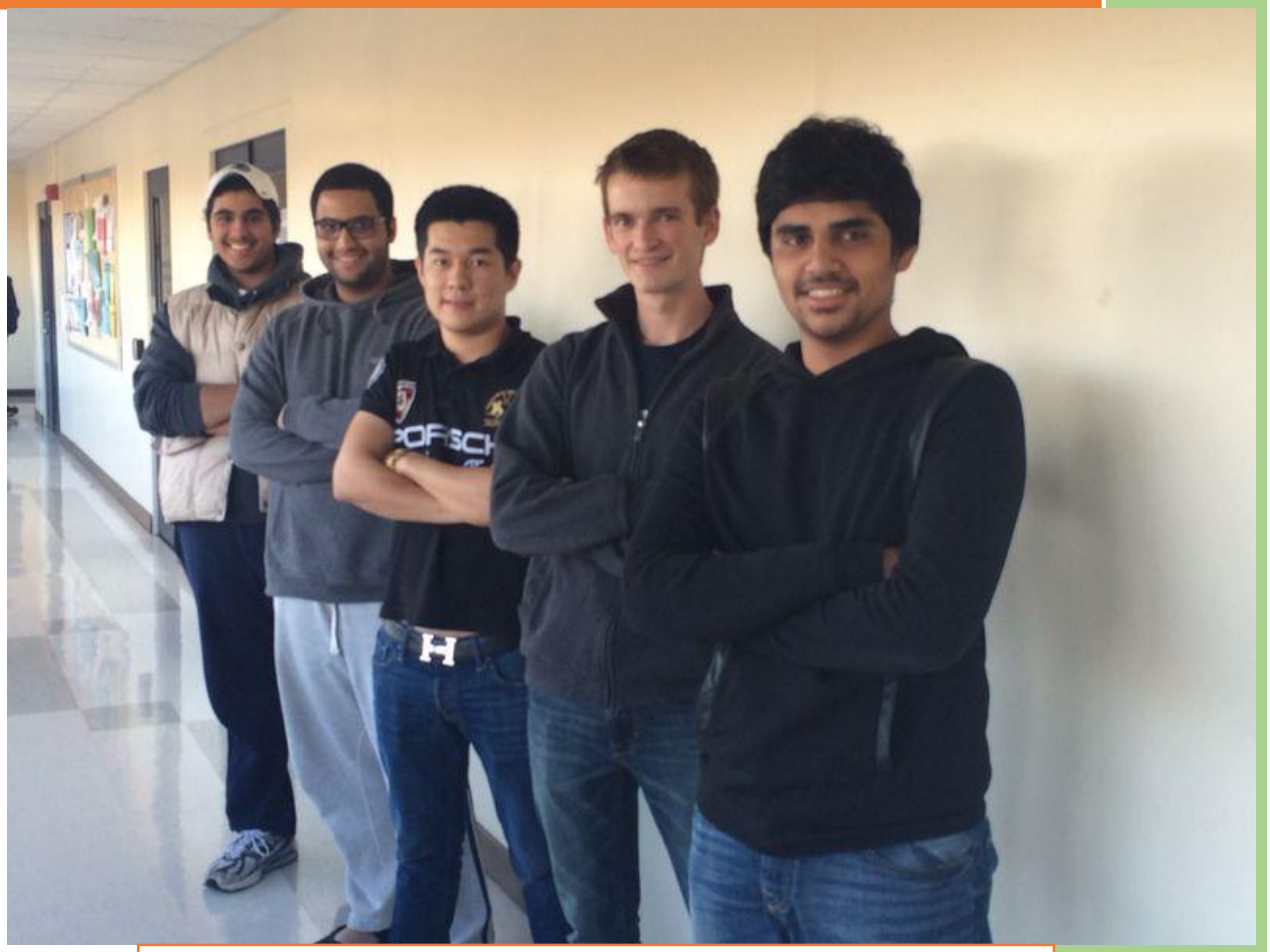
2013

Zero Energy Home Project



From Right: Hamdan Alrmaithy (haa5177@psu.edu), Joseph Taylor (joseph.taylor26@gmail.com), Aslan Aldanganov(axa1000@psu.edu), Ali Aljefri, (asa5325@psu.edu), Sulaiman Alsaqer (sva5362@psu.edu)

Pennsylvania State University

Submitted to: Professor. Bevin Etienne

10/24/2013

Table of Content

Topic	Page
Abstract	2
Introduction	2
Summary Table	3
Customer Need Analysis	4
Mission Statement	5
Research	6
House of Quality	11
Concept Generation	12
Concept Selecting & Scoring	13
Sketches/SolidWorks/Prototype	14
Calculations	17
Final Design	26
Conclusion	26
References	27

Abstract

Our team, Team Exceptionally adequate, we built a zero energy home which has three bedrooms, two for the children and one for their parents. Basically, our zero energy home produces as much energy as it uses for an annual basis and we are getting electricity from stream of river by using pump device. Our other source of energy comes from solar panels. Throughout this project, we all had an experience on how to use the “Eight-Step” Engineering design process to design our zero energy home. Our zero energy home fits a family of four.

Introduction

It’s our duty as human beings to protect the land we are living at. One of the most concerns our modern society faces is the waste of energy that is dissipated into the environment. Thus, reducing the emissions from the excess energy is one of our responsibilities to protect our climate from diminishing significantly. One of the most effective solution for this problem is the Zero Energy Home. This type of homes will basically be able to produce as much energy as it consumes. Therefore, it will benefit the environment as well as the people living in it. Achieving our goal is much easier with the advanced renewable energy technology offered nowadays such as solar systems and geothermal power. However, it is essential to follow a proper design approach to create an affordable and fully functional zero home energy.

