Zero Energy Home Project

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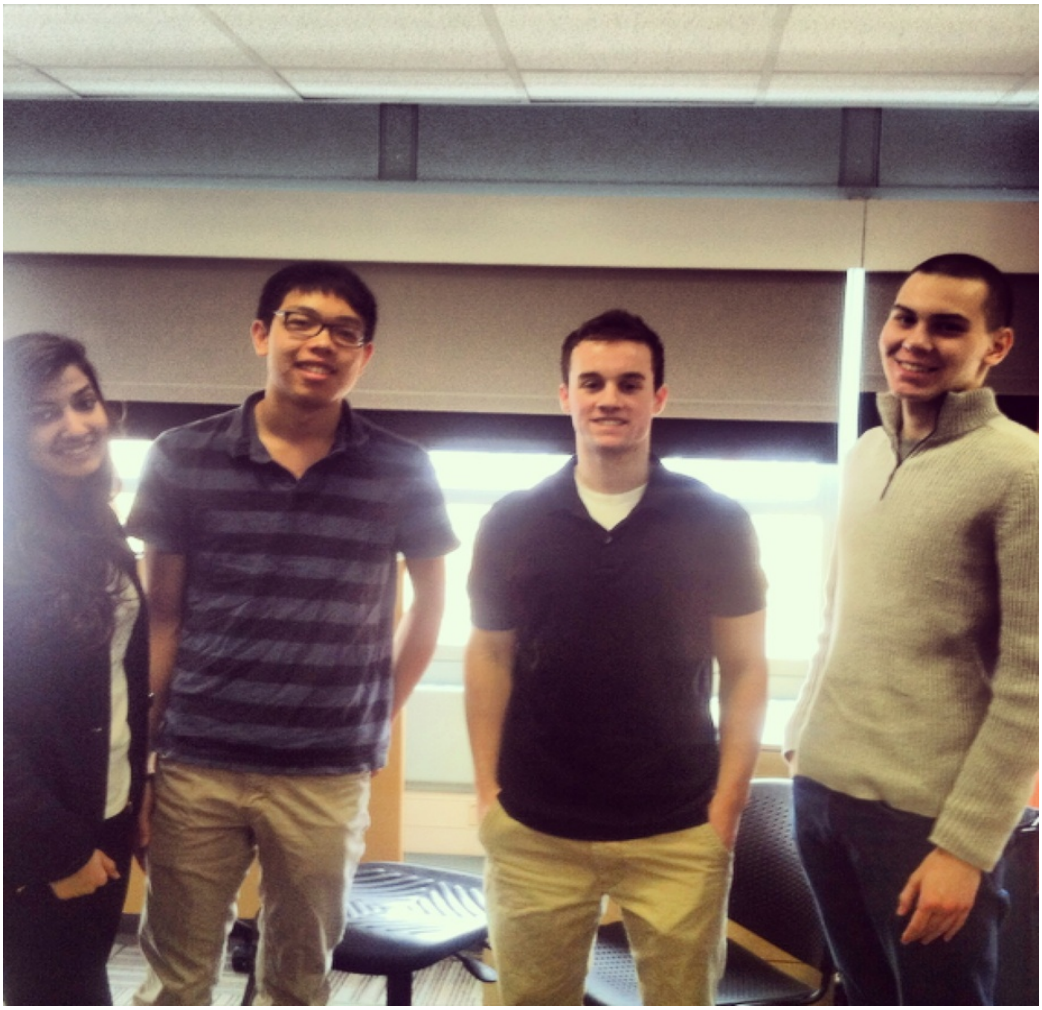

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Abstract

Executive Summary:

Our main goal was to design and build a zero energy home in the state of Pennsylvania. In order to achieve this we split into teams of four each designing a zero home on our own. Our team worked collectively as a group on all of the tasks.

Introduction

Problem Statement:

The environmental impact left by humans is a growing concern as populations grow and societies expand. If left unattended the impact that humans leave on the world would become irreversible. Part of the problem is the growing demand for energy to power our, cities, factories and transportation. Residential and commercial buildings contribute to 40% of the world's energy use and continues to grow at significant rate due population increases and a rise in living standards around the world. A majority of these homes draw their energy from nonrenewable resources and with the increasing population will increase the carbon emission.

Mission Statement:

We set out to build a Zero Energy Home in the state of Pennsylvania. The house was to be constructed under a budget of $140,000 and it had to have the ability to comfortable house a family of 4. Another important characteristic of the house was that it had to be ascetically pleasing and energy efficient. The house also had to meet and exceed to standards of our customers.

ZEH Home Survey

In order to get a better idea of what our customers really wanted out of a Zero Energy House, we conducted a survey. We chose to ask 30 individuals at random where only 15 return with answers. The questionnaire below consists of questions such as:

- Would you buy a ZEH house?

- Does Location matter?

- How many bedrooms would you prefer?

- How many bathrooms would you prefer?

- What types of appliances would you want in the house?

- How many floors should the house be?

- Do you prefer energy efficient appliances?

- Would you want a garage?

- What type of heating system would you prefer?

- Any extra items you would want a ZEH house to have?

