Zero Energy Home

EDSGN 100

Section 014

Team 8

"Team 1"

Alejandro Cuevas

aec5480@psu.edu

Mitchell Higgins

mlh5670@psu.edu

Pat Bahls

prb5156@psu.edu

Sean Daniels

sjd5412@psu.edu

Submitted to: Professor Wallace Catanach

Pennsylvania State University

TABLE OF CONTENTS

Customer Requirements/City Selection……4

Executive Summary……5-7

Surveys……8-9

Research of ZEH's……10-12

Patent Research……13-16

Concepts Considered……16-23

Brainstorming for Concept Screening……24

Concept Generation……24-25

Concept Screening……26

Concept Selection……27

Final Concept……28-29

Conclusion……30

References……31

Introduction

As we enter this new century, we are more challenged than ever before to look towards a greener world. Our planet's resources will not be available for future generations if we don't take awareness of this issue. There are multiple ways in which can we achieve a more sustainable lifestyle. One of them is incorporating it into our homes.

Living in a more sustainable way doesn't always mean spending enormous amounts of money or sacrificing comfort. These two factors can be properly intertwined into a house with a proper design, and we aim to do so with this project.

With our design we seek to aim the needs of an American middle-class family of four incorporating renewable sources of energy. In doing so, we hope that our project will have a positive impact on a long-term by helping the Earth and by promoting awareness.

Customer Requirements

Number	Needs	Importance
1	The house needs to withstand cold winters and hot summers	5
2	The house can only cost $140,000	5
3	The house needs to accommodate a family of at least four residents	4
4	There needs to be photovoltaic systems for green energy	3
5	The ceiling has to have insulation with an R-value of at about 60	2
6	The house should include an electrical geothermal heat pump for heating and cooling	2

City Selection

We have selected the city of Philadelphia, PA as the location for our zero energy home. Philadelphia was selected because of its changing seasons and historic landmarks.

Population: 1.553 million people (2013)

Elevation: 40ft

Average warm season temperature: 77 degrees F

Average cold season temperature: 48 degrees F

Executive Summary:

John Doe is looking to have a new house created for his family in Philadelphia Pennsylvania. The objective of this project is to design a zero energy home that is able to withstand the changing seasons of the northeastern climate of Philadelphia. It needs to be able to withstand hot humid summers and long cold winters. This household needs to be able to produce and sustain itself with renewable energy. The house needs to accommodate a single family of four comfortably and have a maximum price of 140,000.

In developing this design, many options were taken into consideration. All of the customer needs were taken into consideration and discussed multiple times at meetings. These meetings were very helpful in evolving the design of this home. After brainstorming all of the ideas and plans, some basic standard parameters were established. The house needs to have photovoltaic systems to produce green energy to run the house. Along with this, the house will have a ceiling insulation with an r-value of 60 with the wall insulation being double

2x4's with 10" foam. This will give the walls an r-value of about 31. On one side of the house there will be a large aperture with a large thermal mass to absorb the heat. Also, the house should operate on an electric geothermal heat pump for heating and cooling. The home will be airtight with a heat recovery system.

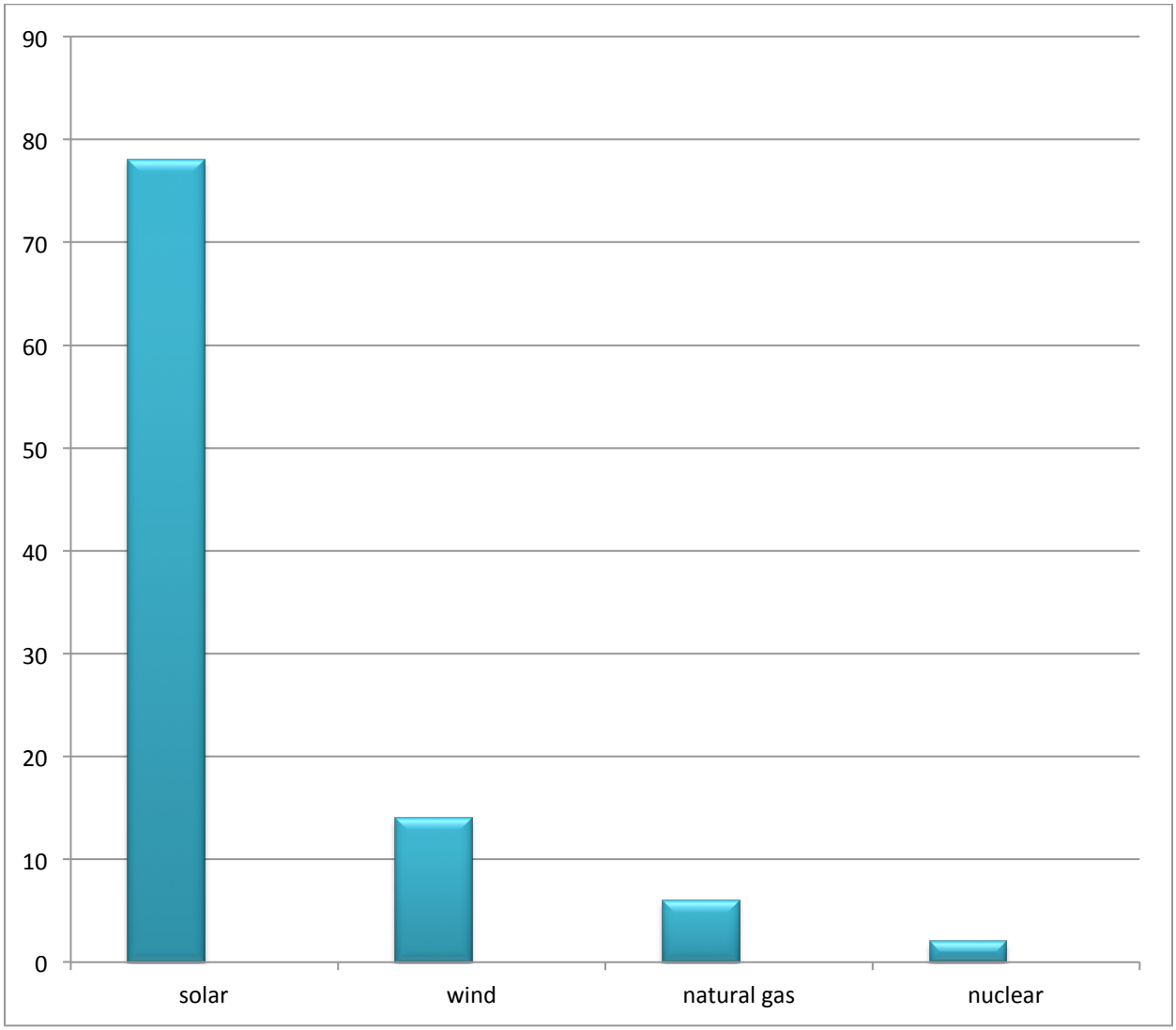
There are a few different risks and constraints associated with this design. The highest risk of this house will be able to make it last during all of the different changing seasons of Philadelphia. The house has to be able to withstand weather like snow and rain while still being able to create enough energy from the photovoltaic system to power the house. This risk will be avoided by making sure the house is designed properly to absorb the most amount of sunlight possible to create electricity. Also, the house will be made very structurally sound to make sure things like the solar panels don't break under the weight of snow. It could also be problematic to keep this house under budget and on schedule. However, we expect to be able to prevent this by having meetings weekly and by reviewing all the materials going into

