Zero Energy Home

EDSGN 100, Section 4

Wallace Catanach

Ngoc Tran

Jumi Pak

Ruiqi Dong

October, 11, 2015

TABLE OF CONTENTS

Team Member 2

Executive Summary 3

Abstract..... 4

Introduction..... 4

Mission Statement..... 4

Analysis of Customer Need 5

External Research..... 6

Online research 6

Benchmarking..... 8

Concept Generation..... 12

Concept Selection 12

Matric & Metrix of Last Chocie 13

Cost Model..... 16

Total House Cost 16

Details of Upgrade Cost..... 16

Operating Cost 17

Design..... 18

Model..... 20

Elevation Drawing 20

3D Models by Solidworks 20

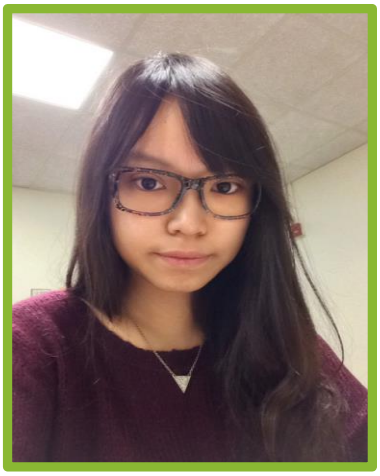
3D Models Made with Cardboard..... 21

Reneferences..... 22

TEAM MEMBER

Ngoc Tran
ntt5051@psu.edu

Jumi Pak
jkp5218@psu.edu



Ruiqi Dong
rzd5229@psu.edu

EXECUTIVE SUMMARY

As the natural resources get deeper in the devastated state, the need for producing houses with sustainable ability is established. Harrisburg city has the average temperature of 52, 7-Fahrenheit degree for high and 44.3-Fahrenheit degree for low. In addition, the amount of rain and precipitation can get as high as 41.5 inches per year. The objective for this ZEH project is to design a house, in a cold-climate city, that only use clean resources as solar panels to provide enough energy sustainable for a whole year. The energy produced need to be able to support a typical American family of four people, and an electric car. In addition, the budget for the entire project should not exceed the amount of 140,000 dollars.

In order to meet the budget, many solutions have been carefully evaluated. Surveys and polls were conducted for the specific customer's needs. A specific needs matrix is necessary to conduct the frame of the design. The concepts then were ranked from 1-5 based on the Pugh scoring method, mainly lean towards the idea of how to save the space. The house has a dimension of 13 x 7 meter square, with an open kitchen, which is linked with the living room. The space is conserved by joining the laundry room with the kitchen by installing the multi-purpose washer and dryer. Another space-saving design was conducted in the bedroom: The Murphy bed is used in the children's bedroom. A full-sized Murphy bed, included with a desk will cost $2749.9. The house design will have many window areas to receive the appropriate amount of sunshine to store in the thermal mass.

The risks of ZEH house involves various aspects. The hardest part of the technology aspect was to ensure the appropriate amount of heat for daily uses. This condition will be met by installing big windows facing the South direction. The solar panels will be installed on both sides of the roof. Another risk involving in this project is meeting the budget and time limitation between the group members. In order to ensure the efficiency of the project, regular meetings and updating files on google drive have helped the members to keep up the progress on time. The report will be finalized and submitted by the deadline of October 16th, 2015.

ABSTRACT

Concerning with deficit of natural resource, there are possible solutions that replace the natural resources. Among the solutions, building eco-friendly house is the one of the most effective solution since houses are also essential factor of lives. Derived from this idea, zero energy house has invented. Zero energy home achieves “0” energy consumption overall with using recyclable energies such as solar power.

INTRODUCTION

For past two months, our team designed a zero energy home, which is suitable for four people family, in Harrisburg, PA. Our project starts from basic research like find proper location to making real model of house. The house requires net zero consumption within certain budget, which is $140,000; it still needs to be functional and affordable. Not only these, there are more needs from customers: parking area, eco-friendly, limited budget, and so on. Additionally, our group tries to fit in to best locations and all ZEH home features to maximize the benefits such as using the solar power maximally and minimize the loss. There is following result in detail:

MISSION STATEMENT

This project requires designing eco-friendly, functional, and affordable home for family size of four within $14,000; the house needs to me requirement from the consumer.

