Methodology for Cleaning and Processing Baseline Fuel Oil Consumption 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 (DHPs) are one way to help reach this goal because they can 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 need to have baseline data for residential energy usage so that we can compare post-retrofit data after one heating season. In this project, we researched different algorithms for cleaning and processing baseline fuel oil consumption data based on seasonal heating degree days.

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 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. One of those ways is through the Thermalize Juneau campaign and the installation of DHPs.

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) for residential heating. DHPs are two to four times more efficient than a fuel oil furnace or electric resistance heater and can help save on average 10,000 pounds of $CO2$ annually per unit. [3] But one of the largest barriers to the adoption of heat pumps is the installation cost, which in February 2021, could 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 165 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]

Figure 1: Installation of a Thermalize Juneau Campaign DHP, image courtesy of AHS

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. If the source of electricity is renewable, such as in Juneau which relies on hydropower, the appliance is fully renewable. 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 from a central unit 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.

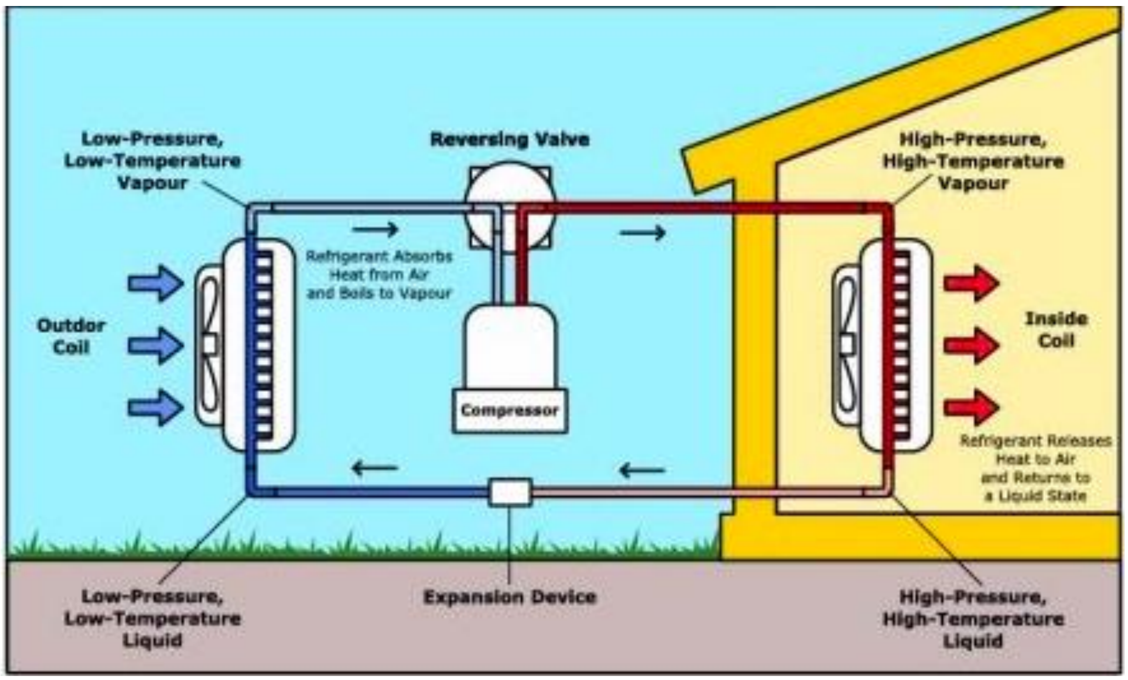

Figure 2: ASHP refrigeration cycle in heating mode [9]

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 establish baseline conditions for energy usage 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 python accessible or readable format. Access to this data and information is critical to the evaluation of the energy savings of the campaign.

During the fall of 2021, we established and analyzed baseline electrical data. However, as thermalization efforts may increase, we need to document the electrical baseline data algorithm to provide a coherent method for future researchers, program managers and stakeholders as a benchmark and metric for success in future campaigns. In addition, we need to develop a method to clean and arrange the baseline fuel oil consumption data based on seasonal heating degree days.

This report explains different algorithms we researched for cleaning and processing baseline fuel oil data based on seasonal heating degree days. All methods were developed based on functions found in Python 3.6.9.

II. DOCUMENTATION

A. Electrical Data Documentation

Within this paper, documentation is the written process that captures what the code is doing and how it works, so that others can understand the logic and reproduce the process. There are two types of documentation: documentation inside the code and supporting documentation about the code. Both types are necessary when creating documentation for users, other developers, and the programmers themselves.

To ensure Thermalize Juneau 2021 participant privacy, we also removed any personally identifiable information from the code. For the electrical baseline data analysis, we documented it by explaining the functions used and how they work. Figure 3 shows a portion of the code and documentation. We documented the cleaning and processing algorithm to provide a coherent method for researchers to duplicate, revise, and implement in future thermalize campaigns. We also hope to make this code available nationwide to help other deployment campaigns.