the house to create it properly and be under budget. The final design is schedule to be delivered to John Doe on October 15th, 2014.

Surveys

100 people were asked: If you were to become president, which renewable energy would you give preference to?

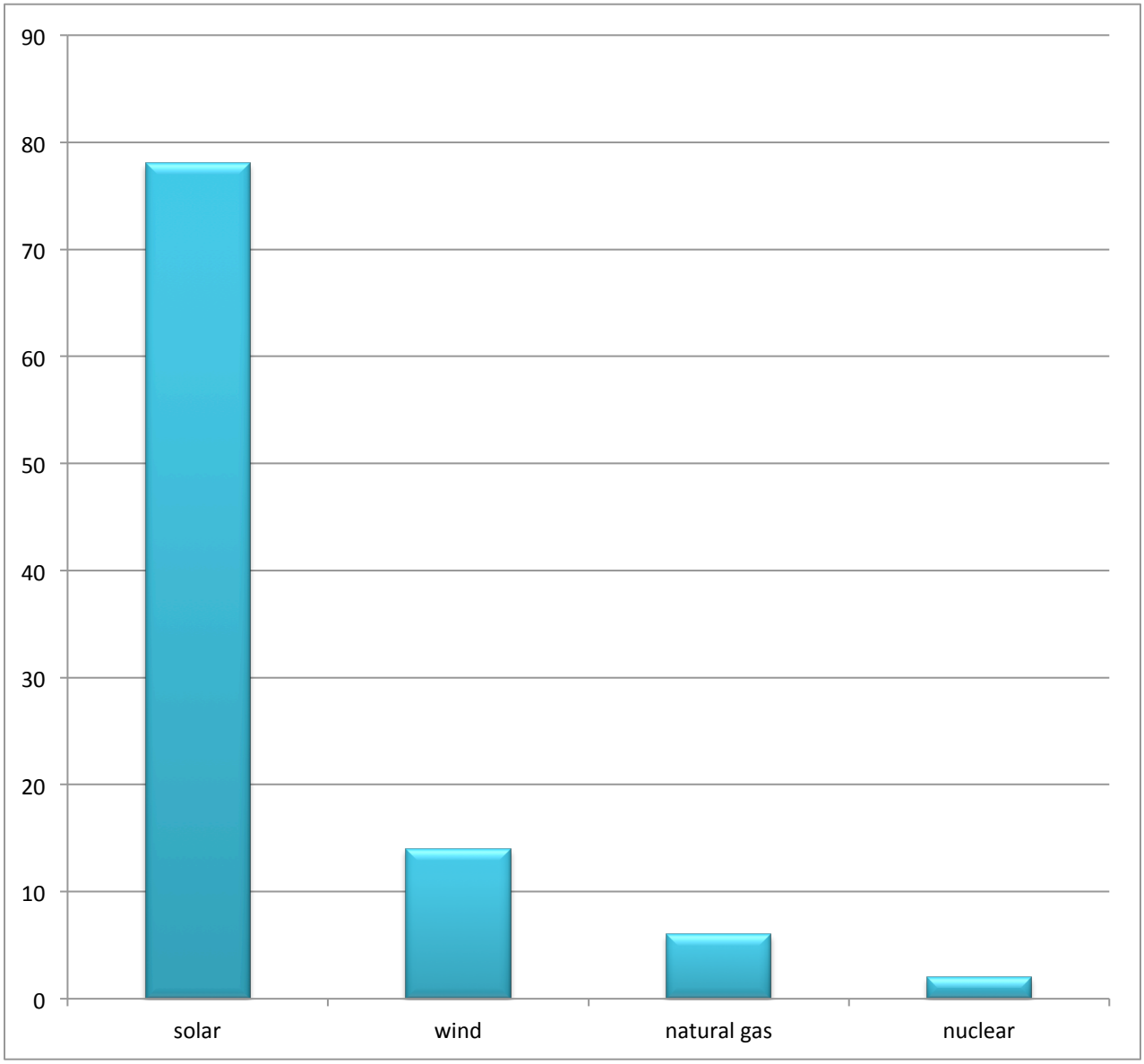
These are the results.



Penn State Survey

We personally conducted a survey of PSU students and asked them which renewable energy resource they thought would become the most useful in the future.

These are the results.



