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Harvest Thermal Pilot

Measurement and Verification Report

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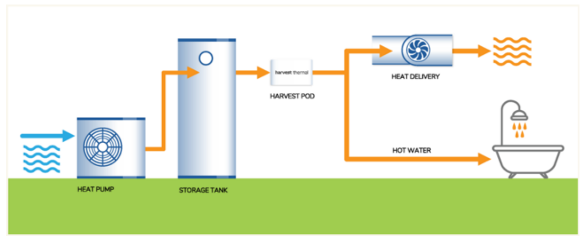
1 Executive Summary

Peninsula Clean Energy piloted a new technology by Harvest Thermal that combines residential space and water heating into one electric system to potentially enable electrification at a lower installation and operating cost than two separate system retrofits. Peninsula Clean Energy installed the Harvest Thermal system at four single-family homes in which TRC conducted independent M&V.

The four homes in the pilot study, are in: Daly City, Redwood City, South San Francisco, and Menlo Park. They were built between 1947 and 1980, and range in floor area from 1060 to 1950 square feet. Each home has between 2 and 4 occupants and do not have air conditioning.



The Pilot Study and M&V analysis found:

Installed Costs Similar to Installing Separate Equipment

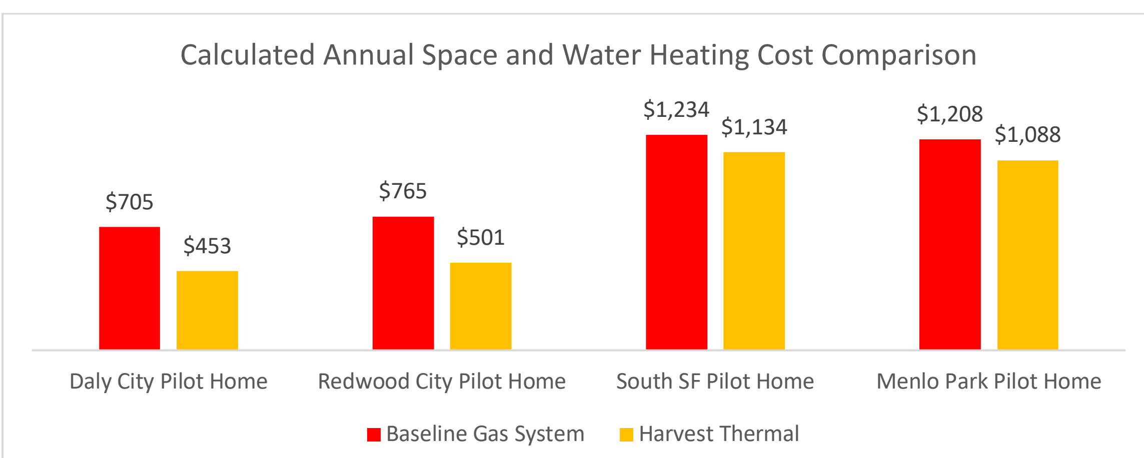
By leveraging a single compressor to serve both water heating and space heating needs, there is a potential opportunity for cost reductions. However, the system is also a more complex installation. According to Peninsula Clean Energy and Harvest Thermal, the Harvest Thermal system total installed costs averaged $28,600 per home, and $22,500 after incentives. This is a similar cost to installing a unitary heat pump water heater and split system, ducted space heater in a single-family home in San Mateo County.

Energy Cost Savings at Each Home

The energy savings of the Harvest Thermal System are due to the:

- High-efficiency, all-electric heat pump system instead of methane gas
- Ability to leverage the storage tank to move loads from times of high, peak-load electricity rates to times of lower, off-peak electricity rates.

