ME4429 Project #1 - BEopt Project

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Introduction

When designing a building there are plenty of key factors to consider. One of the most important of which is the energy efficiency. No building is perfectly efficient, it is nearly impossible with today's technology. The issue is the energy efficiency of a building is dependent on numerous factors that would be extremely time-consuming to calculate by hand. Fortunately, the software BEot (aka Building Energy Optimization) allows the user to create a rough design of the building and simulate the utility costs and how energy efficient it is. Within this project, we will look at BEopt in-depth to learn what factors affect a home's energy efficiency and by how much.

Background

The National Renewable Energy Laboratory (NREL) in Jefferson County, Colorado publicly released BEopt in 2012 to advance sustainable building practices and promote energy-efficient construction. BEopt was created to fill the void of tools that could evaluate the energy performance of residential buildings. BEopt helps architects and engineers make informed decisions to reduce overall energy consumption. The software utilizes climate data, cost information, and various building science principles in order to create an accurate simulation. The end goal of BEopt is to achieve Zero Net Energy (ZNE) which is the idea that a building can balance its energy needs with that of energy produced by renewable sources such as solar or hydropower. [1] By achieving Zero Net Energy we are one massive step closer to creating a sustainable planet for generations to come.

House 1

The first home we designed is modeled after one of our teammate's own home on Cape Cod. The house is 2214 sqrt ft. The location of the house can be seen in the figures (1) and (2) below.

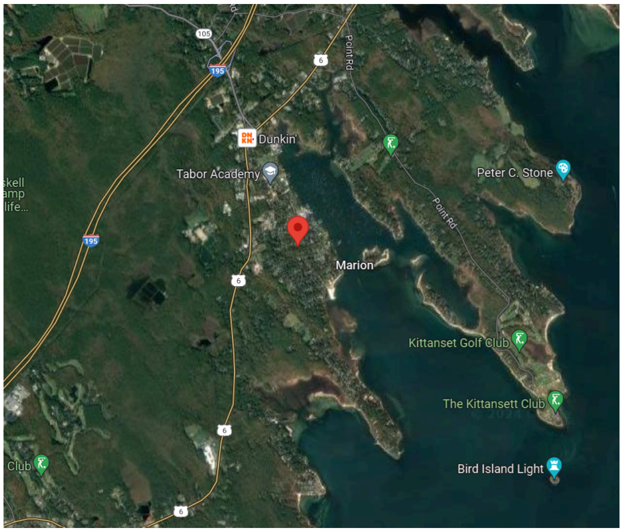
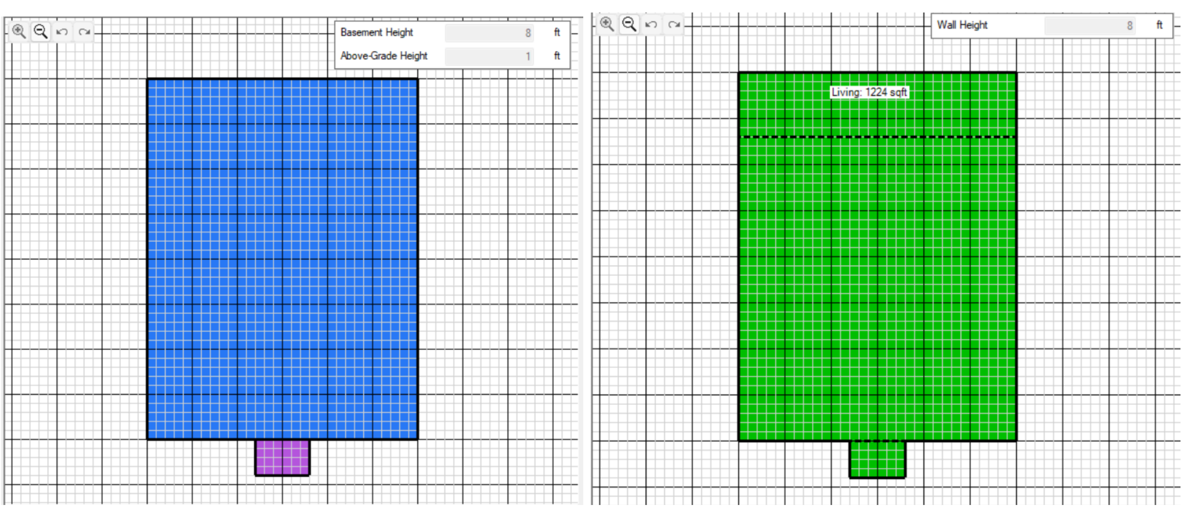


Figure (1): Top geographic location of the house. Figure (2): Top-down satellite view of the home

Floor Plan

The floor plan of this house can be seen in Figure (3) which shows all 4 floors, the basement (top left), 1st floor (top right), 2nd floor (bottom left), and 3rd floor (bottom right) The first floor is made entirely up of 1224 sq. ft in a 30 x 40 room of living space plus a small mudroom. The second is 990 sq. ft. of living space and 210 sq ft. of deck space in the rear of the home. The 3rd floor is made up entirely of a 30 x 33 unfinished attic making 990 sq. ft. Finally the 30 x 40 unfinished basement is a total of 1200 sq. ft.



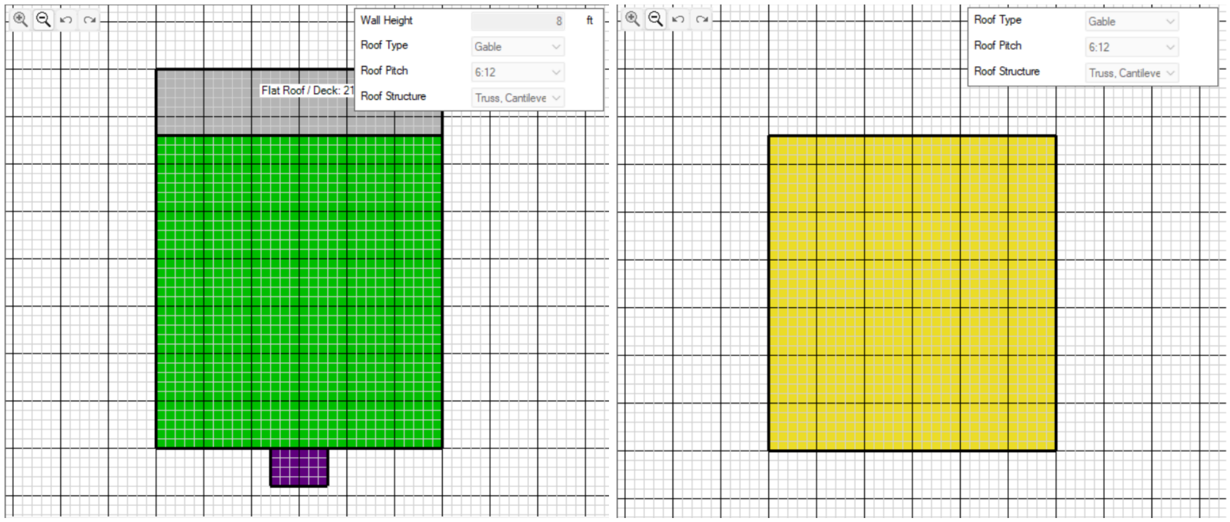


Figure 3: Floor plan for the first house

<u>Input Parameters</u>

When choosing input parameters for this house we made an effort to make it as accurate as possible to the actual home that can be seen in Figure 2. The house has 3 bedrooms and 2 full baths. Table 1 displays the initial input parameters of the home structure itself before making changes to see the effects of different changes.

Table 1: Input parameters for the home itself within BEopt.

Parameter	**Value**
Orientation	West (13)
Neighbors	Left/Right at 20 ft (2)
Wood Stud	R-45 Fiberglass Batt. 24 in o.c. (6)
SIP	7.4 in EPS Core, OBS int (4)
Wall Sheathing	R-12 Polyiso (7)
Exterior Finish	Wood, Medium/Dark (6)
Interzonal Walls	R-13 Fiberglass Batt 2x4 (5)
Unfinished Attic	Ceiling R-60 Fiberglass, Vented (8)

Finished Roof	R-19 Fiberglass Batt (10)
Roof Material	Asphalt Shingles, Medium (2)
Radiant Barrier	None (1)
Slab	Under Slab 4ft R10 XPS (5)
Unfinished Basement	Whole Wall R-6 Polyiso (10)
Carpet	60% Carpet (4)
Floor Mass	Wood Surface (2)
Exterior, Partition, and Ceiling Wall Mass	½ in Drywall (2)
Window Areas	F15 B15 L15 R15 (3)
Windows	Low-E, Double, Non-metal, Arg, L-Gain (9)
Interior Shading	Summer = 0.7, Winter 0.95 (5)
Doors	Wood (1)
Door Area	20 ft (2)
Eaves	3 ft (2)
Overhangs	2ft, First Story, All Windows (3)

Our next set of parameters are the appliances around the home that use electricity or gas. These we expect to be a major factor in our energy consumption, especially considering the home's hot tub. These factors can be seen in Table 2.

Table 2: Input parameters for the appliances in the home within BEopt.

Appliance(s)	**Attribute**
Lighting	20% LED (8)
Refrigerator	Bottom Freezer EF = 19.8 (7)
Cooking Range	Gas (6)
Dishwasher	270 Rated kWh (5)

Washer	IMEF = 1.57 (2)
Dryer	Electric CEF=3.73 (2)
Hot Water Fixtures	1.00 (3)
Plug Loads	1.00 (5)
Extra Fridge	Top Freezer, EF = 15.9 (10)
Hot Tub/Spa Heater	Electric (2)
Hot Tub/Spa Pump	1.0 Efficiency (2)
Gas Fireplace	1.0 Efficiency (2)
Gas Grill	1.0 Efficiency (2)

Below, Table 3 shows the final set of parameters that have to do with home heating and cooling. The choice of climate control options opens up the possibility of a wide range of energy costs. Being in New England the weather is always fluctuating and a good heating and cooling system is required to keep a comfortable temperature year round. For heat, the home has a boiler system running off of natural gas which is set to a rather warm 72 degrees Fahrenheit. When it comes to cooling we are using room air conditioners as well as natural ventilation. Being in New England we do have hot summers but a large portion of the time simply opening the windows for a crossbreeze is enough to cool the house comfortably. When the air conditioners are on though, they are set to 73 degrees Fahrenheit. In Massachusetts, the cooling months are March through October, and the heating months are September through April.

