NET ZERO

CALVIN Engineering

ENGR333 Classes A&B

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Technical Memo

From: ENGR 333 Classes A&B
To: Professor Heun
Date: 12/16/2014

Introduction

The net-zero homes project that this class worked on throughout the semester was designed to determine what it would take to bring a home in Grand Rapids, Michigan to the status of net-zero and whether or not it is feasible to do so. The idea behind a net-zero home is to reduce the energy usage in the home, whether it is by lifestyle changes, insulation additions, or by appliance upgrades, and then produce the remaining energy deficit from renewable sources, so that the homeowner has a net usage of zero at the end of the year. This report details the steps which each design team took to determine whether it was feasible for their client's home to achieve net-zero status as well as an overview of the technologies used to achieve this status.

Procedure

For the design teams to come up with a design that would work for the home, a three step process was used. In short, the steps were as follows: understanding the home's energy usage, identification of energy reduction areas, and designing an energy production plan.

Each team met with their client to obtain the energy (both from gas and electricity) data of the home over a certain period of time. This data was plotted and analyzed to determine usage averages and the costs associated with these usages. Plotting the data was helpful in identifying the baseline average usage for electricity and gas. This helped differentiate what components in the home were contributing the most to the overall usage in the home. The energy bills, coupled with the other resources such as Home Energy Saver[1], gave the teams an accurate breakdown of where the energy was being used in the home. Some of the teams even used Kilo-A-Watt in the home to determine exactly how much could be saved with an appliance upgrade. Once the home's energy usage was known, the teams were able to identify the areas where improvements could be made.

Some teams identified older appliances as the easiest way to make energy reductions, while others chose to upgrade the lights in the home from incandescent to LED. The savings associated with these changes were found by estimating the time in use, then comparing the electricity draw of the existing unit to the substitution to find the savings. Another area of reduction many teams chose to pursue was a reduction in natural gas usage, by incorporating a geothermal system which is discussed in Appendix A. Some teams even recommended lifestyle changes to reduce electricity usage. When the energy reductions were subtracted from previous usage calculated in step one, the amount of energy needed for production was found.

Teams then began researching energy production methods to meet the remaining amount of energy used after reductions. Most teams settled on implementing a solar photo-voltaic panel array to make up some of the electricity deficit. Other teams recommended slightly different methods of making up the energy deficit. These generation options are discussed in the technology breakdown in Appendix A. The generation plans were designed to be the most cost effective methods to produce electricity, and each one allowed the homeowner to become net-zero. This is shown visually in the "Becoming Net-zero" graph included in each group's appendix. These graphs incorporate initial usage, energy reductions and energy generation into one simple graph which helps to identify trends between the groups. These graphs are further explained in Appendix B.

[1] http://homeenergysaver.lbl.gov/consumer/

Findings/Results

Extensive group and individual research left project teams with many similar decisions on energy saving and production measures. Six of the eight teams chose geothermal systems to handle the majority of their home's heating and cooling needs. These systems added significant electrical energy demand to the homes in which they were utilized, but the coefficients of performance (COP's) of at least 3.0 associated with these systems made them extremely viable for displacing natural gas heating and electrical air-conditioning. Every team used solar PV panels as well, powering the base electrical demand each home and providing additional power for geothermal systems in the homes implementing this technology. Solar panels were especially necessary for homes with geothermal systems, as the geothermal systems require a large amount of electricity to run and producing electricity is less expensive than purchasing it from the grid.

A common theme in individual group results was implementing a technology that was possible to get to net-zero, but not economically feasible. Most net-zero home implementations offered exceedingly long payback periods, leading groups to conclude that living in a net-zero home was more of a lifestyle choice than a financially-beneficial decision.

There were a few situations and results unique to single groups. The most significant of these was Team 5's development of a net-zero project proposal with a realistic investment requirement and payback period. The team attributed this conclusion mainly to the availability of land on the property to produce fuel for a wood burning stove in a self-sufficient manner. See Appendix C5 for details on the rest of the project. Team 6 also took on a unique project: a home that already produced some of its own electricity using solar panels. This required the team to get creative in additional energy production measures, leading to their decision to use evacuated solar thermal tubes. See Appendix C6 for details on this energy production method.

Conclusion

When seeking to make a home net-zero, the ENGR 333 students recommend first taking small steps towards energy efficiency. These steps include: making the transition from compact fluorescent and incandescent lighting to LED lighting, adding more efficient appliances within the home, adding and maintaining a well-insulated home, and cutting out some of luxurious lifestyle features within the home. The initial cost for making the conversion to LED lighting varied from home to home, but the payback period remained relatively similar. On average, the payback period for implementing LED bulbs was 2 years. When making the change to more efficient appliances, the payback periods vary but overall to help reduce energy consumption and greenhouse gases. Depending on the state of your current appliance, it will it make sense to exchange it with a more energy efficient one. When it comes to the state your house is currently in, insulation installation costs range from hundreds to a couple thousand dollars (as seen in our studies) and the payback period turns out to be around 12 years on average. Lastly, making lifestyle changes can greatly reduce the amount of energy used in a home. Lifestyle changes are easy steps that may be taken by a family to reduce energy use on a day-to-day basis. Quite obviously, the payback period is 0 years, but depending upon the changes enacted, the house could go on to see drastically reduced energy consumption.

In regards to implementing energy production systems, the class found solar panels feasible for homeowners who are committed to living within their home for quite some time, as we were able to get an average payback period for solar panels of 30 years. This is only feasible because unlike wind turbines, solar panels are rated for a much longer time which outlasts the payback period. While looking into wind energy generation options, the class does not recommend it as a solution to reach net-zero. With wind turbines come restrictions and regulations in order to maintain a safe community/environment. Another aspect that deems wind energy as not feasible is the high capital investment with a payback period greater than 40 years. Lastly, when looking for an option to heat the home, six out of eight house chose to use a geothermal system. With a geothermal system, the ENGR 333 class did not find it feasible to implement this system because of the high initial cost and a return on investment of 40 years.

Appendix A: Technology Breakdown

Throughout the course of this project, many common technologies were used in the effort to reach Net Zero. For convenience and ease of understanding, the following tables and discussion provide an overview of these technologies including name, function, and key factors of each. Table 1 describes the common technologies used for energy reduction. Table 2 describes technologies chosen for energy generation. Finally, Table 3 indicates which technologies were recommended by each project team, organized by customer name.

Table A1: Energy Reduction Technologies

Technology	Function	Key Factors
Alternative Lighting	Light-emitting Diode (LED): a two-lead semiconductor light source	Wattage, lumens
Building Envelope	Insulates against heat loss (Ex. Insulation, windows)	R-Value
Appliance Efficiency	Increases electrical or gas efficiency of household appliances.	Energy-Guide, Energy Star, wattage

Table A2: Energy Generation Technologies

Technology	Function	Key Factors
Solar PV	Solar Photovoltaic panels convert light energy into electrical energy	Efficiency, degradation, solar hours per day
Wind Turbine	Converts kinetic wind energy into electrical energy	Average wind speed, efficiency
Geothermal	Geothermal heat pumps exchange energy with the earth for heating and cooling	Horizontal loop vs. vertical loop, depth
Wood Furnace	Converts biomass into heat energy by means of combustion	Heating value, efficiency
Solar Absorption Heating	Solar energy is used to heat fluid in a solar collector	Roof space, shade, solar hours per day

Table A3: Technologies Recommended

Home	LED	Building Envelope	Appliance Efficiency	Solar PV	Wind	Geothermal	Wood Furnace	Solar Absorption Heating
Affholter	X		X	X		X		
Boer	X	X	X	X		X		
Cooper	X		X	X		X		
DeMaagd		X	X	X		X		
Evenhouse	X			X			X	
Heffner		X	X	X				X
Koetje		X	X	X		X		
Newhof	X		X	X	X	X		

Appendix B: Net-Zero Energy Graph Explanation

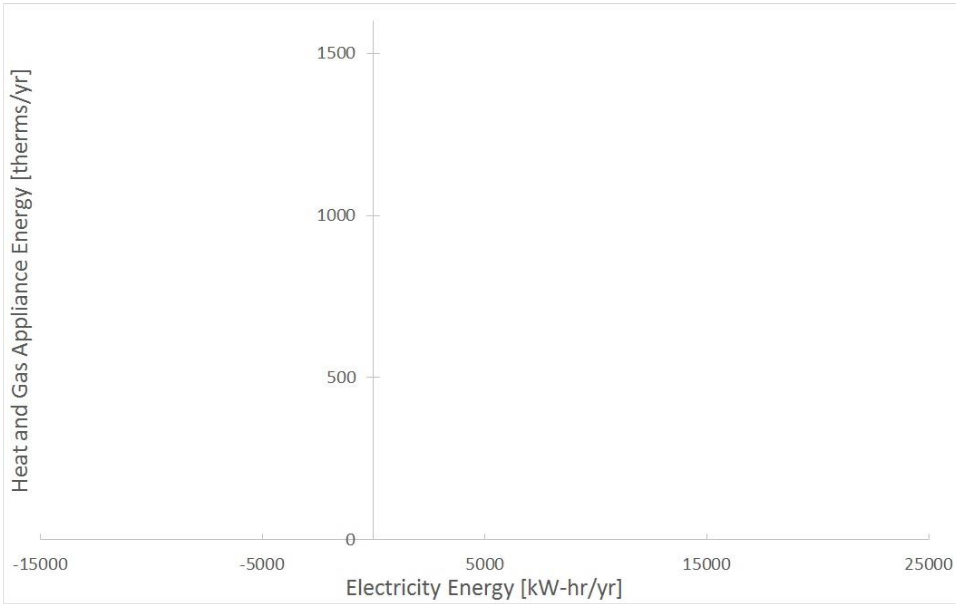

Figure B1. Axes of Net-zero Energy Graph

Each group deemed it appropriate to use similar graphical representation of their data.

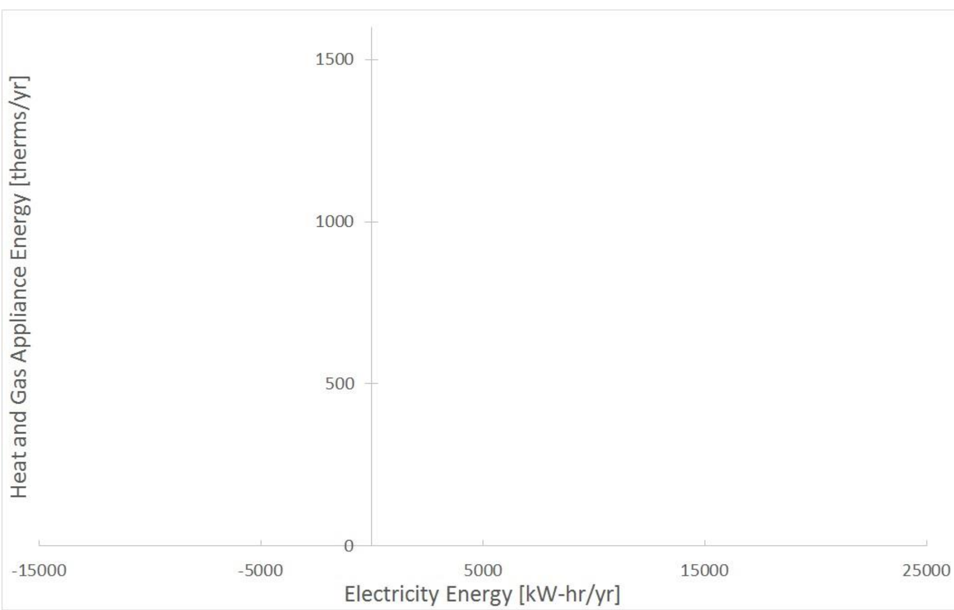

Figure B1 above is the template used by each group. The X-axis depicts the amount of electrical energy the house used on an annual basis. The Y-axis depicts how much gas energy the house used on an annual basis.

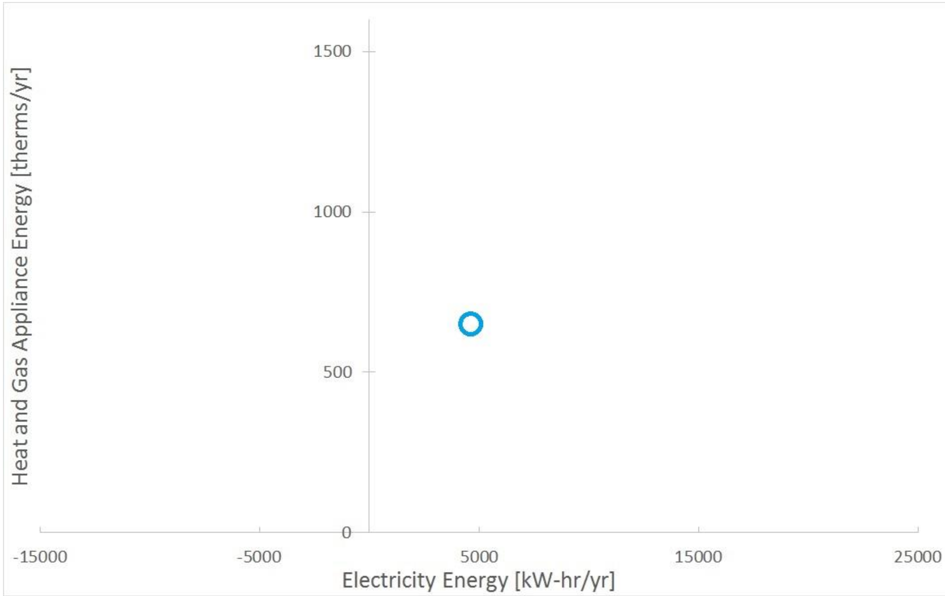

Figure B2. House Starting Point

The circle in Figure B2 represents the house energy consumption. For this example, it can be seen that annually, the house uses roughly 5000 kWh of electricity and 700 therms of natural gas.

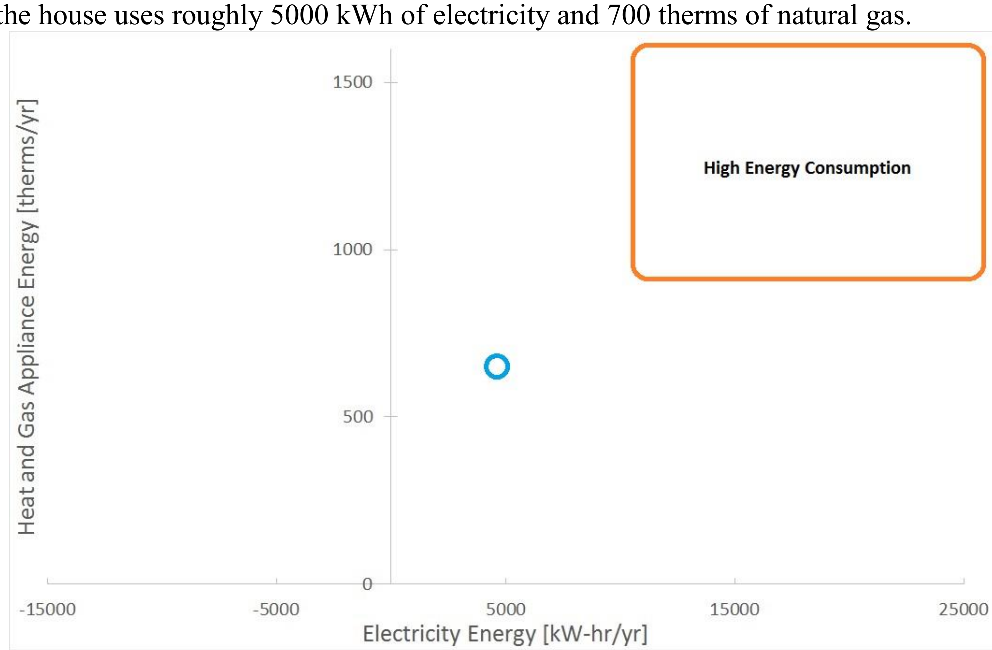

Figure B3. High Energy Consumption

The orange box located in the upper right portion of Figure B3 represents high energy consumption. Any of the houses represented by the circles located in this region will most likely have low efficiency appliances and low efficiency lighting, among other low efficiency aspects. Consuming this much energy is not desirable for the customer.

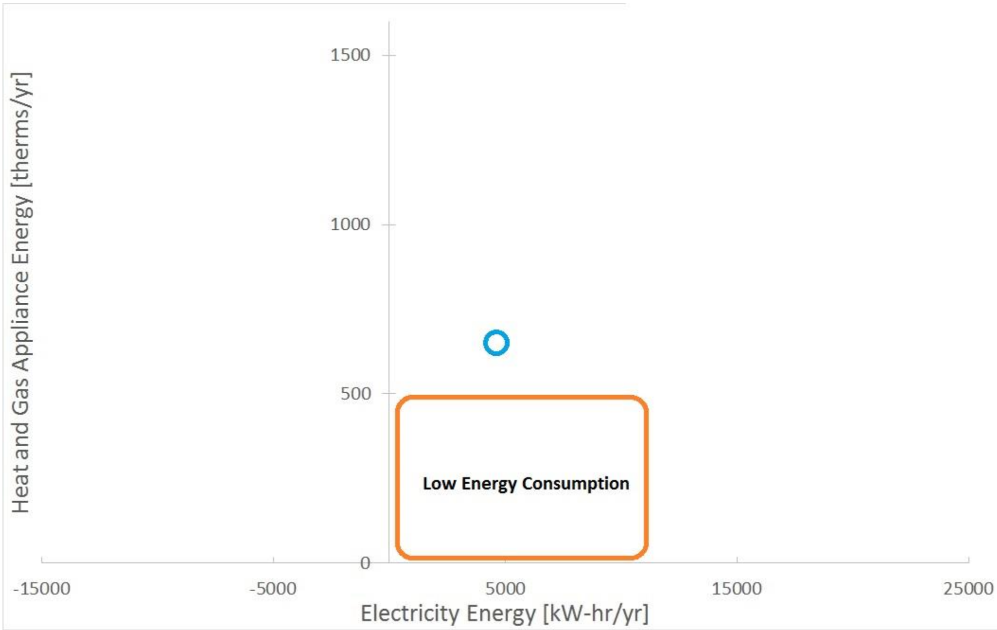

Figure B4. Low Energy Consumption

Any house located in the orange box in Figure B4 would be considered desirable and most likely to have high efficiency appliances or to be occupied by individuals living energy conscious lifestyles.

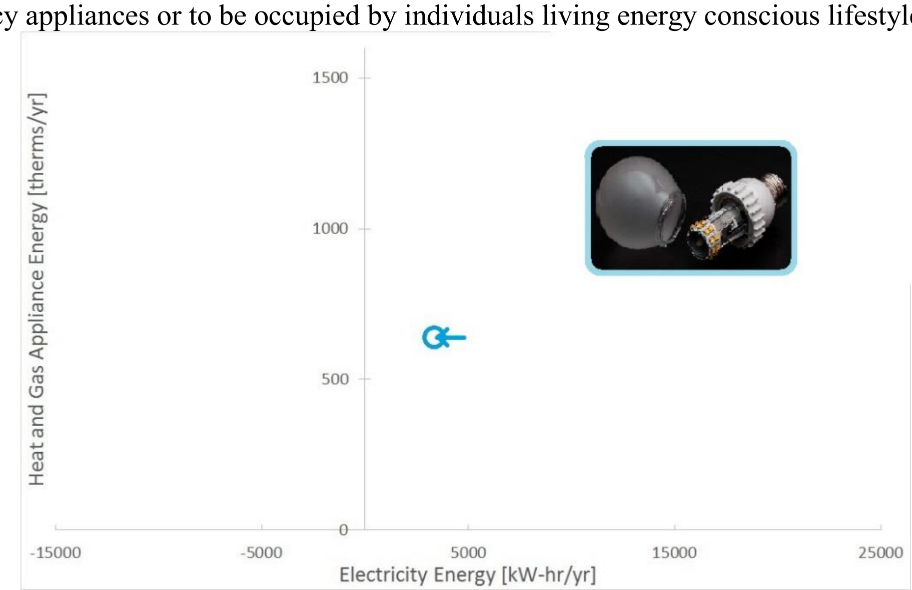

Figure B5. LED Lighting Implementation *(Cree LED bulb flaw, 2013)*

The arrow in Figure B5 represents the implementation of LED light bulbs in place of standard fluorescent or incandescent lighting. LED bulbs consume substantially less energy than the previously mentioned standard lighting. This arrow depicts the change in a house's energy consumption. This moves the circle from right to left.

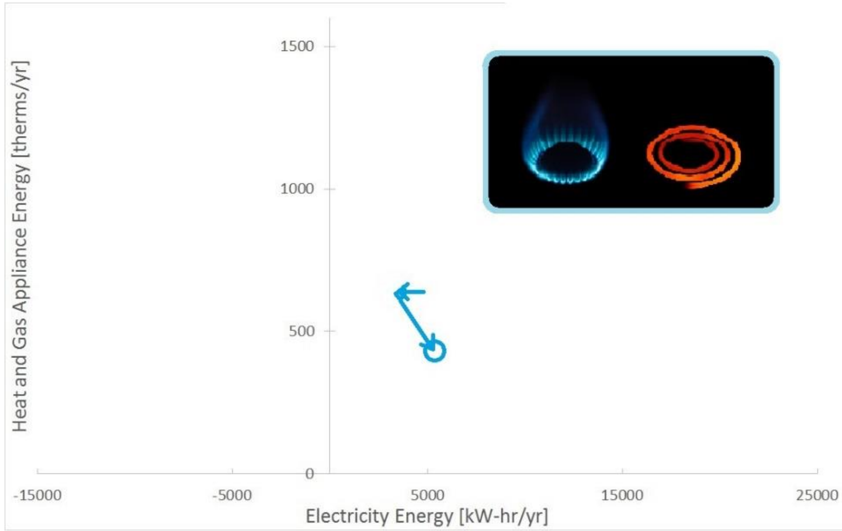

Figure B6. Electric Stove Implementation *(Cooktops and Rangers: Gas or Electric?, 2013)*

The arrow in Figure B6 represents the changes that saves one type of energy but cost another, which in this case is switching a gas stove to electric. The arrow moves down which represents the reduction in gas usage, and moves to the right which represents the increase in electricity usage.

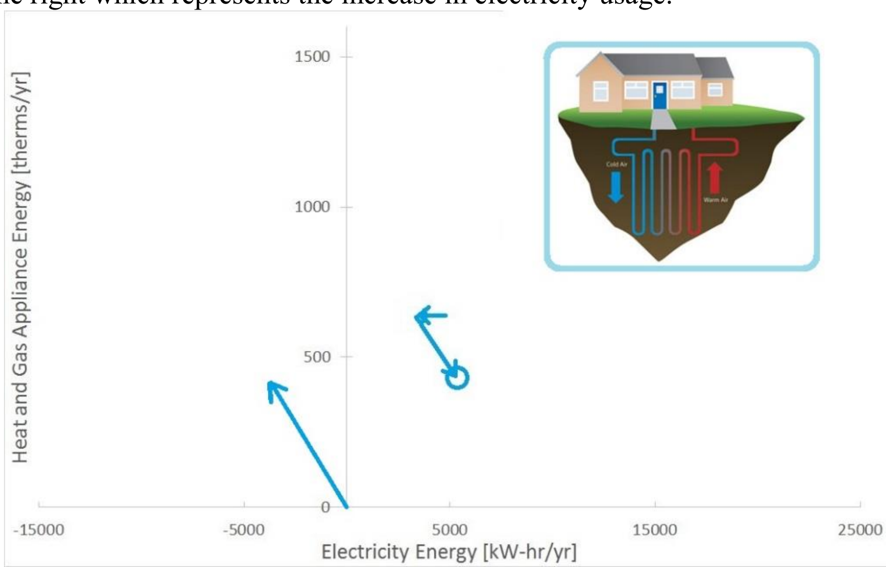

Figure B7. Geothermal Implementation *(Geothermal Heat Pumps, n.d.)*

The arrow pointing up and to the left in Figure B7 represents the implementation of a geothermal system. This system requires electricity to run, and as a result, it can be seen that the geothermal system gets rid of the need for natural gas. This is depicted by the arrow connecting to the zero point on the graph. Since the system requires electricity, the arrow points left representing an increase need for electricity.

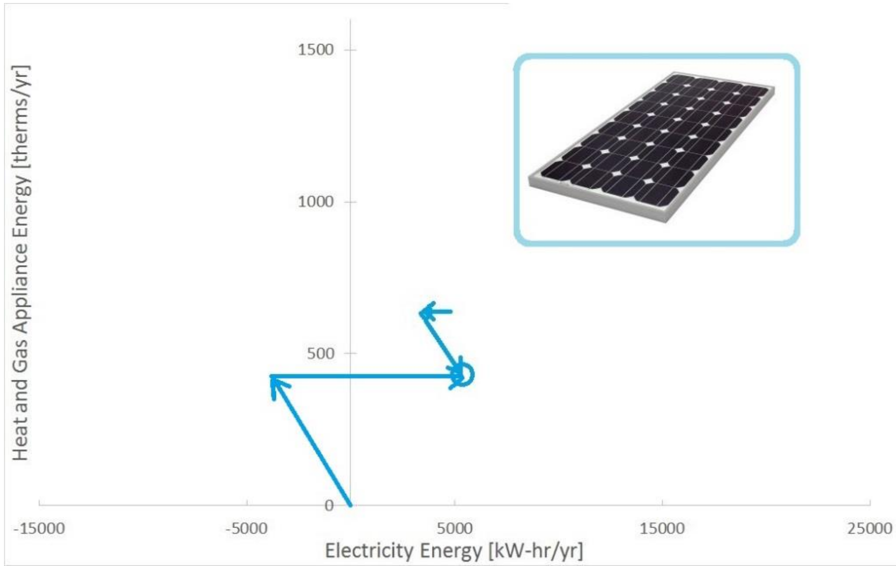

Figure B8. Solar Panel Implementation *(Technical Downloads, n.d.)*

The arrow moving to the right towards the circle in Figure B8 shows the implementation of the solar panel system. Unlike geothermal systems, solar panel systems do not require energy to run, thus the arrow only moves to the right which represents production of electricity. The arrow for energy production meets the arrow for energy reduction, thus the house reaches net zero.

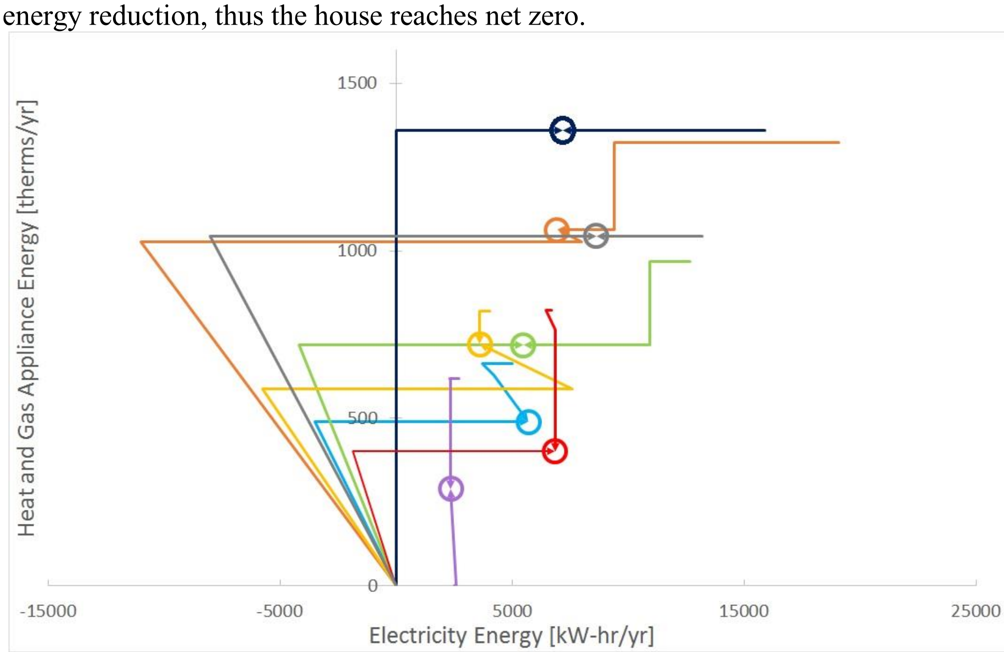

Figure B9. Overlay of all Houses

The process for net zero was repeated for the 8 houses in Grand Rapids, where each team followed the same format: assess, reduce, generate and offset. This graph represents each of the different ways the houses took to reach net zero.

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Appendix C1

Net-Zero Analysis of the Affholter Home

Team 1: John Sherwood, Jonathan Crow, Nicolaas Ourensma, Zak DeVries
Clients: John and Linda Affholter
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department

December 16, 2014

Abstract

The Affholters volunteered their home to be analyzed for the purpose of discovering what would be required to reach net-zero in energy usage. This was achieved by analyzing the current consumption of the house, reducing the consumption of the house and implementing power generation possibilities. Over 20 years of data were compiled in order to determine an average baseline energy consumption of the Affholter's home. The Affholters currently consume 5000 kWh/yr of electricity and 663.5 therms/year of natural gas. In order to reduce the need of natural gas, all appliances that use gas were replaced by electric appliances. In order to reduce the amount of electricity required by the house, standard incandescent bulbs were replaced with LED light bulbs. Due to this change the natural gas consumption decreased to 0 therms/year and the electricity need increased to 5709 kWh/yr due to the new installation of electric appliances. In order to generate energy to heat and cool the home a geothermal heat pump was installed. While this system eliminated the need for natural gas it also increased the electricity usage by 3500 kWh/yr. This electric need is offset by the implementation of a solar photovoltaic system which will generate the 9209 kWh/yr that is needed by the Affholters. These implementations will allow the house to become net-zero in energy usage.

Technical Memo

Purpose:

The purpose of this project was to answer the question: *What would it take for a home in Grand Rapids to become net-zero?* A net-zero home produces as much energy as it consumes in a year.

Background:

The house studied for this project was the home of John and Linda Affholter. They are the builders and current owners of a beautiful 2400 sqft (1200 sqft basement) house in Ada, Michigan. Built in 1992, the house was designed for an occupancy of four, however John and Linda are the only current residents.

Procedure:

In order to complete this project, three main steps were taken. First, the house was analyzed in its current state in order to develop a baseline energy usage for the Affholter residence. Second, options for the reduction of energy consumption were analyzed. Finally, energy production technologies were examined to determine which ones could feasibly be implemented for residential homes in West Michigan.

The baseline energy usage for the Affholter's house was determined using previous utility statements. The Affholters rigorously recorded this information from the day they moved into the house, over twenty year ago. The graphs containing this data can be viewed in Appendix A. The data collected shows that the energy usage of the Affholters was not consistent over the last twenty years. Therefore, in order to calculate an accurate baseline energy usage a monthly average over the past five years was taken. This approximated the energy usage solely of John and Linda Affholter, not including their children. From this analysis, it was determined that the Affholters consume on average 5000 kWh/yr of electricity and 663.5 therms/yr of natural gas. This data can be viewed as the starting point in Figure A4 of Appendix A.

In order to reduce the energy consumption of the Affholter's house, the largest energy using areas and appliances were analyzed first. A graph of energy consumption per location can be viewed in Figure A3 in Appendix A. This shows that the majority of the energy is consumed is in the kitchen and used by the appliances. These areas were analyzed first and for a comparison of these energy saving techniques please see Appendix A. In order to reduce gas consumption, the gas stove and water heater were replaced with electrical versions of these appliances. This allowed the overall gas consumption for the house to fall to 0 therms/year, and conversely increased the electricity consumption to 5709 kWh/yr.

A variety of energy generation sources were analyzed in order to produce the amount of energy that was needed by the Affholters. For an in depth comparison between the energy generation technologies please refer to Appendix A. A geothermal system was selected for its ability to produce enough thermal energy for the heating and cooling of the house. The geothermal system will replace the need for a heater and air conditioner for the house. The geothermal system is run on electricity, and will therefore keep the natural gas consumption at 0 therms/yr. However, the geothermal system will cause the annual electricity consumption to rise another 3500 kWh/yr. This electric consumption will be offset by the electricity production of the solar photovoltaic (PV) system that is installed. In order offset the total electricity that is consumed with updated energy system the solar photovoltaic system will need to produce 9209 kWh/yr.

Results:

From this analysis it was determined that the Affholter residence could achieve net-zero energy usage. Figure 1 provides a visual representation of the energy reduction and production technologies that were recommended. This graph displays the baseline usage of the Affholters as the starting point in the top right corner. The vertical axis of the graph relates to the amount of thermal energy whereas the horizontal axis refers to the amount of electrical energy. The point surrounded by a circle where the two arrows meet is proof that the Affholter house would be able to produce the same amount of energy that it consumes. A detailed explanation of the graph shown below can be found in Appendix A.

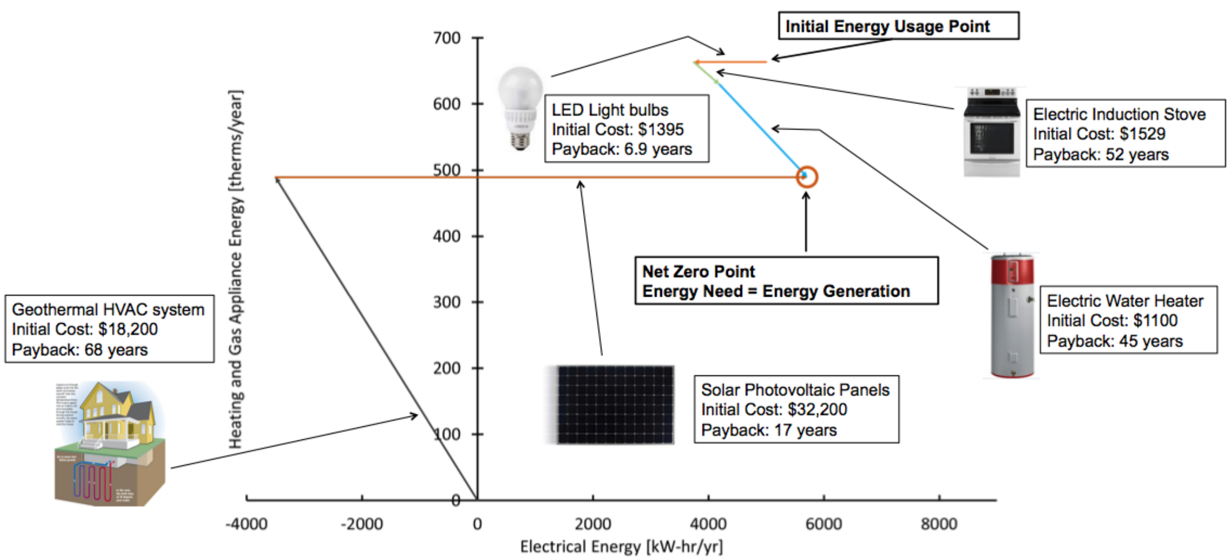

Figure 10: Overall Energy Reduction and Production

The costs associated with converting the Affholter's house to net-zero is $54,500. With this system in place it would pay for itself in 28 years. This is a sizeable investment, and with the lengthy payback period a net-zero retrofit is not economically feasible and should not be implemented with this motive.

However, if energy reduction and energy generation are still desired it would be beneficial to install LED lighting as well as a 5000 kWh/yr solar photovoltaic system. With these two changes in place, the Affholter's home would become net-zero in terms of electrical energy consumption. However, they would still consume their baseline amounts of natural gas. If the LED lighting and 5000 kWh/yr solar photovoltaic system are implemented it would cost $21,000 with a payback period of 14.6 years. This is still a sizeable investment, but by reducing their energy consumption and generating a part of their energy needs the Affholters can reduce their carbon dependence and become better stewards of the resources available to them.

Net-Zero Energy Story

Assessment:

In order to assess the baseline usage of the Affholter residence the utility bills were recorded over the past twenty years. This data was compiled in Excel and normalized for seasonal variations and graphed. These graphs can be viewed in Figures A1-2. This data was very helpful in determining a baseline energy consumption for the house. It is also interesting to observe the drop in electricity, water and natural gas usage during the years that the Affholter's children left for college. Also of interesting note is that even though the energy consumption of the Affholters has decreased over time the cost of electricity has increased.

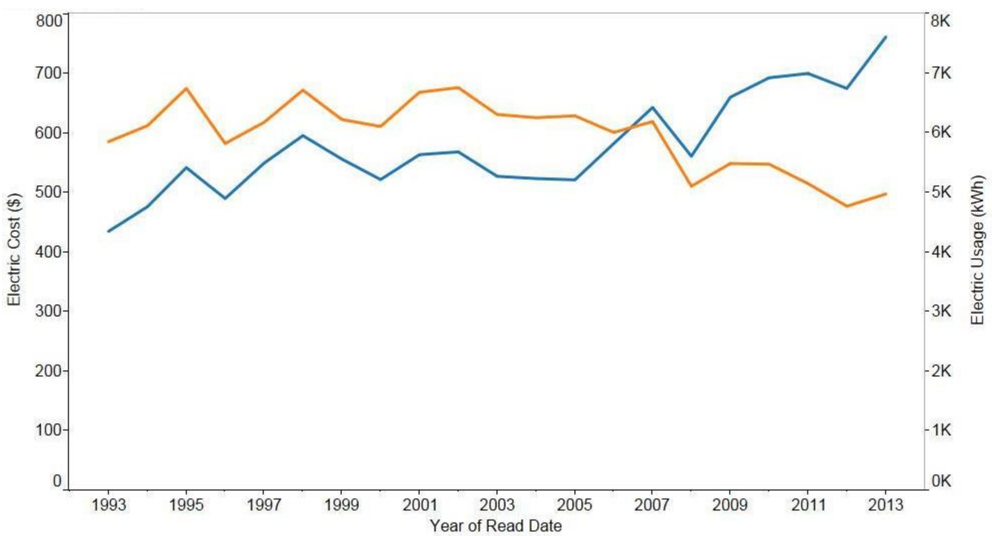

Figure A1: Historical Electricity Usage

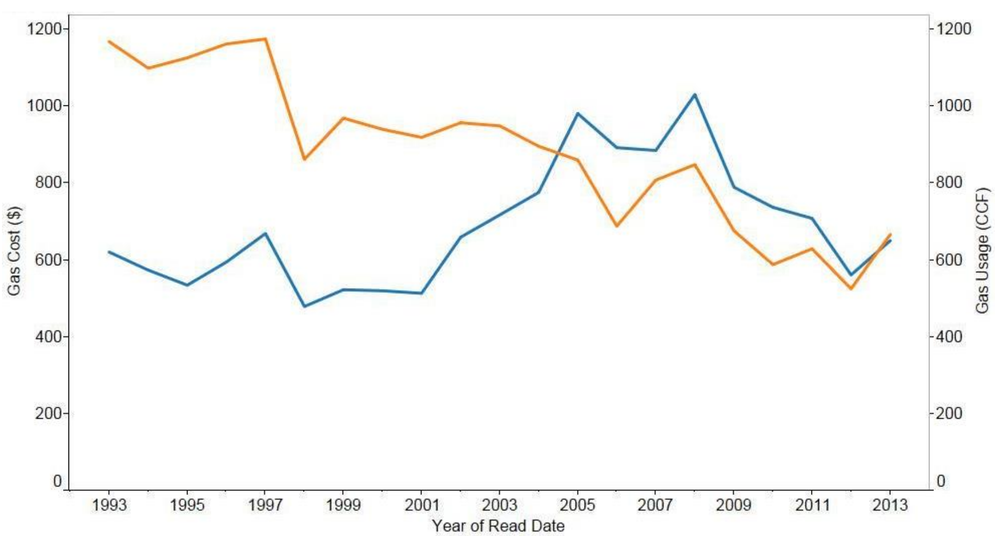

Figure A11: Historical Gas Usage

An energy audit was also performed on the house. This involved recording the energy usage of every item in the house including: appliances, lighting, stereo, TV, computer and almost everything that used electricity. In order to generate this breakdown the energy star ratings for the appliances were used whenever possible, if energy star ratings were not available simple power calculations were performed. For instance, the peak power used times how often it is run during the day generates the average power usage. Daily time usages were estimated by the Affholters in an interview during the initial house energy audit. This was done in order to determine which areas or appliances in the house use the most electricity, and provided a starting point for the energy reduction analysis. Graphs of the energy breakdown can be viewed in Figure A3.

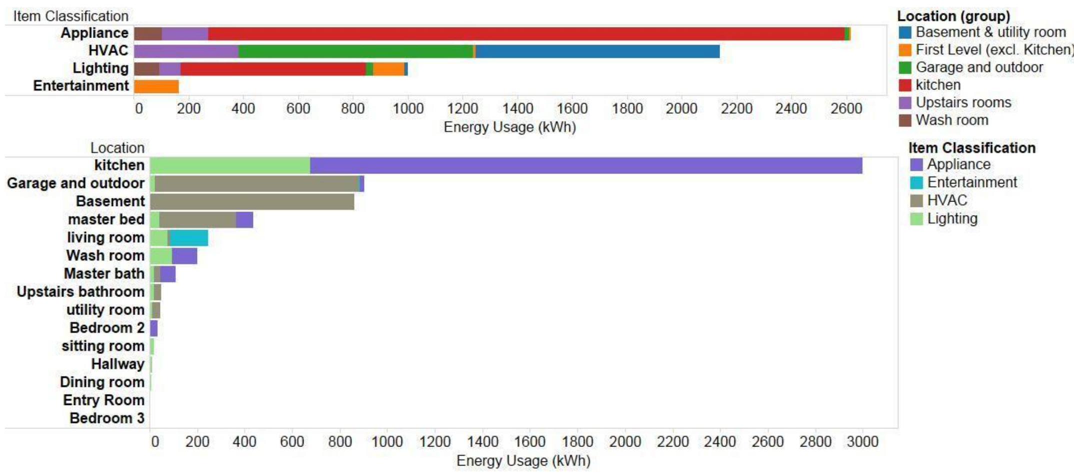

Figure A12: Electric Energy Breakdown

The energy breakdown described areas where high energy usage occurred. This provided guidance for the decision on which appliances and areas of the home should be focused on initially. In order to determine the baseline energy usage for the Affholter residence and an average of the last five years of utility bills was taken. The entire data set was not averaged as this would pull the average up due to the increased number of occupants in previous years. The five year average provided an annual baseline consumption of 5000 kWh/yr of electricity and a natural gas consumption of 663.5 therms/yr, for two residents living in the Affholter's house. These values were used as the coordinates for the initial energy consumption in Figure A4. The Affholter residences was also compared to the other seven houses that were included in the net-zero study.

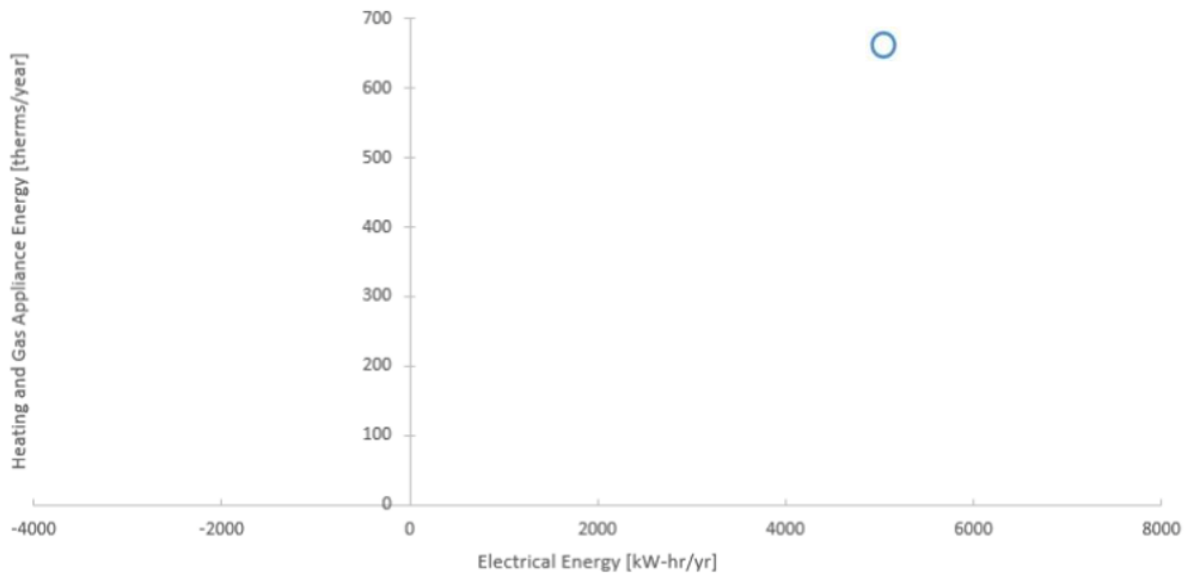

Figure A4: Initial Energy Consumption

The relative energy consumption compared to the other houses in the study can be viewed in Figure A5.

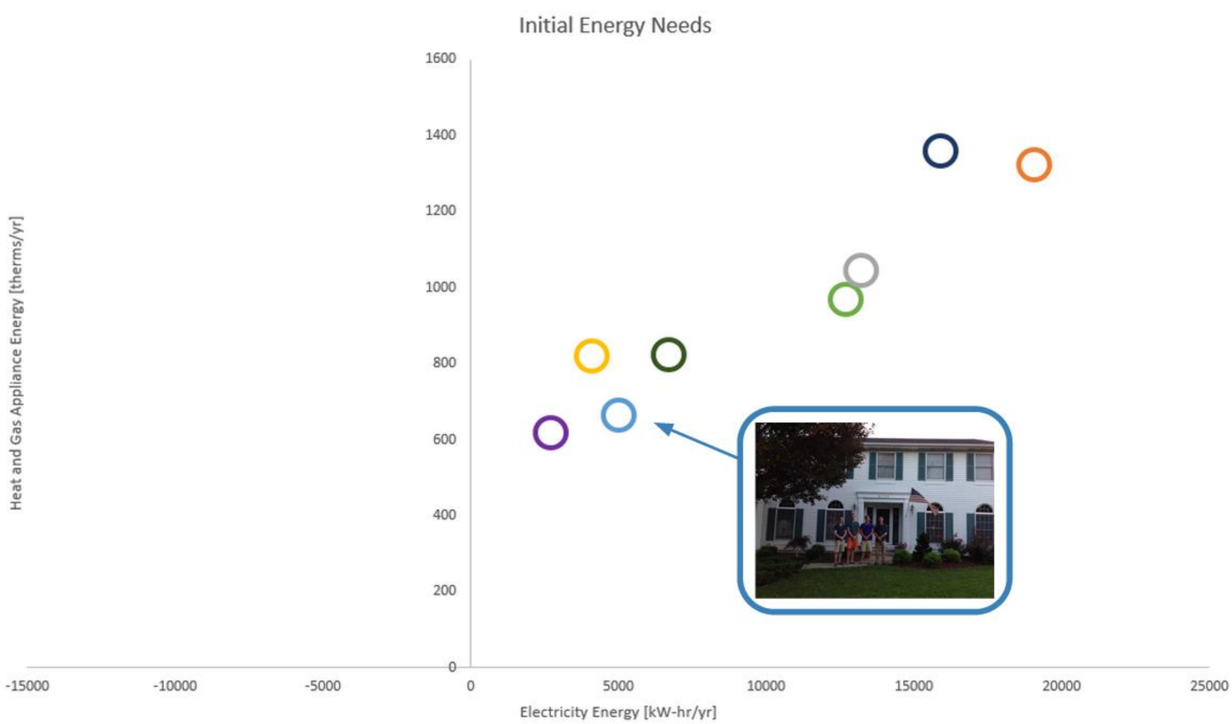

Figure A5: Relative Energy Consumption

Reduce:

Once the usage assessment was complete, alternative appliances were researched as possibilities for energy reduction. The major energy users further investigated include the refrigerator, dishwasher, dehumidifier, and air conditioner. These four units combine for a yearly usage of 2334.15 kWh and a cost of $373.46. Research into high efficiency appliances resulted in a possible energy reduction of only 645 kWh/yr. Upgrading of appliances was deemed unfeasible based on the resulting payback period of 60 years. Table A1 below shows the usage and cost comparison.

Table A1: Appliance Comparison

Item	Item Classification	Location	Power Draw (W)	Time used per day (hr/day)	Days/year	Energy Usage [kWh]	Notes
Air Conditioner	HVAC	Garage and outdoor	6800	6	21	856.80	
Dehumidifier	HVAC	living room	765	12	90	826.20	
Refrigerator	Kitchen Appliance	Kitchen	700	2	365	511.00	
Dishwasher	Kitchen Appliance	Kitchen	1152	0.3333	365	140.15	
Total				Total kWh		2334.15	
				Cost per kWh		$0.16	
				Cost per year		$373.46	

New System							
Item	Item Classification	Initial Cost [$]	Power Draw (W)	Time used per day (hr/day)	Days/year	Energy Usage [kWh]	Notes
Better AC	HVAC	5000	2200	6	21	277.2	
Dehumidifier	HVAC	259.95	745	12	90	804.6	
Refridgerator	Kitchen Appliance	519	690	2	365	503.7	
Dishwasher	Kitchen Appliance	399	852	0.3333	365	103.65	
				Total kWh		1689.149634	
				Cost Per kWh		$0.16	
				Cost Per Year		$270.26	
				Payback time		59.86	years
				Installation cost		6177.95	
				kWh reduction		645.00	

After the major appliances were analyzed, the energy used for heating was inspected. This was done in order to reduce the amount of natural gas that was needed to heat the house during the winter, options like insulation, new windows and a more efficient furnace were analyzed.

Since the Affholter's built the house, wall insulation is known to be of good quality and there is at least ten inches of insulation in the attic. Because of this, it was decided that adding insulation was not worth the investment. The current windows were modeled as two-pane, low-E, 13mm gap (standard) and air filled because Affholters suspect the gas has leaked out.

A potential upgrade was modeled as the top-of-the-line, three-pane, super low-E, sun filtering coating, 9.8mm gap because that is the max for three-pane, and filled with argon. Using a simulation from Cardinal Glass Industries, savings of $30/yr in gas and $243 in electricity were estimated [4]. At a rate of $600 a window, replacing the Affholter's 26 windows would cost $15,600 [5]. If the current windows are kept, increasing the generation capabilities of the system by the same amount would cost $5000. Because of this, it was decided that money could be better spent on energy generation.

In order to reduce the gas usage of the house the furnace was the first appliance that was analyzed. The efficiency of a furnace is rated by an AFUE rating. This rating relates to the Annual Fuel Utilization Efficiency. The best AFUE rating that is currently achievable is 97%, whereas furnaces built in the 1970 do not exceed 65%. Therefore, significant gas savings can be made if a 30-40 year old furnace is replaced with a modern one. In order to get the best cost estimate and appropriately sized furnace Shoemaker Heating & Cooling Inc. was called for quote. They recommended the 96% AFUE, two stage ECM gas furnace. This furnace would have a $2,000 purchase and installation fee. Given that the Affholter's furnace was replaced within the last five years the efficiency gain was not large enough to justify a new furnace installation. While the payback period was calculated to be 9.28 years the gas reduction was not very significant. Due to the fact that the ability to produce natural gas on site was not possible and that the use of a natural gas furnace as a renewable source for energy was very difficult a different heating source for the house was investigated. The standard natural gas furnace would be replaced with a geothermal heat pump system in order to heat and cool the home. This eliminated the natural gas consumption required to heat the home.

After the heating analysis was performed, lighting options were investigated. More specifically, the energy savings that could be achieved by converting the current incandescent bulbs to LEDs. LEDs are the most efficient lighting source except the sun. A full house conversion to Cree LED bulbs was found to cost $1395 with a payback period of 6.9 years. This cost is high for lighting because of the decorative lighting throughout the house. The resulting energy savings can be seen in Figure A6 below.

Figure A6: Effects of LEDs

During the investigation into the reduction of natural gas consumption it became apparent that the use of gas appliances were difficult to use in a renewable system. It is very difficult to produce natural gas on location, especially in a residential location. The amount that the consumption of natural gas can be reduced is limited as certain thresholds have to be meet for a house to stay warm. Upon this realization, it was decided that all appliances that run on natural gas will be replaced with equivalent appliances that run on electricity. This was done for the stove and water heater. This change eliminated the Affholter's need for natural gas and increase their overall need for electricity.

The main electric stove types are conventional coil electric heating and induction heating elements. An induction stove was selected due to its high performance and energy efficiency of 84%. As a comparison, typical gas ranges offer an efficiency of only 40% [1]. The effect of replacing the stove with a high efficiency induction variety is shown in Figure A7 below.

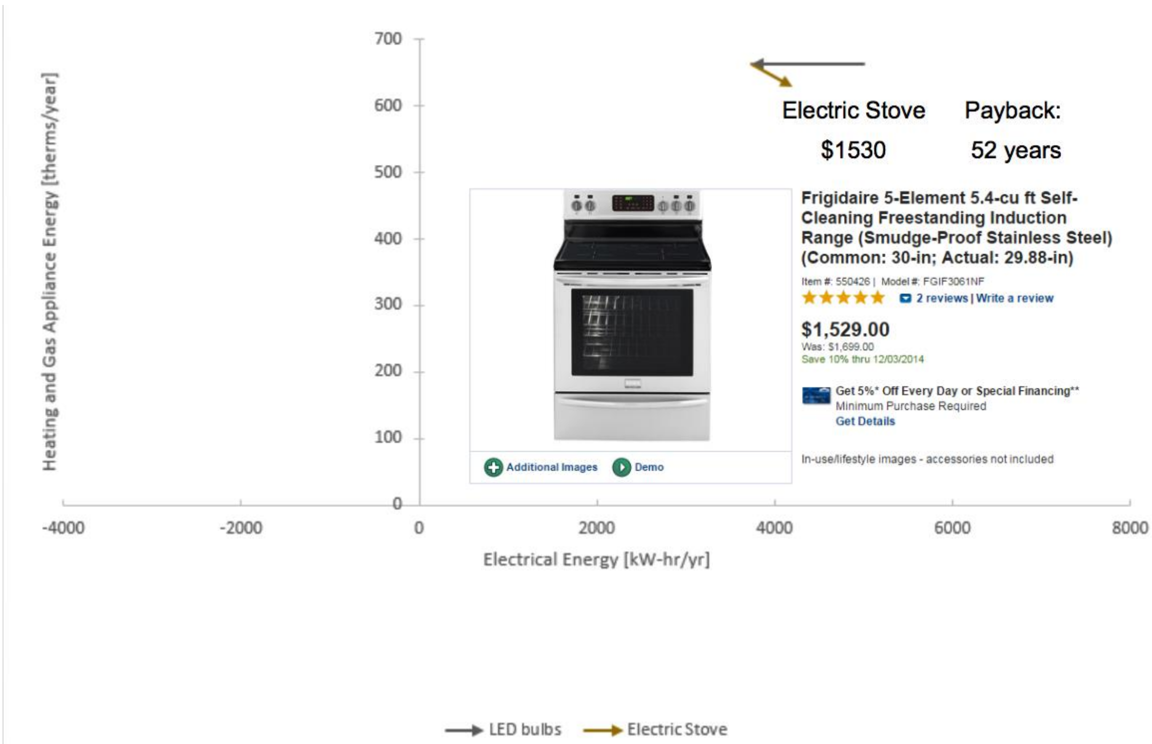

Figure A7: Effect of Induction Stove

In order for the Affholters to eliminate their gas consumption an electric water heater needed to replace their current gas water heater. There are three main types of electric water heaters available: tankless water heaters, point of use water heaters, and standard electric water heaters that heat a tank of water. Point of use water heaters provide the most efficient transfer of thermal energy. The water is heated by many individual water heaters throughout the house that are located very close to their point of use. Such as under the kitchen sink, or in a closet behind a shower. The point of use water heaters heat up the water as it is being used which reduces heat loss through storage, and also heat loss associated with travel through the pipes. However, these unit typically cost $100 to $300 dollars each and they are necessary at every point of hot water use in the house. A standard double vanity bathroom with shower would incorporate three water heaters, at a cost of $300 to $900 dollars depending on the quality of water heater desired. With a standard or tankless water heater cost of approximately $1500 for an entire house application, the point of use water heater was deemed to be not cost effective. The second type of water heater that was analyzed was the tankless water heater. This system works much the same as the point of use water heater, by heating the water as it is needed. However, a tankless water heater is typically mounted in a central location and water is distributed throughout the house. This is a great system and quite cost effective. Yet, in order to get a high output tankless water heater that would provide comparable water heater performance to their current water heater, it would require a 240v connection to the grid. This would necessitate a complete replacement of their electric system and require a new transformer and breaker be installed in order to run their water heater. Due to the complications with high output tankless water heater power requirements they were deemed unfeasible for this application. This left a standard electric water heater as the replacement for the current gas water heater. By installing an electric water heater, the Affholter's natural gas consumption will reduce by 140 therms/year and their electricity usage will increase by 1516 kWh/yr. The effect of this change on the overall energy usage of the house can be seen in Figure A8.