ANALYSIS OF CUSTOMER NEEDS

Customer Need	Need Statement	Need Analysis
"House built in the city cold in winter like Penn State"	The house is cold resistant enough.	Each part of the house should have high thermal resistance.
"Energy produced enough for the house and an electric car over a year and excess energy into the grid."	1. The house produces enough energy for the house. 2. Each part of the house uses energy with high efficiency. 3. The house will give back energy to the grid.	1. Solar panel needs to be installed at the highest estimate. 2. Choose more energy efficient equipment such as low-e windows and floor mass to save the energy.
"Solar-powered and use green building principles."	1. The house is based on solar-powered. 2. The house uses green building principles.	Use the floor mass and install many solar panels to become eco-friendly home.
"For a typical family of four."	The house is suitable for a family of four.	Design to have two bedrooms, two bathrooms, and one kitchen and laundry room.
"Attractive appearance."	The house has attractive appearance.	Consider appearance as criteria when doing concept selection.
"Limited fund: less than 140000 dollar."	The house will be built with limited fund: less than 140000 dollar.	Make smaller house and maximize efficient of the space with using space efficient furniture.
"Park area"	The house possesses a garage.	Extrude the place for garage.

Commented [A1]: Wat is need statement for "attractive appearance" any idea??

EXTERNAL RESEARCHES

ONLINE RESEARCH

Zero Energy Home

Commented [A2]: ttp://energy.gov/eere/buildings/zero-energy-ready-home

- Purpose of ZEH is achieving consumption of zero energy. Currently in the United States, there are more than 14,000 ZEH homes, and these houses saves million dollars in saving energy. The most common energy resource is solar panel. In addition, the home needs to be high functional and should be affordable for people.

Harrisburg Climates:

- Harrisburg is a city that is located in the Northeast side of United States. The city lies in the cold climates, but still has distinguished four seasons. The annual temperature can get as high as 52.7-Fahrenheit degree and as low as 44.3-Fahrenheit degree. The total days Harrisburg can experience the sun is about 196 days on average. The amount of precipitation and rain can go up to 41.5 inches per year

Insulation

- Purpose of ZEH is achieving consumption of zero energy. Currently in the United States, there are more than 14,000 ZEH homes, and these houses saves million dollars in saving energy. The most common energy resource is solar panel. In addition, the home needs to be high functional and should be affordable for people.

Floor Mass

- By using the floor mass, it can save the energy a lot and it provides the place for store the energy. Mostly, Asian countries use the floor mass in their homes, rather than Western countries. Also, floor mass is more expensive than any just carpet; but once it is purchased, it helps to save a lot of money through saving energy a lot.

Murphy Beds

- Murphy bed is convertible bed; when the bed is in used, the mattress can be folded to the wall. From using the convertible bed, it can save many spaces and use the space very efficiently. In addition, some of the murphy beds can be used both as beds and as desks. As a result, it is going to be very helpful. Generally, the price of murphy is quiet expensive than just regular bed.

Solar Panels

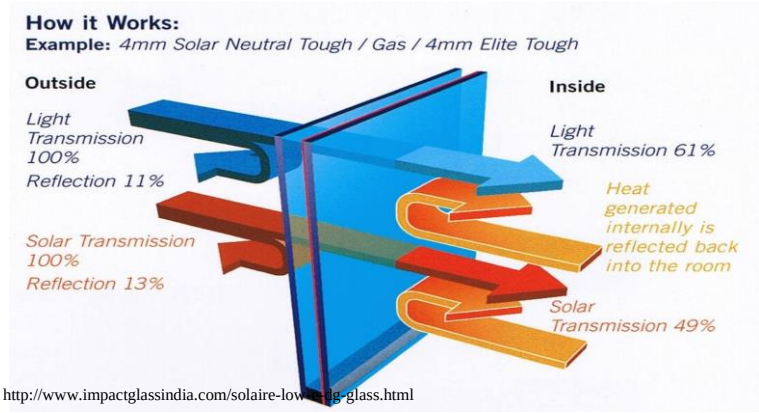
- Solar Panel is a panel that use to convert sunshine into solar energy so that the energy can be applied to the home. Nowadays, many people use solar panel at their personal houses instead of using electricity or other source of energy. By using solar power, it can tremendous amount of money.

