ZERO ENERGY HOME (ZEH) PROJECT

SP 2014 – ELC INDUSTRIES

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INTRODUCTION

Through the design process, our group developed a zero energy home. We identified the needs of a comfortable house and established target specifications or goals that our house should meet, including that of zero net energy. Next, we researched other ZEH designs and developed our own ideas for home designs. We then rationally chose the best concept. A detailed design and energy analysis was complied. Our group produced a scale model and conducted an experiment to measure heat retention and energy efficiency during day (light bulb) and night (fan and ice). We observed the results and found while our ZEH home possessed flaws, we learned from them and nonetheless managed to create a house that utilized passive and active solar features.

Our Goal – Abstract

Currently in our society, we have a tendency to consume much more than nature can produce. As our non-renewable resources begin to dwindle, attention has been turned to ways to cut back on consumption and find alternative ways to gain energy. The rise of zero energy homes is evidence of such an effort, whose name comes from the idea that such a house consume a net zero amount of energy. In other words, a zero energy home is one that generates as much energy as its residents use, being self-sustainable. Our goal was to design a livable zero energy home to minimize utility costs and maximize solar gain. Our zero energy home was a product of our research and design analysis, evaluated based on solar gain and heat preservation.

Mission Statement

Our mission is to design and construct a model of a realistic zero energy home for a family of four that effectively retains heat, supports solar and other renewable energy technologies, and is aesthetically pleasing.

CONCEPT AND DESIGN

Research

Before creating our ZEH, we researched what other people have done in order to get a better idea about what a ZEH house should include. Included are only a few houses we looked at.

U-Mass - 2011 Solar Decathlon

Location (city, state)	Boston, Massachusetts
House size (floor area in square feet)	1000 sq. ft.
Number of floors	1
URL of web site where info is found	http://4dhome.us/engineering/ http://www.uml.edu/News/stories/2010-11/solar_decathlon_2011.aspx
Number of occupants	---
Number of bedrooms	1
Type of heating system (forced are, hydronic, radiant floor, heat pump, etc.	Heat pump and exchanger

Main heating fuel (electricity, natural gas, wood, oil, etc.)	electricity
Size of photovoltaic system (kilowatts)	6.4 kW
Solar water heater (yes or no)	Yes
R-value of wall insulation	R-56
R-value of ceiling insulation	R-64
Ventilation air heat recovery (yes or no)	yes
Predicted or measured annual energy use	None, but PV system produces 6.4 kW
Any other pertinent info	Designed by UMass and UMass-Lowell students for the 2011 Solar Decathlon competition, where they placed 9/19

Wolfworks - 2012

Location (city, state)	Harwinton, CT
House size (floor area in square feet)	3,561 sq ft
Number of floors	2-story
URL of web site where info is found	http://www.ctzeroenergychallenge.com/participant_specs.php?ID=Paul_Honig_
Number of occupants	Single-Family, detached
Number of bedrooms	4 BD
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Air Conditioning – air source heat pump Water heating – solar thermal/electric
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Space Heating (primary only) – air source heat pump
Size of photovoltaic system (kilowatts)	10.7 kW photovoltaics
Solar water heater (yes or no)	yes
R-value of wall insulation	R-49, Rigid foam & Cellulose
R-value of ceiling insulation	R-83, Blown-cellulose
Ventilation air heat recovery (yes or no)	yes
Predicted or measured annual energy use	Heating: 4.7/$232 Cooling: 4.9/$248 Water Heating: 0/$0 Lighting & Appliances: 21.6/$1075 Photovoltaics: -17.4/-$3980 Total: -17.4/-$3980
Any other pertinent info	Passive House Certified: • Heating Energy Demand less than 4.75 Kbtu/sf/yr • Air leakage less than 0.6 ACH50 • Primary Energy Demand for all building energy needs less than 38 Kbtu/sf/yr Orientation: • oriented 14 degrees from true south to relate to desired

 	site features while allowing the south facing windows to capture solar energy Insulation and Air Sealing: • "Sandwich Wall" • Ceiling created by the truss roof is sheathed and taped with no penetrations to maintain a continuous air barrier • Rigorous attention to the sealing of all potential sources of air leakage Heating & Hot Water: • Drain water heat recovery system which uses the hot water coming down the drain from showers to pre heat the water to serve the shower Ventilation: • balanced system recovers most of the heat from the steady and balanced flow of air it is designed to regulate Electrical: • lighting will consist of LEDs and CFLs in nearly all fixtures • most energy efficient appliances have been selected, including an induction range Renewables: • The 10kW photovoltaic array is designed to provide all the energy necessary, on an annual basis, to power the home and all its functions, as well as the capacity to charge an electric vehicle