Summary Table

Location (state)	Pennsylvania, United States
House size (floor area in square feet)	App. 1400 sq. ft.
Number of floors	1
Number of occupants	4
Number of bedrooms	3
Type of heating system (resistance, heat pump, etc.)	geothermal
Size of photovoltaic system (kilowatts)	519 per month
Solar water heater (yes or no)	yes
R-value of wall insulation	8
R-value of ceiling insulation	6.88
Type of windows	Double pane
Total Cost ($)	$156,000

Customer Need Analysis

Customer Statement	Need Statement
"My home should be located in Pennsylvania"	The home is located in Pennsylvania
"My home should have its energy output equal to, or less than energy input"	The home is a Zero Energy Home (ZEH)
"My son is suffering from Asthma"	The home is purified
"My home must have an efficient water heater"	The home has a heated water supply
"I really hate the cold winters"	The home is warm in Winter
"I want to have a cooling system in my zero energy house"	The home is cool in Summer
"I would like to have each of my son have a separate room"	The home accommodates the privacy of each brother
"My home should have spacious storage and basic appliances"	The home has kitchen with modern appliances and storage
"A laundry room will save me a lot of time"	The home has a Laundry Room
"Large windows should be present in my new home"	The home has big Windows
"My home should have effective insulation"	The home is effect insulated
"My building cost should be less than $160,000"	The home costs no more than $160,000
"My home must be comfortable for a family of four"	The home fits a family of 4

The above customer statements were converted into need statement, which is essential in the design process. Target specification, which is based on the customer needs, must be set before moving on into concept generation. The need statement was analyzed and ranked based on importance, from 1 to 5, as shown below.

#	Need	Importance
1	The home is located in Pennsylvania	4
2	The home is a Zero Energy Home (ZEH)	5
3	The home is purified	2
4	The home has a heated water supply	4
5	The home is warm in Winter	4
6	The home is cool in Summer	4
7	The home accommodates the privacy of each brother	3
8	The home has kitchen with modern appliances and storage	4
9	The home has a Laundry Room	2
10	The home has big Windows	3
11	The home is effect insulated	4
12	The home costs no more than $160,000	5
13	The home fits a family of 4	2

Mission Statement

To design a zero energy home which is efficient, effective, and cost consistent for a low-income family of four. Energy output must equal, or be less than the energy input.

Mission: Zero Energy Home Project	
Product Description	A home in which it's energy output must equal or be less than the energy input
Benefit Proposition	No reliance on government electricity, whereas energy is constantly generated to satisfy the demand
Key Business Goals	To influence the building of more zero energy homes, which leads to a less dependent, and a greener world.
Primary Market	Low/middle class income families
Secondary Market	Environmentalists, Construction companies
Assumptions	Independent house which generates electricity based on mother nature, aided by efficient appliances
Stakeholders	The family, construction companies, Pennsylvania's government, realtors

Research

Insulation

Fiberglass-the most common kind of insulation, it is fairly effective but it does not fill small cracks/gaps, which lead to inefficiencies.

Closed cell Icenyne- very effective, with a very high R value of 6 per inch. Fills cracks/ gaps to reduce inefficiencies.

Cellulose insulation- starts out as very effective/efficient with a fairly high r value, but settles over time leading to inefficiencies.

Land based/water based

We considered two types of home, a land based model and a “floating” home. In the end we decided on the land based model because while a floating home would be very easily cooled in the summer, it would be very difficult to heat in the winter. Also, there are higher long term maintenance costs associated with floating homes.

Sources of power

When considering types of power generation, we considered a number of factors such as geographic location, local regulations, cost, resource management, and upkeep costs. In the end we decide on a hybrid system, (for redundancy), based off of solar power and hydroelectricity. Hydroelectricity is up and coming in Pennsylvania, but is surprisingly efficient and as a standalone power system can recoup initial capital in less than 10 years through federal subsidies and electricity cost savings. Solar power is a good additional power source, with capital returns

in roughly 20 years. Using a hybrid system we produce much more electricity than is used in our home, (thanks to conservative appliances), electricity that we would be able to sell back to our electrical company for profit.

Windows

We used double glazed windows, because they have a much higher R value than single paned windows, but let through a lot of natural light; light that will reduce our dependence on indoor lighting during the daytime.

Solar panels

We decided on Canadian Solar CS6X-305M solar panels, which are relatively inexpensive for the value, competitive in electricity generation, and require minimum maintenance.

Natural gas appliances

Gas appliances are very efficient and are a cheap alternative to other stove options. What's more, they provide a more even heat than other types of stoves, which can greatly improve food quality and consistency.

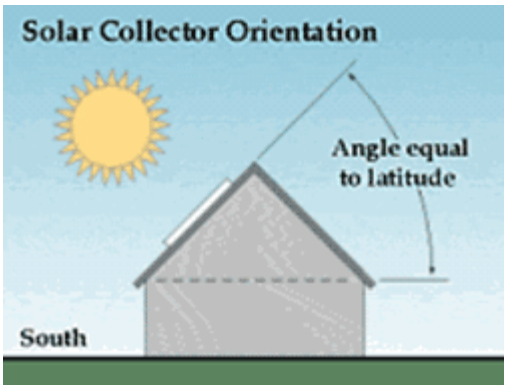
Battery

While we will send most excess electricity back to the electrical grid, we will have a battery system in place for storage; the 12v 4D SCADA Solar Battery for SBS Storage Battery Systems S12V200. A lead acid battery rated to 200 amp hours, this model should meet our short term storage needs.

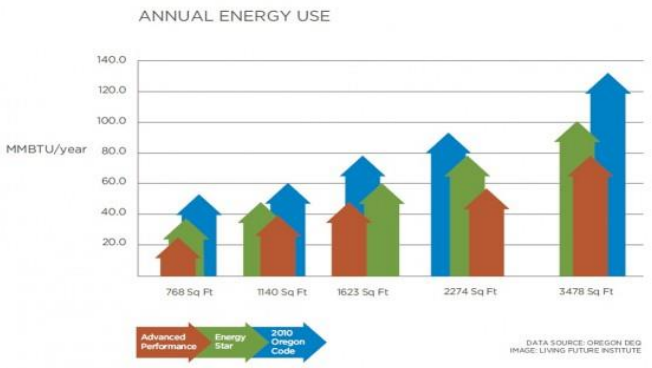
Heat pump

Elite series XP16 heat pump. A good balance of cost and efficiency, boasts an efficiency rating of 16.5

Because the orientation of the sun changes every season, and it is expensive to buy solar trackers, the angle of the solar panel must be the same as the latitude in Pennsylvania, which is 40.69 degrees. Proper angle orientation is significant because it "maximize the exposure, (Solux)" to the sun rays. This means that more sun rays are absorbed by the solar panels which leads to an increase in energy input. Figure 1 gives a visual concept of how the roof must be angled to accommodate the incoming solar rays. From this outcome, our team have decided that it is a must to include a roof which is tilted at an angle of around 40 degrees to maximize the home's energy input.



