The Pennsylvania State Universtiy

Zero Energy Home

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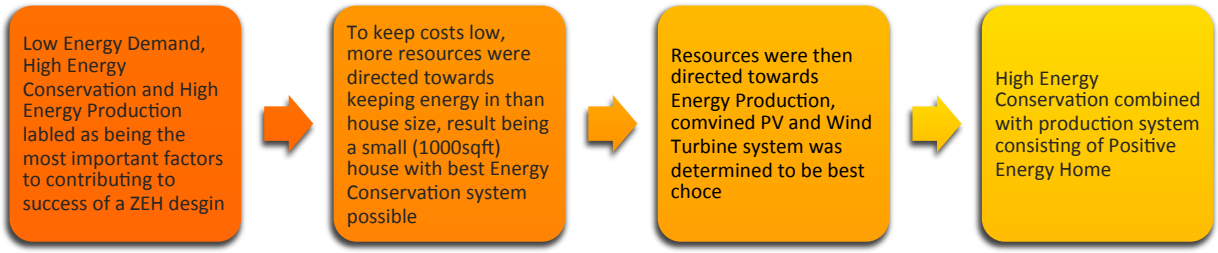
Zero Energy Home Abstract

Our major design goal was to create a relatively low cost Zero Energy Home that still retains all of the comfort and protection of any modern Pittsburgh home today. The key to fulfilling this design goal was attacking the two main problems with Zero Energy Homes, which are Energy Production and Energy Conservation. Utilizing a small and open-floored house design, the best insulation system we could find, and high efficiency appliances and low-flow water fixtures we were able to create a housing system with a very high rate of Energy Conservation and a very low level of Energy Demand. By taking advantage of the relatively high winds and above average sun conditions we were able to design a system consisting of a wind turbine and a Photovoltaic System we were able to produce much more energy than we required, and as result ended up surpassing our goal and designing a Positive Energy Home for a relatively low final cost of about $170,000.



This is a quick summary of the design process that we went through showing how we applied our resources and (self-imposed) budget to come up with the best possible design at the best possible price.

Summary Table of Design Elements

Location	Pittsburg, PA
House Size	1018 square feet
Number of Floors	1 (plus half-finished basement)
Number of Occupants	4
Number of Bedrooms	2
Type of Heating System	Geothermal Heat Pump
Size of Photovoltaic System	3 kW
Size of Wind Turbine System	4.5 kW
Solar water Heater	Yes
R-value of Wall Insulation	R19
R-value of Ceiling Insulation	R60
Type of Windows	Triple low-e
Ventilation air heat recovery	Yes
Total Cost	$170,426

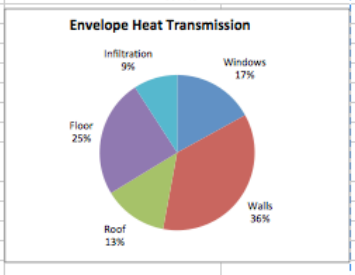
ZEH Calculator and HOMER Data

Penn State Center for Sustainability

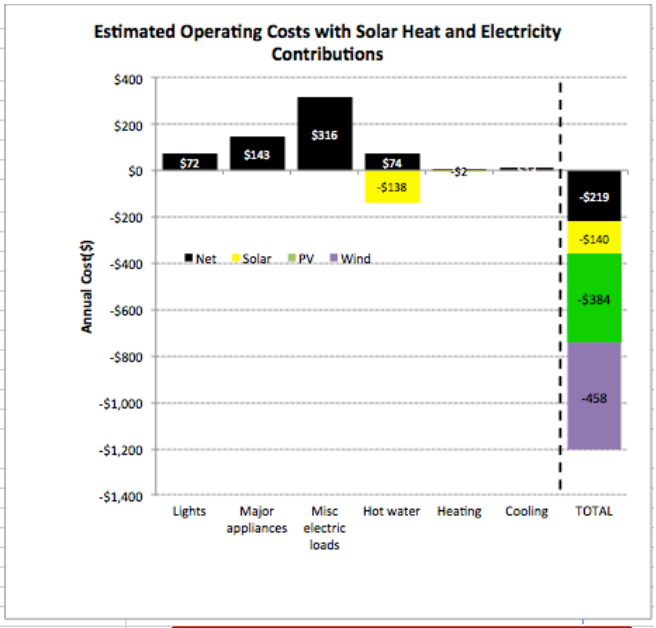
General Info	
Location	Pittsburgh
Electricity cost ($/kwh)	0.1
House type	1.5 story
Conditioned floor area (sq.ft.)	1018
Number of bedrooms	2
Envelope Details	
Wall construction	Double 2x4 with 10" foam
Ceiling Insulation	R60
Window type	Triple low-e
Upper floor ceiling area (sq.ft.)	600
North wall area (gross) (sq.ft.)	282.74
East wall area (sq.ft.)	282.74
South wall area (sq.ft.)	282.74
West wall area (sq.ft.)	282.74
North window area (sq.ft.)	19
East window area (sq.ft.)	19
South window area (sq.ft.)	30
West window area (sq.ft.)	9
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Best
Clothes Washer	Best
Dishwasher	Best
Small Appliance Input	
Extras	
Garage	a. None
Hot Tub	a. None
Pool	a. None
Energy Production	
Wind Turbine Output	**11114 kWh/yr**
PV System Power Output	**3841 kWh/yr**
Total Electric Demand	**6230 kWh/yr**
Net Electric	**(-7229kWh/yr)**

