BEopt

BEopt

Building Energy Optimization
with Hour-by-Hour Simulations

NREL

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
www.nrel.gov

Building Energy Optimization Software

BEOpt | Introductory Tutorial
Building Energy Optimization Software

Introduction

In this tutorial, you will be introduced to an Energy Modelling and Building Simulation Software entitled "BEopt"**.** This tutorial will use the Warrior Home Design team model for the 242 Kehl St. project in Kitchener, Ontario to introduce the basic functions of BEopt. This model was created by the energy modelling lead team members.

What is BEopt?

BEopt is a user-friendly energy modeling software that evaluates residential buildings to identify optimum cost efficiency and energy saving strategies with the goal of achieving low or net zero energy. The program is published by the U.S. federal government and is free to download and use. Analyses can be completed for existing home retrofits or new construction of single-family detached and multi-family buildings. BEopt runs detailed hour-by-hour simulations; without requiring the same detailed input as eQUEST, BEopt can still provide reliable energy modelling results.

The Interface

Geometry Screen

- Building floor plans are drawn on the **Grid** and the resulting 3D drawing is presented in a small square on the bottom right.
- View: there is an arrow on the side of the 3D window from which you can control the size of the view.
- The three boxes in red shown in Figure 1 are the **Tool bar**, **Spaces bar** and **Units bar**.
    - **Tool Bar**: allows you to save, open, run the simulation and switch between the geometry, options and site screen
    - **Spaces Bar**: choose the space you want to build
    - **Units Bar**: determines the number of bed, bath and total area

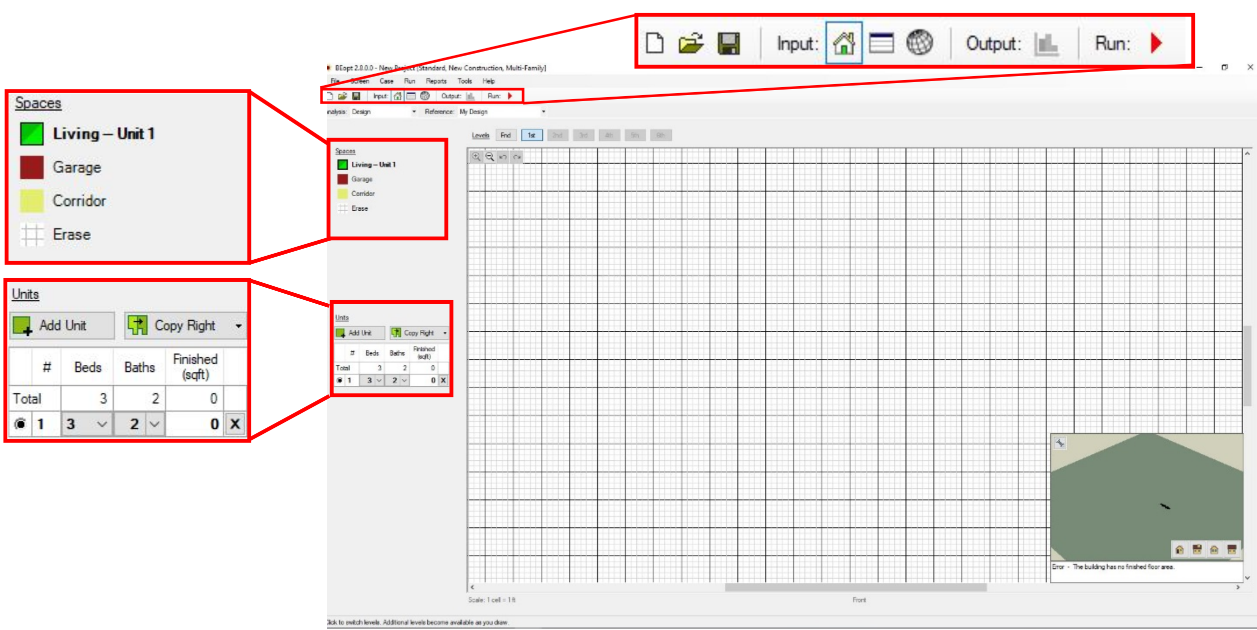

Figure 1: The BEopt Geometry Screen Interface

Options Screen

- Clicking on the square icon in the **Tool bar** will switch the screen to the **Options screen**.
- On this screen you can enter exact specifications of the building such as building orientation, number of neighbors, plug loads, etc.
- Later, you will be able to edit some of these characteristics to produce a model for the 242 Kehl St. project.
- Figure 2 shows the **Options screen**.

