Zero Energy Home

Engineering Design 100 Section 20
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Introduction

In this modern age, technological needs are constantly evolving. Technological advancements made in the past few decades have greatly improved the quality of life for people around the world. However, human development, energy resource depletion, pollution, and an increasing global population is impacting our global environment. The ideas of renewable energy, zero-emissions, and sustainability have become hot topics for Engineers today. The average American household is very energy inefficient and does not contribute to sustainability. Recent developments in renewable energy have allowed Engineers to design remarkable homes that are completely energy efficient. These homes produce as much energy as they consume using clean energy sources resulting in a home that has a net zero usage of energy. The zero energy home is the next big step for Engineers towards global sustainability.

Executive Summary

Our first design project has required our team to develop an efficient, comfortable, and self-sustaining zero energy home. After identifying our customer needs and our project constraints, we developed a plan for an effective zero energy home. This home must produce, at least, as many kilowatt hours per year as the amount of energy that is consumed. With a 200,000 dollar budget, we have developed a plan for a 1,250 square foot home that comfortably accommodates a family of four located in Cochranville, Pennsylvania. Through brainstorming, external research, and our concept generation process, we chose to implement a 4.5 kW PV solar system, a geothermal heat pump, and a passive-solar house design in order to reduce energy usage and meet the house's energy demand of 5,900 kilowatt hours per year.

Mission Statement

We must design a self-sustaining and comfortable home for a family of four in Pennsylvania that has a net energy usage of zero kilowatt hours per year within a 200,000 dollar budget.

Customer Needs Analysis

Need-Metric Matrix	Metrics	Square footage	House orientation	Energy production	Affordability	Interior design
Customer Needs		1	2	3	4	5
Within budget ($200,000)	1	x		x	x	x
Accommodates a family of four	2	x				x
Located in Pennsylvania	3		x			
Uses renewable energy technology	4			x		
Comfortable living enviroment	5	x				x
Self-sufficient energy usage	6		x	x		
Operates under climate restrictions of location	7		x	x		

Meeting the customer's needs is essential for our design process. Based on our customer's needs, we must design a comfortable home for a family of four that is self-sufficient, uses renewable sources of energy, is located in Southeastern Pennsylvania, and has a net-zero energy consumption level all within a 200,000 dollar budget. By keeping all of these needs in mind during our design, we have developed a house that accommodates this family of four's requirements.

Target Specifications

Target Specifications Based on Needs				
metric #	Needs#	Metric	Imp	Units
1	1	Within $200,000 budget	5	Dollars ($)
2	4,6	Has a at least a zero net energy usage	5	kWh
3	2,5	At least 1000 square feet of living space	3	ft^2
4	3,7	Located in Pennsylvania	5	n/a
5	7	Home design optimizes sustainablilty	4	ft^2

Concept Generation

In order to generate solutions we must first fully grasp the most challenging issue at hand: the customer requires a net zero energy home. We must break down this request to its constituents and clarify the problem. Achieving net zero energy is simply a matter of reducing energy used, reducing energy lost, and producing our own energy on site. With these three goals in mind, we can approach external research with a vision.

We begin our external research by reviewing the general construction process and evaluating how standard building practices and materials can be optimized to suit our problems that require solution.

Insulation : This is a material intended to resist the conductive transfer of heat from warmer to cooler areas. Used in homes, insulation supports moderate dwelling temperatures. Insulation's effectiveness is rated by terms of R-value, with effectiveness varied due to material type and its thickness. The higher the R-value the greater the resistance to conductive transfer of energy. There are many different kinds of insulation suitable for different requirements in terms of R-value and locations in the home. (http://energy.gov/energysaver/articles/insulation)

Windows : The primary concern with windows is that they create large potential for energy transfer. Windows can transfer energy conductively, convectively, and radiantly. In order to combat conductive transfer and maximize radiant gain windows have varied designs. Preferable windows would be those with multiple panes to minimize the U-factor (conductive transmission factor) and maximize Solar heat gain coefficient (SHGC) to meet the needs of a passive solar home. (http://energy.gov/energysaver/articles/energy-performance-ratings-windows-doors-and-skylights)