Zero Energy Home Calculator

Heating & Cooling	
Type of heating & cooling system	Electric geothermal heat pump
Solar Technologies	
Size of PV system (kw)	3.00
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	A lot
Thermostat setback	A lot
Heat thermostat setting (F)	65
Cool thermostat setting (F)	75
Results	



Base House Cost	$	125,160
PV Cost	$	15,000
Upgrade Costs	$	22,562
Wind Turbine Cost	$	5,000.00
House Cost	$	167,721
Total House Cost (w/ Appl.)	$	174,821



Cost Envelope for entire house project; note the choice of best possible appliances, windows, and insulation (Discuss in-depth later)

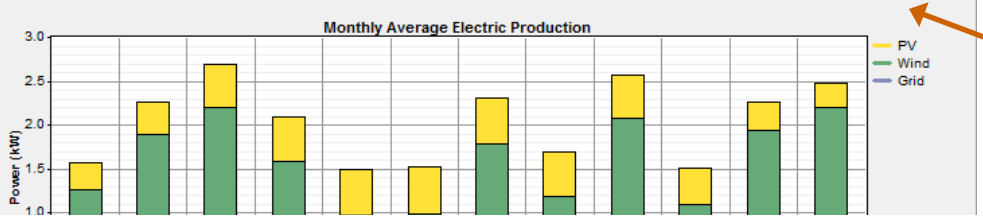
System Architecture: 1,000 kW Grid, 3 kW PV, 1 Generic 3kW, 6 kW Inverter, 6 kW Rectifier

Cost Summary | Cash Flow | Electrical | PV | G3 | Converter | Grid | Emissions | Hourly Data

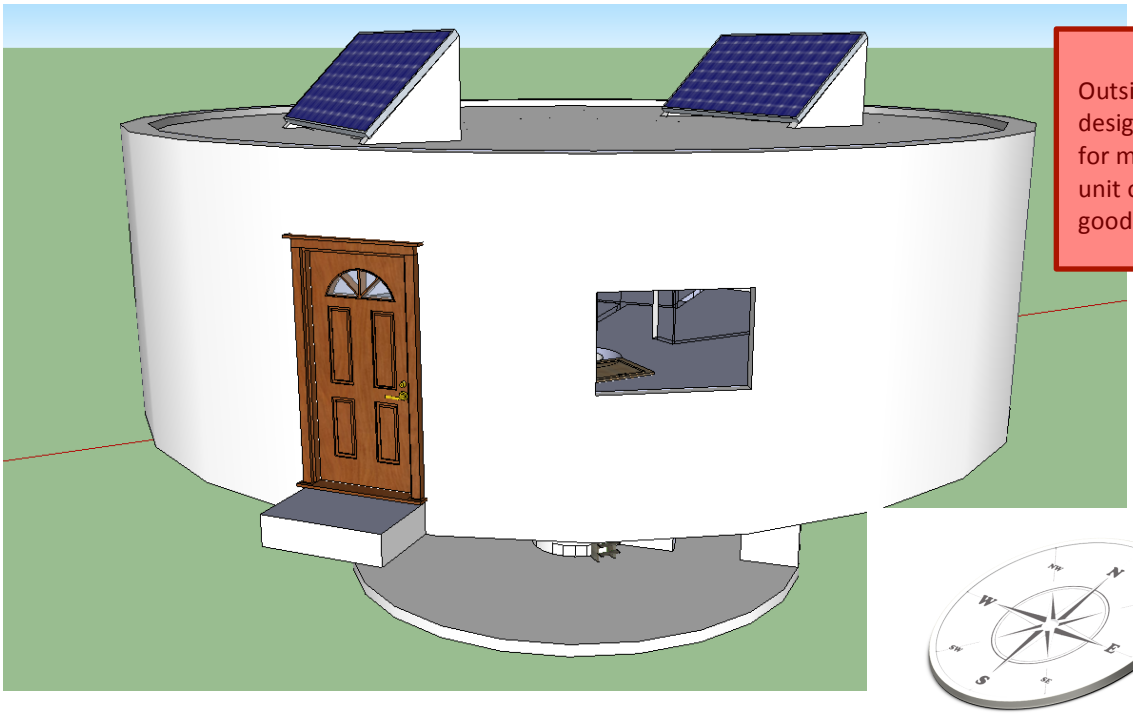
Production	kWh/yr	%
PV array	3,841	22
Wind turbine	11,114	62
Grid purchases	2,856	16
Total	17,812	100