Research of ZEH's

In order to understand how zero energy homes are made, it was necessary to conduct research on other previously built homes. Some topics of research were house size, number of floors, number of occupants, number of bedrooms, heating systems, heating fuels, size of photovoltaic systems, ceiling r-value, wall r-value , and predicted energy use.

http://www.zdnet.com/

Location (city, state)	Turner Falls, Massachusetts
House size (floor area in square feet)	1,152 square feet
Number of floors	1 floor
URL of web site where info is found	http://www.builditsolar.com/Projects/SolarHomes/MAZeroEnergy/MAZeroEnergy.htm
Number of occupants	Single Family
Number of bedrooms	Three Bedrooms
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	Fujitsu 9RLQ mini-split air source heat pump
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Electricity from solar panels
Size of photovoltaic system (kilowatts)	5.56 kilowatts
Solar water heater (yes or no)	Yes
R-value of wall insulation	R=42
R-value of ceiling insulation	R=100
Ventilation air heat recovery (yes or no)	Lifebreath 155 ECM heat recovery ventilator with a high efficiency ECM motor
Predicted or measured annual energy use	1,949KWH
Any other pertinent info	

Location (city, state)	Charlotte, Vermont
House size (floor area in square feet)	2,700
Number of floors	2
URL of web site where info is found	http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/vermont-house-wins-10000-net-zero-energy-prize
Number of occupants	More than 2
Number of bedrooms	
Type of heating system (forced air, hydronic, radiant floor, heat pump, etc.	A 3-ton ground source heat pump
Main heating fuel (electricity, natural gas, wood, oil, etc.)	Electricity
Size of photovoltaic system (kilowatts)	10 kilowatt Bergey wind turbine
Solar water heater (yes or no)	No
R-value of wall insulation	1 inch thick foil-faced polyisocyanurate
R-value of ceiling insulation	
Ventilation air heat recovery (yes or no)	No
Predicted or measured annual energy use	6,269 kWh
Any other pertinent info	Won a 10,000 dollar prize

PATENT SEARCH:

Below is a list of patents that would be useful for our Zero Energy home.

United States Patent 7,941,975

Ingjaldsdottir , et al. May 17, 2011

Affordable, sustainable buildings comprised of recyclable materials and methods

thereof

Abstract

An affordable, sustainable building, comprising substantially entirely mass-produced, prefabricated constituent parts manufactured off-site, the prefabricated constituent parts comprising a foundation, a frame module comprising a plurality of frames, wherein the frame module is secured to the foundation, a reversible connector to connect the plurality of frames to form the frame module, a wall panel configured to be mounted onto the frame module, a floor panel configured to be mounted onto the frame module, and a ceiling panel configured to be mounted on to the frame module. Each constituent part forms part of a library of parts from which the constituent parts are selected. The

constituent parts are preferably made in standardized sizes to facilitate efficient mass production. The constituent parts are predominantly made of recyclable material so as to be environmentally friendly. Computer software may be developed to facilitate design and construction of the affordable, sustainable building and to calculate proper attachment points for lifting and moving frame modules.

United States Patent 6,329,589 Tang , et al. December 11, 2001

Solar Panel

Abstract

A solar panel arrangement for capturing solar energy and supplying power for use in a building. Solar cells are embedded in a window pane and generate electrical direct current that is converted, by an electrical circuit permanently attached to the pane, to an oscillating current that is fed to a ferrite core mounted to the pane. An external ferrite core is mounted in close proximity to the core, so that the oscillating current

can be picked up and supplied to a building. The arrangement allows window panes to be pre-formed or manufactured with certain built-in electrical components, and, without the need for skilled labor, to be easily connected to a power circuit external of the window pane.

Patent 8,791,417Scelzi , et al. July 29, 2014

Determining energy consumption in a structure

Abstract

Methods, apparatus, and systems are provided for measuring the supply of a consumable product/energy source, such as electrical power, to a facility over time and analyzing the measurements to determine the consumption or supply of the product by one or more loads and/or sources in the facility, and to determine induced and residual heat flow through the facility's envelope. Various aspects compare the measured supply of the consumable product to a database of consumption signatures, which characterize access to the consumable product by particular users. Operating conditions and

facility characteristics, such as temperatures, load factors, insulation factors, etc., may be further considered in determining a particular user's access of the consumable product. To aid in the controlling of energy use, thermal resistance factors of the building are determined, which are based on the induced and residual heat flow through the facility.

Concepts Considered

The group unanimously decided on a basic design for the house: the energy sources, the basic structure, insulation, and the window type. Variables such as the PV system, for instance, were calculated on the energy consumption of an average American family. According to the U.S. Energy Information Administration, a typical an average family uses 10,837kWh per year. 1kW of photovoltaics will produce approximately 1300kWh per year. Therefore, by dividing 10,837kWh

(the yearly consumption) with the photovoltaic capacity we can estimate the PV system that we'll need. In this case it is 8,34kW.

We can later deduce the size of our PV system by using the data we obtained before. 100 square feet of high-efficiency solar panels are equivalent to 1kW. Therefore, considering Philadelphia's climate and the available size of the house's roof. We opted for a 10.0Kw PV system.

This variable, as well as the appliances, water savings, thermostat settings, insulation materials (foam, windows, etc), and air tightness stayed the same throughout the three concepts. However, a concept selection was necessary to select the best dimension for the house: window sizes, wall sizes, floor dimensions, ceiling dimensions, interior design, costs, and aesthetics.