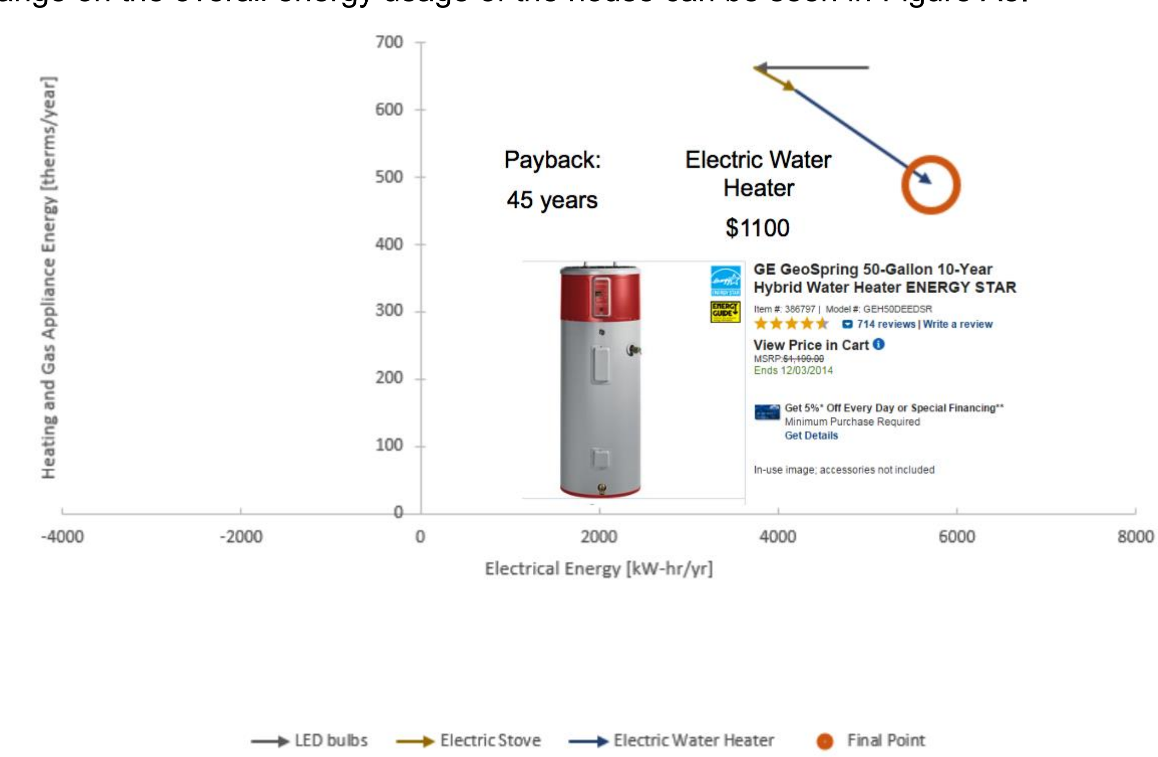

Figure A8: Effect of Electric Water Heater

The installation of the water heater was the last step that was taken in order to reduce the consumption of energy. Other energy reduction methods were analyzed such as a change in lifestyle. However, the Affholters currently use their house very efficiently. They make sure to only use lights and appliances in the rooms that they are currently in. The heat and air conditioning are set at conservative levels and they always make sure to turn their lights off when they leave. These consistent actions have paid off as their utility company has ranked them 15th out of the nearest 100 homes in energy usage efficiency. The only possible area for a reduction in energy usage that was found was to turn of the dehumidifier that was running in the basement. However, there are health side effects to turning off the dehumidifier, and it must stay on. As a result, the energy usage of the Affholters has been minimized. In order to reach net-zero energy production methods need to be analyzed.

Generation:

In order for the Affholter's house to become net-zero the house needed to produce as much energy as it consumes. Energy generation sources such as solar photovoltaic, solar water heating, wind turbines and geothermal heat pumps were investigated in order to determine the feasibility of implementation.

In the interest of reducing the load on the water heater a solar water heating system was analyzed. This system works by pumping water or glycol through a closed loop system that is mounted on the roof of the house. The working fluid is pumped through black tubes that are heated by the sun. This causes the fluid to heat up and it is then run through a heat exchanger that is connected to the water supply of the house. These systems are beneficial in in some applications, however, the solar intensity of Michigan is not sufficient enough to produce constant hot water for a house. This system would only assist the hot water heater, not replace it. The temperatures that can be achieved by a solar water heating system are also much less than the water temperatures of a standard water heater. Due to seasonal fluctuation, low water temperature, and limited hot water output a solar water heating system was not justifiable. It is more beneficial to use the available roof space for solar photovoltaic panels.

In addition to solar water heating system, wind power generation was also investigated. As with solar, SAM was used to analyze the system. The specific turbine investigated was a SkyStream 2.4kW model with a 3.7 meter rotor length. The initial cost of this model is $10,800. For modeling purposes, an average wind speed of 5m/s was assumed as well as a Weibull distribution for variations. SAM provided an estimated cost savings of $435/yr based on these conditions. Unfortunately, building codes in Ada include a height maximum of 30ft from the ground or 15ft from the roof. Due to these restrictions, the low, inconsistent winds in the area, and the high initial cost, wind turbine power generation was deemed unfeasible.

A geothermal heat pump system was selected to provide thermal energy to the house. A geothermal system works by using the earth as an energy battery. In the summer, heat is removed from the house and stored in the ground to be pulled out again during the winter. A geothermal heating and cooling system can completely replace a traditional HVAC system comprised of a furnace and air conditioner. However, the implementation of these systems can become quite costly. There are two main forms of geothermal systems, horizontal and vertical loop systems. A horizontal loop system is less expensive to install but requires more areas. Whereas a vertical loop systems requires less area, but is more costly. Due to the land restrictions available to the Affholters property size a vertical loop system was required. The design of the geothermal system was based upon a residential geothermal system that was installed in Pennsylvania [2]. This system was chosen because it was installed on a similar sized house in approximately the same thermal climate as west Michigan. This case study provided the data and real world costs that are associated with the actual implementation of a geothermal system. Based upon this study the cost of a geothermal system for the Affholter residence was determined to be $18,200. This system would pay for itself in 38 years. While this is a long payback period the geothermal system will completely replace a furnace and air conditioning system. This means that natural gas costs will be eliminated and that greater cost savings will be achieved if gas prices increase. While this system would produce sufficient thermal energy for the climate control of the house, it is not feasible to use a geothermal system for water heating. A typical water heating system keeps water at 120 °F. These high temperatures are not feasible for a geothermal system to achieve. The effects of the geothermal system on the energy generation of the Affholter's house can be seen in Figure A9. While the geothermal system does not need any natural gas to run it does require a significant amount of electricity. The geothermal system is capable of producing 489.5 therms/year which is the heating equivalent of the furnace. This value is lower than baseline thermal energy usage due to the reductions of changing the water heater and stove to electric. However, the geothermal system will increase the Affholters electricity consumption by 3500 kWh/yr [2]. This brings the Affholters total electricity needs to 9209 kWh/yr.

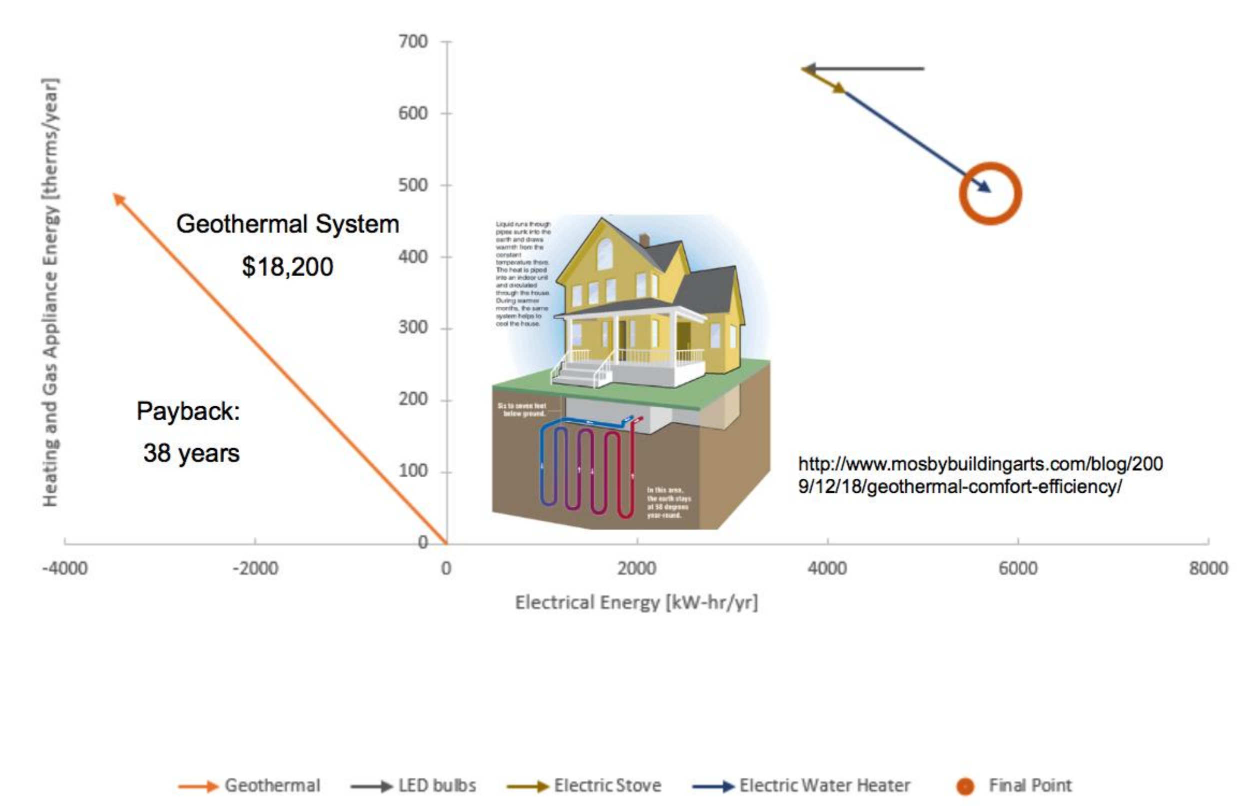

Figure A9: Effect of Geothermal System

In order to produce the large amount of electricity required a solar photovoltaic system was explored. To determine the size and type of system that should be used a program called SAM, System Advisor Model. This program "is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry" [3]. This program incorporates geographic location, climate patterns, available solar photovoltaic systems and tax breaks that are provided in that location. This system was analyzed for Grand Rapids, Michigan. The use of this modeling system provided accurate results for the actual energy production that could be expected for a solar photovoltaic system that is installed on the Affholter's house. The SAM analysis specified that 24 solar panels were needed in order to generate the required amount of electricity. The solar panels that were selected for this application were the Sandia Modules SPR-315E. These solar panels have a 25 year warranty at an 80% output rating. In order to convert the solar energy into the usable electricity for the house two inverters are needed. These inverters were specified to be the SMA America SB50000TL-US. The purchase and installation costs of the solar panels, racking and inverters was $32,200. At this price the system would pay for itself in 17 years, which is before the warranty expires for the solar panels. The size of this system was a concern due to the limited area that is available on the south west facing side of the roof. The available roof area is 600 sqft, the designed solar system will use 421 sqft. Figure A10 shows the relative area that is required for the solar panels.

Figure A10: Area Required for Solar Panels

With the implementation of this solar photovoltaic system the Affholters will be able to produce 9209 kWh/yr. This is the required electric energy that is needed to reach net-zero. The results of this implementation on the overall energy generation can be seen in Figure A11.

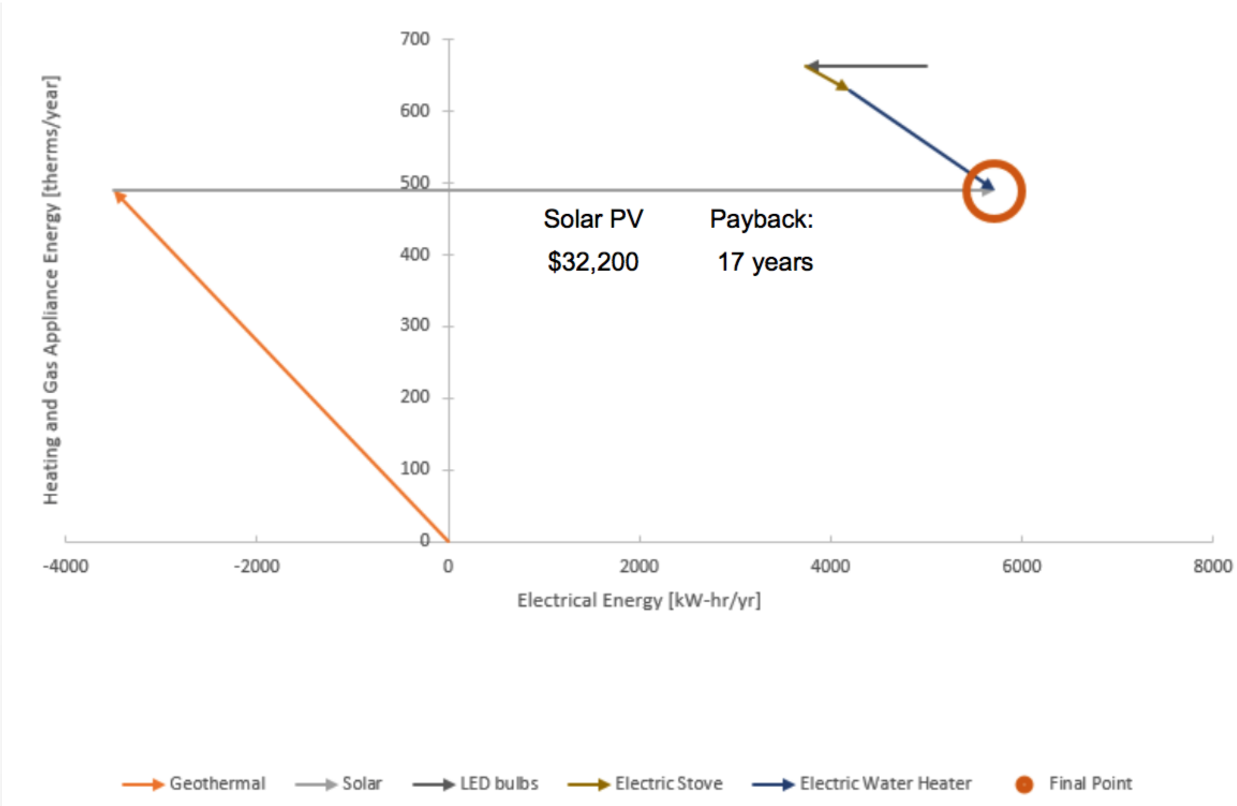

Figure A11: Effects of Solar PV

If all of the energy reduction and generation methods described above were implemented the Affholter residence would function as a net-zero home, producing as much energy as it used in a year.

Results:

The initial energy usage of the Affholter's home was 5000 kWh/yr of electricity and 663.5 therms/yr of natural gas. Switching the gas appliances to electric alternatives increased the electricity need to 5709 kWh/yr. The addition of the geothermal system also increased the electrical need for a total of 9209 kWh/yr. These conversions eliminated all natural gas consumption meaning that all required energy can be generated on site by the solar photovoltaic system. The total cost of system implementation is $54,500 with a payback period of 28 years. A graph of the financial plan for this implementation is shown below in Figure A12. This graph displays the timeline and actual costs associated with retrofitting the Affholter house with net-zero technologies.

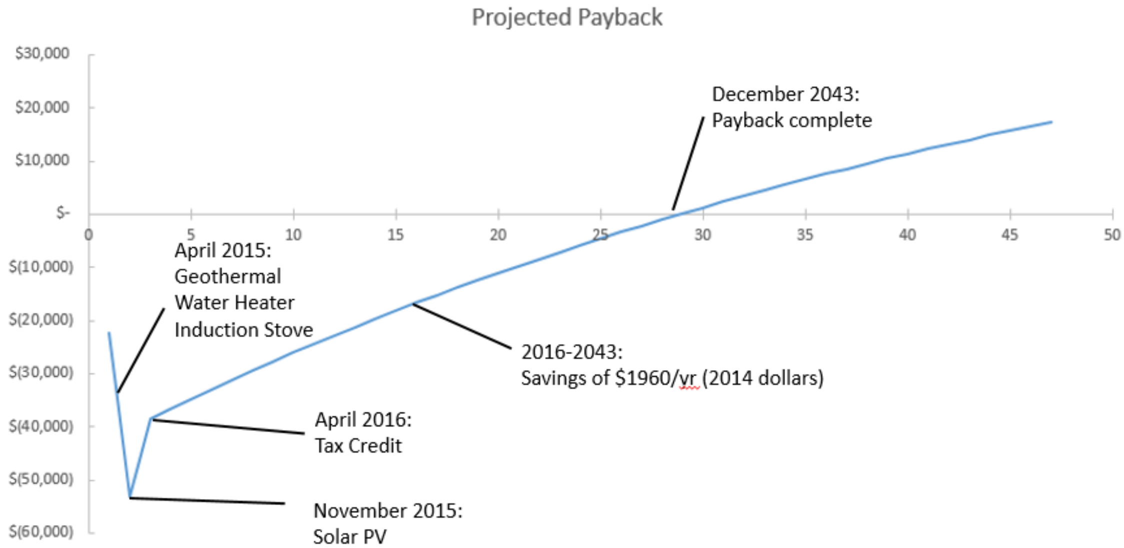

Figure A12: Cost Timeline of Net-Zero Implementation

It should be noted that the cost of a net-zero implementation can be greatly reduced or offset if it is implemented at construction. Decisions on items such as insulation, geothermal, windows and appliances make a large impact on the efficiency and productivity of the house. If these technologies are implemented during the construction phase, the cost associated with a retrofit will be eliminated, as well as the sunk costs of the technology they are replacing. If a net-zero house is desired it is most economically feasible if implemented during the design and construction of the house.

Data, Bibliography, Acknowledgments

Data:

Team name	Affholter							
Team members								
Home size (living area)	4000	ft^2						
Number of people	1.7	people						
Initial Energy Need	*Heating and Gas Appliances*		*Electricity*					
	663.5	*[therms/year]*	5000	*kW-hr/yr*				
Initial Energy Supply	*Heating and Gas Appliances*		*Electricity*					
	0	*[therms/year]*	0	*kW-hr/yr*				
Energy Savings (Step 1)								
Intervention	*ΔHeating and Gas Apliance need*		*Δelectricity need*		*Investment Cost*		*Annual $ Savings*	
LED bulbs		*[therms/year]*	1258.48	*kW-hr/yr*	1395	$		$/year
Electric Stove	34	*[therms/year]*	-452.3809524	*kW-hr/yr*	*1528.99*			
Electric Water Heater	140	*[therms/year]*	-1516	*kW-hr/yr*	1105.03			
		[therms/year]		*kW-hr/yr*				
		[therms/year]		*kW-hr/yr*				
		[therms/year]		*kW-hr/yr*				
		[therms/year]		*kW-hr/yr*				
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		[therms/year]		*kW-hr/yr*				
		[therms/year]		*kW-hr/yr*				
		[therms/year]		*kW-hr/yr*				
Total Energy savings	174	*[therms/year]*	-709.9009524	*kW-hr/yr*				
New Energy Need	489.5	*[therms/year]*	5709.900952	*kW-hr/yr*				
Energy Supply (Step 2)								
Intervention	*ΔHeating and Gas Appliance supplied*		*Δelectricity supplied*		*Investment cost*		*Annual Savings*	$/year
Geothermal	489.5	*[therms/year]*	-3500	*kW-hr/yr*	*18200*			
Solar		*[therms/year]*	9209.900952	*kW-hr/yr*	32200			
		[therms/year]		*kW-hr/yr*				
Δ Energy Supply	489.5	*[therms/year]*	5709.900952	*kW-hr/yr*				
New Energy Supply	489.5	*[therms/year]*	5709.900952	*kW-hr/yr*				
Net Energy Consumed	0	*[therms/year]*	0	*kW-hr/yr*				

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[1] http://theinductionsite.com/proandcon.shtml

[2] http://www.geothermalgenius.org/thinking-of-buying/geothermal-installation-by-the-numbers-in-pennsylvania.html

[3] https://sam.nrel.gov/

[4] http://www.cardinalcorp.com/technology/applications/energy-calculator/

[5] http://www.triplepanewindow.net/

Acknowledgements:

The team would like to sincerely thank John and Linda Affholter for their interest and willingness to participate in this project.

Appendix C2

Net-Zero Analysis of the Boer Home

Team 2: Andy Frandsen, Jack Kregel, Ryan Rhodes, Connor VanDongen
Client: Eric Boer
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department
December 16, 2014

Abstract

The intention of this project is to make a customer's home net-zero. The question posed by Professor Heun upon each individual group and the class as a whole was, "what will it take for a home in Grand Rapids to become net-zero?"

A net-zero home is one whose energy consumption equals its energy production. For the Boer house, this was a difficult task. Being a house occupied by college students, the priority of the owner was not to have an energy efficient house and consequently, the monthly gas and electric bills were quite high. Because of this, the team was able to suggest many ways to reduce energy usage, produce electricity, and ultimately become net zero. The first step in this process was to reduce energy consumption. The house had an initial electric consumption of 12691 $\frac{kW-hr}{yr}$ and initial gas consumption of 961 $\frac{therms}{yr}$. By simulating the implementation of more energy efficient appliances, increased insulation, LED light bulbs, and suggesting lifestyle changes, electric needs were reduced to 9649 $\frac{kW-hr}{yr}$, and gas needs were reduced to 719 $\frac{therms}{yr}$. The next step in the next in the net-zero process is to determine ways to produce enough energy to meet the consumption needs. For this step, the team investigated solar panels to produce all the electricity needs and a geothermal heat pump to eliminate the need for natural gas. By implementing reduction and production technologies, the team was able to determine that it was possible to become net zero. Although the team was able to determine that it was possible to become net zero, the real question was "What would it take for a home in Grand Rapids to become net-zero?" To answer this, the team had to do a financial analysis of all the changes recommended. By analyzing every change and new piece of technology, the team determined that in order for the Boer house to become net zero, an upfront cost of $68,095 would have to be supplied. This upfront cost resulted in a payback period of 29.80 years. Although this was not deemed feasible, the team succeeded in answering the question, "What would it take for a home in Grand Rapids to become net-zero?

Technical Memo

Introduction

The net-zero building movement is an attempt to reduce the energy consumption of residential and commercial buildings. More specifically, net-zero buildings have equal energy production and consumption throughout the entirety of the year. (Heun, 2014)

The Boer house proved to be a unique challenge for several different reasons. First, the house was constructed in 1905. Old houses such as this one are typically constructed using different techniques and materials that are not as efficient as those used by current builders, resulting in higher energy needs. Another challenge of studying the Boer house was the fact that four college students occupy it. Because of this, the occupants were accustomed to a certain lifestyle, one that the team found to be highly inefficient.

Procedure

The process of becoming net-zero is typically a four step procedure: assess, reduce, generate, and offset. The first step, assess, is the process of determining what your house is currently consuming in gas and electricity. The next step, reduce, involves determining what can be done to reduce the homes energy needs. This can include implementing newer and more efficient appliances, improving the insulation of home and suggesting lifestyle changes. The third step, generate, is simply determining energy production technologies such as solar panels, to be recommended for the home. The final step is offset. This is the idea of using renewable energy credits to help offset the remaining energy costs as well as selling excess electricity produced by the home to pay for the natural gas needs of the home.

For the Boer house, the team focused on the first three steps, assessment, reduction, and generation. For the assessment segment, the team used several different techniques to assess the energy usage of the house. The first technique used was to analyze past energy bills. By doing this, the team could get a better handle of what kind of consumption the house had and what consumption to expect in the future. The next technique, was to use a Kilo-A-Watt to measure the actual energy consumption of specific appliances such as the refrigerator, dishwasher, TV, and washing machine. By using the Kilo-A-Watt meter and the past energy bills, the team was able to perform an energy audit. This energy audit helped the team get a better understanding of the distribution of energy usage. Usage could be split into categories such as appliances, lighting, entertainment and HVAC as well as splitting consumption into its respectable rooms (living room, kitchen etc.).

The next step in the process, reduction, involved the team investigating ways to reduce energy consumption. The first thing the team looked at was upgrading the appliances. The team investigated the efficiencies of the current appliances and investigated newer and more efficient appliances. The team determined how much energy would be saved by purchasing new appliances. The appliances the team looked at included a refrigerator, dishwasher, oven, stove, dehumidifier, washer, and dryer. The next step of reduction step was to investigate the insulation of the home. Since it is an older home, the team assumed that there was minimal insulation in the home. By performing an insulation assessment, the team determined that this was true, and that there was lots of potential for reduction by installing new insulation. The next step in the reduction process involved looking at more efficient lighting. The home had an array of incandescent and compact fluorescent bulbs, which require quite a bit of energy. The team determined that the electricity need could be reduced significantly by using LED bulbs. The final step in the reduction process involved lifestyle changes. The team determined that because of the occupants (college students), there was opportunity for reduction by changing the lifestyle. Although this would not be popular among the occupants, it would be a viable reduction technique. These suggested lifestyle changes included eliminating excess mini-refrigerators, multiple TV's, and other entertainment devices such as gaming systems and stereo systems.

The final step in the process used by the team was determining ways to produce energy in the home. Because of the homes small size and small yard the team had to best determine ways to do this. The team looked briefly at wind energy but determined it would be impossible because of legal codes. This left the team with few options. The first task was to determine a production technique to eliminate the homes need for natural gas. This was found to be best achieved by implementing a geothermal heat pump. Because of the small yard, the team established that a vertical loop system would be the only option. The next step was establishing a way to produce enough electricity to reach net-zero status. The team concluded that the best option for doing this would be solar panels.

By following the three-step process; assessment, reduction, and generation the team was able to find a way for the Boer home to become net-zero.

Conclusion

Figure *13* shown below shows all the changes the team recommended to the Boer house in an attempt to become net-zero. The starting point in energy consumption is shown represented by the furthest right point on the graph. The lines represent reduction and generation technologies that the team decided to recommend. The goal was to get all the lines to meet at the origin, which would signify a successful implementation of net-zero.

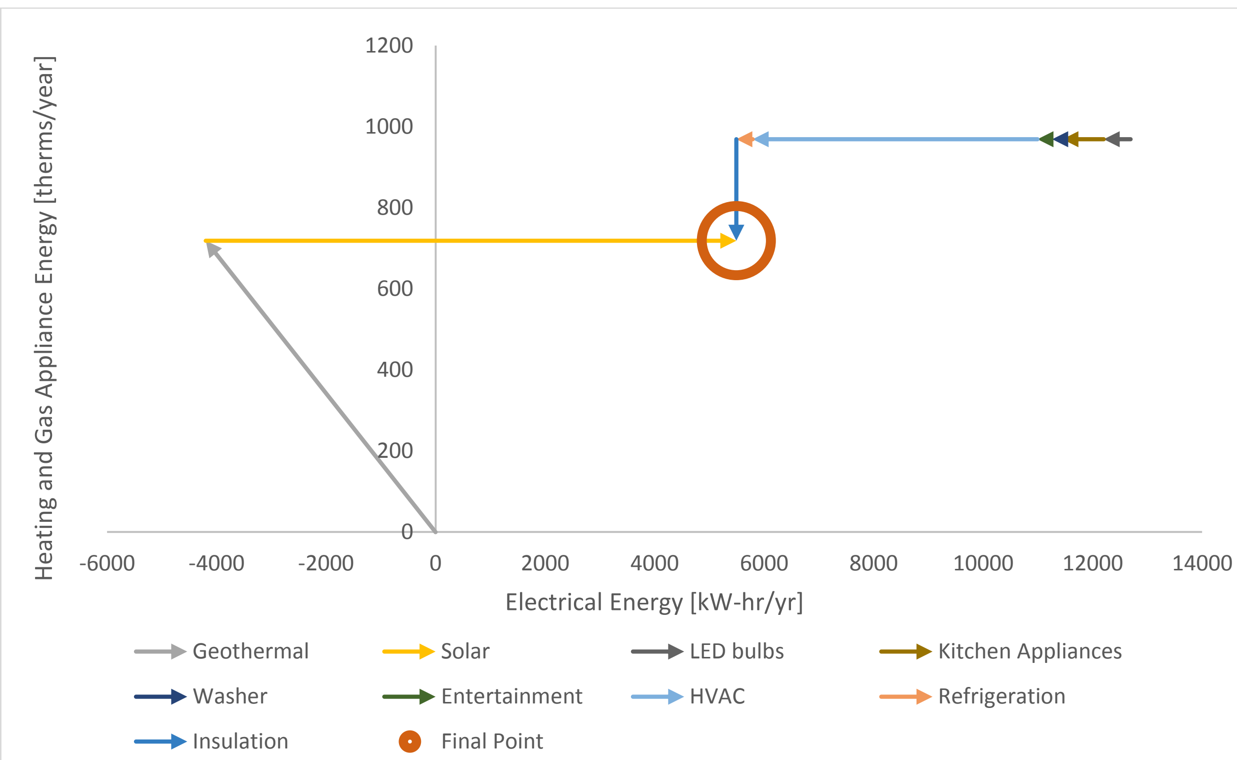

Figure 13. Final overlay plot with reduction implementations

After the team determined everything necessary to achieve a net-zero home, they decided to do a financial analysis to determine the economic sustainability of becoming net zero. This consisted of preforming a break-even analysis on individual components as well as all the components as a whole. What the team found was that in order to make the Boer house net zero, an upfront cost of $68,095 would need to be supplied. In addition to determining the upfront cost, the team calculated the payback period to be 29.80 years, much longer than the life of the technologies that may be implemented in the home. Because of this extreme cost, the team determined that yes, net-zero status could be achieved, but it may not be in the best interest of the homeowner.

Appendix: Table of Contents

Net-Zero Energy Story

Appendix 1: House Assessment

The ENGR 333 class was divided into 8 teams. Each team was to decide on a home and a customer in which they would analyze the energy status. One of the observations that was made at the beginning of the semester was that each house has an initial consumption of energy, and with that initial consumption comes a story. Each team wrote a story through their methods to make each of their homes net-zero. The story begins with an assessment. Where does the house currently stand in terms of energy usage and what are the conditions and living styles? Following this is the next chapter in the story about energy reduction and efficiency. The third chapter in our book contains the generation techniques used to produce energy for the homes. Provided below in Figure 14 is the initial energy consumption of each of the 8 homes analyzed. On the x-axis is the electricity consumed in terms of $\frac{kWh}{yr}$ and on the y-axis is the natural gas consumption in terms of $\frac{therms}{yr}$. The Boer residence is in the middle of the pack in terms of energy usage in the home.

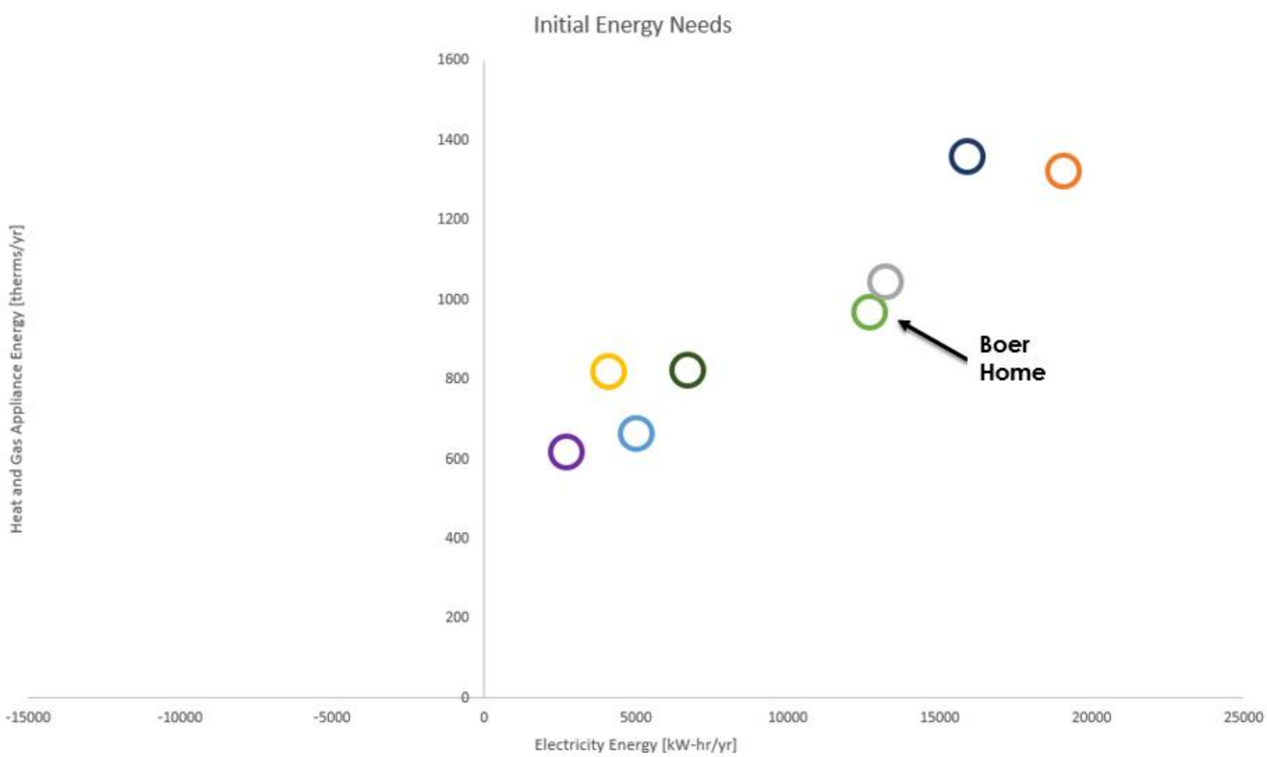

Figure 14. Initial Energy Consumption

In order to come to any conclusions about making this home net-zero, the first step is to understand the energy consumption history of the house. Found below, are both the electricity and natural gas usage of the Boer house. These show a breakdown according to the monthly bills obtained by the tenants.

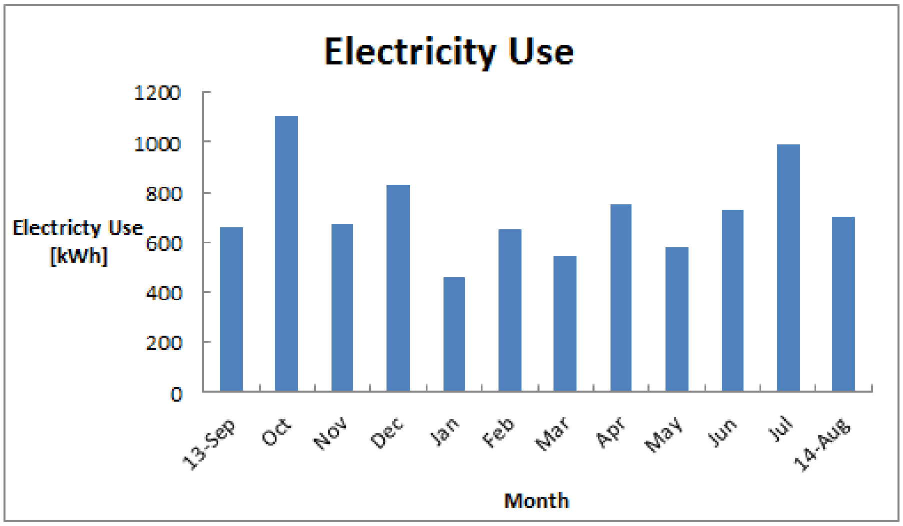

Figure 15. Electricity Usage for the year 2013-2014

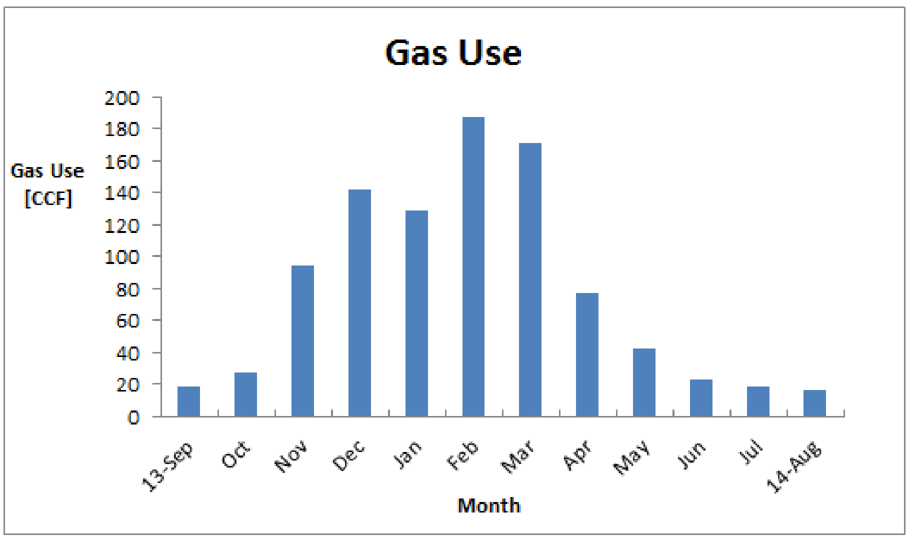

Figure 16. Gas Usage for the year 2013-2014

It was important to understand the breakdown of the energy usage for both electricity and gas. As part of the energy reduction stage, newer, more efficient appliances would be applied to our search for net-zero. In order to find more efficient appliances, the energy consumption of each appliance is required. A kilowatt-meter is a tool designed to take readings of these energy consumption rates. The gas appliance consumptions were found using estimations from reliable online sources. The kilowatt-meter could be plugged into each appliance and over a period of 24 hours. Readings were taken every time the appliance was in use. The meter could determine what the average $\frac{kWh}{yr}$ usage would be for that appliance. The findings for energy consumption breakdown are found in the following two figures.

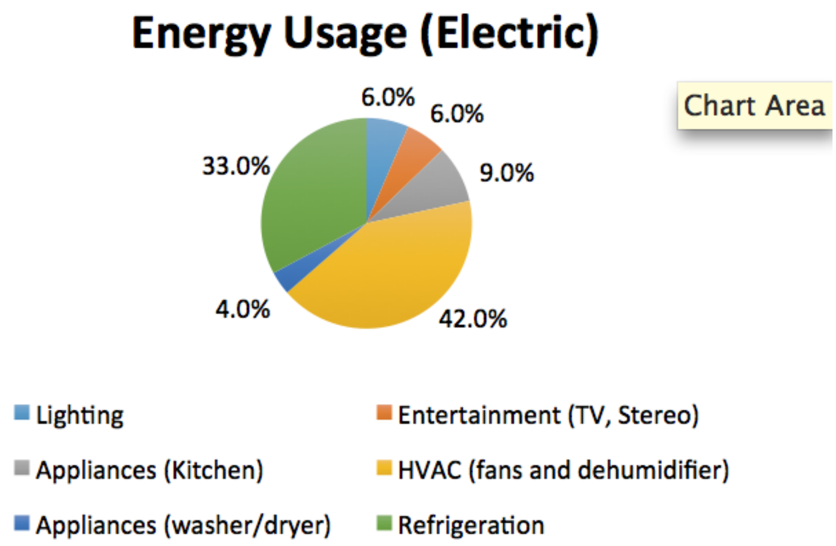

Figure 17. Electrical Appliance Breakdown

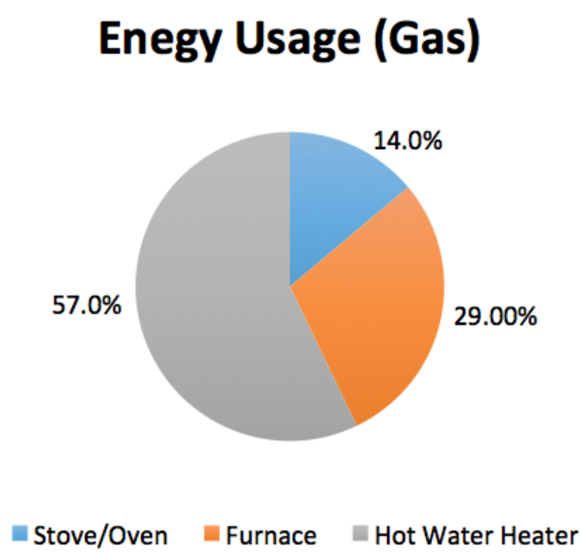

Figure 18. Natural Gas Appliance Breakdown

When looking at Figure 17 and Figure 18, it is important to observe what appliances are using the most energy because those are the ones that must be reduced if possible. When looking at Figure 17 specifically, it can be seen that the HVAC system and Refrigeration are the two largest consumers of electricity. These two appliances will seriously be considered for replacement. Another thing to notice is that both lighting and entertainment use 6% of the overall electricity. These things can easily be reduced or eliminated by changes in lifestyle. When looking at Figure 18 specifically, the hot water heater consumes most of the gas (57%) followed by the furnace. These two gas appliances will be considered for replacement with a geothermal heat pump system later in the generation chapter.

Appendix 2: Energy Reduction

Reduction of energy in the Boer home was conducted in a series of steps. The first step considered by most groups was the replacement of incandescent and fluorescent light bulbs with LED light bulbs. This was recommended because LED bulbs are proven to be very energy efficient. Figure 19 below shows the reduction in electricity along the x-axis as a decrease of 491 $\frac{kWh}{yr}$. This is changing all the lights in the house to LEDs. The initial investment cost is $48, but there is an annual savings of 59 $\frac{\$}{yr}$; therefore the LEDs would be paid for in less than a year (0.81 years).

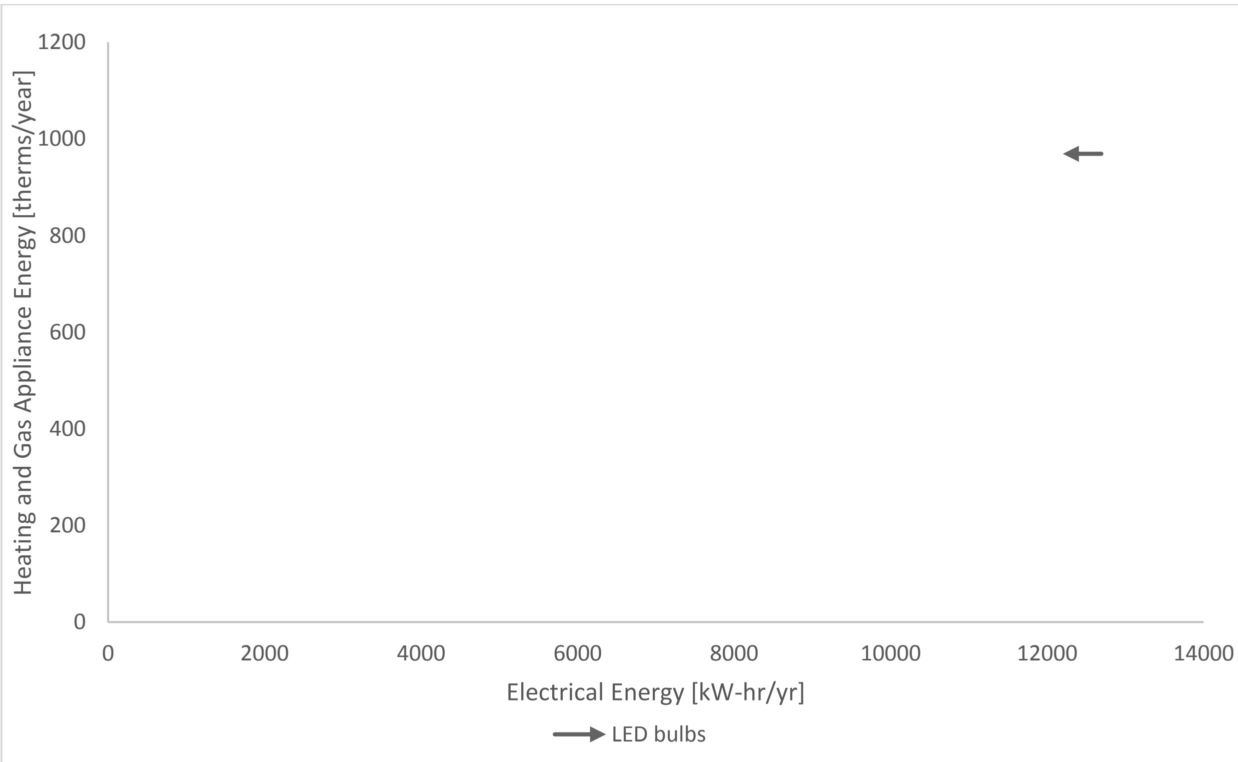

Figure 19. LED Implementation

The next energy reduction considered were the smaller kitchen appliances that were outdated such as the microwave and coffee maker. By replacing these appliances with newer more efficient ones such as a Kenomore 2.1 cu ft Over-the-Range Microwave and a Mr. Coffee K-Cup Brewer, the annual energy reduction was found to be 750 $\frac{kWh}{yr}$. The initial investment cost was approximately $529, but the annual savings with the reduction in energy usage was 90 $\frac{\$}{yr}$. This results in a payback period of 5.9 years. This can be seen in Figure 20.

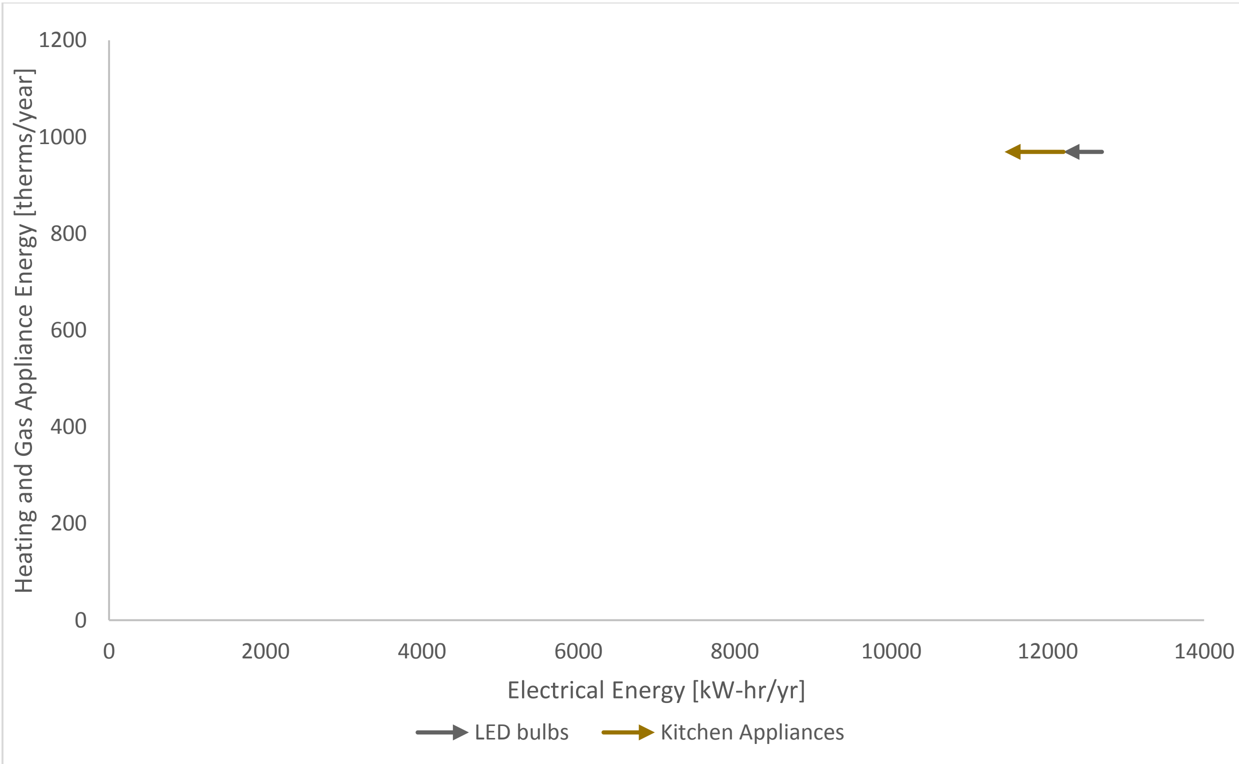

Figure 20. Kitchen Appliance Implementation

The current washing machine uses approximately 300 $\frac{kWh}{yr}$. Implementing a new washing machine can optimistically save 191 $\frac{kWh}{yr}$. The investment cost for the more efficient machine, chosen to be the Kenomore Elite 5.2 cu. ft. Front-Load Washer, is about $1400. Using this new machine saves $23 on the electric bill every year. The break-even point comes 61 years later. Utilizing this device brings the annual consumption down to 11,258 $\frac{kWh}{yr}$. Figure 9 below, shows the electrical energy reduction when installing the new washing machine.

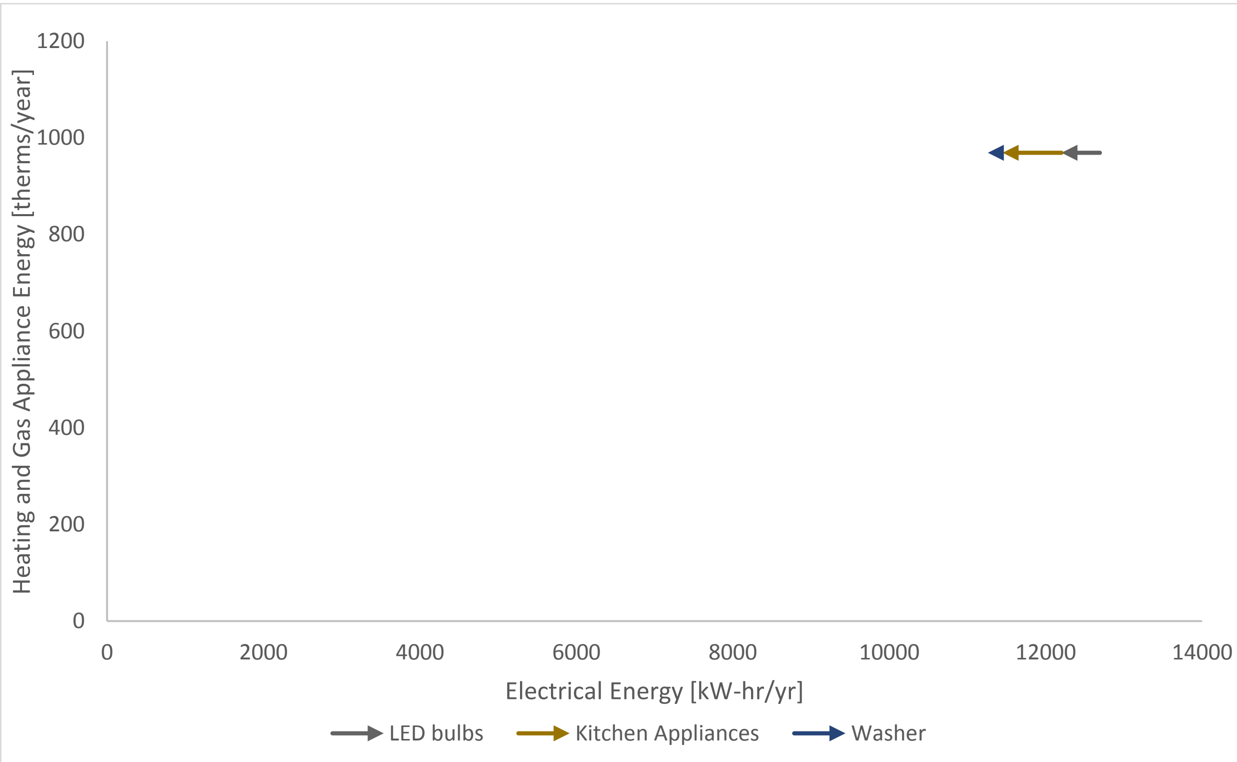

Figure 21. Washer Implementation

By eliminating unnecessary entertainment devices, the Boer residence can reduce its electricity consumption by 265 $\frac{kWh}{yr}$. The chosen devices eliminate two TV's, one X-box, and a surround sound system. Eliminating the entertainment is a lifestyle change that is essential for the overall goal of becoming net-zero. The lifestyle change does not only need to be applied to minimally used TV's, but also to other aspects in the household. Being a conscious energy consumer is enough to impact electricity consumption.

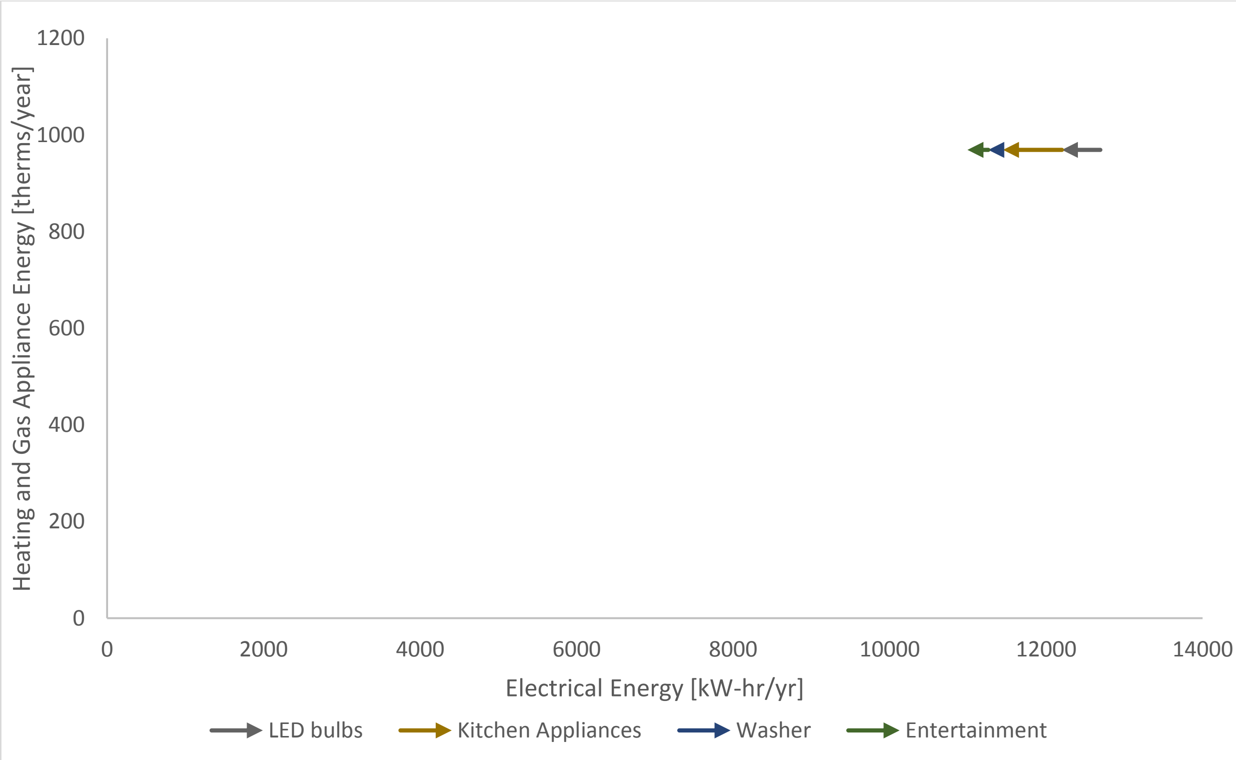

Figure 22. Entertainment Usage Minimization

The HVAC system stands for Heating, Ventilation and Air conditioning. The current HVAC system in the Boer home was estimated to use approximately 5200 kWh/yr for all purposes of heating during the winter, ventilation and air movement throughout the entire year, and especially air conditioning during the summer. The reason the electricity consumption is so high in this system is because the college students currently living in the home like to remain comfortable. This means that during the winter months their house remains at a constant 72°F and during the summer months it would remain at a constant 68°F.

