Introduction:

In this project, the aim is to model a 2-story apartment unit, calibrate the model to match measured utility data, and then use that model to find the most cost-effective retrofit package that will reduce the site's energy usage while still having a relatively low payback period of around 10 years. The modeled space is a unit in The Altitude Apartments (Figure 1) in Golden Colorado, with neighbors 10 ft offset to the right and left (Figure 2). The building was constructed in (1996), and each unit in it has a (945 ft^2) floor area made up of 2 bedrooms 2 bathrooms, a kitchen, and a small living space.

Figure 1: Photo of Modeled Building

For validation, data from the year 2018 (January to August) for both the natural gas and electricity usage was used. Although the project focuses on one unit out of four, a model for the entire building was used to achieve an improved accuracy (Figure 3).

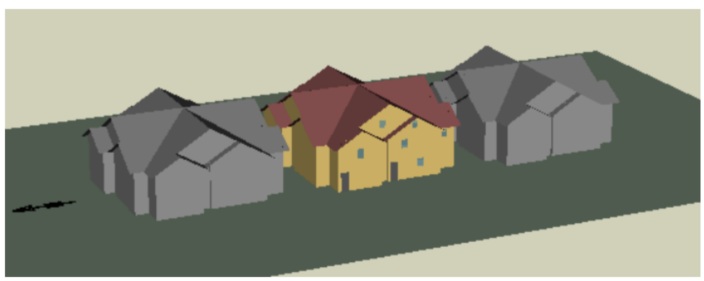

Figure 3: BEopt 3D model of the building

Methodology:

BEopt 2.8.0.0 was used with the Retrofit, Multifamily option, the dimensions of the house were measured including the windows and doors. For the other units (neighbors) a symmetry assumption was made, and the units were modeled using a rotational mirror. The weather file used was for Colorado, Golden (suburban) and the utility rate was defined based on previous bills to estimate savings.

Some of the unknown construction materials were chosen through the retrofit section from the Building America house simulation protocols and the information in the Building component library at NREL's website. The components were selected from a list of filtered results for residential 5B zone.

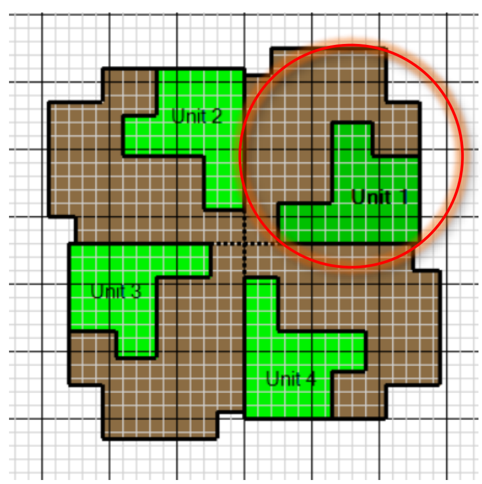

Figure 4: Unit layout (2nd floor in green)

After selecting the most likely construction materials, data was entered for the central air conditioning unit, the furnace, the ducts, the water heater, lightning, appliances, plugged in loads, etc... usage schedules were then defined.

Some of the inputs were customized since the default available options in BEopt did not match what was measured, those included the windows front and right areas and all the perimeter to area ratios. the hot water fixture and the cooling and heating set point schedules were also customized.

Some of the options selected were based on educated guesses. Those selections were later optimized by comparing the output of the simulation to electric and gas utility data. The mean absolute percent error and mean square error were used as a metric to refine those options. The simulation was repeated multiple times with different options until an option that made those metrics sufficiently low was identified.

To reduce the utility bills by 15% the following options will be investigated:

1) Switching the finished roof from (Uninsulated, 2x8) to (R-30 Fiberglass, 2x8).
2) Switching the finished Roof from (Uninsulated, 2x80 to (R-47 closed cell spray foam).
3) Switching the windows from (Clear, double, Metal, Air) to (Low-E, double, insulated, air, H-gain).
4) Reducing the air leakage from (10 ACH50) to (7 ACH50).
5) Changing the central air conditioner from a (SEER 13) to a (SEER 16) unit.
6) Switching the furnace from a (Gas,80% AFUE) to a (Gas,95% AFUE) unit.
7) Changing the water heater from a (Gas Standard) to a (Gas tankless, condensing) unit.
8) Changing the lights from (100% Incandescent) to (100% LED).