1 Story Design

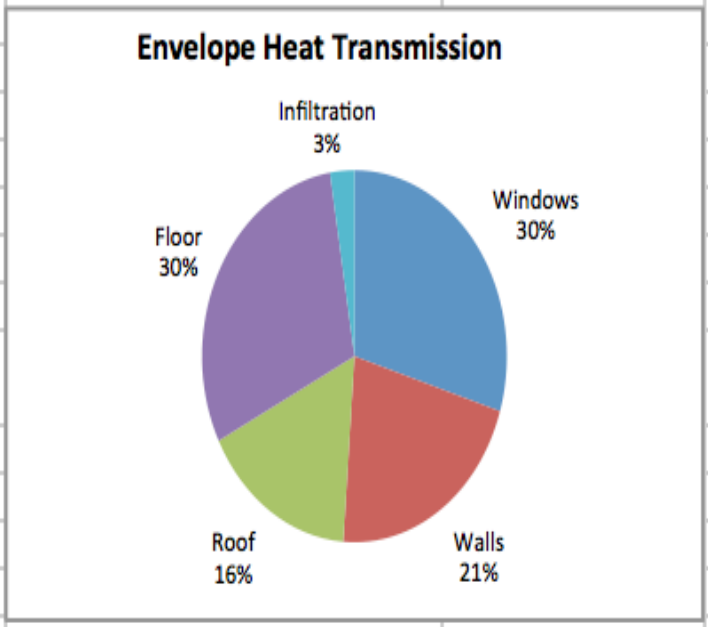
enn State Center for Sustainability

General Info	
Location	Philadelphia
Electricity cost ($/kwh)	0.1
House type	1 story
Conditioned floor area (sq.ft.)	600
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.)	1536
North wall area (gross) (sq.ft.)	480
East wall area (sq.ft.)	320
South wall area (sq.ft.)	480
West wall area (sq.ft.)	320
North window area (sq.ft.)	10
East window area (sq.ft.)	80
South window area (sq.ft.)	153
West window area (sq.ft.)	40
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Energy Star
Clothes Washer	Energy Star
Dishwasher	Energy Star
Small Appliance Input	
Extras	
Garage	a. None
Hot Tub	a. None
Pool	a. None

Zero Energy Home Calculator

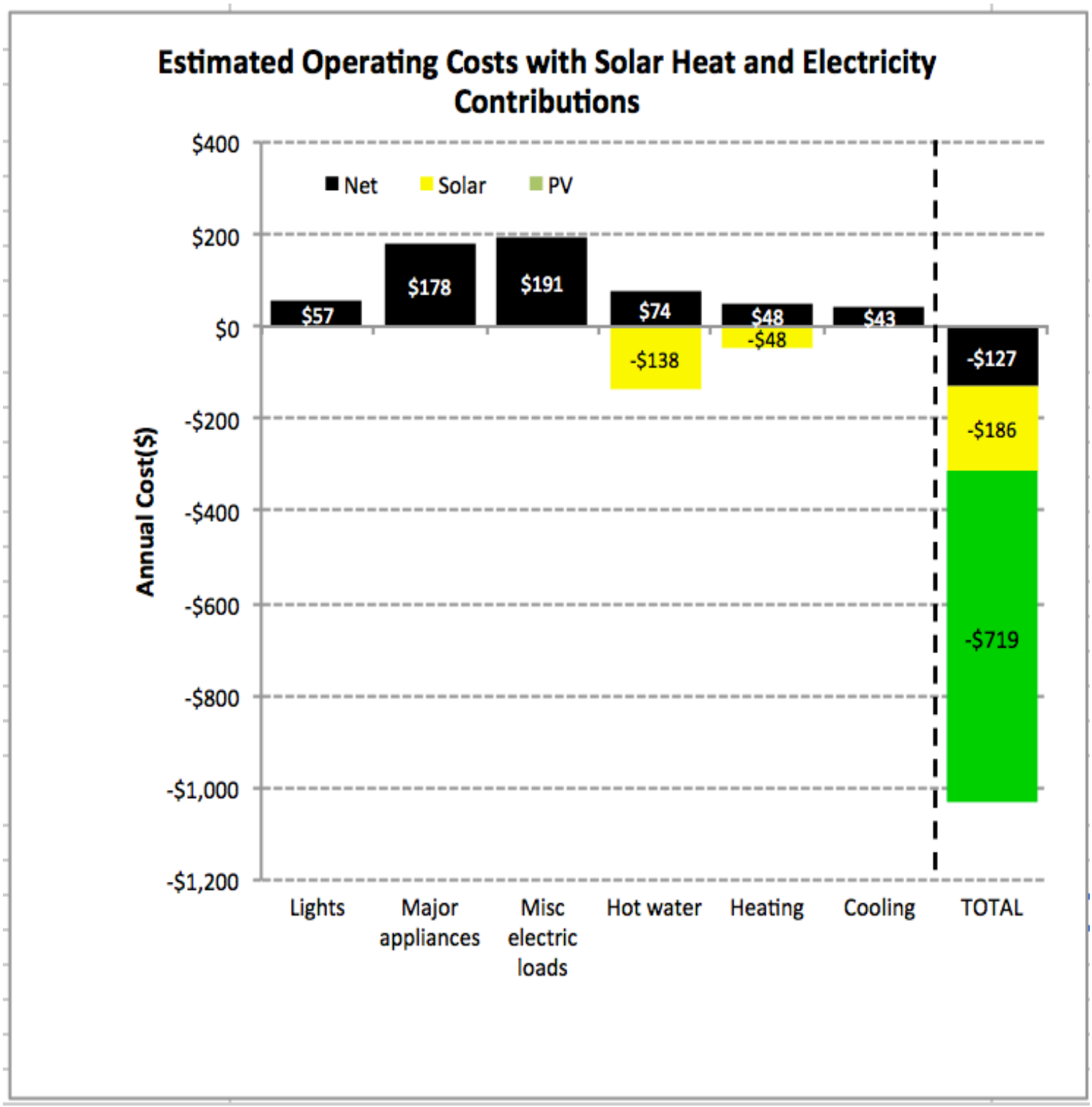
Heating & Cooling	
Type of heating & cooling system	Electric geothermal heat pump
Solar Technologies	
Size of PV system (kw)	5.35
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	Some
Thermostat setback	Some
Heat thermostat setting (F)	70
Cool thermostat setting (F)	76

Results



Base House Cost	**$**	**93,129**
PV Cost	**$**	**26,750**
Upgrade Costs	**$**	**19,699**
Total House Cost	**$**	**139,578**