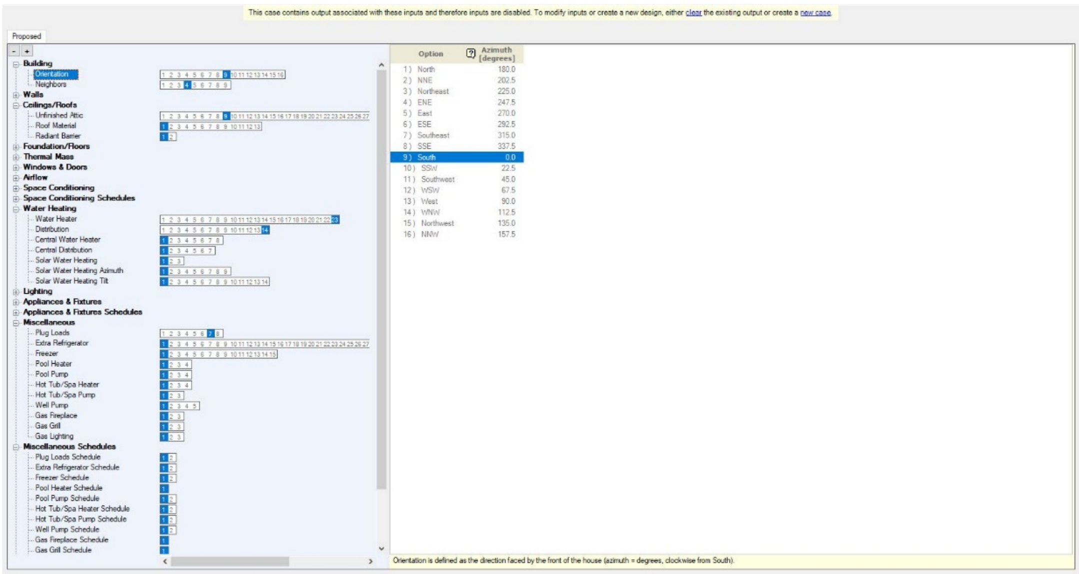

Figure 2: The BEopt Options Screen

Site Screen

- Clicking on the globe icon in the **Tool bar** will switch the screen to the **Site screen**.
- Here you can input information such as weather data, and economic/financing assumptions.
- Figure 3 shows the **Site screen**.

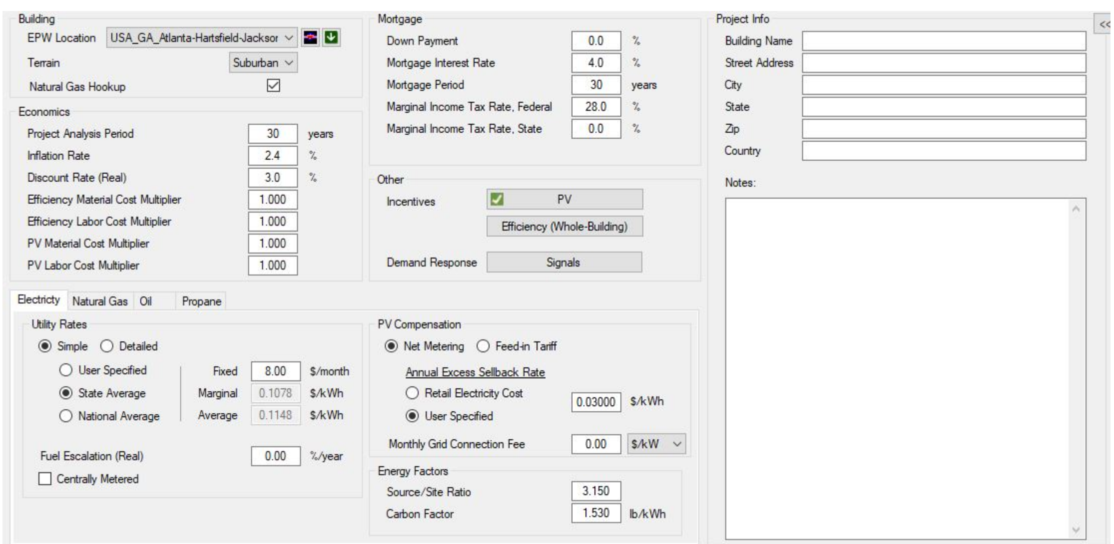

Figure 3: The BEopt Site Screen

Output Screen

- Clicking Run: will result in the **Output screen**, which includes cost/energy graphs, the end-use graph, and an options graph.
- Figure 4 shows the **Output screen**.

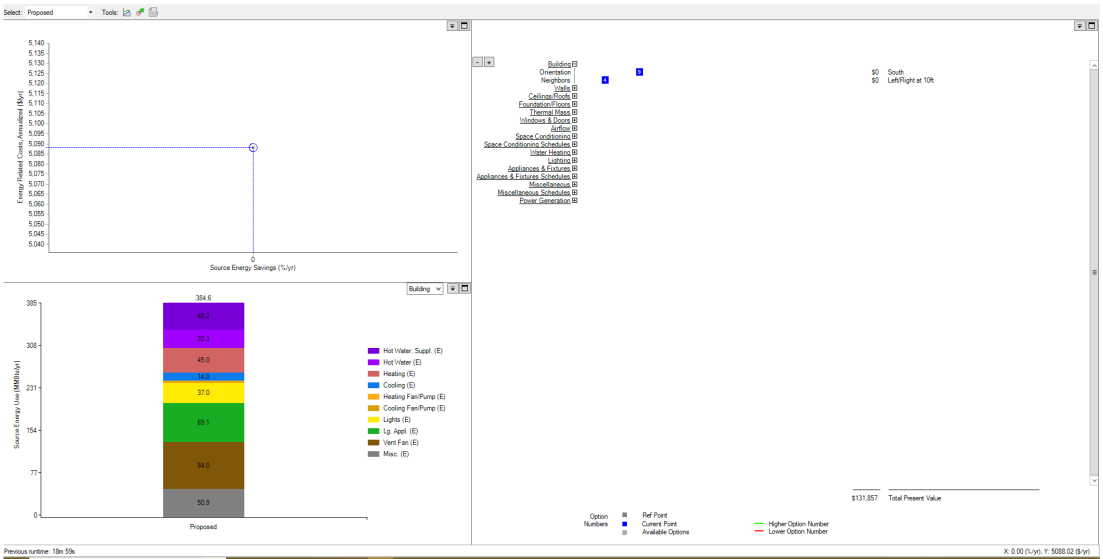

Figure 4: The BEopt Output Screen

Step 1: Starting a New Simulation

- **Starting BEopt:** Double click on the icon located on your desktop.
- **Creating a new model:** BEopt gives you multiple options to consider for your base model. These options are divided into *Project type, Application type* and *Building type* as presented in Figure 5.
  - The program default is: Standard, New construction and Single-Family Detached
  - For this tutorial simply change the building type to *Multi-Family*

