Establishment and Analysis of Baseline Electrical Data for Thermalize Juneau Campaign

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ABSTRACT

The City and Borough of Juneau has a goal to reach 80% renewable energy for heating and transportation sectors by 2045. [1] Ductless heat pumps are one way to help reach this goal because they reduce heating costs for residential units and are fully renewable space heating appliances when combined with Juneau's hydropower grid. Our project, Thermalize Juneau 2021, focuses on the education, deployment, and analysis of DHPs within Juneau, Alaska. We are researching ways to make DHPs affordable as well as evaluate their efficiency in cold climates. To do so, we needed to have baseline data for energy usages so that we can compare post-retrofit data after one heating season. In this project, we established and analyzed the statistical time series analysis of baseline electrical consumption data.

I. INTRODUCTION

The DOE Office of Energy Efficiency and Renewable Energy's mission is to transition America to net-zero greenhouse gas emissions by 2050. [2] However, cold climate housing, such as those in Juneau, Alaska, can have difficulty finding fully renewable energy for heating due to their high heating load. The National Renewable Energy Laboratory (NREL) researchers at Cold Climate Housing Research Center (CCHRC) are finding ways to effectively provide heat in cold climate housing conditions, in hopes to lower energy costs and greenhouse gas emissions.

A. Thermalize Juneau 2021

Juneau, Alaska's main source of electricity comes from hydropower plants, but it only accounts for 20% of the city's total energy consumption. [3] The remaining 80% of energy usage is associated with fossil fuel consumption and over one-fourth of it is used for building heating. [3] In response to climate change and energy resiliency concerns, the City and Borough of Juneau, Alaska has set an ambitious goal to reach 80% renewable energy deployment for heating and transportation by 2045. [1]

One proposed way of reaching this goal is through the installation of ductless heat pumps (DHPs). DHPs are three to four times more efficient than a fuel oil furnace or electric resistance heater and can help save on average 10,000 pounds of CO_2 annually per unit. [3] But one of the largest barriers to the adoption of heat pumps is the installation cost, which can run between $4,000 and $5,000.[4] CCHRC, along with several local partners including Alaska Heat Smart (AHS), obtained funding from the Department of Energy to use a thermalize campaign, Thermalize Juneau 2021, to lower the cost of DHP installations through bulk purchasing.

Thermalize Juneau is an energy efficiency project and a community wide campaign that promotes the adoption of DHPs. This initial round of the campaign has 196 registered participants. The project facilitated a competitive selection process for heat pump installers and energy efficiency contractors. It also provided Juneau residents with free heat pump assessment and energy audit, and heat pump and weatherization incentives. The major objective is to reduce the cost of heating houses in Juneau using renewable energy powered heat pumps and improve residential unit energy efficiency. [5]

B. Air Source Heat Pumps (ASHPs)

Heat pumps are innovatively different from other commonly used heating methods and technologies because they use energy to move heat instead of to create heat. An air source heat pump is a partially renewable heating appliance that gathers heat from outdoor air, uses electricity to step it up to a usable temperature and delivers it to indoor units. Surprisingly, cold ambient air still contains heat which can be extracted using a refrigeration cycle. This cycle uses a fluid, called a refrigerant, that changes in temperature as it transforms from liquid to gas due to different pressurizations.

In an ASHP, the refrigerant travels through outdoor heat exchanger coils, or the evaporator. It loses pressure and turns into a gas that is much colder than the temperature outside. Based on the 2nd Law of Thermodynamics (heat flows from hot to cold), the refrigerant can extract heat from the outside environment through the transfer of energy. This gas then goes to a compressor, which uses electricity to raise the temperature of the refrigerant gas until it is suitable for space heating. [6] Afterward, this gas passes through indoor heat exchanger coils, or the condenser, where it releases heat as it condenses back into liquid. Finally, the liquid refrigerant moves into an expansion valve, which lowers its pressure, and begins the cycle again. [6]

In a traditional ducted ASHP system, heat is distributed to individual rooms by ducts. Mini-split ductless ASHPs, or ductless heat pumps (DHPs), have indoor wall-mounted units that deliver heat directly to a room. [7] The manufacture and model used for Thermalize Juneau is Daikin's AURORA ductless heat pump. [8] Within this campaign, heat pumps are considered 100% renewable heating appliances because they are air-sourced and use electricity generated by Juneau's hydropower plants.