Operating Cost



1.5 Story House

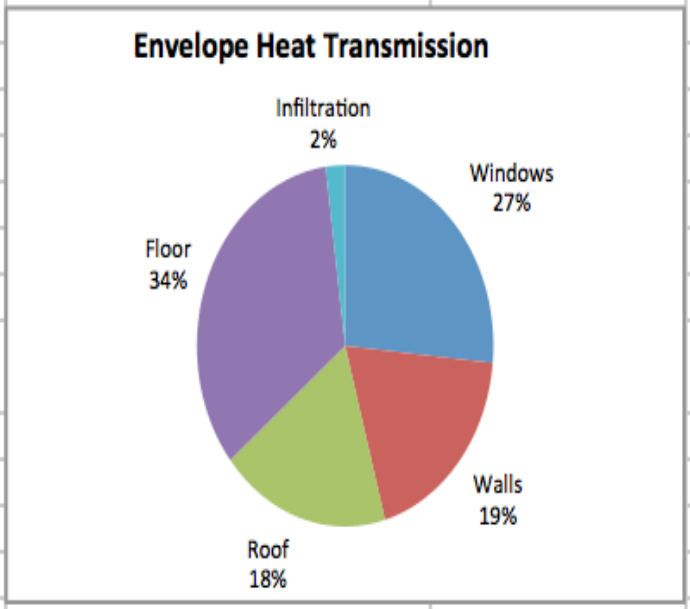
Penn State Center for Sustainability

General Info	
Location	Philadelphia
Electricity cost ($/kwh)	0.1
House type	1.5 story
Conditioned floor area (sq.ft.)	600
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.)	2120
North wall area (gross) (sq.ft.)	480
East wall area (sq.ft.)	360
South wall area (sq.ft.)	530
West wall area (sq.ft.)	380
North window area (sq.ft.)	15
East window area (sq.ft.)	80
South window area (sq.ft.)	173
West window area (sq.ft.)	40
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Energy Star
Clothes Washer	Energy Star
Dishwasher	Energy Star
Small Appliance Input	
Extras	
Garage	a. None
Hot Tub	a. None
Pool	a. None

Zero Energy Home Calculator

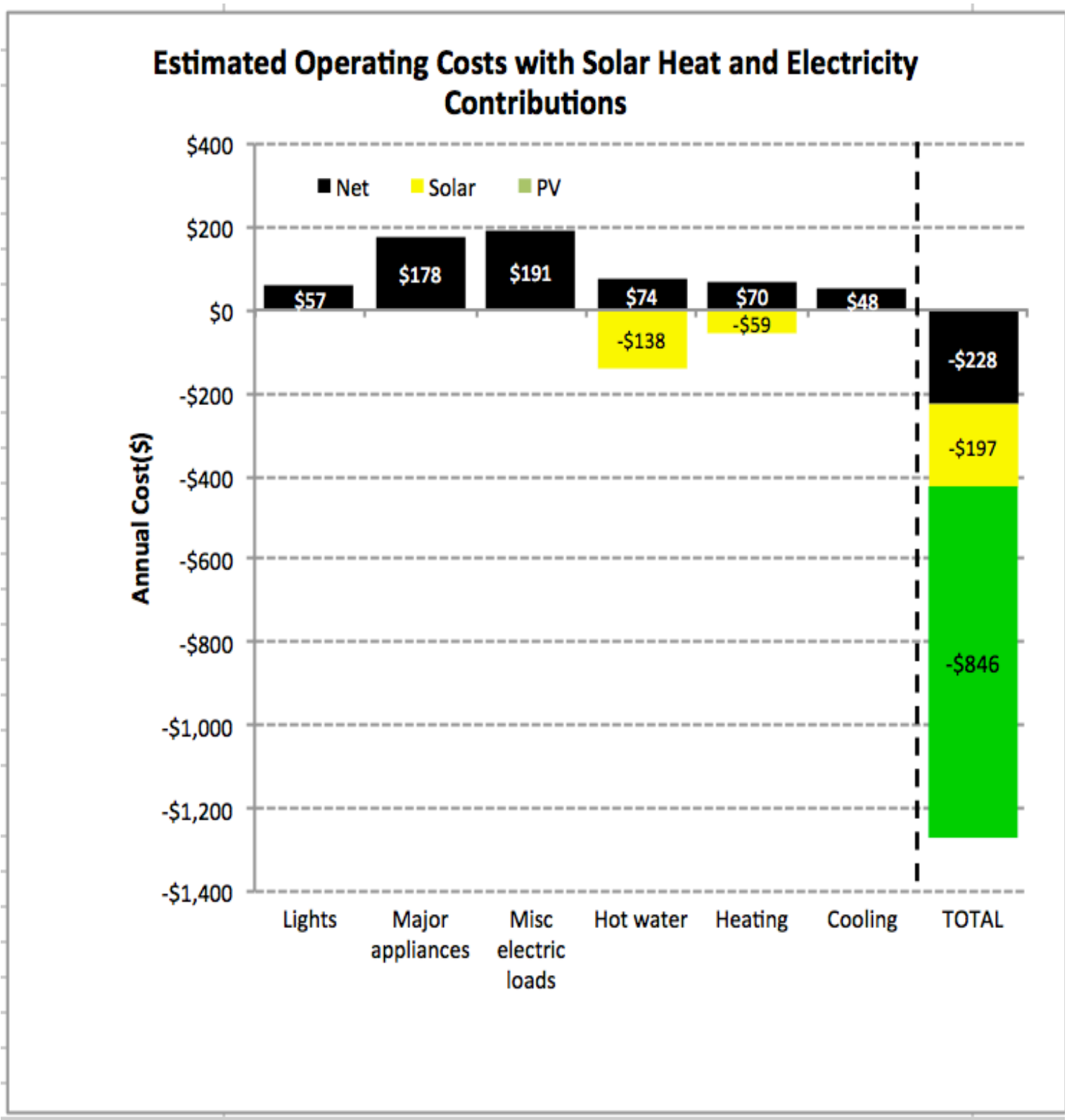
Heating & Cooling	
Type of heating & cooling system	Electric geothermal heat pump
Solar Technologies	
Size of PV system (kw)	6.30
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	Some
Thermostat setback	Some
Heat thermostat setting (F)	70
Cool thermostat setting (F)	76

Results



Base House Cost	**$**	**98,951**
PV Cost	**$**	**31,500**
Upgrade Costs	**$**	**19,803**
Total House Cost	**$**	**150,254**