Preferred Builders – 2012

Location (city, state)	Old Greenwich, CT
House size (floor area in square feet)	3,671 sq ft
Number of floors	3-story
URL of web site where info is found	http://www.ctzeroenergychallenge.com/participant_specs.php?ID=Peter_Fusaro
Number of occupants	Single Family, Detached
Number of bedrooms	5 BD
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Air conditioning – central AC Water heating – Indirect tank off boiler
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Space Heating (primary only) – Natural gas boiler 96% AFUE
Size of photovoltaic system (kilowatts)	6.6 kW photovoltaics
Solar water heater (yes or no)	no
R-value of wall insulation	R-28.5, Rigid foam + BIBS
R-value of ceiling insulation	R-50, closed cell foam
Ventilation air heat recovery (yes or no)	yes
Predicted or measured annual energy use	Heating: 38.8/$598 Cooling: 3.6/$191 Water Heating: 18.5/$269 Lighting & Appliances: 22.2/$1217 Photovoltaics: -28.6/-$1509

	Total: 54.4/$766
Any other pertinent info 	Structure: • design aesthetic fits into the neighborhood surroundings, focusing on long-term durability Orientation: • South side glazing will allow heat gain in the winter months. During the summer months, when the sun is higher, the 2' overhangs will shade the heat gain Heating & Hot Water: • natural gas Buderus ultra efficient 96% AFUE wall-mounted boiler with a Grundfos Alpha Circulating pump. This sealed combustion unit was chosen to eliminate the possibility of back drafting which will support the indoor air quality Ventilation: • Ultimate Air Energy Recovery Ventilator (ERV) Electrical: • electric vehicle (EV) charging station located in the garage • Shutoff switches to control items in the house when not in use will be manageable through smartphone technology Resources Sustainability Features: • All concrete, copper, iron and aluminum from the existing structure were recycled

Solar Panels

Photovoltaic solar panels convert sunlight into electricity by the photoelectric effect (metals emit electrons when exposed to sunlight.

Types:

Crystalline Silicon

- higher purity of silicon=higher efficiency.
- 90% of world's photovoltaic systems use silicon.

Mono-crystalline silicon

- High efficiency 15-20%
- Longest life-span
- Most expensive
- Central string-inverted are sensitive to shade, dirt or snow and can break down

Polycrystalline silicon

- Low initial cost
- Lower efficiency 13-16%

Thin film Solar cells-photovoltaic material deposited onto a substrate

Amorphous Silicon

- 6-8% efficient
- Used for small appliances

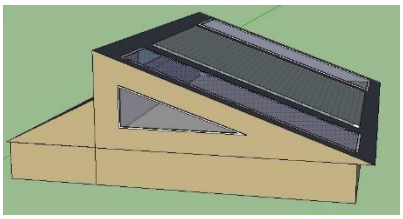
Cadmium Telluride

- 9-11% efficient

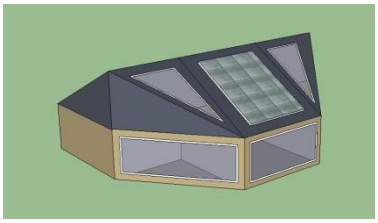
Source http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

Concept Generation

Concept 1



Concept 2



Concept 3

Concept 1 was the first and simplest design we created. It is in the shape of a standard rectangular house with aluminum insulation and rubber floors. Next, Concept 2 expands the roof in order to increase solar gain and amount of space available at the optimal angle towards the sun. This house was also planned to include aluminum insulation and rubber flooring. Finally, Concept 3 gave the south walls a slant to allow more sunlight in during the early morning and late evening when the south windows on either the walls or roof were not directly in sunlight. The slanted wall also makes the house more aerodynamic in case of wind; additionally this concept includes aluminum and rubber insulation.

Concept Selection

		CONCEPT 1		CONCEPT 2		CONCEPT 3	
Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Solar Gain	**50%**	**3**	**1.5**	**4**	**2.0**	**4**	**2.0**
Resistivity to Wind	**15%**	**1**	**0.15**	**2**	**0.3**	**3**	**0.45**
Insulation	**15%**	**1**	**0.15**	**2**	**0.3**	**3**	**0.45**
Aesthetics	**10%**	**1**	**0.1**	**2**	**0.2**	**2**	**0.2**
Ease of building	**10%**	**3**	**0.3**	**3**	**0.3**	**2**	**0.2**
Total	**100%**		**2.2**		**3.1**		**3.3**

After ranking our concepts in our concept selection matrix, concept 3 added to the highest score. Concept 3 provides more solar gain, resistivity to wind, insulation, and aesthetics in comparison to at least one other concept. However, the ease of building this concept was slightly more challenging.