Table 3: Input parameters for the heating and cooling within BEopt.

Heating and Cooling	**Attribute**
Air Leakage	8 ACH 50 (6)
Mechanical Ventilation	Supply (3)
Natural Ventilation	Cooling Months only. 7 days/wk (3)
Central AC	None (1)
Room Air Conditioner	CEER 9.0, 30% Conditioned (5)

Furnace	None
Boiler	Gas 98% AFUE (5)
Ducts	10 % Leakage, R-8 (17)
Ceiling Fan	150 cfm/W (4)
Heating/Cooling Seasons	Heating Sep-Apr, Cooling Mar-Oct (2)
Cooling Set Point	73 F (6)
Heating Set Point	72 F (11)
Humidity Set Point	45% RH (2)
Water Heater	125 F (2)

Initial Results

After imputing all of the parameters, we ran our first simulation in Fall River. This location was the closest to Marion, MA in the BEopt Software. Each utility, such as electricity, natural gas, ect, were set to the national average. We can see in Figure (4) that the home uses a total of 180.3 MMBtu a year. This consumption is primarily made up of heating cots (45.1 MMBtu) and miscellaneous costs (47.4 MMBtu).

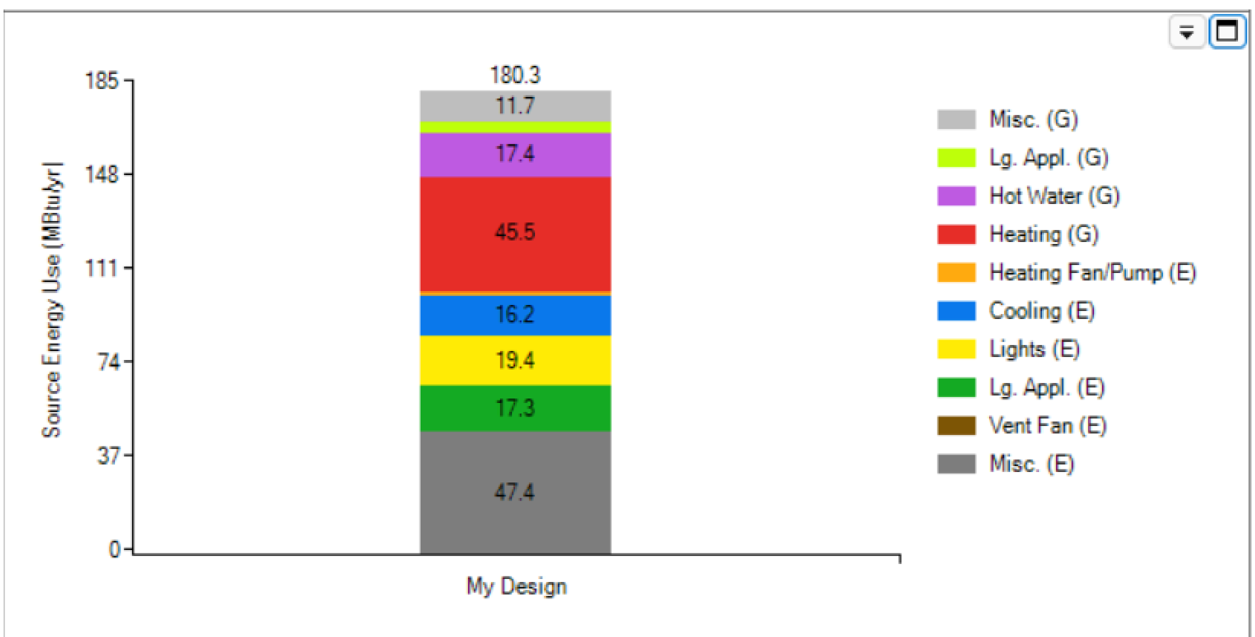


Figure 4: Total Home 1 energy usage

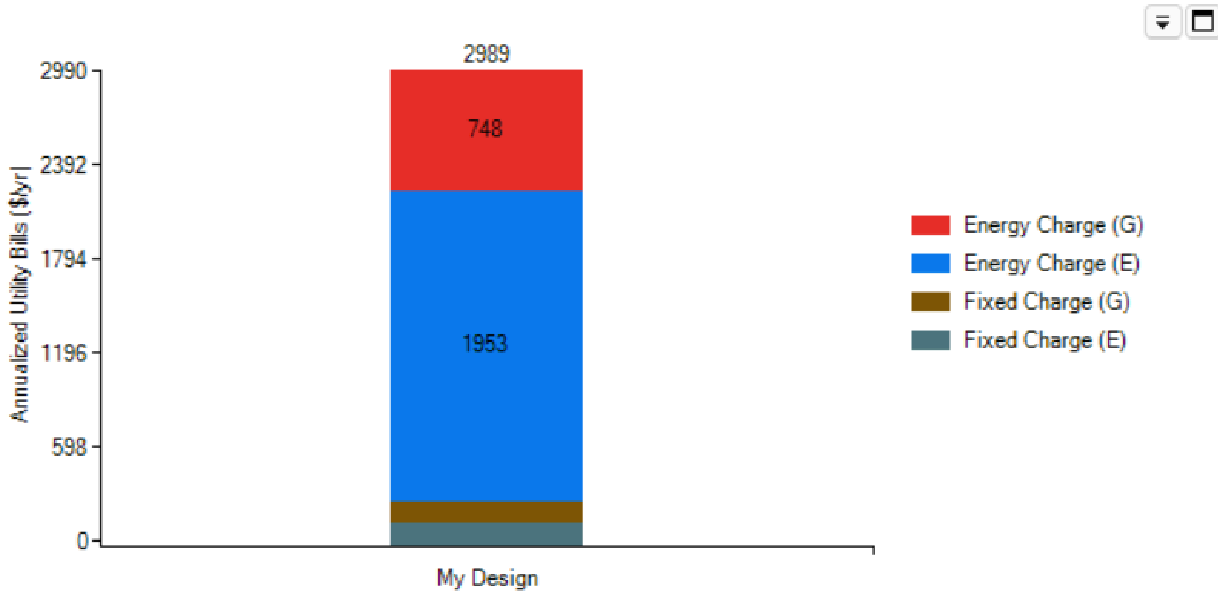


Figure 5: Utility costs per year of Home 1

Figure (5) above shows the utility price per year. The total cost per year for utilities is $2989 a year based on the national consumption averages and our imputed information. This puts us at a monthly average of $249.08. This is significantly less than the Massachusetts yearly average of $3,576. It is important to note that the national average electric bill is $2338 a year. [2]

