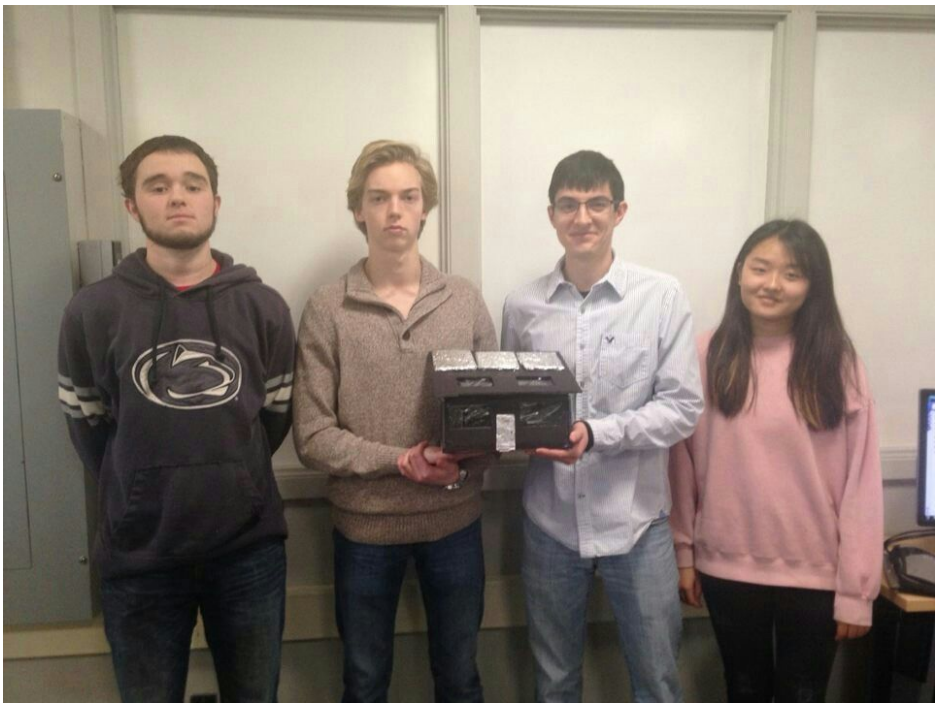
Zero Energy Home Project

Engineering Design 100

Section 003

March 4, 2016



Another One:

Jonathan Balog *jbb5406@psu.edu*

Jordan Reed *jzr5474@psu.edu*

Shijia Zhou *sxz5190@psu.edu*

Garrett Rabian *gkr5062@psu.edu*

Abstract:

Zero energy homes produce enough energy, through natural resources and design techniques, to balance their energy consumption. They are very efficient and try to reduce waste as much as possible. This report details the process of researching, selecting, designing, modeling, and testing a zero energy home design.

Introduction:

With growing concern for the environment and the use of nonrenewable resources, a popular trend has arisen. The concept of producing enough energy to counteract how much you use. This has gained popularity in recent years through the use of renewable energy sources and the creation of innovative systems to more efficiently utilize these resources. This project concerns namely the renewable source of solar energy through the creation, design, and execution of a zero energy home - a home that produces as much energy as it uses or even a surplus.

Our goal is to create, from scratch, a 70 sq in. model of a zero energy home that would be built in State College, Pennsylvania. The house is to be designed for a family of four, assuming all of the energy use and needs of such a family. The following report contains our research on efficient house designs and energy efficient methods that will culminate in one model house with selected ideal energy efficient appliances, solar panels, and passive solar features.

Customer Needs:

Analyzing a family of four, we have determined the customer needs to include having appliances such as:

A washer and dryer
A refrigerator/freezer
A stove/range
A television

We also determined them to need certain living areas such as:

Bedrooms (3 preferably)
At least 2 full bathrooms
A kitchen
A living room
An office

From there, we designed a comfortable living space with energy efficient appliances and ideal circulation design.

External Research

In researching for our home, we focused primarily on two areas to help minimize energy consumption:

- Insulation
- Appliances

Finding a type of insulation that balanced cost and energy efficiency was a major topic of debate within the group. Ultimately, we settled with R-50 wall insulation and R-50 ceiling insulation in the form of 10-inch polyurethane board for both the ceiling and walls, but only after considering a few options.