House is laid out into 3 rooms and a main living, kitchen, and a dining area. One of the most important feature, and which puts us over most of the other projects is that our house is only 1 story tall. The total square foot, is even less than 1400. Size is directly proportional to annual energy use. As seen in figure 2 (Energy.gov) on the left, as the size of the house decrease the MMBTU per year also decrease. MMBTU is a British unit, where it is the amount of energy needed to cool or heat one pound of water by one degree. Hence smaller houses are more energy efficient, as less rooms and space means smaller appliances, less lighting, and an overall less operating costs (Energy.gov).



Having a green roof also aids into the efficiency of the home. In summer, the green roof protects the building from direct solar heat (Greenroof.org). This in result, reduces the amount of energy needed to cool down the house during summer. During winter, the green roof acts as an insulator, preventing heat loss to the environment (Greenroof.org). It is true that maintenance may affect the costs, but the advantages of having a green roof beats the disadvantage. “For example, research published by the National Research Council of Canada found that an extensive green roof reduced the daily energy demand for air conditioning in the summer by over 75%. (Greenroof.org)” Thus, green roofs are a must when designing zero energy homes.

Moreover, the actual building orientation of the zero energy home is extremely important when it comes to maximizing efficiency. Having a horizontal based house with windows facing south is one of best ways to benefit from passive heating and cooling as seen in figure 3. During summer, the sun's path is at a very high angle, around 80 degrees to be exact. Vice versa, the sun's path during winter is at a 30 degrees angle (Greenpassivesolar). Hence, a slanted roof with a small cover for the windows is more than enough to prevent the summer sun's energy from entering directly into the home. In the other hand, during winter, having larger south windows with double or triple glazing and insulation will ensure a much warmer environment. Therefore, "Simply by building in this way, a house can reduce its heating and cooling costs by 85%. (Greenpassivesolar)"

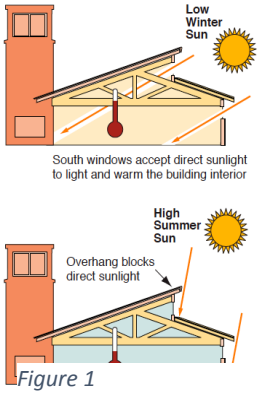
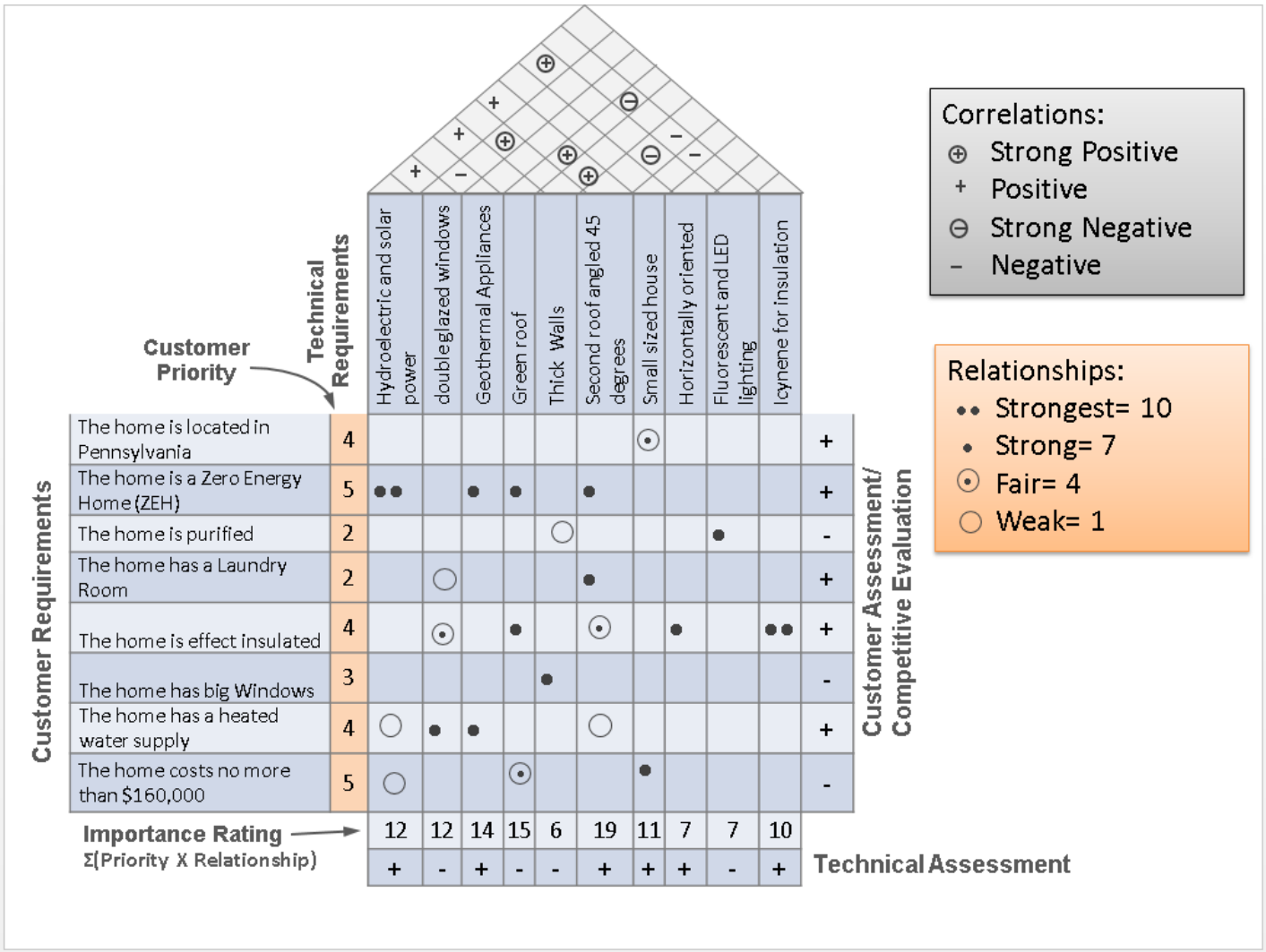


Figure 1

http://greenpassivesolar.com/passive-solar/building-characteristics/orientation-south-facing-windows/

House of Quality



The house of quality helped us to combine customer needs, technical requirement, and bench marketing into one illustrating graph. By the house of quality we were able to compare our design's technical requirements with those on the bench market. It allowed us to choose which aspects of the design is most significant to satisfy customer's needs. From the house of quality analysis we concluded that the most important aspects of our design are: 1. the angled roof. 2. The green roof. 3. Geothermal Appliances. And 4. Using hydroelectric and solar power generation.