Energy Resources

Commented [A3]: http://www.altenergy.org/renewables/renewables.html - energy resource

- **Solar:** the most common way to collect energy
- **Wind Power:** large amount of energy and no greenhouse emission
- **Hydroelectric Power:** power from gravitational forces of flowing water
- **Biomass:** power from living organisms
- **Geothermal power:** generated in the Earth

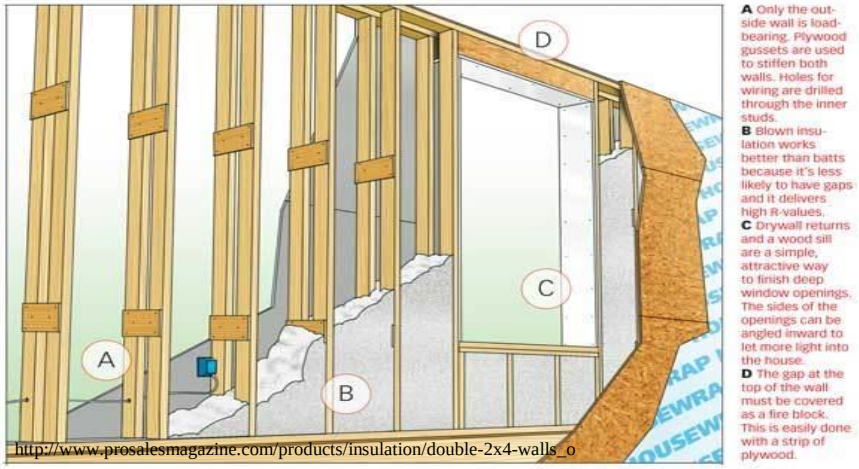
Low –E windows



http://www.impactglassindia.com/solaire-low-e-dg-glass.html

Double 2*4 Foam Wall

- From using this construction, it is expected to be more insulated. In addition, this skill does not require any specific higher level of skills- unskilled people can construct double wall. By using two separate walls, it divides the space into inner and outer; the outer wall bears the entire house. R-value for the wall is indicates the distance between two frames; the distance reduces heat loss.



http://www.prosalesmagazine.com/products/insulation/double-2x4-walls_o

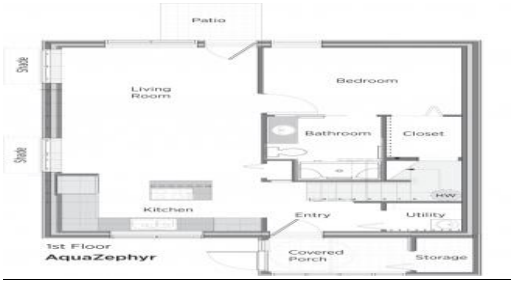
Grid-tied

- Grid-tied systems are connected to the electrical grid allow residents of a building to use solar energy as well as electricity from the grid. Grid-tied systems do not need to produce 100% of the electricity demand for a home or business. When there is no demand for energy, the solar panels send excess electricity back out into the grid for use elsewhere.

BENCHMARKING

Location (city, state)	**Ithaca, NY**
House size	1664 ft^2
Number of floors	2
URL	http://energy.gov/sites/prod/files/2015/06/f22/DOE_ZEH_AquaZephyr_9-

	20-14.pdf
Number of occupants	Approximately 5 to 6
Number of bedrooms	3
Type of heating system	5.5-in. foil-faced polyiso under the slab, polyiso-insulated foundation walls, triple-pane windows, an ERV, and passive solar design with electric back up heat
Main heating fuel	Mainly solar panel - eletricity
Size of photovoltaic system (kilowatts)	a 4-kWh PV system installed
Solar water heater (yes or no)	Yes
R-value of wall insulation	Double 2x4 stud wall with 5-in. gap (total wall depth=12 in.) filled with 3.5-in. (R-22) closed-cell spray foam and 8.5 in. (R-30) cellulose; coated OSB sheathing with taped seams, rain screen furring strips, fiber cement siding
R-value of ceiling insulation	0.42 ACH 50 for air ceiling, metal roof
Ventilation air heat recovery (yes or no)	Yes, ERV with ducts runs continuously to meet ASHRAE 62.2; MERV 12 filter
annual energy use	without PV 10,924 kWh; with PV 16,285 kWh
Any other pertinent info	• DOE Zero Energy Ready Home Path: Performance • Walls: Double 2x4 stud wall with 5-in. gap (total wall depth=12 in.) filled with 3.5-in. (R-22) closed-cell spray foam and 8.5 in. (R-30) cellulose; coated OSB sheathing with taped seams, rain screen furring strips, fiber cement siding • Roof: Metal roof • Attic: 25-in. (R-90) cellulose • Foundation: Slab-on-grade foundation poured on 6-in. gravel bed covered by 6-mil poly vapor barrier and 5.5 inches (R-36) of foil-faced polyisocyanurate rigid foam under entire slab. Stem walls insulated on exterior with 3-in. (R-19.5) rigid polyiso to bottom of footing at 24-in. below grade, then skirt of 3-in. (R-19.5) polyiso extending down and away from footing for 41 in. • Windows: Triple-pane, low-e, U=0.17, SHGC=0.62 • Air Sealing: 0.42 ACH 50 • Ventilation: ERV with ducts runs continuously to meet ASHRAE 62.2; MERV 12 filter