The survey results were then compiled below:

ZEH	LOCATION	BEDROOMS	BATHROOMS	Types of Appliances
No	Yes	3	3	Kitchen Applinces, Bathroom Appilances , Internet
No	Yes	2	1	Sink, Fire Place
Yes	Yes	4	4	Basic Appliances
No	Yes	4	2	Kitchen Appliances, Bathroom Appilances, Washroom Appliance
Yes	Yes	4	5	Fan, Kitchen Appliances, Bathroom Appilances, Washroom Appli
Yes	Yes	5	4	All
Yes	Yes	3	2	All
Yes	Yes	3	2	All
No	Yes	3	1	All
No	Yes	4	2	All
Yes	Yes	3	1	All
No	Yes	4	2	All, Games
No	Yes	3	2	All
Yes	Yes	3	1	All
No	Yes	4	3	All

1 or 2 floors	Energy Effiecnet Applianc	Garage	Type of Heating System	Extra
2	Yes	Yes	Air Circulation	
2	Yes	No	Fire Place	
1	No Prefrance	Yes	Gas and Electric	
2	Yes	No	Gas	Few Windows
2	Yes	Yes	Electic	
2	Yes	Yes	Solar	Hot Tub
2	Yes	Yes	Gas and Passive	
1	Yes	Yes	Passive Solar	Back Up Generator
1	Yes	No	Air Circulation	
2	No Prefrance	No	Gas	
1	Yes	No	Gas and Electric	
2	Yes	Yes	Gas	
2	Yes	No	Solar	
1	Yes	No	Passive Solar	
2	No Prefrance	Yes	Gas	

The survey gave us a good starting point on the direction that we wanted to take our ZEH. We could not expect all of respondents to know about the different types of heating systems therefore our group must be slightly more spectacle about their answers. Overall, the survey gave us a good idea about what the customer wants and a good starting point for our design.

Customer Needs Analysis

When approaching this problem, we wanted to sort out exactly what the customer would find beneficial in a house and see if we can incorporate all of those into our design. However, we realize doesn't actually know what they want, therefore we converted there wants, into needs statements that we could work with.

Customer Wants	Needs Statements
I want a decent size house.	The house is large enough for four people.
I want a finished kitchen.	The kitchen is fully renovated.
I want a laundry room.	The house designates a laundry room
I want the house to be warm.	The house is able to maintain a comfortable room temp.
I need a garage.	The house is able to store an electric car.
I want a ZEH house.	The house is able to create enough energy to sustain itself.

The needs statements are there to help us ensure we are on the right path when trying to build house customers would buy. Therefore, basing our design on statements of customers we can get an idea of what type of houses people want on the market when it comes to ZEH. We realize we can't please everybody and we will get into further detail about playing importance rank on each of these statements to ensure that we hit the most important needs first.

Products Matrix:

Below we set up a products matrix that help give metrics to different needs of the house.

#	Need	Metric	Number of Bedrooms	Number of Bathrooms	Number of Stories	Electric Resistance Heating	Voltaic System	Wall Insulation	Net Energy	Eco Friendly appliances	Number of Garages
1	Large enough for 3 occupants		x	x	x						
2	Complete Kitchen									x	
3	Laundry Room included										
4	House must be heated					x	x	x			
5	Room for storing vehicles										x
6	House must be energy efficent								x	x	

Attaching different metric numbers and labeling which are which helped us to determine what we needed for them. For instance, we were able to see which need was going to affect our energy levels, the overall goal. We then could determine square footage that we would need and all the rooms that needed to be fitted into the house by comparing the amount area would have to work with. With that, the product matrix tool was very influential in keeping al l of our needs in line.

External Research

House #1:

Location (city, state): Asheville, NC (Mountains

House size (floor area in square feet):1900 sq. ft2 home, 1200 sq. ft2 office

Number of floors: 3

Number of occupants: 2

Number of bedrooms: 3 Bed/ 2.5 Bath

Type of heating system: (forced air, hydronic, radiant floor, heat pump, etc. Passive/active solar, Forced and hot water(radiant)

Main heating fuel (electricity, natural gas, wood, oil, etc.): All-electric home

Size of photovoltaic system (kilowatts): 5843 kWh used, 6147 kWh generated

Solar water heater (yes or no): No

R-value of wall insulation: R24

R-value of ceiling insulation: R38

Ventilation air heat recovery (yes or no):Yes

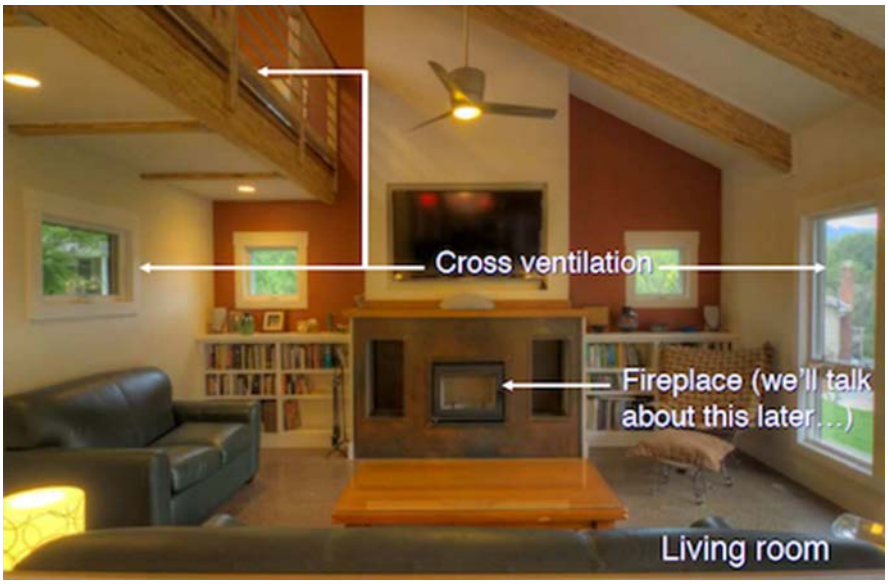
Predicted or measured annual energy use: 6147 kWh of energy generated