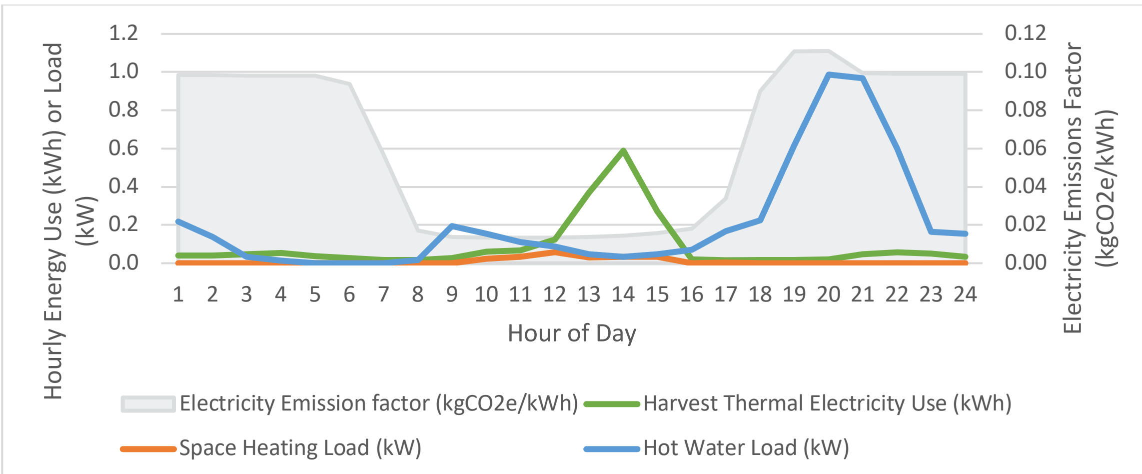
The analysis found an average energy cost savings of 22% versus the gas baseline if the EV2A rate was used, and up to 36% energy cost savings. The study also found that switching to an electrification-friendly rate is key to ensuring energy costs savings. The figure below outlines the annual operating cost comparison at each pilot home.



Load Flexibility Benefits

Grid-integrated buildings are becoming more important as we move to a future with 100% renewable electricity that depends on available wind, solar, geothermal, and hydroelectric resources. The ability to flex loads in our homes helps reduce the amount of battery storage needed on the grid.

For space heating equipment, the ability to shift electricity associated with heating loads to the daytime, when solar electricity is available, is especially important. Traditional heat pump space heating systems do not offer load flexibility. The study found that 3.6 kWh[1] of electricity was shifted away from peak hours on average per day, and that 860 kWh of electricity was shifted per year, on average. These load shifts result in energy cost savings for the customer, help lower infrastructure costs for the state, and can help enable high penetration of renewable electricity.



Summer Daily Load and Energy Use Profile, Daly City

Customer Satisfaction

In general, customers like the Harvest Thermal system better than their previous gas appliances, both for space heating and water heating, and were satisfied with the installation experience.

When asked how satisfied the customers were with the Harvest Thermal system, all four stated that they were extremely satisfied and would likely or very likely recommend a Harvest Thermal system to a friend.

Demonstration Site Homes, clockwise from top left: Daly City home, Redwood City home, South San Francisco home, Menlo Park home

[1] 3.6 kWh was noted from Harvest Thermal analysis of the Pilot Homes. This is aligned with the TRC results in Section 6 "Load Shift Impact," which displays load shift in thermal load rather than electric load.

2 Introduction

2.1 Project Overview

Peninsula Clean Energy's mission is to reduce greenhouse gas emissions in the communities it serves. Peninsula Clean Energy is piloting a new technology by Harvest Thermal that combines residential space and water heating into one electric system to potentially enable electrification at a lower capital and operating cost than two separate retrofits would entail. Peninsula Clean Energy installed the Harvest Thermal system at four single-family homes with the goal of piloting and assessing the system. Figure 1 is a schematic of the Harvest Thermal system. TRC conducted independent M&V at all four homes.

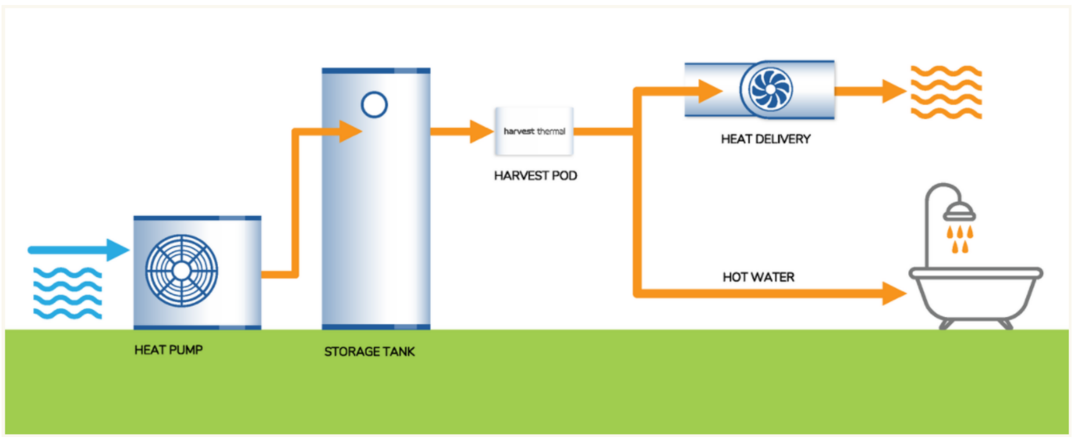


Figure 1. Harvest Thermal System Schematic. Source: Harvest Thermal

2.2 Objectives and Approach

The main objectives of this Harvest Thermal Pilot M&V study were to:

1. Determine the overall energy savings and bill impacts of the Harvest Thermal system compared to the pre-retrofit gas appliances.
2. Characterize the Harvest Thermal system's performance in terms of load shifting.
3. Characterize the Harvest Thermal system's performance in terms of efficiency.
4. Determine customer satisfaction with the Harvest Thermal system.