Design

We planned our house to be small in order to minimize the amount of heat and other utilities that had to be used. The long back wall is 37'6" and it extends a total of 30'9". The shorter front wall will be 15' and both slants will have a length of 18'9". This gives a small house of approximately 1040.7 ft^2. The smaller wall and the slanted walls with windows would be southern facing to allow for the most solar gain in State College.

ENERGY ANALYSIS

Energy Usage Estimate

ELECTRICALLY POWERED ITEM	MONTHLY KWH	$/MONTH
Refrigerator	50.5	3.94
Dishwasher	13	1.02
Oven/ Range	24	1.89
Microwave	11	0.87
Washing Machine	45.3	3.53
Clothes Dryer	57	4.49
TV	10	0.79
Computer	21	1.66
Lighting (4 Rooms)	40	3.15
Water Heater (continuous)	126.3	9.80
Heat Pump 800-1100 sq. ft.	1094	86.84

Estimated KWH Usage: 1,481

Included Efficient Appliances

Washer - Samsung - WF45H63**A*

Load Configuration	Front Load
Volume (cu. ft.)	4.47
Modified Energy Factor (MEF)	3.42
Water Factor (WF)	2.7
Markets	Sears - $1,030

Product Details - https://www.energystar.gov/productfinder/product/certified-clothes-washers/details/2081234

Annual Energy Usage: $4.47\ \text{ft}^3 / 3.42 \frac{\text{ft}^3}{\text{kwh/cycle}} \times 416 \frac{\text{cycle}}{\text{yr}} = 544\ \text{kwh/yr}$

Annual Water Usage: $2.7 \frac{\text{gal}}{\text{ft}^3/\text{cycle}} \times 4.47\ \text{ft}^3 \times 416 \frac{\text{cycle}}{\text{yr}} = 5{,}021\ \text{gal/yr}$

Payback in comparison to $700 washer with 122.2 kwh/yr = 3.32 years

The Samsung washer was the least expensive in cost in energy of the alternative washers we looked at. It's payback time was almost 2 years shorter than the other washers. However, the disadvantage is the small load capacity.

Dryer - Kenmore Elite 9.0 ft^3 Gas Dryer

Depth with Door Closed	33.875
Number of Dryness Levels	5
Temperatures Control	5

Product Details - http://www.searsoutlet.com/9-0-cu-ft-Gas-Dryer-White/d/product_details.jsp?md=ct_md&pid=111508&mode=seeAll.UrZuufRDtd4

This washer is equipped with internal sensors that detect moisture, so it stops when clothes are dry, which also prevents over-drying and keeps your garments safe. Additionally, it provides many levels of adjustment, allowing for less water or less heat to be used depending on your load and decreasing energy consumption when able.

Refrigerator - Kenmore 7131#

Dishwasher - Bosch SHX68E05UC

Energy Star qualified	Yes
Total Annual Energy Consumption	180 KWH
Number of place settings	14

Product Details - http://www.bosch-home.com/us/SHX68E05UC.html

This washer saves up to 484 gallons of water each year and exceeds the Energy Star requirements for water by 150%. Likewise, EcoSense reduces energy usage by up to 20%. There are also options such as a half load option for small loads to save on energy and time.

Oven/ Range - Kenmore 4.2 cu. ft. Freestanding Gas Range w/ Broil & Serve™ Drawer

From research, we found that measuring based on different efficiencies gives rise to varying results of the most efficient stoves. For example, studies show that gas stove cooking is the most efficient in terms of primary energy use, as all the energy gas contains can be directly converted into heat for cooking. Electricity, on the other hand, needs to be produced in power plants and travel through the grid, leading to decreased direct efficiency. In energy efficiency, which is the ratio between energy delivered to the food and consumed, cooking with gas has an energy efficiency of

about 40%. While this is less than induction stoves, gas stoves provide a more comfortable aspect of allowing the user to choose the different strengths of heat for cooking, which is sometimes preferred.

http://www.bigee.net/media/filer_public/2013/03/28/bigee_cooking_stoves_user_savings_20130327.pdf
http://en.wikipedia.org/wiki/Induction_cooking#Benefits

Control Type	Electric
Cooking Surface	Gas: sealed burners
Main Oven Capacity (ft^3)	4.2
Burner Configuration	12,000 BTUs – 3,500 BTUs

Product Details - http://www.kenmore.com/kenmore-30inch-freestanding-gas-range-stainless-steel/p-02272603000P?prdNo=2&blockNo=2&blockType=G2

Extra-large viewing windows let you check baked goods without opening the oven, helping keep temperatures consistent and preventing increases in energy usage.