To identify the best option/mixture of options out of the ones listed above, A BEopt Optimization analysis was carried out over a 20-year simulation period. The site energy savings per year versus the simple payback period was used to select an approach. The approach with the highest percent saving, while having a payback period close to 10 years is going to be preferred.

Results:

• Calibration:

The simulation data output from BEopt did not match measured natural gas and electricity utility data exactly even after modifying multiple options (Figures 5, 6 & Table 1) this could be due to multiple factors:

- The weather file selected for the area (USA_CO_Golden-NREL.724666_TMY3) did not match actual weather data this year (2018).
- Differences between actual and modeled building and equipment degradation could result in a mismatch in performance.
- The appliances and thermostat schedules are not fixed.
- The temperature setpoints for neighbors could create a large temperature differential across shared walls, resulting in energy flow between the units.
- The exact building materials and component information cannot be accurately represented.

After multiple iterations, the root mean square error for the electric bill was reduced to 49.57 (mean absolute percent error of 11.3%) and the RMSE value for the natural gas bill to 4.67 (mean absolute percent error of 9.1%).

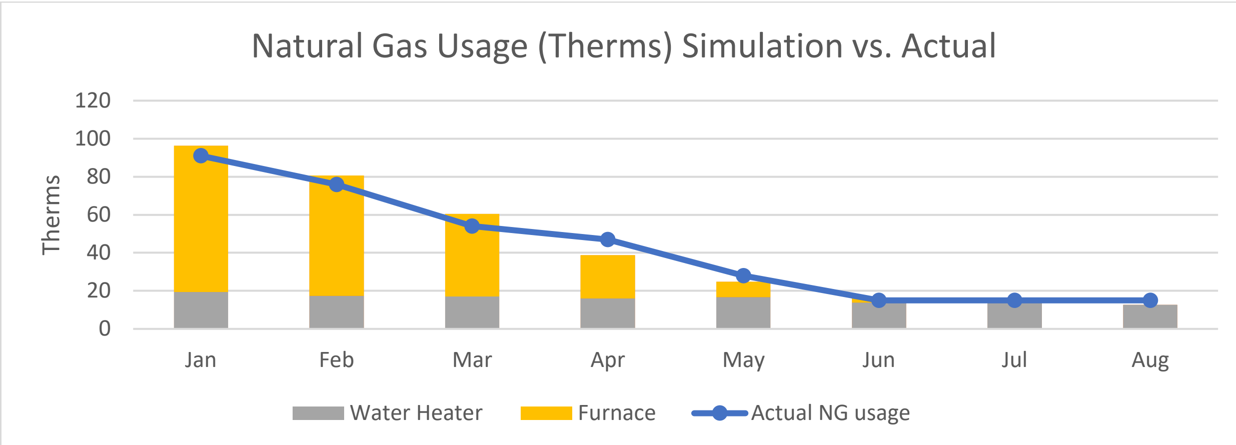

Figure 5: Natural gas usage (Thems) BEopt simulation vs. actual reported on utility bill