Unbin Dates

Since the data was collected based on AEL&P's billing period and not by calendar month, we have to "unbin" electrical consumption per date. This function allows us to calculate 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.

```
[ ] def unbin_by_dates(df: pd.DataFrame) -> pd.DataFrame: # ("->" should return a df)
      ranges = []
    # created a for-loop for each row in the date column
      for i in range(df.shape[0]-1): # takes the entire number of rows of the first column ("[0]"") minus the last row ("-1")
          start_date = df['date'][i+1] # start date of each row, ("i+1") because (bc)
          end_date = df['date'][i] # end date of each row ("i") bc dates are in decending order

    # made it into a list, used date_range function which returns the range of equally spaced time points
    # reversed function used bc the dates are in decending order
    # closed ='right' bc we want to include the end date in the list
          date_range = list(reversed(pd.date_range(start_date, end_date, closed='right')))
          y0 = df['kWh'][i] # for each row of kWh
          dx = (len(date_range)) # length of data_range list
          if dx == 0: # if there is a date row empty, just continue down to the next row
            continue
          consumption_per_day = y0 / dx # take each kWh and divide by the number of days in between and including the start and end date
          uniform_consumption = [consumption_per_day]*dx # allocate that number^ to each day in date_range

    # new df with original data_range dates and uniform_consumption, with column labels
          df2 = pd.DataFrame(zip(date_range, uniform_consumption), columns=['date', 'kWh'])
          ranges.append(df2) # add each new df2's into empty list "ranges" (created in the begining of def)
      return pd.concat(ranges).reset_index(drop=True) # add each new ranges into one df and reset index
```

Figure 3: Example of Electrical Data Code Documentation

III. FUEL OIL DATA METHODOLGY

A. Data Collection

Registered participants of Thermalize Juneau obtained the data from their own fuel oil provider and sent them to AHS. Thus, the data came in different formats, some in excel sheets, and some in PDF files of fuel purchase history. This data measured fuel oil in gallons and established validity because it came directly from the fuel company and is the same data used for billing. The sampling scheme used was random because it was collected based on fuel delivery dates and not by calendar month. The data was available in a form that was inaccessible for coding in python. Varying based on each residential unit, the data was provided in an either an unreadable excel sheet or PDF file. It was unreadable due to the layout complicating the ability of python to automatically read the files.

B. Data Cleaning

Because the fuel oil data was formatted in a variety of ways, we needed to develop a method for cleaning the data and compiling it into an accessible format for programming. In addition to the data pulled from the fuel companies, AHS provided thermalize participants each with a Homeowner Heat Pump Feasibility Report. This report used an excel calculator to extract the monthly and annual oil usage.

CCHRC researchers will gather and consolidate all fuel oil data from the fuel company and feasibility report into a single excel spreadsheet that can later be accessed through python. This process will happen by hand with input from researchers as to how to streamline it in the future. Each entry will include the amount of oil supplied and its corresponding delivery date. Researchers will eventually gather the electricity, fuel and biomass data all into one excel file per residential unit. A future goal is to have all pre- and post- energy use data in one excel file.

C. Data Manipulation

Since the fuel oil data was provided based on delivery date, we needed to develop a method for transforming it based on fuel oil consumption. In a heating season, we only know how many gallons were added for a specific delivery date. The amount added is generally the amount that was consumed since the last delivery date.

However, the start and end dates of the heating season are ambiguous and might include part of a delivery not during the heating season. We explored two different methods for getting the most accurate data possible for fuel consumption by month .

1. Processing Method 1

One proposed way of manipulating fuel oil data is by systematically processing the data based on heating degree days (HDD). HDD is the degrees that a day's average temperature is below 65 Fahrenheit (18 Celsius). [10] This is then used as a measurement designed to quantify the demand for energy needed to heat a building. [10]

From the National Weather Service, we can extract the number of HDD per month for Juneau, Alaska. With these monthly HDD, we will add them up per year to get the annual HDD. Then we will calculate the heating percent load for each month by dividing the monthly HDD by the annual HDD. Finally, we can take the annual gallons of delivered fuel oil and multiply them by the heating percent load to get an equivalent estimate of month fuel oil consumption. Even though there may be fuel deliveries and heating degree days over the summer, we will only use the months that we consider to be within the heating season.

2. Processing Method 2

Another proposed method is adding some randomness to the data values. First, we can equate the amount of fuel oil delivered to the amount consumed for time period between the last delivery date and the current one. We can divide the gallons based on HDD for that time period. In terms of the start and end dates, we can create a confidence interval of estimates based on the total amount of gallons for the heating season. We can do this by calculating the standard deviation to see the amount of variation between the data. Then use the standard deviation to estimate a 95% confidence interval of how many gallons of fuel was consumed for the start and end dates.