Microwave - Sharp R-930CS

Configuration	Countertop
Type	Convection
Capacity (ft^3)	1.5
Microwave Output Power Watts	900

Product Details - http://www.sharpusa.com/ForHome/HomeAppliances/Microwaves/Models/R930CS.aspx?tech_specs=1

Television - VIZIO E390-B1

Class Size	39”
Energy Compliance	Energy Star 6.0
Power Consumption	29.1W
Standby Power Consumption	<1W

Product Details - http://store.vizio.com/e390b1.html

This television provides space saving as well as significant energy savings in comparison to alternative models of televisions.

Computer - Apple iMac desktop

Energy Compliance	Energy Star 5.2
Ranking from EPEAT	Gold
Construction	Environmentally friendly

Product Details - http://www.apple.com/imac/design/

The iMac desktop aims to improve energy efficiency and hardware components work together with the operating system to conserve power. Thus, iMac meets low power requirements as well as creates a small environmental impact based on how recyclable it is, how much material is used, how much energy it uses.

Light Bulbs

Compact Fluorescent Bulbs (CFL)

- Use 1/5 to 1/3 the energy of incandescent bulbs
- Last 8 to 15 times longer (6,000 to 15,000 hours)

- Contain mercury, so proper disposal is essential

Incandescent Bulbs

- 750 to 1,000 hours
- 2-3% luminous efficiency

Light Emitting Diodes (LED)

- Last up to 50,000 hours

From research, we found, when designed well, LED lighting can be more efficient, durable, versatile and longer lasting. LED light bulbs use only 2-17 watts of electricity (1/3rd to 1/30th of Incandescent or CFL). LED bulbs used in fixtures inside the home save electricity, remain cool and save money on replacement costs since LED bulbs last so long. LED bulbs last up to 10 times as long as compact fluorescents, and far longer than typical incandescents. Thus, we plan to use these for our ZEH.

Source http://eartheasy.com/live_energyeff_lighting.htm , https://www.americanlightingassoc.com/Lighting-Fundamentals/Light-Sources-Light-Bulbs.aspx

Heat Pump (geothermal) - WaterFurnace NVV048A1*1

Type	Open Loop Water-to-Air
COP Rating	5.1
Energy Efficiency (EER)	42.5

Product Details - http://www.energystar.gov/productfinder/product/certified-geothermal-heat-pumps/details/1900812

Water Heater (continuous) - Kenmore 153.321151

Energy Factor	2.75
Fuel	Electric
Storage Volume (gallons)	50
Input	4.5 KW
KWH/yr	1516.0
Recovery Efficiency (%)	100

Product Details - http://www.energystar.gov/productfinder/product/certified-water-heaters/details/2194356

Active Solar Calculations

Calculated through http://sroeco.com/solar/calculate-solar-cost/what_size_solar_system_do_i_need/

Calculating Array Size: Array Size (kW) = (Annual kWh usage) / (365 days/year) / (Solar Hours/day) / (0.75 derate factor)

Avg Sun Hours	3.91 KW/m^2 for State College
Annual Electricity Usage	1481 KWH (from estimate)
Solar PV System Size	16.60 KW
Total Area Required	1328.00 sq. ft.
Number of Solar Panels	7-8 panels
Cost per Watt	$5.35
Solar Cost Estimate	$8.881.00
30% Tax Credit	$2,664.30
Total Cost Estimate	$6,216.70

Additional Conservation

More appliances our house would add includes low-flow shower heads to decrease water use as well as ways to reuse heated water from showers through water heat recycling. Used shower water can be used to preheat the water that goes into the heating device in order to reclaim heat. Water that comes into a water heater is close to 11°C, however by preheating the water, the incoming water can be elevated to about 25°C. Overall, water heat recycling greatly lessens the amount the new water must be heated and saves energy.