	• HVAC: Electric baseboard, passive solar design • Hot Water: Solar thermal preheat with electric storage tank, 0.84 EF • Lighting: 72% LED, 28% CFL; ENERGY STAR ceiling fans • Appliances: ENERGY STAR refrigerator and dishwasher • Solar: 4-kW PV and domestic hot water • Water Conservation Features: All WaterSense fixtures • Other: Sustainable landscaping, semipermeable stone around house, native wildflowers and grass, retaining walls to prevent erosion; bio-swales, rain garden and retention pond 

Location (city, state)	**New Paltz, NY**
House size	2,288 ft2
Number of floors	3 bedrooms
URL	http://energy.gov/sites/prod/files/2015/06/f22/DOE_ZEH_Greenhill_09-20-14.pdf
Number of occupants	Approximately 8 to 10 (regularly for one family)
Number of bedrooms	3
Type of heating system	a ground-source heat pump with desuperheater
Main heating fuel	Solar Power - eletricity
Size of	7.26 kWh

photovoltaic system (kilowatts)	
Solar water heater	Yes
R-value of wall insulation	R-22 ICF; EPS foam as drainage plane; vinyl siding
R-value of ceiling insulation	Roof insulated along underside of roofline with 2 in. closed-cell and 10-in. open-cell spray foam coated with ignition barrier paint; foam covers rafters for thermal break; R-60
Ventilation air heat recovery (yes or no)	Yes, MERV 11 filter, ducted to air handler; continual HRV bath
annual energy use	without PV 14,774 kWh; with PV 23,666 kWh
Any other pertinent info	Walls: R-22 ICF; EPS foam as drainage plane; vinyl siding • Roof: Roof insulated along underside of roofline with 2 in. closed-cell and 10-in. open-cell spray foam coated with ignition barrier paint; foam covers rafters for thermal break; R-60 • Foundation: Slab with R-20 closed-cell spray foam under entire slab; R-22 ICF slab edge insulation • Windows: Triple-pane, argon-filled, vinylframed; U=0.20; SHGC=0.23 • Air Sealing: 0.28 ACH 50 • Ventilation: MERV 11 filter, ducted to air handler; continual HRV bath • HVAC: 3-ton ground-source heat pump (5.7 COP, 44.0 EER) modulating condenser; variable speed ECM blower • Hot Water: 1.20 EF desuperheater from ground source heat pump; 50-gal. tank with electric backup heat source. • Lighting: 80% LED, 20% CFL • Appliances: ENERGY STAR-rated clothes washer, dishwasher, refrigerator, microwave oven • Solar: 7.5-kW solar PV panels installed • Water Conservation: EPA WaterSenserated showerheads, faucets, toilets; 90% of lot landscaped with drought-tolerant turf and native plants; no irrigation • Other: Detached garage; 49% waste diversion from landfill

CONCEPT GENERATION

- **For design of the whole house**

#	Need Statement	Imp	Metric	Double 2*4 with 10" foam wall	2*6 with R19 batt wall	Triple low-e windows	Supper double low-e windows	Double low-e windows	Air tightness: tight with heat recovery	Air tightness: tight	Detached garage	Attached garage	Built in garage	Electric heat pump	electric geothermal heat pump	solar water heater	water conservation	thermostat setback	clothesline	high efficiency solar panel
1	The house is cold-resistant enough.	5		o		o	o		o											
2	The house produces enough energy for the house.	5												o	o	o				o
3	Each part of the house uses energy with high efficiency.	5		o		o	o		o								o	o	o	
4	The house will give back energy to the grid.	3																o		
5	The house is based on solar-powered.	5														o				o
6	The house uses green building principles.	3		o		o	o		o				o			o	o	o	o	o
7	The house is suitable for a family of four.	4			o						o									
8	The house has attractive appearance.	2					o	o			o	o								
9	The house will be built with limited fund:less than 140000 dollar.	5			o		o	o		o			o	o					o	
10	The house has a garage.	4									o	o	o							

- We valued the importance of each need statement at first. Then all members processed brainstorming to come out with concepts to satisfy the need statement. All corresponding relationships between need statements and metrics are exhibited by the above graph.