The interesting thing about the HVAC system is that it can be completely eliminated with the introduction of geothermal generation. This system will be explained later, but simply put, geothermal takes care of all of your heating and cooling needs. This decision acts as straight gain for the home, or rather reduction, on the path of net-zero for the Boer home. As shown below in **Error! Reference source not found.** is the energy representation with the elimination. As you an see, there is a loss of 5200 kWh/yr. The initial investment cost for this decision is $0. This is because the owner does not have to purchase anything. Not looked into for this project, but it could be possible for the home owner to actually sell their HVAC unit and make a profit.

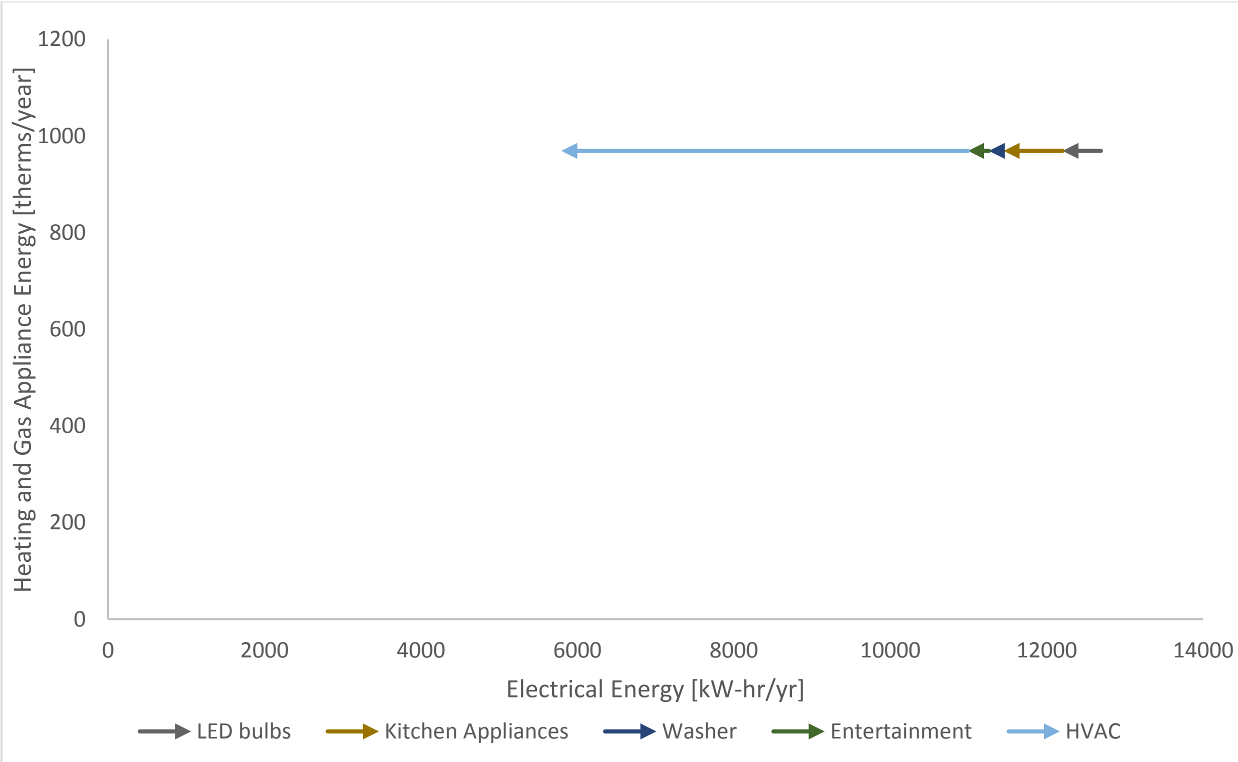

Figure 23. HVAC Reduction

The refrigerator in the kitchen utilizes about 1700 $\frac{kWh}{yr}$. Introducing a more efficient refrigerator saves about 300 $\frac{kWh}{yr}$. The refrigerator chosen by the team is a Kenmore 22 cu. ft. Counter-Depth French Door Refrigerator which cost $2199 and has a savings of $36 annually. This brings the payback period to 61 years. From Figure 10, one could see that the implementation of the refrigeration helps reduce the overall electrical energy consumption from 11,258 to 10,958 $\frac{kWh}{yr}$.

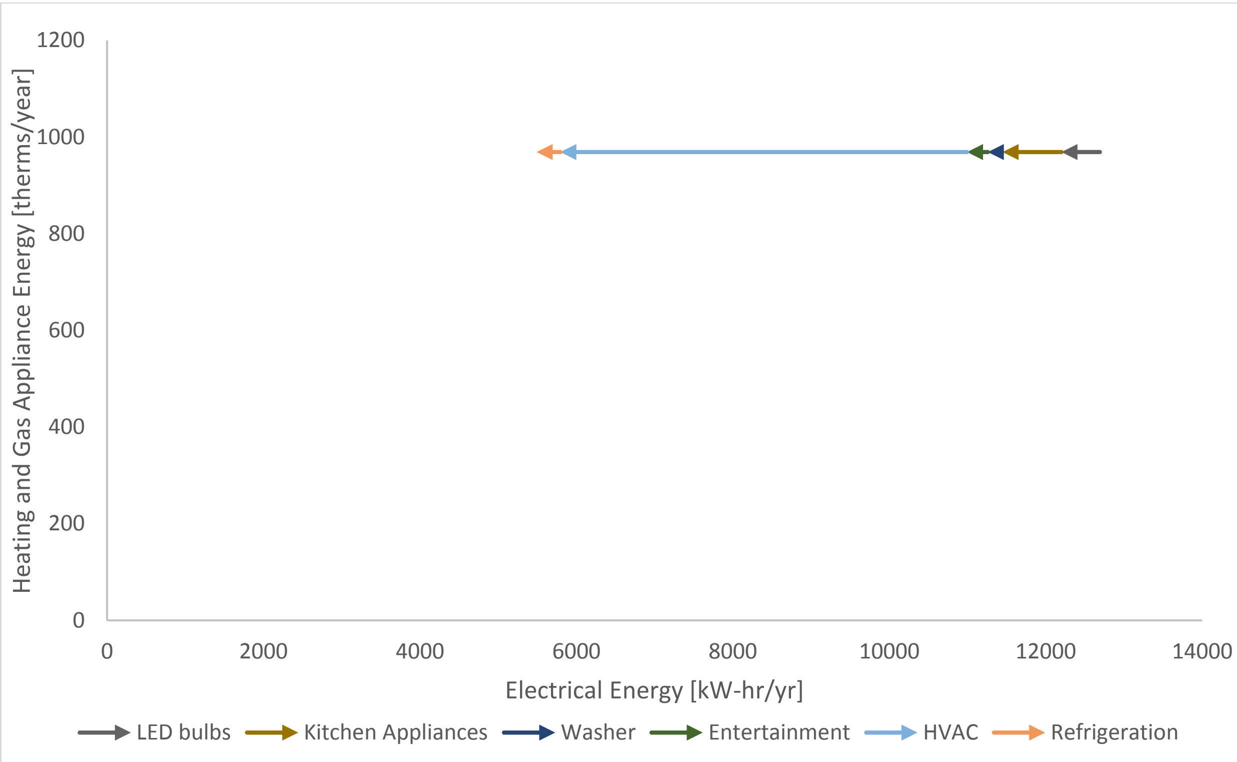

Figure 24. Refrigerator Implementation

It was determined that within the current house, there was essentially no insulation. This was determined by going into the attic of the house along with examining the walls and looking for any existing insulation. The next step was to calculate the R-value of the entire house. The calculations for doing such can be seen in the Appendix 4: Results section. The house was found to have an R-value of 8.7 (input units). It has been determined that the whole wall R-value can be up to 20% less than the insulation within the wall due to windows and doors. (Cox-Smith). Since heat also escapes due to the opening and closing of doors along with cracks, adding R-15 insulation will only add an R-value of 6 $\frac{\mathrm{hr*ft^2F}}{\mathrm{BTU}}$ (40%) to the overall house R-value. With the existing resistance to heat escape from the house and the new insulation, an overall home R-value of 14.7 $\frac{\mathrm{hr*ft^2F}}{\mathrm{BTU}}$ can be obtained. The increased resistance to heat loss will save 250 $\frac{therms}{yr}$, which is equivalent to $227.5 annually. Using the Homewyse insulation cost calculator and the cost of insulation, it was determined that it would cost $1700 to insulate all of the walls and attic. (Cost to Insulate Your Home, 2006) (Types of Insulation, 2012) With the new annual savings in heating, a payback period of 7.62 years can be obtained.

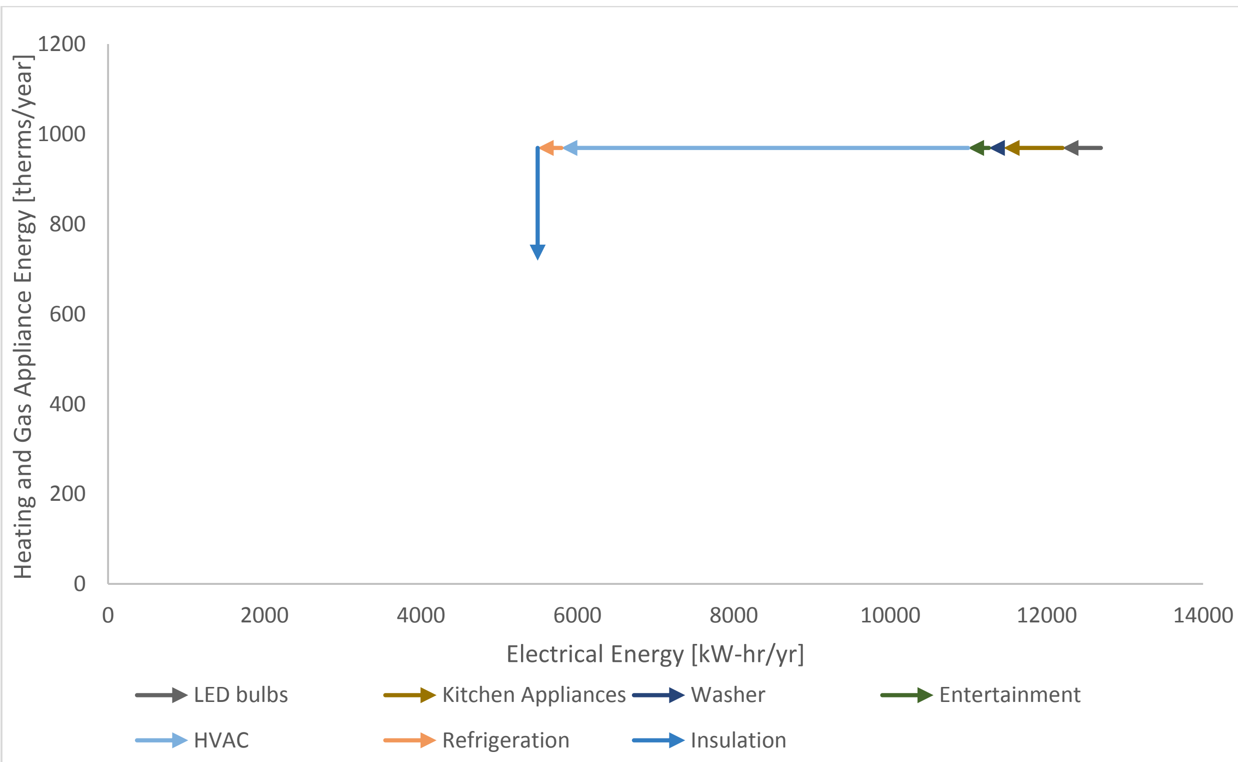

Figure 25. Insulation Implementation

Appendix 3: Energy Generation

Now that our initial energy consumption has been reduced as far as possible by buying new appliances and making some simple lifestyle changes, it is time for the next chapter in the net-zero story. That next chapter is energy generation or production. Energy generation is of course the opposite of consumption. Rather than pulling electricity from the power grid and natural gas from power plants, the user actually creates the energy they need to use. We see various forms of generation. We see solar panels on rooftops and fields of wind turbines while driving down the highway. Other alternate forms to produce energy include geothermal heat pump systems, hydroelectric systems found in dams, and biomass. Of these forms, solar panels and geothermal systems will be discussed as applications for the Boer home net-zero project. Both of these applications are renewable sources of energy. Later, a discussion will take place as to why other forms of energy were not explored or recommended.

The first step to net-zero in energy generation is the implementation of a geothermal heat pump. Geothermal heating and cooling is the use of the Earth's heat, hence geo-thermal energy. Geothermal systems are dug into the ground in order to maximize the heat from the ground. These systems are capable of taking over all needs for heating and cooling in a residential home. The reason we looked into a geothermal system is because our natural gas consumption was not yet zero after energy reductions through the insulation improvement. There was still 719 $\frac{therms}{yr}$ to produce. Geothermal systems typically come in two different loop forms, vertical and horizontal. A horizontal loop is a system that requires a larger area. The coils, which retract the heat from the Earth, are placed horizontally into the ground, hence the name. This system is far more energy efficient and far less expensive. A vertical loop system requires far less area to dig. The same size system must still be applied, so the loops for the system are dug hundreds of feet into the ground. This type of system is used for buildings with limited area access to ground. Because it must be dug far into the ground the initial investment cost is three times that of a horizontal loop. Due to the yard space limitations of the Boer home, a vertical loop was required.

A local company by the name S&J Heating and Insulation was called in order to determine system requirements and system costs due to limited access to information online. Representative Harry Jonivan was the spokesman to most groups in this project. The requirements for the Boer home were provided to Harry, which included reduced heat consumption of 719 $\frac{therms}{yr}$ and the requirement for a vertical loop. In order to fulfill these requirements a 3.5-ton system was required. The cost of this size system is $4,250 per ton, giving a total system cost of $12,750. This is not including the installation. The installation of this sized vertical loop geothermal system would be approximately $17,250, giving a grand total cost of approximately $30,000. Not taken into consideration yet is the power required to run the geothermal system. The pump for the system would consume 4200 $\frac{kWh}{yr}$. With electricity costing $0.12 $\frac{\$}{kWh}$, the cost requirement for our geothermal heat pump would be approximately $1000 annually.

Implementing this vertical loop geothermal system would result in an annual savings of $655. That means that after 46 years, the geothermal system will be paid off. As seen in Figure 26, the heating energy consumption has met our 719 $\frac{therms}{yr}$requirement. Our electricity need gap has also increased by 4200 $\frac{kWh}{yr}$.

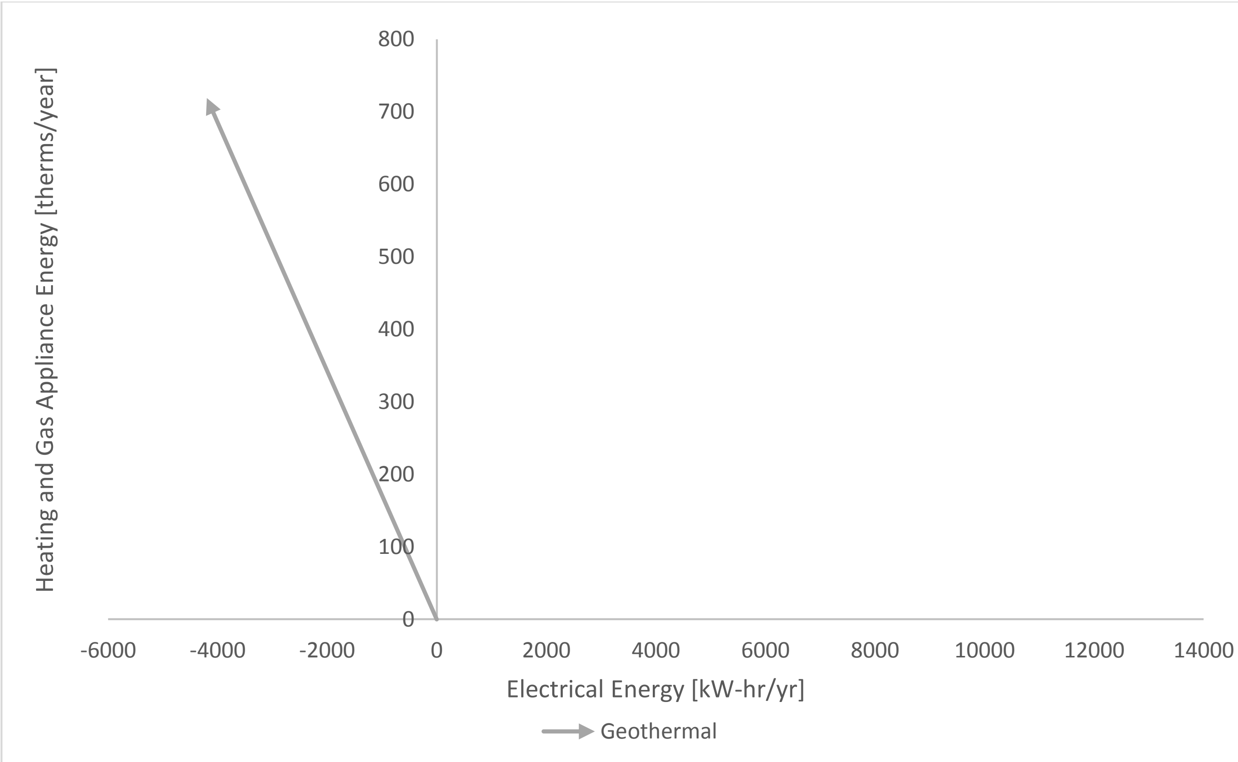

Figure 26. Geothermal Implementation

With the necessary production of heating and cooling met, the only energy production left would be electricity. After implementing the geothermal system, the electrical energy supply increases 4200 kWh. The total amount of electricity needed to become net-zero is now 9694 $\frac{kWh}{yr}$. There was a standardized solar panel system being used, this allowed for all groups to use similar data when it comes to different efficiencies of modules and panels. The program that was used was the NREL (National Renewable Energy Laboratory) SAM (system advisor model). The group used SunPower SPR-315E-WHT modules and SMA America: SB500TL-US-22 inverters. The NREL program utilizes many different variables such as: Installation costs including equipment purchases, labor, engineering and other project costs, land costs, and operation and maintenance costs. Numbers of modules and inverters, tracking type, derating factors for photovoltaic systems. Collector and receiver type, solar multiple, storage capacity, power block capacity for parabolic trough systems. Analysis period, real discount rate, inflation rate, tax rates, internal rate of return target or power purchase price for utility financing models. Building load and time-of-use retail rates for commercial and residential financing models. Tax and cash incentive amounts and rates.

Utilizing these variables allows for a very realistic analysis of residential solar power systems in the Grand Rapids region. The NREL program provides information on factors such as annual energy usage, payback period, system performance factor, power, area of solar panels, and total cost.

The total cost of the solar panel system, including installation costs, is $32,186.31 with a solar panel area covering 40.8 square meters. The system produces about 9696 $\frac{kWh}{yr}$ producing a payback period of 16.9569 years, which includes net metering. The area covered by the solar panels is enough for 25 modules. The space on the roof of the house as well as the roof of the garage will be utilized to cover this amount of panels. As seen below in Figure 27, the geothermal system and the solar panel system create enough energy production to meet our energy needs, thus meeting net-zero.

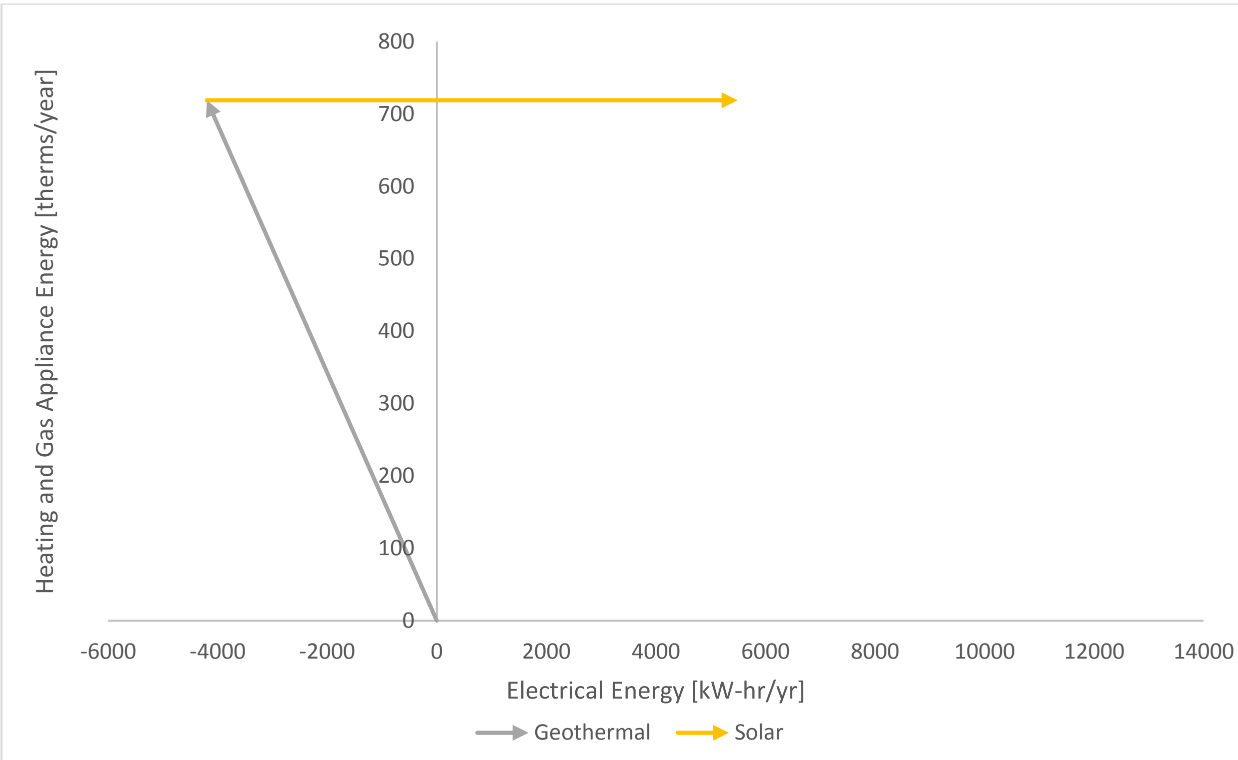

Figure 27. Solar Panel Implementation

Appendix 4: Results

Shown below in Figure 28 is the final plot indicating all energy reducing and generation methods with calculations. The final point, as labeled by an orange circle, proves that the Boer home has met the goal of becoming net-zero.

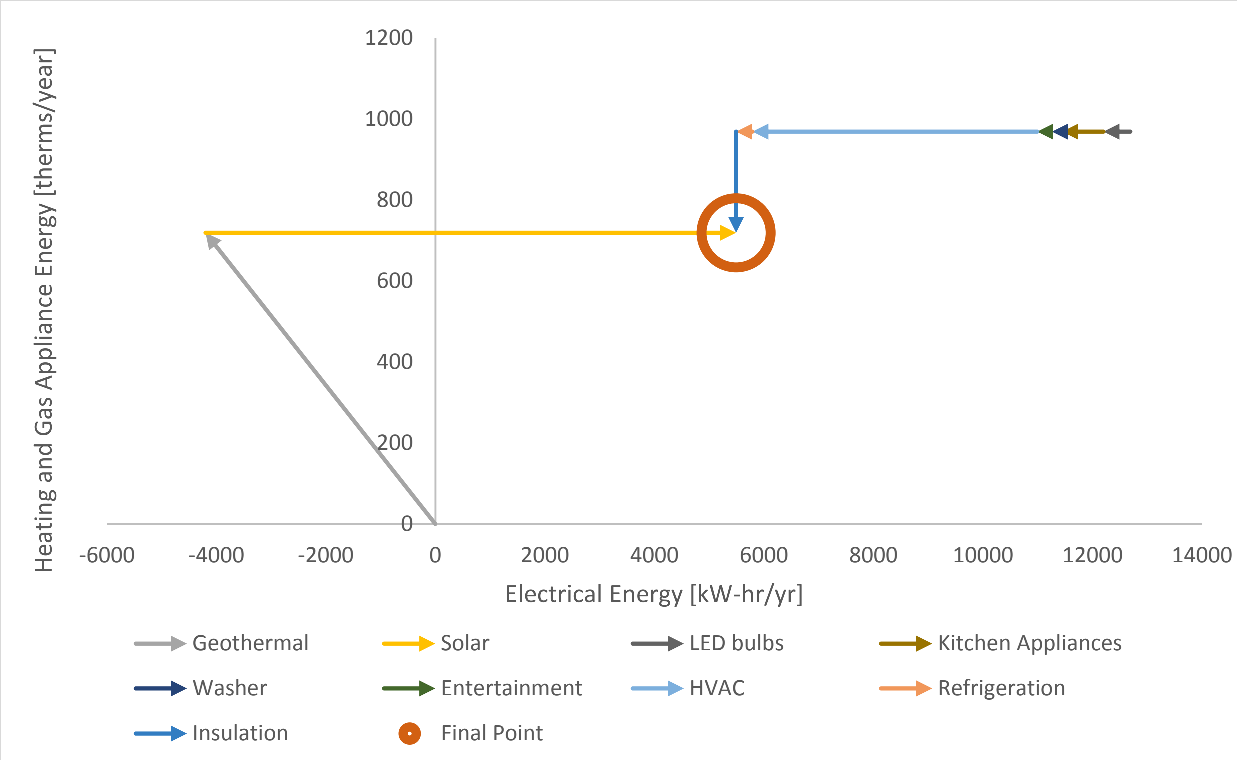

Figure 28. Final Overlay Plot

Data, Bibliography, Acknowledgements

House Data

Table 1: House Data

Square Footage	1542	Ft^2	Not including basement	
# of occupants	5	persons		
	Last Year	Average Year	Projected after improvements	Energy Units
Gas Usage	1.2734	1.2734	0.4663	$\frac{therms}{yr/ft^2}$
Electric Usage	6.0668	6.0668	3.5629	$\frac{kWh}{yr/ft^2}$
Gas energy equivalent	37.6912	37.6912	13.80181582	$\frac{kWh}{yr/ft^2}$
Gas Usage	392.7016	392.7016	143.8	$\frac{therms}{yr/person}$
Electric Usage	1871	1871	1098.8	$\frac{kWh}{yr/person}$
Gas energy equivalent	11506.1564	11506.1564	4213.34	$\frac{kWh}{yr/person}$
Potential Heating generation	719			$\frac{therms}{yr}$
Potential Electric generation	5494			$\frac{kWh}{yr}$
Total cost of improvements	68095	[$]		
Payback time	29.8	[yrs]		
Gas Provider	DTE			
Electric Provider	Consumers			
Number of floors Conditioned	2	Not Including Basement		
House R value based on Heun calculation	5.464	$\frac{hr * ft^2F}{BTU}$		
Carbon Footprint	35258	35258	$\frac{lb_{CO_2}}{yr}$	
Year built	1915			

EES Calculations

```
"Degree Days"
T=6470.4*convert((F-day)/yr, (F-hr)/yr)

"Amount of Gas to Heat House"
Q_dot=969*convert(therm/yr, BTU/yr)
Q_dot_therm=Q_dot*convert(BTU/yr, therm/yr)

"Wall Dimensions"
L=28[ft]
W=30[ft]
h=10[ft]
A_wall=(L*h*2)*2+(W*h*2)*2

"Roof Dimensions"
L_roof=25[ft]
W_roof=28[ft]
A_roof=L_roof*W_roof
A_tot=A_wall+A_roof

Q_dot=U*A_tot*T
R_value=1/U

"New Insullation"
"Fiberglass"
Insulation_Rvalue=15[(hr-ft^2-F)/BTU]
Insulation_Efficiency=0.4
"R_value=(8.7[(hr-ft^2-F)/BTU]+Insulation_Rvalue*Insulation_Efficiency)"
Cost=.30[$/ft^2]
Cost_labor=1700[$]
Cost_mat=Cost*A_tot
Cost_supplies=150[$]
Cost_tot=Cost_mat+Cost_labor+Cost_supplies
```

Appendix 5: Bibliography

[1] P. M. K. Heun, *Net-Zero Homes Project,* Grand Rapids, Michigan, 2014.

[2] I. Cox-Smith, "CONFERENCE PAPER No. 92 Whole-Wall R-Values".*Presented at the CIB World Building Congress,.*

[3] "Cost to Insulate Your Home," 09 Dec 2006. [Online]. Available: http://www.homewyse.com/services/cost_to_insulate_your_home.html.

[4] "Types of Insulation," Enegy.gov, 30 May 2012. [Online]. Available: http://energy.gov/energysaver/articles/types-insulation . [Accessed 09 Dec 2014].

Appendix 6: Acknowledgements

On the behalf of the Boer residence team, we would like to thank all who participated in the energy analysis of the home. Eric Boer assisted in providing the energy bills for both electricity and natural gas. Professor Heun provided guidance and suggestions toward feasible energy production and reduction alternatives. We would also like to thank Harry Jonivan from S & J heating and cooling-geothermal. Harry provided much of the information utilized in the geothermal analysis.

Appendix C3

Net-Zero Analysis of the Cooper Home

Team 3: Schieffer Kwong, Jee Myung Kim, & Matthew DeYoung
Client: Dale Cooper and Phillip Beezhold
ENGR 333: Thermal Systems Design
Dr. Matthew K. Heun, Calvin College Engineering Department
December 16, 2014

Abstract

A net-zero house is a house that produces as much energy as it uses over the course of a year. The purpose of this project is to determine what it would take to bring a home in Grand Rapids, MI to become a net-zero house. To achieve net-zero, the house must undergo assessment, reduction, generation and offset studies. The Calvin College owned Cooper's house used 19,085 kWh of electricity and 1,369 CCF of natural gas in the year of 2013. The team propose to replace current appliances such as the washing machine, dryer, oven etc. to decrease energy usage, and install a $1{,}068\ ft^2$ solar array on top of a parking lot canopy and a vertical geothermal system to reach the goal of becoming a net-zero home. The projected new energy usage is 17,933 kWh of electricity per year and 33.8 CCF of natural gas per year. To become a fully net-zero house, the total cost of the proposed changes is $138,840 with a simply payback period of 45.22 years.

Technical Memo

Introduction

The purpose of this project was to answer the question: *What would it take for a home in Grand Rapids to become net-zero?* A net-zero home is a dwelling that produces exactly as much energy as it consumes. A net-zero home will draw energy from the grid while producing the equal amount by on-site power generation methods

Background

The client of this project is Mr. Phillip Beezhold, Director of Physical Plant at Calvin College. The house is located at 3230 Burton St. SE, Grand Rapids, MI 49546. The current tenants are Mr. and Mrs. Cooper. Mr. Cooper currently works at Calvin Institute of Christian Worship. The two story house was built in 1941 and has an estimated area of $3764\ ft^2$ total, excluding an attached garage and including an estimated area of $1532\ ft^2$ of basement. The house does not have an attic, and its insulation materials are currently unknown. The house used a total of 19,085 kWh of electricity and 1,369 CCF of natural gas (equivalent of 41,481 kWh of electricity) in the year of 2013.

Procedure/Method

To achieve net-zero, the team took four main steps: Assess, Reduce, Generate, and Offset. First, the house was assessed and analyzed for its current energy usage. Then, the team made suggestions on how to reduce energy usage by recommending changes, for example changing to a more energy efficient appliance. Third, the team looked into onsite energy generation methods and determined which options would be technologically feasible for implementation.

Results

To reduce energy usage, the team proposes to replace current appliances: light bulbs, dryer, washing machine, oven, refrigerator and water heater. The team proposes to change all current incandescent light bulbs to LED, which are much more energy efficient. The team also proposes to replace the dryer, washing machine, oven and refrigerator to more energy efficient ones. Next, the team proposes to change the current 135 gallon water heater to a hybrid water heater, which is more energy efficient. The proposed changes should lower the energy need to 17,933 kWh of electricity per year and 33.8 CCF of natural gas per year.

After reducing energy consumption, energy generation methods were investigated to cover the consumption. For energy generation, the two major systems were recommended:

geothermal unit and solar panel system. The geothermal unit will replace the usage of water heater during the winter and summer, and it will completely replace the usage of furnace and air conditioner. The 1068 ft^2 solar photovoltaic system will produce all of the electricity used in the house, and the equivalent kilowatt-hour amount of gas used by the water heater for offset.

Conclusion

As seen in Figure 1 below, the house was able to reach the goal of becoming net zero.

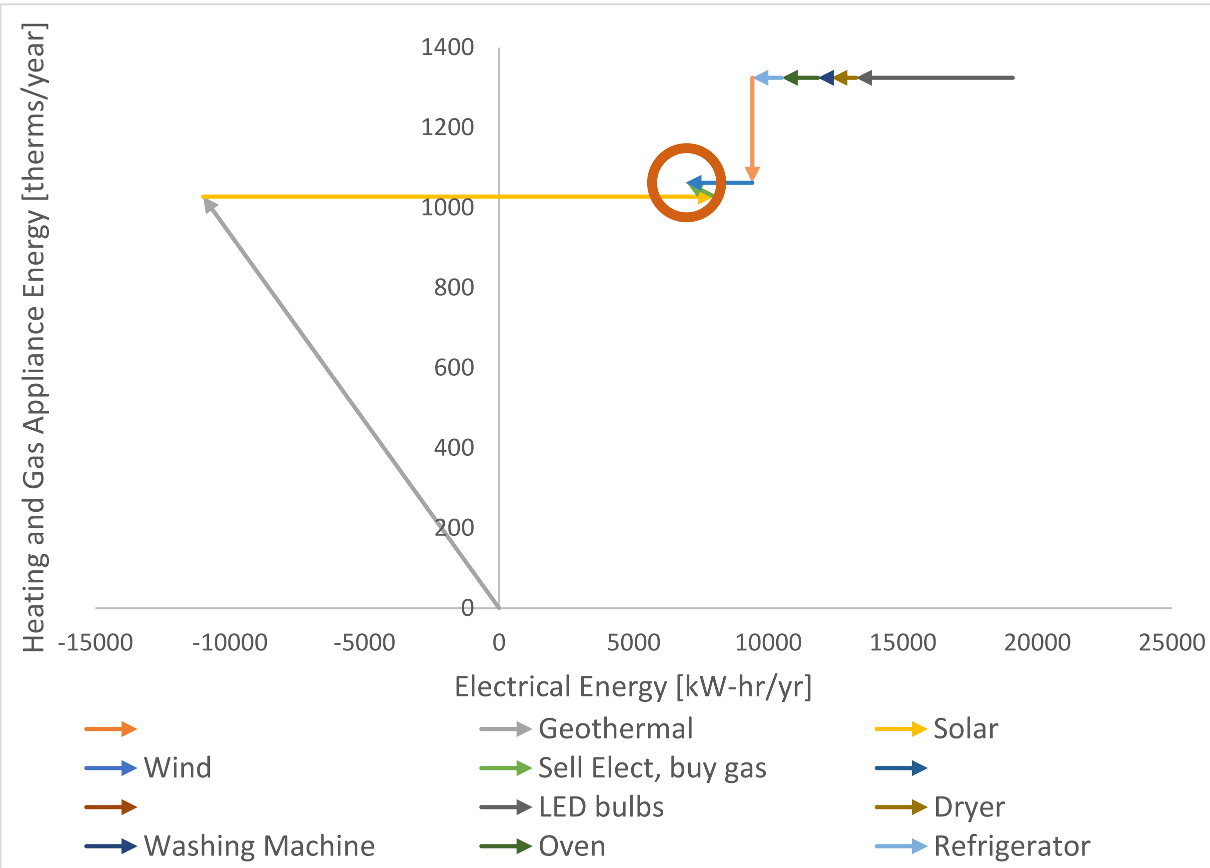

Figure 29 Overlay of the Energy Reduction and Generation

The energy reduction point and the energy generation point meet, meaning the house will reach net-zero. The total cost of modification is $138,840 and the simple payback period of the investment is 45.22 years. The cost is extremely high because the initial energy consumption rate was high, and the recommendations may seem economically not feasible by the Calvin College. However if the client is strongly willing to pursue net-zero, then the team recommends to make the modifications recommended by the team, because the investment will pay off in just a few decades.

Net-Zero Energy Story

Appendix A: Assess

Assessment

The Cooper's house will be represented in orange. The current energy consumption of the Cooper's house relative to other houses of study is shown in Figure 2 below.

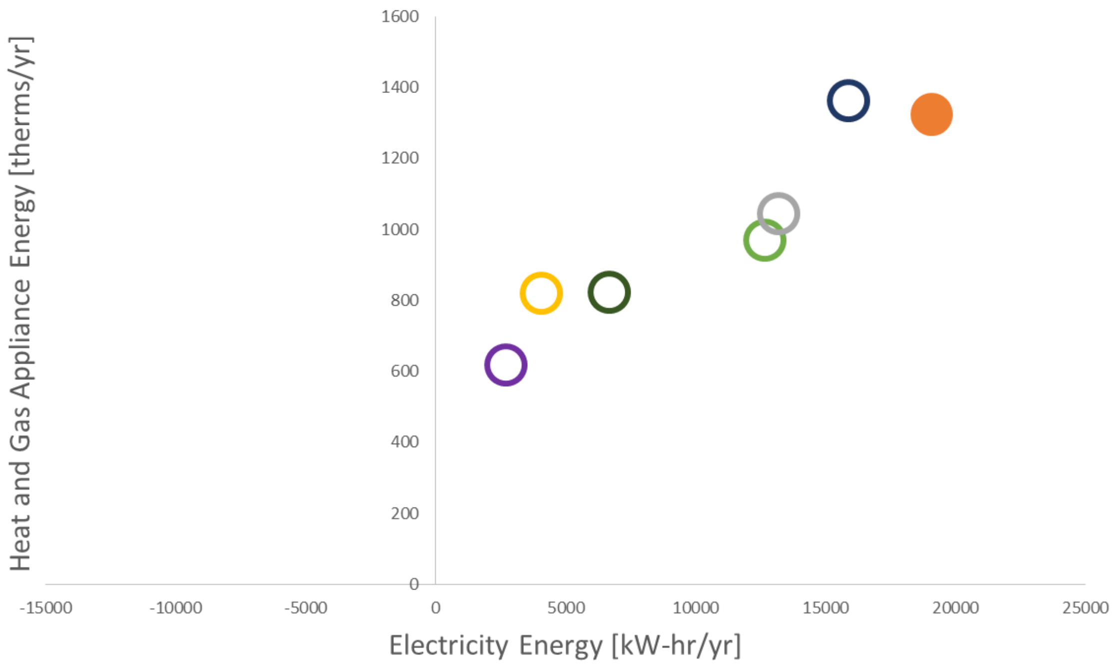

Figure 30 Initial Energy Needs

As shown on Figure 2, the Cooper's house has the highest electricity consumption rate and second highest gas consumption rate among the eight houses that were taken into the study. The initial energy consumption rate is shown in Figure 3 below. The initial electricity usage breakdown is shown in Table 1, and the initial gas usage breakdown is shown in Table 2.

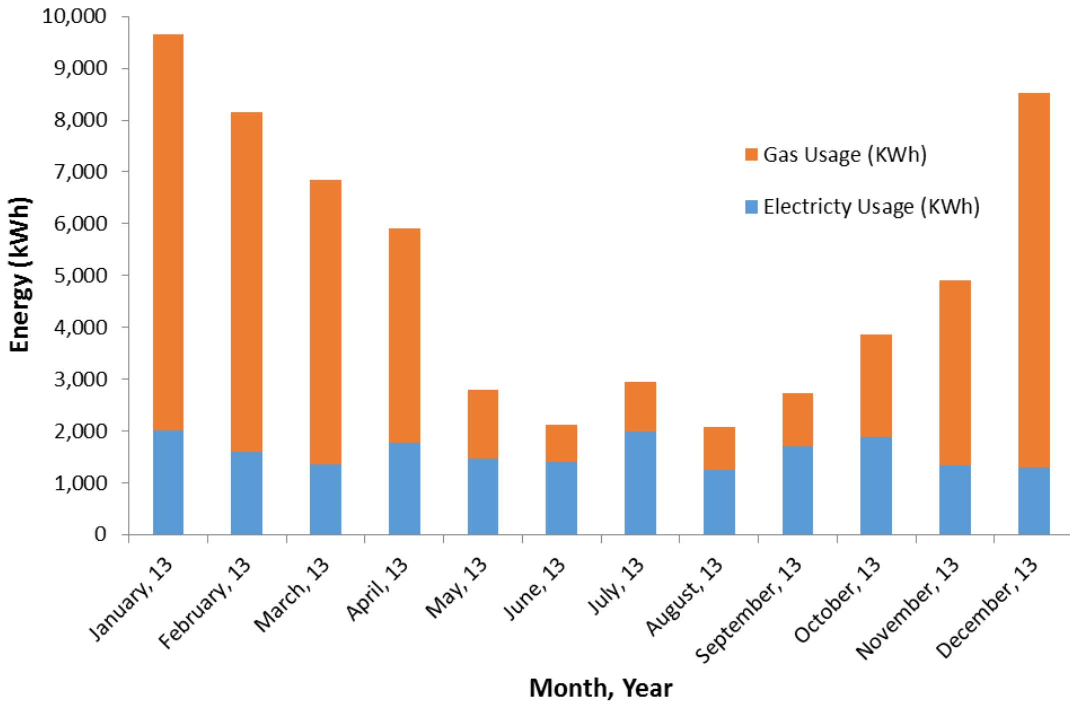

Figure 31 Initial Energy Usage

Table 2 Initial Appliance Data

Appliance	Electricity Usage [kWh/yr]
Dishwasher	294
Washing Machine	629
Dryer	1747.2
Microwave	273.75
Oven and Stove Top	1872
Refrigerator	1994.4
Air Conditioner	2475
Light Bulbs	7218
Miscellaneous	1581.65
Total	19,085

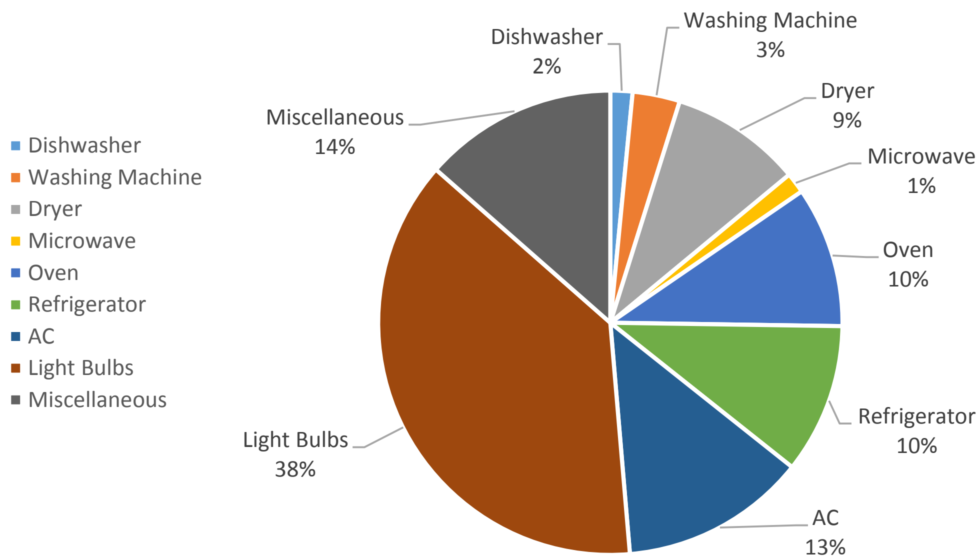

Figure 32 Initial Appliance Data

Table 3 Initial Gas Consumption Data

Appliance	Gas Usage [therms/yr]
Water Heater	402
Furnace	1027
Total	1429

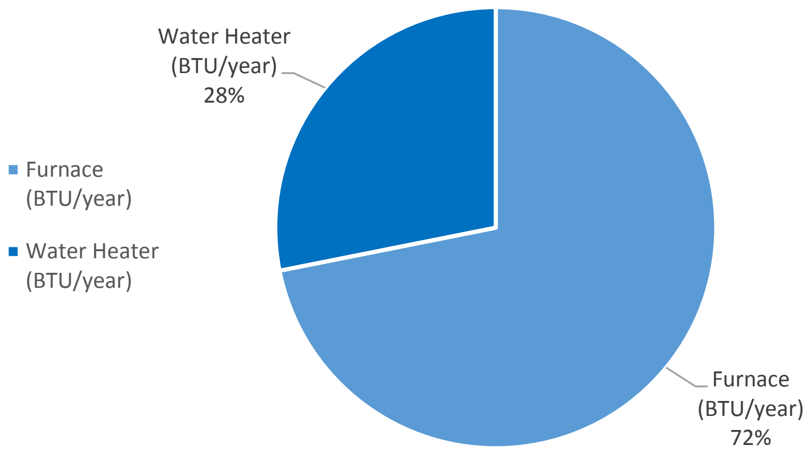

Figure 33 Initial Gas Consumption Data

Appendix B: Reduce

Reduction

In order to decide which electrics to replace and which not to, decision matrices were created for each. For the house appliances, three different current models were researched for each appliance, and then the decision matrix was used. The following will be recommended for replacement: light bulbs, dryer, washing machine, oven, refrigerator and water heater. Air conditioner and furnace will be replaced with geothermal system. The dishwasher and the microwave are relatively recent and energy-efficient compared to the ones in the market, thus they will not be recommended for replacement.

Currently, the Cooper's house used standard incandescent light bulbs, which consume a lot of energy. For replacement, Compact Fluorescent Lights (CFL) and Light Emitting Diodes (LED) light bulbs were looked into, which are extremely energy-efficient compared to the standard incandescent light bulbs. After comparing the pros and cons, the team decided to recommend replacing with LED light bulbs. Table 3 below shows the pros and cons of the two types of light bulbs.

Table 4 Pros and Cons of CFL and LED

CFL		LED	
Pros	**Cons**	**Pros**	**Cons**
Widely available	May dim over period	Lasts 8 times longer than CFL	More expensive
Relatively inexpensive	Contain toxic mercury	Contain no hazardous materials	Not widely sold
_	Require warm-up period	Create less heat	_

While keeping the same lumen value, which is a measurement unit for the brightness of light bulbs, replacing to LED light bulbs would cut down the electricity consumption rate from 7218 kWh/yr to 1391.4 kWh/yr. The cost of replacement is approximately $957.50, with the payback period of 428 days.

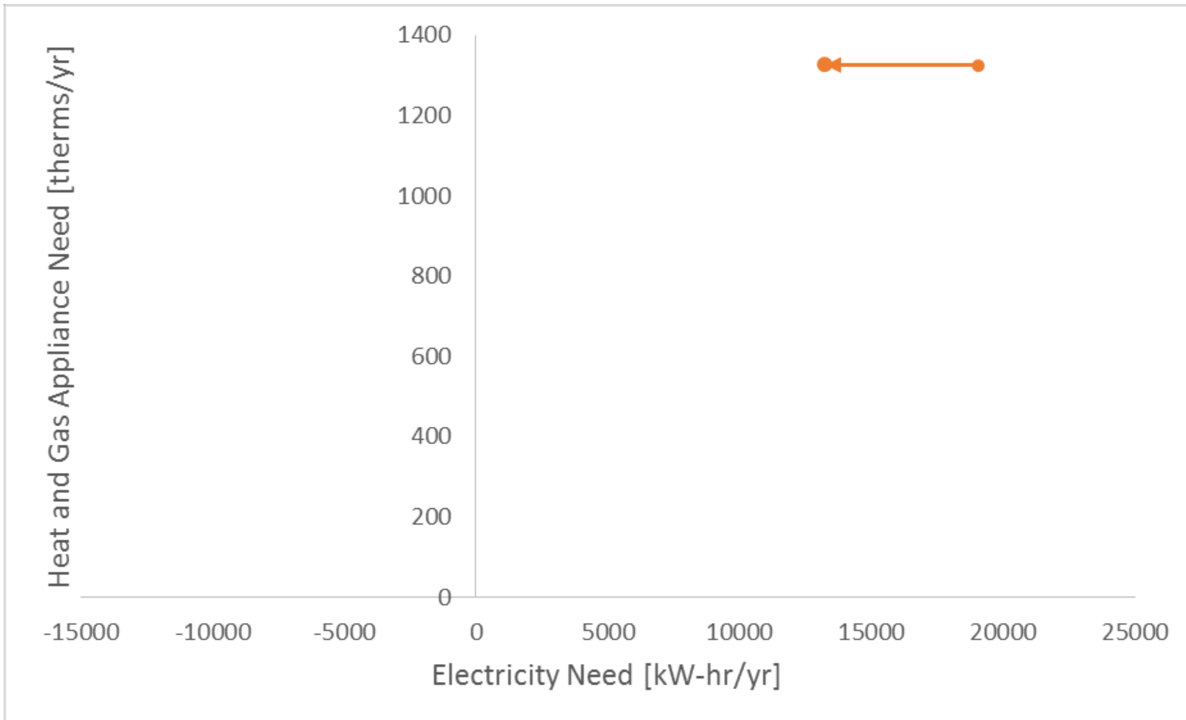

Figure 34 Energy saving on Light Bulbs

The first appliance to be recommended is the dryer. The recommended dryer is Whirlpool 7.4 cubic feet Cabrio Electric Dryer, which will bring down the electricity consumption rate from 1747.2 kWh/yr to 835 kWh/yr with the cost of replacement of $585 and the payback period of 4.58 years.

Table 5 Decision Matrix of Dryer

Criteria	Weight	Original	WED4800BQ	WED8000BW	WED5500BW
Energy Usage	8	2	3	3	4
Capacity	6	3	3	4	4
Payback Period	5	5	4	3	3
	Total	61	63	62	70

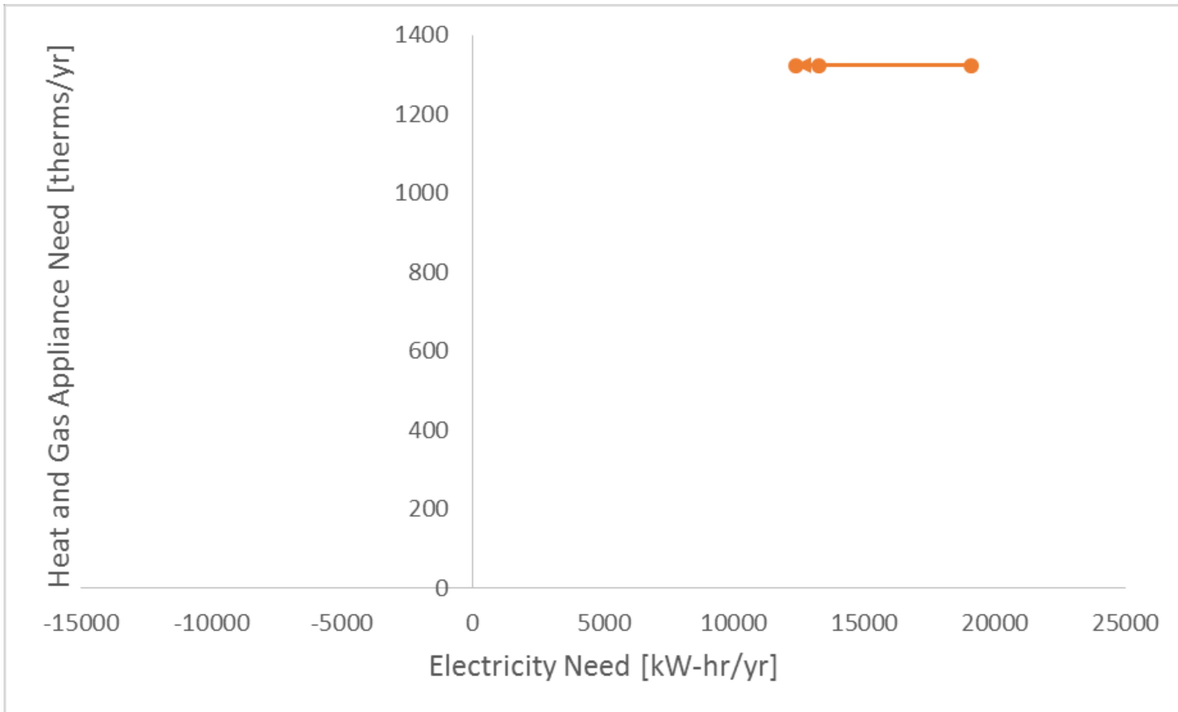

Figure 35 Energy Saving on Dryer

For the washing machine, the Kenmore 4.0 cubic feet Front-Load Washer is recommended, which will bring down the electricity consumption rate from 629 kWh/yr to 130 kWh/yr with the cost of replacement of $545 and the payback period of 7.87 years.

Table 6 Decision Matrix of Washing Machine

Criteria	Weight	Original	Kenmore 28102	Kenmore 210	Kenmore 41182
Energy Usage	8	1	3	2	4
Capacity	5	5	3	4	2
Payback Period	6	5	2	4	3
	Total	63	51	60	65

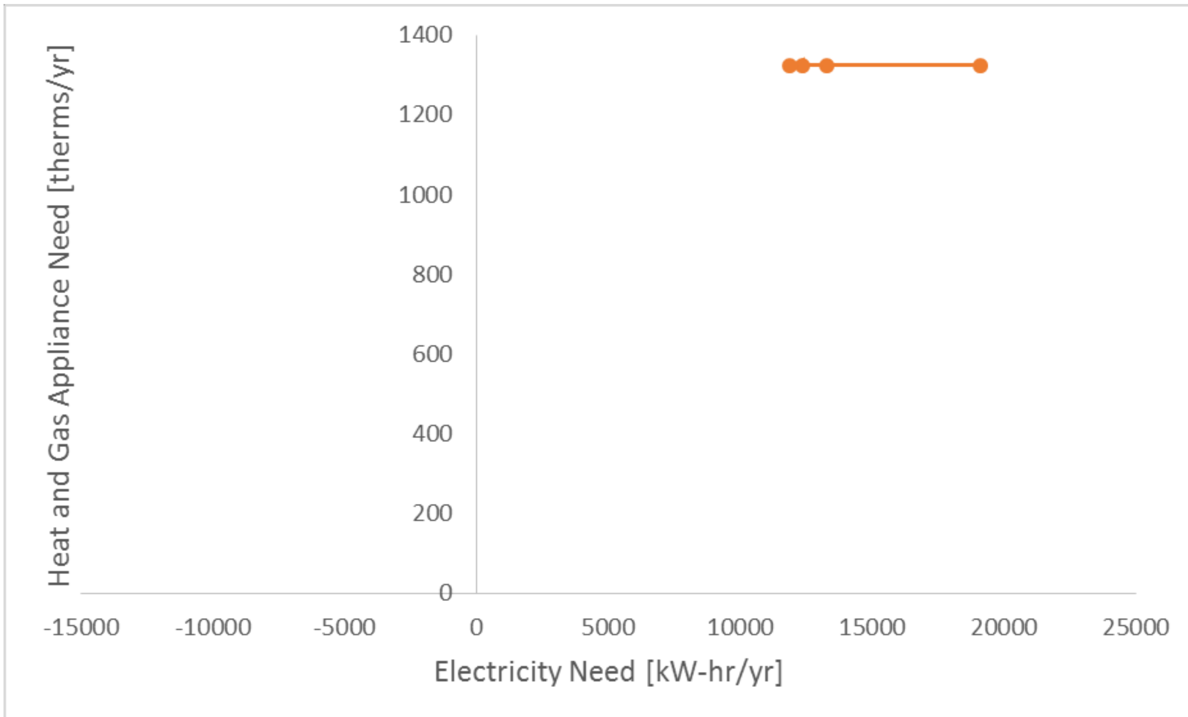

Figure 36 Energy Saving on Washing Machine

For the oven and stove top, the Whirpool 4.8 cubic feet Electric Range is recommended, which will bring down the electricity consumption rate from 1872 kWh/yr to 1339 kWh/yr with the cost of replacement of $549 and the payback period of 7.35 years.

