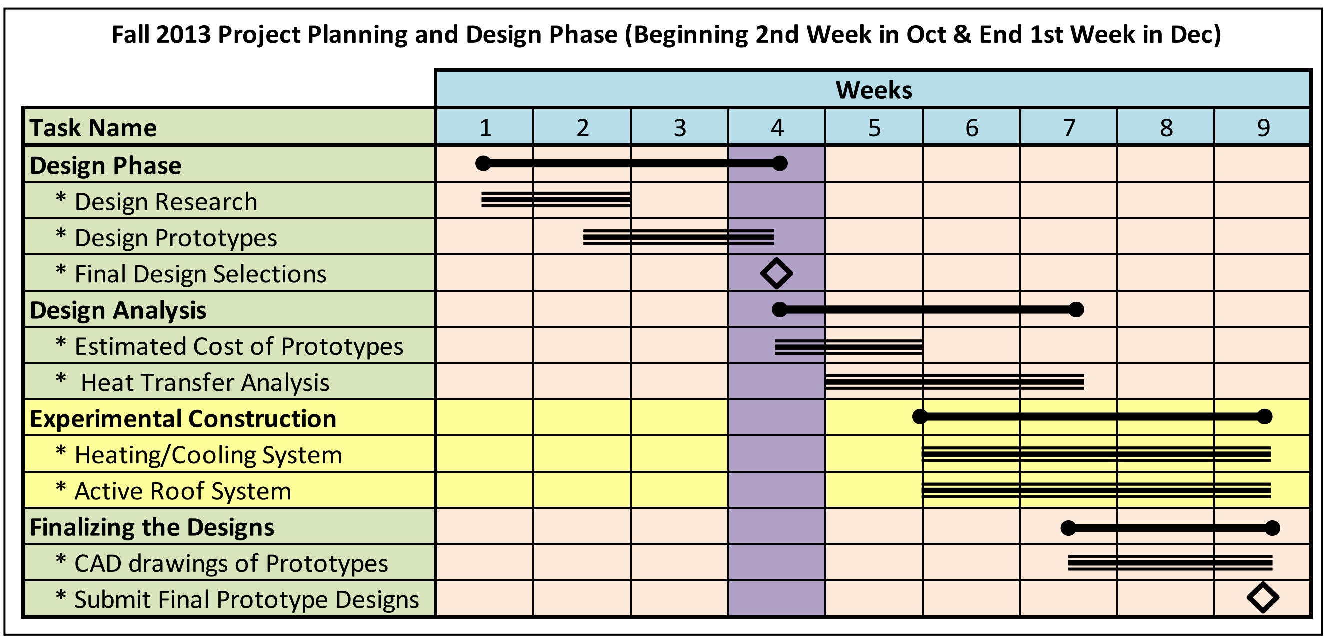

Figure 7: Fully Detailed Fall 2013 Semester Timeline

This new task was added to this semester's (fall) timeline after consulting with our client and he expressed a concern for how complicated actually getting the heating/cooling system and the active roof system operating will be. Since these are our two most complicated systems within our prototypes our goal is to at least start to experiment with how the ardiuno boards controlling these systems can be programmed and start physically constructing the components of these two systems.

10.0 Current Project Timeline

Our project timeline is sub-divided into two semester periods (fall and spring Semester), and each semester's timeline and main tasks are described in the following paragraphs.

The general fall timeline is shown in Figure 8 below:

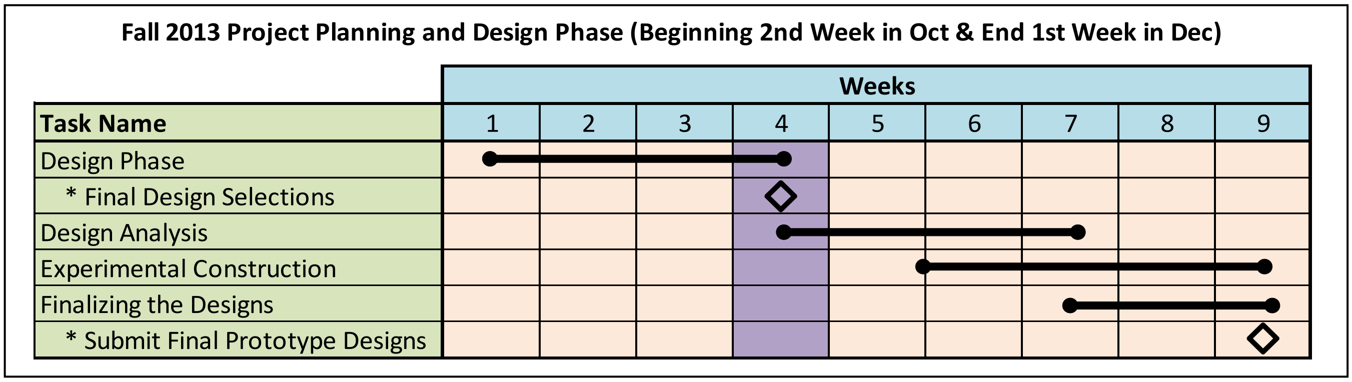

Figure 8: General Fall 2013 Semester Timeline

The 4th week in Figure 8 is highlighted purple because it denotes where we are at in the design phase, and with the completion of this report, we are on schedule with this timeline.