Appliances and Lighting : Roughly 30% of a home's energy use is appliances and lighting. Energy Star certified appliances and lights are designed to increase efficiency, reducing annual energy consumption. LED (light emitting diode) and CFL (compact fluorescent lamp) bulbs use 25% as much energy and last up 25 times longer than traditional incandescent bulbs. LED bulbs are generally more expensive than CFL but are more efficient and last longer. CFLs are more cost effective in areas that require long periods of light. Analysis for each area of the home is require to see which technology is more appropriate. (http://energy.gov/articles/resolve-save-energy-year) (http://energy.gov/energysaver/articles/fluorescent-lighting)

Standard practice calls for Benchmarking, the process of evaluating competitor's successful projects for concepts and procedures. Homes benchmarked are listed below followed by some concepts that will be adapted to our own home.

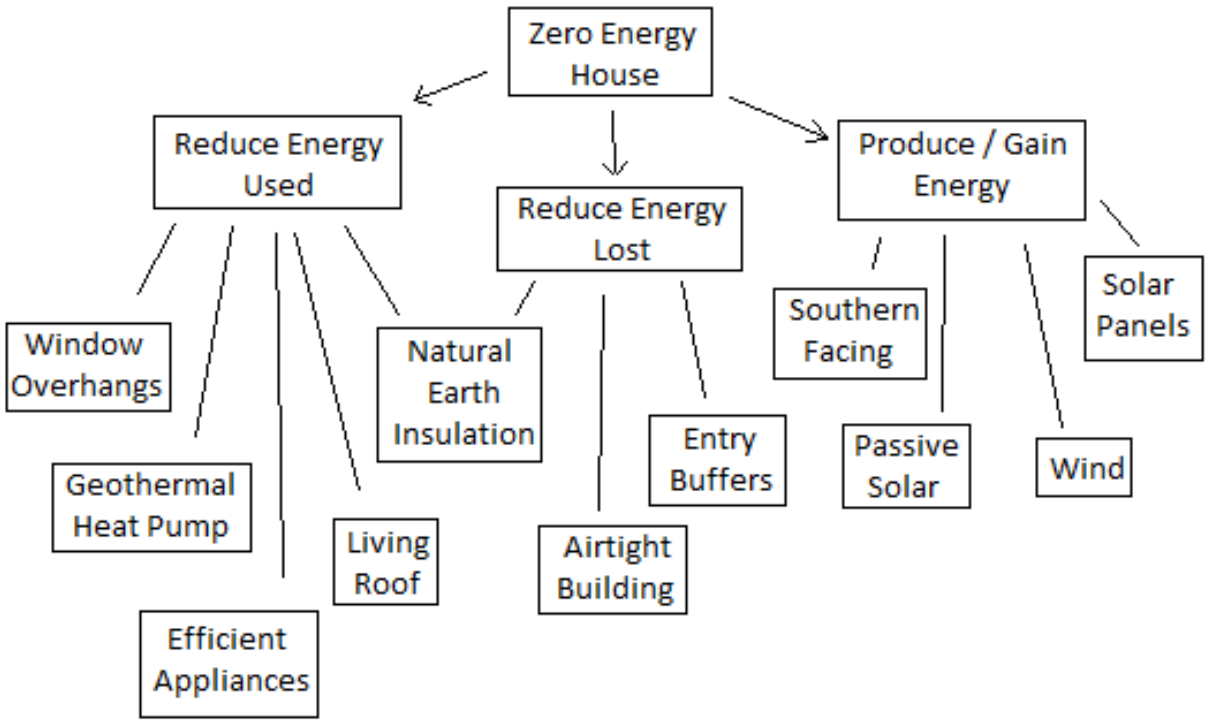
- http://www.builditsolar.com/Projects/SolarHomes/MAZeroEnergy/MAZeroEnergy.htm
- http://www.zerohomes.org/craftsman-net-zero-energy-home/
- http://www.greenbuildingadvisor.com/homes/net-zero-energy-house-125-square-foot

    - Windows utilized had low u-factor and a high Solar Heat Gain Coefficient.
    - Overhangs designed to block out high angle summer sun, but allow low angle winter sun to enter through south facing windows.
    - South side window surface area roughly 11% of total square footage of house.
    - Photovoltaic solar panels to produce renewable energy locally.
    - High R-value insulation in walls, ceiling, and between floor and unfinished basement.
    - Geothermal heat pump used for HVAC purposes.
    - CFL and LED lighting and energy star appliances used to reduce energy demand.