Table 7 Decision Matrix for Oven and Stove Top

Criteria	Weight	Original	WFE320M0AB	WFE540H0AS
Energy Usage	8	2	5	4
Payback Period	6	5	3	2
	Total	46	58	44

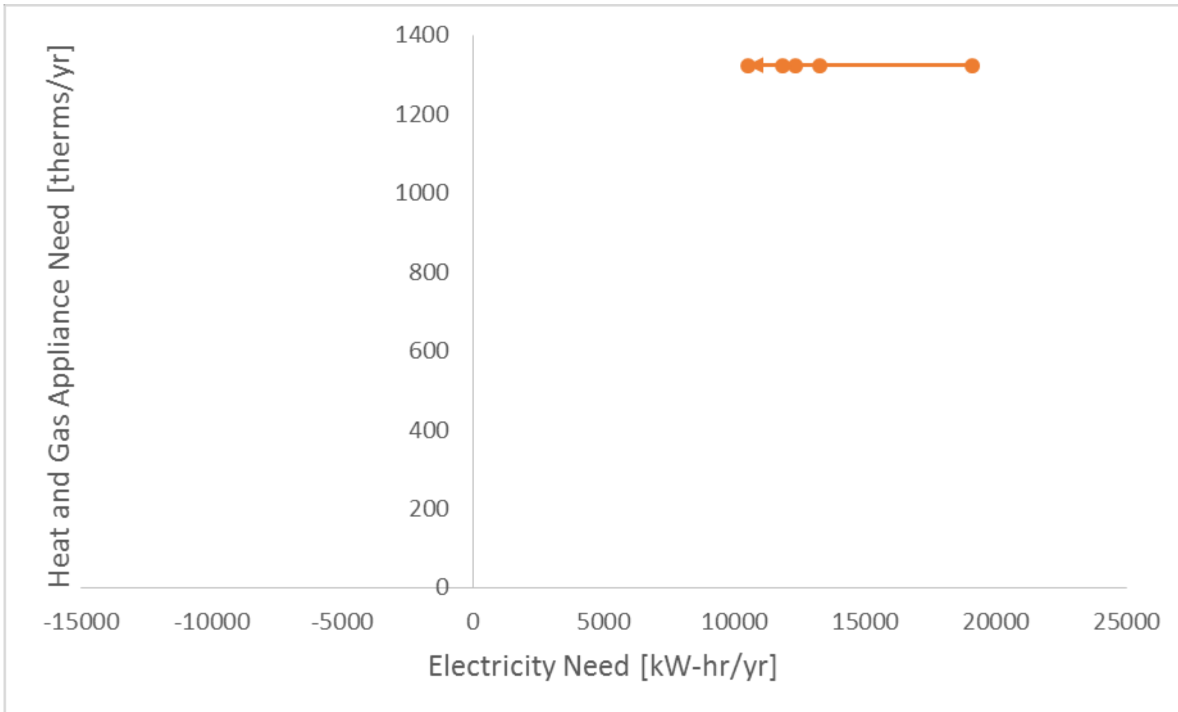

Figure 37 Energy Saving on Oven and Stove Top

For the refrigerator, the Whilrpool 21 cubic feet Top-Freezer Refrigerator with Condiment Caddy is recommended, which will bring down the electricity consumption rate from 1994 kWh/yr to 519 kWh/yr with the cost of replacement of $720 and the payback period 3.49 years.

Table 8 Refrigerator Decision Matrix

Criteria	Weight	Original	WRT511SZD	WRS322FDAW	WRS500FDAW
Energy Usage	8	1	5	3	4
Capacity	5	5	2	3	4
Payback Period	6	5	4	3	5
	Total	63	74	57	82

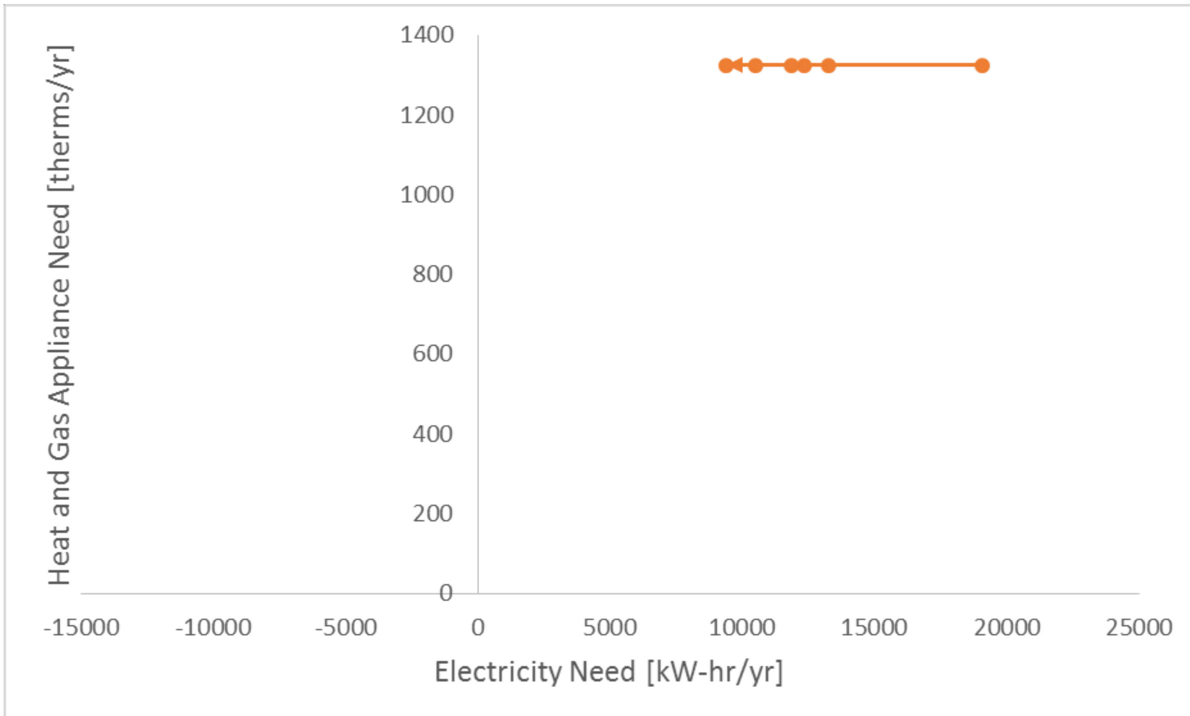

Figure 38 Energy Saving on Refrigerato

Currently, the house has a 135 gallon water heater. The water heater was in an estimated of 20 years of service already, and thus it is very likely that there would be sediment accumulation in the bottom of the tank. The team looked into replace the existing water heater with a hybrid one. The team decided that that a hybrid water heater was the right recommendation make after comparing the pros and cons as shown in Table 7 below.

Table 9 Pros and Cons of Water Heaters

Tank Water Heater		**Hybrid Water Heater**	
Pros	Cons	Pros	Cons
Widely available	Bottom sediments accumulation	No “cold water sandwich”	More expensive
Relatively inexpensive	Efficiency reduction over time	Chances of sediment accumulation decreased	Code update
_	Require constant energy input	Minimize water pressure loss	_

The team chose to recommend the Eternal Water Heater GU195S, because the energy usage was the lowest among other options. In addition, Calvin College already owns several Eternal water heater units. Therefore, it would be advantageous to get the same brand, as getting spare parts would be easier. With this hybrid water heater, the energy used to heat the water is expected to decrease by 60%, as this unit is only used during the spring and fall seasons. The water would be heated by a proposed geothermal system for the rest of the year. The expected life of such a water heater is about 25 years at maximum capacity. The cost of purchase and installation is approximately $4,500, and the payback period is about 66 years.

Table 10 Water heater Decision Matrix

Criteria	Weight	Original	GU195S	GU145S
Energy Usage	8	1	5	4
Payback Period	6	5	2	3
	Total	38	52	50

The microwave and the dishwasher are not recommended for replacement because they were purchased in the year 2012, and are recent in terms of energy efficiency. The air conditioning system was proposed to be discarded, as its function would be replaced by the proposed geothermal system. In addition, this would decrease the electrical energy needed for energy generation.

Appendix C: Generate/Offset

Generation/Offseting

After reduction of energy usage, the team looked into different energy generation. The team looked into replacing the existing furnace and air conditioner with a geothermal system. The geothermal system is required to offset 980.2 CCF of natural gas per year, which is equivalent of 1324 therm/year. The team contacted S&J Heating and Insulation, Inc. and obtained a cost estimate of a vertical geothermal system sufficient enough to replace the current furnace. The system proposed by our contact, Mr. Harry Johnivan, was the 4 ton, 5 Series 500A11 Forced Air Unit. In addition, the system is also capable of producing hot water for the house during winter and summer sessions. The proposed geothermal system has an underground installation below the Cooper house yard, and at most half of the Woodlawn CRC Ministry Center parking lot. The life span of the underground system is at least 50 years while the indoor unit has a life of about 25 years. The cost of the system is estimated to be $36,000, including underground system installation, water heater connection, and house water line code update.

The electricity the team needs to produce after energy savings is 17950 kWh/yr. However the team must take into account the 35 therms/yr from the water heater, which is approximately 1000 kWh/yr. Thus the team proposed a solar panel system that produces 19,000 kWh/yr. System Advisor Model (SAM) from National Renewable Energy Laboratory was used for the analysis. Suniva MVX260-60-5-8B1 model is recommended for the solar panels, and the Advanced Energy Industries AE 3TL-16 is recommended for the inverter, reason being the two companies are renowned for their efficiency and quality. The array will cover 99.2 m^2 of area. The team recommends building a car canopy over the parking lot of Woodlawn Christian Reformed Church Ministry Center, which is under possession of Calvin College, to place the solar panels. The life span of the system is 20 to 25 years, with the payback period of 21 years. Table 2 below shows the cost of the system.

Table 11 Cost of Solar Panel System

Criteria	Cost [$]
Solar Panels	71,229.24
Canopy	23,000
Snow Removal + Labor	550
Total	94,779.24

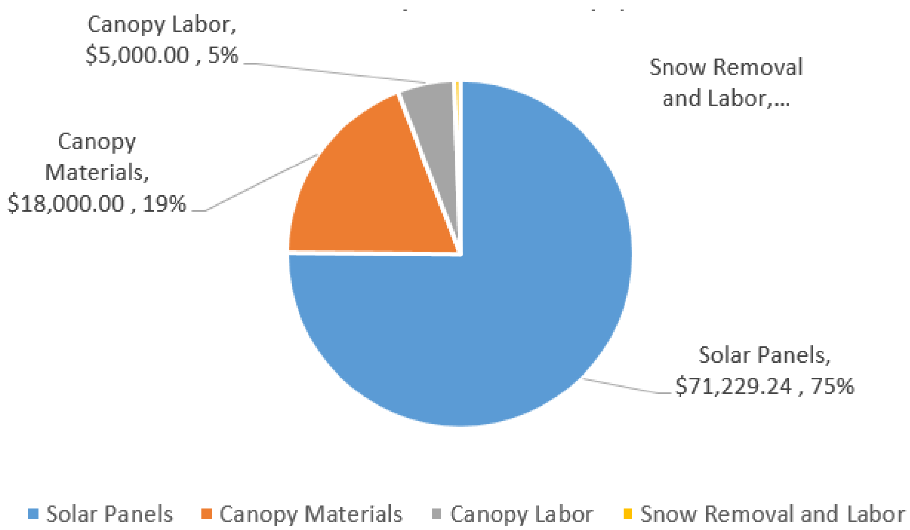

Figure 39 Cost of Solar Panel System

Figure 11 shows the monthly energy output of the system, and Figure 12 shows the yearly energy output of the system. The days of sun per year and the hours of efficient sunlight for different seasons in Grand Rapids are taken into account for the analysis.

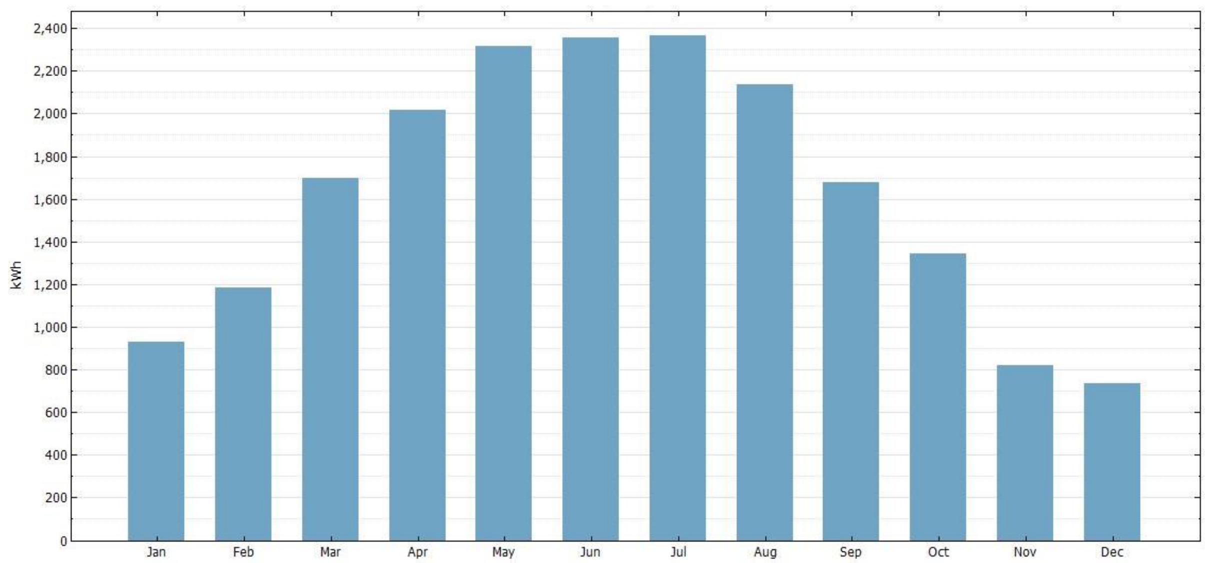

Figure 40 Monthly Energy Output

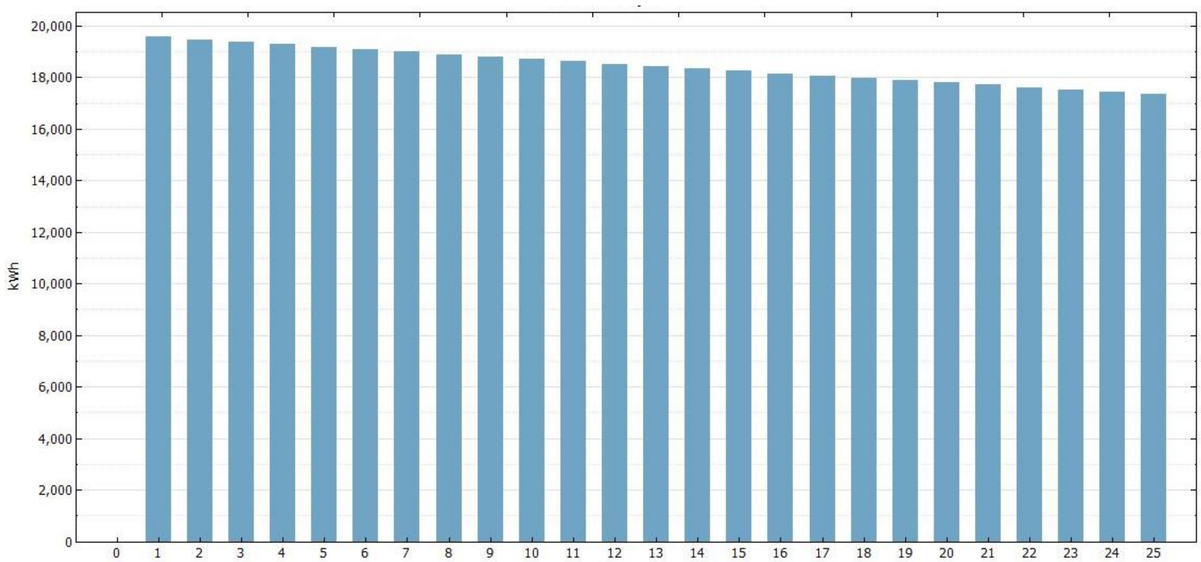

Figure 41 Yearly Energy Output

The declining energy output over the years is due to the degradation of solar panels. To compensate for the loss, the team aimed for the system to produce 19,000 kWh/yr for the 12th year, so that the extra energy from the first half of the lifespan could cover the loss from the second half of the lifespan.

Since the energy production requirement numbers are calculated per year, during the summer months the system will produce more electricity than needed, and during the winter months the system will produce less electricity than needed. To compensate for the losses, the team will consider the grid as a battery, and sell all the electricity the system makes to the grid and buy back from it as needed.

The team also recommends building a contract with Experimental Advanced Renewable Program (EARP). EARP attempts to make residential houses more environmental-friendly by making contracts with the houses to buy electricity produced from their solar photovoltaic systems for high price. By doing this, the team can actually make money by selling electricity through EARP for high price and then buying electricity from the grid for cheaper price, which was done for the payback period calculation.

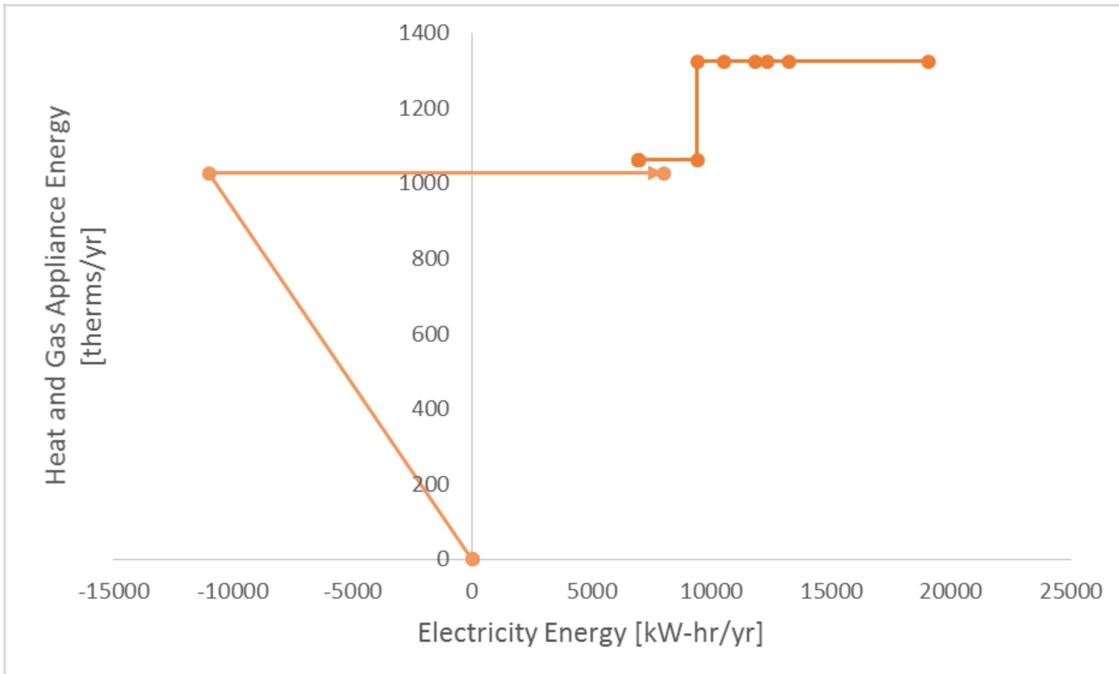

Figure 42 Electricity Generation through Solar Panel

Results

The house was able to meet the net-zero requirement.

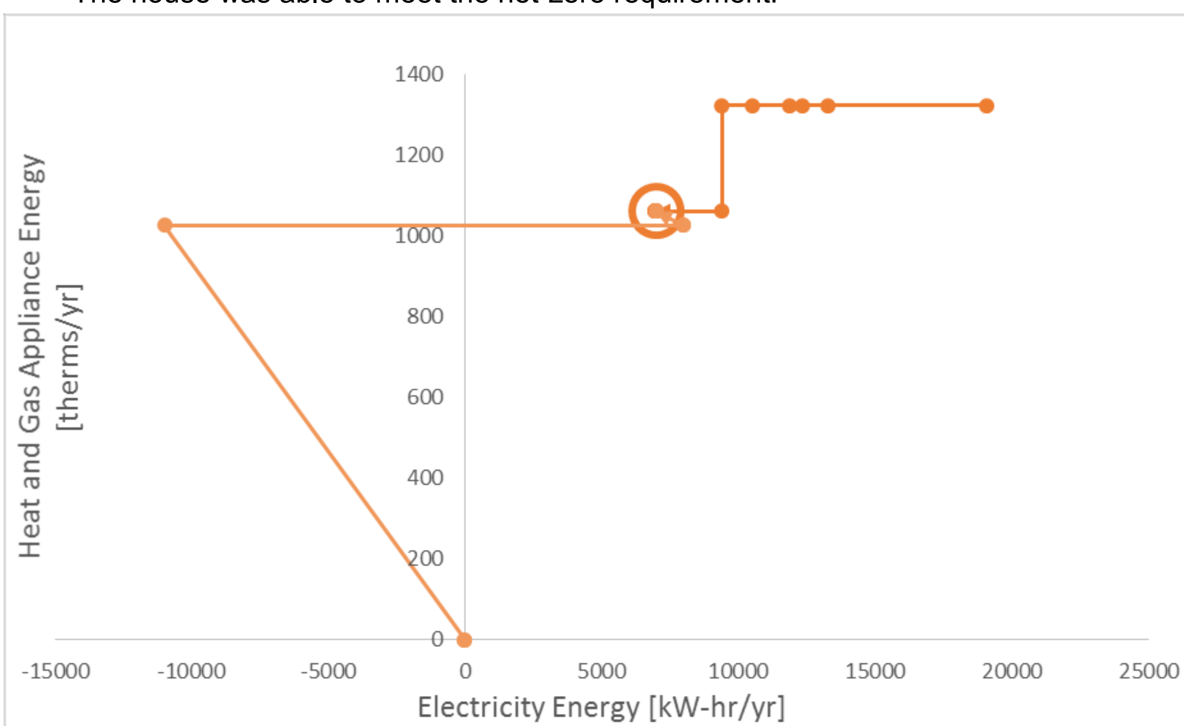

Figure 43 Achieving Net-Zero

The total cost for all the changes proposed is $138,840 as of late November of 2014. The cost distribution is as follows:

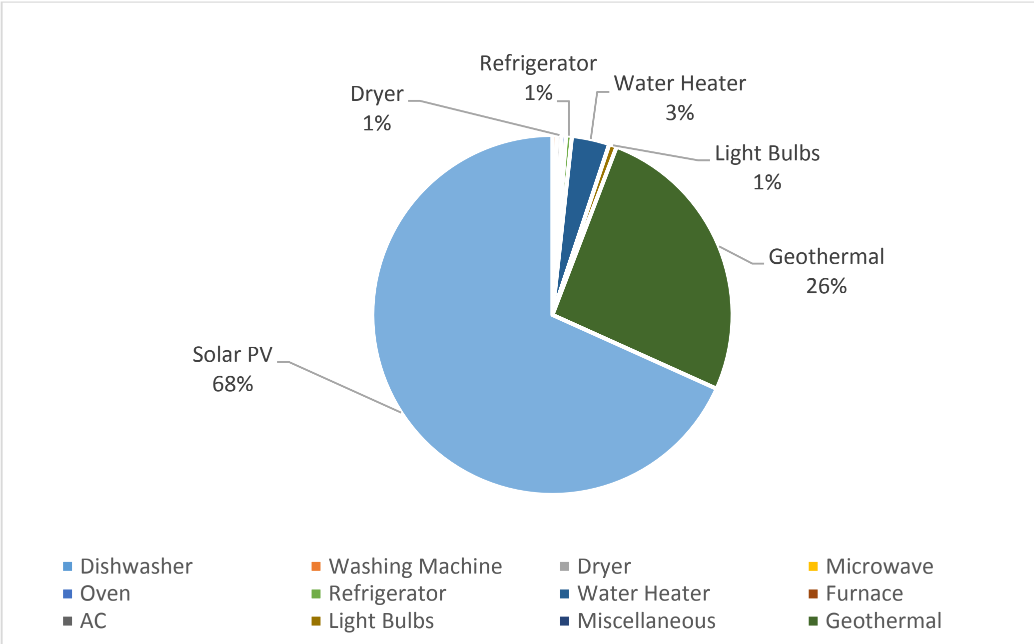

Figure 44 Cost of New System

The total new energy need is 17,933 kWh/ year and 35 therms/year.

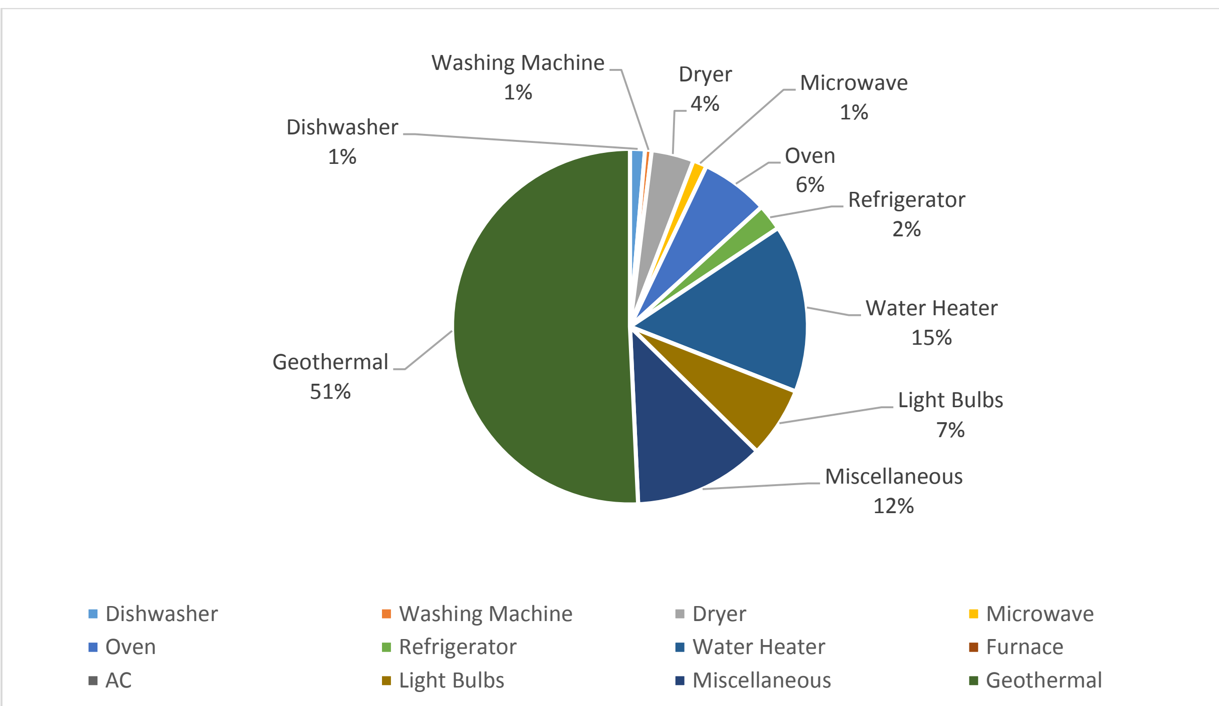

Figure 45 New Energy Usage

Resources, Acknowledgments, and Data

Data

Table 12 Key Data

Customer	Dale Cooper, Calvin College
Year Built	1941
Square Footage (including basement) [ft^2]	3764
Square Footage (excluding basement) [ft^2]	2231.8
Number of occupants [person]	2
Number of floors	3
Gas Provider	DTE Energy
Electric Provider	Consumers
R Value of the House [$\mathrm{hr} \cdot \mathrm{ft}^2 \cdot F$/BTU]	6.8
Carbon Footprint [$\mathrm{lb} \cdot \mathrm{CO_2}$/yr]	35893
Carbon Footprint [$\mathrm{ton} \cdot \mathrm{CO_2}$/yr]	17.95

Table 13 Calculated Data Values

Criteria	Last Year	Projected After Improvement
Gas usage [therms/yr/ft^2]	**0.35171**	**0.0092604**
Gas Energy Equivalent [kWh/yr/ft^2]	**10.305**	**0.27133**
Electric Usage [kWh/yr/ft^2]	**5.0704**	**4.7641**
Gas usage [therms/yr/person]	**707.86**	**17.428**
Gas Energy Equivalent [kWh/yr/person]	**9542.5**	**8966.0**
Electric Usage [kWh/yr/person]	**5.0704**	**4.7641**
Potential Heating Generation [therms/yr]	**N/A**	**1123.16**
Potential Electric Generation [kWh/yr]	**N/A**	**19,000**
	Total Cost of Improvement [$]	**92506.38**
	Payback Period [year]	**25.4**

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Mr. Matthew Heun, Professor of the Engr333 class.

Professor Heun's guidance of the project was essential. The team is grateful for his suggestions and insights.

Mr. Philip Beezhold, Director of Physical Plant

As our primary client, he volunteered his precious time and talked with the team about the house. The team is grateful for his input and his willingness to provide all the data available.

Mr. Jack Philips, Associate Mechanical Director of Physical Plant

One of the team members was able to briefly meet with him and discuss renewable energy options. He was able to provide the team with canopy estimates, provide valuable suggestions and raise potential concerns that the proposal might bring. The team is grateful for his input and his valuable time.

Mr. Cooper and Mrs. Cooper, tenants of the current house

The current tenants of the house was very generous with their time, allowing the team members to visit three times throughout the course of the project. They provided interesting and important background of the house, and estimated usage data for the team. The team would like to thank them for their generosity.

Mr. Harry Johnivan, representative from S&J Heating and Insulation, Inc. of DeWitt, MI

The team was able to contact him via phone and email. His expertise and experience on geothermal system installation and maintenance was most valuable to the team. He kindly looked over the data we were able to release to him and was able to make a rough cost estimate for purchase and installation. The team would like to thank him for his time amidst his extremely busy work schedule.

Mr. Dave Van Middendorp, local Eternal Water Heater representative

The team was able to contact him via phone. His expertise and experience on water heater installation was most valuable to the team. He was able to make rough cost estimates for purchasing and installing the Eternal Water Heater. The team would like to thank him for his time amidst his extremely busy work schedule.

Appendix C4

Net-Zero Analysis of the DeMaagd Home

Team 4: Jeff DeMaagd, Tyler DeVries, Doug Faber, Garrick Hershberger
Clients: Jeff and Liz DeMaagd
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department
December 16, 2014

Abstract

The DeMaagd home currently uses an average of 4100 kWh/year in electric power and 820 therms/year for heating. The home would reach net-zero status through a combination of: 1) energy savings measures including insulation and appliances updates and 2) energy generation techniques including geothermal climate control and solar PV energy production. Adding batt insulation to the currently uninsulated roof would increase the overall R-Value of the house by about 50% and save a significant 61 therms/year. Appliance updates (refrigerator and water heater) would save the home 450 kWh/year and 37 therms/year, respectively. The geothermal system produces 587 therms/year at a price of 5736 kWh/year in electrical energy. The additional and base electrical load in the home will be supplied through solar panels and arrays supplying 13330 kWh/year. 3978 kWh/year will be sold back to the grid in exchange for the additional 136 therms/year required to meet the remaining heating demand and bring the home to net-zero status. These additions would require a cash investment of at least $64,500 and would never effectively pay for themselves, making this project a financial strain for most families.

Technical Memo

Introduction

The DeMaagd home located at 1041 Griswold Ave houses Jeff and Liz DeMaagd, along with their daughters, Olive and Violet. The home will be analyzed for energy consumption and efficiency. The home will then be theoretically outfitted with energy efficiency and production measures to reach a net-zero energy production/consumption point. Once the most effective path to the net-zero point is determined, these measures will be analyzed for economical and practical feasibility.

Methods/Procedures

The first part of the project is the analysis of current energy usage, appliances, and physical state of the house. This data would later be used to determine a cost effective way of reaching the goal of a net-zero house. The information gathered from the analysis of the house helped to guide the project into the savings stage. Here the group focused on how the house can save both electrical and thermal energy. Easy methods for typical home energy savings include replacing old or inefficient appliances and lights or making lifestyle changes, like turning off lights in unused rooms. The last stage of this net-zero project is energy generation. After conducting significant research the group will present a method for the electrical and thermal energy generation to meet the remaining energy demand in the home. Thermal energy being the most significant demand of most homes, the group will first examine thermal energy production, later focusing on electrical energy production.

Results

From the analysis of the house the group found several areas where it would be possible to cut down on the electricity and gas usage. The currently uninsulated roof is one of the most significant sources of heat loss in the home. By insulating the roof with batts of R38 fiberglass insulation, a savings of 61 therms/year could be achieved. With a cost of $610 and a yearly saving of $56, the insulation would pay itself back in 11-12 years.

The group found that the current water heater was old and filled with sediment, decreasing its effectiveness and increase operation cost. A new, tank-less water heater will save 37 therms/year. It will cost $680 and with savings of $34 per year the payback is 20 years. Because most water heaters will not last 20 years it is important to note that if the life of the product does not exceed the payback time, it can be assumed that it will never pay itself back.

The group also suggests that the refrigerator be replaced with a new one to cut down on the electricity usage. The cost a new refrigerator is $1300 and it will save $72 per year in electricity cost. The payback period on the fridge is 18 years, close to the life of the product itself.

The group first examined geothermal climate control to heat and cool the home. A geothermal system sized for the house will cost $40,000. This system will provide almost all of the required heating energy but it will increase the electrical energy usage of the house due to the use of several large fans and pumps to move the air and water through the system and facilitate heat transfer. This increase of 5736 kW-hr/year will need to be offset by the chosen electricity generation system.

Initial research of wind turbine electrical energy production showed these systems to be unreasonable for the group's purposes. At costs of around $90,000 wind turbines are not practical for private energy production. The home's suburban location would also make the space requirements and distance from trees and power lines difficult to impossible.

The group found that solar panels would be the most effective electricity generation system for the home. The home would require thirty-eight 250W panels on the south roof and front lawn to meet its electricity demand. The solar panels, array mounting system, inverter, and grid hook up will cost $30,000 and it will save $825 per year. With this savings the payback would be longer than the life of the panels so it is assumed that the solar panels do not pay themselves back. Figure 1 below shows a graphical representation of the all of the energy savings and generations for the house for both Therms and kW-hr per year. The orange circle represents the final energy usage for the house.

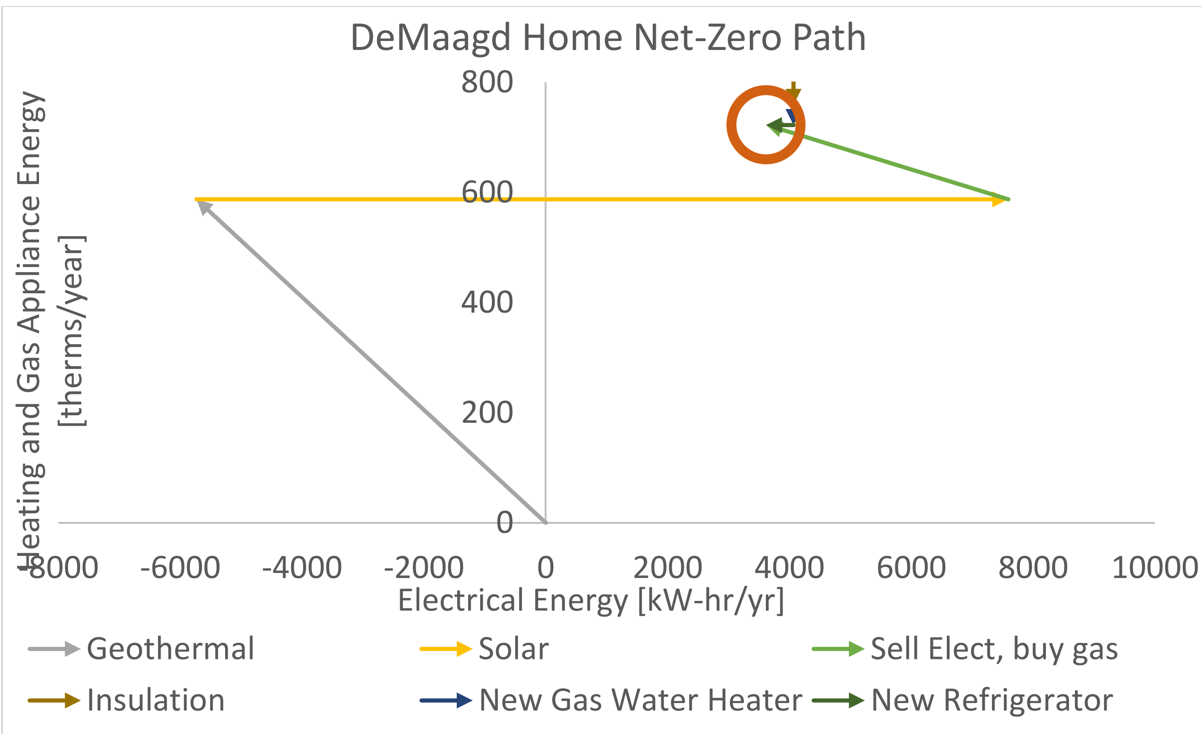

Figure 1: Final Energy Location of the DeMaagd House

Conclusion

To convert the house into a net-zero home requires significant capital investment and some understanding neighbors. If all of the suggested changes were implemented the total cost would be just under $70,000 which is not an investment most people are willing to make, especially when the most expensive things do not pay themselves back. So converting the house into a net-zero home is not feasible but there are some things to take after from this analysis. All of the energy saving measures could be implemented at a relatively low cost of $2600. Also it is important to be mindful that a more expensive, but more efficient appliance could end up saving money in the long run

Net-Zero Energy Story

Assessment

The DeMaagd home was initially evaluated from an energy perspective based on usage reported by Consumers Energy and DTE, the home's electric and gas provider respectively. Data was taken from the most recent 1 year timeline (September 2013-August 2014). Figure 2 shows the electrical usage in the DeMaagd home by month, while Figure 3 shows the natural gas usage in the home by month.

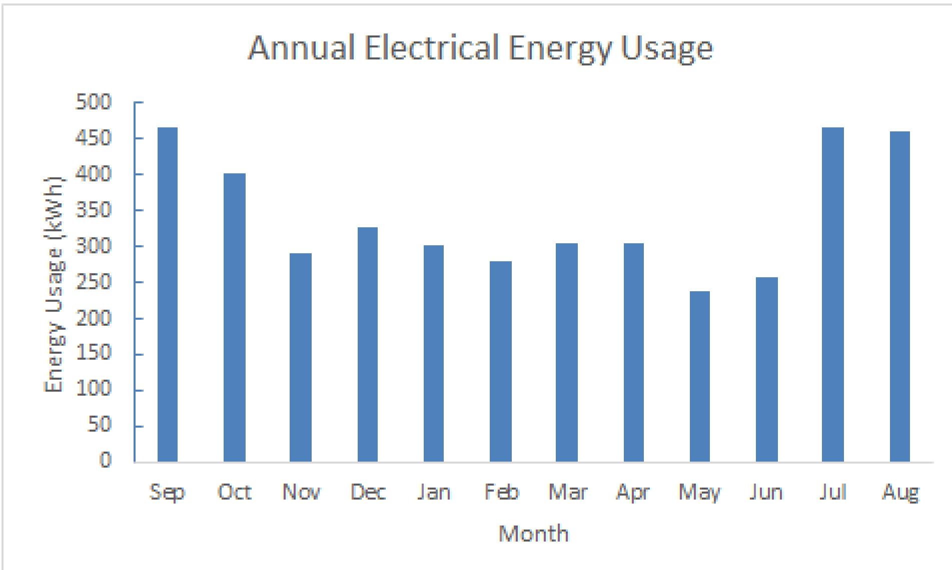

Figure 2: 2013-2014 (12 month) electrical energy usage.

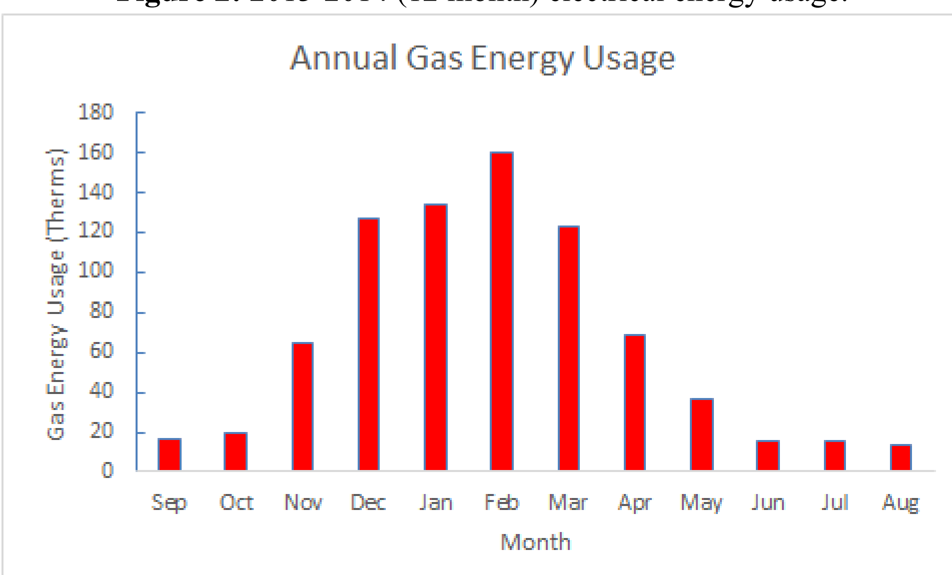

Figure 3: 2013-2014 (12 month) natural gas energy usage.

The total energy usage over this 12 month period was summed and plotted on the graph in Figure 4 to create the starting point from which the house will be brought to net-zero energy usage status.

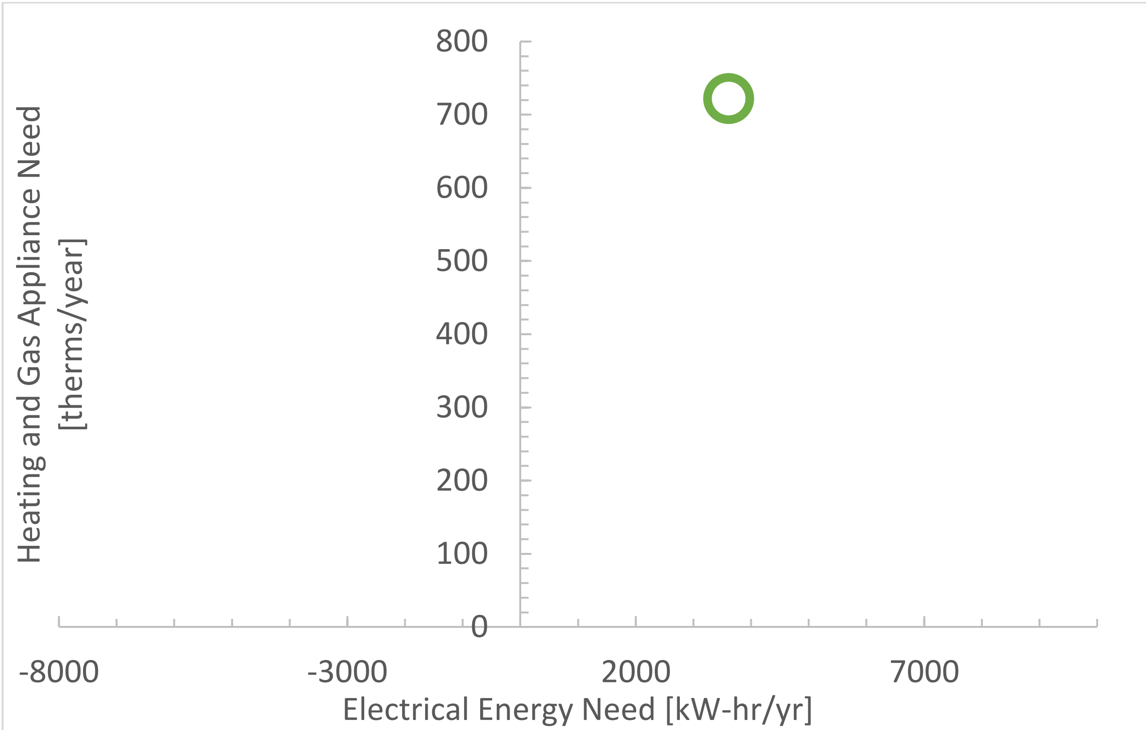

Figure 4: Starting electrical and heating energy demand in DeMaagd home

In anticipation of insulation upgrades in the energy savings phase of the project, the team attempted to identify points in the home that would benefit most from an insulation upgrade. An IR camera was used on a cold night with the heating system in the house set at 80°F to capture thermal pictures indicating zones of with the highest heat transfer rates. Figure 5 shows a few of the pictures taken with the thermal camera. The home's resistance to heat transfer, commonly referred to as the R-value, was evaluated for group comparison purposes and to predict energy saving effects of insulation updates. A study of the yearly heating energy used by the home combined with the heating degree days reported by utilities returned an R-Value of 7.0 hr*ft *°F/BTU.

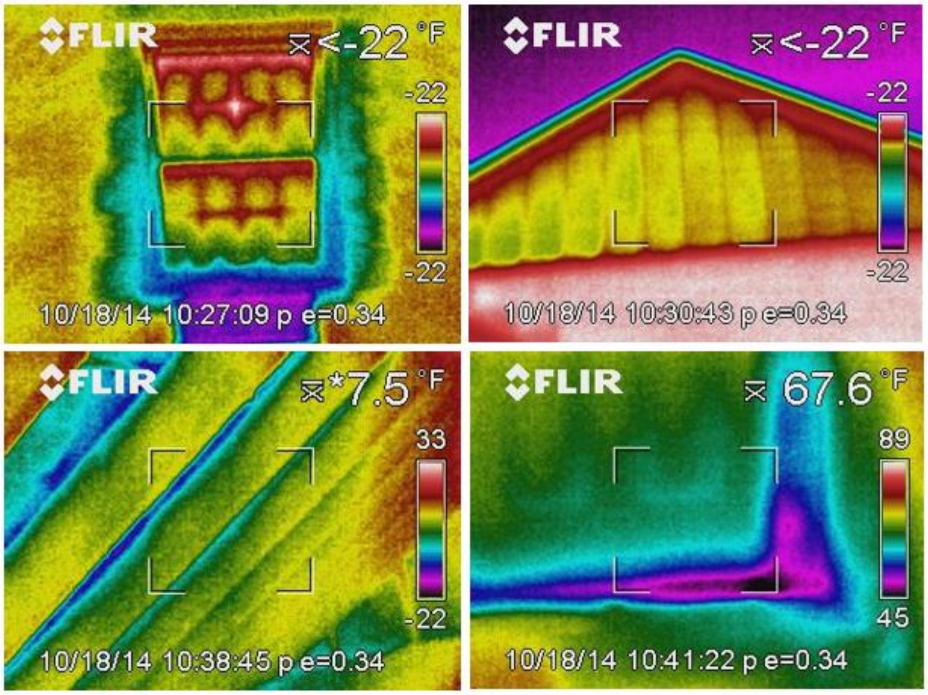

Figure 5: DeMaagd home IR camera pictures: outside rear window (top left), outside front wall (top right, inside west roof (bottom left), and inside basement exterior board (bottom right).

The final stage of the assessment involved a short lifestyle survey of the DeMaagd home and family to provide a better understanding of the specific energy use within the home. The survey covered major sources of energy use in the home (shower, lighting, appliances), along with their frequency of use. Table 1 shows the results of the survey.

Table 1: DeMaagd lifestyle questionnaire results

Energy Uses	**Frequency of Use**
Average Daily Shower Time	20 min shower/day + 5 baths/week
Laundry	5-7 loads/week
Dishwasher	1 load/day
Stove	Used daily
Oven	5 uses/week
Microwave	Used Daily
Refrigerators/Freezers	1 Refrigerator, 1 Freezer (both older)
TV	1 used 1-2 hours/day
Lighting	10 CFL bulbs, 5 incandescent
Average House Temperature	Summer 75 °F, Winter 72 °F
Appliances, Electronics, and Lights are typically turned off when not in use	

Reduction

In the reduction phase the team attempted to outfit the home with updates that would reduce the overall annual energy need of the house. The team found that the lifestyles of the DeMaagd family were lean enough that no reasonable change would make a significant impact on energy need. The following section outlines each savings method and the theoretical energy demand result after the implementation of each.

Insulation Update

The roof of the DeMaagd home is currently uninsulated, making it a significant source of unnecessary heat loss in the winter and heat gain in the summer. The team chose to add R-38 batt insulation between the attic floor joists. Heating degree data combined with theoretical R-Values based on the actual structure were used to calculate a significant whole-house R-Value increase of 2.9 hr*ft *°F/BTU, or 41%. This leads to an annual heat energy savings of 61 Therms/year. Figure 6 shows a graphical representation of the insulation energy savings. Note vertical arrow, representing a drop in heating need with no change in electrical need.

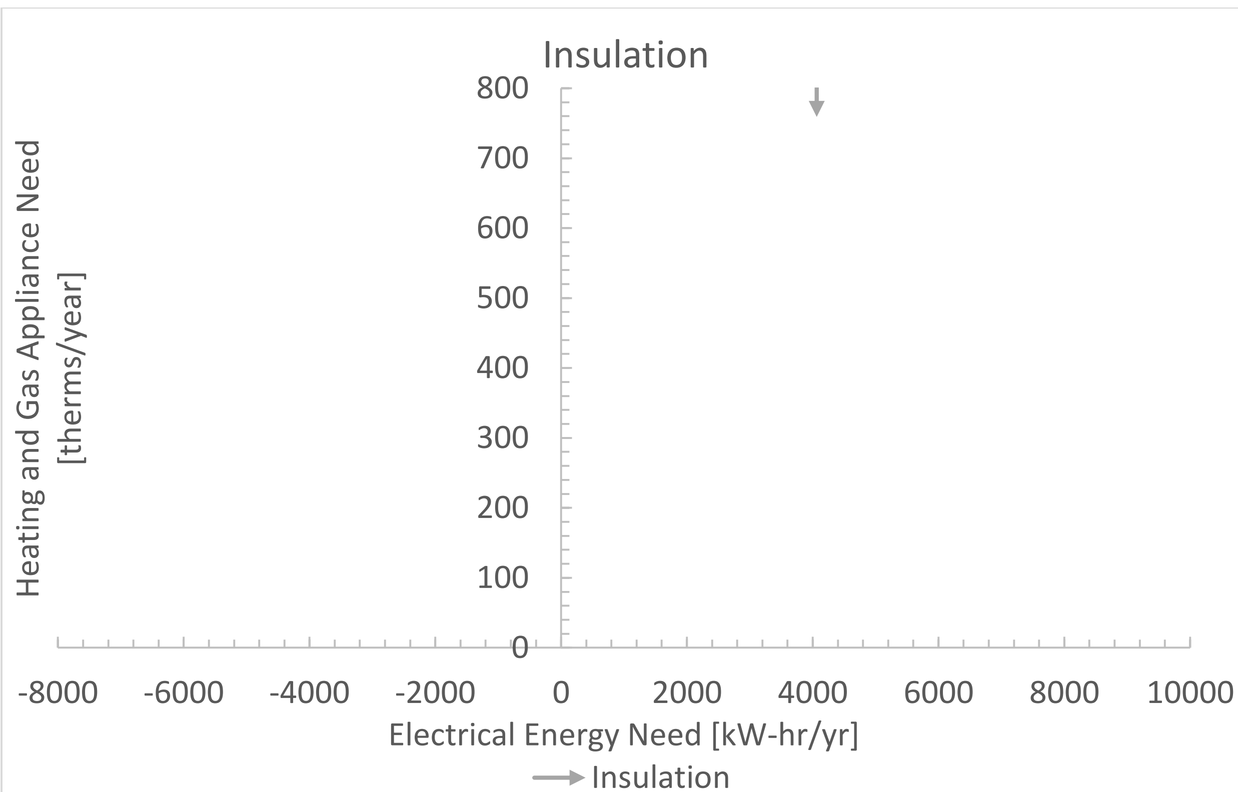

Figure 6: Annual energy need reduction after attic insulation update

The batt insulation was priced at a total of $610 from a standard hardware store (Home Depot). The insulation would provide a yearly savings of about $56 in natural gas, putting the payback period for this measure at 11-12 years.

Water Heater Replacement

The water heater in the home is another significant factor in heating energy need. There is currently significant sediment build-up in the water heater tank, meaning a new water heater would perform much more efficiently. The team will propose a tank-less water heater as a replacement, due to their high efficiency ratings and relatively low cost difference from traditional tank water heaters. Figure 7 shows the heating energy need reduction after the tank-less water heater installation in yellow. Note that the water heater reduction is added to the insulation reduction from the previous section.