Any other pertinent info

- In cold weather, heat pump is biggest energy user by a lot
- Mech. Room isn't big enough
- Toilets hardly flush
- Box Elder Beattles
- Built during terrible recession

- Radiant heat not being an energy saver
- Didn’t need the fireplace
- Success(thermal floors, natural light, rainwater harvesting)

Images:



House #2

Location (city, state): Homestead, Massachusetts

House size: (floor area in square feet)1152 sq. ft2

Number of floors: 1

Number of occupants: 2

Number of bedrooms: 3 beds/ 1 bath

Type of heating system: (forced air, hydronic, radiant floor, heat pump, etc. Solar Energy (Manual J. design heating) Heat pump

Main heating fuel (electricity, natural gas, wood, oil, etc.):Solar, Energy Star

Size of photovoltaic system (kilowatts): 4.94 Kilowatts

Solar water heater (yes or no): yes

R-value of wall insulation: R30

R-value of ceiling insulation: R100

Ventilation air heat recovery (yes or no): Yes

Predicted or measured annual energy use

Energy Used: 1949 KWH

Energy Produced: 4892 KWH

Any other pertinent info:

-super insulated on all sides with fiber glass, triple glazed

- No combustion products in the house

- Low in toxic paint, finishes

House #3:

Location (city, state): Charlotte, VT

House size (floor area in square feet): 2,970 square feet

Number of floors: 2 floors

Number of occupants: 4

Number of bedrooms: 3

Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.
Passive solar heating system, ground-source heat pump

Main heating fuel (electricity, natural gas, wood, oil, etc.): Solar energy

Size of photovoltaic system (kilowatts): 5 kW grid-tied wind turbine

Solar water heater (yes or no): No

R-value of wall insulation: R-21 basement, R-40 above ground walls.

R-value of ceiling insulation: R-58 roof

Ventilation air heat recovery (yes or no): No

Predicted or measured annual energy use

Uses 6092 kWh, creates 6520 kWh (0 net energy)

House #4

Location (city, state): Seattle, WA

House size (floor area in square feet): 1,915 square feet

Number of floors: 2

Number of occupants: 4

Number of bedrooms: 3

Type of heating system (forced air, hydronic, radiant floor, heat pump, etc. Unico UniChiller air-to-water heat pump

Main heating fuel (electricity, natural gas, wood, oil, etc.)Passive Solar Heating

Size of photovoltaic system (kilowatts): 6.4 kW rooftop PV array

Solar water heater (yes or no): Yes; water heated by heat pump

R-value of wall insulation: R-26

R-value of ceiling insulation: R-42

Ventilation air heat recovery (yes or no): Yes

Predicted or measured annual energy use

0 net energy (6,064 kWh used, 7,903 kWh produced)

House #5

Location: (Maynard, Maryland)

House size: (1248 ft2)

Number of floors: (1)

Number of occupants: (4)

Number of bedrooms: (3)

Type of heating system: (Passive solar space system)

Main heating fuel: (Solar heat)

Size of photovoltaic system: (6.15 kw)

Solar water heater: (yes)

R-value of wall insulation: (R-10)

R-value of ceiling insulation: (R-80)

Ventilation air heat recovery: (yes)

Predicted or measured annual energy use: (4000 kw)

Any other pertinent info

(Produces 8000 kw, which leaves a 4000 kw surplus)

Patent Research

The concept of zero energy homes has created a few patents, including filing US 20110253126 A1, created by Huiming Yin and C. Julian Chen. This design calls for elliptic glass panels for the roofing, which would supply heat and energy for the house, and a fluid circulation system that would allow for temperature control. Another patent search found US 20120261091 A1, a low energy building design created by Edmond D. Krecke. This design uses an arrangement of pipes within each other that would manage supply and exhaust air, and an aircraft landing strip that is capable of collecting and storing heat underground. These two designs do not interfere with our model for a zero energy home, as they implement different technologies designed to solve the issues of heating and energy consumption.