CONCEPT SELECTION

Selection criteria	High R-Value	Low R-Value	High efficiency solar panel	Low efficiency solar panel	Space-consuming furniture	Space efficient furniture	Directly gain big size windows	Indirectly gain with living space	Mass floor	Normal floor	Geothermal	No geothermal	Built-in garage	Built-out garage
Energy efficient	+	-	+	-	0	+	0	+	+	0	+	-	0	0
Low price	-	+	-	+	-	+	+	-	-	+	-	+	-	+
Suitable for a family	+	0	+	0	+	+	+	+	+	0	+	0	+	+

Space-saving	0	0	0	0	-	+	+	-	+	+	0	+	-	+
Durability	+	0	+	-	0	0	+	+	+	0	+	+	+	+
Attractive appearance	0	0	0	0	+	-	+	+	0	0	0	0	+	-
Sum +'s	3	1	3	1	2	4	5	4	4	2	3	3	3	4
Sum 0's	2	4	2	3	0	1	1	0	1	4	2	2	1	1
Sum -'s	1	1	1	2	2	1	0	2	1	0	1	1	2	1
Net Score	2	0	2	-1	0	3	5	2	3	2	2	2	1	3
Rank	1	2	1	2	2	1	1	2	1	2	1	1	2	1
Continue?	Yes	No	Yes	No	No	Yes	Yes	No	Yes	No	No	Revise	Yes	No

- According to the customer needs, we set six criteria for concept selection. Using the way of concept screening, our group decided types of main equipment in the house. All advantages and disadvantages are exhibited by the above graph. For the use of geothermal source, considering the cost, we gave up electric geothermal heat pump and adopted electric heat pump at last.

METRIC & MATITRIX OF LAST CHOICE

Metric #	Need #s	Metric	Imp	Units	Value
1	1	Thermal resistance (R-value) of wall	5	ft2°F/Btu	40
2	1	Thermal resistance (R-value) of ceiling	5	ft2°F/Btu	36
3	1,6	Wall area	5	sq. ft	979.45
4	1,2,3,5,8	South window area	4	sq. ft	150.69
5	2,6	Size of PV system	5	kW	3.18
6	3,6	Heat thermostat setting	3	F	53.6
7	3,6	Cool thermostat setting	3	F	80
8	7	Conditioned floor area	4	sq. ft	894
9	9	Total cost	3	$	139960
10	10	Garage area	3	sq. ft	129.2

- **Specific design1: Bed in two children's bedroom.**

Concept Generation:

Selection Criteria	Concepts		
	A	**B**	**C**
	King size bed with cabinet	Bunk with cabinet	Murphy bed
Enough size	+	0	0
Small occupation	-	0	+
Cheapness	-	0	0
Durability	+	0	-
Multifuctional	+	+	+
Sum +'s	3	1	2
Sum 0's	0	0	2
Sum -'s	2	0	1
Net Score	1	1	2
Rank	2	2	1
Continue?	Revise	Combine	Combine

http://www.thefutonshop.com/Manhattan-Platform-Storage-Bed-Frame-Java/p/753/5409

http://www.ebay.co.uk/sch/Vi-Spring-Beds-and-Mattresses/32254/bn_1536262/i.html

http://www.damienzygote.com/fold-twin-bed-decoration/fold-up-twin-bed-furniture/

		Concepts					
		A		**B**		**C**	
		King size bed with cabinet		Bunk with cabinet		Murphy bed	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Enough size	15%	4	0.6	3	0.45	3	0.45
Small occupation	30%	2	0.6	3	0.9	5	1.5
Cheapness	20%	1	0.2	3	0.6	3	0.6
Durability	15%	4	0.6	3	0.45	2	0.3
Multifunctional	20%	4	0.8	3	0.6	3	0.6

	Total Score	2.8	3	3.45
	Rank	3	2	1
	Continue ?	No	No	Develop

- When designing floor plan, we met the first problem was that bed in two children's bedroom is space-consuming. After developing concept screening and concept scoring, we agreed with the plan of murphy bed, which utilizes vertical space to reduce occupation; a design of murphy bed satisfies customer needs about space efficient and low price.