Consumption	kWh/yr	%
AC primary load	6,231	38
Grid sales	10,086	62
Total	16,316	100

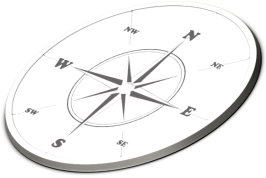
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)
Jan	297	559	-262	7	2
Feb	173	927	-753	7	-29
Mar	200	1,279	-1,079	6	-44
Apr	206	863	-656	6	-23
May	297	509	-212	5	4
Jun	297	500	-203	6	5
Jul	190	1,039	-848	5	-33
Aug	331	597	-265	7	3
Sep	193	1,159	-966	6	-39
Oct	319	517	-199	5	6
Nov	169	986	-817	5	-32
Dec	185	1,152	-968	7	-39
Annual	2,856	10,086	-7,229	7	-219

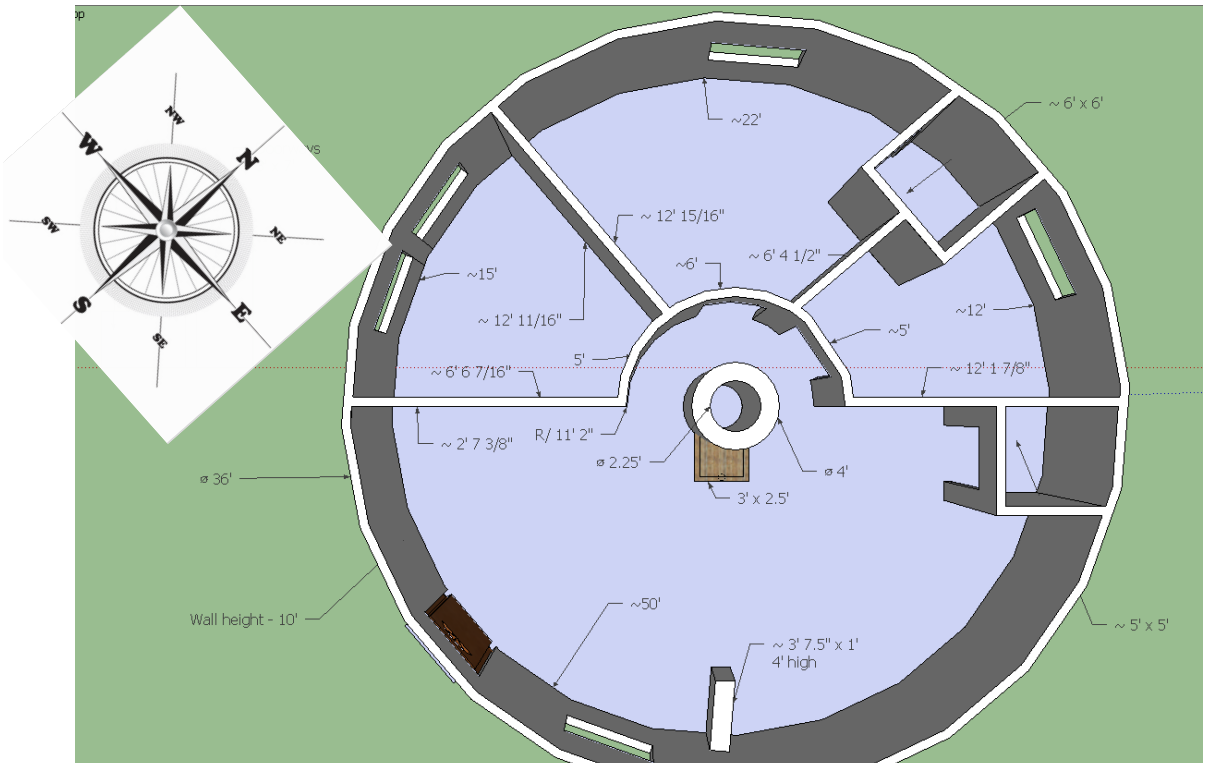


Homer Data shows that house produces a net total of energy; energy charge comes out to **-$219** over the **year**



Outside view of final Home design, circular design allows for more livable space per unit of wall area, as well as good **feng shui**





Our open floor plan, note how almost half the house consists of one continuous room

House Form

From first glance it is easy to see that our house is entirely different than everybody else's. We chose a circular shape, with originally planning to do a dome, but decided in the end to go with a flat roof. We didn't decide to go with a circular shape for simply no reason. By choosing a circular shape, we were able to maximize our usage of square footage, per square foot of walling. This allowed us to limit the amount of energy that was able to escape through the outer walls/windows. This helped us with our preliminary goal of staying cost effective and saving as much energy as possible. By obtaining our maximum usage of square footage, we were also able to avoid creating a second floor for our house (not including the basement), which in turn saved us a vast amount of money. After cost effectiveness, our next concern was the livability and comfort of the house. We gave each member of the family decent sized rooms with which they could live and relax, in a quiet and secluded space. While giving each person a room, we also wanted to have the main rooms of the house to be very open and welcoming. We chose to make half of the house completely open, with no walls or structures that connected to all of the other rooms, and the open kitchen. We also chose to make the walls 10 feet tall, which when combined with the open rooms, makes the house feel a lot larger than it appears. All in all, we achieved our goal of maintaining efficiency, while making a livable and comforting home.