Concept Generation

Once specifications are established, concepts are generated to meet those specifications. Concept generation is effective because it allows the team to consider more than two alternatives. The research that has been done before gave us some ideas with multiple possibilities for creating a zero energy home for our future owners. We have considered lots of choices before we made our final decision. Initially, we considered building a house that will be efficient and will be most suitable in Pennsylvania. So, we considered three choices, our first choice was the floating house, our second option was a house in the mountain with wind turbine, and our third choice was a normal resident house with a combination of energy efficient systems. The three options we considered contain several advantages and disadvantages. Advantages of having floating house are that the owners do not have to pay for land taxes; it is defended by Supreme Court that a floating boat will not be enforced to pay land taxes. Disadvantages of having a floating house are risks of flooding and the dangers during storms that are not safe. In addition to that, water turbines are really expensive. Advantages of having a house with turbine are that wind is free and it does not cause pollution, also the energy that produces turbine is renewable. Disadvantages of having a house with a wind turbine is that the strength of the wind is not constant which means owners will not always have electricity. Furthermore, wind turbines are noisy which are not allowed to build such houses in resident areas in Pennsylvania. Advantages of having a resident house are that we can have solar energy from solar panels and it is closer to the population. Disadvantages of having a normal resident's house are, owners have to pay for land taxes, and the house is small.

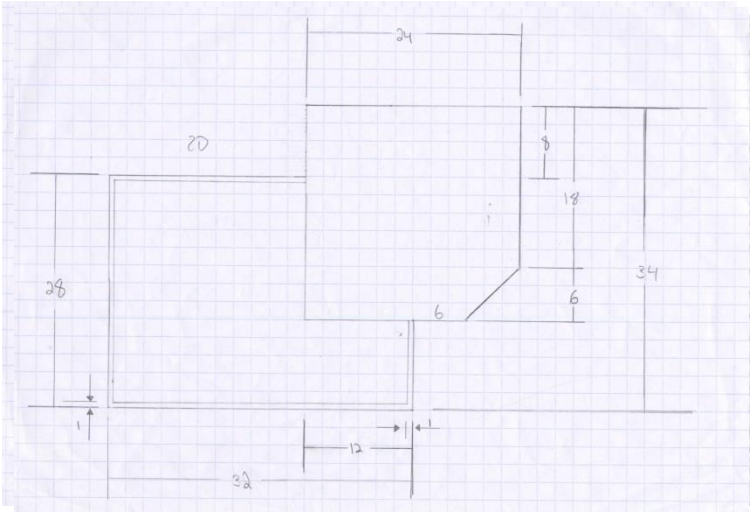
Concept Selection & Scoring

Selection Criteria	Weight	Wind House Rating	Wind House Score	Floating House Rating	Floating House Score	Solar House Rating	Solar House Score
Low Cost	10%	3	0.3	2	0.2	3	0.3
Efficient in Energy	30%	4	1.2	2	0.6	5	1.5
Good Insulation	10%	2	0.2	3	0.4	4	0.4
High quality windows	10%	3	0.3	4	0.4	2	0.2
Efficient Appliance	20%	2	0.4	2	0.4	3	0.6
Spacious	%5	3	0.15	1	0.05	4	0.2
Ease of maintanance	5%	1	0.05	1	0.05	3	0.15
Long lasting	%10	2	0.2	2	0.2	3	0.3
Net score			2.8		2.3		3.65
Rank			2		3		1
Continue			No		No		Yes

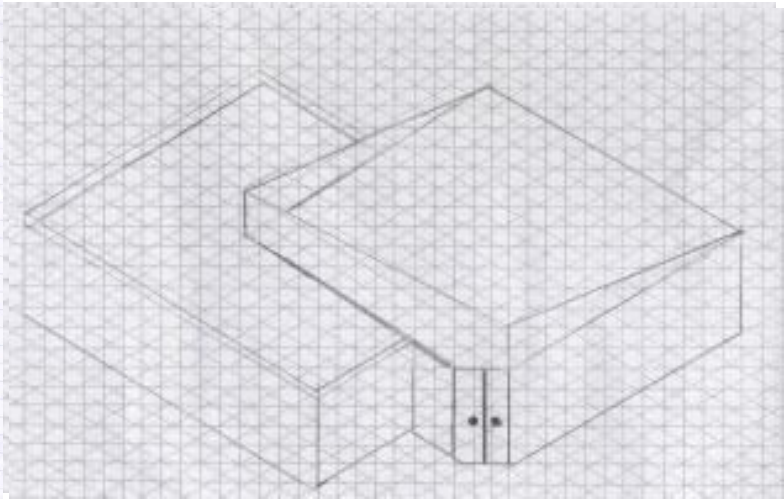
We considered three choices when selecting which house to build for the family of four. However, our final decision depended highly on the scoring metrics. First, we considered the floating house and decided that is not really a good choice because the water turbine is expensive and there are some chances of flooding, which is not safe for the family. The house with a wind turbine is not a good choice, because the wind is not constant and there will be times when the owners will not have electricity. This is not efficient. Furthermore, Pennsylvania's legislature ruled that wind turbines and related equipment may not be included in property-tax assessments. After all choices that we've covered we decided that a normal resident house with a combination of solar and hydroelectric energy is the suitable house to have Pennsylvania for a family in such a situation. Therefore, the normal house turned out to be the product champion.

Sketches / SolidWorks / Prototype

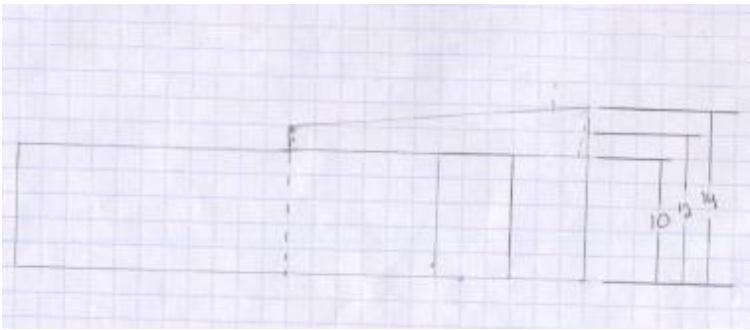
Sketches



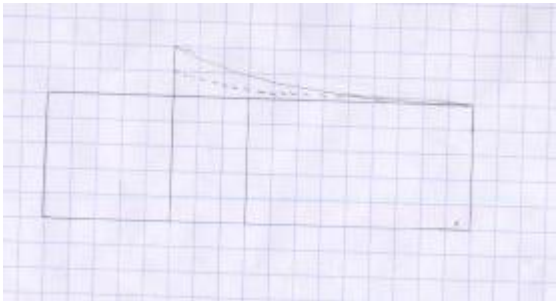
Top



Isometric



Front



Right

Figure 4: This caption displays the initial sketching of the zero energy home. As seen, the house is only one story high. This ensures an overall less energy consumption. The slanted roof which is shown in the isometric view is set to maximize the solar energy input.