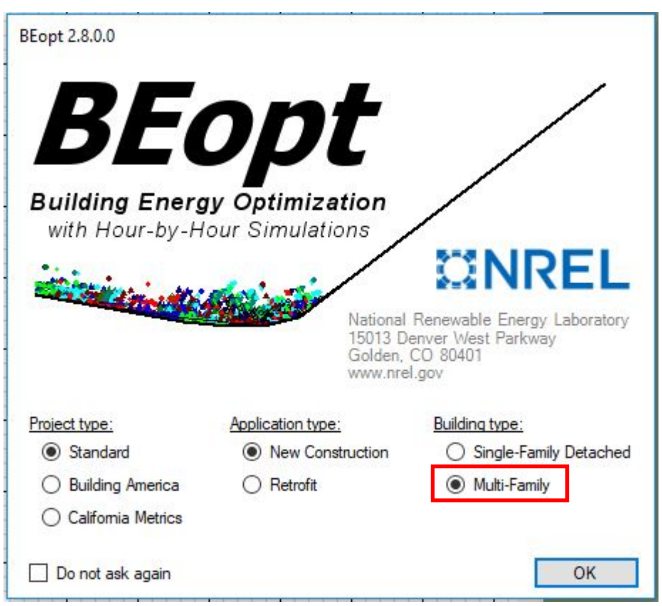

Figure 5: New Model Startup Image

Step 2: Create Geometry

First Floor

- The grid on the page has 1 cell:1 foot ratio
- You can draw on the screen but cannot complete detailed models
- See the accompanied CAD drawing (supporting materials) showing the dimensions of the units
  - To reflect the same dimensions on BEopt you need to start by drawing 18'x34' unit
  - Use the drop down menu to change the number of beds and baths to 4 beds and 1 bath
  - The Kehl street development has 4 units attached to each other. Since these units are identical to one another you can simply click on  as highlighted in red to create 4 units.

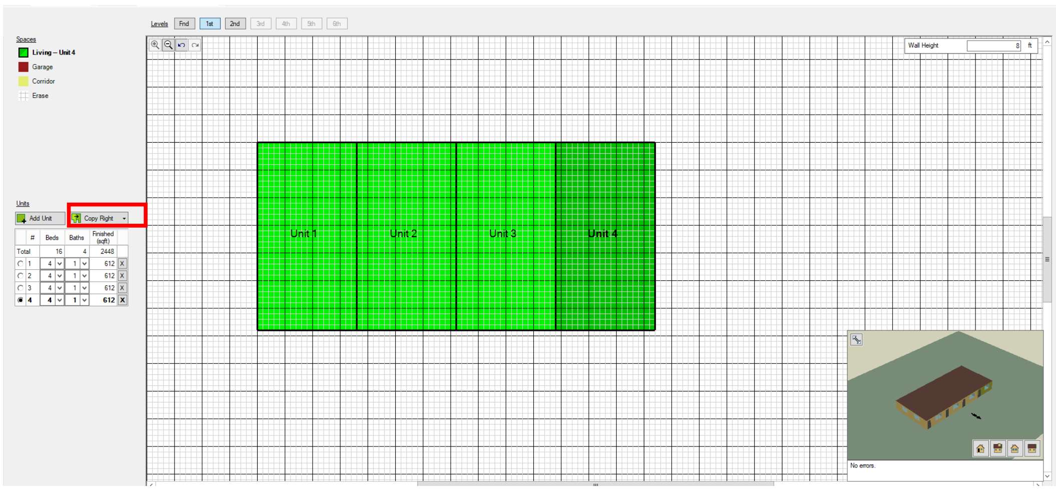

Figure 6: First Floor of Model

Second Floor

- When you click on 2nd under the **Levels Tab** (red box) it will show you the units shaded in grey. This means you must outline where the living spaces are going to be for this floor.
- Choose the unit from the units table on the left side then outline **Unit 1** like you did for the first floor.
- Figure 7 presents units 1 and 2 after the living space has be specified.