C. Research Objective

Recent DHP models have been developed to improve the efficiency of heat extraction in temperatures below freezing. [6] DHPs also have the potential to reduce residential heating costs, because they use electricity only to move heat, not create it and thus use less electricity than electric resistance heating appliances. However, because DHPs have not been utilized as much in colder climates, their capacity to produce energy savings is still being established.

To validate real-world energy savings and analyze post-retrofit data, we needed to first establish baseline conditions for energy use and greenhouse gas emissions for the participants of Thermalize Juneau. Much of the baseline residential unit data from the campaign was not compiled in an accessible or readable format. Access to this data and information is critical to the evaluation of the energy savings of the campaign, therefore we developed a method to clean and arrange the baseline electrical data using Google Collaboratory.

This report shows how we processed and decomposed baseline electrical data and explored its seasonal attributes and the possible effects of Covid-19. All the analysis was done using Python 3.6.9.

II. DATA PROCESSING

A. Collection

Registered participants of Thermalize Juneau gave CCHRC permission to collect their electric data from Alaska Electric Light and Power Company (AEL&P), Juneau's power utility. This data measured electrical intake in kilowatt-hour (kWh) and established validity because it came directly from AEL&P and is the same data used for billing. The sampling scheme used was random because it was collected based on AEL&P's billing period and not by calendar month.

The data was available in excel, and sometimes pdf, formats for each residential unit. However, due to collection and verification issues of a few properties, only data from 165 out of 196 residential units were used in creating baseline electrical data. Depending on the active tenancy of the residential units, the data's timeline ranged from January 2017 the earliest to October 2021 the latest.

B. Manipulation

For this project, we filtered AEL&P data to range from years 2018-2020, with the addition of 2017 and 2021 if applicable. Still retaining 165 residential units, we calculated the number of days between each billing period, divided the electrical consumption by that number and equally allocated the resulting electrical consumption to each of those days. This uniformly created data reflecting daily electrical consumption, establishing accuracy and just consistency.

We resampled the data to reflect the calendar month by converting daily electrical consumption to monthly electrical consumption. Then we combined each of the 165 datasets by month into one coherent dataset of the target population. This resulted in a multi-site dataset, complete with equal probability. This data was now classified as a time series because it is a sequence of observations recorded at regular time intervals.

III. EXPLORATORY DATA ANALYSIS

A. Data Observations

First, we plotted the monthly electrical consumption of all 165 residential units over time, depicted in Figure 1. We saw that the majority of the unit's electrical energy usage ranged between 500 kWh and 1000 kWh, with the possibility of few outliers. We also saw that electrical energy usage constantly spiked up during certain times of the years, suggesting a seasonal component. Notice that most of the houses trailed off as they approached year 2021, because not all units provided the current year's electrical energy consumption.

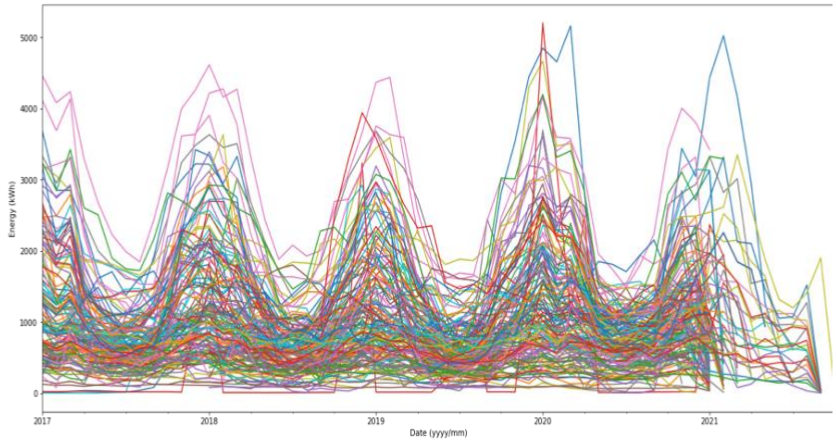

Figure 1: Monthly Electric Consumption of all 165 Thermalize Juneau Residential Units