Insulation- 10 inches

Type	R-Value	Cost
Cellulose blown	37	$0.80 per square foot
Polyurethane board	50	$0.84 per square foot
Polyisocyanurate (foil-faced)	72	$1.03 per square foot

The polyurethane board was much more insulated than the cellulose blown board and for only an additional 4 cents per square foot. The polyisocyanurate board proved to be a source of friction for us, as half the group was willing to spend the extra nearly 20 cents per square foot to benefit from the much more impressive insulation, while the other half thought that the polyurethane board provided as much insulation as we needed for a much cheaper cost. After extended debate, we concluded that since we were saving enough energy elsewhere at a relatively more expensive cost (i.e. solar panels) it would be more optimal for the consumer to have slightly less insulation throughout the house but spend less money on the house. Additionally, we decided to use the same insulation throughout the entire house. This would ensure that one area of the house isn't solely responsible for all the heat loss.

Appliances were a much greater endeavour to undertake. However, it wasn't a major source of debate as well, which certainly helped.

Appliance Breakdown:			Cost (initial):		Electricity Usage (kWH/yr):		Electricity Cost ($0.1011 per kWh):
Refrigerator:	Summit FF1085SS		$684.00		296		$29.93
Television:	Samsung UN48H4203AF		$649.99		57		$5.76
Dryer:	GE GTX65EBSJWS		$629.10		608		$61.47
Washer:	Whirlpool WFW97HEX		$898.00		114		$54.40

Essentially, we allocated the tasks of each essential appliance to one of the group members and trusted them to find the appliance that balanced efficiency and practicality.

Concept Generation:

House #1: Chamberlin Court #75:

This house in Gettysburg, PA is well suited to be a zero energy home for its occupants. It is relatively Large-sized at 6869 ft² and it has a maximum occupation of four people. It has a Photovoltaic system of 6.26 kW with R-24 wall insulation and R-49 ceiling insulation. The thermal blanket wall helps to block out of the noise as well as heat and cold while providing draft-free, quiet, and comfortable interiors.

Location (city, state)	Gettysburg, PA
House size (floor area in square feet)	6,869 sq.ft
Number of floors	2 plus a basement
URL of web site where info is found	http://energy.gov
Number of occupants	4
Number of bedrooms	4
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Heat pump
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Geothermal
Size of photovoltaic system (kilowatts)	6.26 kW
Solar water heater (yes or no)	no
R-value of wall insulation	24
R-value of ceiling insulation	49
Ventilation air heat recovery (yes or no)	Seems like it; essentially pulls heat during summer, cold during winter
Predicted or measured annual	Utilities cost is $1,956 per year; electricity costs $163

energy use	a month (projected, accounts for all utilities and can send energy to grid)
Any other pertinent info	Low VOC; Energy Star rated appliances; exceeded 2015 IECC (International Energy Conservation Code) by 16%

House #2: Asheville, North Carolina

This house, located in Asheville, Carolina, serves as another great example of standard zero energy home design. This house can fit a maximum of two occupants and has a 6 kW photovoltaic system. This house also has R-24 wall insulation and R-38 ceiling insulation. The have a highly insulated basement wall and also use passive solar feature to gain heat. Slabs for thermal mass in basement and first floor.

Location (city, state)	Asheville, North Carolina
House size (floor area in square feet)	3100
Number of floors	2 and a basement
URL of web site where info is found	http://www.energyvanguard.com/blog-building-science-HERS-BPI/bid/59470/A-Really-Cool-Net-Zero-Energy-Home-in-the-North-Carolina-Mountains http://www.resnet.us/blog/wp-content/uploads/2013/03/Net-Zero-Home_VandeMusser-Design.pdf

Number of occupants	2
Number of bedrooms	3
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Ground source heat pump
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Unknown
Size of photovoltaic system (kilowatts)	6 kW
Solar water heater (yes or no)	yes
R-value of wall insulation	24
R-value of ceiling insulation	38
Ventilation air heat recovery (yes or no)	yes
Predicted or measured annual energy use	5843 kWh
Any other pertinent info	6147 kWh produced energy Rainwater harvesting system

House #3: Whidbey Island, Washington:

This is another great example of zero energy house which is locate at Whidbey Island, Washington. It is relatively medium -sized at 2908 ft² and it has a maximum occupation of four people. It has a Photovoltaic system of 9 kW with R-20 wall insulation and R-41 ceiling insulation. This house will save its homeowners more than $2500 a year compared to a home built to minimum code. The house was designed majority of the windows facing south to take advantage of Puget Sound view, natural comfort and daylight.