Figure 7: Second Floor of Model

- Repeat the same steps for units 3 and 4. You should have all 4 units in green.
  - **Note:** The 3D view changes as you outline the living spaces on the second floor
    The finished sqft increases as you outline the areas for each unit

Third Floor

- Click on 3rd on the levels bar to insert the attic area
- The drawn area is going to be in grey so you need to outline it to determine the attic space
- Under the **Spaces** section on the left click on Unfinished Attic and highlight the space
- Figure 8 shows the geometry including the 3D gable roof automatically created

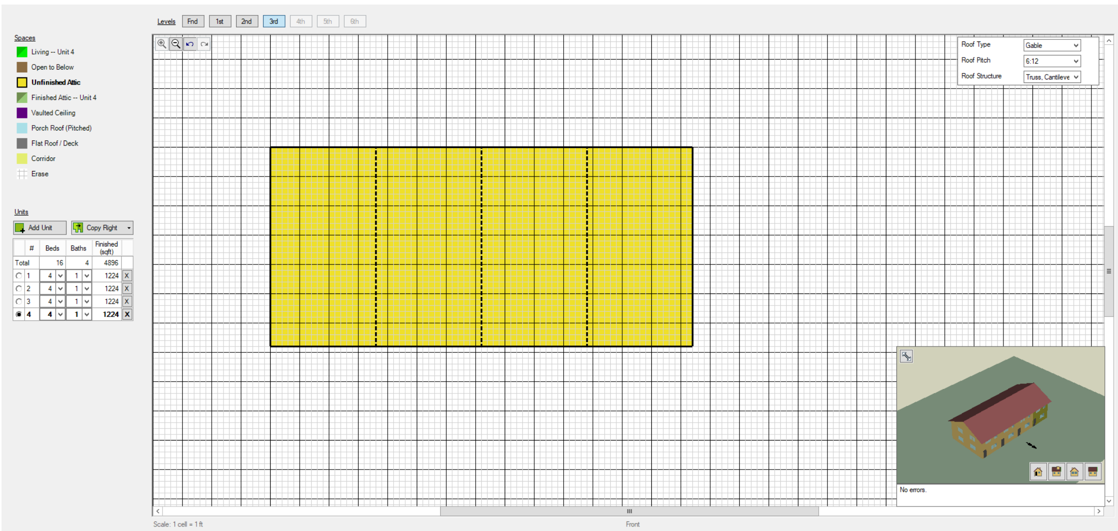

Figure 8: Third Floor of Model with Gable Roof

Basement

- Click on *Fnd* on the levels bar to insert the basement area, the units are shown in purple
- Under the **Spaces** section on the left click on Finished Basement -- Unit 4 and highlight the space to determine the finished basement space
  - **Note:** Make sure you change each unit when highlighting the finished space

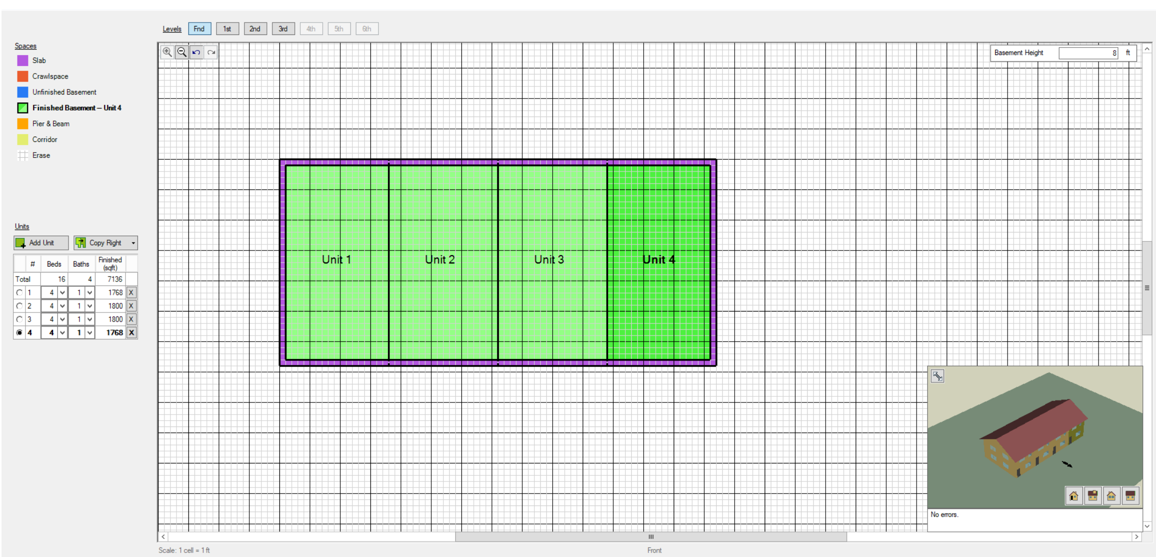

Figure 9: Finished Basement of Model

Step 2: Input Detail

Options Screen

- To input the details for the building click the table on the Tool Bar to access the options screen
- You can hover over each number to change the input quickly or double click on the option to view the detailed characteristics of each option
- All the selected options are BEopt defaults, to customize your own options you must edit the Options Screen
- The details required to create the specific options for the Kehl Street development are outlined in the detail sheet provided under supporting material
- In the detail sheet, you will notice that there are multiple inputs called *Warrior Home* indicating that it is a customized input
- To create your fist customized option, select **Window Areas** under the **Windows and Doors** tab

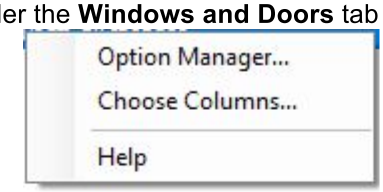

Figure 10: Option Manager

- Right click on the last option then select **Option Manager**
- Click copy to Open the Option Editor, here you can rename the new option "Warrior Home Window to Wall Ratio
  - o Change the Option type to Percent of Each Wall
- Change the values of option editor per the screenshot below then click Next
  - o Note: the calculated values change automatically