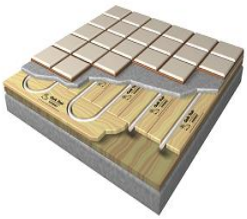
- **Specific design 2: How to reduce the heat loss through windows?**

Concept Generation:

	Concepts		
Selection Criteria	**A**	**B**	**C**
	Smaller size of windows	Transparent big jars	Mass floor
Heat storage	-	+	+
Heat delivery	-	+	+
Small occupation	+	-	+
Cheapness	+	+	-
Uninfluence of light transmission	-	0	0
Sum +'s	2	3	3
Sum 0's	0	1	1
Sum -'s	3	1	1
Net Score	-1	2	2
Rank	2	1	1
Continue?	No	Revise	Yes

http://www.alibaba.com/product-detail/aluminum-small-size-fixed-windows_173318836.html

http://tinyhouseblog.com/solar/morningstar-solar-home/


http://belowzerohvac.ca/heating-ottawa/radiant-heating-ottawa/

		Concepts			
		A		B	
		Transparent big jars		Mass floor	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Heat storage	25%	4	1	5	1.25
Heat delivery	25%	4	1	5	1.25
Small occupation	20%	2	0.4	4	0.8
Cheapness	20%	5	1	1	0.2
Uninfluence of light transmission	10%	3	0.3	3	0.3
	Total Score	3.7		3.8	
	Rank	2		1	
	Continue?	No		Yes	

- The second problem we met is heat loss through windows. Because we chose directly gain big size window, entering light, heat, and losing some heat would happen at the same time. Again, we developed concept screening and concept scoring to come up with the best solution: mass floor. Although mass floor costs more, as a design of ZEH, we thought the priority was the high efficiency of energy use, which was exactly the advantage of mass floor. In addition, we can divert money saved from windows to construct mass floor.

COST MODEL

TOTAL HOUSE COST

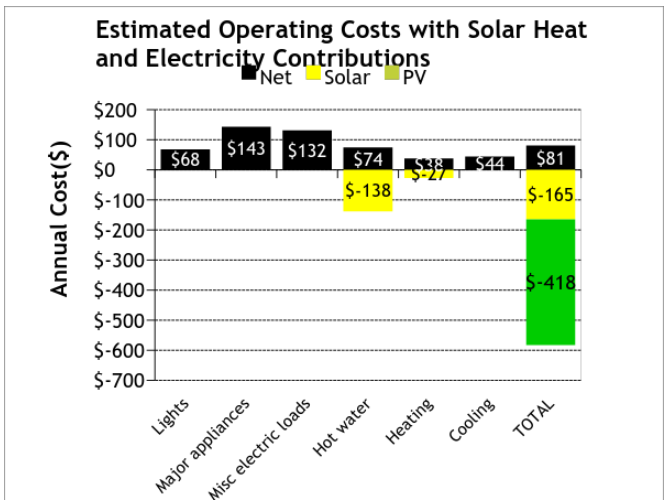
Base House Cost	$112566
PV Cost	$15900
Upgrade Costs	$11494
Total House Cost	$139960

DETAILS OF UPGRADE COSTS

Envelop & Systems	Type	Costs
Windows:	Super double low-e	2438.796306
Attic Insulation:	Ceiling insulation: R40	0
Walls:	Double 2*4 with 10” foam	102.8554247

Air Tightness:	Tight with heat recovery	1500
Water Heater:	Solar water heater	4220.833333
Heating System:	Electric heat pump	4894
Garage	Built-in garage	-1662
Pool	None	0
Hot Tub	None	0
Total upgrades costs:		11494.48506
Appliances:		2120

OPERATING COST

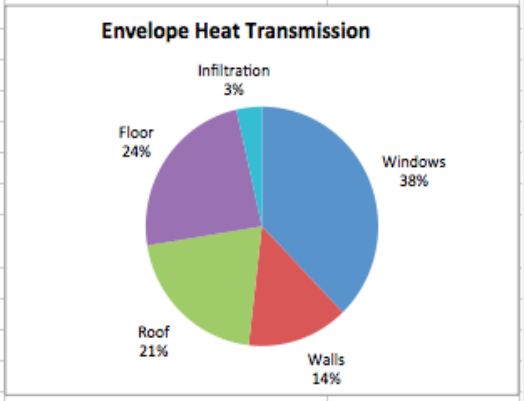


- The model we are choosing here is from Sharp, ND-240QCJ, the cost of this model is $334.18. This model has efficient rate of 24%, and will be able to provide enough energy for the modeled house by using 13 panels. The total area in which the solar panels will occupy the roof is 21.18 m^2