In Figure 2, we plotted the mean and five-number summary of the data. The mean represents the average electricity usage within the target population. Once data is set in numeric order, the five-number summary can provide information about the location, spread and range of the observations. Over time, there was a consistent large gap between the maximum and 3rd quartile monthly electricity usage. This suggests that distribution of the data points was a right-skewed unimodal frequency distribution. This distribution gap solidified the outliers we saw in our initial observation. In this case, the median was a better measure of central tendency than the mean.

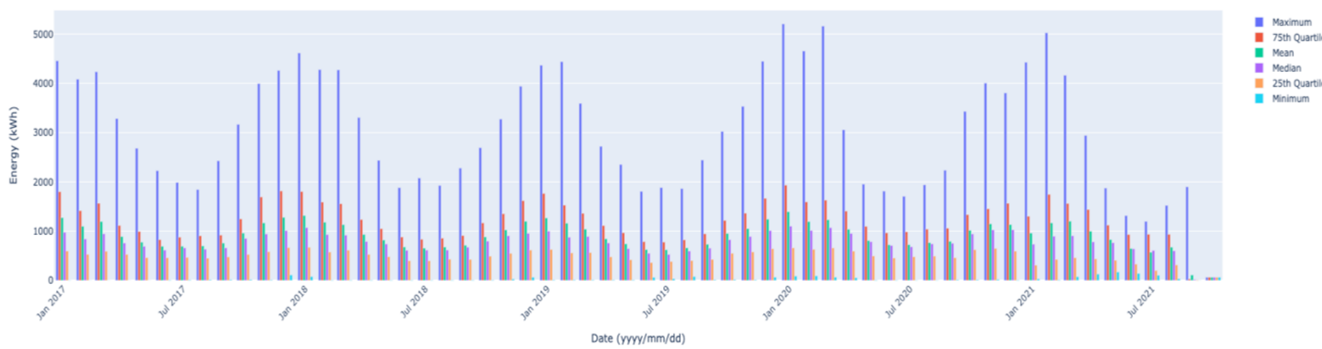

Figure 2: Mean and Five-Number Summary of Monthly Electric Consumption.

We also looked at the five-number summary and overall total of yearly electric consumption for years 2017-2020, seen in Table 1. Within the mean and five-number summary, there was only about 1000-2000 kWh increase between 2019 and 2020. Looking at the yearly totals, there was a significant 5000 kWh increase from 2019 to 2020, but there also was one during non-Covid years from 2017 to 2018. This suggests that there could be many other factors for increase electricity usage. Based on these statistics, it cannot be confirmed that Covid-19 had a significant effect on electricity usage for Thermalize Juneau participants.

Table 1: Sample Table

Year	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	Total
2017	1215.00	5760.00	8497.15	10058.29	13964.86	38647.83	78143.14
2018	957.19	6454.80	9622.84	11202.49	15689.12	35994.00	79920.44
2019	993.71	6098.09	9553.81	10935.56	15034.07	32319.42	74934.64
2020	202.13	7438.34	10890.60	11648.42	15030.97	34617.71	79828.17

B. Time Series Decomposition

We decomposed the time series to understand the inherent nature of our target population, monthly median electricity consumption. Figure 3 depicts our time series decomposition consisting of four plots: observed, trend, seasonal, and residual. The observed plot showed the monthly median electricity consumption over time. The consumption levels tend to be high in the beginning of the year and then decrease drastically six months later. This pattern continued over the four years the data was collected on.