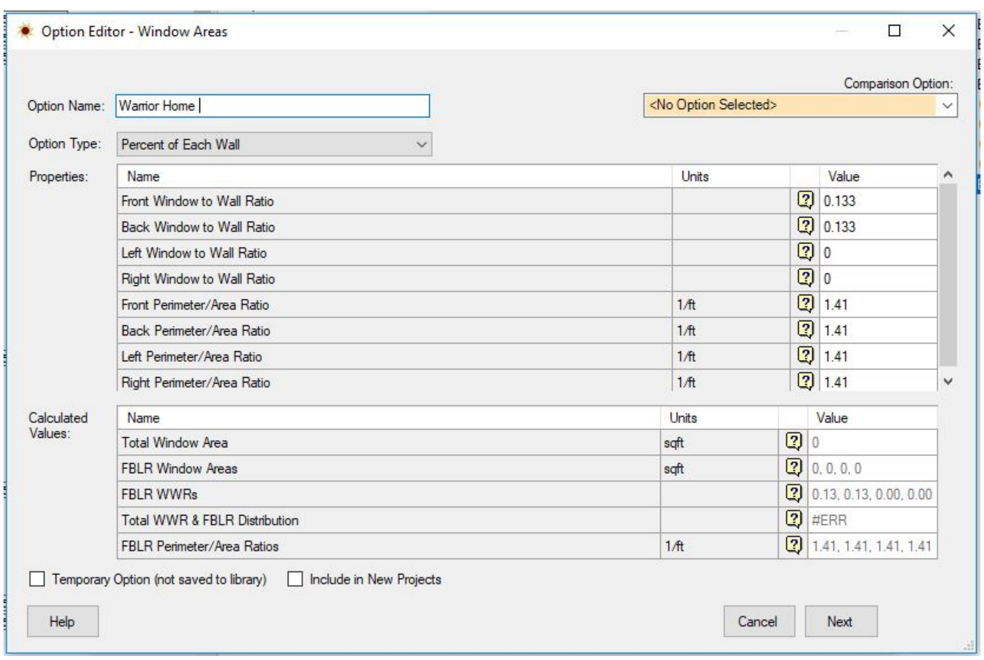

Figure 11: Option Editor – Window Areas

- Again, edit the cost items in the **Option Editor** as shown below, then click **Finish**

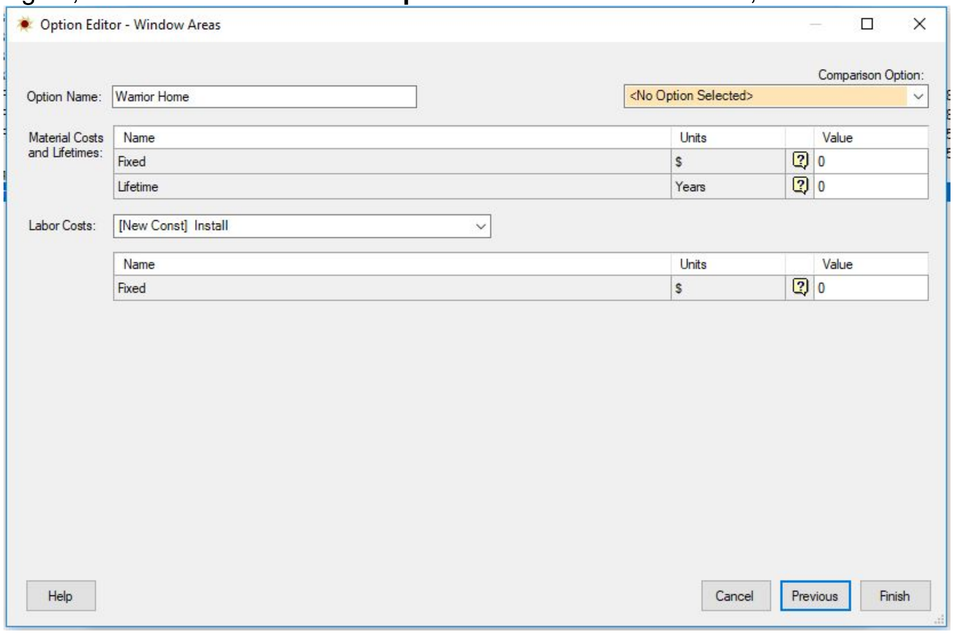

Figure 12: Option Editor – Windows Areas

- The new option created will appear in the main **Option Manager** window. Check 'In Library' and 'In Current Project' to ensure the project you created appears in the **Options Screen.** Then Click Close