SolidWorks

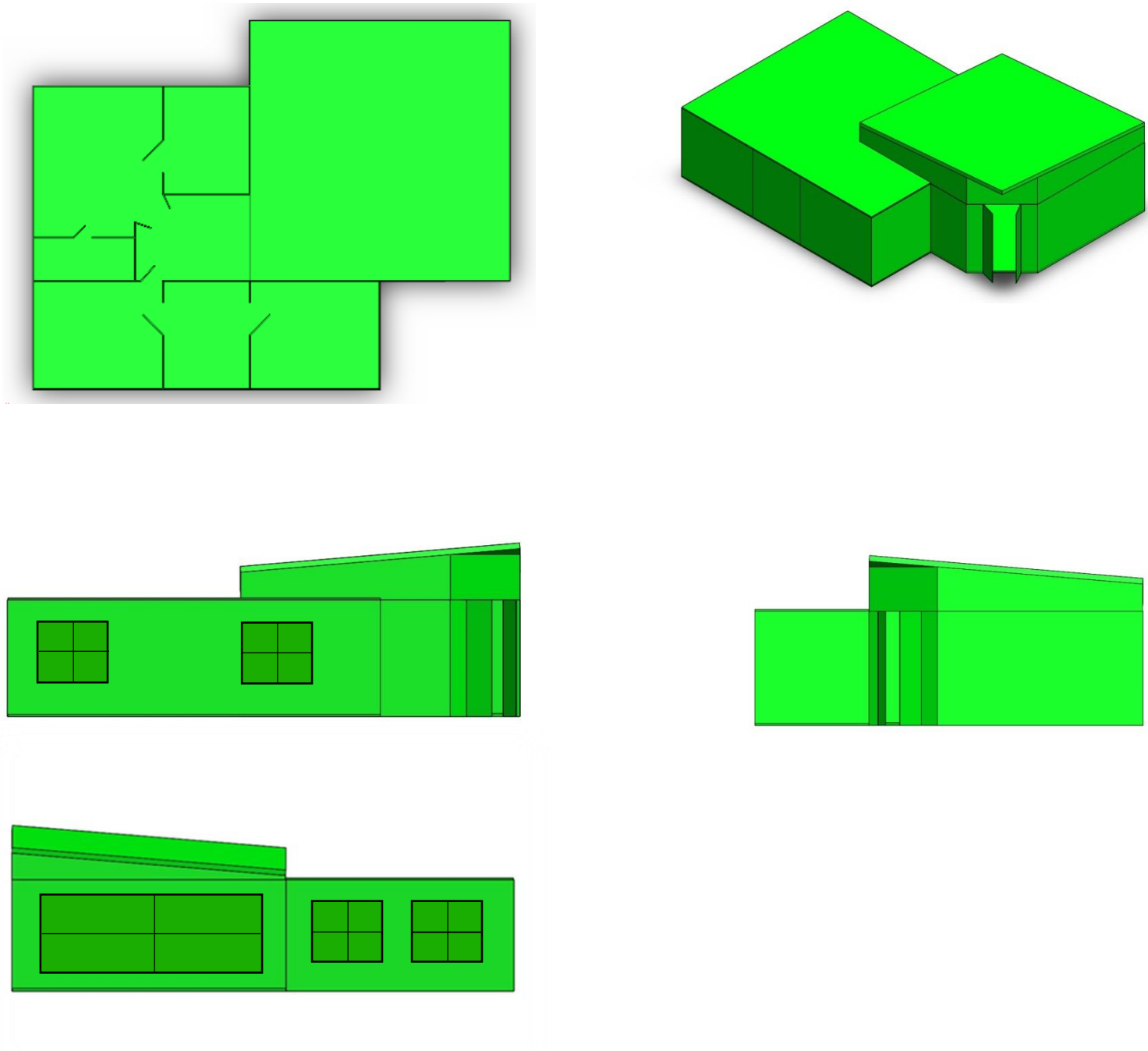
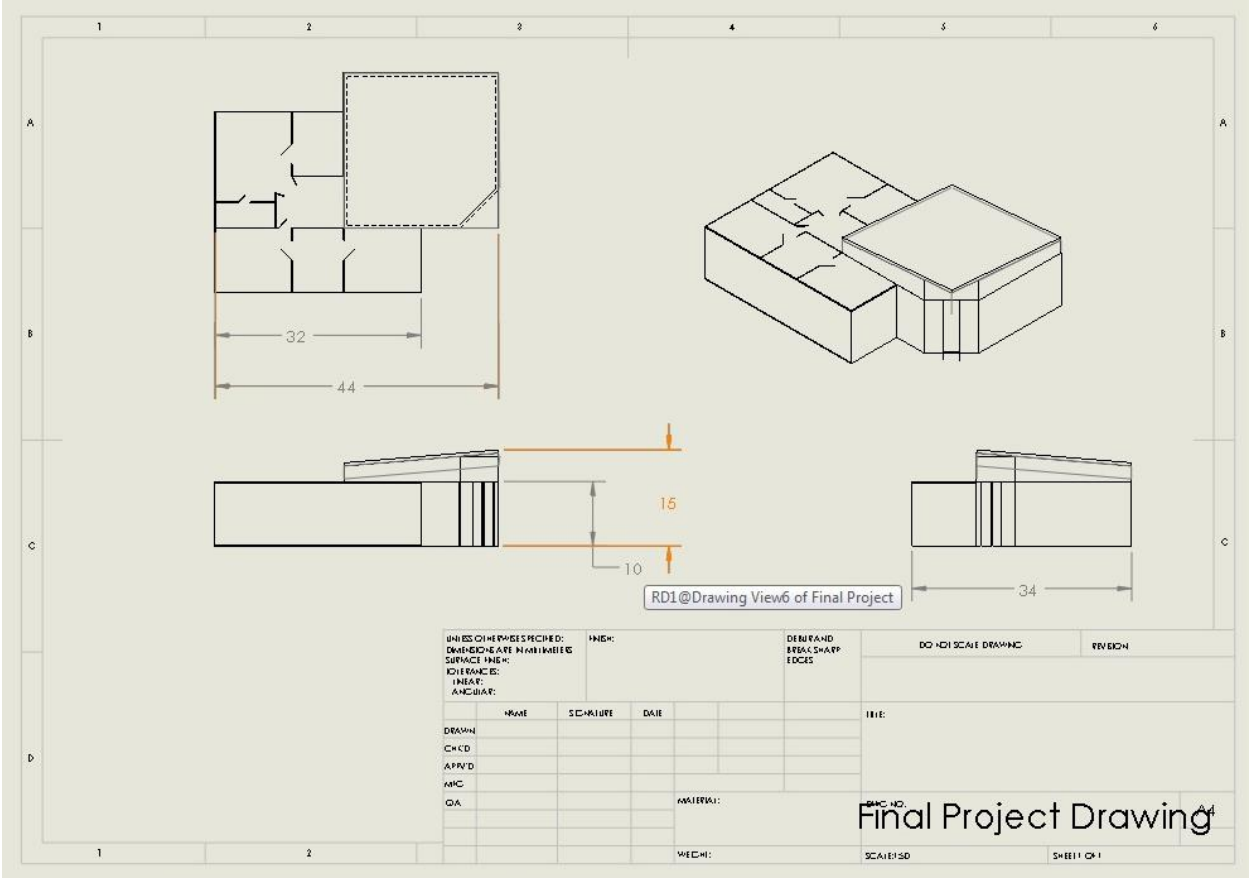
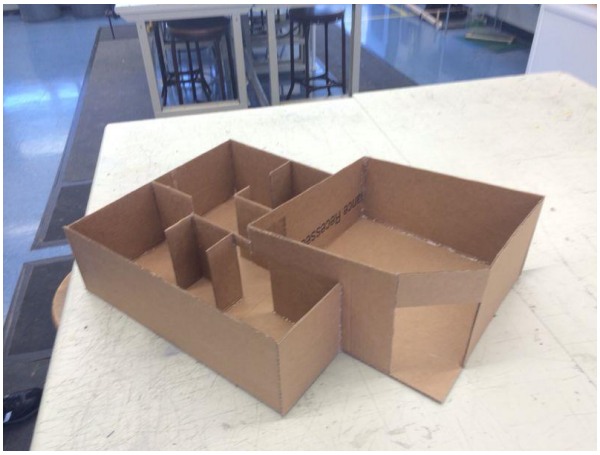