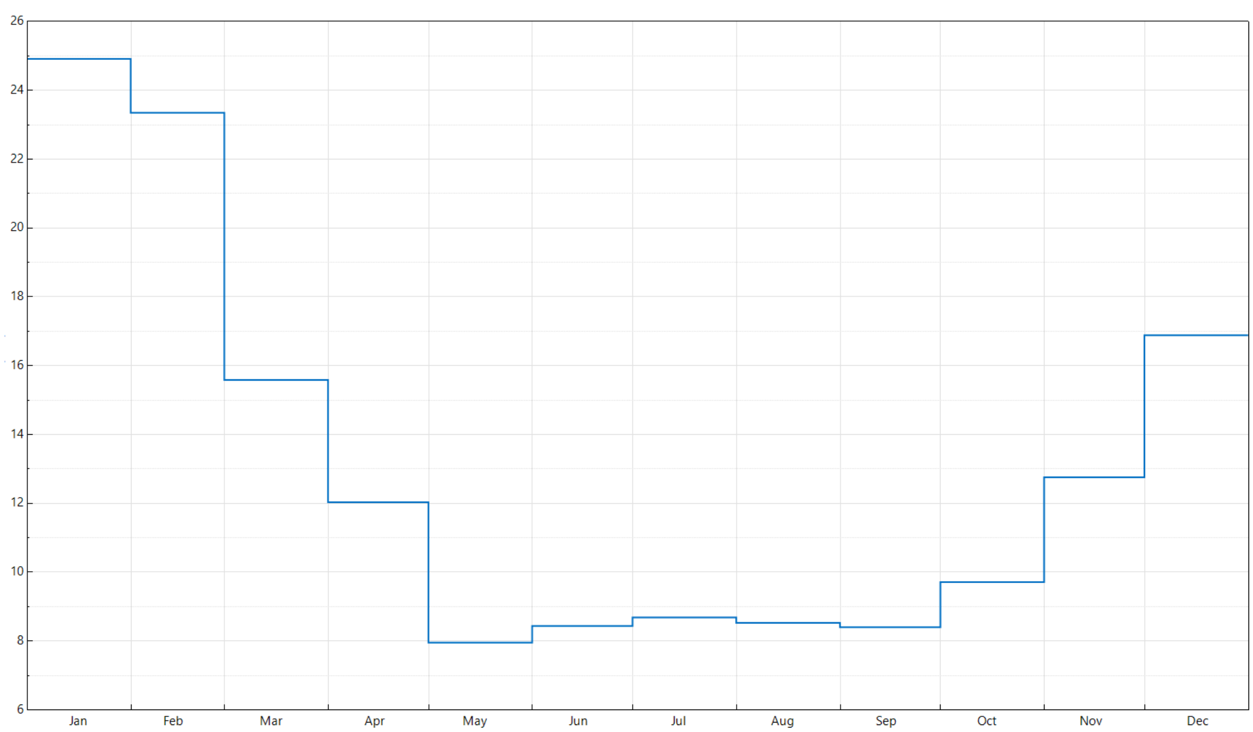


Figure 6: Monthly energy usage of House 1

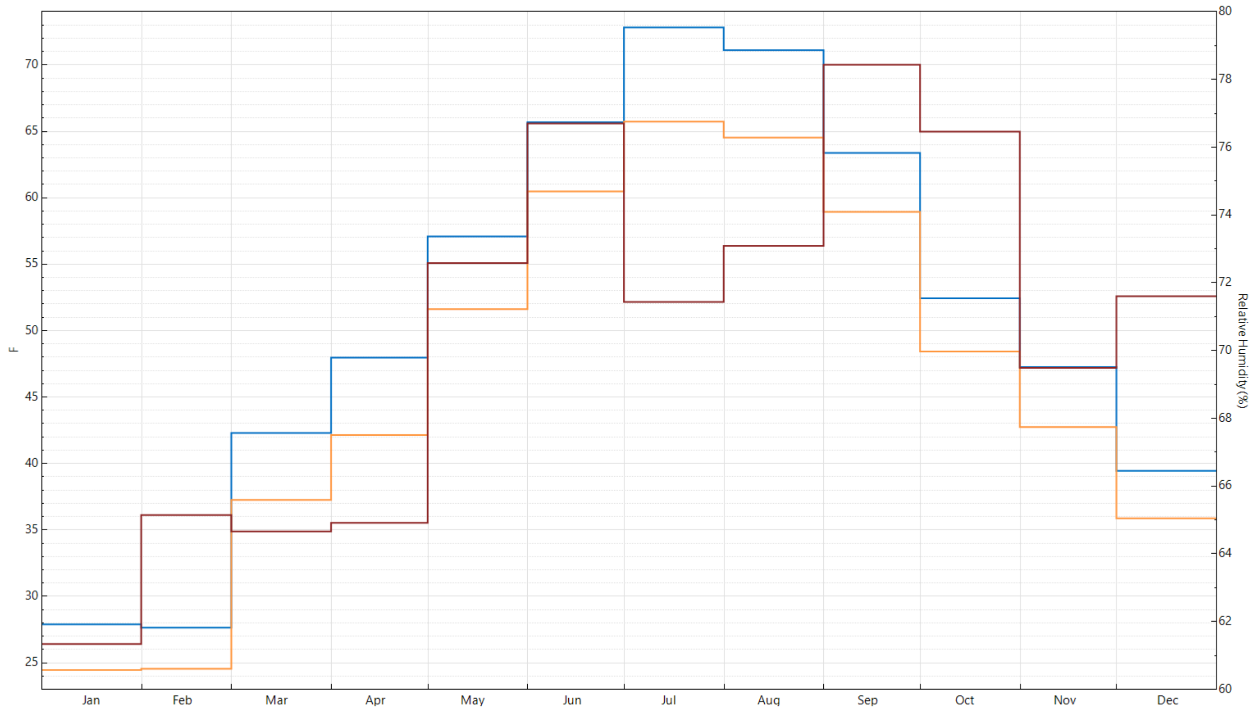


Figure 7: Monthly weather data of Home 1

<u>House 2</u>

Figure 8: Satellite view of the inspiration behind House 2

The second home we designed is a large 7500 sq foot home located in Phoenix, Arizona. The home was designed to be different than the first. Phoenix is about as opposite of a location as you can get within the United States compared to Cape Cod. Arizona is infamous for its hot and dry days and cold nights.

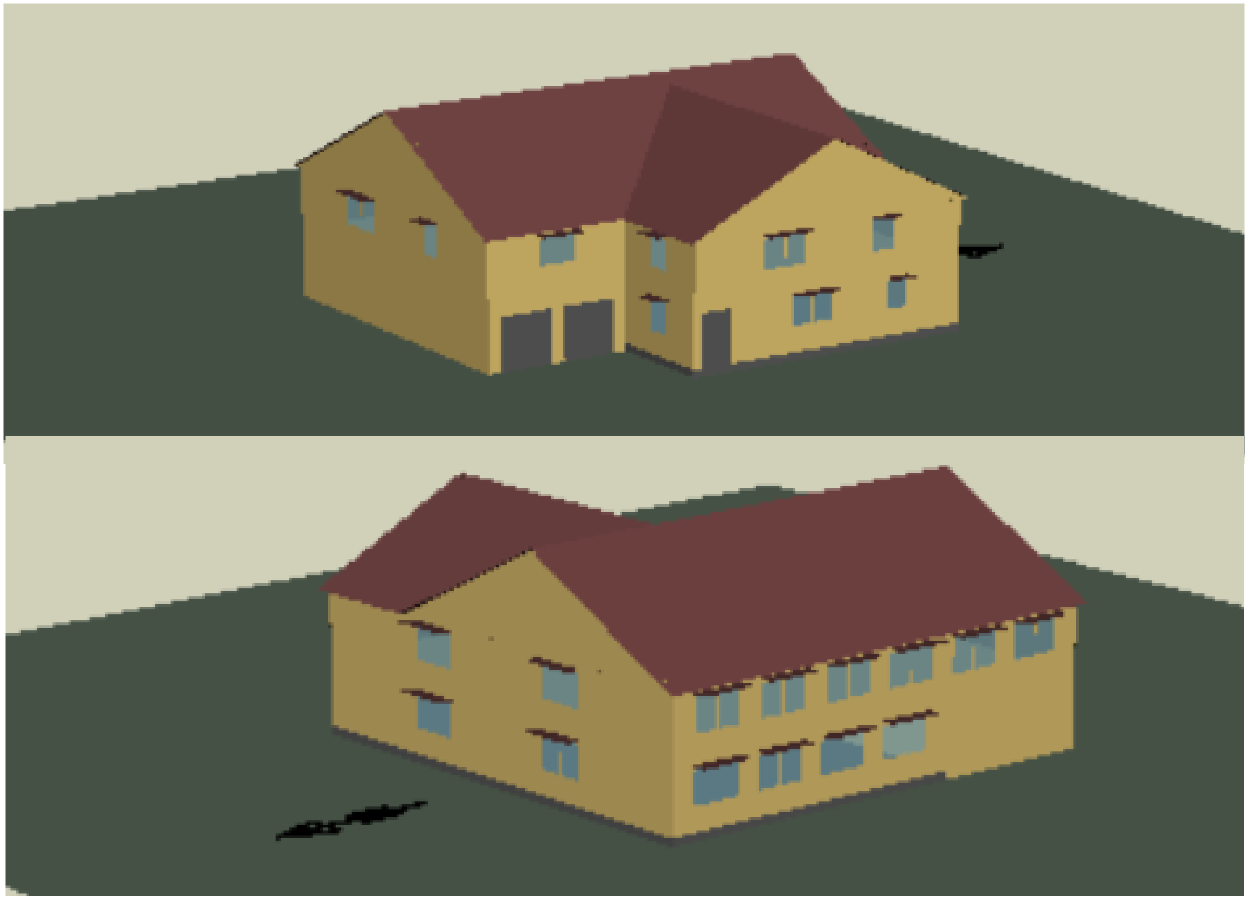


Figure 9: Outside views of Home 2

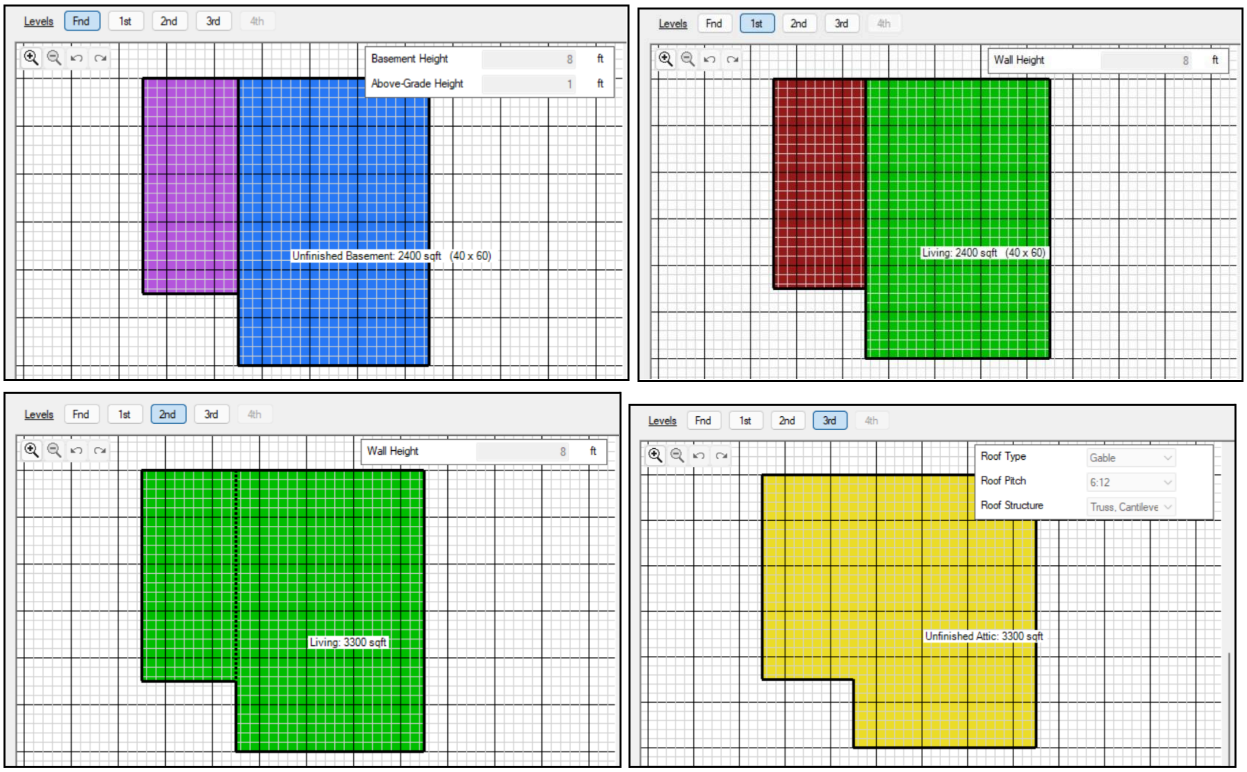


Figure 10: Floor plan for the House 2

Floor plan:

Figure (7) above displays all four levels in the house in Phoenix. The top left image shows the unfinished and partially finished basement. The top right image shows floor level 1, which includes a garage (Red) on the left side. The bottom left image shows floor level 2. The bottom right image shows an unfinished attic, however, it does not show the roofing

<u>Input Parameters</u>

The input parameters of the house were meant to be distinguished from the house above. The parameters below are meant to match that of the simulation. Table 4 is meant to represent the input parameters of the home/area itself. We chose these parameters in an effort to match that of a house in Phoenix, AZ. Overall, we imagine that the house would be more focused on keeping cool, rather than needing to be warmed up, and as for appliances, it was pretty standard down the board. As one can tell, this home seems to be much more suited for a warm climate, rather than the house from Massachusetts, which would have more of an emphasis on insulation and heating. The overall reason these parameters are the way the are, is to simulate a house in a warm climate, contrasting that to the Massachusetts house.