Location (city, state)	Whidbey Island, Washington State
House size (floor area in square feet)	2,908-square-foot
Number of floors	2 floors
URL of web site where info is found	http://energy.gov/eere/buildings/doe-tour-zero-isler-residence-clifton-view-homes
Number of occupants	4
Number of bedrooms	3
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Ground source heat pump for radiant floor
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Sun, geothermal
Size of photovoltaic system (kilowatts)	9
Solar water heater (yes or no)	Yes
R-value of wall insulation	20
R-value of ceiling insulation	41
Ventilation air heat recovery (yes or no)	Yes
Predicted or measured annual energy use	Saves 26,429 kWhr/y
Any other pertinent info	None

Design Criteria:

Before our group began the design process, we individually researched two zero energy homes in similar climates/latitudes as State College, PA.

In order to create a home that we all have a part in, we had to brainstorm design ideas and select ones that we found, as a group, to be the best fit for the project. Our initial ideas generation process was all about what we envisioned a typical family of four having in their household. Some of these ideas include a dining room table, a basement, an office, a living room, three bedrooms, brick or stone exterior, a garage, and many more ideas along these lines. Throughout we stuck with some and eliminated others. Our final design included the following:

Two stories (1st and second floor)
3 Bedrooms (two for kids and one master)
2.5 Bathrooms
A kitchen (but no dining room)
A living room
An office
Two Skylights
Utility Closet

Design Selection:

We evaluated each of our house designs based on the following criteria to determine which one to model our design after.

Criteria	Weight	House 1 Shijia	Weighted score	House 2 Jordan	Weighted score	House 3 Jonathan	Weighted score	House 4 Garrett	Weighted score
Floor plan	30%	5	1.5	3	0.9	4	1.2	3	0.9

Design	20%	3	0.6	4	0.8	4	0.8	4	0.8
Potential for energy savings	50%	4	2.0	2	1.0	2	1.0	3	1.5
Total:	100%	12	**4.1**	9	**2.8**	10	**3.0**	10	**3.2**

Shijia's design ended up with the highest score of 4.1 so we used her internal layout for the design of the house.

House Design:

Our house's exterior design consists of two rectangular faces, two trapezoidal faces, and a roof slanted at approximately 19 degrees up from the horizon. The rectangular faces are located on the front and back of the house and are 30' by 12 ¾' and 30' by 21' respectively. The trapezoidal faces are directed toward the east and west sides of the house. By area, both are identical at 405 square feet. The roof by area is 36'by 28 ½', which allows for approximately 3' of overhang on the east and west sides as well as approximately 2 ¼' of overhang on the back and front. There is also a 9' by 4 ½' door centered lengthwise on the front wall.

Cut into all of these faces are several windows of varying size. The two front face windows are located 6' above the floor (3/4' from the top of the wall) and are both 10 ½' by 6'. They are both offset from the side walls by 1 ⅛' and start 3 ⅜' from the center of the wall. On the roof, there are two 9' by 6' skylights offset from the sides of the roof by 6'. They are also 3' from the centerline running through the middle of the house and located 3 ¾' from the front edge

of the roof. On the east/west faces there are two windows. Both are identical at 2 ¼’ by 1 ½’ and mirror each other along the length of the second story hallway. They are 3’ off the floor of the hallway and are located approximately 10½’ in off the edge of the house. The remaining three windows are all on the back face, with two bringing light into the two bedrooms and another located higher up in the bathroom. The windows to the bedrooms are identical in size at 5 ¼’ by 3’ and sit approximately 1 ⅞’ off the floor. The far edge of each window is located 8 ⅝’ from the edge of the wall. The final window, located in the bathroom, is relatively narrow and long. It is set 7 ½’ off the floor and is centered between the walls of the bathroom.

The interior design of the house is based on a 30’ by 24’ footprint. The first floor contains the kitchen, family room, master bedroom (with a master bath), an office, a utility closet, and a half bath. Entering through the front door, immediately to the left is the kitchen and eating area. Also located in this area is the half bath and doorway to the office. The kitchen/dining area is in the front of the house as that is where most of the light streams in and that is where people will be spending most of their time. The kitchen will have slate tiling to heat the home during the summer and winter via the sunlight hitting the tiles through the skylight and front window. The living room is immediately to the right as one enters the house. It also has slate tiling to make the most of the light entering through the skylight and front window. There are also three closets on this floor with one located in the living room, another in the master bedroom, and the final one in the office.