Operating Cost



2 Story Design

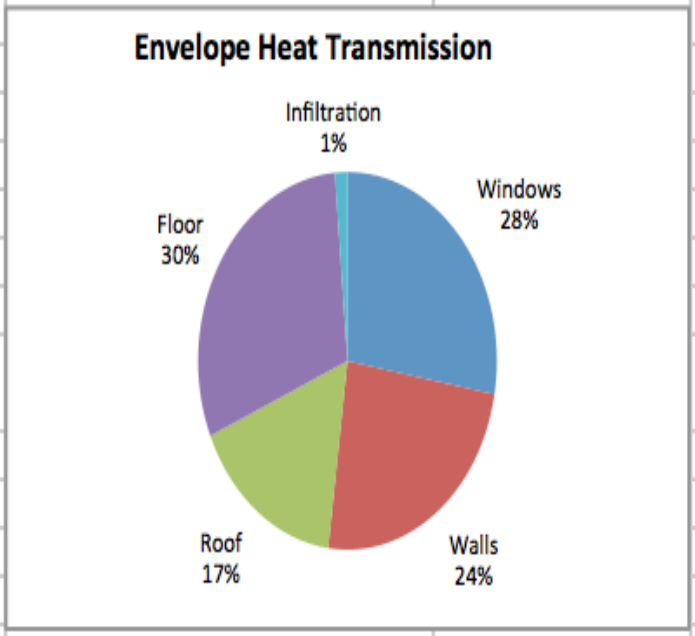
Penn State Center for Sustainability

General Info	
Location	Philadelphia
Electricity cost ($/kwh)	0.1
House type	2 story
Conditioned floor area (sq.ft.)	600
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.)	2960
North wall area (gross) (sq.ft.)	960
East wall area (sq.ft.)	720
South wall area (sq.ft.)	960
West wall area (sq.ft.)	720
North window area (sq.ft.)	30
East window area (sq.ft.)	120
South window area (sq.ft.)	296
West window area (sq.ft.)	60
Air tightness	Tight with heat recovery
Appliances	
Refrigerator	Energy Star
Clothes Washer	Energy Star
Dishwasher	Energy Star
Small Appliance Input	
Extras	
Garage	a. None
Hot Tub	a. None
Pool	a. None

Zero Energy Home Calculator

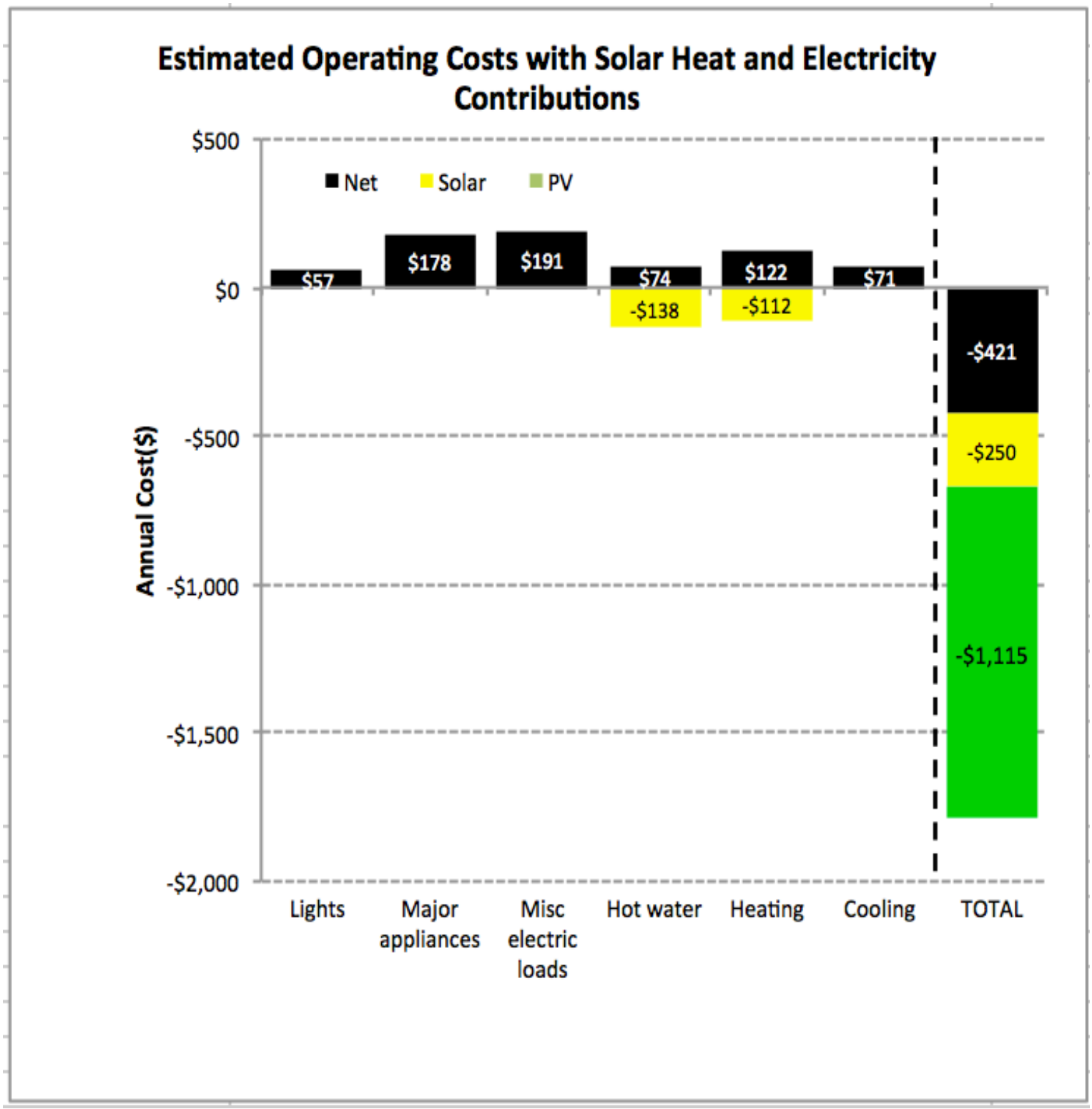
Heating & Cooling	
Type of heating & cooling system	Electric geothermal heat pump
Solar Technologies	
Size of PV system (kw)	8.30
Solar water heater	Yes
Behavior	
Water conservation	A lot
Uses clothesline	Some
Thermostat setback	Some
Heat thermostat setting (F)	70
Cool thermostat setting (F)	76