The trend component of a time series represents the overall direction and long-term movement of the data values. In our trend plot, we saw that from 2017 to the start 2019, there was a constant downward movement of electricity consumption levels. However, towards the end of 2019 throughout 2020, there was a major upward spike in consumption levels, suggesting a possible effect of Covid-19. For the remainder of the period, the consumption levels seemed to stabilize around 900 kWh. Overall, the trend showed a consistent linear incline, with a slight curve as it potentially reaches equilibrium.

The seasonal component of a time series represents the oscillation within yearly variations that is steady over time, direction, and magnitude. Our seasonal plot showed yearly seasonal shifts in electricity consumption levels. This confirmed what we presumed in our observed plot: Electricity consumption periodically fluctuates in value approximately every six months for Thermalize Juneau participants.

The residual component of a time series represents the random unexplainable parts of the data that cannot be assigned to trend or seasonality. The remaining data in our residual plot looked to be inconsistent in values and therefore may not have constant mean or variance.

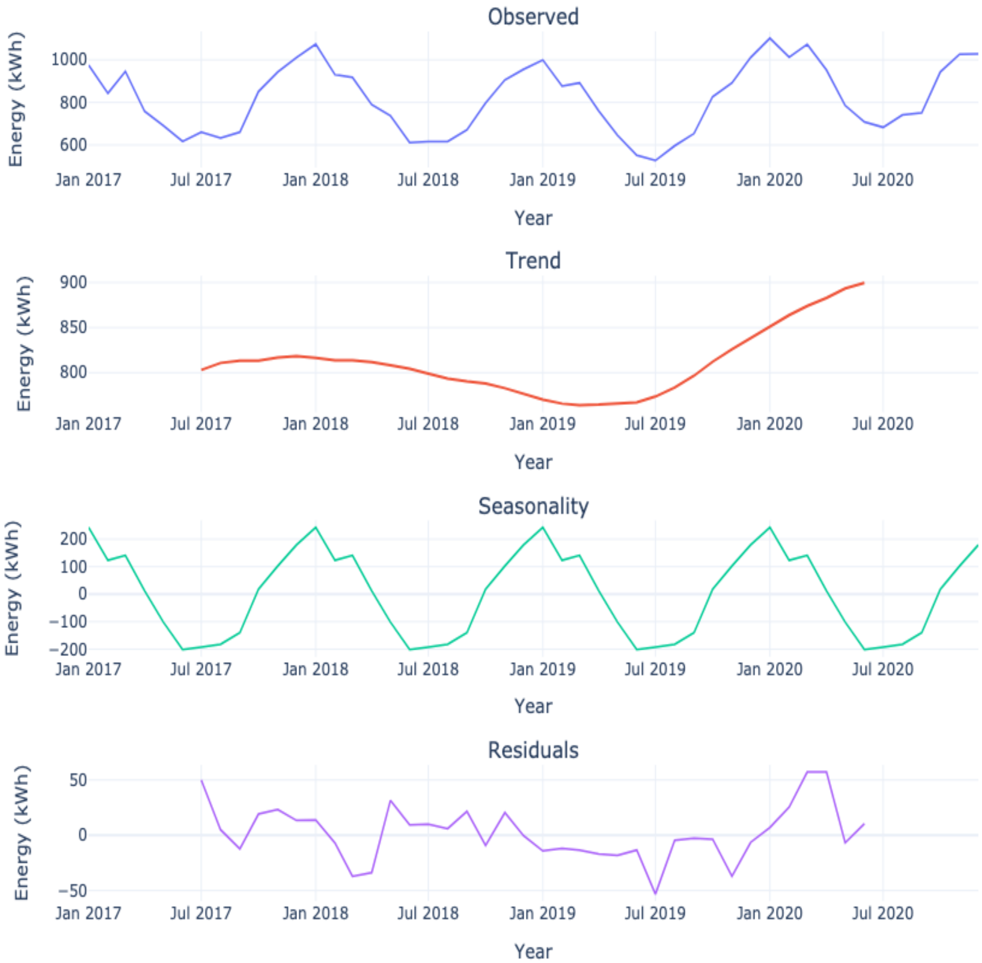

Figure 3: Time Series Decomposition of Monthly Median Electricity Consumption

C. Yearly Patterns

To clearly identify the seasonal components, we grouped the target population by season and took the yearly mean. Figure 4 shows the yearly average electricity consumption per season. Seasons 1, 2, 3 and 4 respectively represent winter, spring, summer and fall. From this plot, we concluded that electricity consumption levels were significantly higher during winter and significantly lower during summer. Fall and spring consumption levels stayed relatively in between the other two seasons.