The second story is half the size of the first at 30’ by 12’ and contains two bedrooms with a full bathroom. It is reached by a set of centrally located stairs that are 3’ wide. The second floor is open to the first floor via a railing and 3’ wide hallway. The bedrooms are mirrored across the bathroom and also have closets located in the corner bordering the north wall and bathroom. The walls on this floor also attach to the roof, giving a spacious feeling to the rooms as well as keeping the room cool or warm by compartmentalizing the hot or cool air. The bathroom on this level is a full bath.

Separating the roof from the interior as well as insulating the exterior walls is R-50 insulation. By keeping the insulation the same across the whole house, the loss of hot or cool air is minimized. The windows are Double low -e type. The house is heated and cooled by an electric geothermal heat pump.

Energy and Cost Analysis/PV System:

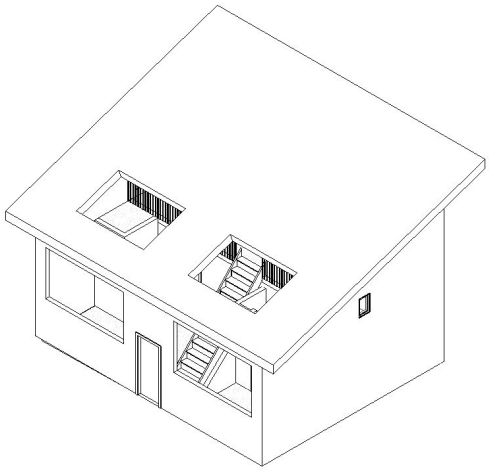
The overall cost of our house amounts to $184,775 with an estimated yearly usage of 6003 kWh/yr.

The PV system our house utilizes is mounted on the roof above the skylights. It consists of Twenty-two ND-240QCJ (240W) solar panels by Sharp® to create a 5.28 kW system for the house. They take up about 366 sq ft. of the roofspace. This leaves us enough room to also include a solar water heater. The solar panels cost $275 each,

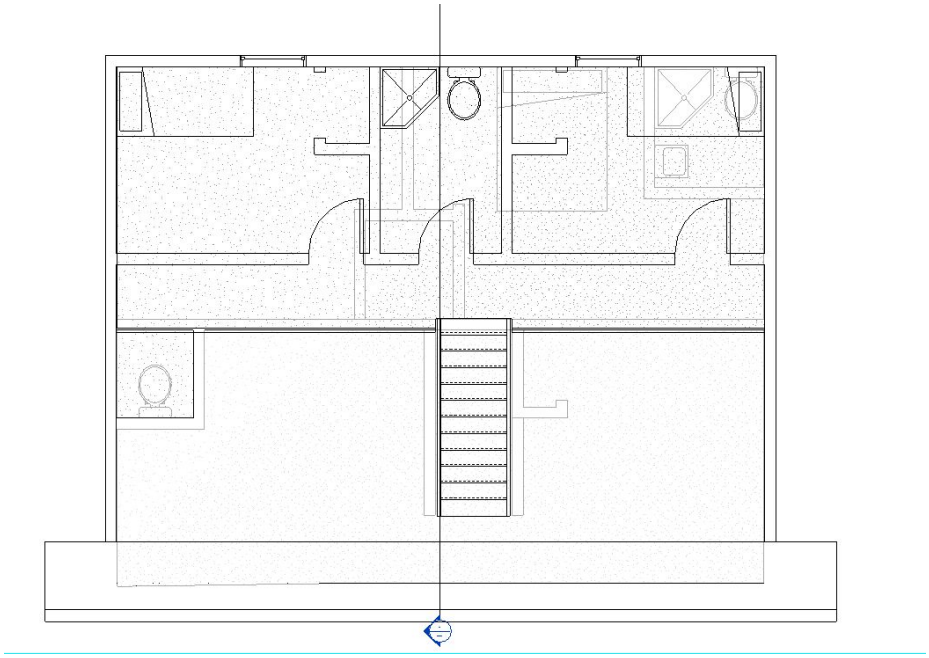
amounting to a total cost of $6050. They produce about 6491 kWh/yr. They offset all of the home's energy needs while producing an additional 488 kWh/yr to put back into the grid. Seeing as normally the cost of electricity for the year would be the amount used by the family (6003 kWh/yr) multiplied by the cost per kWh ($0.11), the family is saving all of this money as well as gaining money from the additional power put back on the grid by the battery. This comes out to $649.10 saved per year. This means that over the course of 9 and a quarter years, the panels would pay for themselves and the family would never have to pay an electric bill for the panels lifetime. The solar panels also come with a 25-year limited warranty for power output as well as a 10-year limited warranty on the materials used in production.