The fall semester will consist specifically on the process of designing and analyzing of the roof prototypes.

- The design phase of the active roof prototypes will take four weeks prior to making a final decision to select what prototype design will best satisfy the projects problem statement.
- Within the fourth week of selecting a prototype design, the design analysis will be initiated unto its completion in the seventh week of the fall semester. This process of analysis will consist of thermal, electrical calculations and then producing 3-D CAD drawings of the three prototype designs.
- Approximately by the end of the fifth week, we hope to start the experimental construction of the Heating/ Cooling System and the Active Roof System
- Once the design analysis is completed, we will begin to finalize the designs of the project unto its final completion for submission for the fall semester.

The general projected spring timeline is shown in Figure 9 below:

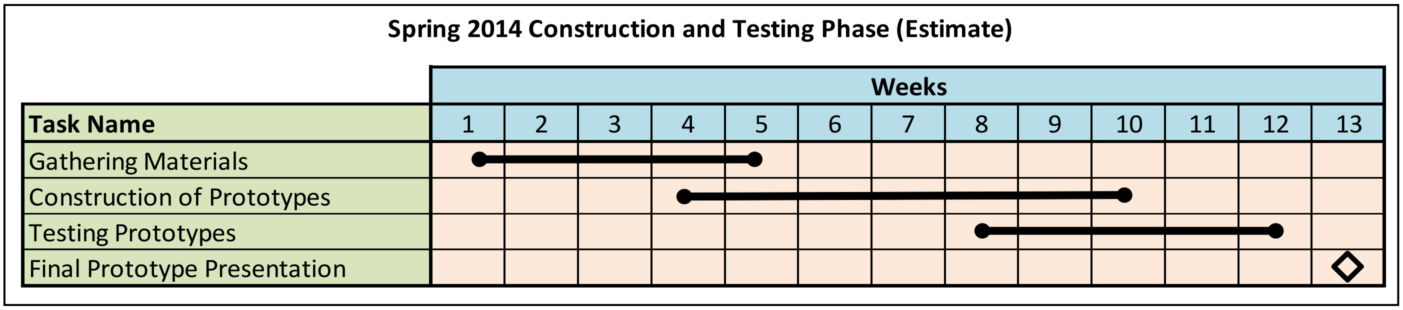

Figure 9: General Projected Spring 2014 Semester Timeline

The spring semester will consist specifically on the construction of the design prototype and the testing of the prototype under the applications of environmental conditions. This semester will consist of a 13 week process until the final prototype presentation.

- For the beginning of the first five weeks, we will collect the required materials to construct the prototype within the project's budget limits.
- At the fourth week, we will construct the prototypes for the following six weeks until the final completion of the prototypes in the tenth week as expected.
- At the eighth week, we will conduct testing of the prototypes under the applications of the environmental conditions for next following four weeks. Within this process we will be making improvements and adjustments to the construction of the prototype based on the testing results.
- We expect to be completed with the testing the prototypes at the twelfth week of the spring semester prior to the week of our final project presentation.

11.0 Conclusions

The amount of power consumption to maintain interior building temperatures at a comfortable temperature is too high. Therefore, this problem situation requires our team to perform engineering quality analysis to design a prototype that will best satisfy the needs and requirements of our client.

This project consists of designing and constructing three prototypes with different roof system: active, passive and control. Each prototype will be a scale model of a small 30,000 square foot Wal-Mart building with 25 foot ceilings. The prototypes will have the interior dimensions of 4.5 feet by 4.5 feet and 0.65 feet tall. These dimensions along with the amount of insulation on the prototypes all were base off the R-value Scale Factor and Thickness Scale Factor which resulted in selecting the 3/32 inch cork to be the prototypes insulation.

Based on the research presented the reflective panels on the roof of the passive prototype will be angled at 43^o, so that it will allow the roof to absorb the sunlight in the winter and reflect the sunlight in the summer.

As for the active roof system, the reflective panels will be rotated by a motor which will be controlled by an arduino board. The arduino board will have a program which will control the power to the motor and will rotate the panels according to the time of day and year. The program for this prototype will be based off of the average sunset/sunrise times and angles for Flagstaff.

Each prototype will have two internal systems: one to measure the temperature and one to heat/cool the interior. Since the prototypes are ideally suppose to be keep at an internal temperature of 70^{o}F, the "Fully Automated" internal temperature measuring system will send data to the attached arduino board every ten minutes, and then based on that reading the arduino board will either turn on or off the "Air Flow" heating/cooling system and switch the system from between blowing hot and cold air.

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