Table 4: Input parameters for the home itself within BEopt.

Parameter	**Value**
Orientation	East (5)
Neighbors	None (1)
Wood Stud	R-13 Cellulose, 2x4, 16 in o.c. (9)
Wall Sheathing	OSB, R-15 XPS (10)
Exterior Finish	Vinyl, Medium/Dark (10)
Interzonal Walls	R-13 Cellulose, 2x4, 16 in o.c. (13)
Unfinished Attic	Ceiling R-30 Cellulose, Vented (12)
Roof Material	Tile, Medium (5)
Unfinished Basement	Double-Sided, Foil (2)
Floor Mass	Wood Surface (2)
Exterior, Partition, and Ceiling Wall Mass	⅝ in, Drywall (3)
Window Areas	F10 B30 L10 R10 (6)
Windows	Low-E, Double, Non-metal, Arg, H-Gain (7)
Interior Shading	Summer = 0.7, Winter = 0.7 (2)
Doors	Fiberglass (3)
Door Area	30ft^2 (3)
Eaves	1 ft (2)

Table 5 below represents all of the lighting and appliances that are implemented in the house. Relatively average values were picked for all washer/ dryer systems. There is no pool on the property, so all pool equipment is unnecessary. There is no fireplace necessary for this home.

Table 5: Input parameters for the appliances in the home within BEopt.

Appliance(s)	Attribute
Lighting	60% LED (10)
Refrigerator	Top freezer, EF = 17.6 (11)
Cooking Range	Electric (2)
Dishwasher	307 Rated kWh, 80% Usage (3)
Washer	IMEF = 1.57 (2)
Dryer	Electric, CEF=3.73 (2)
Plug Loads	1.00 (5)
Extra Freezer	None (1)
Pool Heater	None (1)
Pool Heater	None (1)
Pool Pump	None (1)
Gas Fireplace	None (1)

Table 6 below represents all of the HVAC systems that are implemented in the house. Relatively average values were picked for all HVAC systems. Central AC is normal in warm climates such as Phoenix, AZ. The cooling point is higher than most areas in the country, as it is more expensive to keep cool.

Table 6: Input parameters for the heating and cooling within BEopt.

Heating and Cooling	Attribute
Air Leakage	5 ACH50 (10)

Mechanical Ventilation	Exhaust (2)
Natural Ventilation	Cooling Months Only, 7 days/wk (3)
Central AC	SEER2 20.0 (7)
Furnace	Electric, 100% AFUE (2)
Ducts	10% Leakage, R-8 (17)
Ceiling Fan	100 cfm/W, #Bedrooms+1 Fans, 0.5 Deg F offset (3)
Cooling Set Point	76 F (9)
Heating Set Point	72 F (11)
Water Heater	Electric, Heat Pump, UEF=3.5, 50 gal (5)
Distribution	Uninsulated, Copper (2)

Weather Situation

Figure 10 shows the annual energy usage in terms of BTU. The highest amounts of energy used were in the months of January and July. This corresponds with the extremes of Arizona weather, as July is the warmest month of the year, keeping it hard to keep cool. January is extremely dry and cold, making it expensive to keep warm. The least costly month in terms of energy usage would be November, as the weather during that month is comfortable and requires little to no heating/cooling.

Initial Results

After imputing all of the parameters, we ran this simulation in Phoenix, AZ, as this would show a great contrast in climates compared to the house in Marion, MA. Each utility, such as electricity, natural gas, ect, were set to the national average. With these parameters we expect the home to use 196.4 MMBtu on average per year which can be seen at the top of Figure (11) A majority of the energy consumption is from miscellaneous sources and cooling. We will want to target these two areas when working to reduce our energy consumption. After imputing all of the parameters, we ran this simulation in Phoenix to display a contrasting environment to that from Marion, MA. Each utility, such as electricity, natural gas, ect, were set to the national average.

We can see in Figure (11) that the home uses a total of 196.4 MMBtu a year. This consumption is primarily made up of cooling costs (45.4 MMBtu) and miscellaneous costs (53.4 MMBtu).

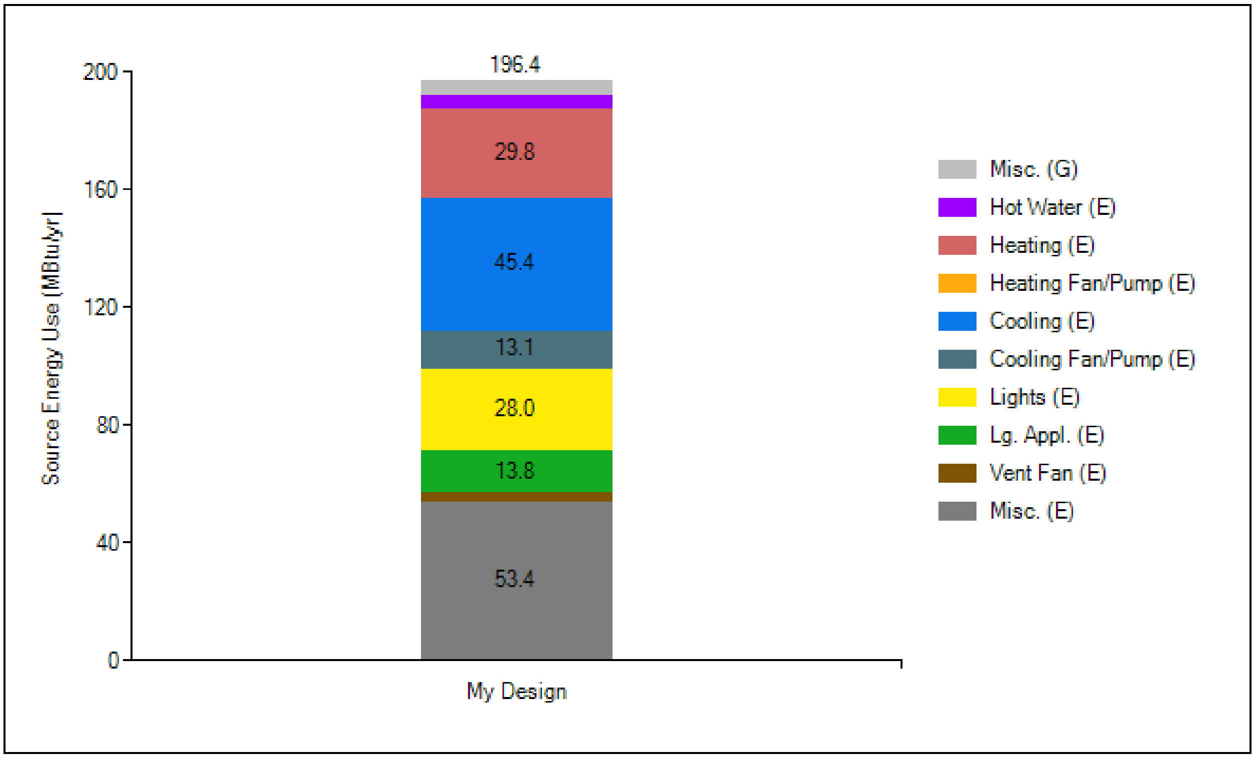


Figure 11: Energy use of House 2

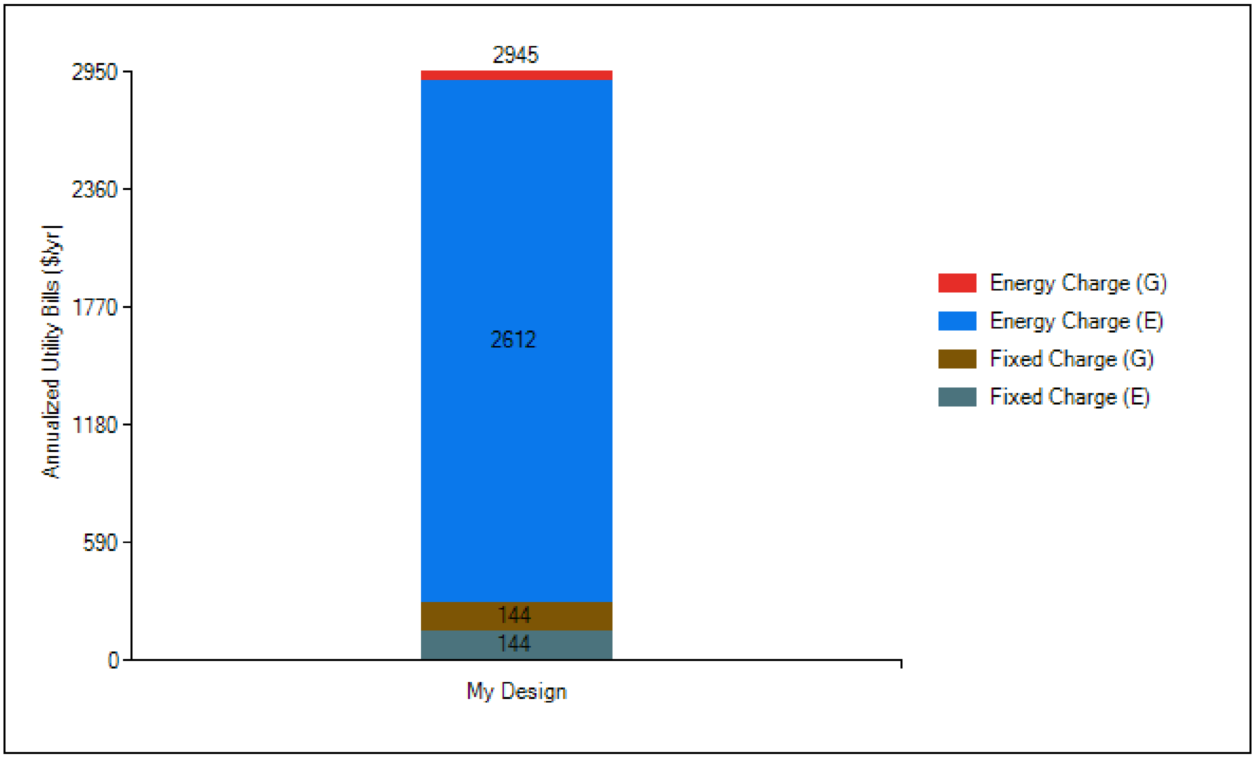


Figure 12: Utility costs of House 2

Figure (12) above shows the utility price per year. The total cost per year for utilities is 2945 $/yr based on the national consumption averages and our imputed information. This puts us at a monthly average of $245.42. This is significantly more than the Arizona yearly average of $2,748. A major factor to this would be the overall size of the house. It is important to note that the national average electric bill is $2338 a year. [2]