Figure 5: The above figure displays the top, front, right, back, and an isometric view of our final design using SolidWorks. The slanted roof is specifically designed to accommodate the latitude angle of Pennsylvania in order to maximize solar energy input.

SolidWorks 2D Sketches Prototype





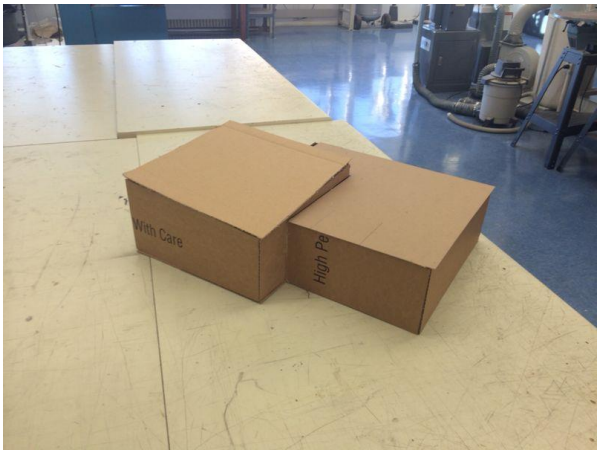
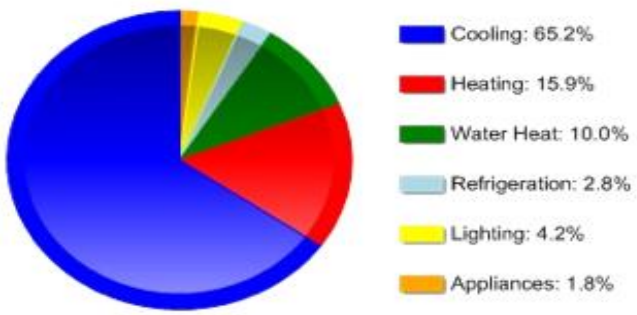


Figure 6: Displays the official SolidWorks 2D sketch. The hidden lines are represented by dotted lines and the dimensioning is identical to the initial sketch found in Figure 4. Although our house is only 1400 square foot big, there is more than enough space for each member of the family. The second and third image represents the physical prototype which our team built from cardboard.

ZEH Calculations (Homer & CPS Energy)---Appliance Decision

- To calculate the annual electricity used and cost for a house of our specifications we used a program called "CPS Home Energy Calculator".
    - We input detailed information about appliances and specifications of our home and got back a comprehensive report with consumption calculations.

The following diagrams show the annual electricity cost distribution:



	kWh	Electric Costs
Cooling	4,353	$391
Heating	1,117	$95
Refrigerators/Freezers	196	$17
Lighting	291	$25
Water Heating	703	$60
Dishwasher	68	$6
Clothes Washer	18	$2
Clothes Dryer	37	$3
Elec. Base Charge	N/A	$99
Total Per Year	6,785	$699
Average Per Month	565	$58

Load	Consumption (kWh/yr)	Fraction
AC primary load	6,753	82%
Grid sales	1,450	18%
Total	8,203	100%

- From this data we found the amount of electricity used per day in our house, which is 18.6kwh. The average electricity used per month is 565kWh.
    - The total cost the family has to pay for electricity is $58 per month and $699 per year.

Energy Supply System

- We used a program called Homer to calculate the amount of electricity the solar panels need to produce per year for our system.
    - The results indicate that the solar panels need to produce an amount of 5361kWh/yr annually.

PV

Quantity	Value	Units
Rated capacity	4.00	kW
Mean output	0.612	kW
Mean output	14.7	kWh/d
Capacity factor	15.3	%
Total production	5,361	kWh/yr

Electrical

Component	Production	Fraction
	(kWh/yr)	
PV array	5,361	58%
Grid purchases	3,843	42%
Total	9,204	100%

    - That means the solar panels in our system need to produce about 446.75kWh per month.