Results



Base House Cost	$	105,609
PV Cost	$	41,500
Upgrade Costs	$	21,723
Total House Cost	$	168,832

Operating Cost



Brainstorming for Concept Screening

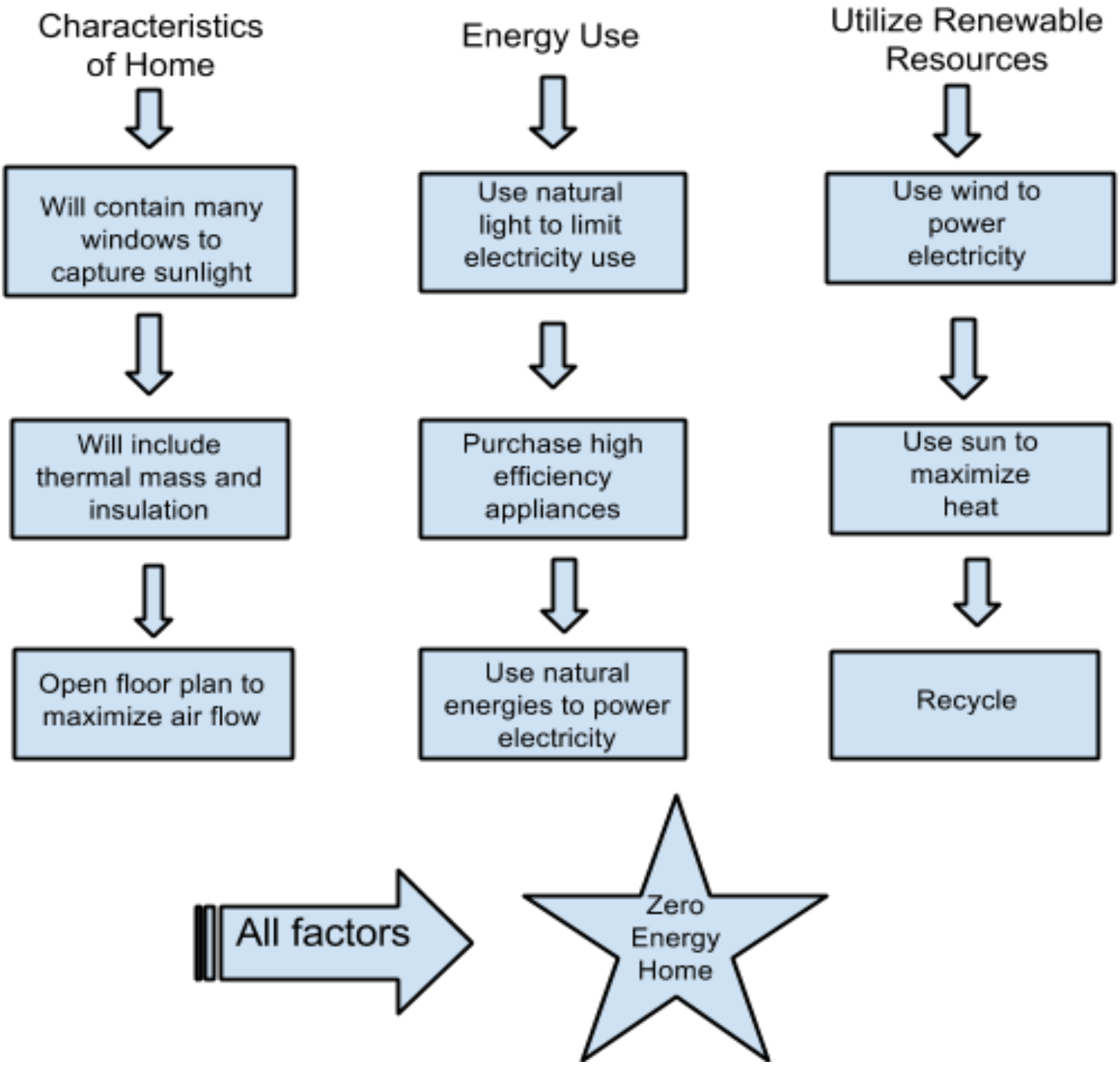
- House is conveniently located--suburban location but also near a city
- House is architecturally appealing
- Has a yard that kids can play in
- Set in an area with an appealing landscape
- House produces enough energy to power daily activities of a family of four
- House has enough windows to heat thermal mass
- House can function in a Pennsylvania climate

Concept Generation:

Problem: Because modern society is becoming more technologically advanced, energy consumption is on the rise. And as a result, the world is quickly using up its limited energetic resources (oil, coal, gas, etc.). In addition to being limited, these forms of energy can prove harmful to the environment. Therefore, one can obviously see that alternate and clean forms of energy must become readily available for societal use. However, alternate forms of energy can often be expensive and inconvenient to use. As a result, our goal is to develop an **affordable**

zero energy home that diminishes the use of the Earth's precious resources. Also, this house must be as livable as a normal home.

Diagram



Concept Screening

	Concepts		
Selection Criteria	A	B	C
	1 Story Design	1.5 Story Design	2 Story Design
Comfort (Size)	-	+	++
Aesthetically pleasing	0	+	+
Open-space design	++	0	-
Natural ventilation	+	+	0
Glazing	+	+	+
Passive solar design	++	+	0
Affordable base cost	+	-	-
PV Size	-	+	+
Overall energy efficiency	+	+	+
Heating effectiveness	+	+	-
Sum +s	9	8	6
Sum 0s	1	1	2
Sum -s	2	1	3
Net score	7	7	3
Rank	1	2	3
Continue?	Yes	Yes	No