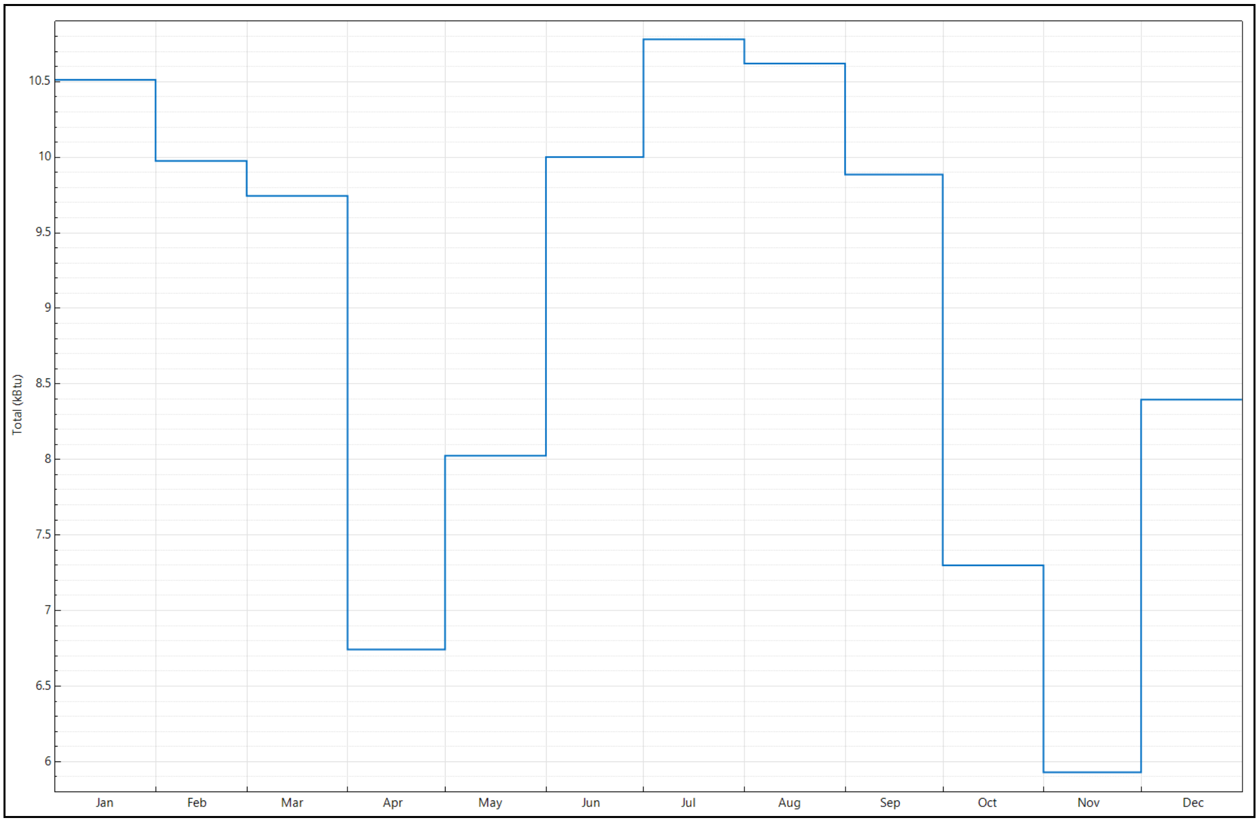


Figure 13: Monthly energy consumption of House 2

Figure (12) shows the monthly energy use in BTU for the house. Based on the figure, it's sure that the maximum energy use peaks during the months of July and January, as those are times when the weather is most extreme. The lowest amount of energy use is in the month of November.

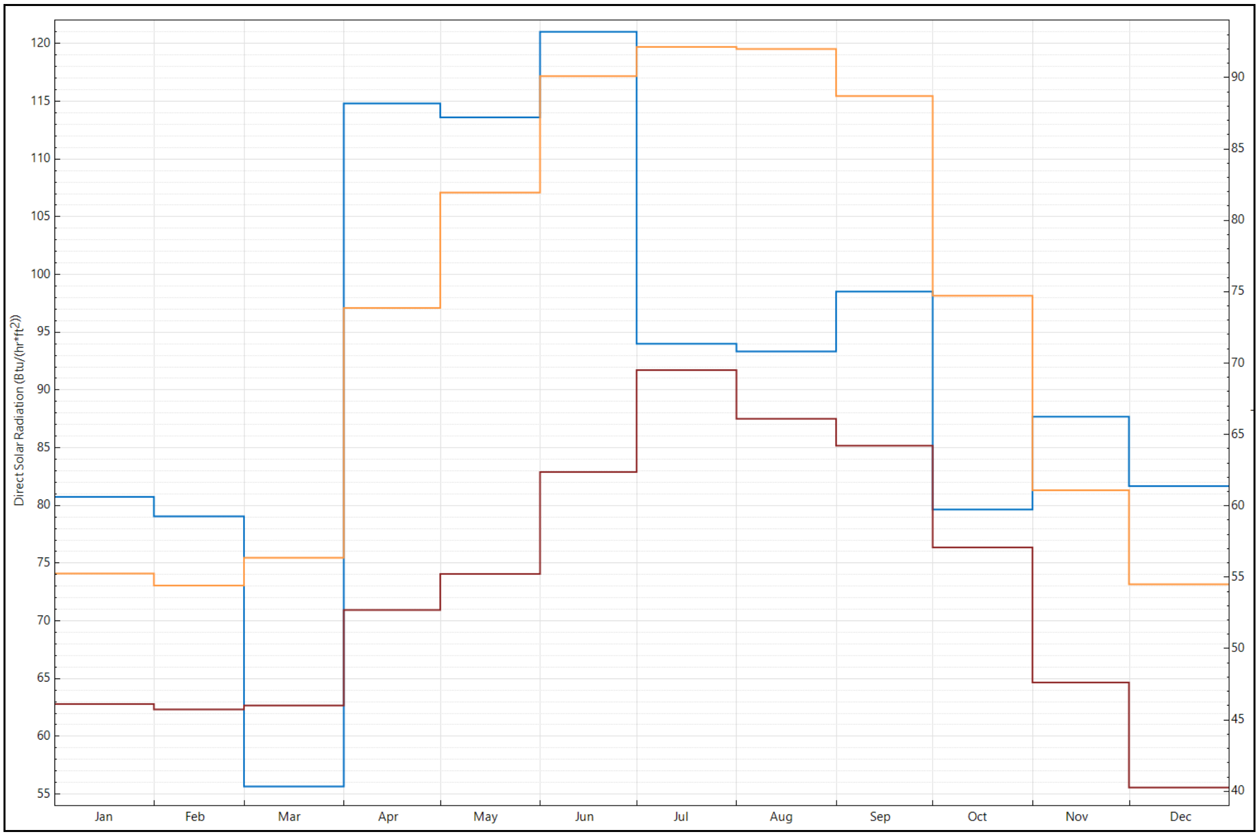


Figure 14: Monthly weather data of House 2.

Figure (13) above shows the monthly weather data. The red line represents the dry bulb temperature, the yellow line represents the wet bulb temperature, and the blue line represents the direct solar radiation.

Effect of Parameter Changes

Changes For House 1

Our goal in changing parameters was to make the house as insulated as possible. This means increasing the R value of the internal and external walls as well as the attic and basement. Furthermore, moving the neighbors closer also would make the house more efficient especially during the cold winter months. Lastly, in an effort to see how direction changes the output, we swapped the direction to North.

Table 7: Changed parameters of House 1

Parameter	New Attribute
Orientation	East (1)
Neighbors	None (1)
Internal Walls	R-36 Closed Cell Spray, 2x6, 24 in o.c. (20)
Finished Roof	R-38 Fiberglass Batt 2x12 (16)
Slab	Whole Slab R40 XPS (15)
Carpet	100% Carpet (6)
Exterior Wall	⅝ in Drywall (3)
Radiant Barrier	Double-Sided, Foil (2)
Ceiling Mass	⅝ in Drywall
Internalized Walls	R-36 Closed Cell Spray, 2x6, 24 in o.c. (8)