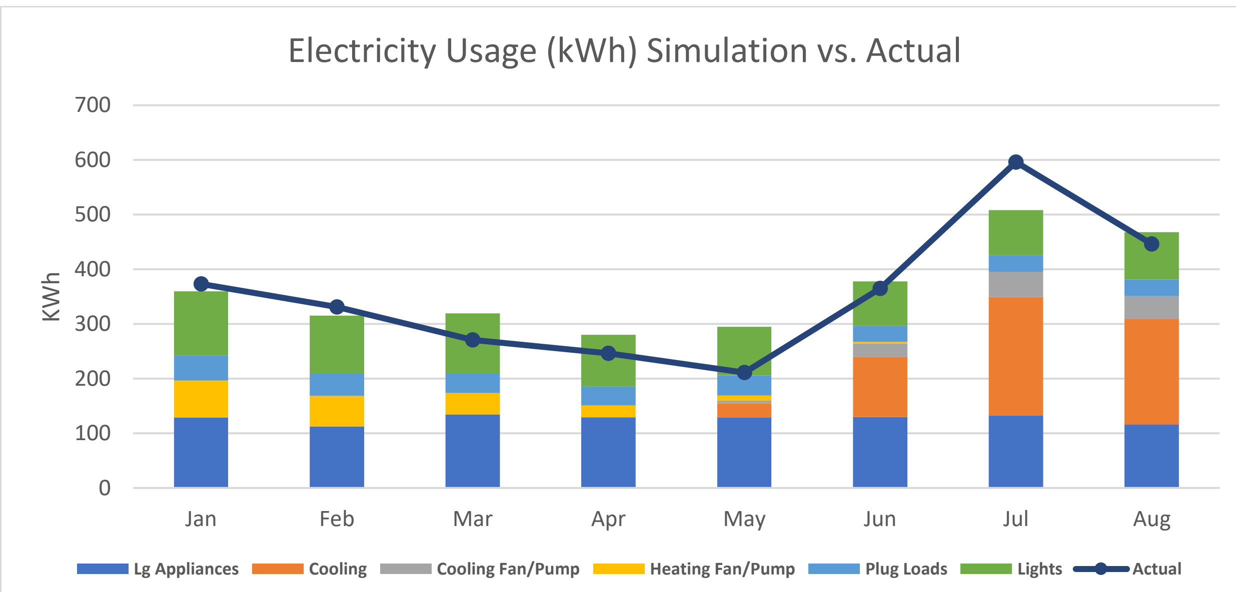

Figure 6: Electricity usage (kWh) in BEopt simulation vs. actual reported on utility bill

Month	Actual Electricity usage (kWh)	Simulation Electricity usage (kWh)	Actual NG usage (Therms)	Simulation NG usage (Therms)
Jan	373	361.63	91	96.26
Feb	331	316.76	76	80.63
Mar	271	320.94	54	60.37
Apr	246	281.93	47	38.8
May	211	296.9	28	24.73
Jun	365	379.53	15	16.22
Jul	596	510.01	15	15.21
Aug	446	469.64	15	12.69

Table 1: Actual usage reported on utility bill vs. Electricity and NG usage from BEopt Simulation

- ## Retrofit analysis:

An Optimization analysis was carried out using BEopt over a 20-year simulation period. The analysis found 8 optimal points which are compared on a site energy savings per year versus simple payback period plot (Figure 6).

Point 8 has the highest % energy saving per year, this package includes switching to a higher efficiency central air conditioning unit (SEER 16) and changing the incandescent lights to LEDs, but taking the payback period of 30 years into consideration, we can conclude that this is not the best energy saving package based on our 10-year payback target.

Optimal point 1 (Switching to LEDs) has a 1-year payback period, but by itself, it only accounts for a 1% energy saving/year. The best 3 approaches considering the payback period would be points (2, 3 and 4) all have a significant effect on energy saving, while keeping the payback period relatively low. Table 2 lists the optimal points, their site energy savings, and their payback period.