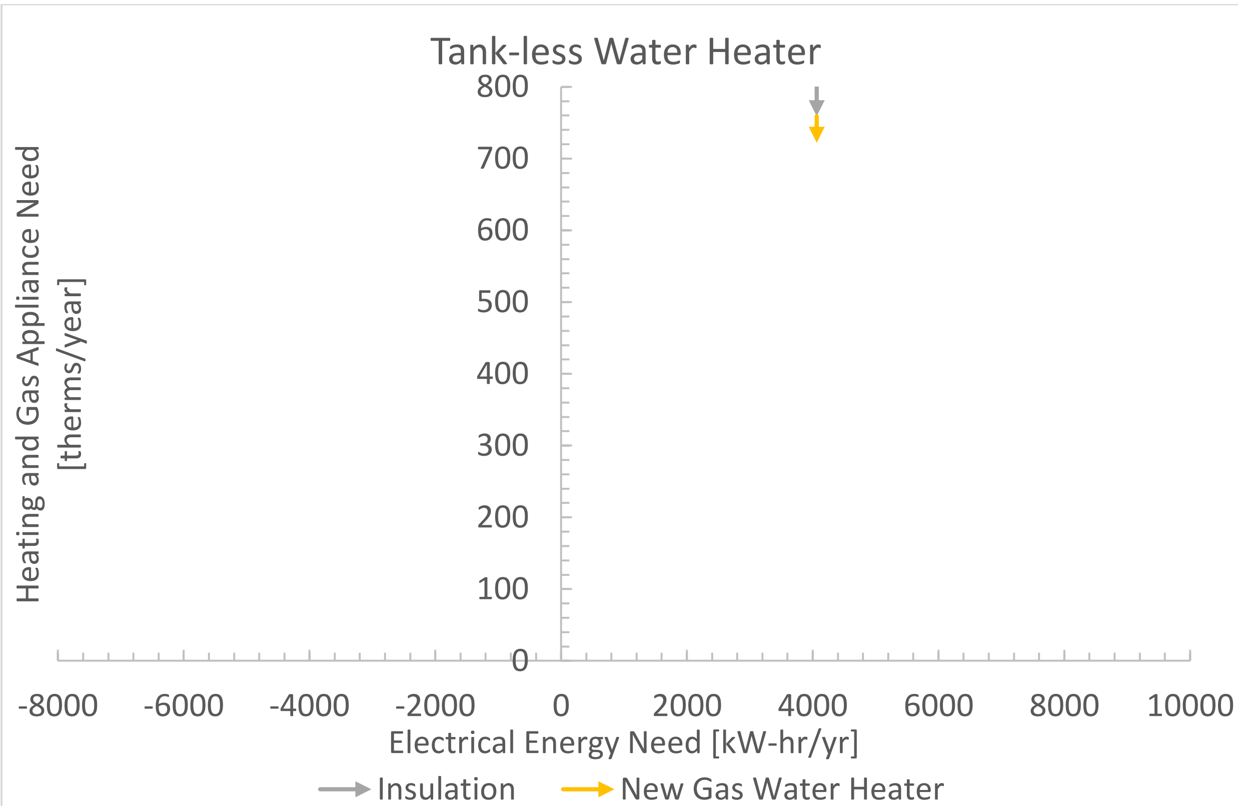

Figure 7: Annual energy need reduction after water heater replacement

The water heater would cost $680, saving $34 per year in natural gas and paying itself off in approximately 20 years. The team sees this investment as essentially cost neutral, as the water heater may not last more than 20 years.

Refrigerator Replacement

The final energy savings update to the home will be a refrigerator replacement. The current refrigerator was purchased and installed in the early 90's. Two decades' worth of technology advances in refrigerator design and production will make a new refrigerator a reasonable electrical energy savings investment for the home, saving the family an estimated 450 kWh/year. Figure 8 shows the electrical energy need reduction after refrigerator replacement. Note the horizontal arrow signifying a reduction in electrical energy demand while heating energy demand remains constant.

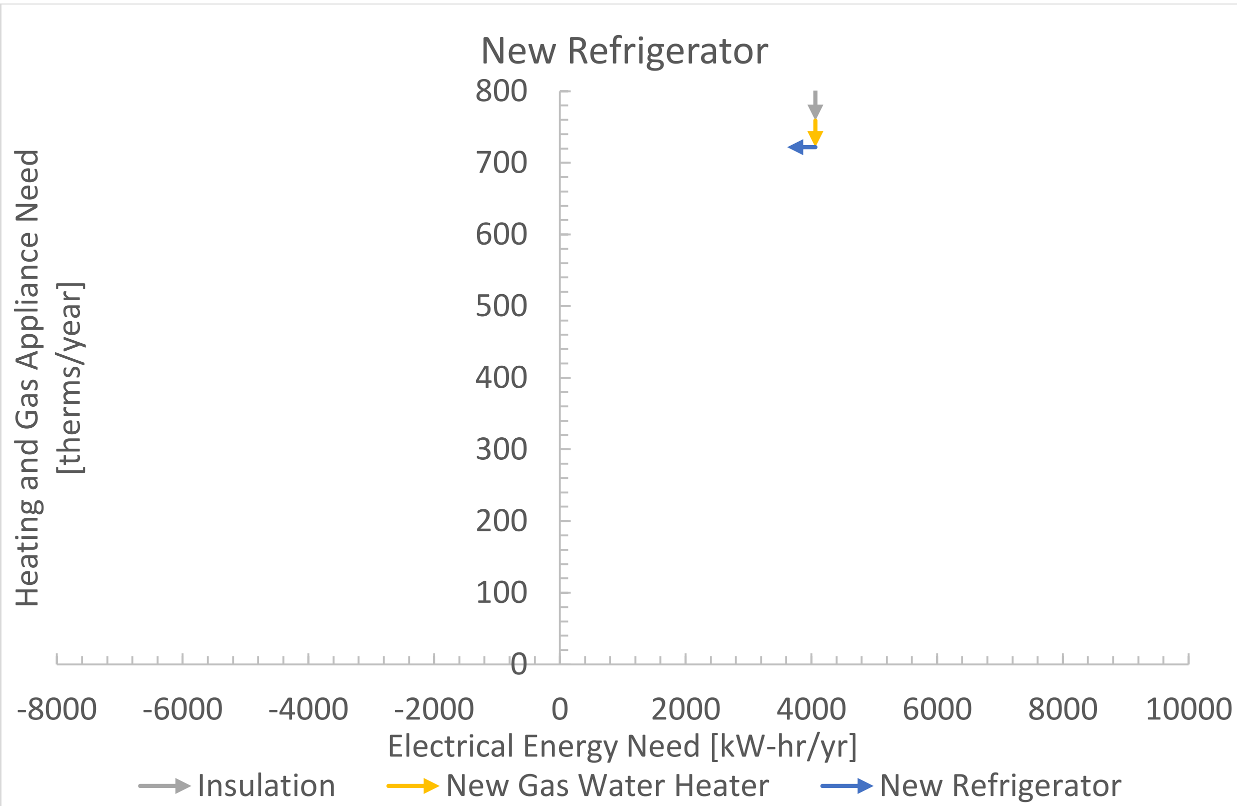

Figure 8: Annual energy need reduction after refrigerator replacement

A new, energy efficient refrigerator would cost $1300 and save $72/year in electricity costs, paying itself off in 18 years. This would also be a cost neutral investment, as the refrigerator may not last any longer than this payback period.

Generation

The reduction phase reduced the overall annual energy demand of the DeMaagd home, but net-zero home requires zero net-energy demand from the grid. It is impossible to completely eliminate the energy need of any home, so the home must produce its own energy. The sections below will outline the steps taken to bring the energy production capabilities of the home to a point where it can meet its own energy need.

Geothermal Heating and Cooling

The most significant energy demand of many homes, including the DeMaagd home, is in the heating and cooling of the house. One of the most efficient heating and cooling systems for commercial and residential buildings is a geothermal heat pump system. A geothermal system uses the earth below the frost line as a heat source (winter) and heat sink (summer). A refrigerant fluid is cycled through a field of pipes as shown in Figure 9.

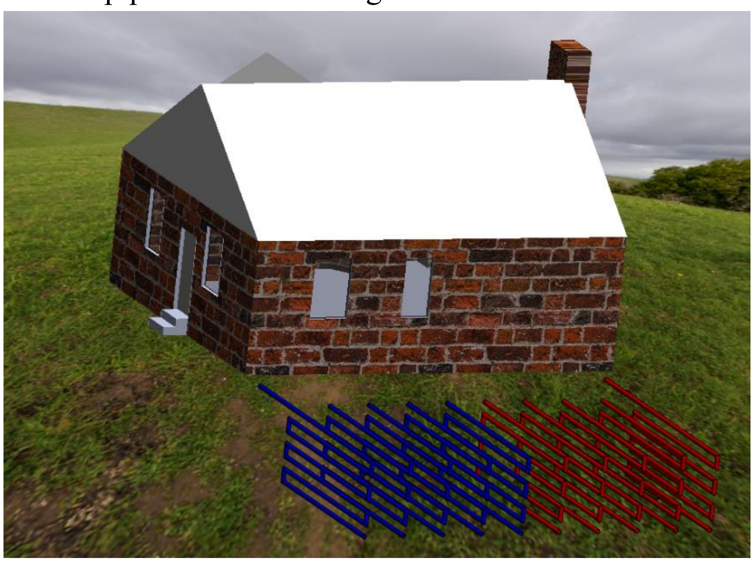

Figure 9: Geothermal field model mock-up. (Note: proposed geothermal field would be vertical, image is shown to illustrate location and general piping layout).

The team chose a vertical, closed loop system capable of delivering 587 Therms/year to the home (approximately 72% of the annual heating need), as well as completely covering the home's cooling needs during the summer. Figure 10 shows the change in the home's energy production capabilities after geothermal system installation. Note that the geothermal system moves the home a good portion of the way to its heating need, but comes with a significant electrical energy cost of about 5700 kWh/year. It takes a great deal of electrical energy to run the heat pump in a geothermal system, nearly doubling the home's electrical demand. This may seem like a step backward in energy production, but it is important to note that the geothermal system operates with a coefficient of performance (COP) of 3.0, meaning the system supplies three times as much heating energy as it consumes in electrical energy.

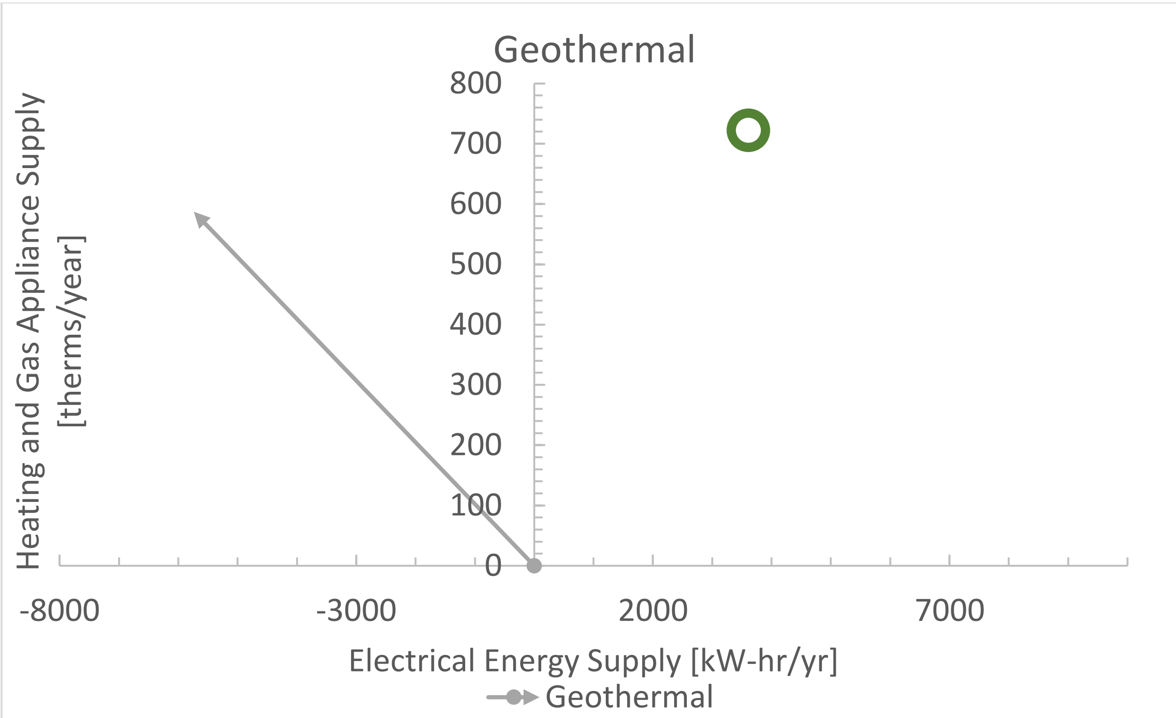

Figure 10: Annual energy production after geothermal system installation

The parts and installation of the geothermal system would cost between $35,000 and $40,000. If the system were powered with electrical energy from the grid, it would cost the homeowners more than they currently pay for heating and cooling. This means for the system to be remotely economical it would need to be powered with energy generated within the home, as discussed in the next section. Even if the electrical cost were discounted, the system would essentially never pay itself back, making it an investment solely in the interest of reducing consumption from the grid.

Solar Energy Generation

The team proposed a set of solar panels mounted on the roof of the home to generate the electricity demanded by the home and the proposed geothermal field. Grape Solar panels were chosen because of ease of acquisition and use. The dimensions of the solar panels chosen for this house were 64-5/8 inches tall by 39 inches wide. Each of these panels are rated for 250 Watts of electricity production.

Professional installation of the panels and inverter, along with connection to the grid. These costs are rolled into the investment cost of the panels below. For upkeep of the panels, the main procedure is to keep the panels clear of debris, such as snow, ice and leaves.

The roof of the modeled home was filled to capacity with panels – the minor peak on the west side was even modified to fit two additional panels - but it quickly became apparent that the home would need additional panels to supply the 9800 kWh/year demand of the home and geothermal field (only 5600 kWh/year could be generated on the roof). A set of solar arrays in the front yard was proposed to supply the remaining 4200 kwh/year, plus additional electrical energy to exchange for the remaining heat energy demand (see next section for details on energy exchange. Figure 11 shows a model of the home with the solar panels installed on the roof and solar arrays in the front yard. Note that there is still 12 feet of clearance between the front of the home and the array, allowing sufficient walking space. Figure 12 shows the change in the home's production capability after the solar panels are installed.

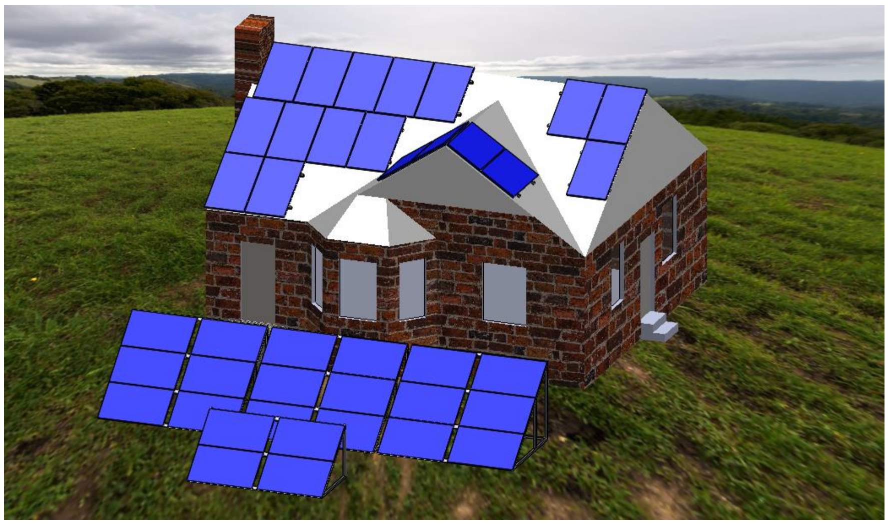

Figure 11: Model home with roof panels and solar arrays

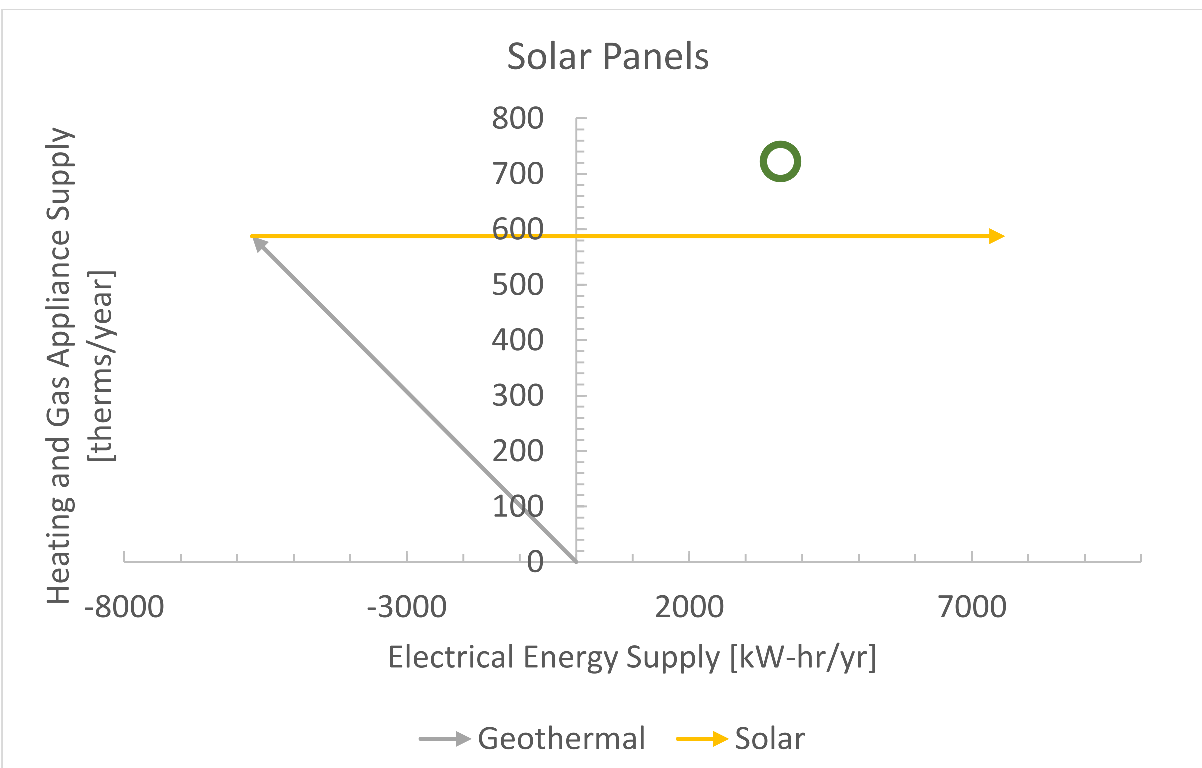

Figure 12: Annual energy production after solar panel installation

The solar panels, mounting hardware, power inverter, and installation would cost nearly $30,000. The panels would represent an energy cost savings of $852 when mated to a geothermal system and $630 without a geothermal system, placing the payback period at over 30 years in either scenario, even without including the value loss in panel degradation.

Energy Exchange

Figure 12 shows a clear "overshot" in terms of electricity generation, with some heating energy demand still not accounted for. The geothermal system discussed above is sized in such a way that it only accounts for about 72% of the home's heating need. This is because a) some of the home's heating energy demands, such as water heating and cooking, are more easily accomplished through the use of natural gas, and b) geothermal systems are typically sized to account for less than 100% of a home's heating load in the interest of economics, as it would be unreasonable to outfit a structure with a system whose full load potential will only be utilized a few days of the year. To that end, some of the heating load (136 Therms/year) will still be handled using a gas furnace. To account for the home's demand of 136 Therms/year from the grid, the solar panels will over-generate electricity, returning an electrical energy value equal to 136 Therms/year (3980 kWh/year) to the grid, keeping the house at net-zero status. Figure 13 shows the energy production capability of the home including the exchange of electrical energy for heating energy. The chart shows the production capability of the home meeting its energy needs, making the home "Net-Zero".

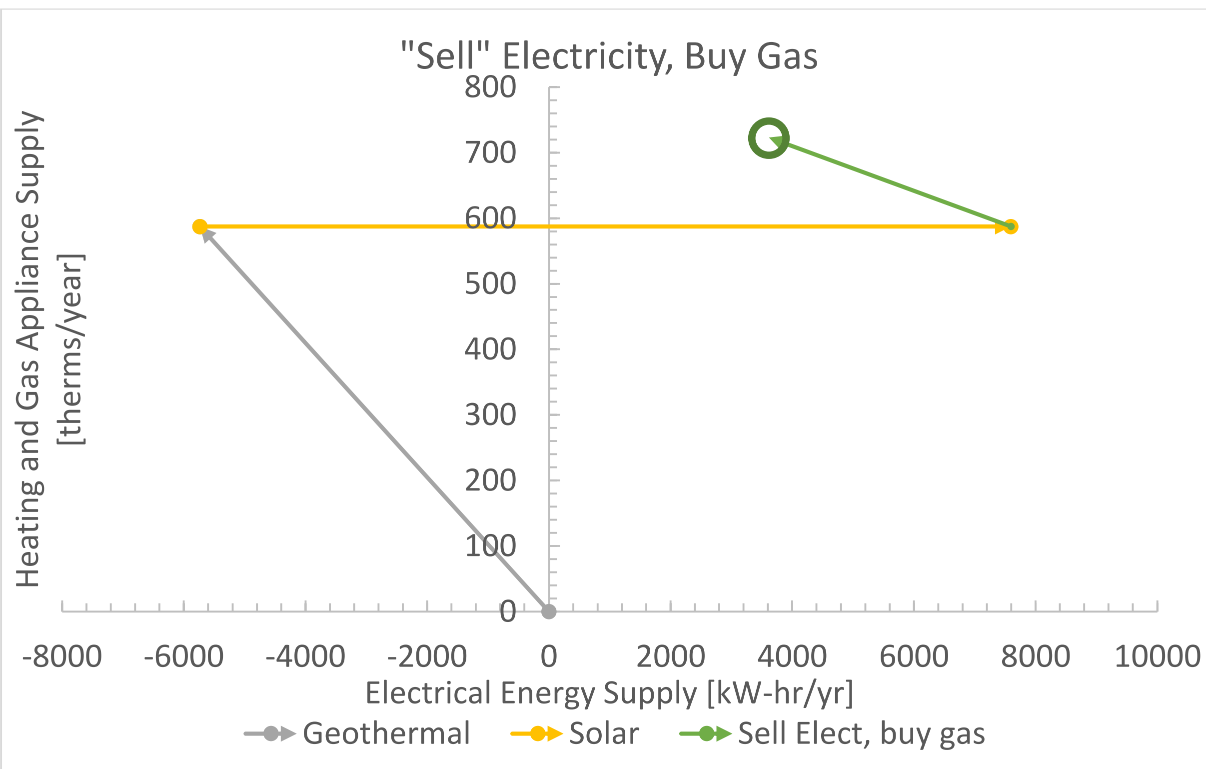

Figure 13: Annual energy production after electricity-gas exchange

Results

To reach net-zero energy consumption from the grid, the DeMaagd home was outfitted with energy savings measures including: insulation updates, a new water heater, and a new refrigerator, reducing the home's energy need from 820 Therms/year in heating and 4101 kWh/year in electricity to 722 Therms/year in heating and 3616 kWh/year in electricity. The team proposed a geothermal system and solar panel system, along with a heat-electricity exchange to meet this new energy demand. Figure 14 shows a theoretical mock-up of the home after projected project completion. Figure 15 shows the savings and production charts combined to tell the "story" of the home's transition to net-zero energy consumption.

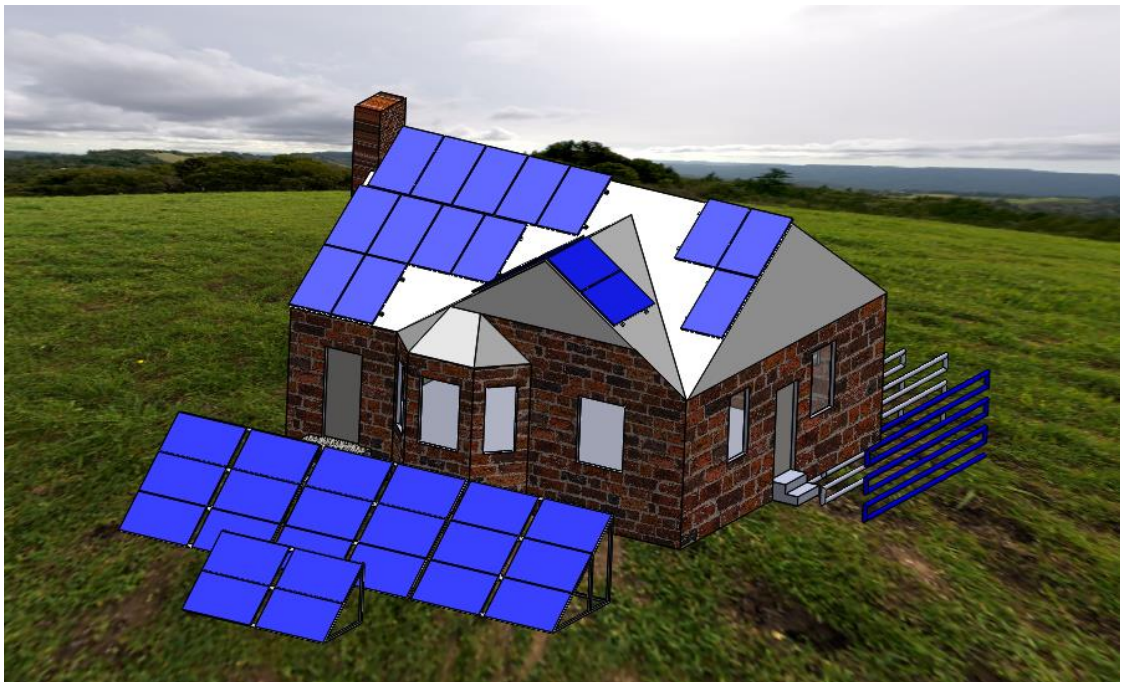

Figure 14: Theoretical Net-Zero home model

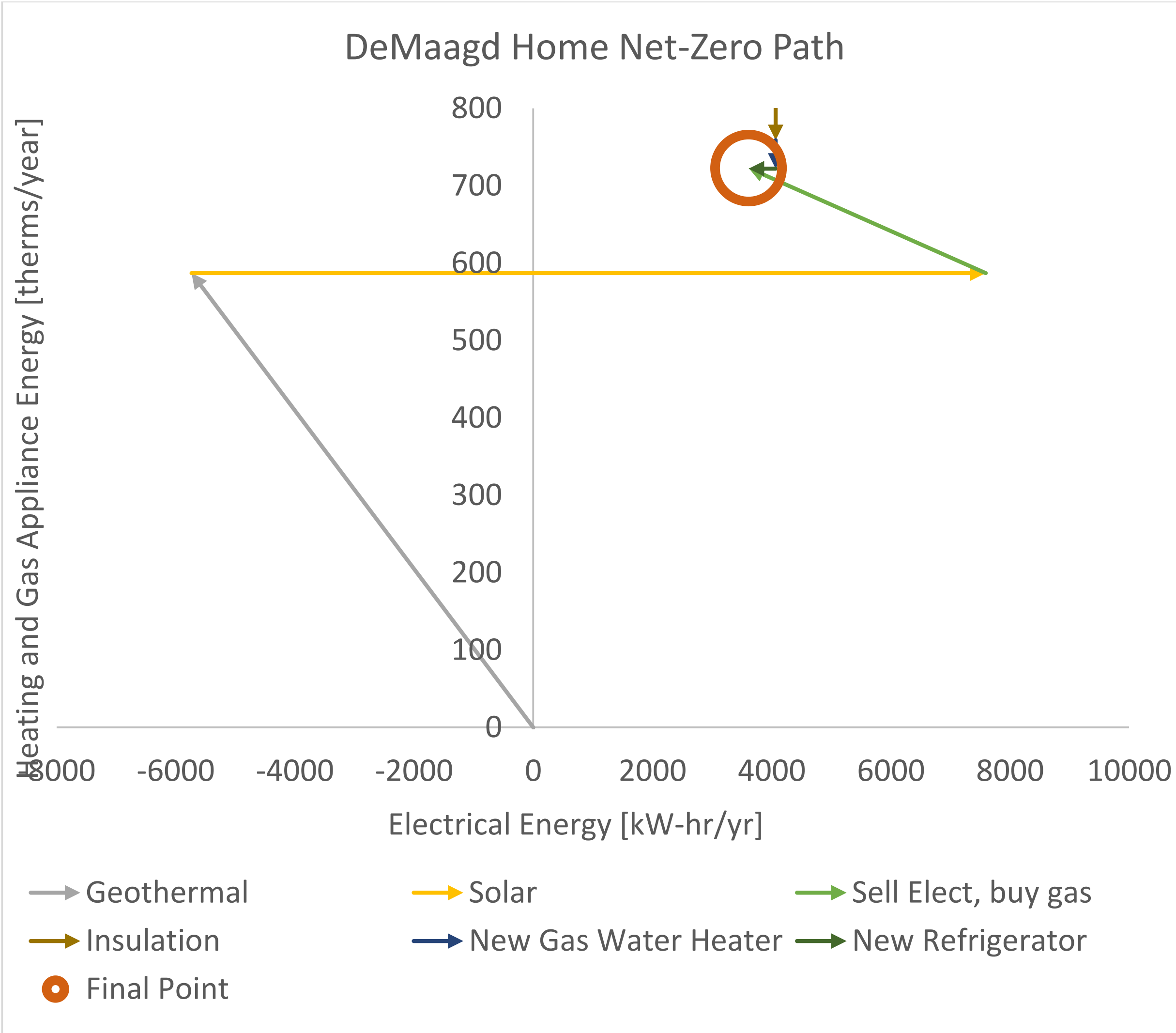

Figure 15: Combined energy saving/production path to net-zero home

Reaching this point on the energy chart would require not only the implementation of the systems listed above, but a significant cash investment and devotion to the upkeep of these systems, not to mention understanding neighbors and city ordinance allowing for such radical changes to the landscape. If the homeowners were willing to spend the nearly $70,000 up front required to implement these changes, they would also need to maintain the systems, monitoring the geothermal system and spending a significant amount of time keeping solar panels clear and clean in particular. The vast majority of homeowners would not be able or willing to make such a significant investment.

To conclude, Team 4 would call the project possible, but not feasible. The team would recommend that, instead of worrying about purchasing such an expensive system, the DeMaagd family simply understand what it would take to reach a Net-Zero energy consumption point, and implement some of the changes listed in the reduction section with realistic investment costs and payback periods.

Data, Bibliography, Acknowledgements

Individual Home Data

Tables 2 and 3 show the basic data used by group 4 and by the collective Engineering 333 class to compare homes. Table 2 shows current and prospective energy use and production, providing data on a per square foot and per home inhabitant basis. Table 3 shows basic home/inhabitant facts.

Table 2: Current and project home energy data

DeMaagd House Energy Usage and Generation Data					
		Last Year	Average Year	Projected after improvements	
Energy Usage per Square Foot	Gas Usage	0.91	0.911	0.16	Therms/yr/ft^2
	Electric Usage	4.55	4.55	4.56	kWh/yr/ft^2
	Gas energy equivalent	26.69	26.67	4.8	kWh/yr/ft^2
Energy Usage per Person	Gas Usage	204.93	204.93	51.19	Therms/yr/person
	Electric Usage	1025.25	1025.25	1025.25	kWh/yr/person
	Gas energy equivalent	6004.60	6004.60	1500	kWh/yr/person
Energy Generation	Potential Heating generation	0	0	615	Therms/yr
	Potential Electric generation	0	0	5110	kWh/yr

Table 3: DeMaagd home facts

DeMaagd House Information		
Square Footage	1250	ft^2
# of occupants	4	person(s)
Gas Provider	DTE	
Electric Provider	Consumers Energy	
Number of floors Conditioned	2	(Basement Heated?)
House R value (HDD)	6.98	hr-ft^2 F/Btu
Carbon Footprint	38078.1	lbCO2/yr

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Acknowledgements

Net-Zero Team 4 would like to thank the following for their support and contributions to the project.

Class Professor – Dr. Matthew Kuperus Heun
Professor Heun proposed the project and provided the initial organization along with invaluable guidance throughout the course of the project. He was available as a constant resource to every team and was happy to provide input whenever it was requested.

Homeowners – Jeff and Liz DeMaagd
Jeff and Liz opened their home and yard to the team on a few occasions and even turned their heat up to 85°F for an evening so the team could take effective IR pictures. Their hospitality made the project much easier to complete.

Engineering 333 Classmates
The Net-Zero Homes project was a combined effort of all members of the Engineering 333 class. Group 4 is grateful for the efforts of the class as a whole and those of specific classmates Jake DeRooy, John Sherwood, and David Evenhouse for their coordination efforts, as well as Wesley Richards for giving the final presentation.

Vredevoogd Heating and Cooling
A representative from Vredevoogd took the time to briefly quote a geothermal system price for the group's economic analysis.

Appendix C5

Net-Zero Analysis of the Evenhouse Home

Team 5: Jake DeRooy, Dustin Brouwer, David Evenhouse, Patrick Anderson
Clients: Mark and Shelley Evenhouse
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department
December 16, 2014

Abstract

The goal of this project is to determine what it would take for a house in the Grand Rapids area to become net zero. A net zero home house produces as much energy as it consumes in a given year. This memo will discuss the Evenhouse home and the steps needed to make achieve net zero. The Evenhouse Team looked at a wide array of implementation options to achieve this goal. First the team visited the home, assessed the amount of energy usage, and looked for ways to reduce energy usage. The team decided to suggest changing to LED bulbs and removing a hot tub to save energy. Next, the team had to find a way to produce the energy needed to meet the house's demand. For thermal energy, the team looked into wood burners since the house was situated on a wooded lot. This proved to be a cost effective option to produce the home's thermal energy demand. The team suggested creating a tree growing plot to grow Osage Orange. The team investigated both wind turbines and solar panels to meet the electrical energy demand. Wind turbines proved to be financially infeasible. The team found that solar photovoltaic panels would be a much more feasible method for generating electrical energy. In conclusion, by switching to LED bulbs, removing a hot tub, adding solar panels, and switching to a wood burning furnace the Evenhouse home could become net zero.

Technical Memo

Goal

This project attempts to determine the necessary steps needed to convert the Evenhouse home into a net zero home. A net zero home produces as much energy as it consumes. In order to do this, the team had to find ways to save or produce 7,200 kWh of electrical energy and an equivalent of 1600 gallons of propane annually. The Evenhouse home is unique in that it has the advantage of being on a large wooded lot. This leads to unique opportunities when attempting to become net zero.

Procedure

First, the team performed an analysis on the amount of energy the house currently consumes. The group made a visit to the home and discussed with the homeowner the electrical and thermal energy usages. The homeowner made this part easy by providing graphical data regarding electrical and propane usage. The team then looked into energy savings options. The team investigated all the appliances, amount of usage of lighting, and the insulation of the windows, walls, and roof. The team decided that replacing standard incandescent light bulbs with LED light bulbs and removing the hot tub was the only financially reasonable option. The LED payback period was to be 2.5 years without a rebate with savings predicted at 3100 kWh annually. The energy savings from removing the hot tub was found by setting a baseline electricity usage for the house and eliminating the excess in the winter months. Refer to Figure 1 to see total energy savings.

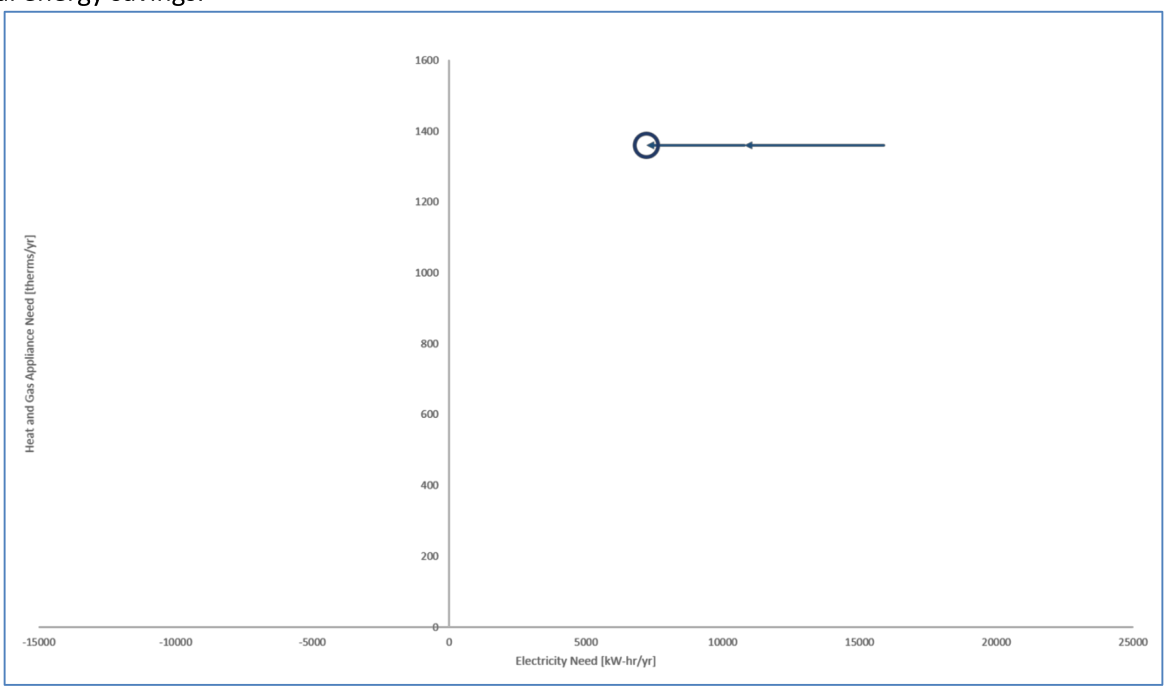

Figure 46 Total Energy Savings

In order to reach net zero, the house still needs to be able to produce the energy that it could not save. First, wind and solar electrical energy was investigated. While looking into wind electricity generation it quickly became apparent that the wind generator would not be cost effective. With costs in the $80,000 range the group decided that this would not be ideal. The team also investigated solar panels for electricity generation. While the costs were still high, the panels were found to nearly pay themselves off over the span of approximately 25 years. Unfortunately the lifespan is less than 25 years. However, the cost can be justified given savings from other implementations. In order for the solar panels to be effective, some minor modifications need to be mad e to the surround area. There are several trees that obstruct the sun that need to be taken care of. On the bright side, the south facing hill adjacent to the driveway is ideal for the placement of the panels. This may limit the amount of frame construction for mounting the solar panels.

The group investigated wood burning furnaces because the house is in a wooded area. This proved to be a very cost effective way to produce the thermal energy necessary. Unfortunately, this does not completely solve the energy problem as the source of thermal energy was just changed from propane to wood. The team researched for a tree with high energy density and fast growth rates. Osage orange is a tree that meets these requirements. The team then found an area in the woods that would be ideal for a plot of Osage. The team decided that in order to limit the amount of tree removal, it would be best to plant just north of the swampland. This would utilize the fact that there would be very few trees large enough to block sunlight to the Osage plots. The area is approximately 1500 ft^2 and is split into five sections. Each section is a different growth year on a four year cycle with a fallow plot. Until the wood is grown enough to harvest, wood from tree's removed for solar panels and the Osage plot can be used to heat the Evenhouse home. Refer to Figure 2 for a total energy savings and production analysis with costs.

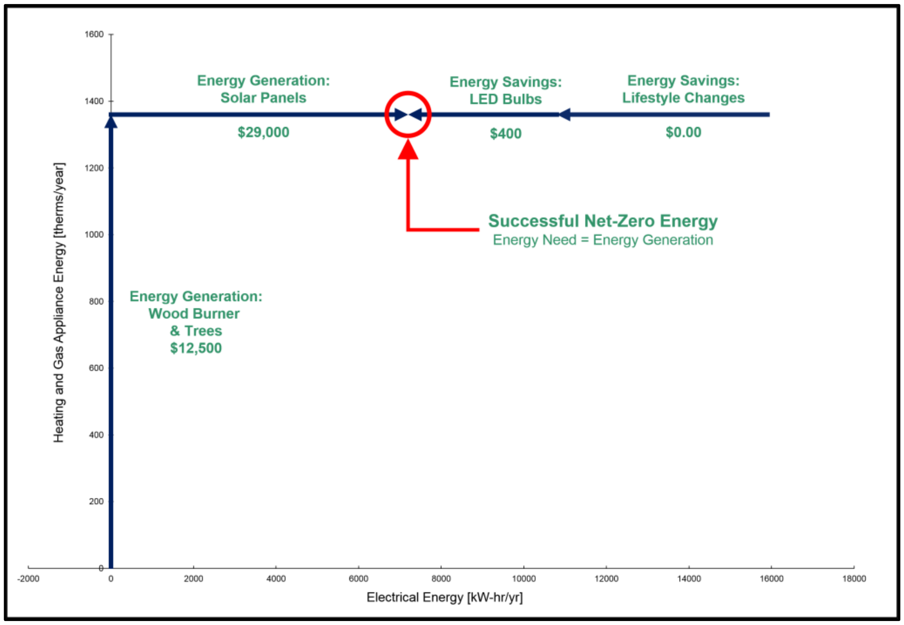

Figure 47 Graphical Net Zero Plan

Conclusion

The team recommends the following actions in order to make the Evenhouse home net zero:

Table 14 Net Zero Options

What action?	Initial Investment	Payback Period
Lifestyle Changes	$0.00	Instant Payback
LED Light Bulbs	$400	2.5 Year Payback (without Rebate)
Wood Burning Stove (with wood)	$12,520	4 Year Payback Period
Solar Panels	$29,000	Never Pays back
Total of Recommendations	$41,920	7 Year Payback

Appendices

1. Home Assessment
2. Lifestyle Changes
3. Appliance Efficiency
4. Lighting
5. Wood Burning
6. Solar Photovoltaic
7. Wind
8. Conclusion
9. References
10. Acknowledgement and Thanks
11. Evenhouse Home Data

Net-Zero Energy Story

1. Home Assessment

The first action taken by the team was to assess the current energy needs and infrastructure within the home. This was done by both visiting the home to make observations, and by analyzing data provided by the homeowner.

1.1 Energy Needs

The energy needs for the home were divided into two distinct forms; demand for gas, and demand for electricity. Gas is provided in the form of Propane, which is stored in a large propane tank located in the back yard. Electricity is provided off the grid by Consumers Energy. The team was provided with yearly usage information on both utilities.

Electricity:

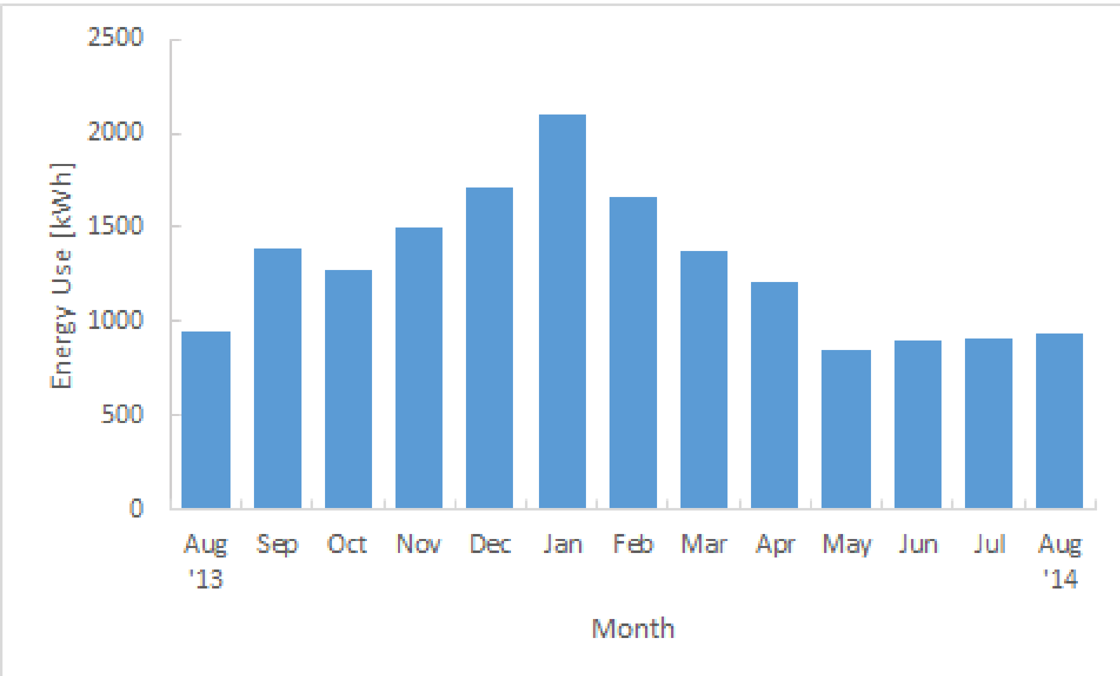

Figure 1.1 Monthly Electricity Usage

Monthly electricity consumption was revealed to increase drastically during the winter months, as opposed to usual increase in the summer to Air Conditioning. It was postulated that this increase in energy usage was due to the Hot Tub owned by the family.

Propane:

Propane usage during 2013 and 2014 were 1,487 gallons and 1,263 gallons, respectively. Directly converting to kWh reveals that the raw energy used for heating far exceeds the energy used by electrical appliances.

1.2 Current Appliances, Lighting, Infrastructure

The current electrical appliances were also noted for later analysis. This includes current lighting and air conditioning, as well as home appliances such as the chest freezer, dishwasher, and refrigerator.

Bulb Description	# of bulbs	Hours/Day	% Usage Day	Bulb watts old
Kitchen Flood Lights	6	6	25.00%	40
Kitchen Flood Lights	6	2	8.33%	40
Kitchen Flourecence	4	6	25.00%	30
Kitchen Flourecence	4	2	8.33%	30
Living Room Chandelier	3	8	33.33%	60
Living Room Lamp	1	20	83.33%	12
Living Room Spotlights	4	4	16.67%	40
2nd Chandeleir	8	1	4.17%	60

Figure 1.2 Portion of initial light bulb assessment

Other items taken into account were the dimensions of the house, the surrounding environment, the lack of Natural Gas lines in the area, and the basic lifestyles of the occupants. Of special note is the fact that the home sits on a 4-acre forested lot, as shown in the image below.

Figure 1.3 Aerial view of the home

1.3 Final Needs Assessment: Net Zero Energy Graph

Using this data, the team was able to establish an origin point for the home on the graphical tool used by all groups in the Net-Zero project, commonly referred to as simply “The spaghetti graph”. This graph is used to visually represent the current home needs, as well as the savings and generation potential required to reach Net-Zero status. This origin point is located using a yearly heating need (calculated from the propane usage) of 1,360therms per year, and a yearly electrical need of 15,900KWh per year.

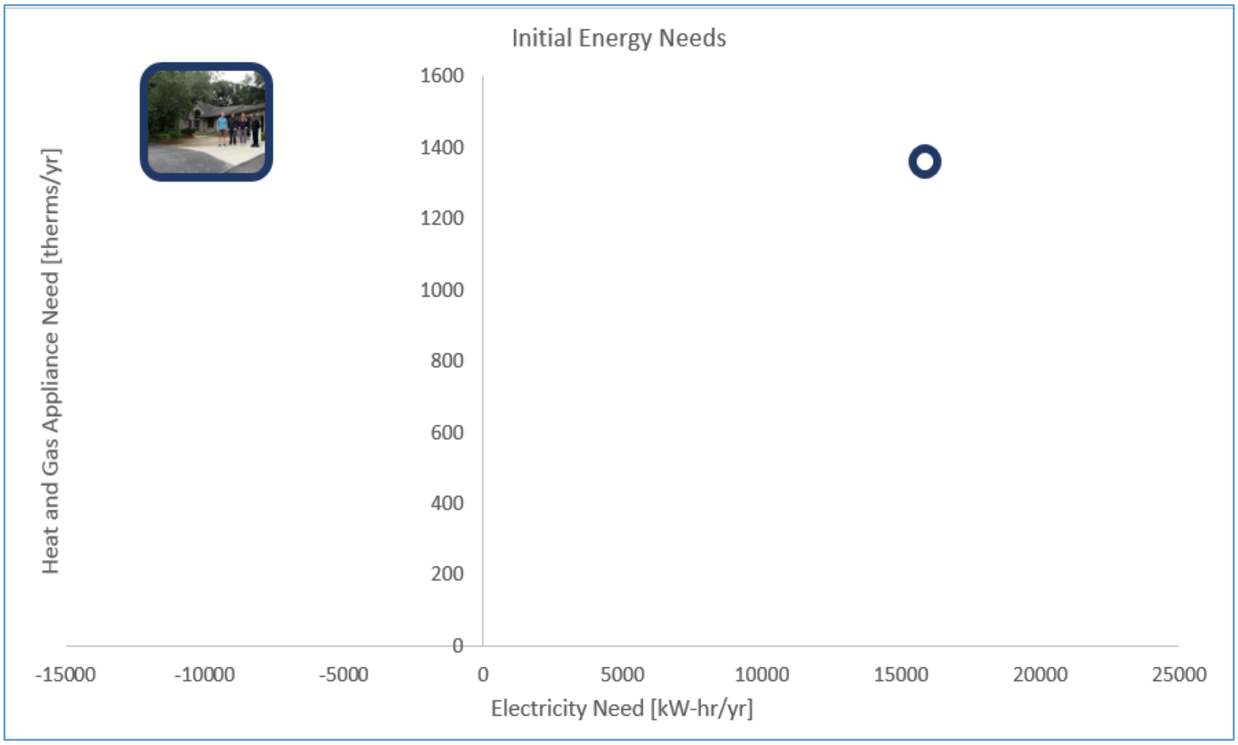

Figure 1.4 Net Zero Energy Graph Home Current Status

2. Lifestyle Changes

The team looked for ways to reduce energy usage by making lifestyle adjustments. The team quickly decided that removal of the hot tub would be a drastic reduction to the amount of energy usage.

2.1 Action Recommended

In order to reduce the amount of energy consumption the team recommends the selling of the hot tub. By selling the hot tub, the team has calculated that there would be approximately 5,000 kWh saved per year.

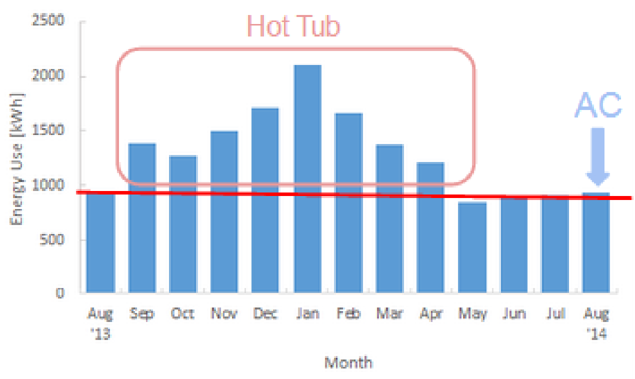

Figure 2.1 Potential Energy Savings

2.2 New Energy Usage

The magnitude of the lifestyle changes can be seen below in Figure 1.

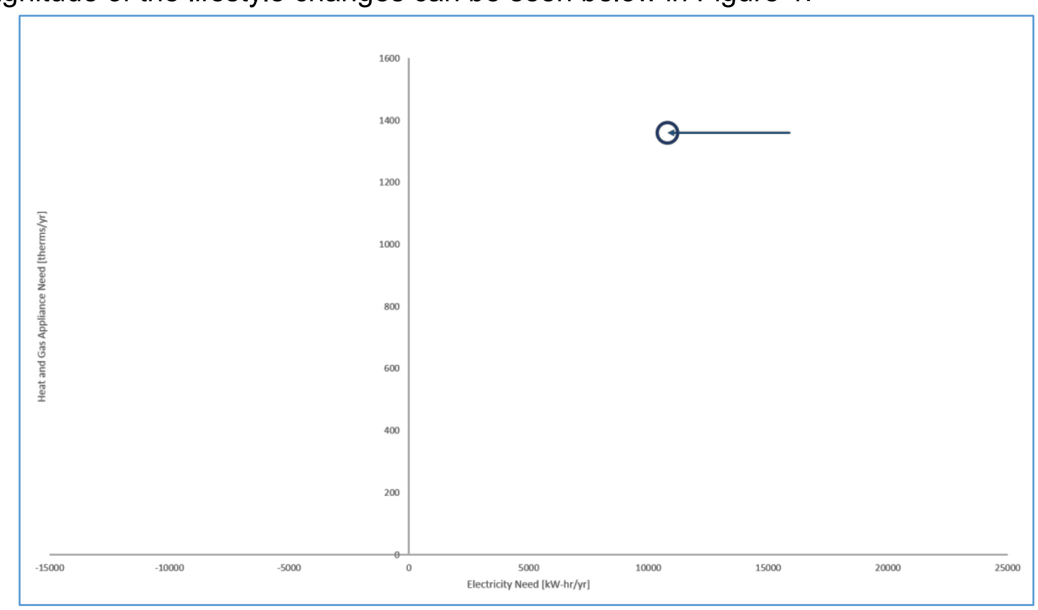

Figure 2.2 Net Zero Energy Graph for Lifestyle Change

2.3 Financial Benefits

By making this lifestyle change, the savings would be approximately $650 annually. This does not factor in the income from selling the hot tub.

3. Appliance Efficiency

3.1 Efficiency and Cost Analysis

Make and model numbers for appliances were taken during a home visit. Some of the best examples from the appliance analysis are listed below.

Dishwasher: Change from SHU43C06UC to SHE3AR56UC

- 353 -> 279kWh (**$9.62 per year**, $150 rebate available)

Fridge: Current model known to be left open, assume 1.5x energy

switch from G.E. PFS22MISBBB to Samsung RF261BIAESR

- 493*1.5 -> 398kWh (**$44.76 per year**, +2.8cu.ft capacity)

Electronics: Install convenient switches on power strips, turn off power as you step away to prevent loss to standby/sleep mode

- 115.2 -> 0kWh (**$14.96** per year, 8 machines for 300 days)

Chest Freezer: No data on current model available. Assume it uses 600kWh/year (574 standard in 1987+depreciation)

- 600 -> 306kWh (**$38.22 per year**, lose 1.6 cu.ft of capacity)

Well Pump: Estimated energy required: 441kWh/year (Study conducted by Consumers Power in 1990)
441 -> 396.9kWh (**$5.73 per year** using all simple methods)
Even taking advantage of the two largest savings options (The refrigerator and the freezer) we would only be saving up to $83 per year, with an initial cost of around $2,500. Energy savings would be minimal, at around 630 kWh per year. The installation of low flow toilets and fixtures, which would save approximately 20% of the water pump's electrical demand per year, translating into $11.50 in savings per year with an initial cost of over $1,000.

3.2 Conclusion

The team determined that it would be beneficial for the family to invest in low-energy devices when the time came to replace their current appliances, but purchasing new appliances to replace working equipment was not economically viable.

4. Lighting

4.1 Lighting Analysis

In recent years, a number of different energy efficient alternatives to the common incandescent bulb have been developed. These technologies may emit different quality light, but generally have a much longer lifespan and require less power.

Two common examples of alternative lighting are CFL bulbs and LED’s. CFL’s contain mercury, a toxic substance, and are plagued by reports of poor light quality and long warm-up times. In comparison, modern LED bulbs now can emit light comparable to an incandescent without the risk of toxic exposure or waiting for the bulbs to warm up. For these reasons, along with expressed customer preferences, the team decided to analyze the viability of LED bulbs as a lighting alternative despite their higher cost.

Figure 4.1 Cree LED bulb

Using the light bulb counts and values taken from the home previously, the team was able to run a financial analysis using cost values for Cree LED light bulbs. These analyses attempted to balance the upfront cost of implementation with the possible electrical savings foreseeable with the new bulbs. The team also analyzed the viability of a SkyTube lighting system, which uses natural lighting and no electricity.

4.2 Energy Savings Potential

Cree LED bulbs use 10W, as opposed to the typical 40W home bulb. It was estimated that, by replacing about just over 80 incandescent bulbs in the home with LED’s, the home would be able to save upwards of 3600kWh per year in electricity. This number factors in actual usage data provided by the clients. SkyTubes would save a fraction of this amount a much higher cost, and therefore were not analyzed as a viable option.

With these lighting changes, in combination with the lifestyle changes mentioned earlier, the monthly electrical energy need of the home was reduced to 600kWh/month, or 7,200kWh a year. This change is reflected on the following figure.