3D Model:

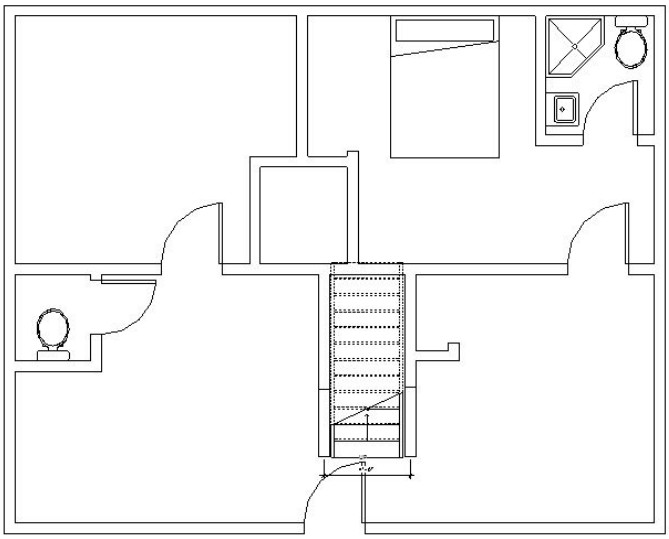
Isometric exterior view (view is of South and West walls):



Top down view of second floor:



Top down view of first floor:



Description of Model:

The scale model of the house was made using black foam board. Its walls match all of those of the digital 3D model with the exception of doors. All walls and floors were made with the foam board. Aluminum foil lined the underside of the roof to reflect rising heat back into the home. Aluminum foil on the west wall to reflect some of the wind and keep heat inside.

We also included thermal mass walls and floors under the skylights to help absorb heat. Other passive features include an overhang from the roof over the front windows. With these features, we hope to absorb a lot of heat through the skylights onto the thermal mass.

The overall layout of the house is living room and kitchen under the skylights, in the front, staircase in the middle with a balcony on the second floor overlooking this area. The back of the first floor has an office on one side with a utility closet and washer and dryer. The other side has a master bedroom with a master bath and closet. The upper floor has two bedrooms with a bathroom in the middle.

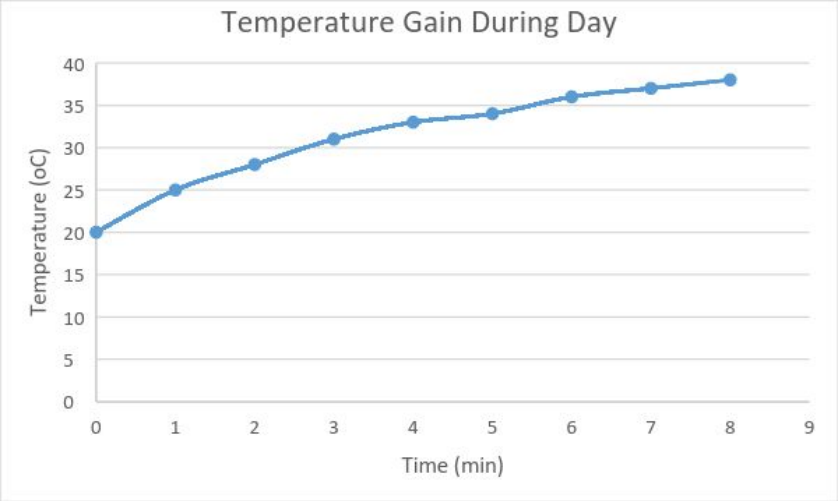
To maximize gain, we used black foam board, to attract heat, black fabric and rubber as thermal masses and absorbers, aluminum foil to help insulate, and hot glue and tape around the edges to produce a seal as best we can. We only used fabric in one location and we definitely could have made better use of that in order to increase absorption. We also could have doubled the windows (two layers of saran wrap) to help insulate them from losing too much heat.