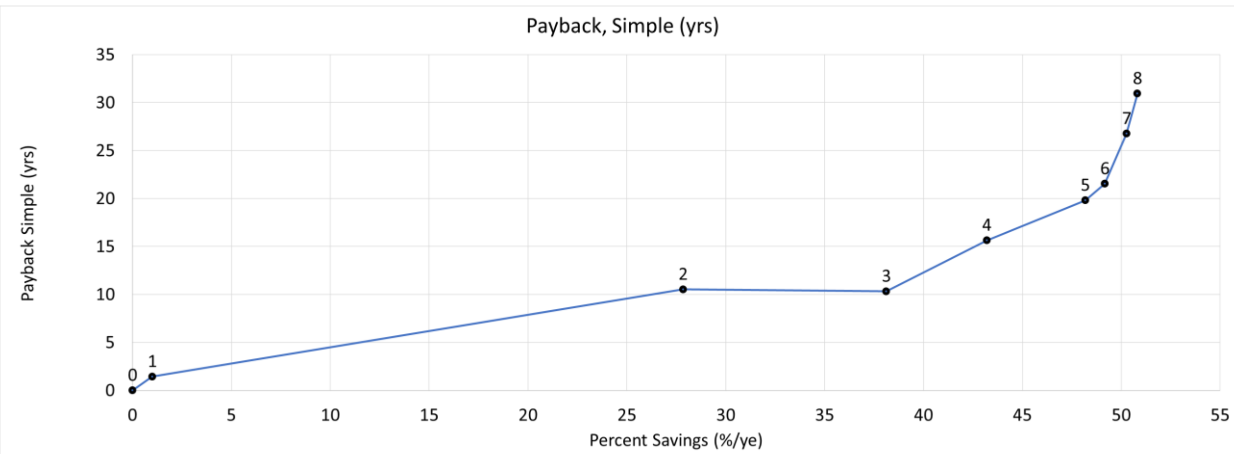

Figure 7: Optimal Points from the BEopt optimization results, Payback Period (yrs) vs. Site energy savings (%/yr)

Saving Package	Point No.	Site Energy Savings (%/yr)	Payback, Simple (yrs)
Original Design	Reference 0	0.00	NA
Lightning (LED)	Optimal Point 1	1.00	1.43
Finished Roof (R-30 Fiberglass) + Lights (LED)	Optimal Point 2	27.84	10.52
Air Leakage (7 ACH50) + Lights (LED)	Optimal Point 3	38.12	10.32
Furnace (95%) + Lights (LED)	Optimal Point 4	43.20	15.64
Water heater (Gas tankless, condensing) + Lights (LED)	Optimal Point 5	48.18	19.81
Windows (Low-E, insulated, air, H-gain) + Lights (LED)	Optimal Point 6	49.17	21.53
Finished Roof (R-47 closed cell spray foam) + Lights (LED)	Optimal Point 7	50.27	26.76
Central Air Conditioner (SEER 16) + Lights (LED)	Optimal Point 8	50.82	30.93

Table 2: The site energy savings and the payback period for the saving packages

Conclusion:

An energy optimization analysis is an easy first step that can be taken to decrease the environmental footprint of a building while reducing utility bills. Simple steps, such as switching to LED lights, or adding spray foam insulation to uninsulated panels can be identified, and their effect on the performance of the building can be compared to other options. Identifying key metrics and targets from the start helps guide the study and having access to utility bills makes the analysis more accurate.

Based on the design goal of achieving the highest energy saving with a 10-year payback period. The best optimal point from Figure 6 would be point 3 (Improving the air leakage to 7 ACH50 + switching to 100% LED lights) this approach is expected to reduce the site energy savings of the building to 38% and has a 10-year payback period.

By calculating the electrical site energy savings alone from package 3, bill reduction is expected to be 18.44%, with a total electricity savings of 757 kWh per year. (Figure 7 & Table 3)