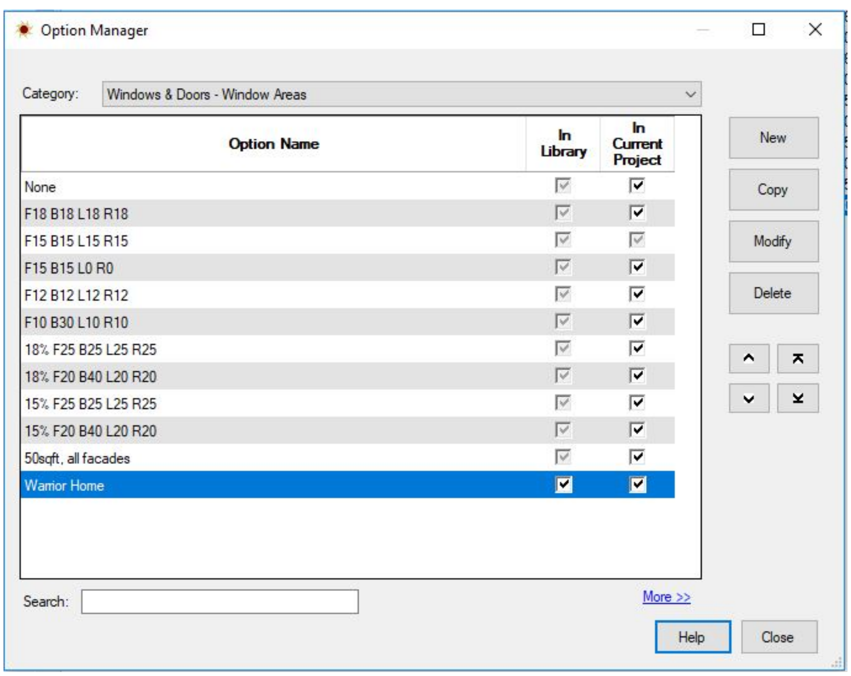

Figure 13: Option Manager

- This will create a new Option called “Warrior Home Window to Wall Ratio” , Select this option as your input for **Windows Area**

Option	Total Window Area [sqft]	FBLR Window Areas [sqft]	FBLR WWRs	Total WWR & FBLR Distribution	FBLR Perimeter/Area Ratios [1/ft]	Window Area Fraction of Wall Area	Front Fraction of Total Window Area	Back Fracti of Total Window Ar
1) None								
2) F18 B18 L18 R18	611	207, 207, 98, 98	0.18, 0.18, 0.18, 0.18	0.18 0.34, 0.34, 0.16, 0.16	1.41, 1.41, 1.41, 1.41			
3) F15 B15 L15 R15	509	173, 173, 82, 82	0.15, 0.15, 0.15, 0.15	0.15 0.34, 0.34, 0.16, 0.16	1.41, 1.41, 1.41, 1.41			
4) F15 B15 L0 R0	346	173, 173, 0, 0	0.15, 0.15, 0.00, 0.00	0.10 0.50, 0.50, 0.00, 0.00	1.41, 1.41, 1.41, 1.41			
5) F12 B12 L12 R12	407	138, 138, 65, 65	0.12, 0.12, 0.12, 0.12	0.12 0.34, 0.34, 0.16, 0.16	1.41, 1.41, 1.41, 1.41			
6) F10 B30 L10 R10	570	115, 346, 54, 54	0.10, 0.30, 0.10, 0.10	0.17 0.20, 0.61, 0.10, 0.10	1.41, 1.41, 1.41, 1.41			
7) 18% F25 B25 L25 R25	611	153, 153, 153, 153	0.13, 0.13, 0.28, 0.28	0.18 0.25, 0.25, 0.25, 0.25	1.41, 1.41, 1.41, 1.41	0.18	0.25	0.
8) 18% F20 B40 L20 R20	611	122, 244, 122, 122	0.11, 0.21, 0.22, 0.22	0.18 0.20, 0.40, 0.20, 0.20	1.41, 1.41, 1.41, 1.41	0.18	0.2	(
9) 15% F25 B25 L25 R25	509	127, 127, 127, 127	0.11, 0.11, 0.23, 0.23	0.15 0.25, 0.25, 0.25, 0.25	1.41, 1.41, 1.41, 1.41	0.15	0.25	0.
10) 15% F20 B40 L20 R20	509	102, 204, 102, 102	0.09, 0.18, 0.19, 0.19	0.15 0.20, 0.40, 0.20, 0.20	1.41, 1.41, 1.41, 1.41	0.15	0.2	(
11) 50sqft, all facades	200	50, 50, 50, 50	0.04, 0.04, 0.09, 0.09	0.06 0.25, 0.25, 0.25, 0.25	1.41, 1.41, 1.41, 1.41			
12) Warrior Home	306	153, 153, 0, 0	0.13, 0.13, 0.00, 0.00	0.09 0.50, 0.50, 0.00, 0.00	1.41, 1.41, 1.41, 1.41			

Figure 14: New Customized Option added to the list of Existing Options

- Repeat these steps for all customized options presented in the detail sheet

Step 3: Running the Simulation

- When you have completed adding the inputs from the detail sheet click on Run:
- Change the running time to 10 minutes as shown in the screen shot below

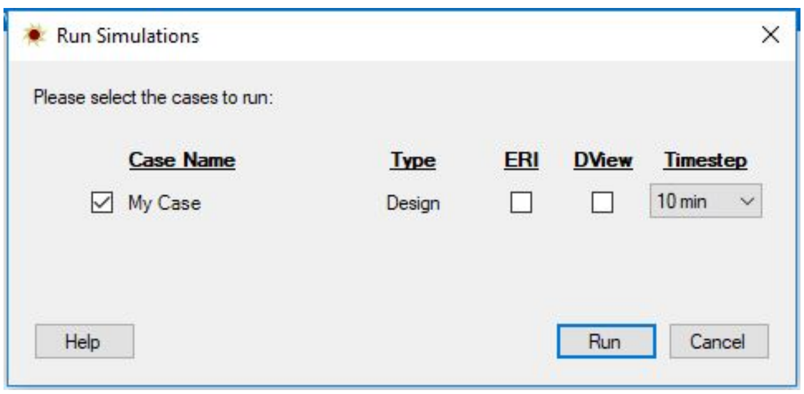

Figure 15: Simulation Run Time

- The output window will give you 3 graphs demonstrating the energy emissions from all four units