Customer needs include a home that is located someplace in Pennsylvania. It is in our best interest to find a location that is conducive to the build process and also to local renewable energy production. The National Renewable Energy Lab, a research lab funded by the Department of Energy, provides the Solar Prospector (http://maps.nrel.gov/prospector) application. The Solar Prospector is a graphical representation of solar energy distribution across the United States and provides annual energy output of the sun based on location. From this resource we found that southeastern Pennsylvania provides relatively prime solar energy. Being a lower latitude and relatively lower elevation results in warmer winters and less energy used. For these reasons we have selected a small town in southeastern Pennsylvania called Cochranville.

In conjunction with external research, the team searched internally. Through means of brainstorming, the team generated many solutions and concepts. These ideas may have been inspired by past experience and education, or may have been entirely new solutions. During the stage of concept generation it was vital to get as many ideas on the table as possible and to not turn away any ideas. Our external and internal research culminates to the flowchart seen below.

Concept Generation



The concepts above may or may not be feasible, so a process of concept selection is necessary.

Concept Selection

In order to narrow down our options we created a selection matrix and screened potential concepts. Concepts are rated and compared relative to an industry standard. In this case we considered our concepts versus successful zero emission homes benchmarked and what technologies they utilized.

Selection Matrix Renewable Energies

	Solar Power	Passive Solar	Wind Power
Affordable	0	+	-
Significant Energy Generation	+	0	-
Feasible in Pennsylvania	0	+	-
Scale to Residential	+	+	-
Sum +'s	2	3	0
Sum 0's	2	1	0
Sum -'s	0	0	3
Net Score	4	4	-3
Use?	Yes	Yes	No

Wind power in Pennsylvania is simply not feasible. Annually Pennsylvania is not windy enough, the cost per kWh makes the technology a poor decision despite being renewable.

Selection Matrix Energy Use and Loss Reduction Concepts

	Affordable	Effectiveness	Easily Incorporated	Commercially Supported	Net Score	Use?
Two stories	+	0	+	0	2	yes
Window Overhangs	+	+	+	0	3	yes
Entrance Buffer Zones	-	0	0	-	-2	no
Geothermal Heatpumps	0	+	+	+	3	yes
Airtight Insulation	-	0	-	-	-3	no
Natural Earth Insulation	-	0	-	-	-3	no
Southern Facing	+	+	0	+	3	yes
Living Roof	-	+	-	-	-2	no
Efficient Appliances	0	+	+	+	3	yes
Drain Water Heat Recovery	+	+	0	-	-1	no

Some concepts were too expensive or creative to easily be incorporated in an affordable home. Realistic concepts survived the screening and continued on to be utilized.

Final Design

Our final design is a culmination of the design process and a product of our research and concept selection. From benchmarking and research into the renewable energy potential of Pennsylvania, we know that solar power is the most feasible option for local energy production. The building itself required appropriate decisions such as high R-value insulation in vital areas including the walls, attic, and floor above basement or in contact with foundation. We selected windows with a low U-factor and high SHGC to encourage passive solar gains and quell loss due to conductive transfer through the window. The R-value, U-factor, and SHGC values were selected based on what the budget would allow, trying our best to approach ideal values. In order to further strengthen passive solar potential the house is two stories and has many windows on the southern facing side. Our ratio of window surface area to home square footage is roughly 11%, a rule of thumb that helps to cut heating costs during the winter months.