Passive Solar Design

As stated early in the design process, keeping our home energy-conservative was one of our major goals, and much of our resources were directed towards making this happen. Our circular house design itself contributes to this, providing the lowest amount of wall surface area per unit of living space. As for windows, we chose to utilize few windows, and those that we did put in were triple glazed low-e, the best high efficiency windows available. The walls are insulated with R19 insulation. Our ceiling was our main concern. Having a large ceiling was a very large energy-leakage concern, but we combat this problem by utilizing R60 ceiling insulation, which is almost **17 inches** of foam insulation. We took this part of the process very seriously, and as a result chose the absolute best options available for every aspect of what we've dubbed out "Energy Conservation System"

House Energy Use

Low energy use is a major requirement for a quality Zero Energy Home, especially a low-cost one such as ours. We assume that our occupants will be very energy conscious, and chose appliances with that in mind. For the big 3 appliance (Refrigerator, Clothes Washer, and Dish washer), we chose 3 Energy Star Rated appliances for each category and weighted their cost effectiveness against each other by looking at price versus energy consumption. We chose a low cost, a mid-cost, and a mid-high cost appliance for each category for the comparison. In each case, we chose the most cost effective by determining if an increase in cost for an appliance led to an acceptable decrease in energy consumption. The bolded choices were chosen and added to the design. For smaller appliances, we used the Energy Calculator to choose generic products so that an average value of yearly Energy Consumption could be calculated. This route was taken so that a family moving into the home could use whatever appliances they had before or purchase any new ones they needed and still come out consuming less energy than they produce. In the end, the estimated energy usage for the year was **6230-kilowatt hours**. The results are shown on the table on the next page:

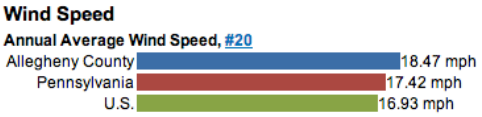
Dishwashers	Energy Usage (kWh/yr)	Cost ($)
Whirlpool WDF310	**282**	**299**
GE 510PGD	275	360
Samsung DW7993	279	450