As well as appliances to reduce energy consumption, our house could be constructed with a garden adjacent to it, allowing for further energy savings and environmental features. The garden provides not only a resource for food for the residents, but also provides an area to place compost and reduce garbage and waste. Additionally, rain water should be collected in rain barrels or troughs in order to water the plants and decrease on the use of municipal water.

http://www.ecohometips.com/drain-water-heat-recovery.html

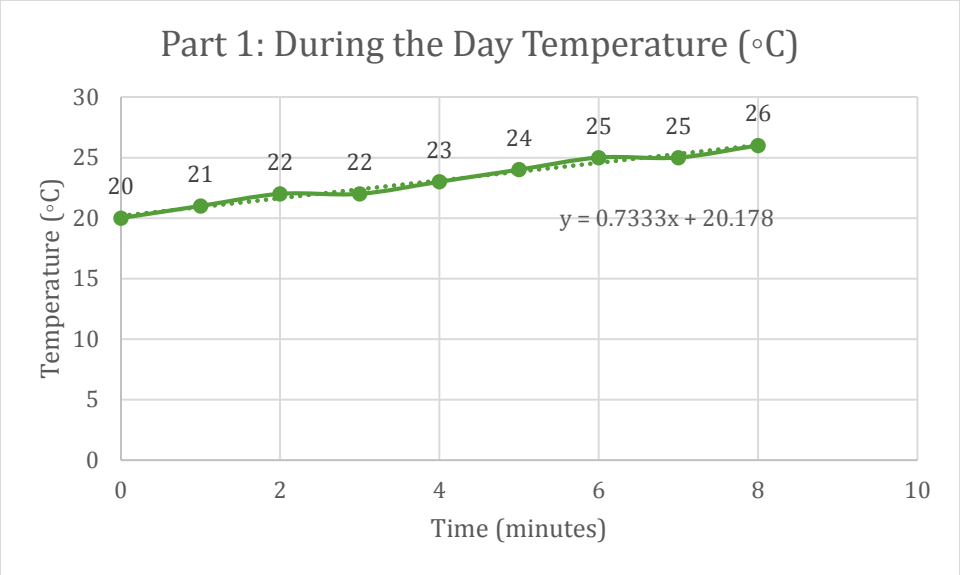
MODEL EXPERIMENTATION

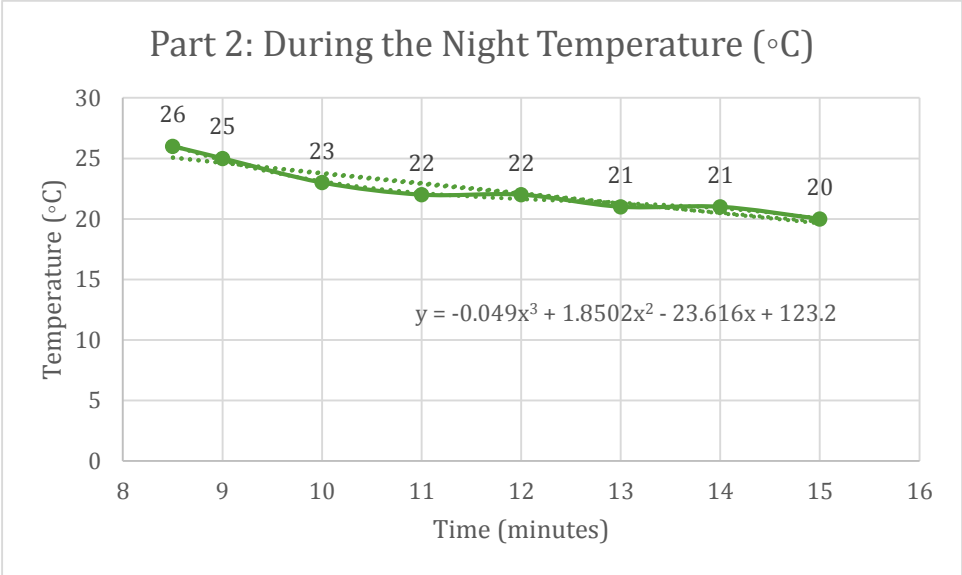
Model Description

We constructed our model with Styrofoam poster board, hot glue, duct tape, plastic wrap, rubber, and aluminum foil. While these materials seem common and elemental, our model included many passive and accounted for active solar features. The model included large windows on the southern facing side as well as on the roof to allow for the maximum solar gain during the day. The roof was tilted at a 45-degree angle to match the solar elevation for State College and let in the most light. We planned our house to have insulation on the walls and floor to retain heat, which we replicated by covering the inside of our model with aluminum foil and the floor with rubber. The aluminum foil was able to reflect light towards the rubber and keep heat inside the house. The rubber floor acted as an effective absorber and any heat released during colder temperatures would rise throughout the house. We wanted a tightly sealed house to better keep heat in, thus we taped over seams of our model with duct tape to prevent heat from escaping and placed the door away from the direction of the wind. Further, we planned that the dividing walls in our house to have thermal mass in order for rooms on the northern side to be warmed through indirect solar gain. We created a slanted wall on the sides not only to let in more sun, but also to provide an aerodynamic design in hopes of decreasing the effects of wind. Our house would include insulating or double sealed windows, so for our model, we covered each window with two layers of plastic wrap to provide better insulation. Finally, we left room on center roof to place solar panels in order to generate electricity. The black cloth in the center of our model represented these panels. The other pieces of cloth on the opposing sides provided further absorption for the house. Our original home had dimensions to add to an area of 1040.7 ft^2, we scaled down our model so the long back wall was 10" and it extended a total of 8.2". The shorter front wall was 4" and each slanted wall was 5", all be a factor of 3.75. Thus, our model's area was the desired 70 in^2.

Testing the Model

The testing of our model consisted of placing the house five inches away from a large incandescent bulb for eight minutes with a thermometer inside of the model to record the changes in temperature. Immediately after the time under the bulb, which can be thought of as simulating the day, the house was removed from the light and placed in front of a fan with ice. This time constituted night with a cold prevailing wind. The model was kept in this environment for seven minutes with the same thermometer and the change in temperatures was recorded.





From our data, we found that we our model gained heat at a linear relationship, about 1 degree a minute. However, our model had trouble retaining the heat it gained and we lost heat rather quickly before leaving out during the simulated night.

CONCLUSION