Literature Review

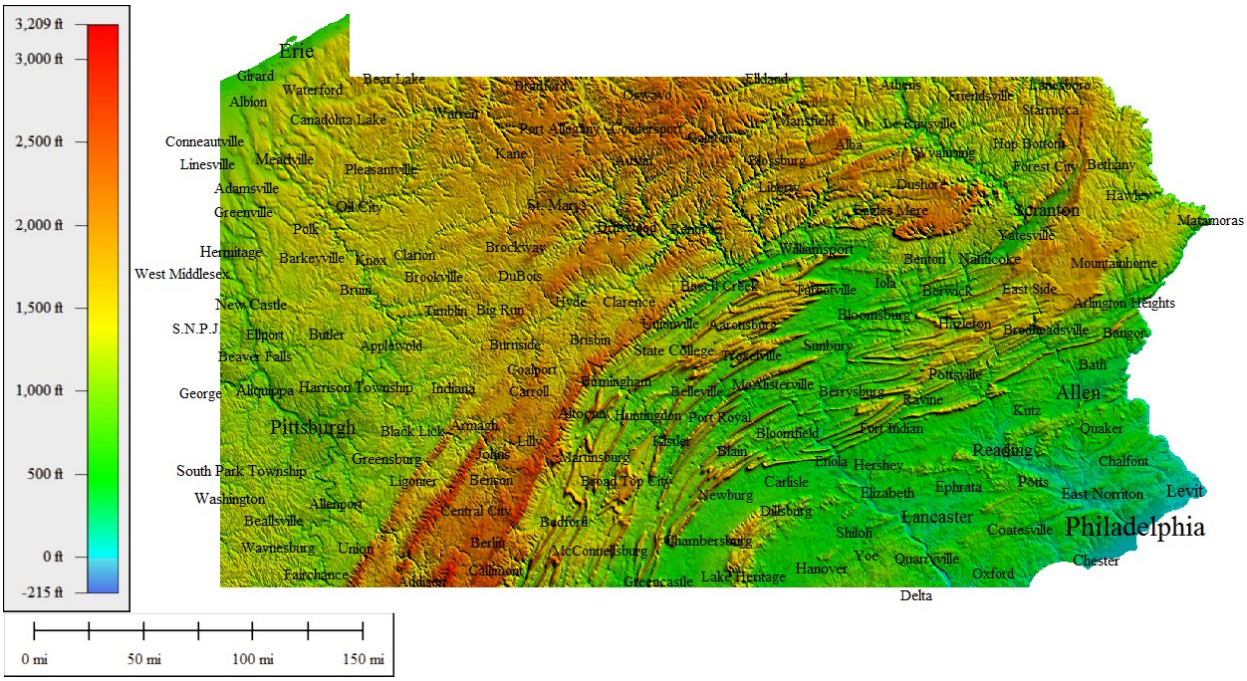
Zero Energy Homes (ZEH) are defined as a home that either produced or secured its own energy source to offset the energy required to efficiently operate the house without leaving an significant impact on the environment. Over the past several years as populations grew and cities expanded there was an increase in energy consumption with residential and commercial buildings consuming 40% of the energy produced. To basis of a ZEH was to provide the energy of the house through renewable resources.

ZEH was first thought to have started around the late 20th century under the direction of German engineers to use the European climate to reduce heating costs in a house, these houses were called passive houses. At first the project started out to make houses low energy cost but eventually the project turned into completely eliminating the energy cost of the houses. These houses used ecofriendly efficient building materials and the solar angles to heat the home. The difference between ZEH and passive houses are the ZEH use alternate sources of energy along a being a passive house and any energy generated by the house is funneled into the grid as excess.

Location Background

Lancaster, Pa:

The picture below is a visual of the elevation levels in Pennsylvania, with a zero energy home needing plenty of sunlight we felt like elevation was extremely important.



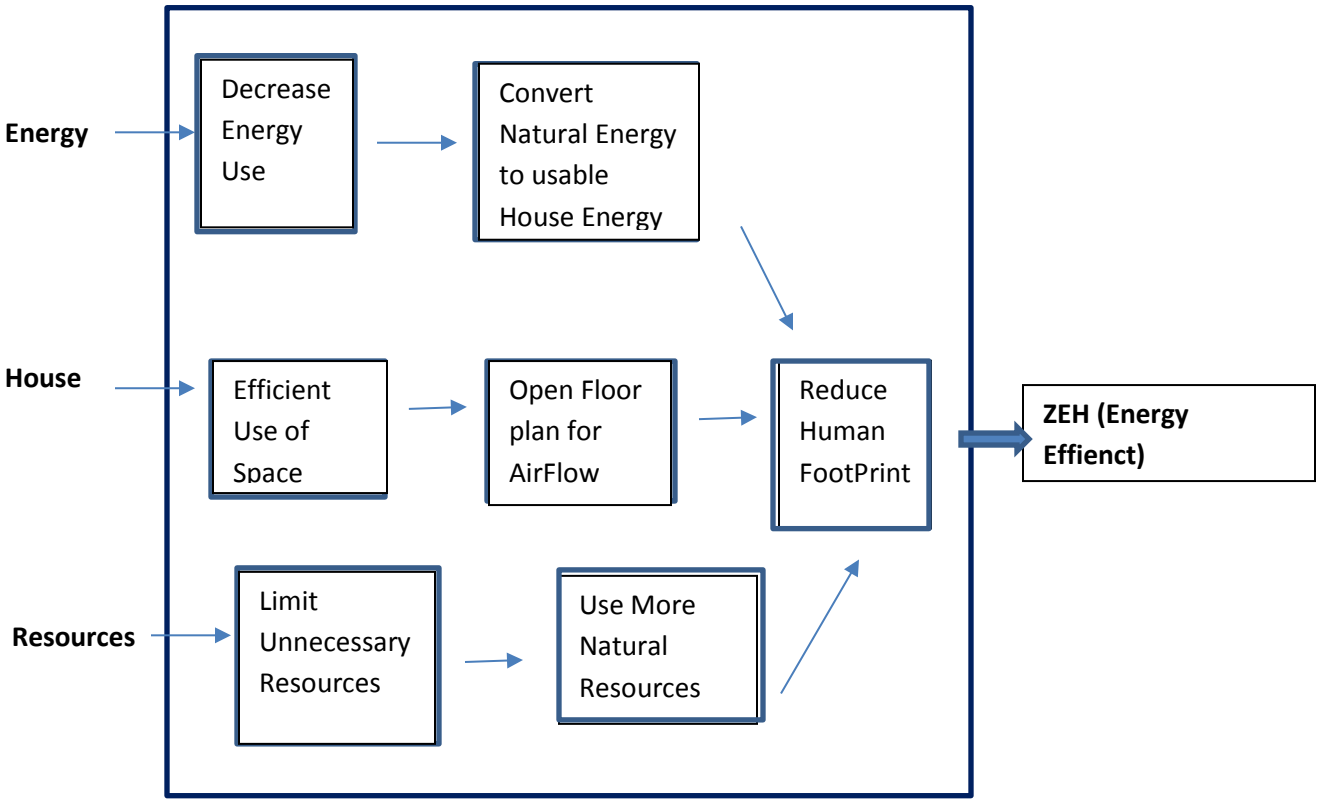
When selecting a setting for the zero energy home design, many factors came into hand. The primary goal for picking a location was to find an environment that had warmer conditions. It was understood that the cities of lower elevation had higher average temperatures, and so the southeast region of Pennsylvania was most appealing. From there, the team decided on Lancaster, Pennsylvania, due to its access to the Susquehanna River. This would allow for a potential hydroelectric energy resource. In addition, by placing the house on top of a hill within this region would allow for more direct sunlight, while still maintaining the benefits of the low altitude.