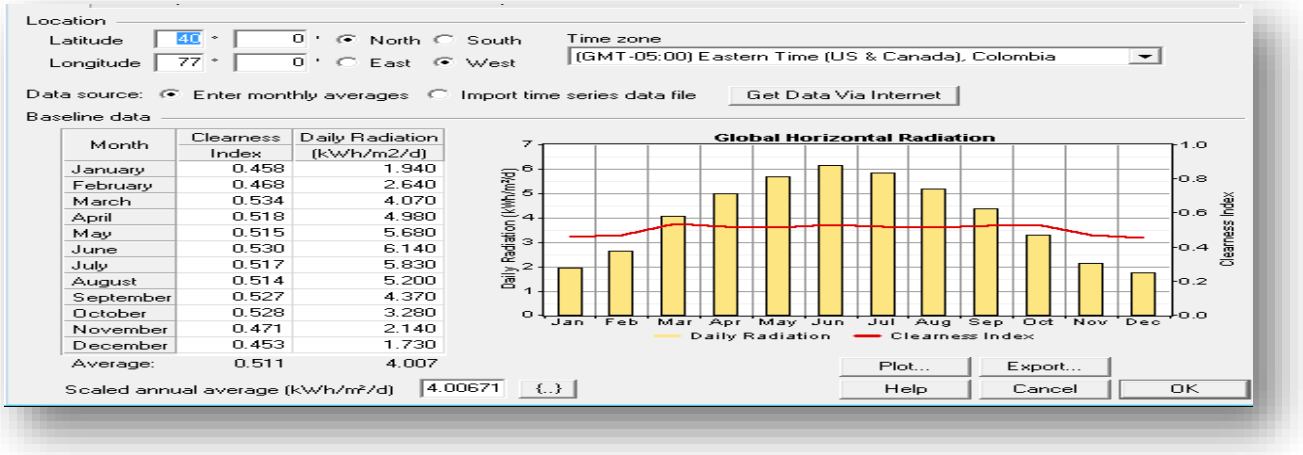
- From these results we searched for the best deal of solar panels for the house.
    - We calculated the number of solar panels we need to provide the amount of electricity needed for the house.

- We found a company that meets our specifications.
- In order to get 446.75kWh per month we need a system that contains 15 solar panels that produce a total of 519.35kWh per month.
- This means that we will get an excess of about 72.6kWh monthly.

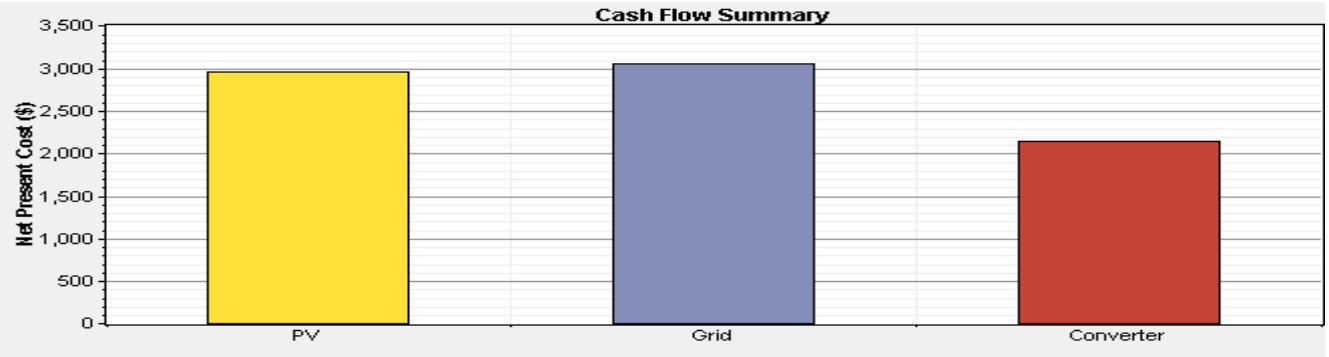
- There is still about 98.25kWh to be covered.
  - The rest of the energy necessary to provide the house with electricity will come from hydroelectric streamlines.
  - The hydroelectric generator cost from $2500 to $4000.
  - It will provide us with 500kWh, which is more than enough electricity than what is needed.

- When selecting the solar panels we took into consideration the size of the panels in order for them to fit roof of the house.
  - Our roof is 576 sqft.
  - Each solar panel is 17sqft.
  - The whole system of solar panels will cover 255sqft of the roof.
  - This means that the solar panels will cover almost half the size of the roof.

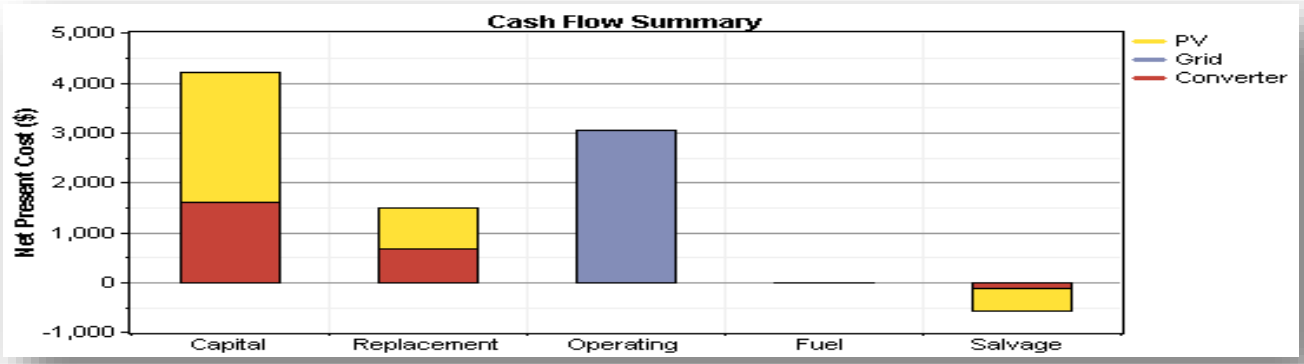
- The price of the solar panels.
  - Installing the system will cost $9,047



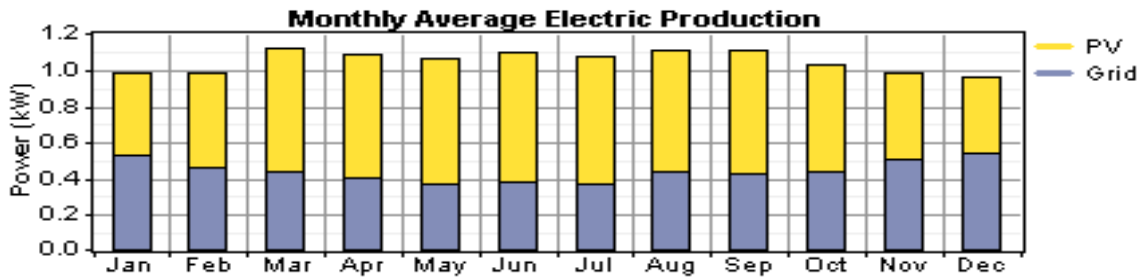
- To get an accurate calculation homer bases its calculation on longitude and latitude of the specific location.