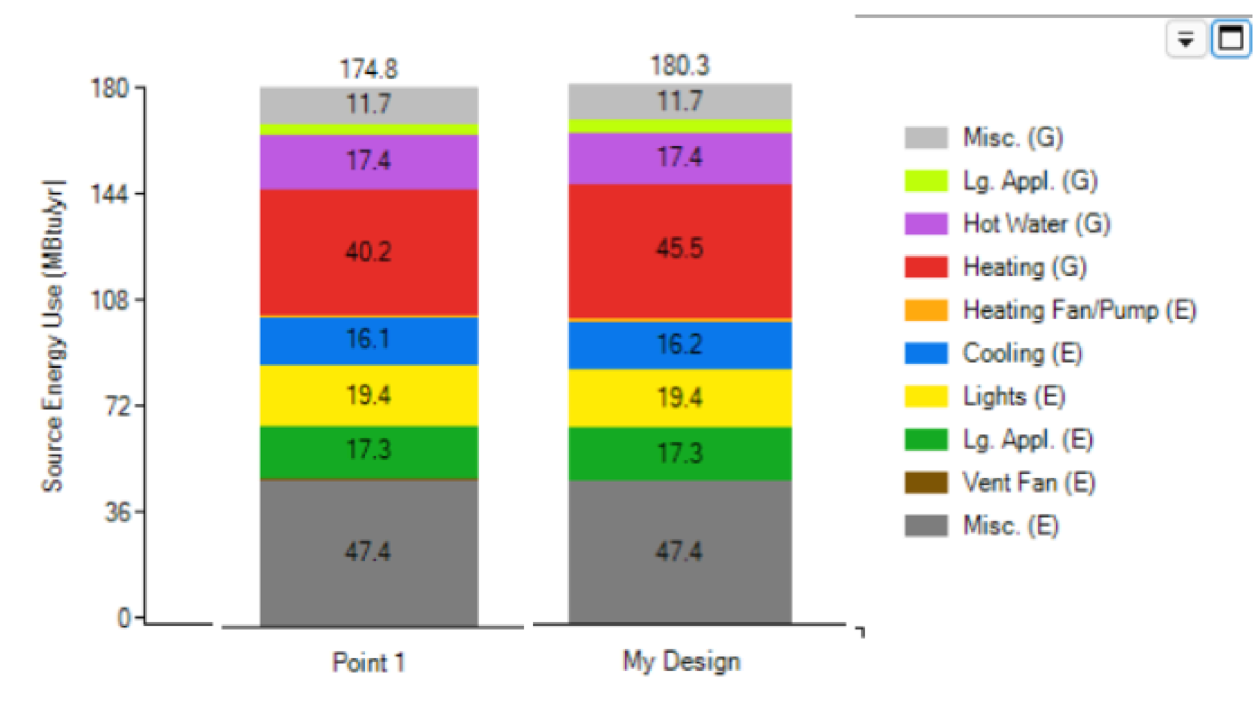


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Figure 15: Updated energy use versus the initial design

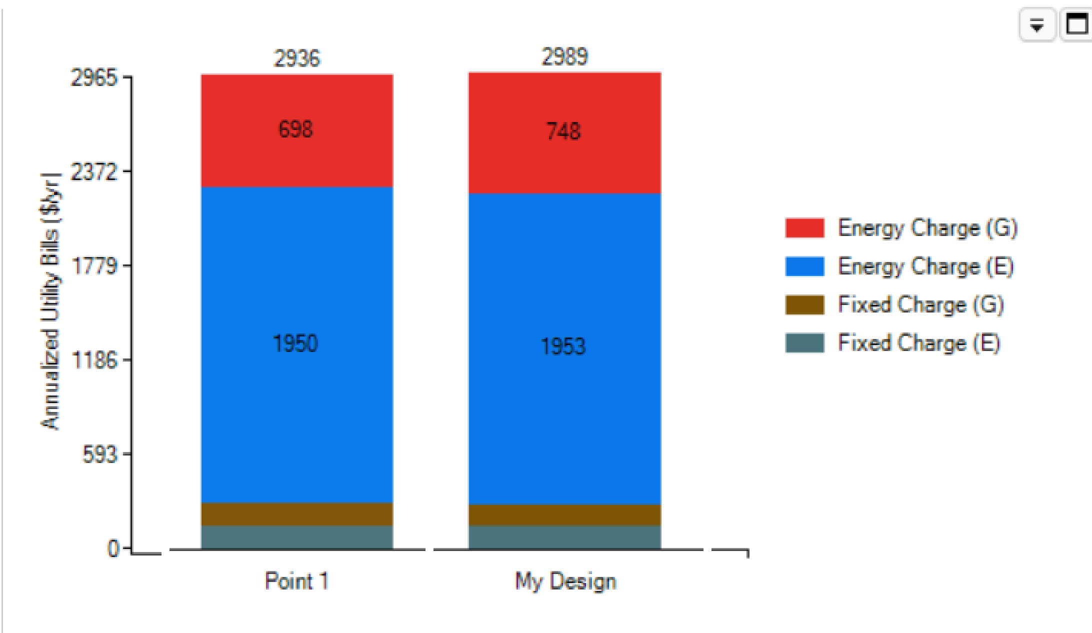

Figure 16: Updated utility cost versus the initial design

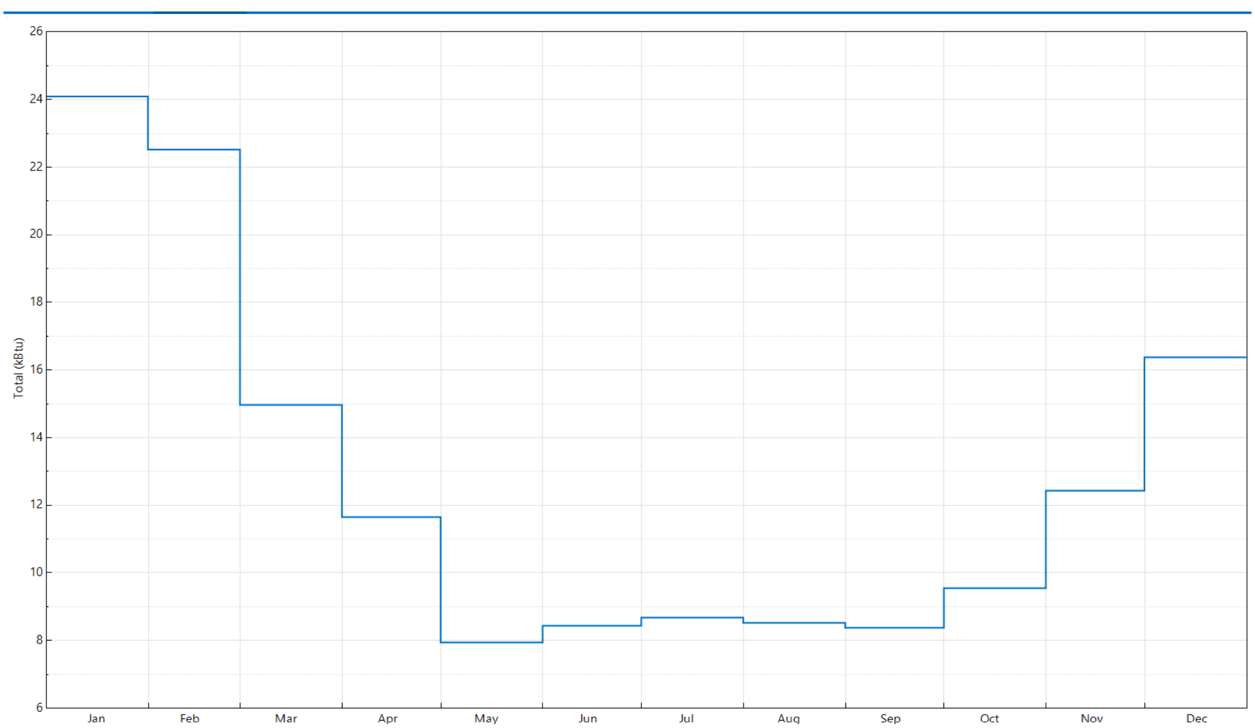

Figure 17: Updated monthly energy consumption of House 1

Changes For House 2

When looking for parameters to change for the second house we wanted to target the overall insulation of the house to see if that would help with its energy efficiency. After switching some of the important parameters such as the Neighbors, wall insulation values, and the carpet %. It was predicted that a more well insulated house would help with keeping it cool, however it would also help keep it warm, but we weren't sure if it would positively or negatively impact the energy efficiency and annual costs.

Table 8: Changed parameters of House 2

Parameter	**New Attribute**
Orientation	South (9)
Neighbors	Left/Right (15 ft) (3)
Carpet	80% (5)
Windows	Low E Double Insulated ARG L-Gain (15)
Unfinished Basement	Whole Wall R-11 Fiberglass Batt, 2x4 (13)
Unfinished Attic	Ceiling R-30 Closed Cell Spray Foam (19)