Concept Generation

Clarify the Problem:

The problem is that we use too much energy. The average footprint per person is too big causing for the faster decay of nonrenewable resources and excess pollution. A direct correlation to this is house sizes. Houses are being built way bigger than they need to. A good way to cut back on energy use would be to only use that the space that you need, not that you want. The bigger the house, the more energy it takes to actually run the house.

Develop a Functional Diagram:



The diagram enables us to get a visual of several angles working together to approach the overall goal of a zero energy house.

Brainstorming

- Build on the side of a hill to maximize the amount of the sun in house
- Put garage under the house to minimize cost of more walls
- Have a master bedroom and a regular bedroom
- Master bedroom gets their own bathroom
- Second bedroom has a communal bathroom
- Sun points towards south of the house
- R40 Walls
- 900 sq. ft.
- Energy Star appliances
- Fireplace
- No fireplace
- White walls
- Slant roof
- Longer roof in backyard
- 1 car garage
- 2 car garage
- Single stairwell
- Hurricane windows
- Tinted windows
- Arched doorways
- White bathroom
- Tile floors
- Wooden floors
- Carpets in family room
- Electric car
- Solar heating on roof
- Flowing floor plan
- Back porch with awning
- Sidewalk to garage

Concept Selection

House:

In order to narrow down the type of Zero Energy House that we want to build, we created a concept selection matrix where (-) were negatives about the idea, (0) meant we were neutral, and (+) meant positives. With this idea we were able to rank these different features of our house and which would be the best one.

House Stories

	1 Story	1.5 Story	2 Story
Pricing	1	0	-1
Space	1	0	-1
Customer Needs	-1	1	1
Heat Conservation	1	0	-1
Ease of Constrution	1	0	-1
Sum	3	1	-3
Comments	Yes	No	No

# of Bedrooms

# of Bedrooms	1	2	3	4	5
	1	1	0	-1	-1
	1	1	0	-1	-1
	-1	-1	1	1	1
	1	1	0	0	-1
	1	1	0	-1	-1
	3	3	1	-2	-3
	Yes	Yes	Combine	No	No

Garage

Garage	Free Standing #1	Free Standing #2	Built in #1	Built in #2	Connected #1	Connected #2
	0	-1	1	1	-1	-1
	0	1	0	1	1	1
	0	1	0	1	0	1
	-1	-1	1	1	0	0
	-1	-1	1	1	0	0
	-2	-1	3	5	0	1
	No	No	Yes	Yes	No	No

Energy:

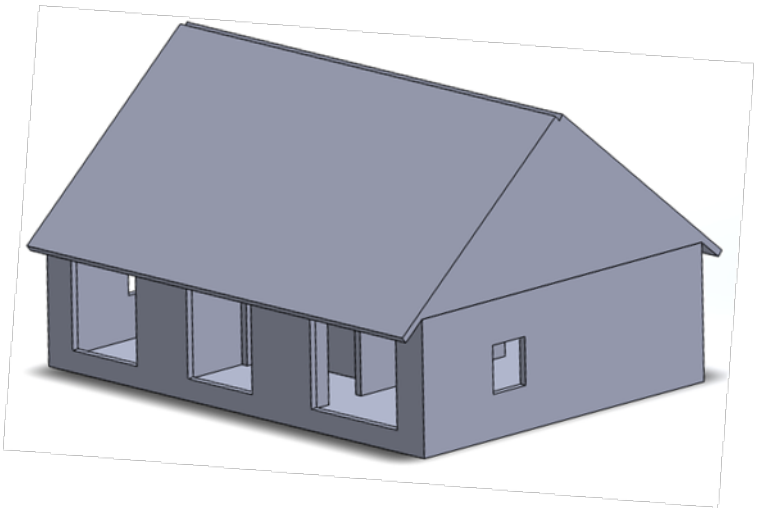
Here we used the same ranking concept, but with energy sources based off of several metrics including price, and aesthetic value. We compared already existing plausible energy sources for our house. They had to be a renewable energy source that was affordable for a house.