DESIGN

General Info	
Location	Harrisburg
Electricity cost ($/kwh)	0.1
House type	1 story
Conditioned floor area (sq.ft.)	894
Number of bedrooms	2
Envelope Details	
Wall construction	Double 2x4 with 10" foam
Ceiling Insulation	R40
Window type	Super double low-e
Upper floor ceiling area (sq.ft.)	1335
North wall area (gross) (sq.ft.)	333.7
East wall area (sq.ft.)	339
South wall area (sq.ft.)	193.75
West wall area (sq.ft.)	339
North window area (sq.ft.)	118.4
East window area (sq.ft.)	0
South window area (sq.ft.)	150.69
West window area (sq.ft.)	0
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Best
Clothes Washer	Best
Dishwasher	Best
Small Appliance Input	
Extras	
Garage	f. Built in 1 car
Hot Tub	a. None
Pool	a. None

Heating & Cooling	
Type of heating & cooling system	Electric heat pump
Solar Technologies	
Size of PV system (kw)	3.18
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	A lot
Thermostat setback	A lot
Heat thermostat setting (F)	53.6
Cool thermostat setting (F)	80
Results	



Base House Cost	$	112566
PV Cost	$	15900
Upgrade Costs	$	11494
Total House Cost	$	139960

- This graph includes specific dimensions and classification we chose for each part of the house.

- **Wall**:

The type of wall is double 2*4 with 10" foam with R-value 40. With the prerequisite of none influence of light entering, we can expand the area of wall to reduce heat transmission.

- **Window**:

South window has the largest area gain as solar source during daytime. The area of south window is 16% of area of floor area, the size being suitable for entering enough light and heat. In order to solve the problem of overheat during summer, we adopt overhangs. Moreover, mass floor will be laid to make up the disadvantage of heat loss through big size of windows. If all floor area of living room is mass floor, the size of it will be 2.47 times of that of south window.

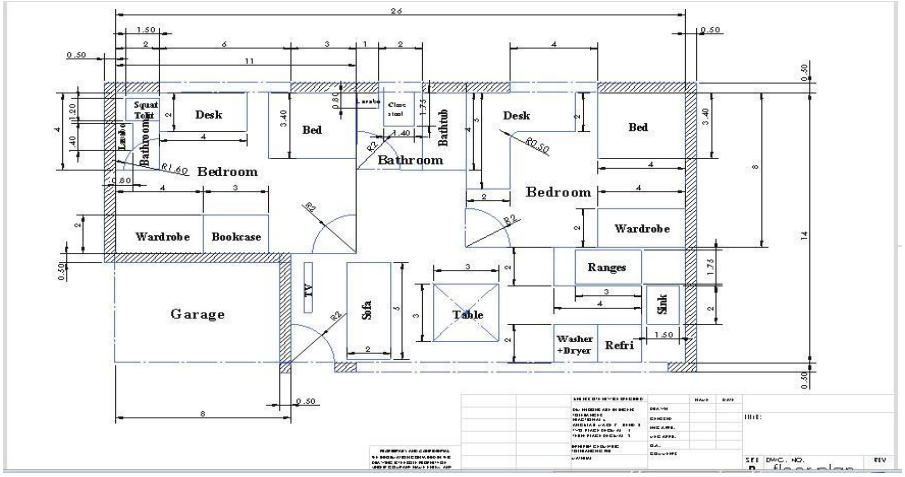
- **Room distribution**:

For a typical family with four people, we designed two bedrooms, one and a half bathroom, a living room, an open kitchen combined with laundry room, and a built-in garage. For two bedrooms, both of them will put murphy beds, which save the space as much as possible. Also in the two children's bedroom, bookcase as an insertion is built in the wall in front of desk. For the bathroom in the parents' bedroom, squat toilet is applied for saving space. Living room changes to dining room when a foldable table is put at the blank place. At last, a built-in garage, as the cheapest plan of garage, can service to store food as a refrigerator in winter.