Appliances are energy star rated for efficiency purposes. It should be noted that customer's habits should be in the interest of conservation. That is, the customer must make decisions that reduce energy used, such as turning off unnecessary lights and reserving usage of appliances to only times of necessity. The home's heating, cooling, and ventilation system is provided by a geothermal heat pump. The geothermal heat pump cuts energy costs significantly by utilizing renewable geothermal energy taken from the ground. In order to cover projected energy usage, 5700 kWh annually, a 4.5 kW solar array will be installed on the southern facing roof of the home. According to the PV Watts Calculator (http://pvwatts.nrel.gov/), a 4.5 kW sized array in Cochranville, PA, will provide enough energy annually to provide a net zero usage. Cochranville was selected because of its potential for solar power based on the NREL solar prospector application.

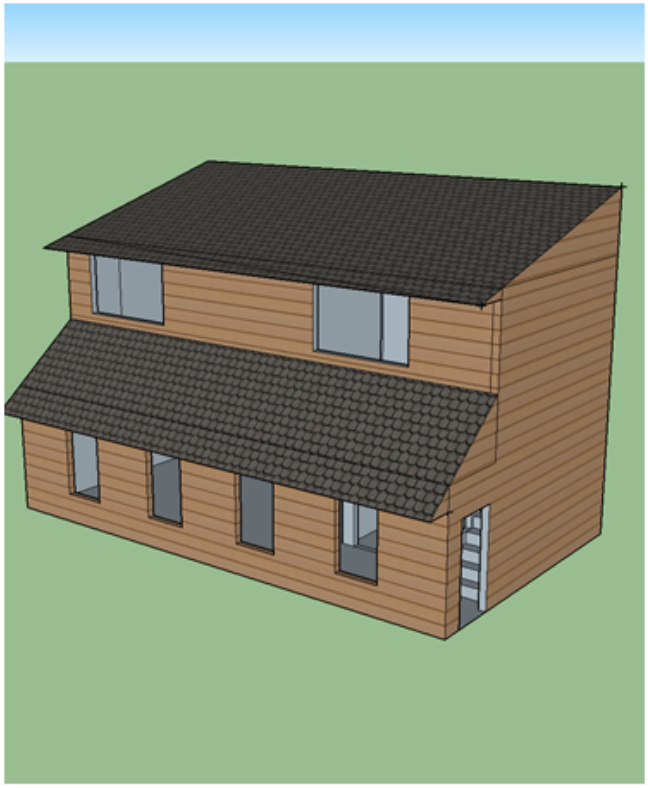
Appliances are projected to require 3,300 kWh annually, and in conjunction with around 1,400 kWh annually for HVAC and water heating, we're looking at roughly 5,700 kWh annual energy consumed by the home. It is necessary to ballpark this figure as energy usage can fluctuate based on habits of inhabitants and the weather outdoors. The solar array size was chosen with deviation from the standard in mind.

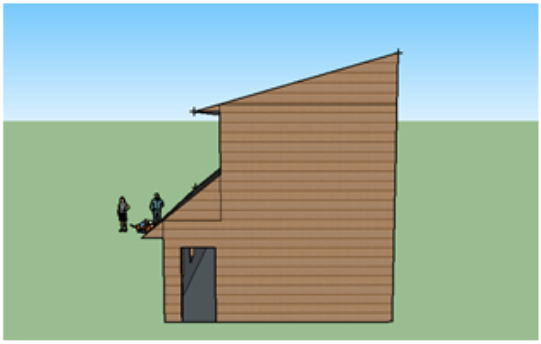
Please see the appendix to see the full appliance listing.

Construction Cost		
Item	**Cost Per Square Foot**	**Cost**
Cost of House	$100.00	$149,375
Free Standing Carport		$995
PV Array (4.5 kWh)		$15,000
Geothermal Heat Pump		$12,000
Appliances		$10,000
Triple Pane Windows	$36.30	$4,356
Ceiling Loose Fill Insulation R60	$2.04	$1,428
Wall Fiberglass Insulation R21	$0.68	$1,176
Wall Sheathing R7	$1.08	$2,246
Floor Insulation R21	$0.68	$476
		Total: $197,052