IV. CONCLUSION & FUTURE RESEARCH

By doing a comparison of these two methodologies, we can research effective ways to manipulate fuel oil data while maintaining the integrity of the results. Since we may not be able to get accurate fuel records from companies, there is an added benefit in coming up with a statistical algorithm for estimating fuel consumption for the heating season start and end dates. If the second method does not give accurate results, then we will use first method where we over generalize the distribution of fuel oil gallons. However, both methods may also give similar results. Future research includes testing both methods and comparing and contrasting the results. Once we have selected the best method, we will then compare pre-retrofit fuel data to post-retrofit data.

V. COMPLEMENTARY RESEARCH

A. Climate Chamber Data Collection

In addition to developing the methodology for fuel oil data analysis, I and another SULI intern conducted laboratory testing using CCHRC's climate chamber. Figure 4 shows what the climate chamber looks like. This chamber simulated cold temperatures from 10 C down to -25C. We maintained a safe working environment by following lab safety protocols. We tested four different models of DHPs in the laboratory by exposing them to different temperatures within this range using the climate chamber.

In order to calculate the performance efficiency of the DHPs in cold climates, we collected five second data using a data logger on the operating parameters of the heat pumps. Figure 5 shows the real-time raw data collected by the data logger. We had to maintain the constant indoor temperature in the laboratory so that all four heat pumps have the same operating conditions. It was important to keep it steady and document any changes in order to collect data as cleanly as possible for future data analysis.

Figure 4: Climate Chamber

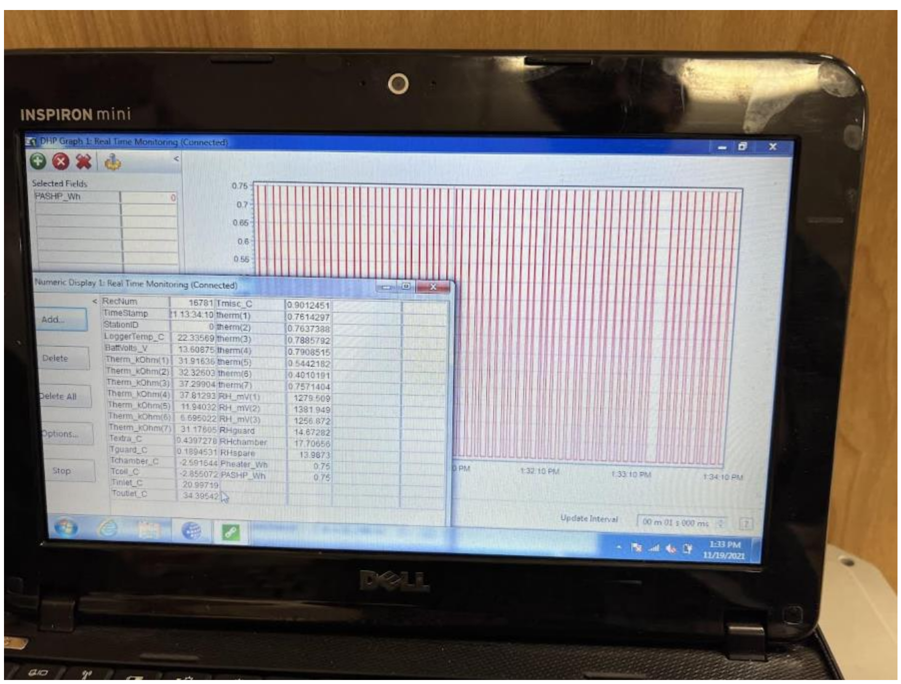

Figure 5: Raw data collected by the data logger

B. Point Lay Housing Survey

In addition to collecting data using the climate chamber in the laboratory, I and another SULI intern joined a team of researchers and scientists on a housing survey trip to Point Lay, Alaska. Point Lay is a community in rural Alaska, located above the Artic Circle. This village depends on cold temperatures to keep the permafrost frozen and practice subsistence living. Permafrost is permanently frozen soil, and when it thaws it can cause issues for infrastructure built on top of it. Figure 6 shows an aerial view of the village on the bare tundra. Point Lay is on the forefront of climate change which is causing the permafrost to thaw. We were there to document and collect data on the housing issues resulting from this permafrost thawing. This data will later be aggerated and reported to help the community obtain funding to address these housing issues.

This research project gave us the opportunity to see first-hand the issues caused by the global warming and understand in a tactile way how climate change is affecting housing in Alaska. From thawing permafrost to installing heat pumps for cold climates, CCHRC is working towards safe durable and sustainable housing for Alaskans and people in the circumpolar north.

Figure 6: Village of Point Lay, as seen from an incoming passenger plane

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