- **Roof**

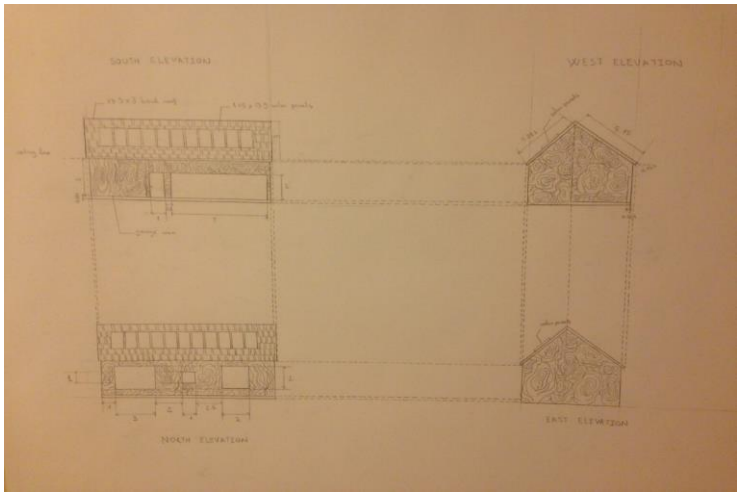
The roof towards south has slop with an angel of 45 degree, which was designed for allowing solar panels to attract as much as sun light. Also the slop increases the height of inner space and kept ventilation.

- **A more detailed floor plan is as following:**

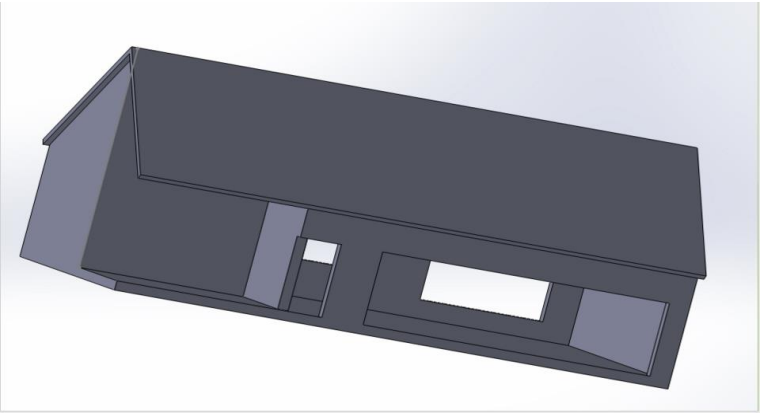


MODEL

ELEVATION DRAWING

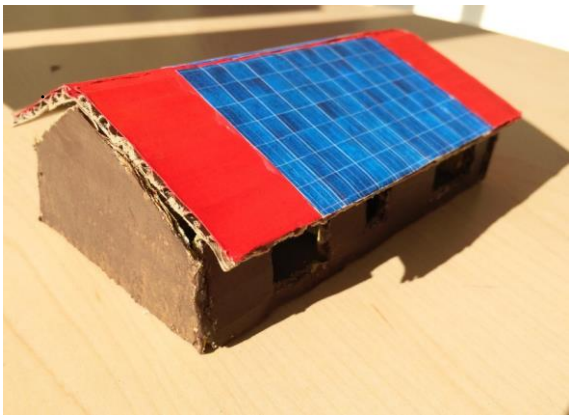


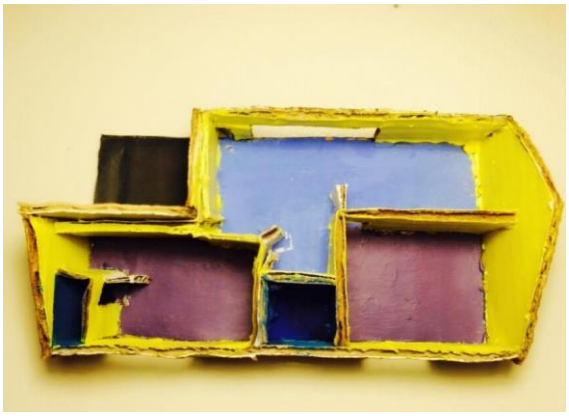
3D MODEL IN SOLIDWORKS



- The Solidworks model exhibits the outside appearance of the house.

3D MODEL MADE BY CARDBOARD





The above picture is the outside appearance, and the left picture is the inside appearance of the house

REFERENCE

- http://www.altenergy.org/renewables/renewables.html
- http://energy.gov/eere/buildings/zero-energy-ready-home
- http://www.greentechmedia.com/multimedia/the-zero-energy-home/
- http://www.greentechmedia.com/multimedia/the-zero-energy-home/
- http://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2015/ENU/Revit-Model/files/GUID-03EABD3A-4736-4762-97F8-F473FEE18162-htm.html
- http://www.solarworld-usa.com/solar-101/how-solar-panels-work
- http://www.impactglassindia.com/solaire-low-e-dg-glass.html
- http://www.prosalesmagazine.com/products/insulation/double-2x4-walls_o