The experiment highlighted the strengths and weaknesses of our model. Some of the drawbacks included could be that the house was too long on the east and west sides, which resulted in more surface area as well as less insulated windows being exposed to the winds. The house could have had a larger south face and roof to increase the heat gain. Shutters might have slowed heat loss at night and the use of more black cloth on the outside of the house may have absorbed more heat.

The house did have large, south-facing windows, which helped it gain heat. The rubber floors absorbed heat let in through the windows and heat reflected off the aluminum. The shape of the house may have been more beneficial if the sun moved east to west, as opposed to being stationary.

Overall, our Zero-Energy Home met our own goals for the project. We were able to keep our beginning and ending temperatures constant, which is a good starting point if we were to continue on building an actual house. It gained and lost 6 degrees Celsius during each part of the experiment. While it was not one of the best models, it met our own criteria for what we wanted. Our design was more suited for an actual rotating sun, in which case we probably would have absorbed more heat and thus had a greater net heat gain after the entire experiment was over. So, our model was perhaps best suited for a real-life model, since all other models did not account for any rotation of the sun. Further, we saw from other groups that adding windows to the roof provided a more direct gain of heat from the light bulb; however, we reserved this spot for solar panels. Another change we could have made to improve the heat retention would be perhaps to include shutters for the windows that were facing the wind. The insulation R-value for windows is usually significantly smaller than for walls, so utilizing shutters or perhaps double- or triple-paned windows would cut down drastically on our heat loss. Another change that would not necessarily helped in this experiment, but would be very useful in reality would be the incorporation of and overhanging roof, to cut down on heat gain during the summer. However, this experiment was all about maximizing heat gain so that would have been counter-productive.

For making our house a truly zero-energy home, our energy calculations were made. We researched top-of-the-line appliances to have the most energy efficient home, which included many minor appliances that other groups did not include, like miscellaneous kitchen appliances. Our monthly energy usage was almost 1,500 kWh, which actually is fairly close to a normal home, but the vast majority of that energy usage we realized was coming from our ground-source heat pump. However, this calculation that we made was based on this heat pump being used in a normal house that was not compensating by having a heavily passive solar design. Therefore, we could cut down on that energy usage significantly with our passive solar design. Another incorporation that we could have made was having a solar hot-water heater, whereas in our calculations we had a continuous hot water heater. This is more efficient than a tank design, but still more than having solar hot water. This could cut down our overall energy load in the house by as much as one-half, especially in the summer when it would be functioning to its highest potential. Our energy consumption is also offset by our solar panel array. It was estimated that 7-8 panels would be sufficient to offset our consumption, which would cost roughly $9,000, but with our government rebate and tax credit would be cut down to about $6,000. After installation, it would also pay itself back in savings from not having to buy energy from a utilities company.