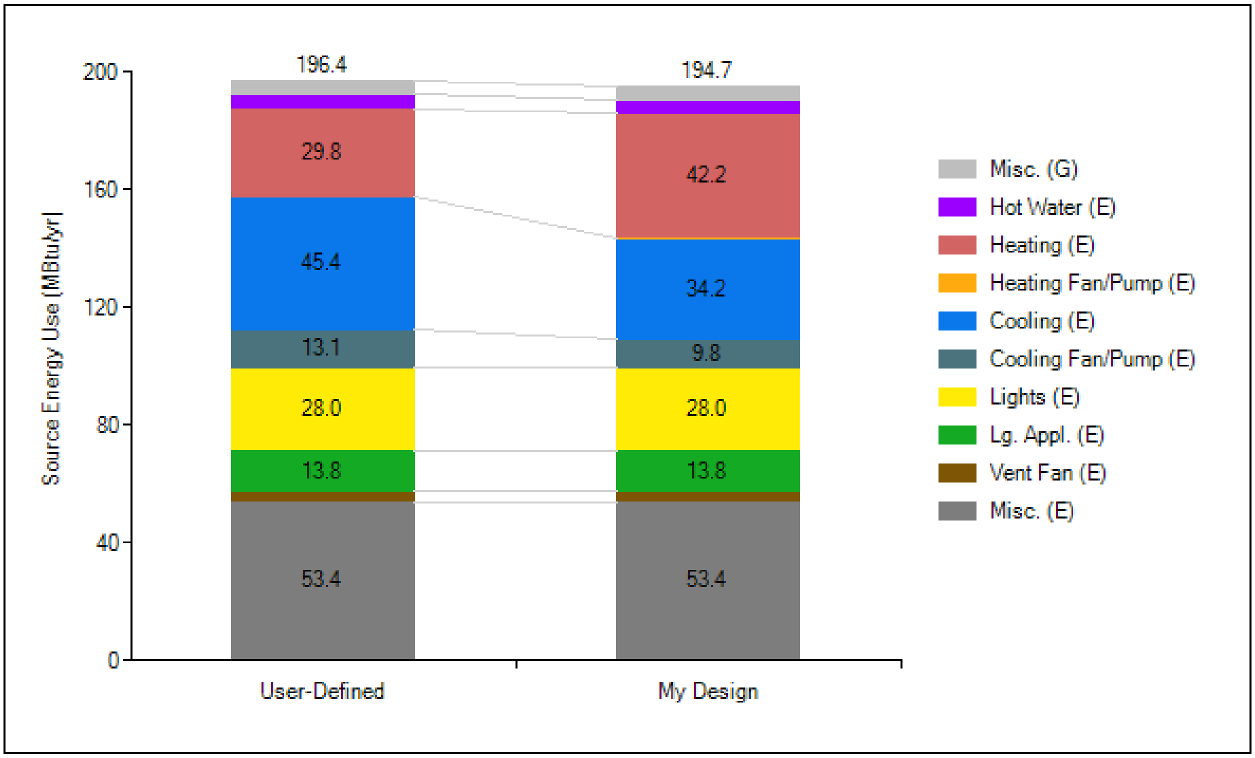

Figure 18: Updated energy use versus the initial design

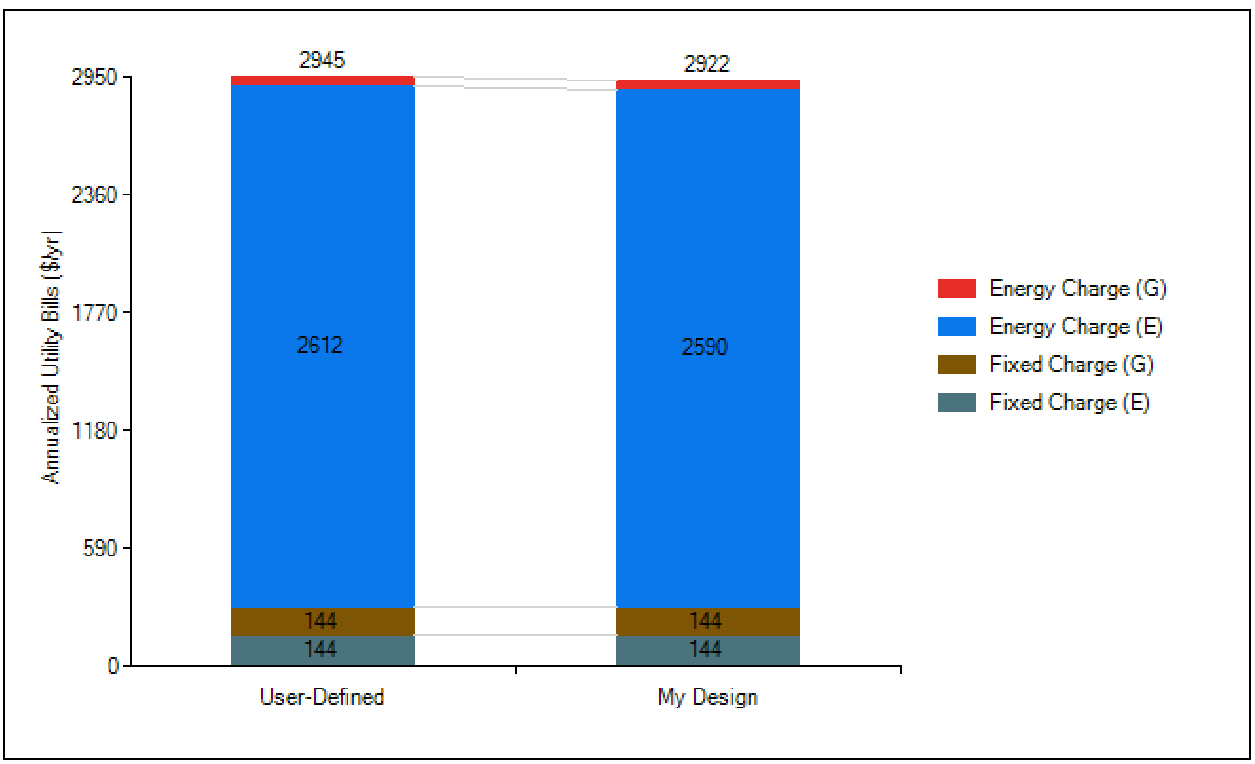

Figure 19: Updated utility cost versus the initial design

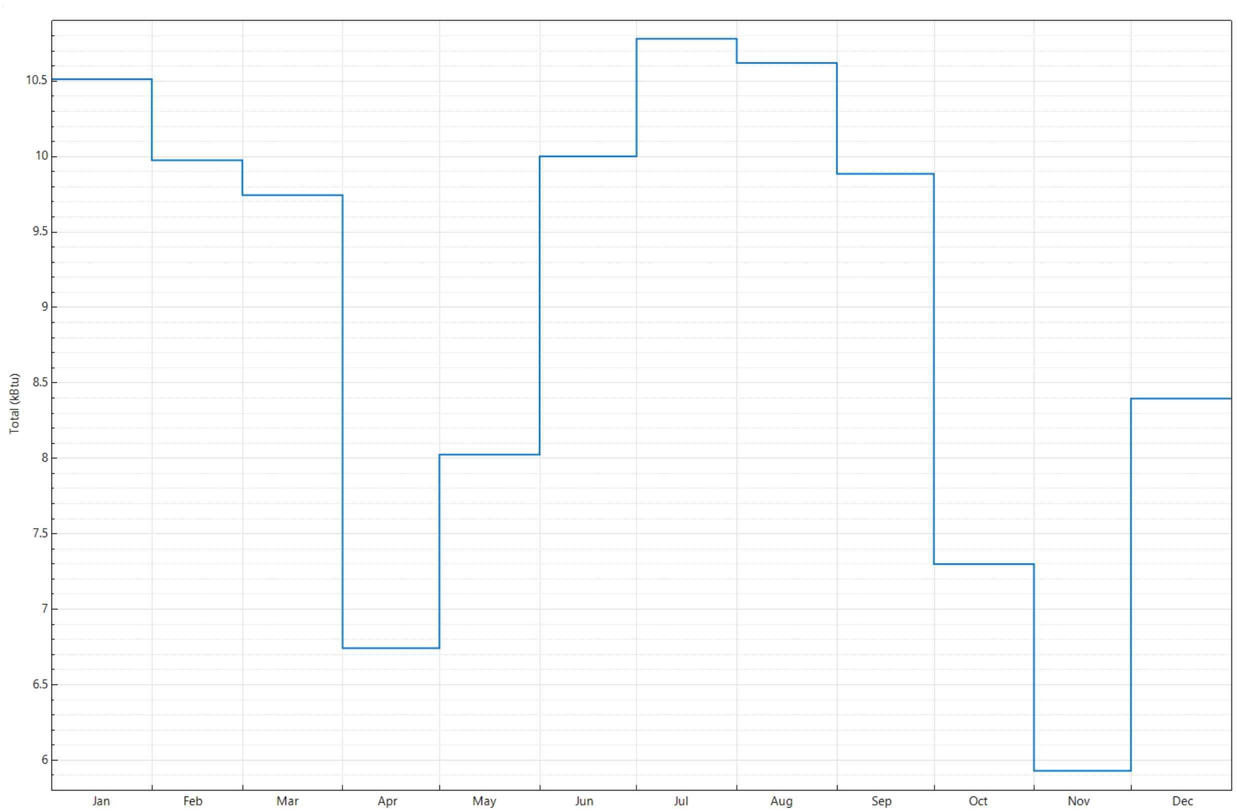

Figure 20: Updated monthly energy consumption of House 2

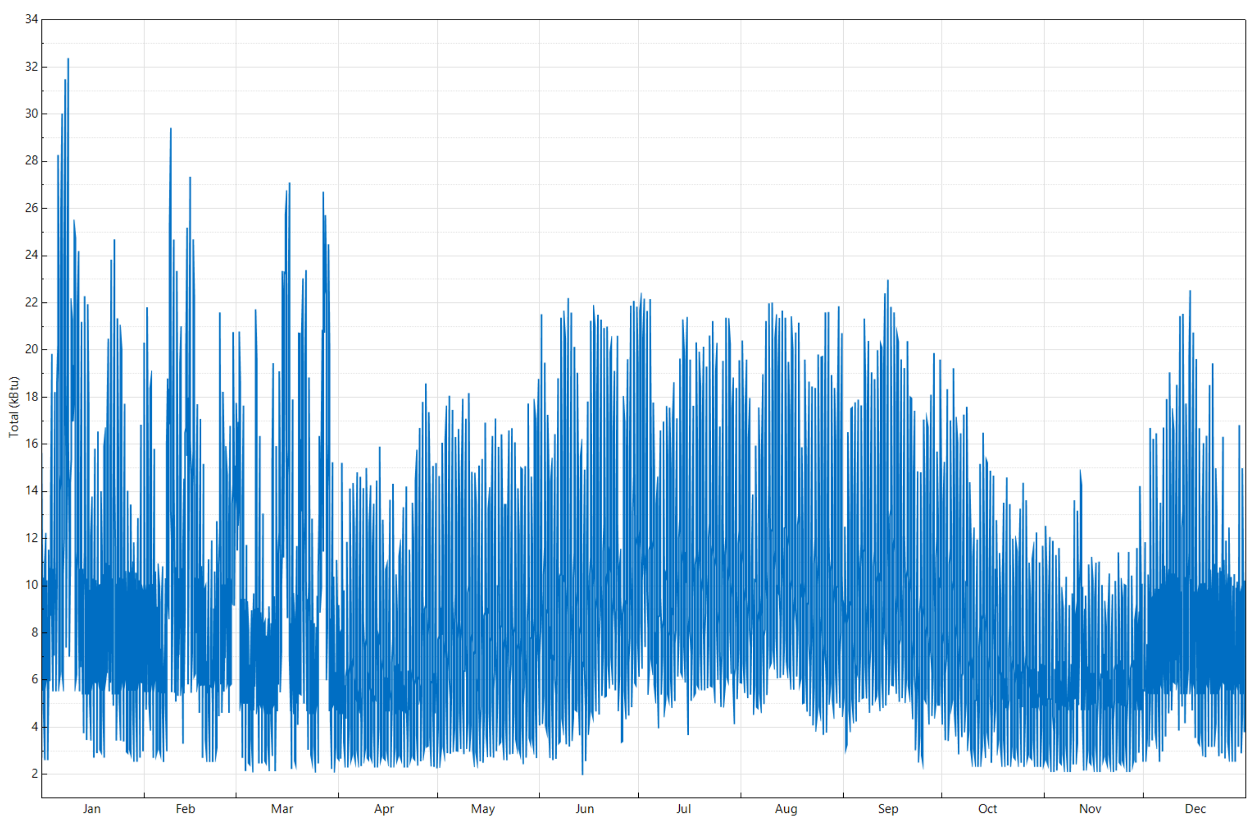

Figure 21: Hourly energy consumption of House 2 with updates

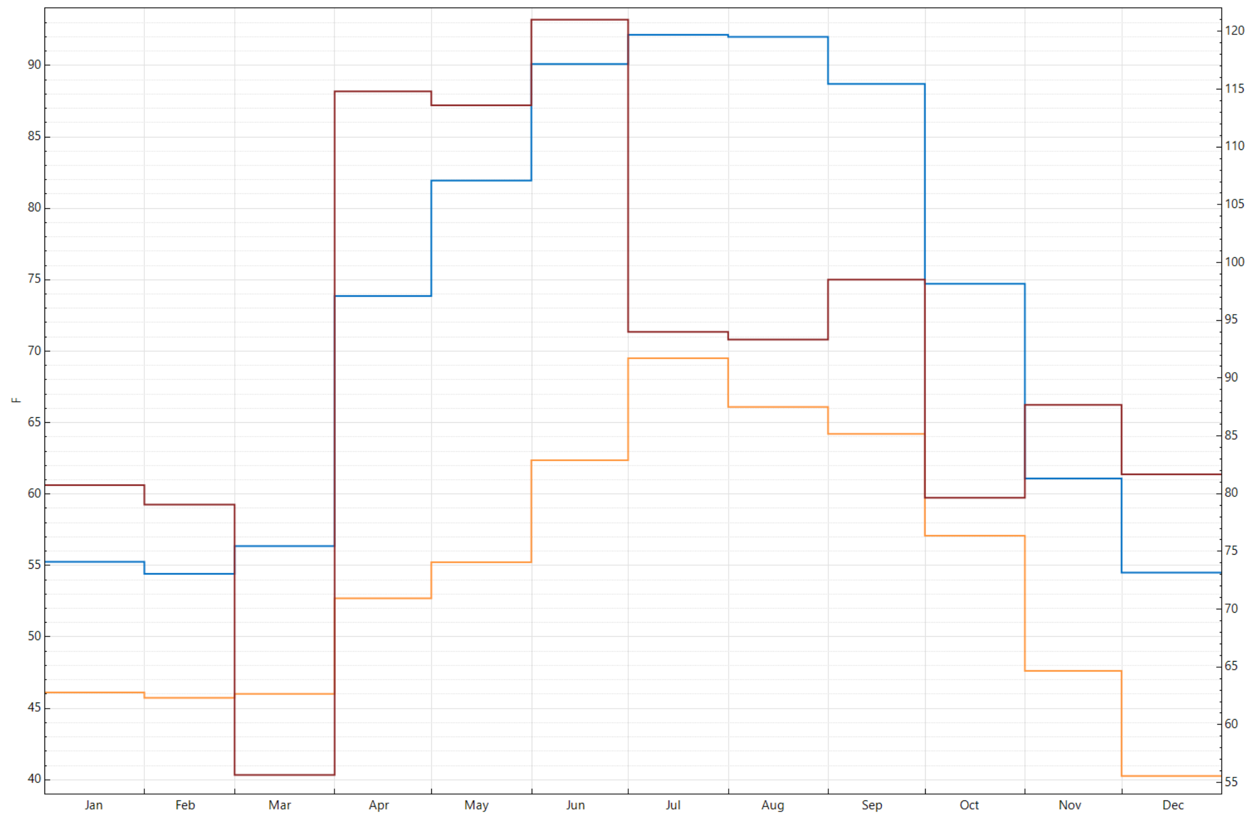

Figure 22: Updated weather data of House 2

<u>Conclusions</u>

Based on the data we received from multiple simulations we can draw some conclusions on the effectiveness of certain changes in the home in regards to energy efficiency. While none of these homes will be reaching the goal of zero net energy we did find some improvement in comparison to our initial parameters. When it comes to House 1 we found a small increase in efficiency. From figures 18 and 19, it can be seen that the overall savings are 5.5 MBtu/yr saving the family $53 a year. Most of the savings are in heating with minimal savings from cooling, and since the house is primarily gas-heated, most of the savings are in gas with slight savings from electricity. This means that the savings can be assumed to be from the better insulation of the roof, basement, and walls causing less thermal leakage through the sides, top, and bottom of the house. Furthermore, the neighbors moving closer means that more thermal energy would be gained from the neighbors. All this means that the house stays heated and cooled longer, requiring less energy to heat and cool the house.

When it comes to House 2, we found an overall increase in efficiency with the modified house. Figure 15 above shows the utility prices per year of the original House 2, and the modified House 2. The total cost per year for utilities dropped by $23 when the select changes were made for the house. This signals that there are ways to go about making your home more cost-efficient, regardless of the location. Figure 14 further proves this, as there was a 1.7 MBTU change between the source energy consumptions. Seeing the comparison of energy uses helps narrow down the inputs that cause this. As seen in Figure 14, the energy usage for cooling drops drastically. The primary reason as to why there would be less cooling needed would be the insulation changes made. The modified house contained more insulation between the walls, the carpet, the attic/basement. All of this combines to make the house stay cool longer, however, this adversely affects the heating usage as well. More heating is required for the house in general, which may in part have to do with the house's orientation. The original was pointed East, while the modified was pointed South. Despite that, the changes made to the input parameters would help keep the house energy and cost-efficient.