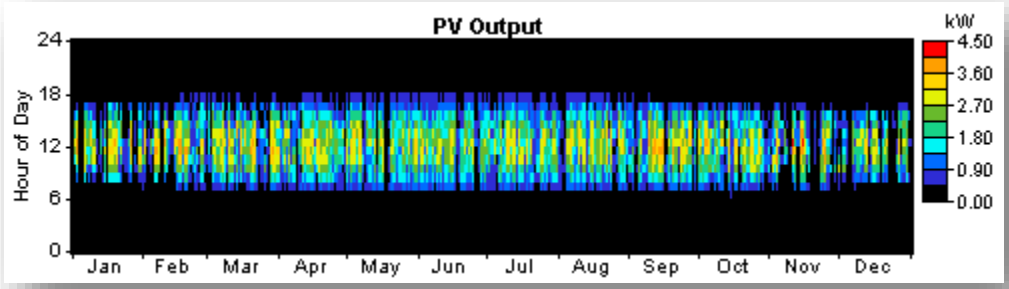
- This diagram shows the distribution of the cash.
- The cash is distributed through PV system, the grid, and the converter.
- The net present cost.



- This is a summary of the net present cost over the capital, replacement, operating, fuel, and salvage.



- The production of electricity on a monthly bases can be shown using homer. The graph shows two parts of the products the PV and the grid.



- The monthly electricity produced from the solar panels. The colors indicate the kilowatt range. Which changes related to time of year, and the time of day.

Appliances:

- The major appliances the family needs is:

  - Cooling system
  - Heating system
  - Refrigerator
  - Cooking oven
  - Water heater
  - Dishwasher
  - Lights
  - Clothes washer
  - Clothes dryer
  - TV

- When choosing the appliances we looked for specific energy and cost efficient appliances.

1. For the cooling system we chose a Geothermal cooling pump:
   - This type of system is more cost and electricity efficient when compared to a typical electric cooling pump system.
2. For the heating system we used a Geothermal heating pump:
   - This type of system is more cost and electricity efficient when compared to a typical electric heating pump system.
3. We chose an energy-star refrigerator:
   - This type of appliance is more energy efficient
4. We chose a natural gas cooking oven:
   - We chose this appliance because natural gas tends to be less expensive, at up to 1/6 the cost of propane.
5. Our choice for the water heater is a solar and electric system:
   - More energy efficient
   - Provided by our solar system.
6. The dishwasher we chose is an energy star dishwasher:
   - This type of appliance is more energy efficient

7. For the clothes washer we chose an energy star front load type:
    - This type of appliance is more energy efficient

8. For the clothes dryer we chose an energy star front load.
    - This type of appliance is more energy efficient
9. For the TV we chose a LCD LED TV.
10. One of the important appliances we added to the house was the air Purifier:

    - We believe that the air purifier is an essential appliance in the house because one of the children in the family has asthma.

Air Purifier which costs: $600

Water heater and cooler costs: $500 - $1000

Heating and cooling system costs: $1000- $2000

Energy star dishwasher costs: $500

Energy star washing machine costs: $500 - $1000

Natural gas cooking oven cost: $100 - $500

Energy star refrigerator cost: $100 - $1000

Lighting costs: CFL is $0.8 and LED is $2.55 - $3.99

Final Design

After extensive research, our team decided that the zero energy home which will be built must include important features that makes it energy efficient. First and foremost, the entire size of the house is just under 1400 square feet. This is significant because it directly reduces the energy consumption. In addition, the house will be horizontally orientated with more windows facing south to benefit from passive heating and cooling. We decided to have two types of roofs a slanted roof at an angle of 40 degrees to maximize solar input, and a regular green roof.

Conclusion

During this project, we designed a Zero Energy Home in which the produced energy is compensated by the consumed Energy. As a matter of fact, due to our efficient design, we now are able to produce extra energy that can be transported back to electric power plants which is profitable for the landlords. Our first choice of producing energy was using solar panels in top of the house. Therefore, to increase electricity generated from the solar panels we designed a part of the roof to be tilted in an angle of 45 degrees. Another aspect of the house that we focused on was the insulation methods. For insulation we used Fiberglass, Closed cell Icynene, and Cellulose insulation. One of the challenges we faced during working on this project was to be under the specified budget while meeting the expectations for our design; however, decision making among the team helped us to come up with the best approach to satisfy the customer needs and to efficiently spend our funds. Overall, this project was a very inspiring and informative experience for our team. Moreover, we believe that the conclusions we reached will be of a great assistance for future Zero Home Energy research.

References

"Calculate Your Home Energy Costs." *Calculate Your Home Energy Costs*. N.p., n.d. Web. 24 Oct. 2013.

"Exploring Wind Turbines Advantages and Disadvantages." *Wind Turbines Advantages and Disadvantages*. N.p., n.d. Web. 24 Oct. 2013.

"Green Passive Solar Magazine." *Green Passive Solar Magazine*. N.p., n.d. Web. 24 Oct. 2013.

"Green Roof Benefits." *GRHC WEBSITE*. N.p., n.d. Web. 24 Oct. 2013.

"Grid-tie Battery Backup with 15 Astronergy Solar Panels." *Grid-tie Battery Backup with 15 Astronergy Solar Panels*. N.p., n.d. Web. 24 Oct. 2013.

"Houseboat vs. Floating Home." *Special Agents Realty RSS*. N.p., n.d. Web. 24 Oct. 2013.

"Pennsylvania." *NRDC: Renewable Energy in*. N.p., n.d. Web. 24 Oct. 2013.

"R-Value." *R-Value*. N.p., n.d. Web. 24 Oct. 2013.

"Soluxe Energy Savings & Efficiency Solutions Rooftop Solar Geothermal Power." *Soluxe Energy Savings & Efficiency Solutions Rooftop Solar Geothermal Power*. N.p., n.d. Web. 24 Oct. 2013.