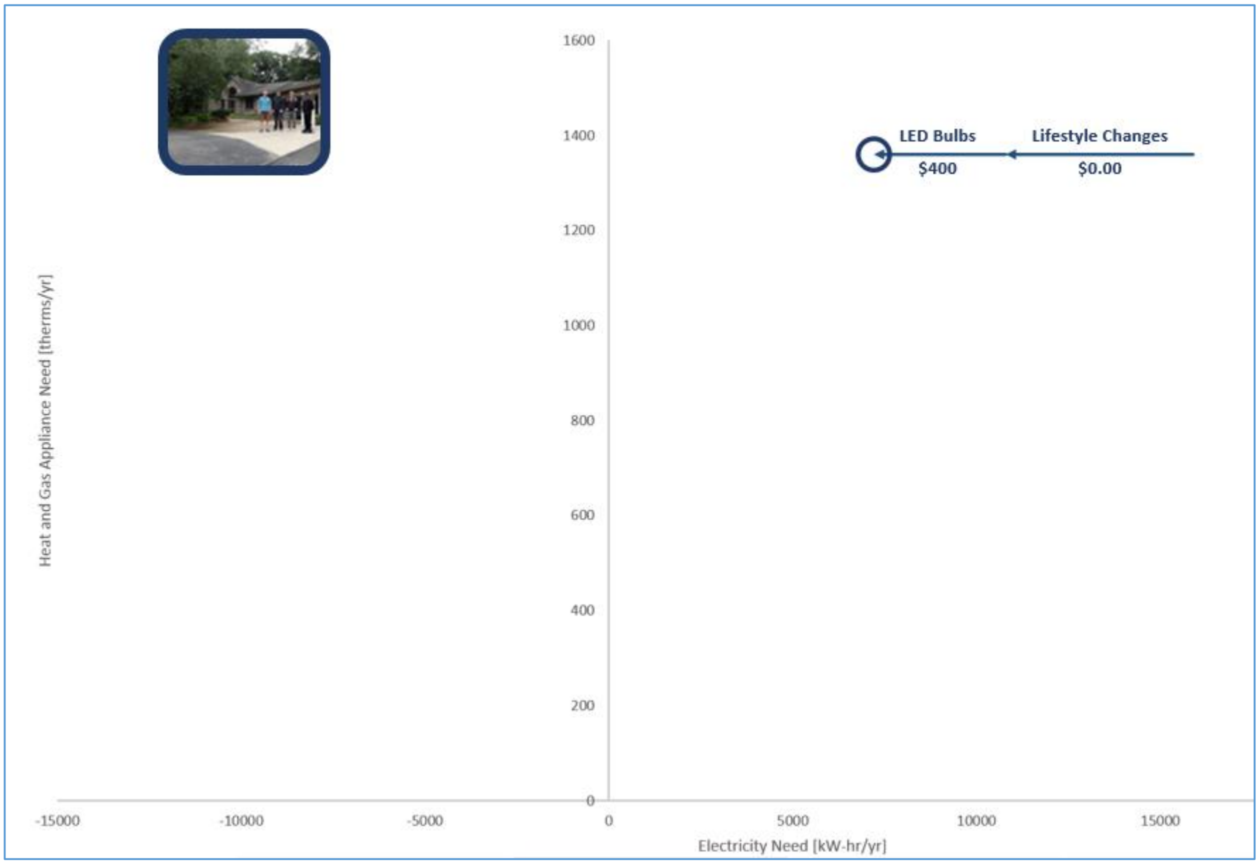

Figure 4.2 Net Zero Energy savings due to LED bulbs

4.3 Financials

Cost information was analyzed in Microsoft Excel. Using the price of LED bulbs provided by Home Depot (a supplier in the client's area) and a nominal electricity cost of \$0.13 per KWh, the team calculated the potential financial savings available to the customer. Due to a 1/2off rebate currently in place at home depot, the capital investment cost of the LED bulbs was only \$400. Cree bulbs have a predicted lifespan of 22.8 years, with a 10 year limited warranty. With this in mind, the team calculated a breakeven point within 2.5 years after purchasing the bulbs. This does not include any potential savings due to not having to pay to replace faulty incandescent bulbs.

With a 2.5 year payback on an item with a warrantied 10 year lifespan, Cree LED bulbs are an extremely attractive economic alternative. In addition, the electrical savings make the prospect of achieving Net-Zero status much more feasible.

5. Wood Burning

5.1 Motivation

Due to the large amount of woodland area on the Evenhouse property, the team decided to investigate biomass as a source of heat energy. Biomass comes in many different forms, including forests, sewage, and agricultural crops, and can be used to convert biological matter and waste into heat. However, in order to achieve net-zero, a house must produce as much biomass as it consumes. The Evenhouse home has the potential to do this because of the woods on the property. This is a unique aspect of the Evenhouse home that many other houses in the greater Grand Rapids area do not have.

5.2 Burner Requirements and Selection

Wood burning stoves come in a variety of sizes and have the potential to heat both small and large houses. In order to generate the total heating requirement of the Evenhouse home, the team researched a stove that could generate heat for a house slightly larger than the listed 4500 sq. ft. This is because a slightly larger stove will be able to also heat water for the hot water heater in addition to air for the furnace. In addition, the team only researched stoves that sit outside of the house; indoor wood burning stoves were ignored at the customer's request. The stove must be safe and burn cleanly.

While there are many large wood burning stoves on the market, the WoodMaster 4400 fits all of the specifications for the Evenhouse home. It is sized to heat an area of 5000 sq. ft. The WoodMaster website describes the model as "Ideal for Larger Homes or Home-Garage Combination" (WoodMaster, n.d.).

Figure 5.1 WoodMaster 4400 wood burning stove.

5.3 Wood Burner Location and Integration

The WoodMaster 4400 system supports both water-to-air and water-to-water heat exchangers for integration with the forced-air furnace and the hot water heater. It can be installed from 25-400 feet from the house and claims an efficient design “for more usable heat with less wood cutting and furnace-filling time” (WoodMaster, n.d.). There is ample space in the backyard of the Evenhouse property to conveniently install the wood burning stove near the woods. There is also room for a wood storage unit next to the stove, which will reduce the amount of time moving wood from storage to the stove.

Figure 5.2 Heat exchanger for WoodMaster stove.

5.4 Selection of Osage Orange

When selection a type of wood for burning, it is important to look at the energy density of the wood. The higher the energy density, the less volume of wood will be needed—this means less cutting and stacking and furnace-filling for the homeowner. Osage orange has one of the highest energy densities of trees in North America (The Chimney Sweep, 2011). While it originated as a hedge tree in the Great Plains, it is now found in many areas of North America. It can be grown as a hedge but it also grows into 26-49 ft. tree (Wikipedia, 2014). It also has a high growth rate. All of these properties make it an excellent candidate for the Evenhouse home.

Figure 5.3 Osage orange tree.

5.5 Plot Location and Rotation

The Evenhouse property has enough area to plant osage orange trees in five plots: four plots in various stages of growth and one fallow plot. The team based their plot calculations on the recommended bed density of 100 seedlings per meters squared (USDA NRCS, 2011).

As seen in the EES calculations below, approximately 5 cords of osage orange wood are needed each heating season (calculated using two different methods with the same result). One cord of wood is a volume of 128 ft^3 (4 ft X 4 ft X 8 ft). Then, the team estimated the amount of land needed to grow 5 cords of wood every year. Assuming that one plot has had four years minimum to grow, based on a growth rate of one foot per year, an area of approximately 160 sq. ft. can produce five cords of wood (Korpella, n.d.).

```
propane=1593[gal] "Propane used during heating season"
propane_conversion=27[kWh/gal]
E_heatingseason=propane*propane_conversion "November to March"
days=215 "Number of days from Nov 1 to March 31"
E_day=E_heatingseason/days
hours=24[hr/day]
E_day_BTU=E_day*convert(kWh/day,BTU/day)
E_day_BTU_hr=E_day_BTU/hours
E_osage_orange=32.9E6[BTU/cord]

cords=E_day_BTU/E_osage_orange
cords_season=cords*days


E_needed=E_heatingseason*convert(kWh,BTU)
cords2=E_needed/E_osage_orange
```

Figure 48.4 EES calculations for wood cord requirements.

cords = 0.02075 [cord]	cords2 = 4.461 [cord]
$cords_{season}$ = 4.461 [cord]	days = 215 [day]
E_{day} = 200.1 [kWh/day]	$E_{day,BTU}$ = 682603 [BTU/day]
$E_{day,BTU,hr}$ = 28442 [BTU/hr]	$E_{heatingseason}$ = 43011 [kWh]
E_{needed} = 1.468E+08 [BTU]	$E_{osage,orange}$ = 3.290E+07 [BTU/cord]
hours = 24 [hr/day]	propane = 1593 [gal]
$propane_{conversion}$ = 27 [kWh/gal]	

Figure 5.5 Results of wood requirement calculations.

This calculation is based on a number of key assumptions. Obviously, a hedge of wood does not contain enough burnable wood as stacks of chopped wood (due to leaves, twigs, and other non-burnable material). Still, osage orange is known as a very dense, tangled plant, which is why is works so well as a hedge. Therefore, the team assumed that the growth would be fairly dense. To anticipate these discrepancies, the team decided that 300 sq. ft. of osage orange hedge would provide the desired amount of wood after 5 years. Based on the desired bed density mentioned previously, five plots of 300 sq. ft. each requires 13,942 seeds. While these seeds will need to be purchased initially, seeds can be gathered from the osage orage fruit to reduce future seed costs.

There is ample space within the woods for 1,500 sq. ft. of osage orange. In fact, much more could be planted in desired. While these plots will not be ready for several years, it would be possible to buy the wood burning stove now and cut down trees around the home until the plots have grown. This is discussed in the appendix on solar panels. It is important to note that these calculations are general estimates. Professional assistance should be sought for planning the osage orage plots.

Figure 5.6 Recommended plots for osage orange trees.

5.6 Financial Analysis

The costs for the wood burning stove and trees are summarized in Table 1, below. Quotes for the WoodMaster 4400, heat exchangers, and installation were obtained by calling a WoodMaster dealer, while the seeds price was estimated from online sources. The team included a $500 budget for clearing the plots and hiring help to cut down and chop trees. The payback period for the investment is shown in Figure X, below. It is quite short at approximately 2.5 years. This is due to the fact that the Evenhouse home will no longer need to purchase large volumes of propane every year. This results in huge cost savings every year.

Table 5.15 Estimated costs for wood burning stove and tree plots.

Investment	Cost [$]
WoodMaster 4400	6,700
Heat Exchangers	700
Installation	3,000
Osage Orange Seeds	1,620
Plot Clearing Assistance	500
Total	12,520

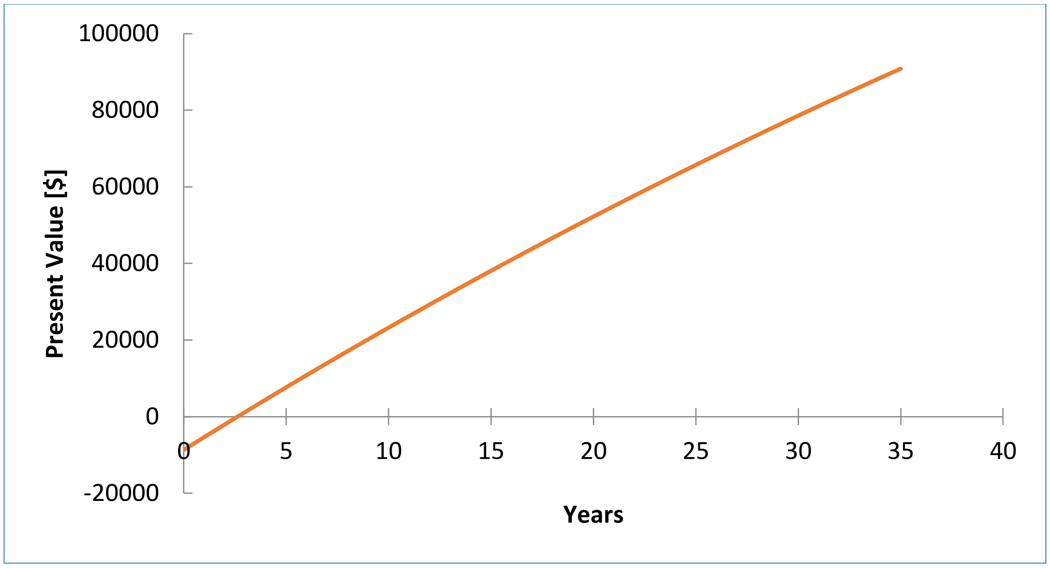

Figure 5.7 Payback period for the wood burning stove.

5.7 Effect on Net Zero Goal

Using a wood burning stove allows the Evenhouse home to generate their entire heat energy requirement. The unique situation created by the home location and property size makes becoming net-zero much more feasible. Other types of heat energy generation, such as a geothermal unit, are much more expensive. The Evenhouse home now only has to generate their electrical energy need in order to become net-zero.

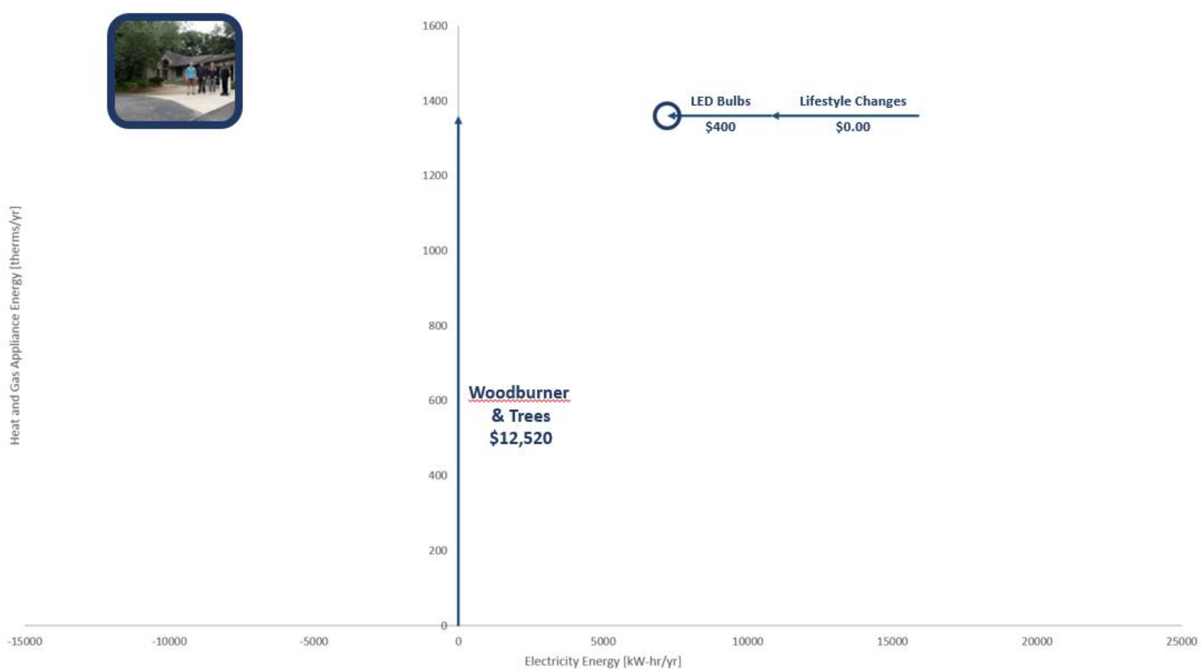

Figure 5.8 Net Zero Energy Graph for Wood Burning Stove.

6. Solar Photovoltaic

6.1 Panel Placement

Solar PV cells were considered as a possible method for generating electricity for the home. From research, the team learned that Solar cells in our latitude operate best when facing South with a clear line of sight to the sun's path. It was also revealed that the angle of these cells may be adjusted over the course of the year in order to increase their efficiency. However, the cost of putting in a Solar Tracking system, or the inconvenience of having to adjust them manually, was determined to offset the miniscule benefit such a feature would provide. Thus, the angle of incidence of recommended by the team is 36 degrees. It is also recommended that the panels be installed on the south-facing hill along the driveway, as shown in the image below.

Figure 6.1 Proposed location of Solar Emplacement

In order to accommodate the 36 degree angle of incidence for the Solar cells, the team would also like to recommend that the Evenhouse family remove a number of trees that lie in the direct path of sunlight. There a few trees that lie close to the house that would require professional help to remove, and are marked as red dots on the figure below. The red line represents the new proposed tree-line along the lawn of the house.

Figure 6.2 Proposed tree removal plan

The potential solar system was analyzed in System Advisor Model (SAM), a free application for renewable energy project simulation provided by the National Renewable Energy Laboratory (NREL). Using data on Grand Rapids weather patterns, latitude, longitude, and a variety of device specifications preloaded into the application, the team was able to come up with an estimate on the requirements for such a solar generation system. The system would generate all of the remaining electrical energy required by the home, approximately 7,200 kWh per year.

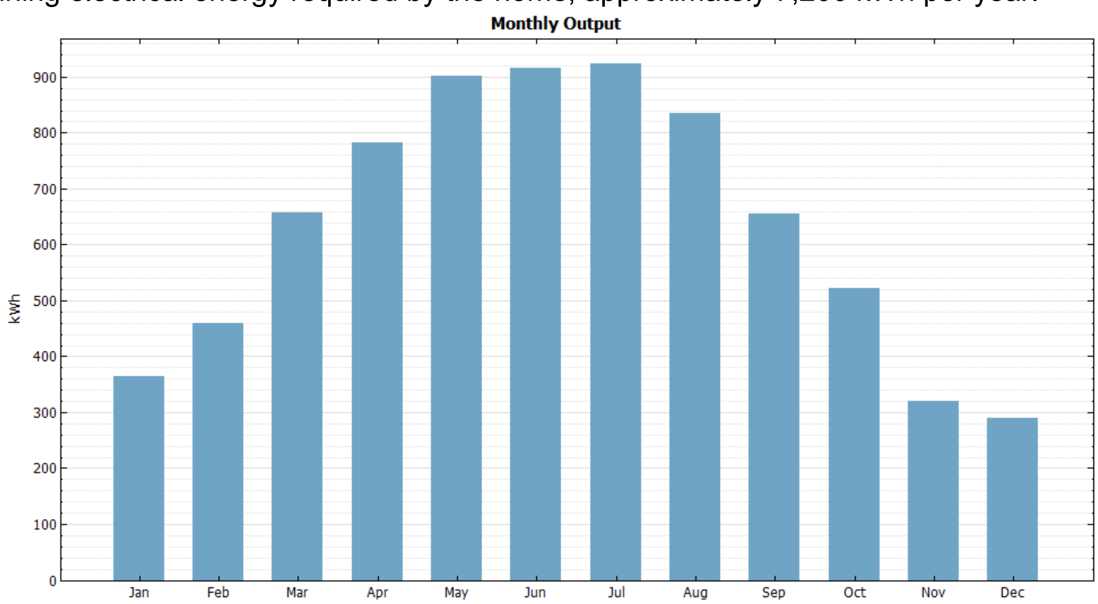

Figure 6.3 Monthly output analysis by SAM

6.2 Net Zero Energy Graph Results

The installation of the system modeled in SAM would completely fulfill the home's remaining electricity requirements. This is based off of the predicted average electrical output of the system over the course of 25 years. This change is reflected in the graph below. Notice that the savings and generation lines now meet inside the blue circle. This means that the amount of energy we have generated are now equal to the amount of energy needed by the house, meaning that the house is now Net-Zero.

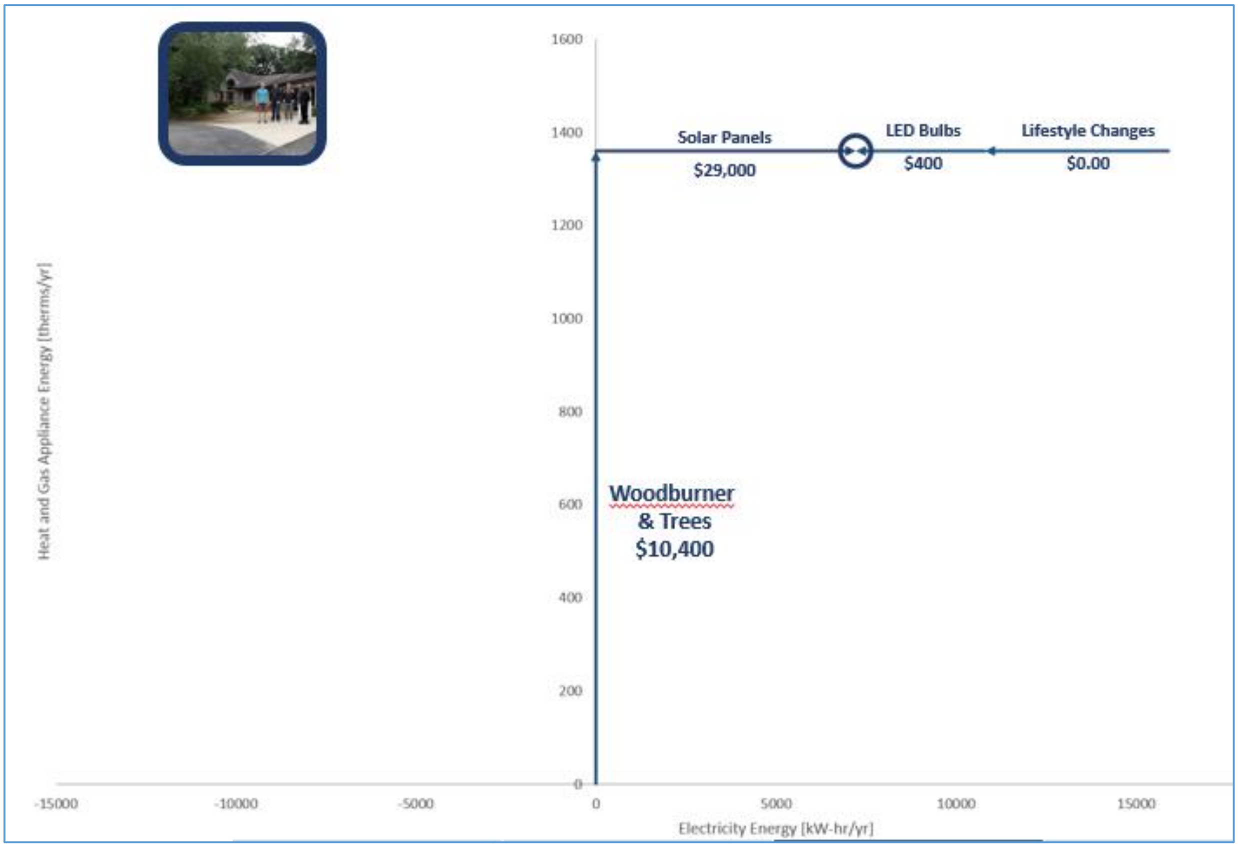

Figure 6.4 Net Zero Energy Graph for Solar PV generation

6.3 Financials and Recommendations

The module used for modeling purposes was the SunPower SPR-315E-WHT, and the inverter used for modeling was the GE Energy GEPVb-3300-NA-240-208-02. Installation, maintenance, and grid tie-in costs were also taken into account in the model. The final predicted system cost from NREL totaled at approximately $24,000 dollars for purchase of equipment, installation, and maintenance for an economic life of 25 years.

This cost however does not include the price of tree removal, which the team also recommends. The cost of tree removal is projected to be between $4,000 and $7,000 dollars. The team ran an economic analysis of the system and tree removal based upon a $24,000 system cost and $5,000 in tree removal. From this analysis, it was discovered that the panels would not be able to pay themselves off in savings within the economic life of the system, requiring approximately 32 years to break even. This includes a significant Income Tax Credit of over $7,000 upon installation of the system.

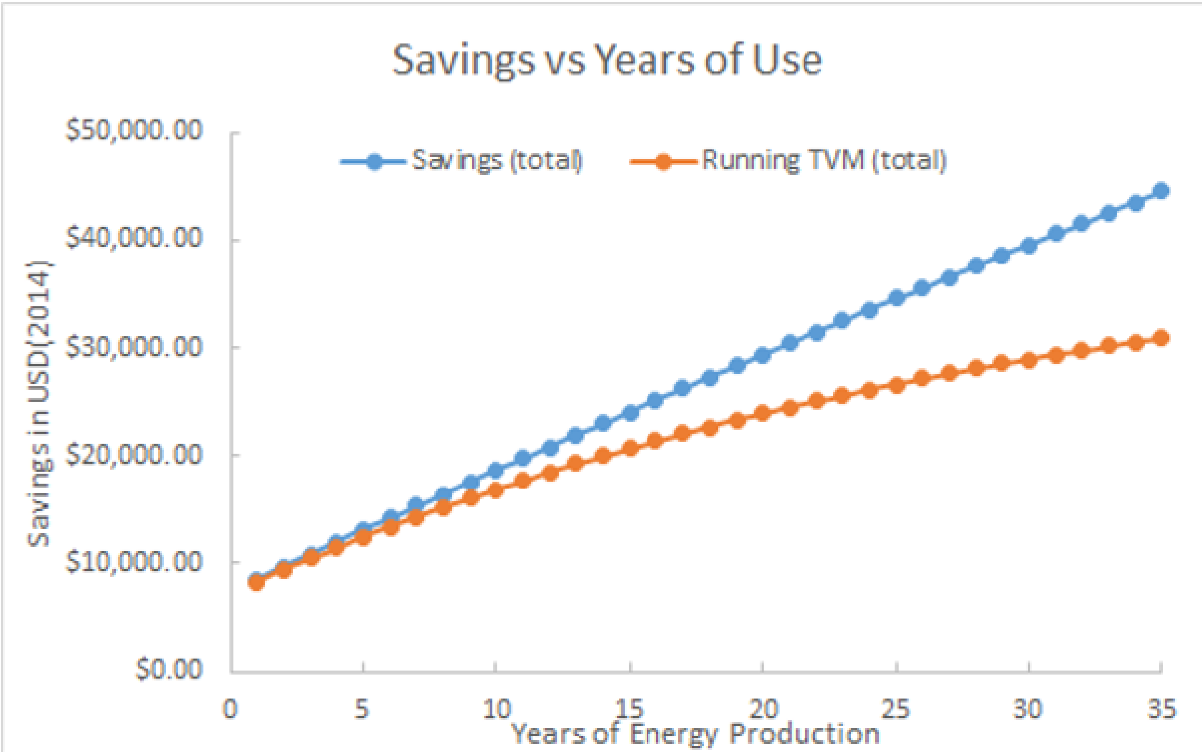

Figure 6.5 Total savings per year with and without Time Value of Money

7. Wind

7.1 Wind Power Proposal

The Evenhouse team considered using wind power to generate electrical energy for the Evenhouse home by installing a wind turbine. The customer suggested that they would not like a wind turbine to be prominently displayed near the home. Therefore, the location shown in Figure was chosen. This location was away from the home, yet elevated by a slight hill. Even with this hill, the wind turbine would need to be mounted above 100 ft off the ground due to the large number of surrounding trees

Figure 7.1 Proposed Wind Turbine Location

7.2 Financial Analysis

A Ventera 10kW Turbine was chosen as the best option for installation at this site. It was chosen because it was available with a 110 ft self-erecting monopole. The self-erecting function was necessary since a crane could not be used this deep in the woods. Ventera provided the team with a detailed quote which included inverters, installation, and shipping, shown on the following page. The total cost of the wind turbine was $87,700. Therefore, the wind turbine was deemed a non-financially feasible project and was not explored further.

NORTH COAST WIND & POWER, LLC

P.O. Box 298
Port Clinton, OH 43452

Estimate

Date	Estimate #
10/9/2014	VWT52716

Name / Address
Calvin College Grand Rapids, MI

Project

Description	Qty	Rate	Total
Ventera 10kW Turbine	1	16,100.00	16,100.00
10.5kW Inverter Package	1	7,900.00	7,900.00
110' Monopole Tower, equipped for hydraulic lift system	1	27,352.80	27,352.80
VENTERA AB&T FOR MONOPOLE TOWERS	1	3,380.00	3,380.00
Subtotal of Equipment			54,732.80
Education/Government Discount		-5.00%	-2,736.64
Subtotal of Equipment			51,996.16
Hydraulic Lift System for 110' Monopole Tower		12,700.00	12,700.00
Concrete Foundation (Labor & Materials)	1	8,500.00	8,500.00
Heavy Equipment for unloading and staging of equipment	1	1,100.00	1,100.00
Labor Charges for Installation of Turbine/Inverters	1	5,000.00	5,000.00
Miscellaneous Materials, includes Conduit and Wire	1	2,610.00	2,610.00
Estimated Freight, Shipping and Handling		5,800.00	5,800.00
Terms: 50% deposit required to secure order			
35% upon completion of foundation/site work			
15% upon completion of installation			
Delivery: 8-12 weeks ARO			
Out-of-state sale, exempt from sales tax		0.00%	0.00

Phone #	419-341-7479	Fax #	419-732-0588	**Total**	$87,706.16

8. Conclusion

8.1 Overall results

The team found that the overall results were positive results. Even though the house has a high usage of energy, there are way to make it net zero *affordably*. Given that the options are affordable and financially beneficial the team recommends the following:

1. Lifestyle Changes (Appendix 2)
2. Lighting Changes (Appendix 4)
3. Wood Burner (Appendix 5)
4. Solar Photovoltaic (Appendix 6)

For a Graphical Financial representation refer to Appendix 11

Resources, Acknowledgments, and Data

9. Resources

Section 1 Resources

Evenhouse home energy data
http://www.propane101.com/propanevselectricity.htm

Section 3 Resources

http://www.bosch-home.com/us/products/dishwashers/
https://www.energystar.gov/index.cfm?c=power_mgt.pr_power_mgt_users
http://www.greatriverenergy.com/aboutus/pressroom/doc101349.pdf
http://akmeier.lbl.gov/pdf/meier-rainer-misc-e-use.pdf
http://www.kenmore.com/kenmore-16-cu-ft-chest-freezer-white/p-04612512000P

Section 4 Resources

http://www.homedepot.com/b/Electrical-Light-Bulbs-LED-Light-Bulbs/N-5yc1vZbm79
www.galleryhip.com

Section 5 Resources

Ball park estimates received from Smart Energy Solutions over the phone.
Smart Energy Solutions
John Clark
357 S. Maple
Grant, MI 49327
(231)834-5900
jclark@visitsmartenergy.com
http://www.woodmaster.com/woodfurnaces_4400.php
https://chimneysweeponline.com/howood.htm
http://en.wikipedia.org/wiki/Maclura_pomifera
http://plants.usda.gov/plantguide/pdf/pg_mapo.pdf
http://homeguides.sfgate.com/growth-rate-osage-orange-57969.html

Section 6 Resources

http://www.heath-zenith.com/solartechdoc.htm
http://www.wholesalesolar.com/
https://sam.nrel.gov/
http://www.treeremoval.com/costs/#.VIjZ3vlT6ao

10. Acknowledgements

The team would like to thank the Evenhouse family for their warm hospitality, time, and willingness to help. Each home visit was an enjoyable experience, and your input was invaluable to the success of the project. Also, the peaches and cookies were delicious.

The team would also like to thank Professor Matthew Heun for his guidance and assistance in this project.

11. Additional Graphs and Tables

Evenhouse Home Data

House #4: Evenhouse		Year Built:	1992
Patrick Anderson, Dustin Brouwer, Jake DeRooy, David Evenhouse			
Square Footage	4000	ft^2	Living area
# of occupants	3	person(s)	
	Last Year	Projected after improvements	
Gas Usage (Heat energy consumed)	0.34015125	0.34015125	Therms/yr/ft^2
Electric Usage	3.95575	1.8	kWh/yr/ft^2
Gas energy equivalent	9.966431625	9.966431625	kWh/yr/ft^2
Gas Usage	453.535	453.535	Therms/yr/person
Electric Usage	5274.333333	2400	kWh/yr/person
Gas energy equivalent	13288.5755	13288.5755	kWh/yr/person
Potential Heating generation		1500	Therms/yr
Potential Electric generation		7200	kWh/yr
Total cost of improvements	41,920.00	[$]	
Payback time	7	[yrs]	
Gas Provider	None - use propane		
Electric Provider	Consumers		
Number of floors Conditioned	1	(Basement heated independently)	
House R value based on Heun calculation	6.426	hr-ft^2 F/Btu	
Carbon Footprint	59798.58975	lbCO2/yr	38.40021705

Time Value of Money Analysis

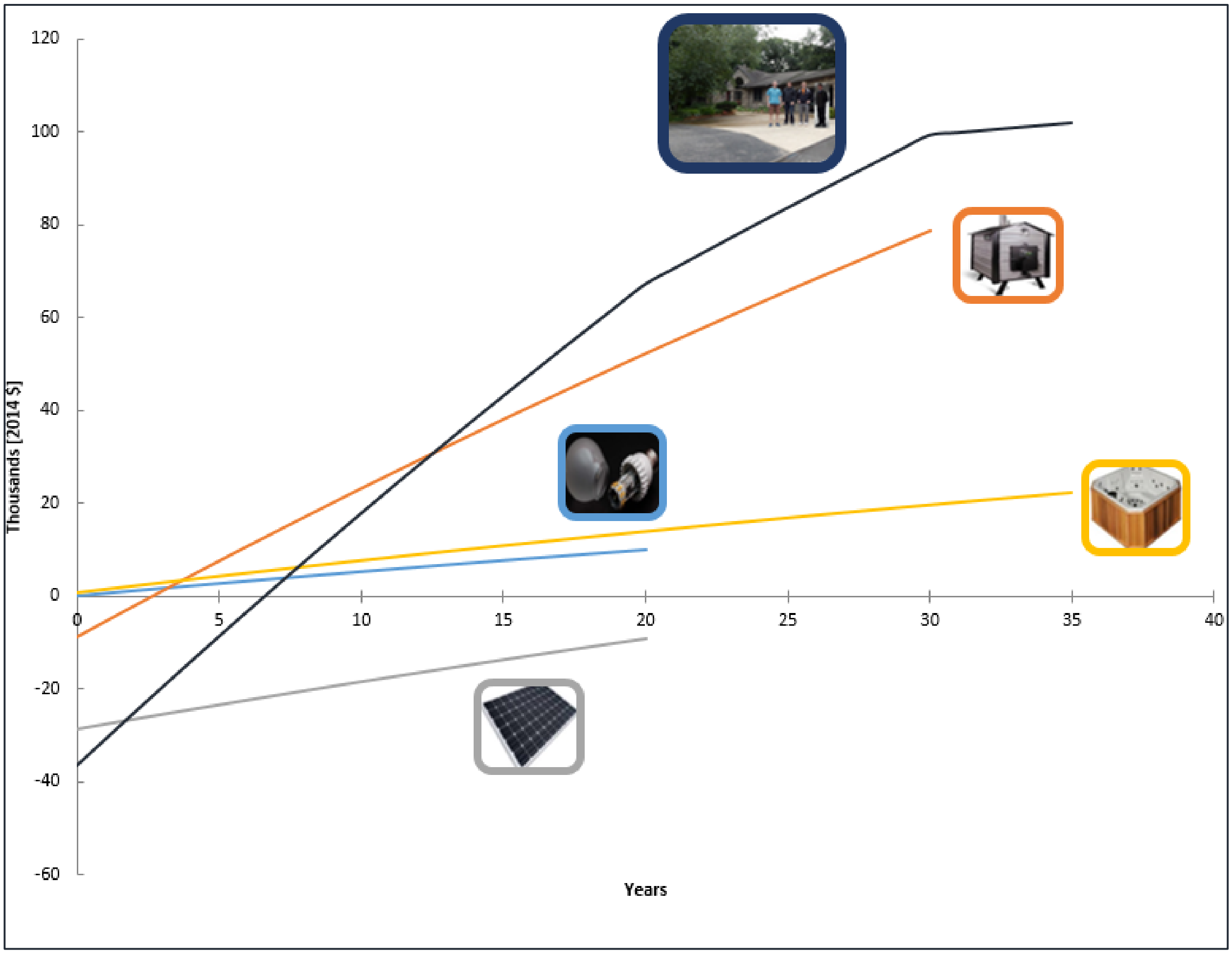

Figure 49 Total Financial Analysis

Appendix C6

Net-Zero Analysis of the Heffner Home

Team 6: Thomas Brown, Ed Smit, Joel Smith, Thane Symens, Kaitlyn Weinstein
Client: Ken and Gail Heffner
ENGR 333: Thermal Systems Design
Dr. Matthew K. Heun, Calvin College Engineering Department
December 16, 2014

Abstract

The purpose of this project is to discover what it would take to bring a specific home to energy net-zero, meaning that the home produces as much energy as it consumes. The team was successful in finding a solution for the chosen home to become a Net-Zero Energy Home through decreasing the amount of natural gas and electricity consumed and increasing the electricity production. Since the homeowners committed themselves to becoming more energy efficient prior to our involvement through the use of a solar panel array and improved lighting, the proposed solution to obtain net-zero status focused primarily on reducing the natural gas usage. To achieve this feat, replacement of old appliances, window replacements, solar heating, addition of thicker insulation, and implementation of a snow-removal device for the existing solar panels could all be applied to become net-zero. While applying these improvements to the house would bring the home to net-zero, it was concluded that many of these would not be possible due to spatial requirements and not recommended due to economic feasibility.

Technical Memo

To: Ken and Gail Heffner
From: Thomas Brown, Ed Smit, Joel Smith, Thane Symens, and Kaitlyn Weinstein
Date: December 16, 2014
Subject: Net-Zero Analysis

Net-Zero:

A net-zero house is a house that produces as much energy as it consumes. This means that a house must generate energy. This generation must meet demands for electricity, heating, and cooling. For our project this means that throughout the span of a year, the amount generated and the amount consumed must equal each other.

Home Introduction:

The home chosen, henceforth referred to as the 'Heffner Home', is the house owned by Gail and Ken Heffner who are current Calvin College employees. The living space of this home is 1794 ft^2, which does not include the basement, and is located in East Grand Rapids, MI. The Heffner Home is second oldest home analyzed, built in 1916. It contains a basement, two full floors, and a finished attic room. The most unique feature of this home is that it has already implemented solar panels in an array of ten units on the roof.

Method:

The process of obtaining energy neutrality was split into two steps. The first step was to analyze different ways to reduce energy consumption and determine which options would be best to implement. The second step was to analyze different forms of energy production and decide which suited the house.

In order to reduce electricity consumption, the team analysis considered replacement of the refrigerator, basement freezer, and washing machine. In order to save natural gas, a new electric stove was purchased, new double pane windows were installed, and three inches of insulation was added to the exterior of the house.

In order to increase the production of the solar panels, a snow removal apparatus was designed. After the new appliances were installed and the snow remover added, the solar panels were able to produce more than enough electricity to run the house. In order to generate heat, 5 solar absorbers were added to the house.

Conclusion:

Becoming net-zero is not currently economically feasible. While the payback time for the entire system implementation is 25.8 years, not considerably long with all updates, the team does not advise using all of the changes that were necessary in order to reach net-zero. As the Heffners were already very efficient with their electricity usage, the only major changes required were for their natural gas usage for heating. The solution of adding 5 solar absorbers meets their needed heating consumption, but is highly unreliable in the winter months when it is needed most. As a backup, natural gas heating would be needed to supplement the heating system. The team advises only making simple changes to electrical efficiency with an updated basement freezer and to heating efficiency with updated windows.

Net-Zero Energy Story

1 Introduction

The Heffner home currently consumes the least amount of both electricity and natural gas of all the homes studied, due to the Heffners' concerns for energy efficiency. The Heffners' lifestyle choices, such as keeping their home cooler during the winter to save fuel used to heat the home and a solar panel array in which to produce clean electricity, are the main reason for the low consumption of resources. Figure C6-1 shows that they are extremely close to the origin, meaning that small amounts of both natural gas and electricity are consumed, just 618 therms/year of natural gas and 2725.5 kW-hr/year of electricity.

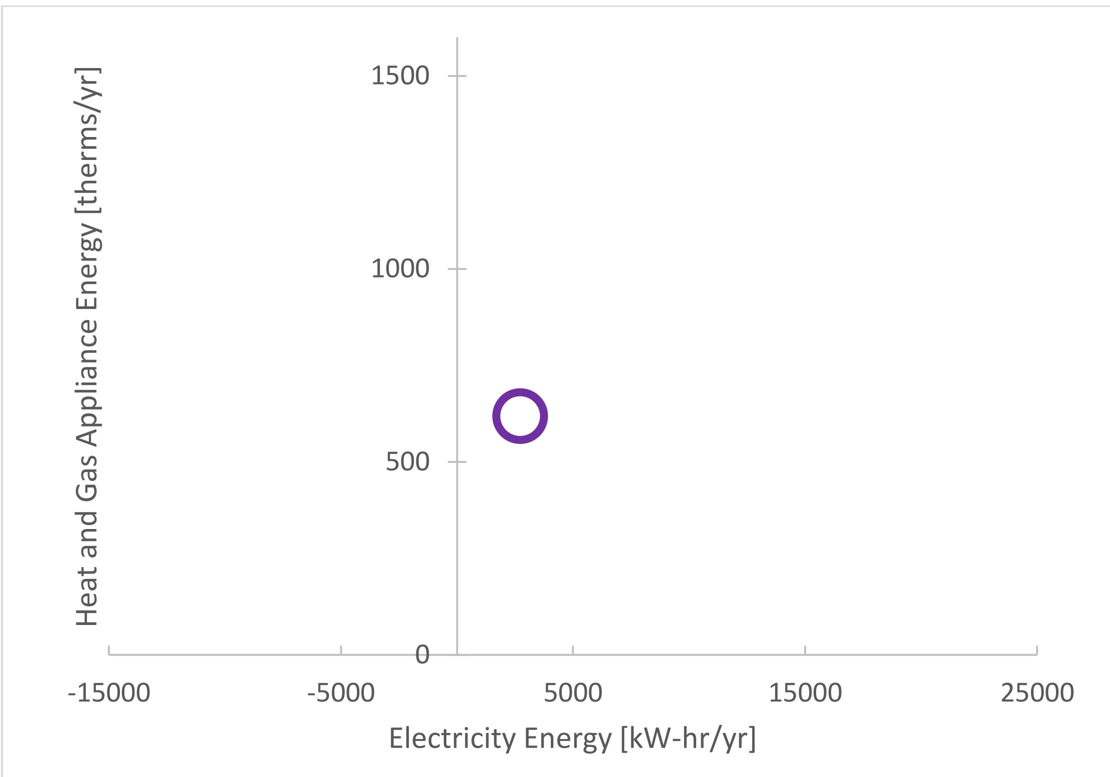

Figure C6-50. Starting energy consumption of the Heffner house

2 Home Specifications

2.1 Location and Dimensions

The Heffner home is located in East Grand Rapids on Hampton Avenue in a closely packed neighborhood. This is an older area of the city and has many large trees providing continuous shade. The home includes two stories, a finished basement, and an attic. The square footage of the house is 1794. The plot is 4600 ft^2 with a backyard of 1400 ft^2 and a front yard of 1500 ft^2. The roof space facing south that already has a solar panel array mounted to it is 414 ft^2. This is ample space for the two Heffners and their numerous guests.

2.2 General Information

The cost for natural gas is 0.91$/therm, per the U.S. Energy Institute Association (US Energy Information Administration). The cost for electricity used is 0.12$/kWhr while they sell their electricity to the grid for 0.14$/kWhr.

3 Research and Data Gathered

The first step in the process was to gather data on the Heffner's energy usage and research methods of energy production and usage. This gave the team an idea of where the Heffner's were starting and what technology was available.

Table C6-16. Consumption, production, and price of utilities

Utility	***Usage***	***Price per unit***
Natural Gas	618 therms	$0.91
Electricity	2725.5 kWh	$0.11
Production	2524 kWh	$0.14

3.1 Natural Gas Consumption

On average, the Heffner's annual natural gas consumption is 618 therms, which is equivalent to 375.7 therms/person/yr, or 18,110 kWh/yr. The Heffners purchase this fuel from DTE Energy of Michigan. Their average yearly bill is $666. The monthly natural gas consumption can be seen in Figure C6-51. As is expected, their natural gas usage is significantly more in winter months due to increased heating.

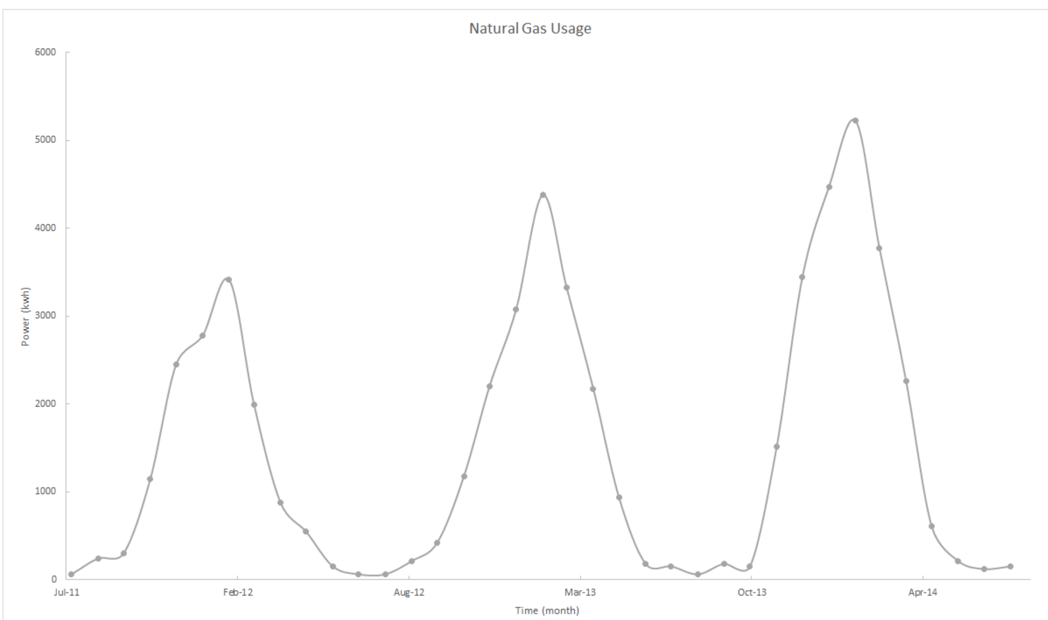

Figure C6-51. Past natural gas usage

3.2 Electricity Consumption

On average, the Heffner's annual electricity consumption is 2725.5 kW-hr/yr, or 1378 kW-hr/yr/person. This is purchased from Consumers Energy of Michigan. The monthly electrical consumption can be seen in Figure C6-52. Similar to the natural gas consumption, electrical consumption increases during winter months which can be explained by an increase in demand for electronic components such as lighting when the length of day is much shorter.

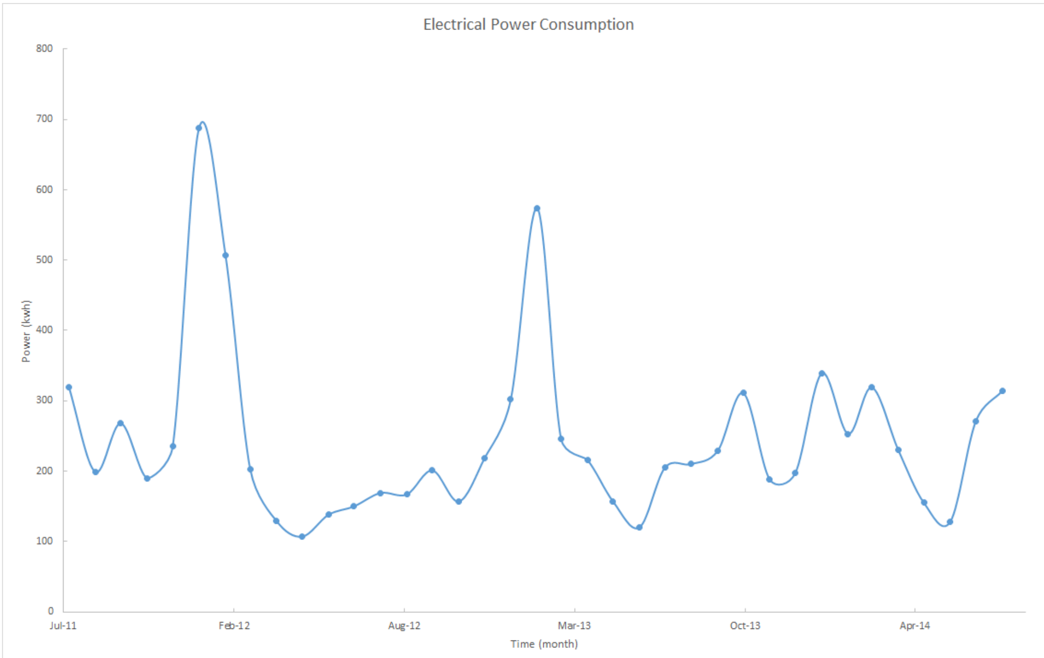

Figure C6-52. Past electricity usage

3.3 Solar Electric Production

The home is already equipped with a 2.2 kW solar array which produces, on average, 2524 kW-h/yr. This power is sold to Consumers Energy of Michigan. The monthly production of the array can be seen in Figure C6-53. It can be observed that during the summer months when the days are longer, a significantly larger amount of power is produced.

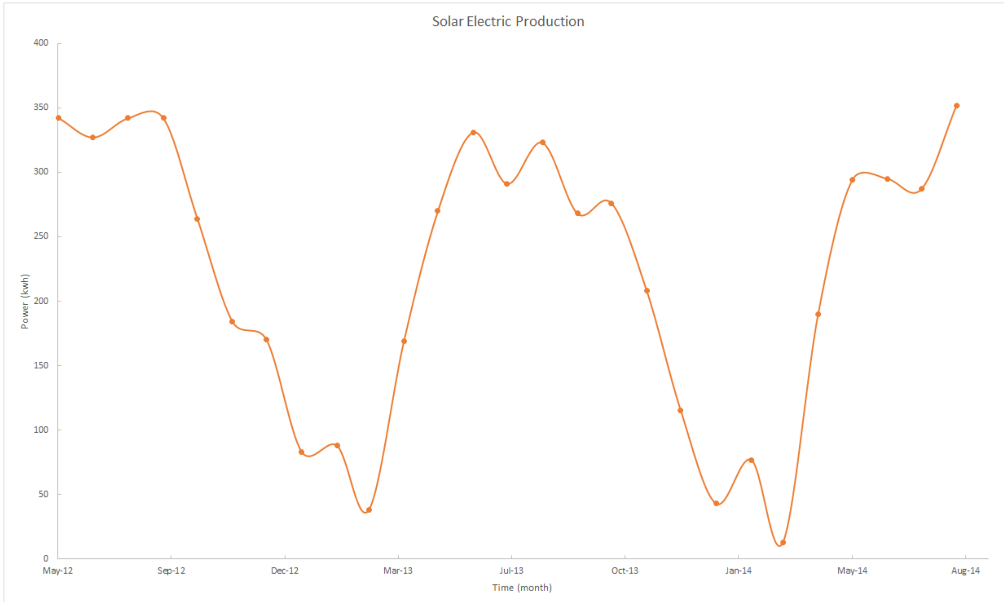

Figure C6-53. Past Electricity production from solar array

The average electrical consumption and production were compared in Figure C6-54 for a graphical representation of what the net electrical consumption is. It should be noted that the gap between production and consumption is significantly greater in the 2013-2014 year. This increase can be attributed to a harsher winter with more snow accumulation preventing solar production combined with the usage of a humidifier that consumed an excessive amount of electrical energy.

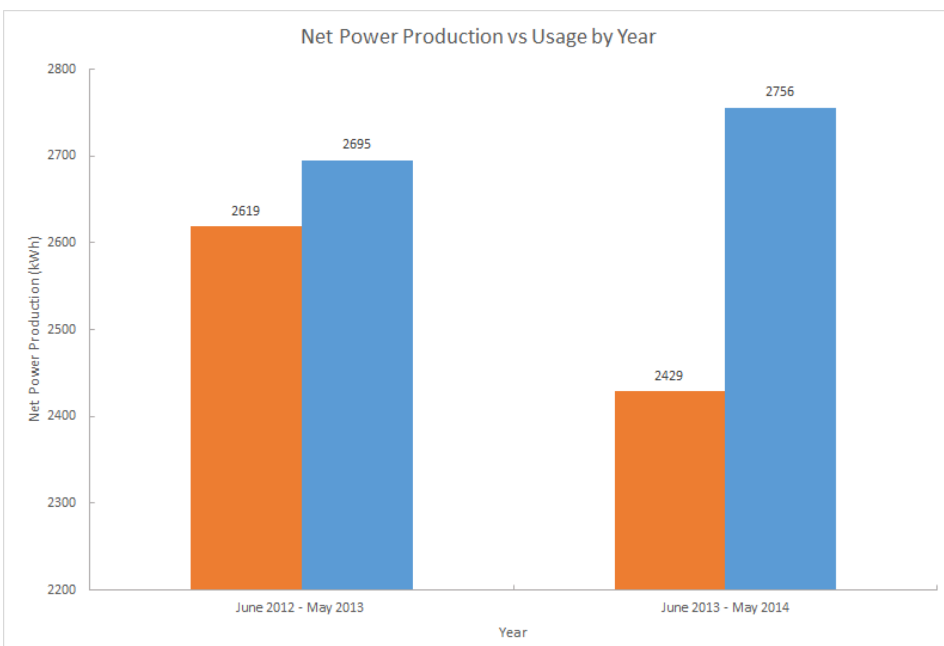

Figure C6-54. Comparison of electricity consumption and production.

4 Appliance Analysis

In order to reduce energy usage, each major appliance was evaluated in order to determine the cost to replace, the energy saved by replacing, and the return on investment. By reducing energy usage, the Heffner's won't have to generate as much energy.

4.1 Refrigerator

The kitchen refrigerator can be replaced to save a small amount of energy. The current refrigerator is 14 years old and is relatively energy efficient already. Due to the low energy saving replacing the fridge would be very expensive compared to the yearly monetary savings. This expense would be necessary however in order to achieve net-zero status. Table C6-17 shows the cost and savings of the upgrade as well as the ROI.

4.2 Freezer

The freezer is very old and is not very energy efficient. However, the Heffners have limited its energy usage by using an energy reducing plug that limits the energy supplied to the freezer. But even with this reduction, replacing the freezer with a new, more energy efficient model would greatly decrease the amount of energy used per year. The cost of this freezer is also the lowest of all appliance replacement costs. Table C6-17 shows the cost and savings of the upgrade as well as the ROI.

4.3 Range

The Range is not frequently used but is currently powered by natural gas. This would need to be replaced with an electric model in order to reach net-zero energy conditions. This is due to the need to take the home completely off natural gas. Electricity is the only viable power option for the oven that would be dependable all year round. Table C6-17 shows the cost and savings of the upgrade as well as the ROI.

4.4 Water Heater

The electric water heater that the Heffners own works perfectly for their needs and uses very little energy. It is a batch heater and only heats water a couple times a day, rather than using a tank and keeping it warm like most water heaters. Since it is not running all day, the energy it draws is minimal. There is no need to find a different model as they already have the best one.

4.5 Washing machine

Replacing the washing machine was deemed not to be economically feasible, but could be replaced to save energy. The Heffners do not do very much laundry, only one or two loads per week, so the energy saved by upgrading the washing machine is very small relative to the cost of a new machine. Table C6-17 shows the cost and savings of the upgrade as well as the ROI.

4.6 Other Appliances

The dryer was another potential appliance that could be replaced, but after learning that the Heffners hang dry their clothes, and the dryer is only used for the rare occasions that they need to clean large batches of towels from Calvin College events through the Student Activities Office. Thus the team deemed it too costly to replace the dryer. If it did save energy, the return on investment would be far longer than the life of the machine.

4.7 Snow Removal Apparatus

In the winter snow builds up on the solar panels during the more extreme snow storms. This causes the electrical production to drop to zero at times. The panels are on the roof of the three story house without any way to safely access them. In order to combat this, a snow removal apparatus was designed. The effect of snowfall can be clearly seen during December of 2013. The following graph compares the recorded daily snow accumulation and the solar panel power generation.