Overall we found that heating and cooling are by far the largest two independent cost factors when it comes to your home. A higher quality insulation is able to retain the thermal energy of the home creating less temperature fluctuation. Insulation isn’t the only aspect to look at when reducing your home’s energy waste, windows are important too. A lot of energy can be lost by installing cheap windows. Most windows have a layer of air between the panes to help insulate them as in a stagnant state air is a fantastic insulator. We found that more carpet within the home also helps reduce heating costs as it helps insulate the lowest part of your home where most cold air will settle. Additionally, carpet tends to be more comfortable to stand on than a cold tile floor so the homeowner will be less inclined to increase the heat (although I’m not sure if this is actually factored within BEopt). The orientation of the home is also a key factor in maintaining a proper climate. The direction the sun hits your home can determine how much natural heat is gained without spending a dime. Southern-facing homes tend to provide the most all-day natural light while also providing seasonal benefits. During the summer (in the Northern

Hemisphere) the sun swings over the house meaning the majority of rooms will be shaded in the peak heat. When winter comes around the sun's path crosses on the south side of the home helping heat the house. [3]

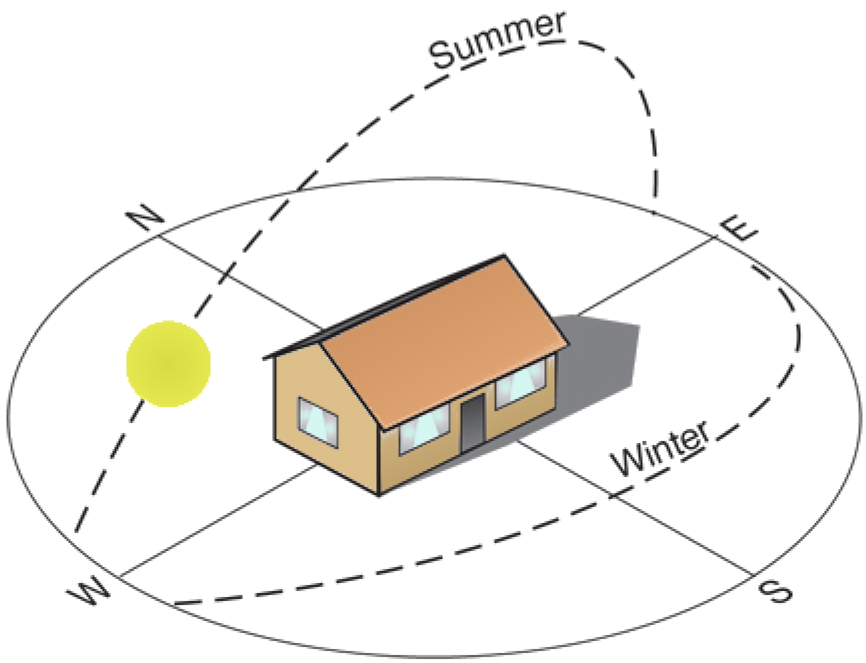

Figure 23: Diagram of the sun's path

Neighbors also make some changes to the energy efficiency of a home in this regard. The nearby homes can block out the sun earlier and later in the day reducing the light and heat gained during the summer especially.

Overall we found this project to be very helpful in learning BEopt. The software provides valuable data for planning a new home or optimizing an existing one. We look forward to adding this to our revitour of skills and resume.

Sources

[1] National Renewable Energy Laboratory (NREL): The official NREL website (https://www.nrel.gov/) is likely to have information on BEopt, including its development, updates, and significance. Check the publications section for relevant reports or articles.

[2] “Electricity Cost in Massachusetts: 2024 Electric Rates.” EnergySage, www.energysage.com/local-data/electricity-cost/ma/#:~:text=We%20give%20you%20access%20to,up%20to%20%243%2C576%20per%20year. Accessed 10 Feb. 2024.

[3] “Building Orientation for Optimum Energy.” InterNACHI®, www.nachi.org/building-orientation-optimum-energy.htm#:~:text=Orient%20the%20floor%20plan%20%E2%80%93%20not,the%20sun%20in%20the%20summer. Accessed 12 Feb. 2024.

[4]“Electricity Cost in Arizona: 2024 Electric Rates.” *EnergySage*, www.energysage.com/local-data/electricity-cost/az/. Accessed 12 Feb. 2024.