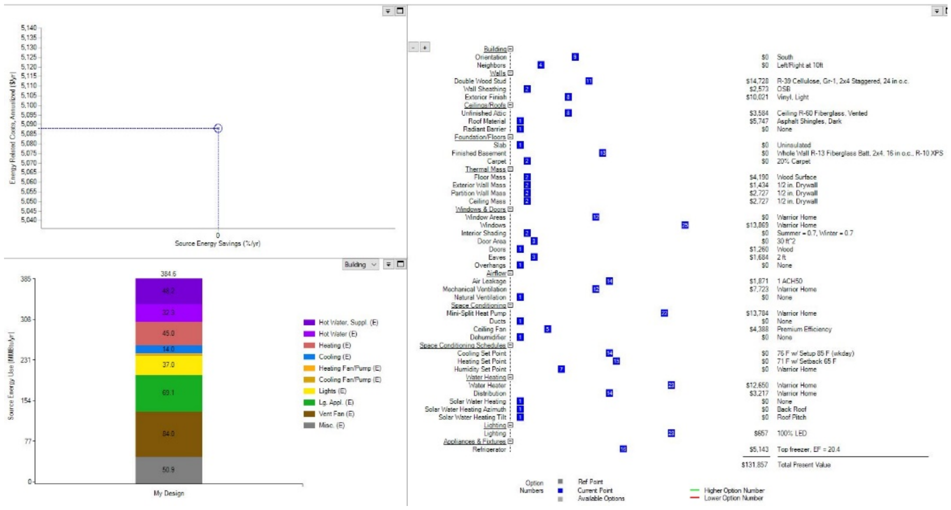

Figure 16: Output screen

- If you want to change the input right click on each you can customize the data that you want view. The table below lists all the graphs you can view:

Table 1: Detailed Results of the Energy Modelling Simulation

Output	Unit	Value	Total
Source Energy Use (MMBtu/yr)	1	99.4	384.6
	2	93.7	
	3	94	
	4	97.5	
Annualized Utility Bills ($/yr)	1	1305	5088
	2	1248	
	3	1244	
	4	1297	
Site Energy Use (MMBtu/yr)	1	31.6	122.1
	2	29.8	
	3	29.9	
	4	31.0	
Site Energy - Electricity Use (kWh/yr)	1	9250	35785
	2	8719	
	3	8751	
	4	9071	
Site Energy – Natural Gas (Therms/yr)	Whole Unit	0	0
Site Energy – Oil (gal/yr)	Whole Unit	0	0
Site Energy – Propane (gal/yr)	Whole Unit	0	0
CO2e Emissions (Metric tons/yr)	1	6.4	24.8
	2	6	
	3	6.1	
	4	6.4	
Delivered Energy (MMBtu/yr)	1	30.1	111.9
	2	25.9	
	3	25.8	
	4	30.1	

Loads Not Met (Hours/yr)	1	1952	7029
	2	1580	
	3	1537	
	4	1960	
HVAC Capacities (kBtu/hr)	1	8.2	32.3
	2	8	
	3	8	
	4	8.2	

- If you need to re-run the model you will have to clear the output you have because by default BEopt locks editing when the output is viewed.

Supporting Material

**needed to complete tutorial*

- *CAD Drawings
- *242 Kehl St. Input Details
- BEOpt Website:

References

[1] Greenhouse Gas Emissions Associated with Various Methods of Power Generation in Ontario. Intrinsik, 2016. Obtained from: https://www.opg.com/darlington-refurbishment/Documents/IntrinsikReport_GHG_OntarioPower.pdf

[2] Global warming potentials. Government of Canada, Intergovernmental Panel on Climate Change. 2012. Obtained from: https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/quantification-guidance/global-warming-potentials.html

20 Mill Street | Assignment

Notes:	- Complete the following calculation and discussion questions. - Always show units, and cite sources, where appropriate. - Clearly indicate final answers. - Minimum standards of neatness are expected.

Calculation Questions:

1. How much energy, in gigajoules (GJ), would 3,000 m^3 of natural gas yield? Is this a reasonable amount of natural gas for a home in northern Canada to use in a given year if it uses natural gas as its primary fuel source? *Hint: Compare to the Canadian average from 2011 given on page 3.*

   Solution:

$$3{,}000\text{m}^3\left[\frac{37.3\text{MJ}}{\text{m}^3}\right]=111.9\text{ GJ}$$

   Yes, this is a reasonable amount of energy for a typical northern Canadian home to use, considering the 2011 average yearly energy use of 105 GJ. Some electricity use would put the total household use higher than 111.9 GJ, but it is still a reasonable value.

2. How much energy, in gigajoules (GJ), would 85 kWh of electricity yield? Is this a reasonable amount of electricity for a home in Canada to use in a given year if it uses electricity as its primary fuel source? If not, over what period of time might a house use this much electricity?

   Solution:

$$85\text{kWh}\left[\frac{3.60\text{MJ}}{\text{kWh}}\right]=0.306\text{ GJ}$$

   No, this is not a reasonable amount of energy for a typical Canadian home to use in a given year, considering the 2011 average yearly energy use of 105 GJ. This would be more representative of a single day. A typical Tesla model S has a batter this large (can travel ~ 500 km).