In the same way, we looked for patterns by grouping the target population by quarters and taking the yearly mean. Figure 5 shows the yearly average electricity consumption per quarter. Quarter 1 is from January to March, quarter 2 is from April to June, quarter 3 is from July to September, and quarter 4 is from October to December. We saw that quarter 1 and 4 steadily remained the highest quarters of consumption levels just as quarter 2 and 3 remained the lowest.

Figure 4: Mean Yearly Electricity Consumption Average per Season

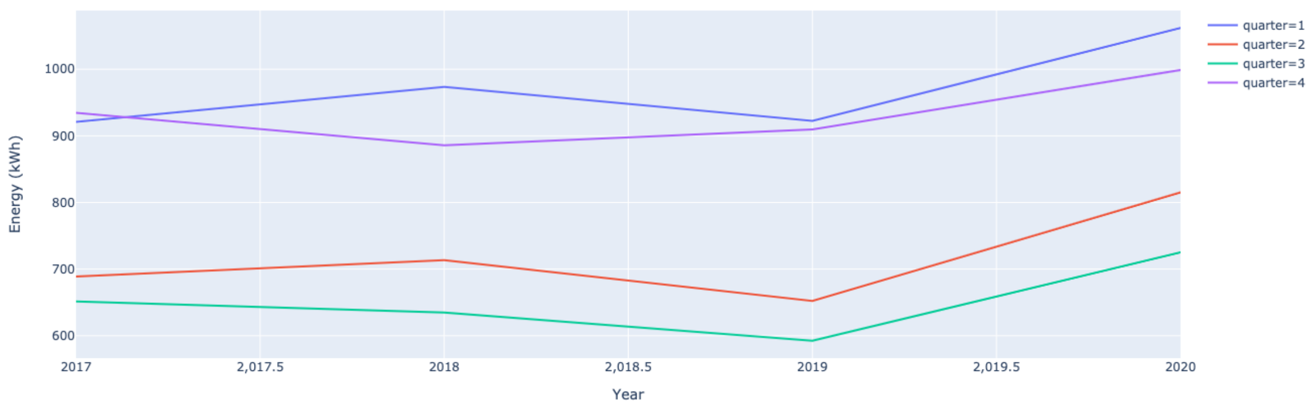

Figure 5: Mean Yearly Electricity Consumption Average per Quarter

IV. CONCLUSION & FUTURE RESEARCH

By filtering and manipulating raw data, we effectively established baseline electrical consumption data for 165 Thermalize Juneau residential units. Using this baseline data, outliers were detected and therefore we used the monthly median values for an unbiased analysis. We found that this data was consistently seasonal and had an upward trend. Specifically, electrical consumption increases during winters and decreases during summers. Though there was an increase trend during 2020, we did not find a significant difference in electrical consumption between years 2019 and 2020 that would otherwise suggest effects of Covid-19 and shelter in place mandates.

However, we did not immediately dismiss the possible effects of Covid-19 for all energy usages. Future research involves cleaning and analyzing baseline Thermalize Juneau residential units' fuel oil and biomass data. We will then use this baseline data to get a more holistic analysis of energy usage from 2017-2020. Afterwards, we will compare it to post-retrofit data of 2021-2022 and verify if DHPs produce real-world energy savings. The success of this project will hopefully accelerate the research, development and deployment of renewable energy technologies that transition to net-zero greenhouse gas emissions throughout Alaska by 2050.

V. ACKNOWLEDGEMENTS

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