Final Specifications		
Metric	**Value**	**Units**
Total square footage (house)	1250	ft^2
Total square footage (windows)	120	ft^2
Total square footage (roof)	625	ft^2
SHGC of windows	0.6	n/a
U-factor of windows	0.18	n/a
PV energy production	6100	kWh/yr
PV array size	300	ft^2
Geothermal heat pump BTUs	23,000	BTU
Number of bedrooms	2	n/a
Number of bathrooms	2	n/a
Location	Cochranville	n/a
Number of stories	2	n/a

Home Design

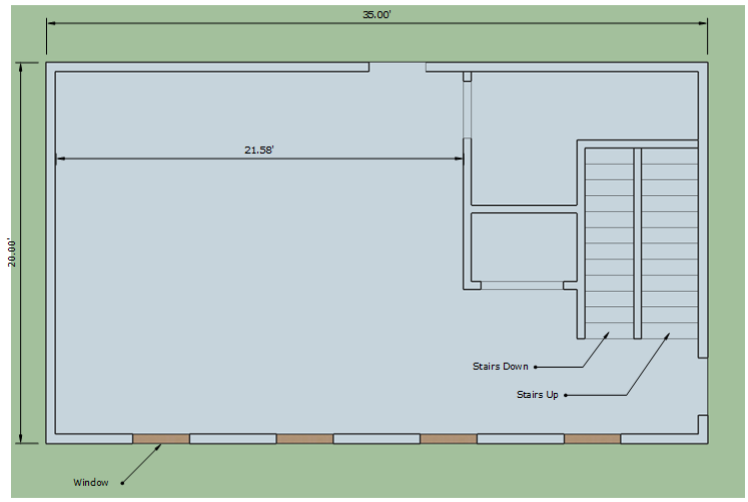


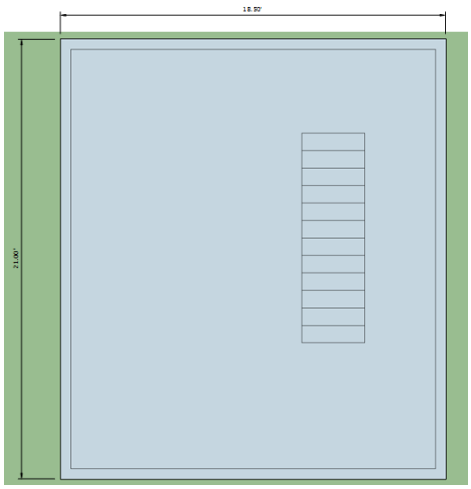


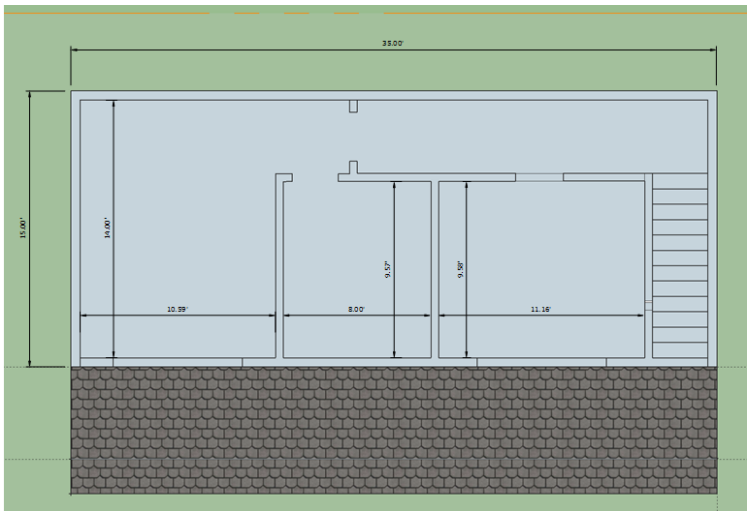
Our final home design considers certain factors and is designed in support of being a zero energy home. Only the southern facing walls of the home sport windows, a decision with passive solar in mind. Windows on the east and west ends of the home let in sunlight unchecked, unlike the southern facing windows which have overhangs designed to block out high angle summer sunlight. North facing windows let in little light, no solar thermal energy, and serve as conduits for conductive transfer of energy into or from the home.