3. Table 1 displays costs of fuel types in Ontario that were used for the Hot2000 Analyses of 20 Mill Street. These costs will not necessarily remain stable as time goes on but were reflective of the conditions at the time of renovation. Compare the relative cost of energy from Electricity, Natural Gas, Heating Oil, and Wood, normalized per MJ. Take the density of heating oil to be 0.92 g/cm^3, and 1 chord of wood to weigh 3,000 kg. *Hint: Use* ***Error! Reference source not found.****.*

Table 1: Hot2000 Fuel Cost Library [7]

FUEL TYPE	COST
Electricity	0.11 $/kWh
Natural Gas	0.45 $/m³
Heating Oil	0.80 $/L
Propane	0.95 $/L
Wood	300$/chord

   Solution:

FUEL TYPE	COST (cents/MJ)
Electricity	3.06
Natural Gas	1.21
Heating Oil	1.88
Wood	0.62

We see that Natural Gas is about 2x more expensive than wood per energy yield. By comparison, heating oil is 3x more expensive, and Electricity is 5x more expensive.

4. The HOT2000 report for the REEP House provides a comparison of energy consumption before and after the renovations. This includes space heating, domestic heat water, space cooling and appliances. Consult each report and find the sections titles: ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY. Use the total fuel consumption listed to calculate greenhouse gas emissions for both before and after the renovation. For natural gas use the emission factor given in **Error! Reference source not found.**, and for electricity use 150.6 g CO_2e/MJ.

5. Add up the total energy used by the house in a given year, before and after the renovation (use total fuel consumption and convert to energy in MJ). Comment on how much energy usage was reduced, compared to greenhouse gas emissions calculated in question 4.

Solution to 4 and 5:

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	5.75	
					54,013.54	MJ	6.547	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	5.08	
					202,155.56	MJ	13.554	tonnes CO_2e
Natural Gas to CO^2 e	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**150.60**	g/MJ	0.000151	tonnes/MJ				

Even though energy was reduced by a factor of 4, the emissions were only halved. This is because the electricity emission factor used was 150.6 g/MJ, three times higher than the natural gas emission factor of 50.32, and the newly renovated home actually used more electricity after the renovation! Emissions would be drastically reduced if the source of the electricity was altered.

6. Derive the 21.6 g/MJ value given for the emission factor for Ontario electricity in 2015. Visit https://cns-snc.ca/media/ontarioelectricity/ontarioelectricity.html and calculate the emission factor for electricity in Ontario for today.

Solution:

OPG Report					
Type	**Distribution**	**LCA g/kWh**			
Nuclear	59.0%	17	10.03		
Hydro	24.0%	18	4.32		
Solar	1.0%	39	0.39		
Wind	6.0%	14	0.84		
Gas	10.0%	622	62.20		
	100.0%		77.78	g/kWh	
			21.61	g/MJ	
LIVE! 10/26/2018					
Type	**Generation MW**	**Distribution**	**LCA g/kWh**		
Nuclear	9,991	57.0%	17	9.70	
Hydro	4,905	28.0%	18	5.04	
Solar	1,287	7.3%	39	2.87	
Wind	1,233	7.0%	14	0.99	
Gas	99	0.6%	622	3.52	
	17,515	100.0%		22.11	g/kWh
				6.14	g/MJ

7. Repeat question 4 using an electricity emission factor of 7.8 g/MJ for British Columbia, and a 225 g/MJ value for Alberta (2013 values). Comment on the results.

   Solution:

   British Columbia

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	0.30	
					54,013.54	MJ	1.095	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	0.26	
					202,155.56	MJ	8.739	tonnes CO_2e
Natural Gas to CO^2 ec	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**7.80**	g/MJ	0.000008	tonnes/MJ				

   Alberta

After Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	424.92	m^3	**37.3**	**MJ/m^3**	15,832.23	MJ	0.80	
Electricity	10,605.92	kWh	**3.60**	**MJ/kWh**	38,181.31	MJ	8.59	
					54,013.54	MJ	9.388	tonnes CO_2e
Before Renovation	**Total Consumption**		**Energy Factor**		**Energy**		**Emissions**	
Natural Gas	4,520.78	m^3	**37.3**	**MJ/m^3**	168,441.16	MJ	8.48	
Electricity	9,365.11	kWh	**3.60**	**MJ/kWh**	33,714.40	MJ	7.59	
					202,155.56	MJ	16.062	tonnes CO_2e
Natural Gas to CO^2 ec	**50.32**	g/MJ	5.0323E-05	tonnes/MJ				
Electricty to CO^2 eq	**225.00**	g/MJ	0.000225	tonnes/MJ				

Discussion Questions:

1. Rank the fuel sources of Wind, Solar, Hydro, Natural Gas, and Nuclear on their overall sustainability. Why have you chosen the order you have? Consider more than just carbon emissions – what unintended downsides result from the use of each of these fuels?

   Nuclear (risk of disaster, storage of radioactive nuclear waste, heating of mass quantities of water for cooling, large transmission distances)
   Hydro (damming of rivers and associated ecological damage, large transmission distances)
   Wind (upset farmers, micro-vibrations in the soil, low yields at times of power usage)
   Solar (recycling of equipment, large amount of real estate taken up)

2. Using the results from questions 4 and 6, comment on how the electrical grid in Ontario has changed from the year 2009 (when the 20 Mill Street renovation was completed), to the year 2015, to today. Do you anticipate future changes? What strategy would you recommend to a local political for Ontario's future?