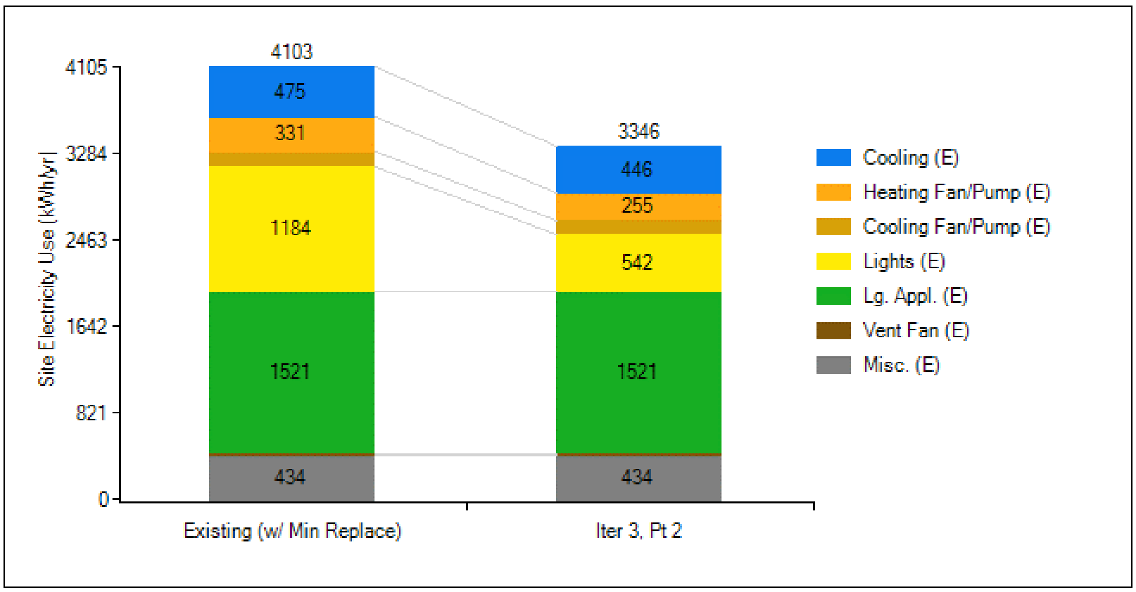

Figure 8: Electrical site energy savings from optimal point 3

	Original Design	Optimal Point 3
Misc. (E)	433.77	433.77
Vent Fan (E)	20.52	20.52
Lg. Appl. (E)	1521.11	1521.11
Lights (E)	1184.06	542.2
Cooling Fan/Pump (E)	136.87	128.08
Heating Fan/Pump (E)	331.18	254.98
Cooling (E)	475.23	445.78
Total	4103	3346

Table 3:Electrical site energy savings from optimal point 3

Natural gas usage after package 3 measures are taken is expected to be reduced by 15.94%, with a total NG savings of 84.5 Therms per year. (Figure 8 & Table 4)

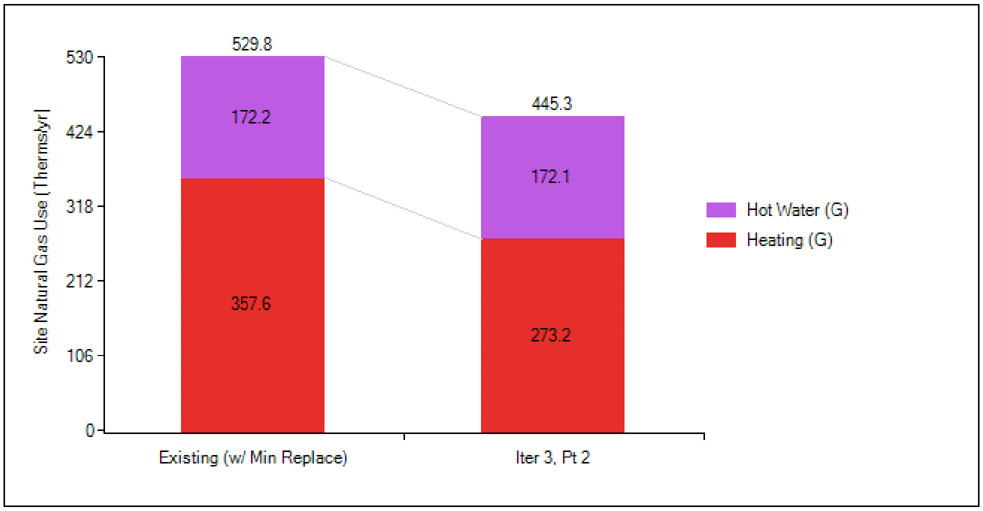

Figure 9: Natural Gas site energy savings from optimal point 3

	Original Design	Optimal Point 3
Heating (G)	**357.6**	**273.2**
Hot Water (G)	**172.2**	**172.1**
Total	**529.8**	**445.3**

Table 4: Natural Gas site energy savings from optimal point 3