The upper roof supports the 300 ft^2 Photovoltaic Array and is designed with an angle of 40 degrees. Matching the roof angle to the latitude of the home's location is a rule of thumb in the interest of maximum sun exposure for the panels. The roof is also oriented toward the south.

The home has a small unfinished basement in support of utilities such as hot water and HVAC. The unfinished basement is insulated from the rest of the home.







The first floor has a large open area of 20’ x 20’ which supports the kitchen, dining area, and living area. The first floor also has a full bathroom, coat closet, and stairs to the second floor and basement. There is a backdoor on the northern side of the home.

The second floor has a master bedroom, full master bathroom, and second bedroom to be shared by the children. Customer needs called for a small home in support of the budget and said nothing explicitly about the two children and their living quarters. Our design has space saving in mind, so the children will share a bedroom.

The small basement is unfinished and houses the utilities of the home. There is enough room for the geothermal heat pump, water heater, and also some storage area.

Conclusion

Our team has developed a self-sustaining zero energy home located in Cochranville, Pennsylvania that comfortably accommodates a family of four. We have confidently approached our total cost budget of $200,000 with a total overall cost of $197,052. The family can live comfortably with our 2-story, 1,250 square foot home design. We have maximized our energy savings by using energy efficient appliances, a passive solar house design, and a geothermal heat pump for hot water and the HVAC system. Our total number of kWh consumed annually comes to 5700 kWh/yr. With 300 square feet of a 4.5 kW PV array system, we can generate up to 6100 kWh/yr, thus covering our yearly energy requirement. After completing this project, all of us have developed a strong understanding of the Engineering Design Process and have experienced some of the workload that comes with the Engineering process through hard work, practice, research and trial-and-error.

Appendix

Appliances...

Item	Model	Number of Items	Energy Usage (kWh/yr)	Cost ($)
Ceiling Fan		2	87	200
HVAC Control Panel		1	20.3	
Circuit Breaker		2	12.4	60
CO Detector		1	17.5	30
Smoke Detector		3	10.5	60
Doorbell		1	44	50
LCD TV		1	215.5	1,500
Blueray Player		1	71.3	60
Speaker System		1	24.4	200
Subwoofer		1	68.3	250
Cable Box		1	153	
Microwave		1	135.2	160
Coffee Maker		1	99.3	40
Toaster		1	43.7	55
Blender		1	7	50
Crock pot		1	16	50
Laptop Plugin		1	47	700
Desktop w/ Speakers		1	143.9	765
PC Monitor		1	119.8	150
Printer		1	40	150
DSL/ Cable Modern		1	17.6	80
Hair Dryer		1	0.7	50
Electric Shaver		1	10.5	70
Vacuum Cleaner		1	32	200
Cell Phone Charger		2	154.8	
Portable Fan		1	11.4	40
Power Strip		1	3.8	20
Iron		1	54	45
Washing Machine	Kenmore 417.717151	1	175	720
Dryer	Whirlpool Duet WED	1	610	1,120
Refridgerator	Summit-FFBF101ss w/ Icemaker	1	412	1,570
Stove	Kenmore 2.6 kW 24" Wall Oven	1	270.4	1,150
LED 60 W Light Bulb	9.5 Watt	8	108.1	80
LED 100 W Outdoor Light	18 Watt	2	17.14	42
CFL 60 W Light Bulb		8	19	16
Total MEL load			3,272.54	9,733

References

House of Quality Template:
http://www.qfdonline.com/templates/qfd-and-house-of-quality-templates/

External Research:
http://energy.gov/energysaver/articles/insulation
http://energy.gov/energysaver/articles/energy-performance-ratings-windows-doors-and-skylights
http://energy.gov/articles/resolve-save-energy-year
http://energy.gov/energysaver/articles/fluorescent-lighting
http://maps.nrel.gov/prospector
http://pvwatts.nrel.gov/

Benchmarking:
http://www.builditsolar.com/Projects/SolarHomes/MAZeroEnergy/MAZeroEnergy.htm
http://www.zerohomes.org/craftsman-net-zero-energy-home/
http://www.greenbuildingadvisor.com/homes/net-zero-energy-house-125-square-foot

House Model and Floor Plan:
http://www.sketchup.com/