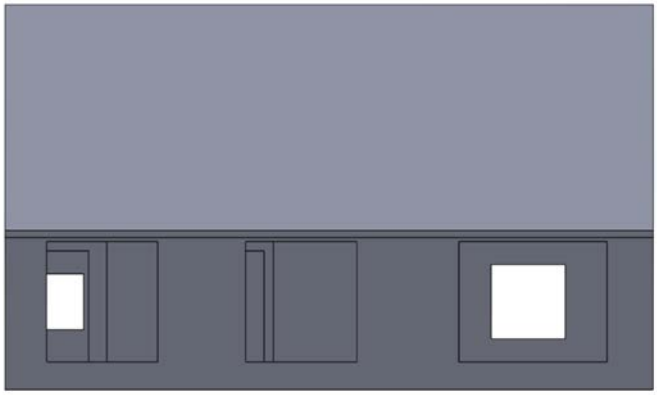
Energy

Concept Selection Energy Source	Solar	Hydro	Wind	Geothermal	BioMass
Ease of Use	0	-1	1	-1	-1
Cost	1	0	0	-1	-1
Ease of Access	1	1	1	-1	-1
Production	1	0	1	-1	-1
Aesthetic	0	0	-1	0	0
Expected Lifespan	-1	-1	-1	0	0
Sum	2	-1	1	-4	-4
Rank	1	3	2	4	4

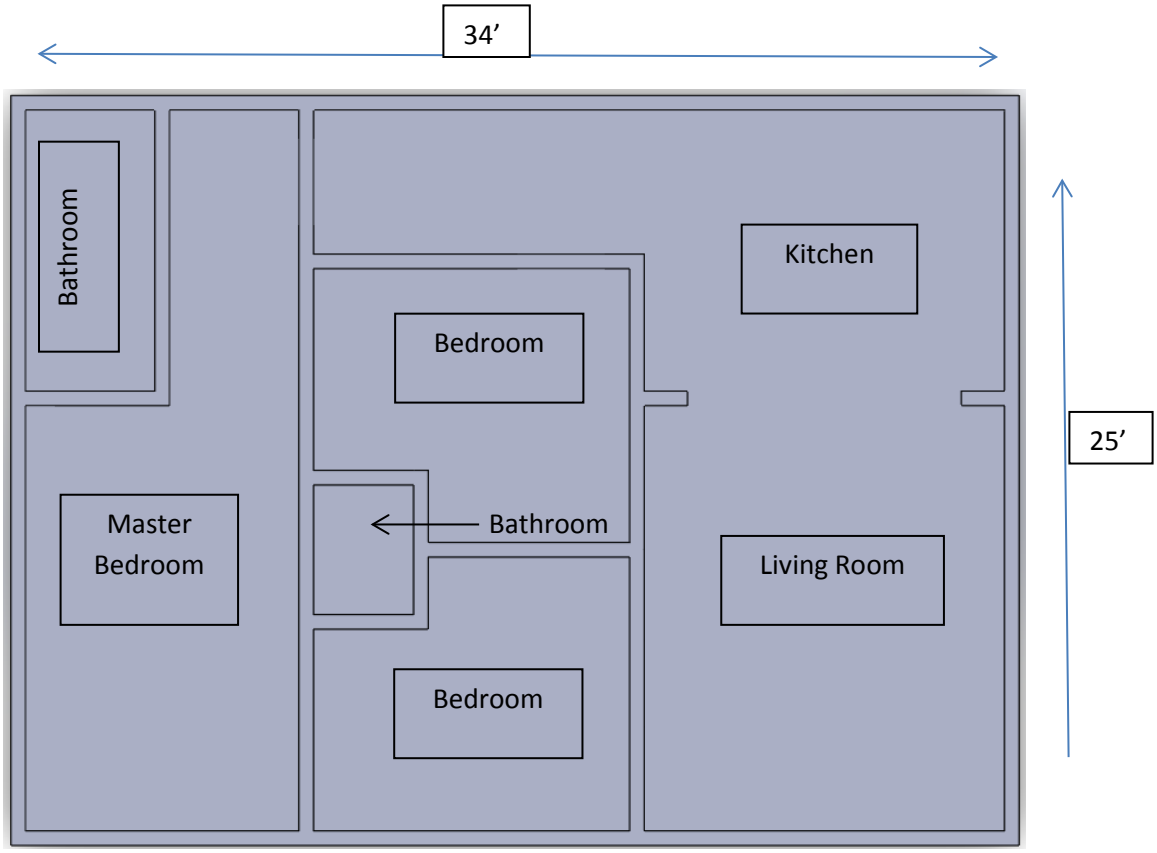
After creating our matrix we scored and ranked our energy sources. We determined that the best source of energy for our house was solar energy. Compared to the other energy sources, solar energy was easy to use, affordable, and easy to procure.

Embodiment Design





This 3D Solidworks representation of our design shows an 850 foot square foot house, with 130 square feet of window along the south side wall. These large windows provide passive heating, by allowing for large amounts of sunlight to flow through the house. Also, the roof of the house contains a 2 foot overhang. Due to the nature of varying solar angles over the year, the roof's design will allow for shade during the summer, while allowing sunlight to enter during the cold months of winter.



The above floor plan shows that the heavily trafficked rooms, such as the living rooms and bedrooms, have direct access to the south windows, meaning they will benefit most from the passive heating system. In addition, the floor plan is relatively open, which will allow for the heat to flow throughout the house, without being blocked by unnecessary walls.