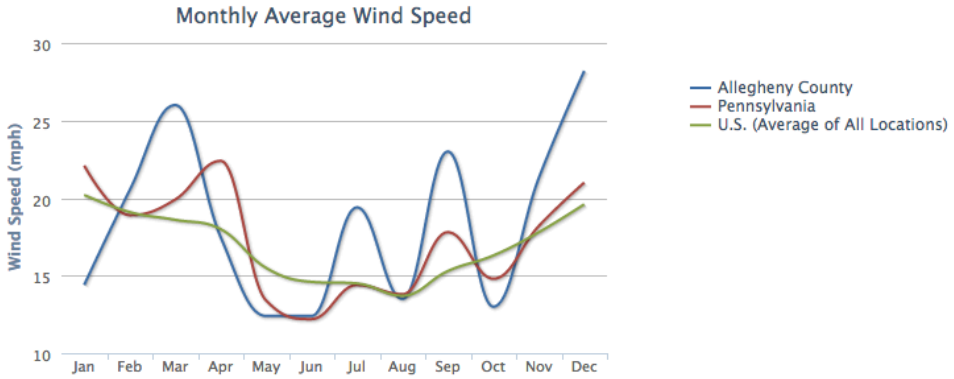
Clothes Washers	Energy Usage (kWh/yr)	Water Usage (gal/yr)	Cost ($)
Whirlpool WTW4950	123	5080	540
Samsung WF316B	**94**	**4187**	**650**
GE GFWR4800	162	4851	800

Refrigerators	Energy Usage (kWh/yr)	Cost
Frigidaire LFHT15 (16 cu. ft)	355	350
Whirlpool W5TX (18 cu. Ft)	**354**	**510**
Whirlpool W8RXEG	378	810

Energy Production System

After discovering the above-average wind speeds that Pittsburg (chart source in appendix), we decided to go with a combined wind-turbine and PV system in order to save some costs, as PV systems are much more expensive per kW than Wind Turbines. We searched for residential- sized wind-turbines and ended up deciding that a max rated 4.5 kW wind turbine (3 kW normally). According to our HOMER data sheet, with the average winds from the chart our turbine outs **11,000 kWh/yr**. This estimation number is very high, but leaves a lot wiggle-room to keep our house a Zero Energy Home even if they wind turbine fails to perform at the estimated energy output.





As for the PV system, we decided to go with a 3kW system, so that our rated Energy Production (3 kW + 3 kW) exceeds our recommended value of energy production as given ZEH calculator (5.08 kW). As for the panels themselves, we searched for fairly mid-level solar panels, as we decided our wind turbine system would be our main source of energy production, to save some costs where we could. We decided on going with 12 250-watt LG MONO X panels at $260 a piece. The panels (before installation) costs $3120, so in the ZEH calculator we kept the original ZEH calculator estimate in order to account for installation, an inverter, a converter, and any other costs that may spring up during the course of installing the system. These panels will be set up in 2 rows placed far apart on the roof as to not shade one another from the sun, and would **all** face south. The roof square footage is equal to the floor square footage (1018 ft^2), so there will be ample room to fit the 220 ft^2 of solar panels that will be placed there. According to our HOMER data, this array will produce a total of **3841 kWh** over the course of the year.

Basic Economics

Our project started with a strict budget of $160,000. When that budget was lifted, we decided as a team that we would still strive to create an affordable Zero Energy home, capping ourselves at the original budget of $160,000. As we progressed through the design, it became apparent that a strict budget was unmanageable. With our necessity of the highest quality Energy Consumption system available, our budget needed to increase or we were going to be able to complete the project. Our total final cost (House, Upgrades, Heating System, PV System, Wind Turbine, Major Appliances, and Small Appliances) was **$174,821**. Even more impressive than that is our yearly estimated energy charge of **negative** $219 over the course of the year. At that rate, the initial $20,000 investment on the Energy Production system will pay for itself in **27** years, which is inside the target range of 30 years, the average length of a mortgage on a home. (Calculation performed by using an average charge of 8 cents a kilowatt-hour, which was found to be an average charge for the Pittsburgh area)