To meet the first objective, TRC used the International Performance Measurement and Verification Protocol (IPMVP) Option B (Retrofit Isolation with All Parameter Measurement) to quantify energy savings resulting from the Harvest Thermal system. TRC determined the energy savings and bill impacts of the Harvest Thermal system compared to the pre-retrofit gas furnace and gas water heater at each demonstration site. TRC determined energy savings using three different approaches. In each approach, TRC simulated the baseline energy use using space heating and water heating loads measured during the monitoring period and applied the pre-retrofit appliance efficiency. The three approaches were:

1. **Measured energy usage and cost**: We compared the space and water heating energy use of the Harvest Thermal system during the monitoring period to the calculated baseline of the old gas

space and water heating systems during the monitoring period. We calculated the energy costs based on rates during the monitoring period.

2. **Normalized energy usage**: We created models for both the pre-retrofit and post-retrofit based on time of week and outside air temperature. We applied the models to typical weather data for a year to determine energy use and savings during a typical year.
3. **Bill comparison:** We compared the utility bills in the 12-month monitoring period (post-retrofit) with the 12-month period before the retrofit (pre-retrofit) to get a direct bill comparison of energy use and costs.

To meet the second objective, we assessed the load shift impact of the system by comparing the space and hot water load profiles to the Harvest Thermal system's electricity load profiles. With this, we estimated the kWh and BTU shifted away from peak hours and the bill savings from this load shifting. TRC estimated the hours when the water heating load was not met based on the hours of hot water draw where the hot water supply temperature was less than 110 °F.

To meet the third objective, TRC calculated the Harvest Thermal system's hourly coefficient of performance (COP) by dividing the heating load by the unit electrical input. We then analyzed how the COP varied with outside air temperature and load conditions.

To meet the fourth objective, TRC determined customer satisfaction with the Harvest Thermal system by administering three separate surveys to each household. The surveys captured customer feedback on their existing gas appliances around the time of the Harvest Thermal system installation, early customer feedback on the Harvest Thermal system three months after system installation, and final customer feedback on the Harvest Thermal system at the conclusion of the study.

2.3 Demonstration Site Overview

Table 1 gives a summary of the four homes, which each serve as a demonstration site in the study.

Table 1. Summary of Demonstration Sites

	Home 187	Home 267	Home 296	Home 81
				
City	Redwood City	Daly City	South San Francisco	Menlo Park
Floor area (sqft)	1,060	1,390	1,950	1,366[2]
Owner or renter?	Owner	Owner	Owner	Owner
Home type: Single-family, condo, townhome, apartment	Single-family	Duplex; no shared equipment or services	Single-family	Single-family
Average occupants last 12 months?	2	4	4	3
Average occupants next 18 months?	2	4	2	3
Year built or last whole house renovation	1949	1980	1962	1947
Heating	Central furnace located in attic	Central furnace located in garage	Central furnace located in garage	Central furnace located in garage
Air Conditioning (A/C)	No central A/C; uses window units	No central A/C	No central A/C	No central A/C

[2] Includes a 196 square foot addition that was added at the end of 2022.

3 M&V Methodology

This study required the collection of the following data:

- Pre- and post-installation utility gas and electric consumption
- Post-install Harvest Thermal data and equipment electric use
- Pre-and post-installation customer experience

TRC used the data to:

- Determine post-installation hot water and space heating loads.
- Calculate any energy savings and utility bill impacts associated with the retrofit.
- Evaluate Harvest Thermal system's performance.
- Determine customer satisfaction.

Section 3.1 gives the data collection plan, including what meters TRC installed. Section 3.2 details the data processing. Section 3.3 details how TRC determined the baseline.

3.1 Data Collection

This section provides an overview of the data collection methods that TRC implemented.

3.1.1 Data Collection

After the Harvest Thermal system was installed and commissioned, TRC monitored and collected energy, temperature, and water flow data for 12 months (May 2022 through April 2023), as detailed below. For one site, the Menlo Park site, the system installation and monitoring occurred in October 2022, which shortened the monitoring period to seven months (October 2022 through April 2023). Figure 2 summarizes the data collection timeline.