One model we especially liked was the townhouse (or rowhouse) model because it was very realistic, well thought out, and was ideal for a small, efficient home with enough roof space for a solar panel. We found it was a great application of the assignment and very applicable.

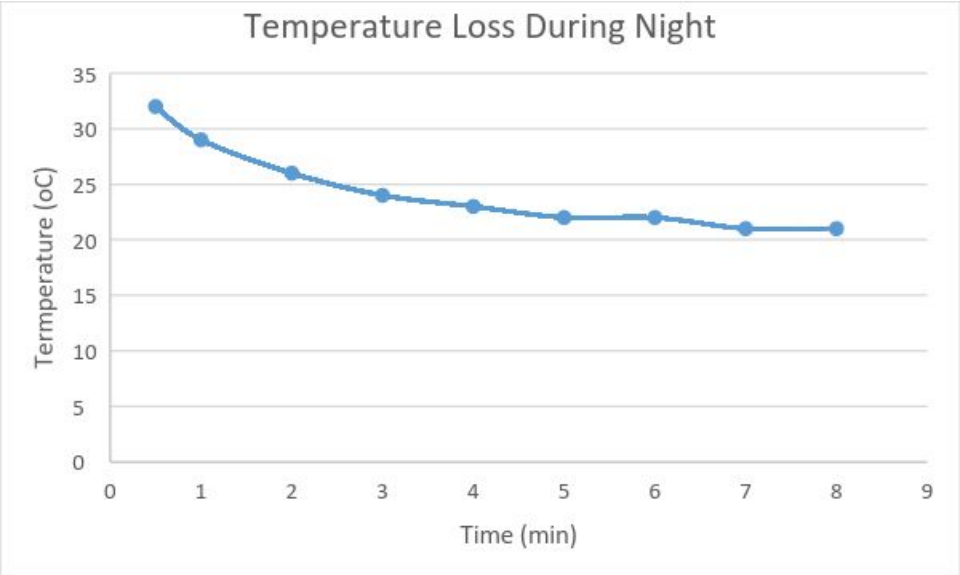
Experimental Data:

When our design was tested on February 26th, 2016, we had to goals in mind. First, we wanted our house to gain as much heat over an eight minute period of direct exposure to sunlight, which was simulated by a light. Second, we wanted the house to retain as much of gained heat as possible as a fan blows cold air at the west side of the house for eight minutes. Before we began with the experiment, we took a base interior temperature, which was 20 degrees Celsius. The results of the experiment were mixed at the very least. The house gained heat excellently, reaching the temperature of 38 degrees Celsius at the end of the eight minute period. However, during the time the fan was blowing the cold air, the temperature dropped very rapidly until at the end of the eight minute cooling period, the temperature had dropped all the way to 21 degrees Celsius.

After looking at the results, our group came up with numerous explanations for the massive gain and subsequent loss in heat. In regards to gaining heat, the space that any light from the skylight could reach was a thermal mass and colored black, which absorbs all of the light.



During The Day	
Time (min)	Temperature (℃)
0	20
1	25
2	28
3	31
4	33
5	34
6	36
7	37
8	38



During The Night

Time (min)	Temperature ℃
0.5	32
1	29
2	26
3	24
4	23
5	22
6	22
7	21
8	21

Conclusion:

In conclusion, our zero energy house ended up success not only on energy efficient that produced more energy than what we need, but it also aesthetically pleasing and comfortable house. Although our model did pretty good during the testing process, we still have more features can be added or approved. From the testing, we find out that our model can gain heat very well but can not retain the heat perfectly. For the windows areas, we should use more well-insulated material to prevent heat losing. We only insulated the edge of our walls,which is a big cause of losing heat.Therefore, we should have the wall well insulated, so that they do not outflow that much heat. Overall, from this project, we learned how to design with production in mind, how to choose the suitable material, how constant communication and collaboration are required.

References:

http://precisionboard.com/products/high-density-urethane-pblt/
http://www.greatdayimprovements.com/insulation-r-value-chart.aspx
http://www.homewyse.com/services/cost_to_install_blown-in_cellulose_insulation.html
http://www.fypon.com/literature/pdfs/catalog/pricelists/PUR%20Price%20List.pdf