Energy Calculator

Cost Model:

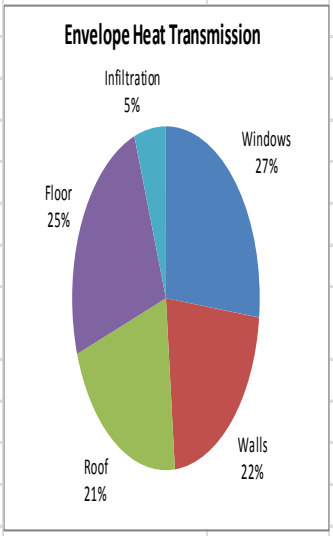
Here are the calculated values for our zero energy home:

Penn State Center for Sustainability — Zero Energy Home Calculator

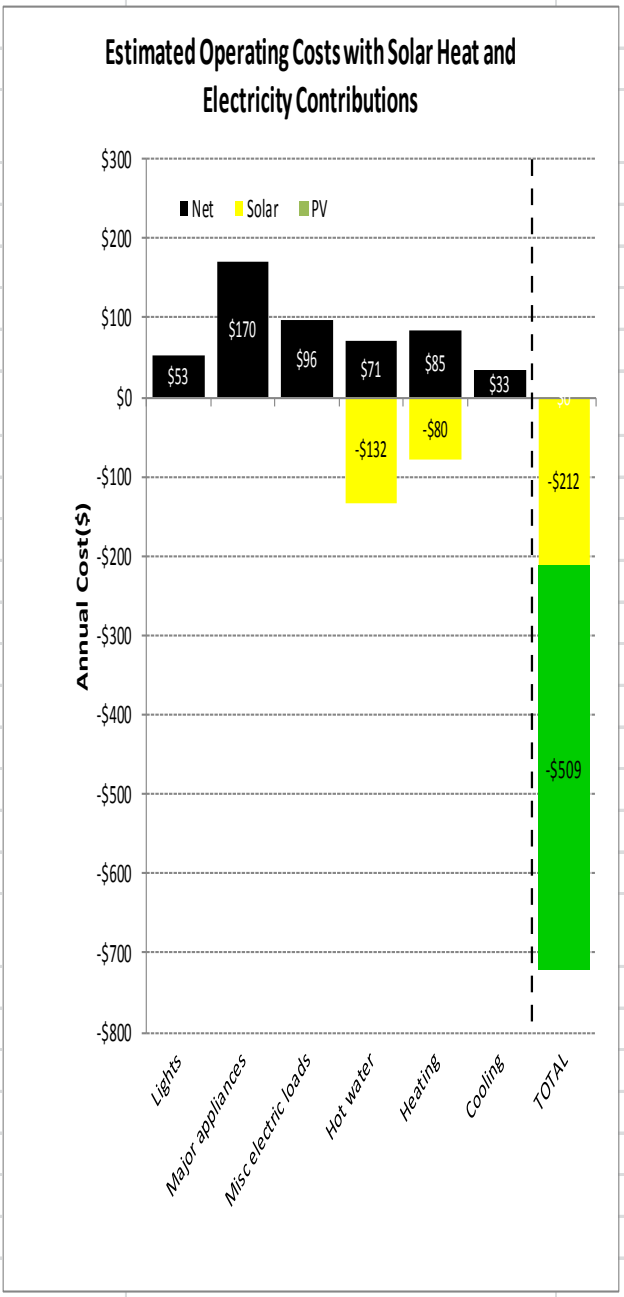
General Info	
Location	Philadelphia
Electricity cost ($/kwh)	0.08
House type	1 story
Conditioned floor area (sq.ft.)	850
Number of bedrooms	3
Envelope Details	
Wall construction	Double 2x4 with 10" foam
Ceiling Insulation	R40
Window type	Triple low-e
Upper floor ceiling area (sq.ft.)	850
North wall area (gross) (sq.ft.)	306
East wall area (sq.ft.)	225
South wall area (sq.ft.)	306
West wall area (sq.ft.)	225
North window area (sq.ft.)	25
East window area (sq.ft.)	5
South window area (sq.ft.)	130
West window area (sq.ft.)	10
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Best
Clothes Washer	Best
Dishwasher	Best
Small Appliance Input	
Extras	
Garage	g. Built In 2 car
Hot Tub	a. None
Pool	a. None

Heating & Cooling	
Type of heating & cooling system	Electric resistance
Solar Technologies	
Size of PV system (kw)	4.74
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	None
Thermostat setback	Some
Heat thermostat setting (F)	70
Cool thermostat setting (F)	76

Results



Base House Cost	$	109,657
PV Cost	$	23,693
Upgrade Costs	$	6,643
Total House Cost	$	139,993