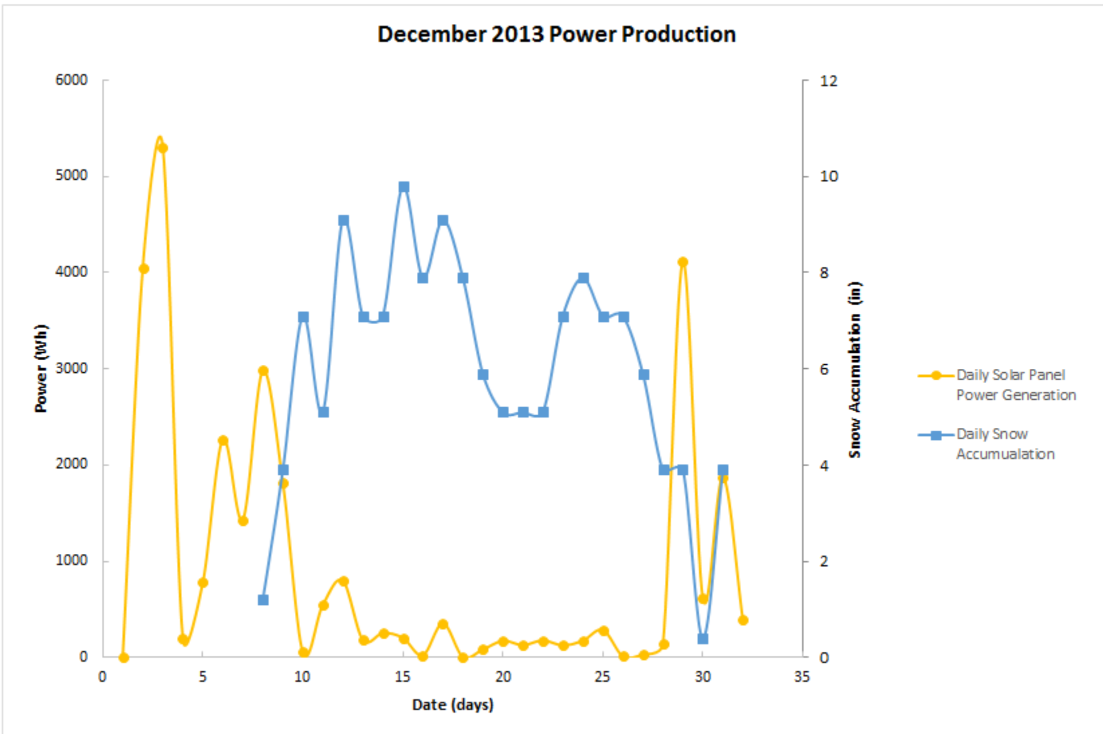

Figure C6-55. Comparison of solar panel energy generation and snow accumulation.

This apparatus will be controlled by a pulley system with ropes located by a window that can be pulled to clear the snow off of the device. It is not essential that the panels be completely cleared off because when some of the panel is exposed to the sun, the panel heats up and melts off the rest of the snow. This allows for a simple design that can be easily built and installed for about $100. The preliminary plan is seen in the following figure:

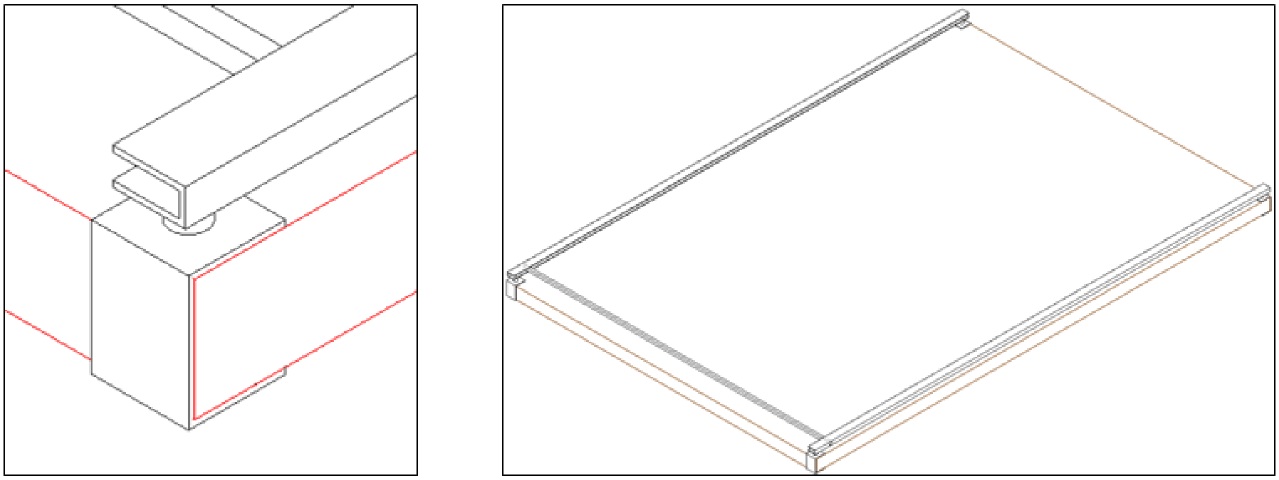

Figure C6-56. Overall view and close-up of snow removal device.

Implementing this design would increase production by about 90 kW-h/year. This value was calculated by comparing weather conditions and solar panel production for the winter months. The times when the electricity production was decreased by snow were replaced by low production times with no snowfall. The difference between the yearly averages was then found. Further calculations can be found in Sub-Appendix C6.

Table C6-17. Appliance upgrade and associated metrics

Proposed Change	***Cost ($)***	***Savings ($/yr)***	***Individual ROI (years)***
Washing Machine	720	15.95	45.23
New Freezer	500	21.78	22.96
New Fridge	841	9.47	88.81
New Oven	649	2.439	266.09
New Windows	3,912	162.22	24.1
Snow Removal Device	100	4.4	22.72

5 Heat Efficiency Analysis

Most of the appliances use electricity. After replacement, the home will use significantly less electricity; however, it is still heavily dependent on natural gas in the winter months. The team evaluated what could be done to reduce the amount of heat lost in order to reduce the amount of heat that needed to be generated.

5.1 Home R-value

The R-value calculations were done to find the equivalent resistance of the home to losing heat through the walls and the roof. This was done by the equation $Q=UA\Delta T$. Q, or the amount of heat passing through the house, was assumed to be the amount of heat used in BTUs. A was the total surface area of the surfaces losing heat to the surroundings. ΔT was the solar heating days for the location of the home. The equation was solved for U which is 1/R. This R value is a comparison that can be used against other homes. With four inches of insulation the R value of the Heffner's home is 14.8 hr-ft^2-F/BTU.

5.2 Windows

The windows in the Heffner home are a major source of heat/energy loss. Most of the windows are original to the house, meaning that they do not use the advances in window insulation technology that are standard for energy efficiency today. For this reason it was deemed necessary for many of the windows in the house to be replaced. This will drastically reduce their heating bill due to the loss of heat through the windows during the cold winter months.

There were many types of improvements to the windows that can be made. The two main improvements are replacing the single pane windows with double pane, gas-filled windows. The other improvement was replacing the windows with ones having wood or vinyl frames. Because the thermal conductivity of aluminum is much higher than the thermal conductivity of wood or vinyl, the heat loss is much greater. Thus replacing these old aluminum framed windows with ones having wood or vinyl is highly suggested. Both of these improvements decreased the U-factor of the windows (the parameter which dictates the amount of heat loss) significantly.

The main parameter that affects the heat loss for windows is the U-factor of the whole window, which includes the glass as well as the frame. Energy Star provides information on what ranges of U-factor should be implemented for various locations throughout the country. The state of Michigan is considered the "Northern Climate Zone," which means that windows should be designed for minimum heat loss over other factors. According to Energy Star, the U-factor for windows in Michigan should be less than or equal to 0.3 BTU/hr ft^2 ºF, and for skylights less than or equal to 0.55 BTU/hr ft^2 ºF. These U-factor requirements were the main criteria about which the replacement windows were searched for and chosen to implement.

A spreadsheet was implemented for the calculations of the heat loss in the old and new windows. Temperatures could be varied to see the impact of temperature to the savings from heat loss by replacing the windows. As seen in Figure C6-57, the annual energy savings decreases as the average temperature outside increases.

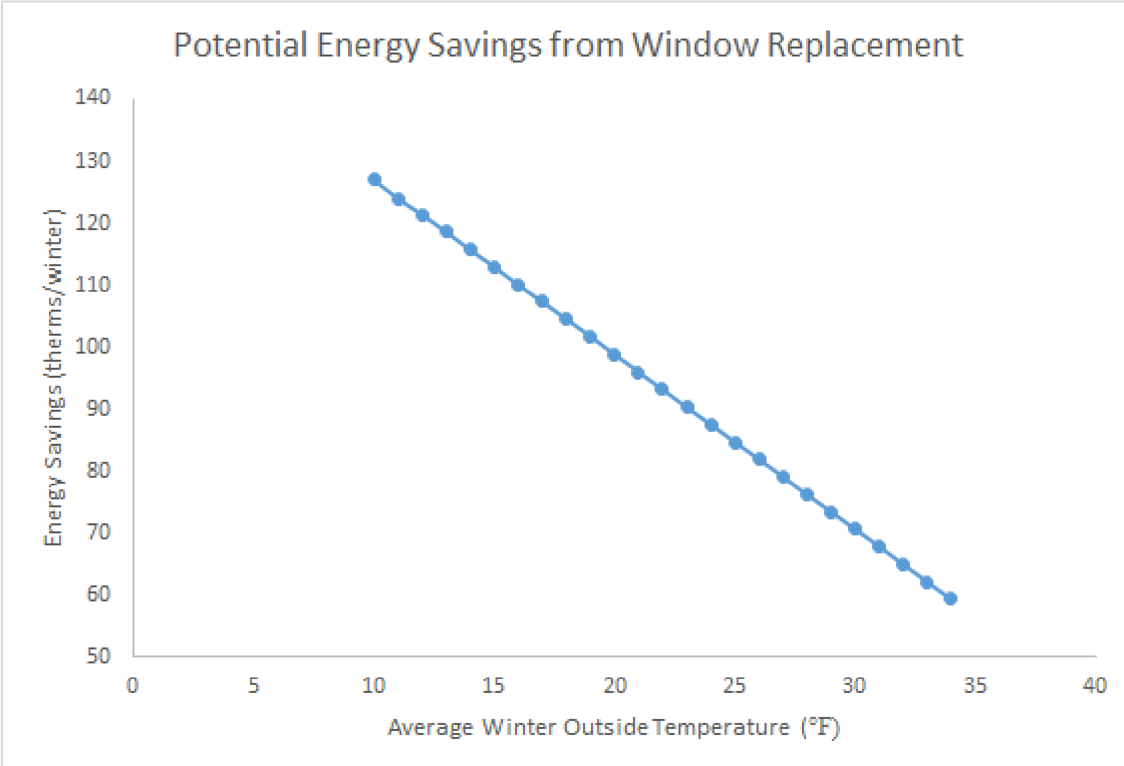

Figure C6-57. Effects of outside temperature on savings from window upgrade

Using the NOAA National Climatic Data Center's archives, the average temperature during the winter months was 21.7 ºF, and was the temperature used for the main analysis. Using this value, the annual energy savings from replacing the windows is 94 therms per winter.

5.3 Exterior Insulation

In order to decrease the amount of heat production, exterior insulation was recomended. Since the Heffners have previously supplemented the interior insulation, exterior insulation was determined to be the best method. This would keep the benefits of the interior insulation and be less intrusive to the home. The exterior cladding would be removed and Owens Corning FOAMULAR exterior foam insulation would be added. The cladding would then be replaced.

To determine the amount required, the R-value required in order to reduce the number of solar absorbers was calculated. The amount of insulation required to obtain this R-value was calculated. A graph comparing the number of solar absorbers to the amount of insulation was then generated as seen below.

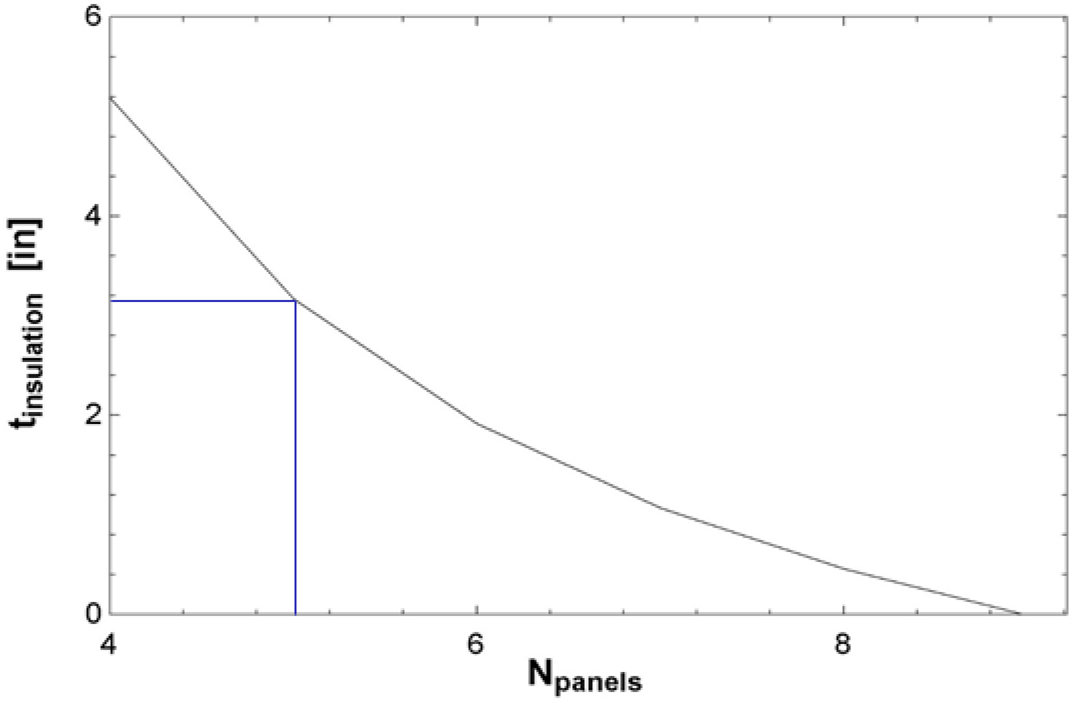

Figure C6-58. Combination of solar-heating panels and insulation needed to cover heating needs

6 HVAC Analysis

Since the current solar panel array produces enough electricity to maintain the home after the electricity saving actions are determined, the only thing left to do was determine a system to provide heat for the home.

6.1 Geothermal

A geothermal system takes water and runs it through tubes underground that then heats the water and runs it through the house and heats the house. It was decided that a geothermal system is not a feasible system to implement for the Heffner home. While it does eliminate the need for natural gas, the electricity needed to power the pump offsets any gains made for heating. The costs associated in producing the additional electricity are make a geothermal much more expensive than other options. The Heffners also have limited yard space (approximately 3115 ft^2), so the only option would be a vertical-loop system, which is a significantly more expensive system, before the electricity use is added into the cost. Because of this, the payback time on the system is very high.

6.2 Electric Furnace

An electric furnace is simply a furnace that generates heat using an electric heating coil via electric resistance. Switching to an electric furnace is another option for eliminating the need for natural gas to heat the house. The electric furnace has the potential to reduce the house to net zero; however, the large power draw needed requires many, many more solar panels. The cost of heating the house with electricity currently is more than the cost of heating it with natural gas so there is no return on investment. Their current furnace also has an AFUE of 91% so the gains are negligible in terms of efficiency. Again, the electric furnace is not a feasible option for heating the house.

6.3 Solar Heating

Solar evacuated tube absorbers absorb energy from the sun and transfer it into a water tank. This heated water is pumped around the house using radiative heating. The benefits of solar heating are that the energy transfer is more direct, making it more efficient and it can be used to heat water in the summer, reducing electricity usage for the electric water heater. Solar heating is the best option for eliminating natural gas usage despite its upfront cost. It requires almost no maintenance costs and no fuel costs.

Each solar absorber is capable of producing 44 therms per year. This would save $15 per year in natural gas. The gross area of the absorbers is 43.03 ft^2. In order to completely offset the natural gas usage, the house would require nine absorbers. However, they do not have enough roof space for these large appliances and there yard is almost completely shaded by trees. In order to implement this technology, they would have to rent their neighbors roof space. This technology would require the use of a pump which would draw electricity. With other improvements, there is enough electricity produced by the solar panels to accommodate this. Also, in the summer the heaters can be used to heat the Heffner’s water, saving electricity.

The drawbacks are that solar heating is inconsistent. The peak heating time is during the middle of the day, but early morning and night time are when the most heating is required. The heat can be stored for short periods of time in the water tank, but during long spans of cloudy weather, it will not perform well.

It was determined that to obtain net zero status, 5 solar absorbers would be used and insulation would be added to the house. This will limit the amount of roof space needed and help smooth heating fluctuations. The optimization for the number of solar absorbers and amount of insulation can be found in the insulation section.

7 Results

The following graph (Figure C6-10) shows that after implementing all of the energy saving and energy production methods, the home will obtain Net-Zero status.

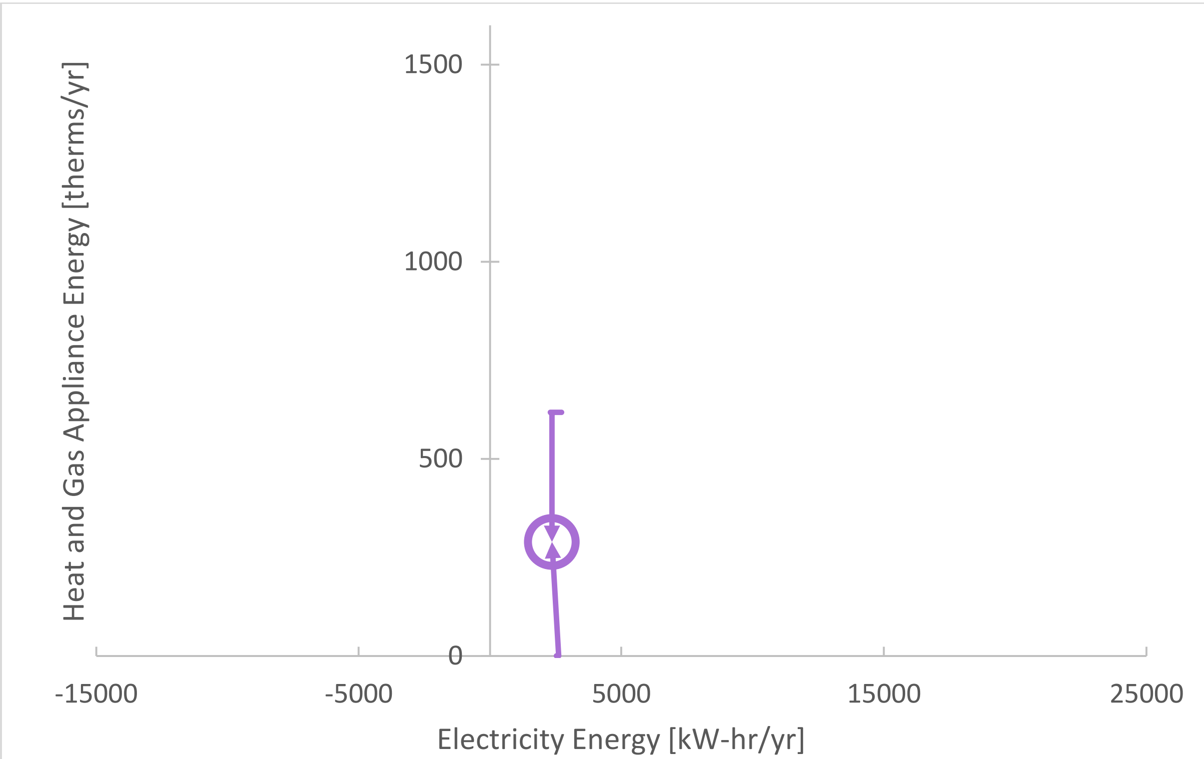

Figure C6-59. Final energy needs and production for Heffner house

7.1 Recommendations

The final design specification needed to reach net-zero status includes:

- Updating all appliances according to the model updates found in Table C6-3
- Installing a snow removal device for increased solar electric power generation in winter months
- Updating windows throughout entire house
- Installing 4 inches of additional insulations onto house exterior
- Implementing a solar heater array to generate needed heat

7.2 Electricity Offsetting

The final recommendations for getting to net-zero electricity usage are to update the fridge, freezer, washing machine, and get the snow removal device. This will cost the Heffners $2161 and will allow the house to have zero electricity consumption.

7.3 Natural Gas Offsetting

The final recommendations for getting to net-zero heating usage are to get solar heaters, upgrade the windows, update the oven, and increase the insulation on the house. This would cost the Heffners $17,661. The largest contribution to attaining net-zero status is the insulation.

7.4 Cost Analysis

The total cost for these changes is estimated at $19,822. This accounts for the purchase costs of every recommended item and the respective installation cost. The cost of each component can be seen in

Table C6-18.

7.5 Return on Investment Period

Given the savings of each and every recommended change, seen in

Table C6-18, the system would save $767/year. With the total cost of $19,822 the return on investment is 25.8 years. At this point the system has paid itself back and all the saved money will be extra in the Heffner's budget.

Table C6-18. Final recommendations with savings and ROI

Proposed Change	**Model Number**	**Cost ($)**	**Savings ($/yr)**	**Individual ROI (years)**
Washing Machine		720	15.95	45.23
New Freezer		500	21.78	22.96
New Fridge	Whirlpool Model: WRT359SFYF	841	9.47	88.81
New Oven		649	2.439	266.09
New Windows	Thermastar by Pella 10 Series Model:748171609843 American Craftsman Hopper Model: 70 FARKO (Fixed Tempered) Model: 68706	3,912	162.22	24.1
Snow Removal Device	Home made	100	4.4	22.72
Insulation	Owens Corning FOAMULAR	6,800	295	23.05
5 Solar Absorbers		6,300	371	16.98
Total		19,822	882.26	22.5

8 Final Results after Completion of Recommendations

The recommendation listed in section 8.1 would bring the Heffners home to net-zero status. The home is currently closer than average to net-zero when compared to other homes in Grand Rapids. It is especially close to net-zero for its age, due to major changes to the efficiency and energy production of the home. These changes made the gaps between current usage and net-zero easier to fill, but also made them more expensive because the easier, cheaper solutions have already been implemented leaving only the expensive solutions. The proposed changes above result in an overproduction of 0.02 therms/yr and 3.2 kW-hr/yr. The team was successful in finding a net-zero energy system that would fulfill the needs of the Heffner's home. The team was disappointed that even with the best possible system the payback period could not be less. Many recommended changes will be beyond their useful life by the time the entire system is paid back, meaning that they may have to be replaced before they are fully paid back. This is not ideal, but is unavoidable in order to achieve net-zero status for the Heffners' home.

Resources, Acknowledgements, and Data

Resources

The following resources were used for this project:

- http://energy.gov/energysaver/
- www.efficienctwindows.org/
- www.homedepot.com/
- www.lowes.com/
- www.menards.com/
- www.dudadiesel.com/
- www.energystar.gov/
- www.eia.gov/naturalgas/
- https://accessmygov.com/MunicipalDirectory?uid=115
- http://www.eia.gov/electricity

Acknowledgements

Team 6 would like to thank the following people who have contributed to our project:

- Gail and Ken Heffner
- Professor Matthew Heun
- S and J Heating, DeWitt Michigan

-

Customer name	*Ken and Gail Heffner*	
Square Footage	1794	ft^2
Year built	1916	
# of occupants	2	person(s)

	Last Year	Average Year	Projected After Improvements	
Gas Usage	0.419	0.345	0.2894	$Therms/yr/ft^2$
Electric Usage	1.51	1.519	1.258	$kWh/yr/ft^2$
Gas energy equivalent	12.27190635	10.095	9.828	$kWh/yr/ft^2$
Gas Usage	375.695	309.045	259.56	Therms/yr/person
Electric Usage	1378	1362.75	1128.4	kWh/yr/person
Gas energy equivalent	11007.9	9054.965	8815.65	kWh/yr/person
Potential Heating generation	0	0	289.14	Therms/yr
Potential Electric generation	2429	2524	2614	kWh/yr

Total cost of improvements	19822	[$]
Payback time	25.8	[yrs]

Gas Provider	DTE Energy	
Electric Provider	Consumers Energy	
Number of Floors Conditioned	3	
House R value	14.862	hr-ft^2 F/Btu
Carbon Footprint	7531	lbs CO2

Appendix C7

Net-Zero Analysis of the Koetje Home

Team 7: Seth Koetje, Nick Memmelaar, Austin Juza, Matt Ramaker
Client(s): Professor David Koetje
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department
December 16, 2014

Abstract

For this project, the team assessed a specific home in the Grand Rapids area. The current energy status of the home was determined using past gas bills. Improvements for energy usage were assessed. After a new predicted energy usage was evaluated, energy generation options were explored. For this home, the starting energy usage is 6,690 kW-hr/yr for electricity and 822.8 therms/yr for gas. In order to reduce this consumption, the team recommends adding wall insulation to the house, replacing the refrigerator, and replacing the dryer. The new predicted energy needs are 6858 kW-hr/yr for electricity and 401.5 therms/yr for gas. For energy generation, the team recommends a geothermal system and solar panels. To become fully net-zero through all these improvements, there will be an initial cost of $44,822 and a payback period of 18.2 years.

Technical Memo

Introduction

A home that is net-zero means that the energy being consumed is equal to the amount of energy being produced for an entire year. The Koetjes' have already made steps towards net-zero by implementing the wall insulation recommendation.

Method

What had to be done first, for this process was to analyze the Koetjes' energy usage. Team 7 studied which appliances were consuming the most energy with a kill-a-watt meter, and then found alternatives that were more energy efficient. Figure A7.A1 contains the kill-a-watt meter data obtained. Based on the high energy usage of some of the appliances, Team 7 decided to look for alternate options for the upstairs and downstairs refrigerators, the stove, the washer, and the dryer. Before searching for alternative appliances, Team 7 realized that it would be more beneficial to cut out the dependence for gas and therefore rely only on electrical appliances. This then takes away the need for a water heater, furnace, and the need for a gas driven dryer. While looking into options to reduce energy consumption, Team 7 found that the most cost effective appliance implementations included replacing the upstairs refrigerator and an electrical dryer. The team suggested the replacement refrigerator because its payback period was shorter than the electrical generation payback period of the solar panels. The replacement electric dryer suggestion was recommended to get rid of the gas component requirement of the current dryer and replace it with an electrical usage because it is easier for the house to generate electricity than gas. The additions of these appliances, as well as the installation of insulation can be seen in Figure A7.A7.

Team 7 has significantly lowered its heating energy and slightly raised its electrical energy consumption, and in order to reach net-zero, energy generation systems will be needed. To reach the heating energy required from the improvements, about 400 therms will be needed per year. Implementing a horizontal trench loop 5 Series Furnace from S&J Heating, Team 7 was able to sufficiently supply the amount of heating needed for the new current state of the Koetje residence. Although we met the heating goal for this project, the geothermal system added more electrical consumption due to the pump found within the system. Now, to meet the electricity requirements, the System Advisory Modela program (SAM) was used to model the tax incentives, racking, and inverters needed by the system, and with that, the houses' solar panels were selected.

Conclusion

In conclusion, it is not financially reasonable to bring this house to net-zero. Several of the required updates are not going to save money, but only reduce electricity consumption by a little bit or switch from gas usage to electric usage. This means that while becoming net-zero is possible, it is more of a lifestyle choice than a financial decision. The group has shown that it is possible to become net zero in the Grand Rapids area if the house owners are willing to put in the financial investment, but that it is not a financially optimal decision at the moment.

Net-Zero Energy Story

First, Team 7 visited the house. The current energy status of the house needed to be evaluated. The team acquired more than two years of gas and electric bills from the homeowner. All the information for the current appliances were recorded. To get actual appliance energy usage, the team had the homeowner use a kill-a-watt meter. A schedule was made for the appliances and actual data was recorded. From this information, the team could make better recommendations for appliance improvements. An actual electric energy distribution can be seen in Figure A7.A1. The initial energy usage of the house can be seen in Figure A7.A2. This includes the gas and electric usage.

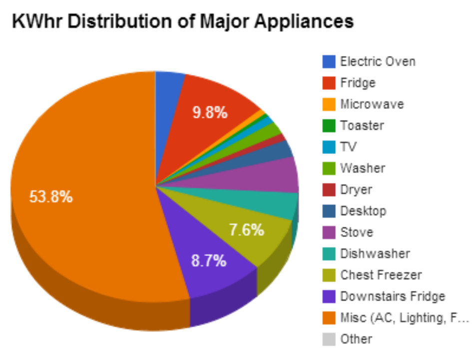

Figure A7.A1 Distribution of Energy Consumption By Appliance

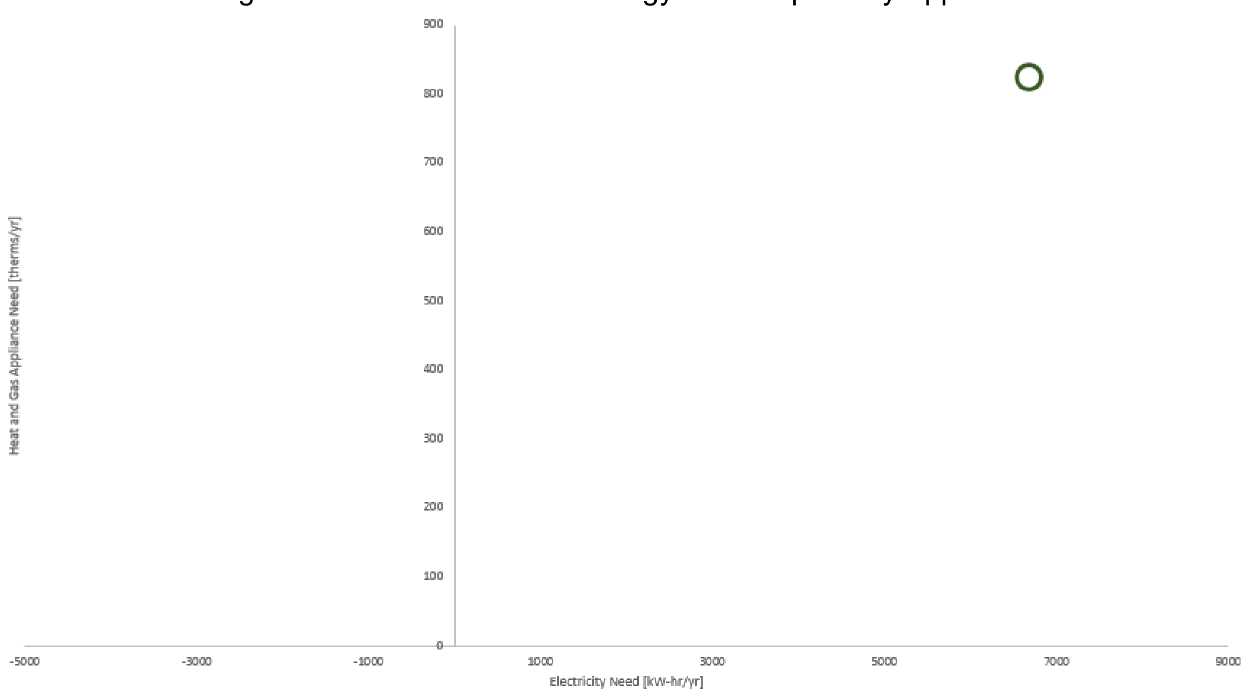

Figure A7.A2 Initial energy usage information

From this starting point, the team was able to explore possible improvements. The house already had many sunlights and LED lights, so there was no lighting improvement options. Wall insulation seemed very favorable because of the cold winters in Grand Rapids. The house had already made the insulation installation a week before the team selected the study the house. Therefore, the energy data of the house did not yet reflect the wall insulation savings, so the team calculated the expected energy and costs savings. The team included this improvement in the recommended updates because the energy data did not reflect the new wall insulation yet. Figure A7.A3 shows the predicted energy savings from the wall insulation with the cost and payback period. To find this, the R-value of the house without insulation was found based off of past data. A new R-value was calculated with the new insulation layer added.

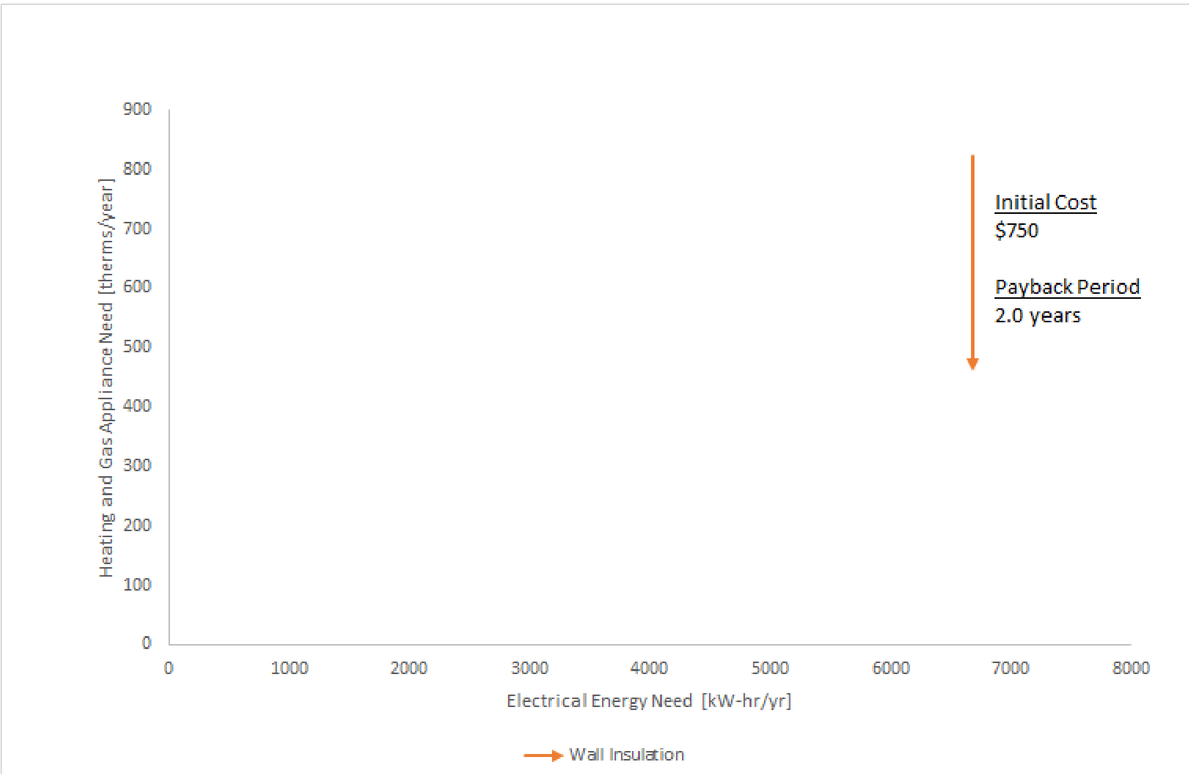

Figure A7.A3 Wall insulation improvements

All appliances were considered for replacement. The refrigerator used the most energy of the appliances the team was able to measure. The refrigerator was also pretty old, so the team recommended buying a new one. The team recommended an Amana Top Freezer. An image for this can be seen in Figure A7.A4. The predicted energy savings can be seen in Figure A7.A5. An energy rating of the new refrigerator was used to calculate the new energy usage value.

Figure A7.A4 Recommended refrigerator
http://www.gerritsappliances.com/en/catalog/product/157235-Amana-A8TXNGFBW

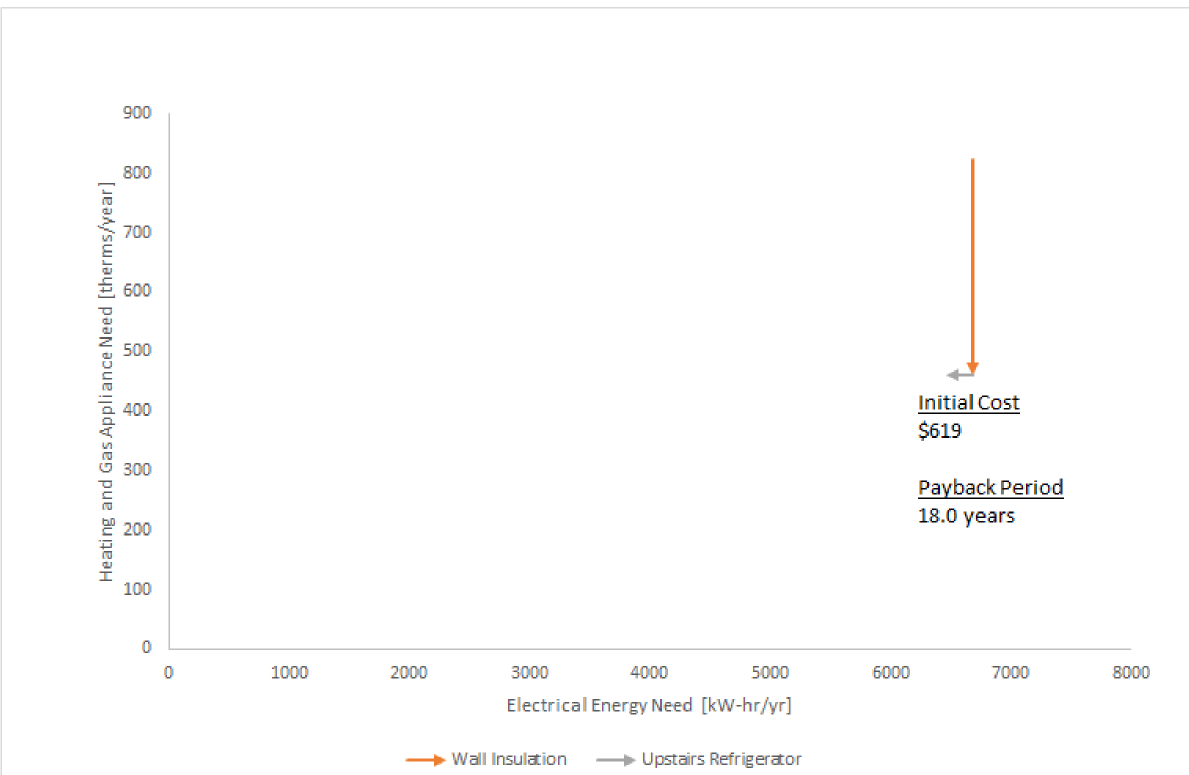

Figure A7.A5 Predicted refrigerator savings

Thinking ahead to the teams need to supply gas energy, it was decided that we would make all of our appliances that use gas to use electricity instead. The home is heated by gas, but this can be fueled by a geothermal system. We have no easy way of producing actual gas. The dryer is an appliance in the house that used gas and electricity. The team recommended a dryer that only uses electricity to get rid of this problem. This dryer can be seen in Figure A7.A6. The changes in energy usage can be seen in Figure A7.A7. The payback period of this change is not attractive because gas is much more effective at supplying energy that electricity is.

Figure A7.A6 Recommended dryer

http://www.searsoutlet.com/7-4-cu-ft-Duet%C2%AE-Electric-Dryer-w-Steam-Refresh-White/d/product_details.jsp?pid=131107&mode=seeAll

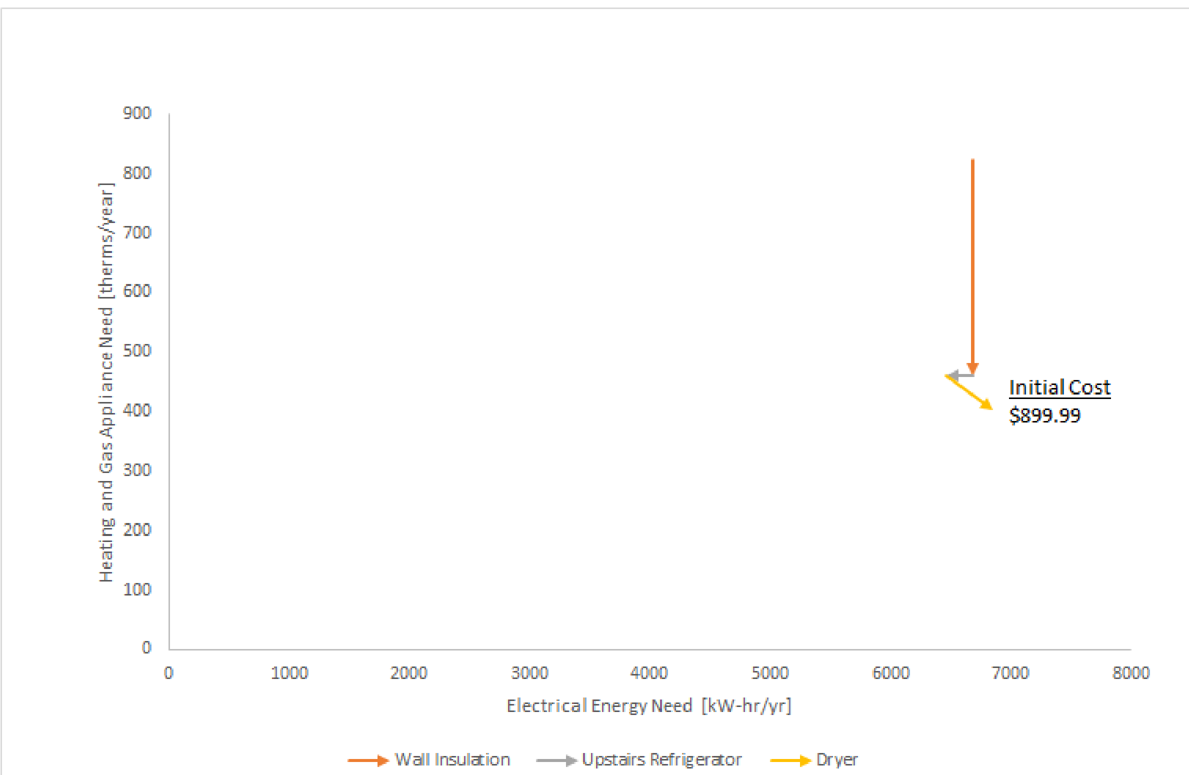

Figure A7.A7 Dryer energy change

These are all the energy reduction decisions the team made. Next, the team investigated ways to produce the energy still needed.

There a few options for heating a home using renewable energies instead of a gas furnace: using a biomass furnace, a solar thermal panel system, an electric furnace and water heater, or a geothermal heat pump. The Koetjes' have a large vegetable garden in their backyard. They have indicated that they would not want to replace their vegetables with a biomass crop. Replacing the grass in the backyard with a biomass crop would likely not be aesthetically pleasing for the homeowners or the neighbors (there are no fences surrounding the yards in the neighborhood). For this reason, Team 7 decided to not pursue the biomass furnace alternative.

The next gas alternative option was solar thermal panels (also referred to as solar absorbers). The Koetjes' have two large trees in their front yard which block the sun from hitting most of the house. This reduces the cooling needs of the house in the summer, but it also limits the solar power potential of the roof. There is a 520 ft^2 area of roof above their garage which can have solar panels on it, but the solar photovoltaic panels will require most of this space. Solar thermal panels also have a fundamental issue in the Grand Rapids area: they cannot produce sufficient heat during the cloudy winter months for the house. Because of these concerns, Team 7 decided against suggesting solar thermal panels for the house.

The third option for heating the house was an electric furnace and water heater. This would have been a viable option for the house, but would have required removing the two large trees in the homeowner's front year. Without these trees, the house would be able to have more sunlight on the south facing roof and therefore install more solar panels to cover the additional heating needs. In the end, this option proved to be more costly than the suggested heating system for the house.

The final heating system that team 7 could explore was a geothermal heat pump system. The team contacted S&J Heating and Insulation Incorporated based out of DeWitt, Michigan about their geothermal heat pump options. Based on the size of the Koetje house, Harry Johnivan of S&J provided estimates for a horizontal trench loop system, horizontal bore loop system, and a vertical loop system. The horizontal trench loop system was the least expensive option and the vertical loop system was the most expensive. All the systems have the same performance, but the horizontal loop systems have a large spatial requirement in the homeowner's yard. Because the Koetjes' have a large backyard, Team 7 decided to suggest the inexpensive horizontal loop trench system. The initial cost of this system was around $20,000 before tax incentives. After factoring in the tax incentives, the initial cost of the system would about $14,200 and have a payback period of just under 24 years (vastly improved from the other houses geothermal vertical loop system payback periods of about 30-40 years). Figure A7.A8 shows the gas energy production and the associated additional electrical energy need of the geothermal system.

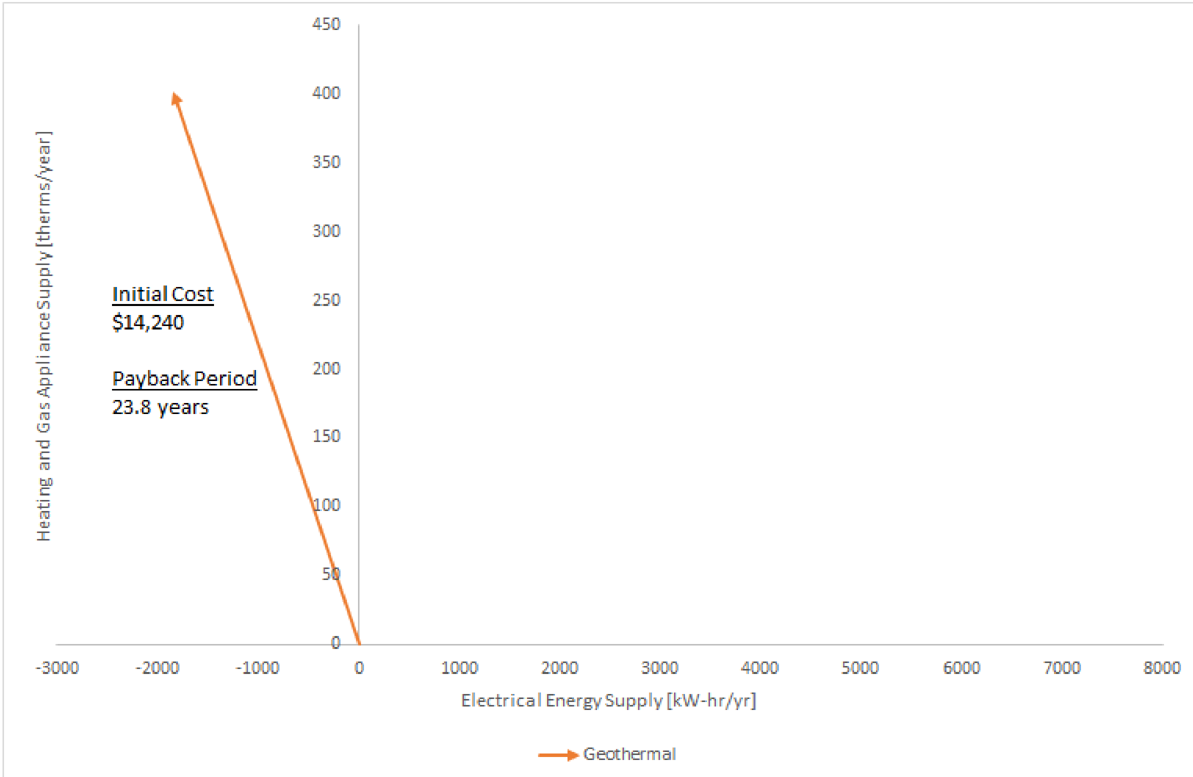

Figure A7.A8 Geothermal energy change

The rest of the energy needed was electricity. Solar was the first thing we considered and researched. The team first considered electrical power generation with wind turbines. It was decided wind turbines were not feasible because they are very expensive and there are also zoning laws for structures that tall. They also had payback periods much larger than those of the suggested electrical power generation method.

During the team's initial visit to the home, the roof was observed. The front of the house was on the south side of the house, but there are two large trees shading most of it. The roof over the garage does get a large amount of sun over the course of a day, so this would be the best location for the solar panels. Team 7 discovered that there was a lot of costs for installing solar panels besides the cost of the panels. Racking costs, installation costs, inverter costs, and costs to connect to the grid also needed to be considered. There are, however, rebates for buying solar panels, which alleviated the costs slightly. The team found many different options for solar panels. Solar panels with a lowest cost per kW and lowest cost per area were desired. The team did many calculations for payback periods on a solar panel system that would supply enough energy for its lifetime. The final payback period graph can be seen in Figure A7.A9.

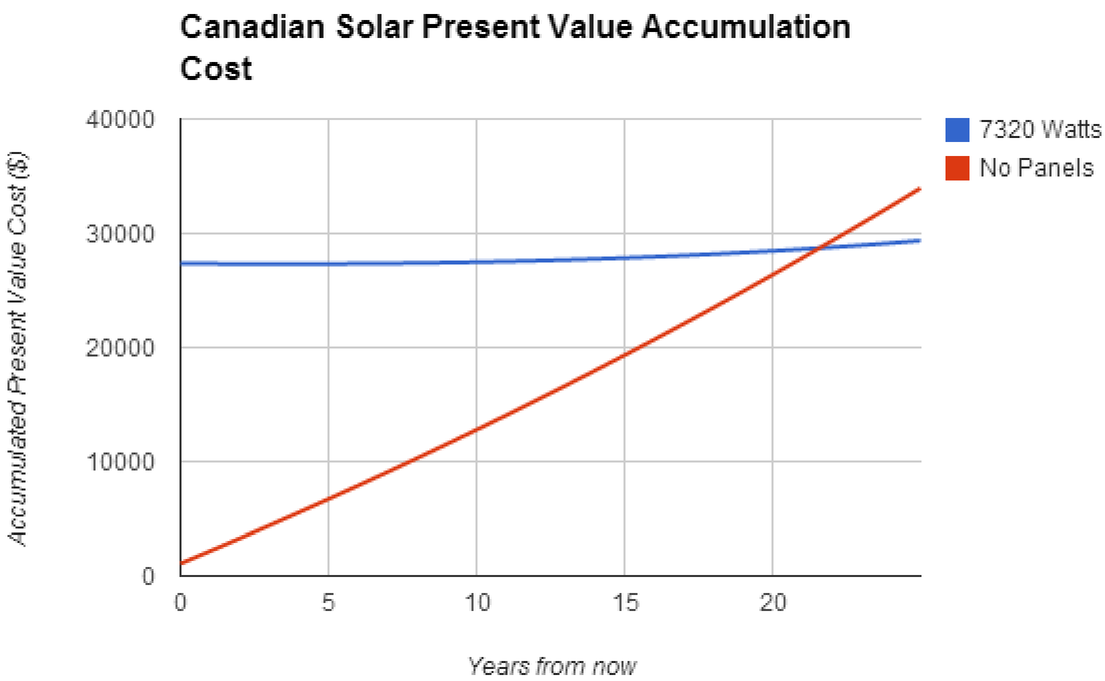

Figure A7.A9 Initial cost and payback period of a considered solar panel

A great understanding of solar panels was developed from this. In the end, the group used a program that the rest of the teams used called SAM. This program takes into account all the considerations mentioned earlier. The team was able to select a certain solar panel system through this program. Figure A7.A10 shows the energy production from the solar panels.

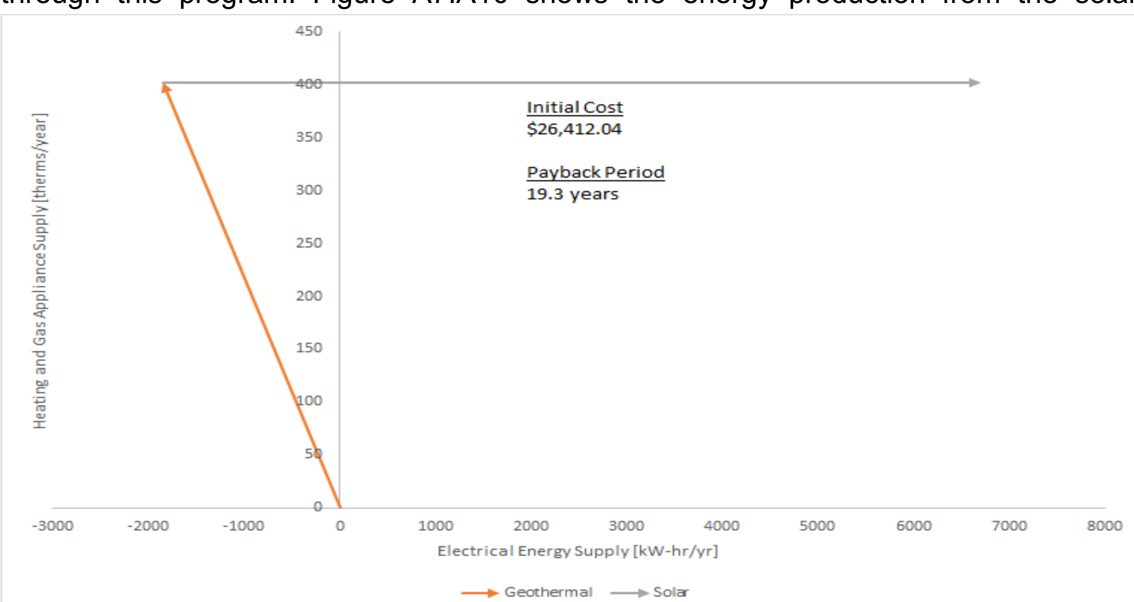

Figure A7.A10 Solar panel energy production

The energy reductions and production recommendations were combined on the same graph. This can be seen in Figure A7.A11. Since the arrows touch (energy usage equals energy production), the team was successful in achieving net-zero for this home.

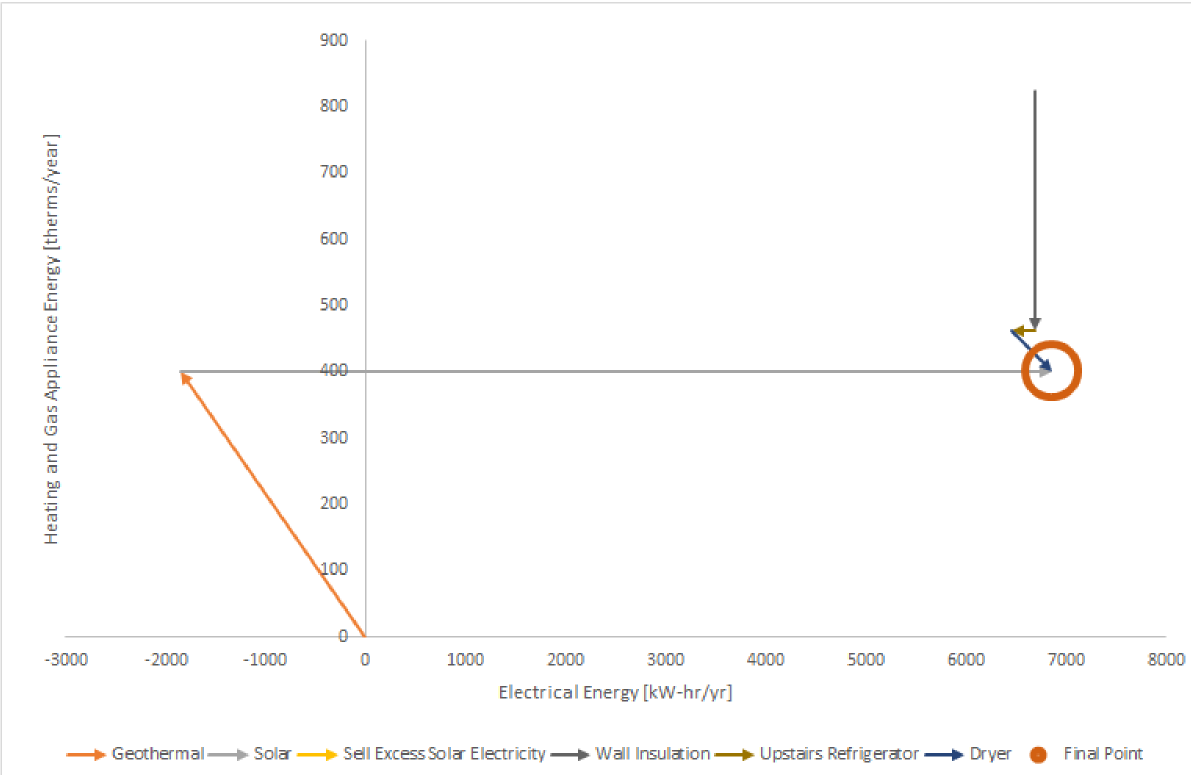

Figure A7.A11 Achieving Net-zero

In order to make all of these improvements, it will cost $44,822 and the payback period is 18.2 years.