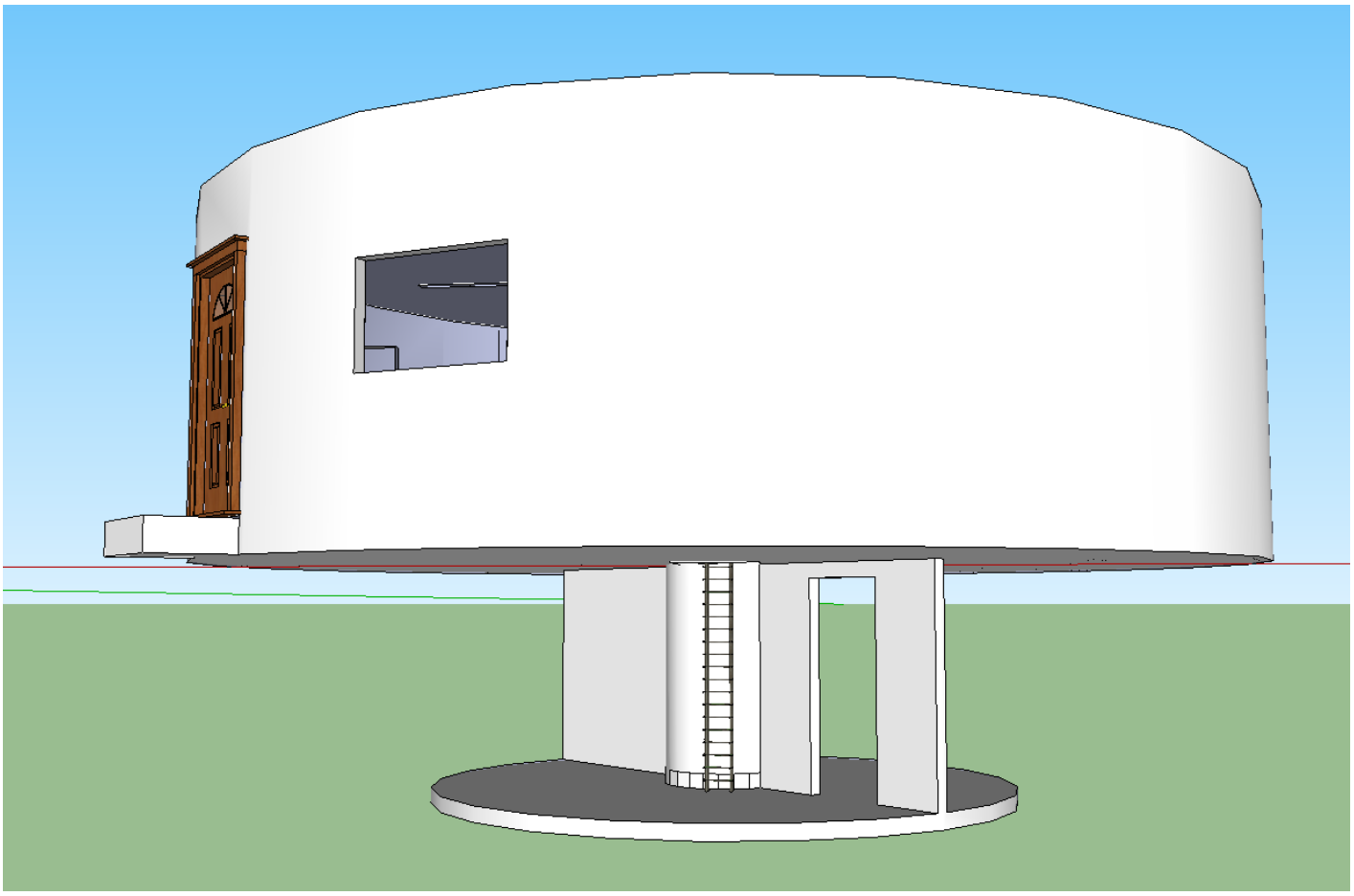
ZEH Calculator Majorly Affected Design Decisions

The Zero Energy Home calculator was our greatest resource during the design process. We utilized it during every step of the way in order to see where we could save our resources in order to design the cheapest and best home possible. The ZEH calculator made its way into every part of our design process. Since our major objective was low cost and high energy conservation, we used the calculator to find out how much money we had left in our (self-imposed after the budget was lifted) budget of $170,000 after choosing the best insulation, windows, heating system, and appliances possible for the home. This focus on house construction quality as opposed to house size led to our final house size (1018 ft^2) and our signature open-area circular design. The calculator also allowed us to design our energy production needs, as it calculated our total energy demand and suggested how much energy our home should produce in order to be a Zero Energy Home. All in all, the ZEH calculator was an invaluable resource for our design process, and was the basis for most of our design process decisions.

Appendix

Sources:

Wind data: http://www.usa.com/allegheny-county-pa-weather.htm
HOMER Software Website: http://homerenergy.com/
Appliances priced at: http://www.bestbuy.com/
Solar Panels Priced at: http://www.gogreensolar.com/
Wind Turbine Priced at: http://www.saferwholesale.com/

Extra Images

ZEH Side View
Shows half-finished basement and ladder that leads down there