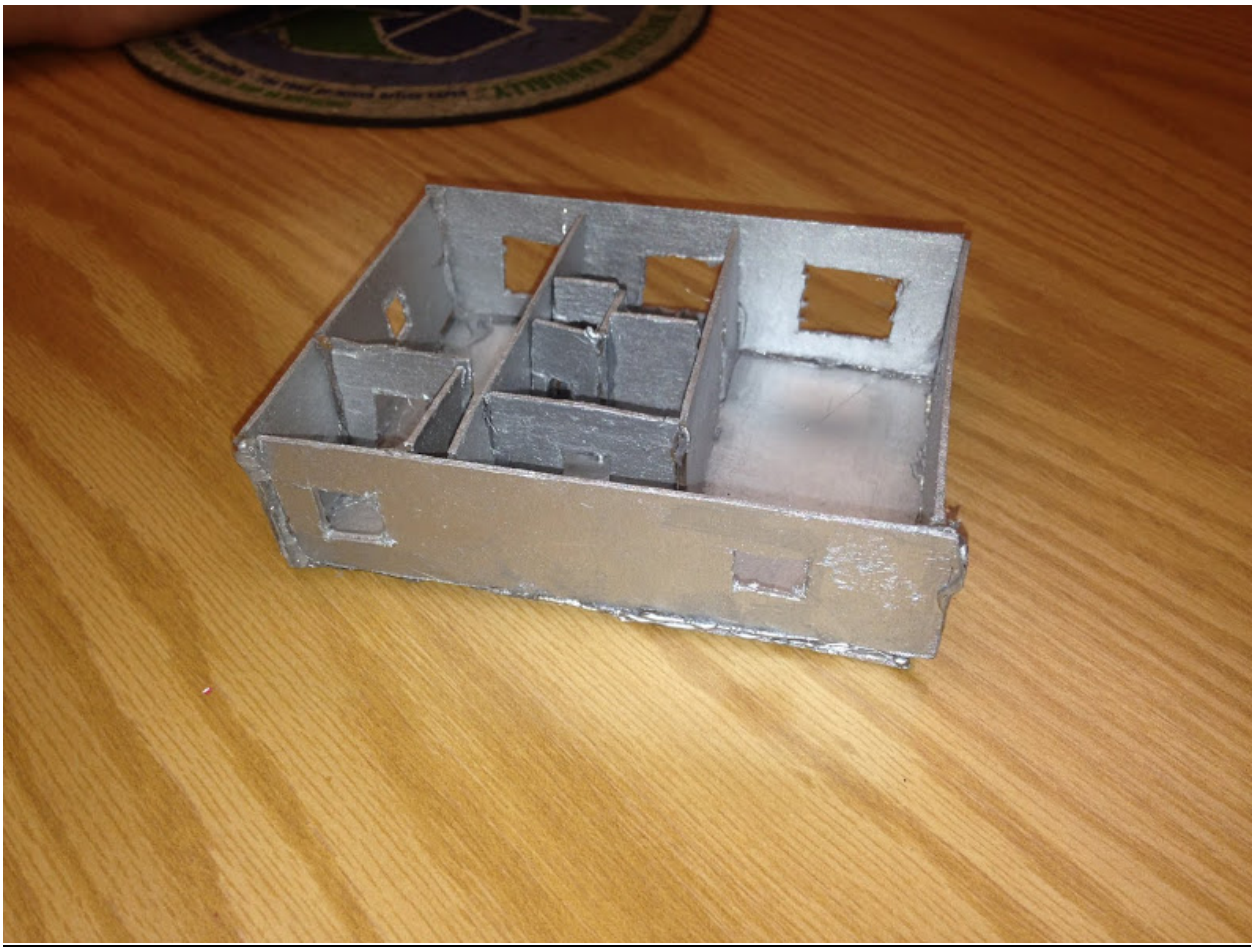
When initially approaching the cost model, we had the restraint of keeping the house under $140,000. That quickly forced us to change our initial ideas and find ways to only keep features that seemed like necessities. We came in thinking we could build a 1500 sq. ft. house and decided that in order to keep it zero energy, it had to be much smaller. There was a direct correlation in the cost model between size of house and total cost. Therefore, we agreed upon the build of a 850 sq. ft. house that we felt could still be livable. Other positive house features consist of the window sizes. The south facing window has the most open window area to allow for maximum sunlight. This area will allow for greater sun absorption and energy throughout the day.

When it came to appliances, we chose to go with the “best” in everything. The best is to be considered energy star appliances and other items that would minimize the energy the house had to use. Adding the two car garage separates us from some groups. The ability to be cost conscious and still find money to add a two car garage shows that we were able to spend our money wisely along with having some extra features.

Overall, the cost model displays a total house cost of $139,939. We were able to stay within the budget for the house along with getting the best appliances.

Final Design Description

We designed our house to maximize our budget and energy sources. The house we wanted had to have an open floor plan, meet the customer need and maximize the use of passive solar heating. The customer requirements for our house had to have three bedrooms, two bathrooms and basic necessities such as a kitchen and living room. Our house had a total floor area of 850th square feet. We wanted to maximize the sun's rays for heating so we designed our three largest windows to face the south side. Then we design our three largest rooms to be assigned a window each. Those three large rooms are the living room, one of the smaller bedrooms, and the master bedroom. After designing these three rooms we designed the rest of the house around them. We used all available space we had to maximize space efficiency.



Conclusion

Using a step by step engineering process we managed to design a zero energy home within our budget of $140,000. Through our research we managed to gather information on zero energy homes, the impact of humans on our environment and techniques to reduce our carbon footprint. Using a several matrixes we generated and selected concepts and ideas through an efficient and quick process. After gathering our ideas we design a house accordingly and we believe we designed a home which we believed to be the most efficient design. In conclusion our team designed a comfortable zero energy home for a family of four. We believe our design met and exceed the customer's needs and wants. The layout of the house also maximized the use of the sun's rays thus the dependence on electric heating sources are reduced. Overall as a team we learned a lot about the engineering design process and also about zero energy houses. The numerous steps that we had to take as a group showed us the difficulty and time consuming process that an engineer faces. We also learned about zero energy houses and the problem posed by humans on our environment. This process open our eyes to the problems faced by engineers and look forward to the day we could take part in that process.

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