Acknowledgements and Data

Acknowledgements

The design team would like to thank Professor Matthew Heun for his expertise and guidance throughout this project. Also, Chuck Holwerda for supplying kill-a-watt meter for analyzing the electrical consumption of different components around the house. Finally, the group wants to thank the Koetje family for allowing the team to analyze their home and their energy usage history. The team is thankful for the Koetjes willingness to spend time meeting with the group and attending the monthly update presentations. Without all of these people, the project could not have run as smoothly as it did.

Data

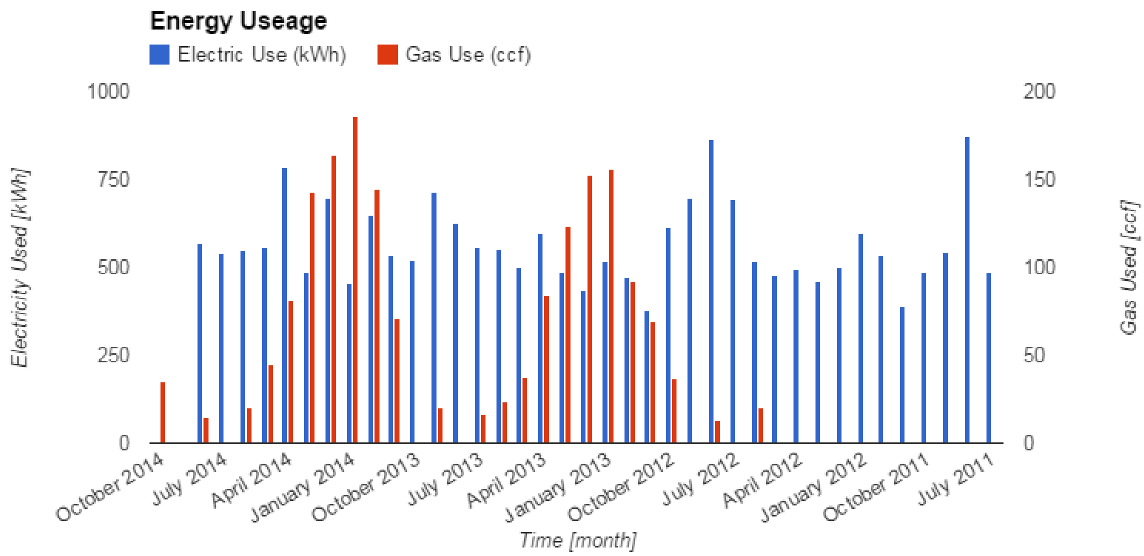

Figure A7.A12 Initial Energy Usage by Month

Table A7.A1 Breakdown of Energy Usage Measured by Kill-A-Watt Meter

Appliance	kWh	Hours with KWh Meter	kWh/yr
Fridge	2.52	31.55	79.5
Microwave	0.28	43.78	12.3
Toaster	0.12	31.05	3.7
TV	0.62	74.317	46.1
Washer	0.97	65.75	63.8
Dryer	0.31	36.95	11.5
Desktop	0.66	33.77	22.3
Chest Freezer	1.29	20.8	26.8
Downstairs Fridge	1.98	27.92	55.3

Table A7.A2 Payback Period of Suggested Renovations

Suggested Renovation	Payback Period (yrs)
Insulation Installation	1.97
Electric Dryer	246.5
Upstairs Refrigerator	18
Downstairs Refrigerator	20
Washer	87
Induction Stove	62.7

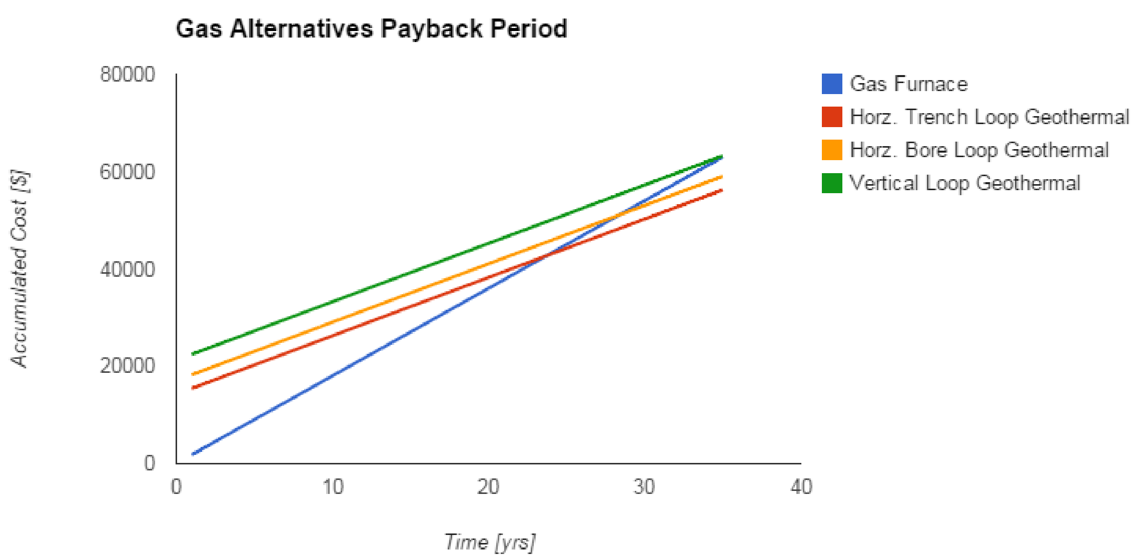

Figure A7.A13 Payback Period for Geothermal Alternatives

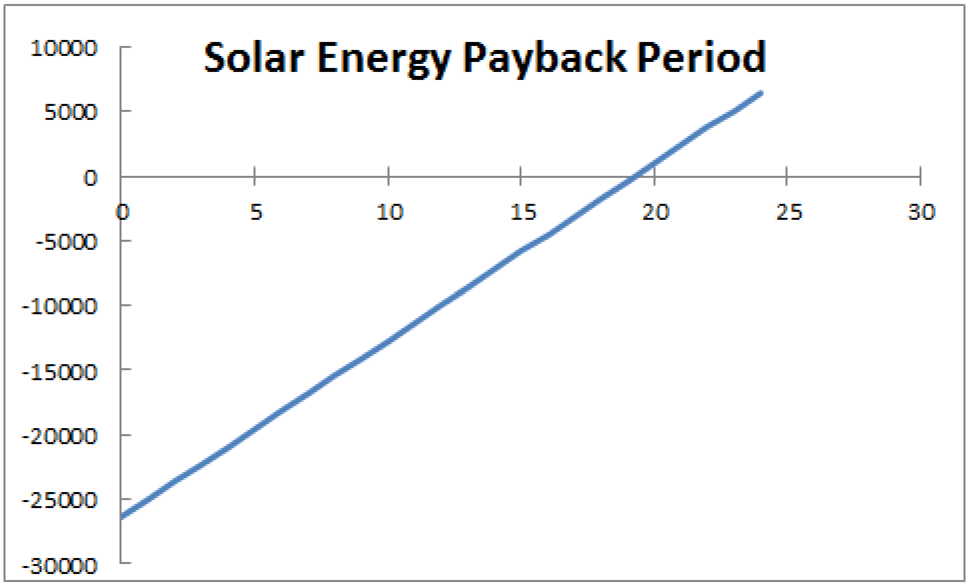

Figure A7.A14 Payback Period for Solar Panels

Appendix C8

Net-Zero Analysis of the Newhof Home

Team 8: Ryan DeMeester, Jordan Newhof, Wes Richards, Josh VanderByl
Client(s): Meribeth Newhof
ENGR 333: Thermal Systems Design
Dr. Matthew Kuperus Heun: Calvin College Engineering Department
December 16, 2014

Abstract

The goal of this ENGR 333 project was to determine if it was possible for the Newhof home to become net-zero, meaning that they pay zero dollars per year to the energy companies. The design team discovered that it could be done by a series of steps. First changes could be made to reduce the energy in the home by replacing the incandescent lights in the home and by removing the air conditioning unit. Next, a solar panel array in combination with a 5 kW wind turbine could offset the electricity usage of the home. The natural gas used was then offset by the installation of a geothermal heat pump to heat the air and water, using heat from the ground and electricity. These improvements to the home allow it to become net-zero, but also will not be paid back by the savings of the new system during its lifetime. The design group also provided the customer with their own recommendation of what they should do in terms of home improvement to save on their energy bills without investing too much money up front.

Technical Memo

Objective

The net-zero homes project on which this team worked throughout the semester was designed to provide you, as the customer, a recommendation on whether or not pursuing a net-zero home would be a wise decision. From an environmental standpoint it would be great if every home would take the steps to become net-zero, but the economic benefits are often a lot harder to see. Our goal in this report is to accurately describe the steps we took in analysis, and then provide clear reasoning for our recommendations.

Procedure

In order for our design team to come up with a design that would work for the home, we took a four step process. In short the steps were as follows: Identification of energy usage, energy reductions, energy production options, and economic analysis to determine feasibility. Let's begin with the identification of energy usage in your home.

The team obtained three years of energy (electricity and gas) data from Mr. Tom Newhof at the beginning of the semester. This data was plotted and analyzed to determine usage averages and the costs associated with usages. Plotting the data was helpful in identifying the baseline average usage for electricity and gas. This helped differentiate what components in the home were contributing the most to the overall usages in the home. The energy bills coupled with the program *Home Energy Saver* gave the team an accurate breakdown of where the energy was being used in the house. This allowed us to move forward to the next step of determining the areas where energy usage could be reduced.

The team toured the home earlier in the semester to determine the performance specifications of items in the home such as the refrigerator, freezer, furnace, air conditioner and the lighting. The first step in reduction came from lighting improvements in the kitchen, living room, dining room and front hallway. These fixtures all use incandescent bulbs and are in high usage areas of the home, so they contribute a large amount to the daily electricity usage in the home, especially in the winter months (see Figure 1, Appendix 1) during which time the lights are on for a longer time. To reduce consumption GU 10 Cree LED bulbs are recommended for the client. The reductions from using these bulbs may be found in Table 1 in Appendix 2. The type of bulbs used may be seen in Appendix 2. Another area in which reductions could be made was in the natural gas usage of the home. Currently the home has a very inefficient furnace and inefficient fan motor in that furnace. To get the home to net-zero the gas usage in the home would have to be reduced to zero or electricity production would have to become incredibly high in order to offset the energy-dense natural gas. This caused us to look into ways of heating with electricity instead of gas. The only viable option for a house of this size was a geothermal heat pump system. The size of the system was sized for the heating requirements of the previous furnace, and the hot water needs of the home. The system eliminated the need for any natural gas along with the electricity used by the air conditioning system. In order to make up for the reduction in natural gas the heat pump uses electricity to heat the home. This would add an additional 8000 [kW-hr] of electricity needed a year. These two improvements are the only two reductions the team recommends for achieving net-zero status. Upgrading your appliances is not recommended unless you are unsatisfied with the performance because the electricity savings will not make upgrading worth it within the lifespan of them. Knowing how much energy could be saved told us how much would now need to be generated.

Even with the reductions to energy usage the amount that needs to be generated is quite a bit. There are two generation options for your home are: solar PV panels and a wind turbine. The solar panels and turbine were selected and sized using an NREL (Nation Renewable Energy Laboratory) software package. These two, when used together, would be able to produce the needed electricity for your home. The production information for both of these generation options are found in Appendix 4 and the investment required may be seen in Table 1 below.

Analysis

To determine whether or not these improvements should be pursued in your home we performed a cost benefit analysis. What we found was that the investment to become net-zero was going to be incredibly high. The costs of the improvements for the net-zero design are highlighted below in Table 1. The pricing for the geothermal system is not an exact number, but is a very conservative estimate based on installation costs of similar systems. The rebates shown below come from the Residential Renewable Energy Tax Credit courtesy of the U.S. Department of Energy[2]. The rebate states that "A taxpayer may claim a credit of 30% of qualified expenditures for a system." The rebate can be applied to the heat pump, the solar panels and to the wind turbine.

Table 1 – Net-Zero Improvement Investment

System	Investment
Lighting	$ 195.00
Geothermal Heat Pump	$ 30,000.00
Solar PV System	$ 37,000.00
Wind Turbine	$ 35,500.00
Rebates	$(30,750.00)
Total Investment	$ 71,945.00

The initial investment for the upgrades is substantial and the payoff period for the new system is longer than the expected life of the system. Also due to residential restrictions in your neighborhood the installation of the wind turbine is not allowed. For these reasons we do not recommend pursuing a net-zero design.

Recommendation

As a design group our recommendation is to pursue some of the improvements that were mentioned before, in order to save on your energy bills and increase the selling value of your home. These improvements include installing LED lighting, the solar panel array and a new high efficiency furnace (shown in Appendix D). This plan is a much more affordable option than the previous one but it still provides you the owner with considerable savings over the course of the year. This option is a much better alternative than the net-zero design for the following reasons:

1) The existing furnace is very inefficient and is nearing the end of its useful life
2) Furnace replacement is relatively cheap compared to heat pump installation
3) Natural gas prices are low enough to extend the heat pump payback period beyond its useful life
4) There are no other generation options to make up for the added electricity of the geothermal system because wind generation isn't an option

[2] http://energy.gov/savings/residential-renewable-energy-tax-credit

Appendices

1. Home Assessment
   A. Energy Needs

2. Electricity Reduction
   A. Lighting

3. Natural Gas Reduction
   A. Geothermal Heat Pump

4. Energy Production
   A. Solar Photovoltaic
   B. Wind Turbine

5. Furnace Replacement

6. Total Investment Costs

7. Overall Calculated Data Values

8. Energy Production and Consumption Overlay Graph

9. Financing Options and Additional Information

1. Home Assessment

The team's first goal was to take a house visit to the Newhof house and assess their energy needs. The team looked at the layout of the house, recorded the location, quantity, and type of light bulbs used within the house. The different types of appliances in the house were recorded as well the size and number of windows in the house. Previous records of gas and electricity bills were presented to us by the customer as well.

A. Energy Needs

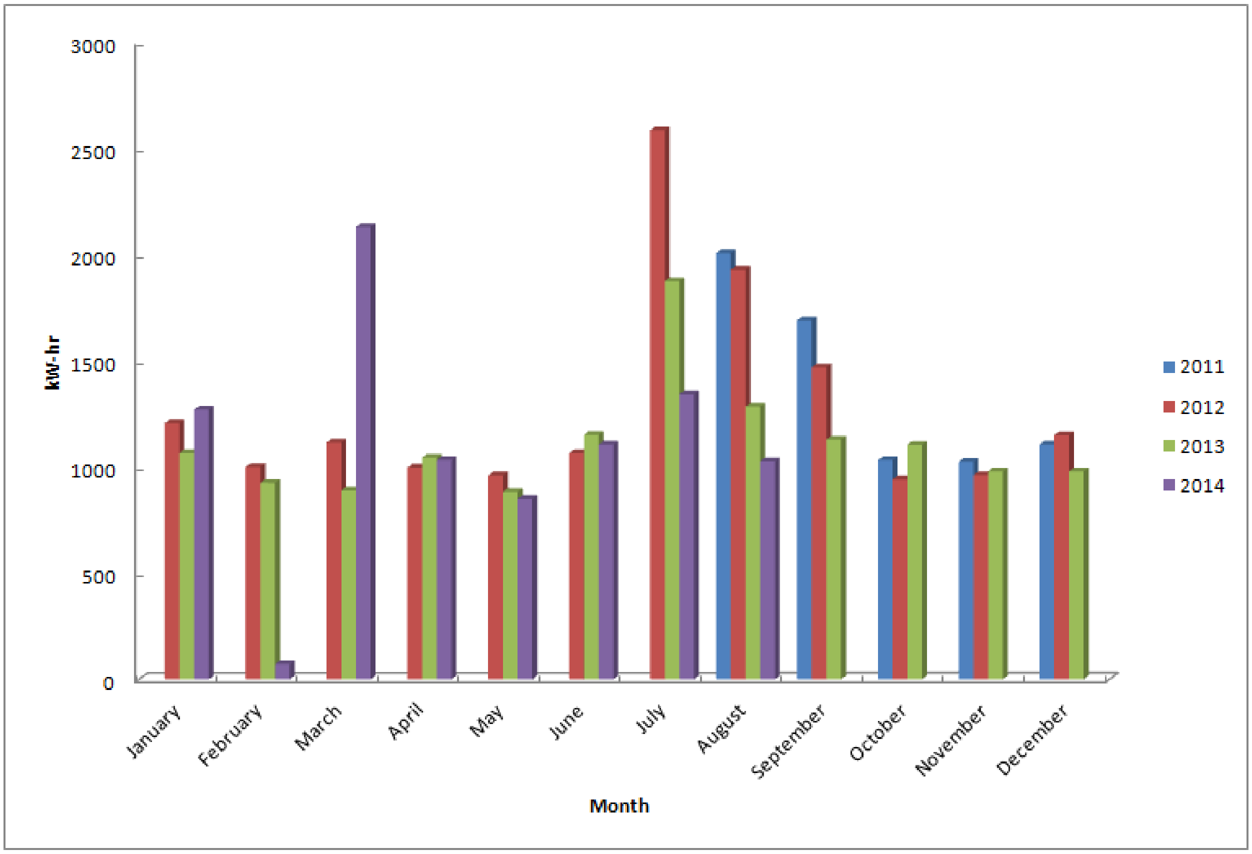

Figure 1 - Monthly Electricity Usage

As you may see in Figure 1 above, electricity needs dramatically increased during the summer months and leveled out throughout the rest of the year. This was due to the fact that the air conditioning unit was run more often during the warmer summer months. Another fact to point out was that the Newhof house decided to run their furnace fan continuously throughout to provide circulation and increase air quality. This caused an increase in electricity usage during every month.

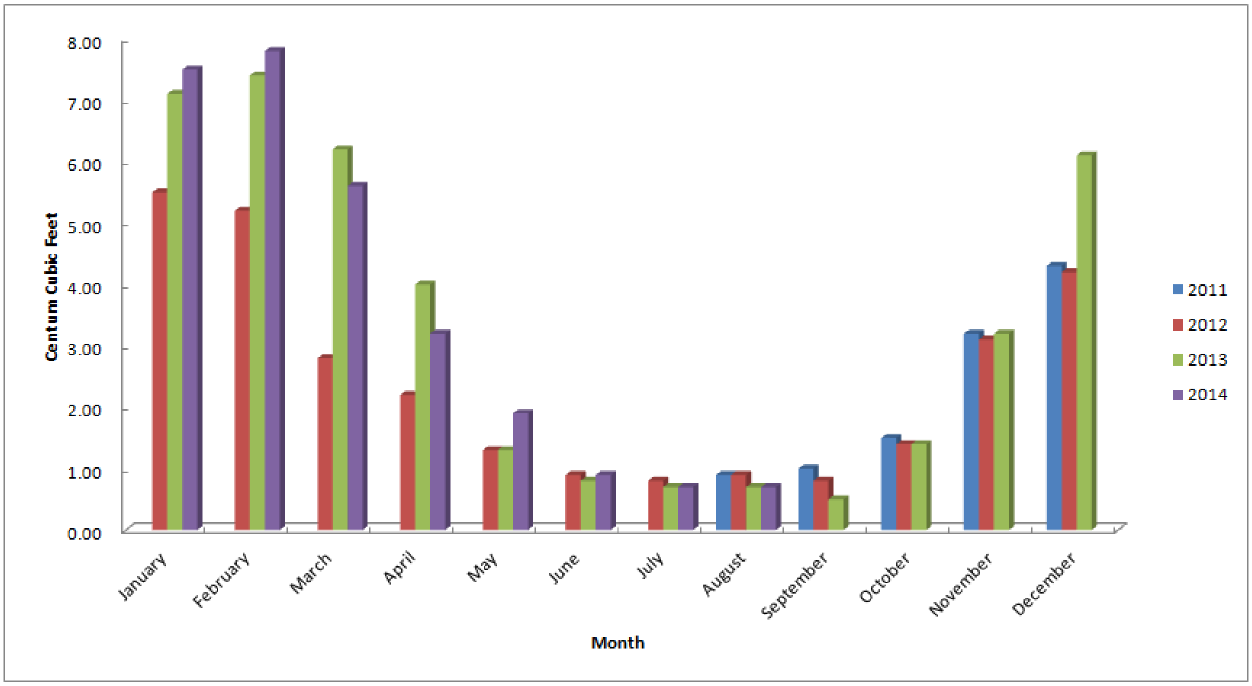

Figure 2 - Monthly Gas Usage

As seen above in Figure 2, the monthly gas average shows an opposite trend compared to the monthly electricity usage. During the summer months the amount of natural gas consumed was significantly less than during the winter months. This is due to the fact the furnace was running much more during the winter months to provide space heating required by the homes occupants.

2. Electricity Reduction

A. Lighting

In order to reduce the amount of electricity used in the house several options were considered such as lighting. It was observed that the majority of lights used in the house were incandescent light bulbs. It was decided that these light bulbs would be switched out with CREE LED and standard base LED light bulbs seen in Figure 3 and Figure 4 below.

Figure 3 - GU 10 LED Bulbs

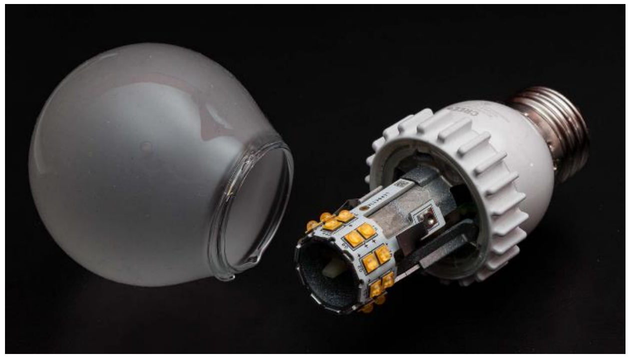

Figure 4 - Standard Base LED Bulbs

The potential location for LED bulb replacements and their associated cost savings may be seen below in Table 2.

Table 1 – Light Location and Savings

Location	KW-Hr/Year Saved	$ Saved
Kitchen	679	81.48
Living Room	149	17.88
Family Room	315	37.8
Bathrooms	101	12.12
Upstairs Hallway	315	37.8
Total	**1559**	**187.08**

Overall it would give a calculated energy savings of 1559[kW-hr/yr] with a cost savings of 187.08[$/Year]. This would give our home a new electricity consumption of 11,641[kW-hr/yr]. The capital cost required in order to implement this change would be $195.00.

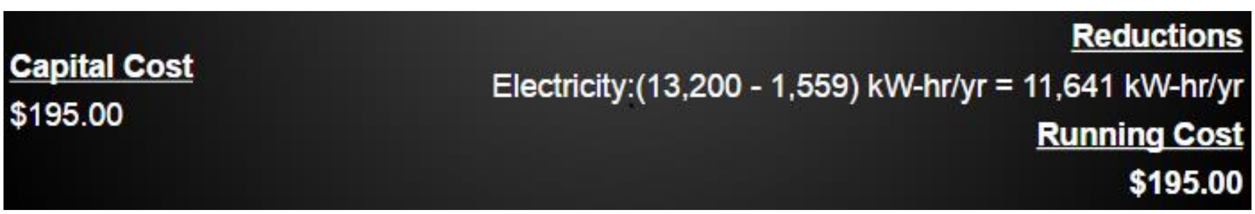

Figure 5 - Light Energy Reductions and Capital Cost

3. Natural Gas Reduction

A. Geothermal Heat Pump

In order to eliminate the use of natural gas for the home a geothermal heat pump was decided upon. A horizontal heat pump was decided to be appropriate in which a simple diagram may be seen in Figure 6 below.

Figure 6 – Horizontal Geothermal Heat Pump

By implementing a geothermal heat pump would reduce the natural gas consumption to zero, but would require an extra 8000 [kW-hr/yr] annually. The geothermal pump would also reduce the current electricity consumption by 3000[kW-hr/yr] annually. The cost associated with installing a heat pump would be $30,000. A 30% tax incentive of $10,000 would also be issued. These numbers may be seen below in Figure 7.

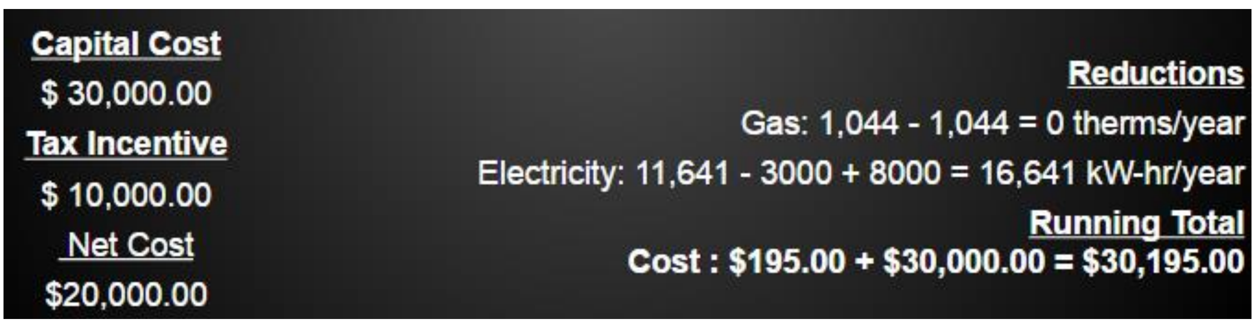

Figure 7 – Geothermal Energy Reductions and Capital Cost

4. Energy Production

A. Solar Photovoltaic

In order to produce the necessary electricity needed to make the Nehof home net zero, a solar panel array was explored. The house would require 27 panels in total with 18 of those panels facing to the south and 9 facing north. This would give an annual calculated output of 9,500[kW-hr/yr] annually. In Figure 8 seen below, an estimated monthly kW-hr potential may be seen.

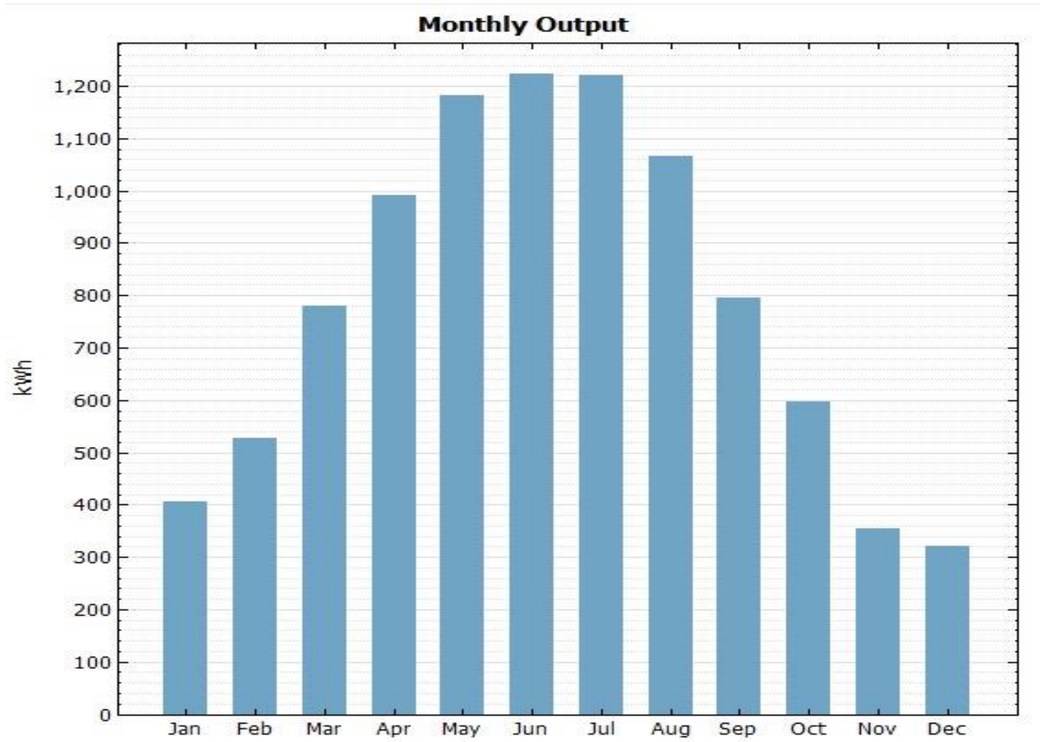

Figure 8 - Potential Solar Array Monthly Output

This would incur a capital cost of $37,000 with a tax incentive of $11,100. Figure 9 may be seen below for an overview of energy and cost savings.

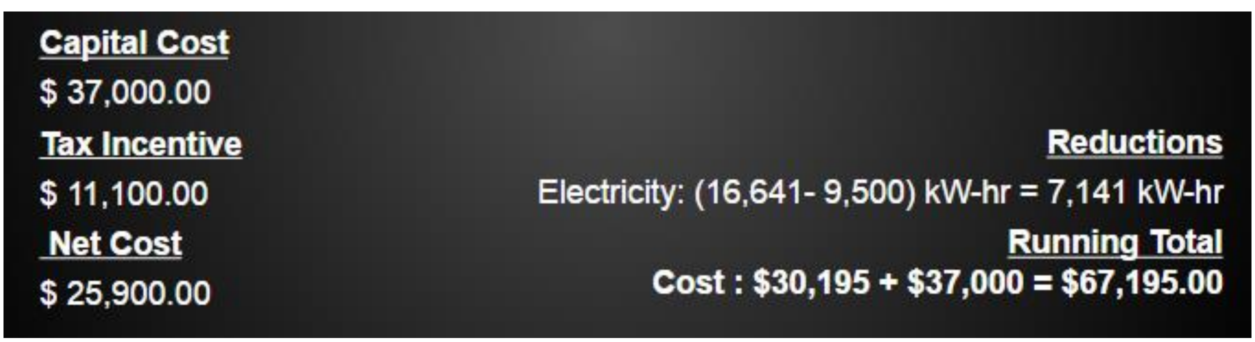

Figure 9 - Solar Array Energy Reductions and Capital Cost

B. Wind Turbine

To make up the rest of the electricity needed to make the Newhof home net zero a wind turbine was decided upon. In order for a wind turbine to be installed certain regulations would need to be overcome. The estimated monthly output in kW-hr may be seen below in Figure 10.

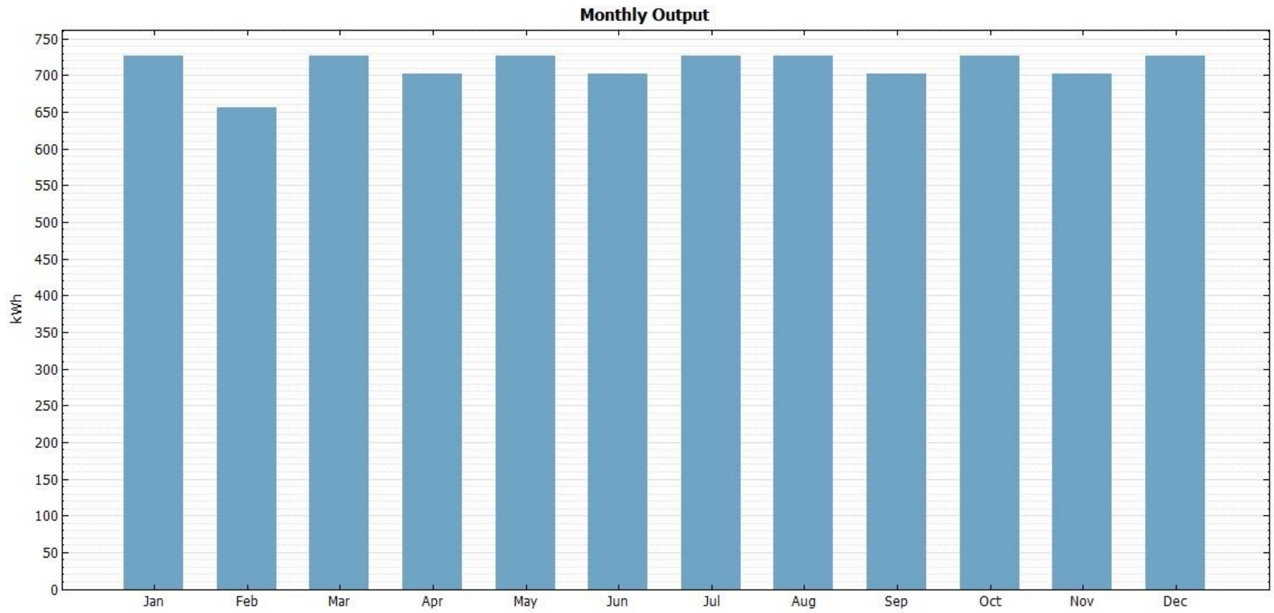

Figure 10 - Potential Wind Turbine Monthly Output

In order to install a wind turbine it would have a capital cost of $35,500 with a tax incentive of $10,650. This turbine would provide 7500[kW-hr/yr] annually. Figure 11 may be seen below for an overview of energy and cost savings for the wind turbine.

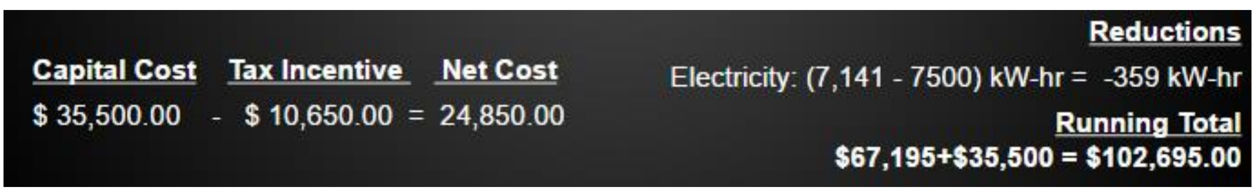

Figure 11 - Wind Turbine Energy Reductions and Capital Cost

5. Furnace Replacement

Our team recommended the Newhof house replace their current furnace with a 90,000[BTU/hr] AFUE furnace. This would cost approximately $2,200, but would save 370 [therms/yr] annually in natural gas. This furnace has a variable fan to increase efficiency and would have a simple payback of 5 years. An image may be seen below in Figure 12.

Figure 12 - 90,000 [BTU/hr] 95% AFUE Furnace

6. Total Investment Costs

The overall investment costs may be seen below in Table 1 in the text. These would be the costs associated if all of the systems and lighting options were implemented. A total capital investment cost of $71,945 would be required for these upgrades.

7. Overall Calculated Data Values

Table 4 - Energy Need, Savings, and Supply

Initial Energy Need	*Heating and Gas Appliances[therms/year]*	*Electricity [kW-hr/yr]*	*Home size[sq ft] (living area)*	*Number of People*
	1043.9	13200	3000	5
Initial Energy Supply	*Heating and Gas Appliances*	*Electricity [kW-hr/yr]*		
	0	0		
Energy Savings (Step 1)				
Intervention	*ΔHeating and Gas Apliance need[therms/year]*	*Δelectricity need*	*Investment Cost[$]*	*Annual Saving[$/year]*
LED bulbs	0	1559	195.00	127.84
Insulation	0			
Gas to Elect Water heater	0	0		
Air Conditioner	0	3000		
Geothermal	0			
Total Energy savings	0	4559		
New Energy Need	1043.9	8641		
Energy Supply (Step 2)				
Intervention	*ΔHeating and Gas Appliance need[therms/year]*	*Δelectricity need*	*Investment Cost[$]*	*Annual Saving[$/year]*
Geothermal	1043.9	-8000	25000.00	
Solar		10000	37200.00	
Wind		7000	34000.00	
Sell Elect, buy gas	0	-359		43.08
Δ Energy Supply	1043.9	8641		
New Energy Supply	1043.9	8641		
Net Energy Consumed	0	0		

8. Energy Production and Consumption Overlay Graph

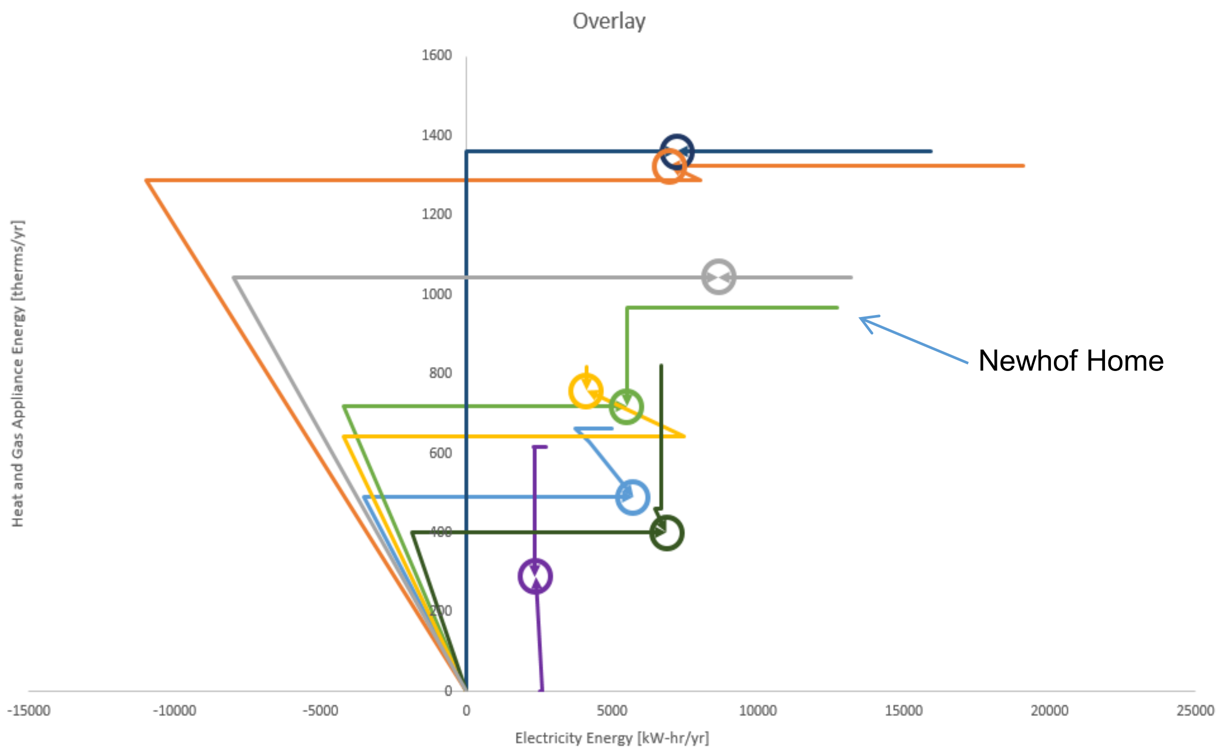

Figure 13 - Net Zero Homes Energy Production and Consumption

As seen in the above overlay plot, Figure 13, the Newhof home's consumption, reduction, and production needs may be seen graphically. The Newhof house is represented by the grey line in which the reduction and production lines meet. This can be seen by the arrows touching in the middle of the circle meaning the home has reached net zero status.

9. Financing Options and Additional Information

Additional financing options and information that the group researched may be seen below in Figure 14.

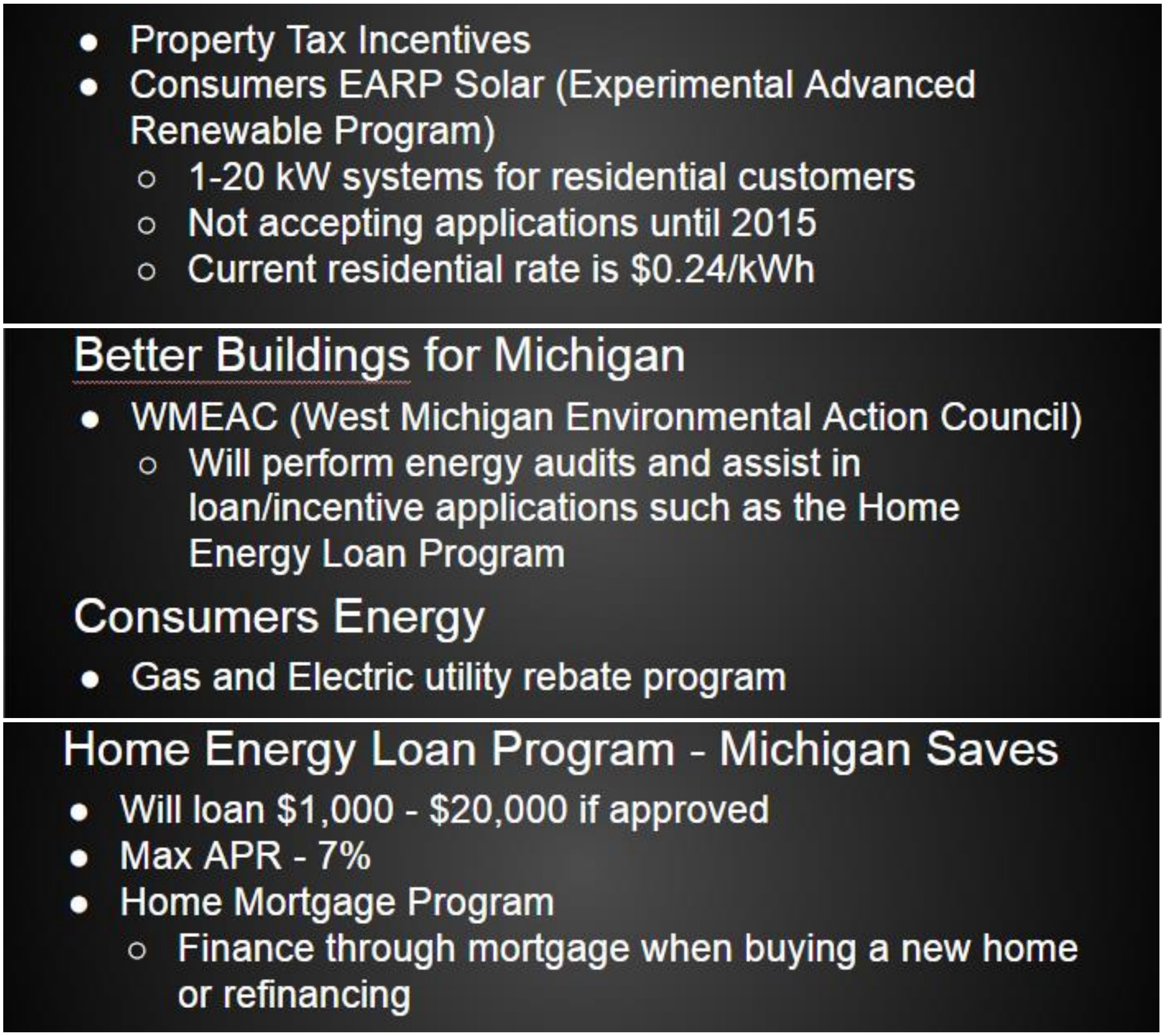

Figure 14 – Additional Financial Options and Information

Acknowledgements

We would like to acknowledge and thank the Newhof family for letting us access their house, their energy bills and their time in order to provide us with first-hand design experience and we are incredibly thankful for that.

Net-zero Homes Project: Problem Statement

Fall 2014
ENGR333ab
Calvin College
Prof. Heun

Residential consumption accounts for a significant fraction (22%) of all energy in the US. (See Figure 1 below.)

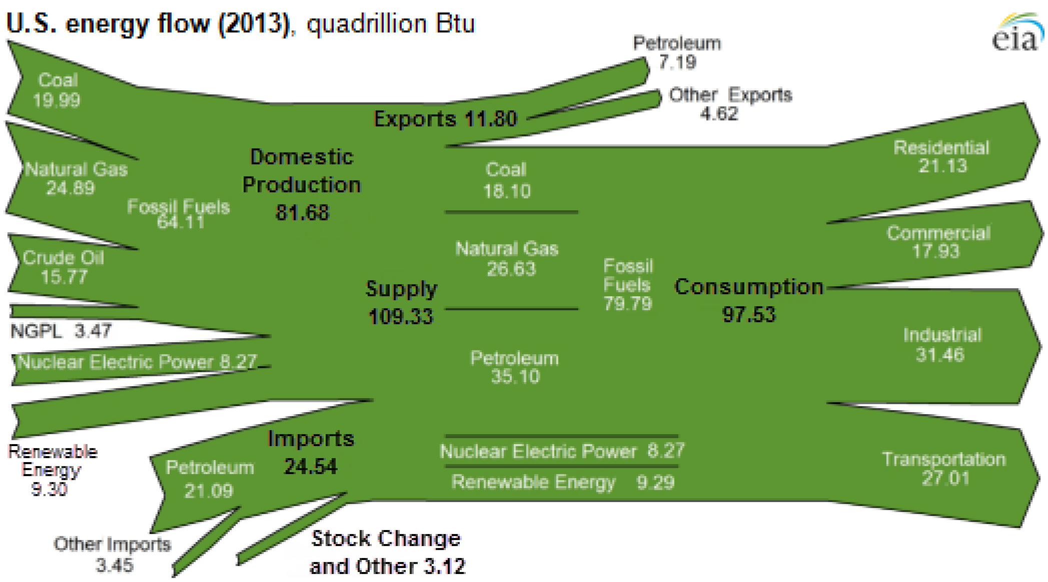

Figure 1. US Energy Supply and Consumption.
(Source: http://www.eia.gov/todayinenergy/detail.cfm?id=16511&src=Total-b1)

The *net-zero building* movement is an attempt to reduce the energy consumption of residential and commercial buildings. Net-zero buildings have equal energy production and consumption over the course of a year.

Your question for this semester is:

What would it take for a home in Grand Rapids to become net-zero?

To answer the primary question, you will find the need to explore several additional questions, including, but not limited to:

- What energy generation technologies are available to homeowners in Grand Rapids?
- What energy savings technologies should be employed to achieve net-zero status?
- How can energy production and savings technologies be implemented in homes?
- How can energy generation technologies be financed?
- How can energy savings be financed?

You will pursue this question in groups of 3–4 students each. Your response to the main question ("*What would it take…*") should take the form of a single report containing comprehensive and accurate information on your approach to achieving a net-zero building in Grand Rapids. A single final written report must be submitted. Both sections (ENGR333a and ENGR333b) must contribute to the report. A suggested outline is a main technical memo with one appendix for each house. Each appendix should be its own technical memo. Each appendix must be thorough and provide the homeowner with enough information to make a wise decision whether to pursue a net-zero home.

The deliverables are:

(a) a final, combined written report for both sections that provides a detailed description of your work during the semester and a recommendation to each homeowner whether to pursue net-zero status for their home,
(b) an Engineering department seminar on **Tuesday, 2 December 2014** at 3:30 (venue TBD).
(c) one poster per group to be presented at the Calvin Environmental Assessment Program (CEAP) conference at 3:30 PM on **Thursday, 4 December 2014** (venue TBD)

Each student must attend either (a) the Engineering Seminar or (b) the CEAP Poster Session.

The final report for the project will consist of:

(a) paper copies of your final technical memo with extensive appendices,
(b) an electronic copy of your final report (.pdf format, one single file) to be posted at http://www.calvin.edu/~mkh2, and
(c) a CD or DVD containing electronic copies of all posters, presentations, programs, and analysis tools that you developed during the project.

You must distribute copies of your final report (all three elements) to all customers and your professor. Final reports are due at the end of the final exam time for ENGR333b (Noon on Tuesday 16 Dec 2014). Each team must send notes of appreciation to each person who provided assistance during the semester.

Prior to the first class meeting each week (typically Monday), each student must submit a weekly timecard that includes

- hours worked on the project
- brief (1 paragraph) description of work accomplished.

Each team is responsible for identifying both a home and a customer for their work. You will do well to ensure that at least one member of each team has a connection to a home to be studied.
Home: Choose a home in the Grand Rapids area that has the following characteristics:

a. easily accessible
b. energy records (electricity and natural gas) are readily available
c. has meaning to one of your group members
d. has an interested person who can serve as the "customer" for your group

Good options for a home include a parent's home of one of your group members, an off-campus house that you're renting, an on-campus home, the home of a Calvin staff member, administrator, or professor, etc.
Customer: Choose a customer:

a. for whom your study will be both relevant and meaningful
b. who can attend in-class progress reports (see **bold events** in schedule below)

Good options for customers include the homeowner or landlord for the home you select.
Please give the attached "Information for Customers" sheet to your customer.

During the first week, your tasks will be to select homes, select customers, and form groups. No more than two students from any single design team are allowed in the same ENGR333 group. Groups are encouraged to share relevant information throughout the semester. Each group must submit a 1-page description of their group, project, home, and customer by **Friday, 5 September 2014** before lecture. The 1-page description must include a photo of your group in front of your customer's home.

After forming groups, an initial task for each group is to develop a schedule of your activities for the semester recognizes the dates of important events throughout the semester. Schedules must be discussed during oral progress reports (see below). Schedules must be coordinated with your customer.

There will be three short, in-class progress reports in the form of oral presentations. There will be a longer in-class final presentation that summarizes the results of the project. Each student must give either (a) a progress report presentation or (b) part of the final presentation. The presentations must be professional quality, must concisely report your progress, and must provide sufficient technical detail for customer, professor, and peer review of your progress. Only 1 student may participate in oral progress reports and 2 students (at most) may participate in the final in-class report.

The in-class progress reports must follow the following outline:

- Status relative to your schedule (and any re-planning that has occurred since your last report)
- Work accomplished since your last report (including technical and cost details)
- Issues or concerns (and plan for addressing them)
- Work planned for upcoming reporting period

The final in-class oral report should not follow the outline above. Rather it should summarize the final technical details of your work, how your technical work was used in the final recommendations to your customer, and the conclusions for your group.

You must bring printed copies (6-up, double sided to save paper) of all in-class presentations for customers and the professor.

Despite the presence of an external customer for your work, the professor will assign final grades (possibly in consultation with customers). Students will be assessed on (a) the quality of their team's report, (b) peer evaluation, and (c) hours worked.

ENGR333
Net-Zero Homes Project Schedule
Fall 2014

Note: bold schedule items will include participation of customers.

Day	Date	Activity
Tue	2 Sep	Project introduction, objectives, deliverables
Fri	5 Sep	Team, homes, and customers due to Prof. Heun at class.
Tue	9 Sep	Project work day (Meet in the classroom for group work)
Tue	**16 Sep**	**In-class group presentations (7 minutes + 2 for questions) Use required outline.**
Tue	23 Sep	Project work day (Meet in the classroom for group work)
Tue	**30 Sep**	**In-class group presentations (7 minutes + 2 for questions) Use required outline.**
Tue	7 Oct	Project work day (Meet in the classroom for group work)
Tue	14 Oct	Project work day (Meet in the classroom for group work)
Tue	**21 Oct**	**In-class group presentations (7 minutes + 2 for questions) Use required outline.**
Tue	28 Oct	Project work day (Academic Advising)
Tue	5 Nov	Project work day (Meet in the classroom for group work)
Wed	12 Nov	Project work day (Meet in the classroom for group work)
Fri	14 Nov	Project work day (Meet in the classroom for group work)
Mon	17 Nov	Project work day (Meet in the classroom for group work)
Tue	**18 Nov**	**Project final presentations (15 minutes + 5 for questions) Report on final results.**
Wed	**19 Nov**	**Project final presentations (15 minutes + 5 for questions) Report on final results.**
Mon	1 Dec	Peer and Project Evaluations due (3:30 PM)
Tue	2 Dec	ENGR Department Seminar 3:30 PM (SB010)
Thur	4 Dec	CEAP Poster Session, 3:30 PM (SB010)
Tue	16 Dec	Final written report due by Noon

Information for Customers
Net-zero Homes Project

Fall 2014
ENGR333, Calvin College
Prof. Heun

Thank you for your willingness to serve as a "customer" for the net-zero homes project in ENGR333.

As you can see from the assignment for this project, the goal is for students to understand what it would take to make a net-zero energy home in Grand Rapids. The students will provide a report to you at the end of the semester that outlines steps that you *could* take in this direction. Students will make no modifications to your home during the course of this project.

The customer role is vitally important for student learning, making the project "real" to the students. By graciously volunteering your time and your home, you will provide the students with a real-world engineering experience that would otherwise have been impossible. As customer, you will support the students by providing checks and balances on their investigations, designs, and reporting, and you should feel free to raise real-world concerns and questions. (E.g., "Will the solar panels you're proposing cause any roof leaks?")

It will be very helpful to the students for you to provide the following:

- Historical energy consumption data for your house, including electricity and natural gas bills
- Access to your home for purposes of assessing energy consumption patterns, options for energy efficiency, and options for energy production. Students will pre-arrange meetings at times that are convenient for *you*.
- Suggestions, but not answers, for improving the energy efficiency of your home, based on your lived experience.

In addition, your presence at the following in-class progress reports will be essential. (Students must complete the table with the time and room number for their section):

		Time	Venue
Tue	16 Sep 2014		
Tue	30 Sep 2014		
Tue	21 Oct 2014		
Tue	18 Nov 2014		
Wed	19 Nov 2014		

Please note that all work on this project should be initiated and accomplished by the students. You are not expected to do any research, design, or report writing.

I have discussed with students expectations of professional conduct at all times. Please feel free to contact me if you have any questions or concerns about the project or the students.

Sincerely,

Dr. Matthew Kuperus Heun
Calvin College
Engineering Department
(616) 526–6663
mkh2@calvin.edu

Peer and Project Assessment
Net-zero Homes Project

Fall 2014
ENGR333
Prof. Heun

Throughout this semester, you performed analyses and worked toward net-zero energy for homes int eh Grand Rapids area. Now, your professor would like your feedback about the process. Part of your grade for the Net-zero project will be determined by the quality of your submission. Your response is and will remain confidential. Peer and project assessments are due at **3:30 PM** on **Monday 1 December 2014** in Prof. Heun's office.

1) Write one paragraph identifying one or two members of the class who performed exemplarily during this project. Provide examples of their supererogatory efforts.

2) Write one paragraph answering these questions: If you put this project on a resume, would you list it as "community service?" Does engineering (as a discipline) value volunteer work and community service? Why or why not?

3) Write one paragraph describing if or how your participation in this project caused you to alter your behavior this semester. Did you see any connections between your own personal behavior and energy efficiency? If you didn't change your behavior at all, describe why not.

4) What nontechnical skills did you learn in the course of this project? Do you expect that these non-technical skills will be relevant to your future work as an engineer? If so, why? If not, why not?

5) Write three paragraphs addressing this question: what are the connections between (a) energy efficiency and (b) the twin challenges of (i) energy resource depletion and (ii) climate change caused by global warming?

6) Write one paragraph detailing your role and contributions to your small group team. Conclude the paragraph by assigning yourself a letter grade for your work on the project. Justify your grade.

7) Write one paragraph each detailing the roles and contributions of the three (or four) other team members. Conclude the paragraphs by assigning a letter grade for your teammates' work on the project. [Total of three (or four) paragraphs and three (or four) individual letter grades.]

8) Write one paragraph indicating any topics relevant to the content of ENGR333 that, in your opinion, would be interesting for future classes to study. Also provide any suggestions for improvements to the structure of this project in future years.

When writing paragraphs assessing yourself and your peers, you may wish to use the following rubric.

Did the individual:

- Research useful information for your group?

- Display punctuality in meeting deadlines?
- Thoroughly complete assigned duties?
- Share equally in work performed by the group?
- Perform work of high quality or did their work often require revision?
- Help direct the group in setting goals?
- Help direct the group in meeting goals?
- Encourage group members to share ideas?
- Display empathy during group discussions and work?
- Listen to ideas from other group members?
- Participate in helping the group work together better?