Concept Selection

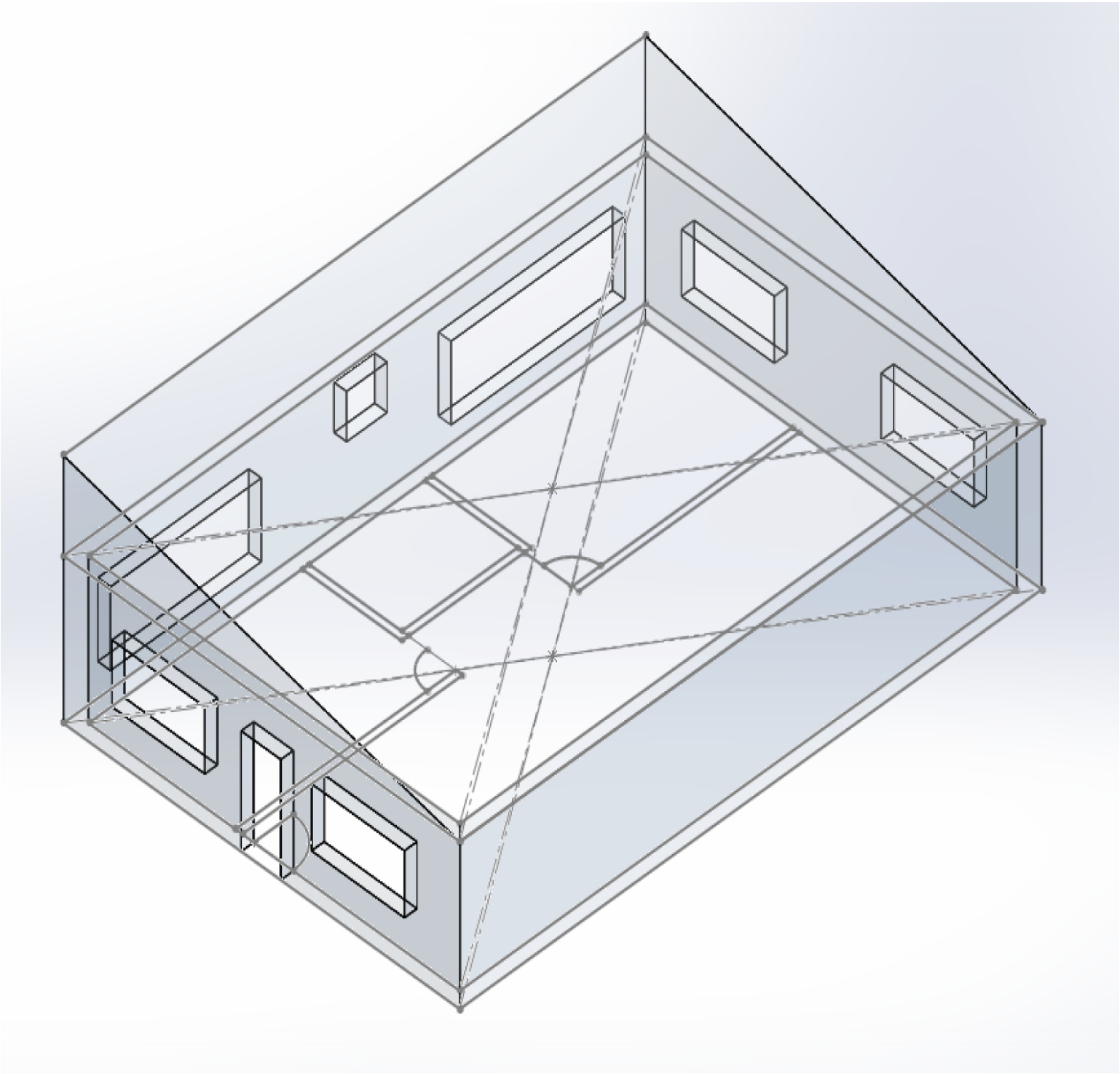
	1 Story Design			1.5 Story Design	
Selection Criteria	Weight	Rating	Weighted Score	Rating2	Weighted Score3
Comfort (Size)	5%	2	0.1	3	0.15
Aesthetically pleasing	5%	2	0.1	3	0.15
Open-space design	10%	5	0.5	3	0.3
Natural ventilation	10%	4	0.4	4	0.4
Glazing	5%	4	0.2	4	0.2
Passive solar design	15%	5	0.75	4	0.6
Affordable base cost	15%	4	0.6	2	0.3
PV Size	15%	4	0.6	3	0.45
Overall energy efficiency	10%	4	0.4	4	0.4
Heating effectiveness	10%	4	0.4	4	0.4
Total Score			4.05		3.35
Rank			1		2
Continue			Yes		No

Final Concept

With our concept generation we managed to establish a design that satisfied most of our customer needs. We desired to design a house that could satisfy the requirements of an average American family completely with solar energy. This was not possible due to budget constraints (the size of the Photovoltaic System). Nonetheless, we assume that our final customer has a reduced annual consumption of energy (hence the desire to buy a ZEH). This means that despite the fact that the PV size will not be able to completely sustain the typical American family, it will at least satisfy a good percentage of our targeted customer's energy requirements.

According to our research, 5.35 kW of photovoltaic capacity translates to 6955 kWh annually. Considering the house's appliances (refer to the 1 Story Concept Graphs) and energy-saving tendencies, we can safely affirm that the provided PV size will fulfill a great part (75-85%) of our customer's energy requirements, making this concept a suitable design.

By taking all these factors in count, we settled for the 1 Story House concept, and we proceeded to choose it as our final design.



Overall, as a team we were able to develop and create the best possible house to meet all of our customer's needs within the price budget. The house was able to be created with a price of $139,578 so it was just under our budget of $140,000. In terms of making the home zero energy, we were slightly off in that. The photovoltaic system that was put into this home is a 5.35 KW system which covers about 75%-80% of the electricity costs. With a little bit more budget we would have been able to create a home with a net energy of zero. Even with this small problem, we still believe that our customer is very happy with this home. It fits perfectly with a family of four being about 1,500 square feet. We have also learned to think bigger about zero energy than just with this home, this has shown us that the world needs to start moving in the direction of zero energy homes and the use of renewable resources.

Final prototype

References

1. http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3
2. http://www.mcmurrayandsons.com/MCQuestions.htm
3. www.alternatives-energy-news.info/survey-alternative-energy-sources-vital-survival/