Figure 2. Data Collection Timeline

3.1.1.1 Data Provided by Others

TRC collected and stored sensor data provided by Harvest Thermal, as detailed in 3.1.4.

Refer to Figure 3 for sensor locations, which are indicated by the point name in parenthesis. Harvest Thermal provided data with readings every 64 seconds on a biweekly basis to TRC. Note that 64 seconds is the default data interval provided by Harvest Thermal. Figure 3 shows the Harvest Thermal Pod powered by a battery, but at all of the demonstration sites, each Harvest Pod has a 24-volt DC power supply connected to an AHU fan board via low-voltage wiring.

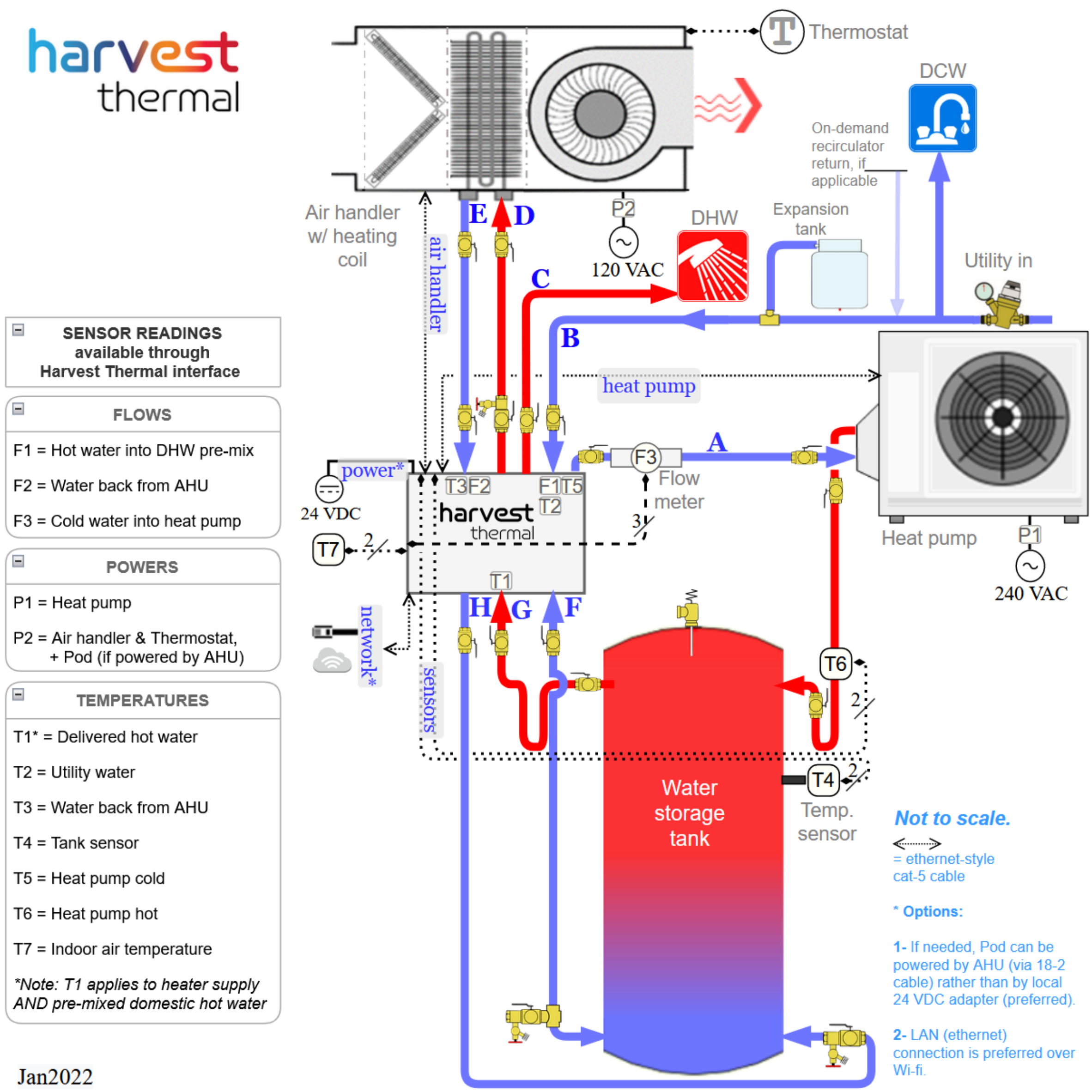


Figure 3. Harvest Thermal System Sensor Schematic. Source: Harvest Thermal

TRC also used the following data provided by Peninsula Clean Energy:

- Advanced Metering Infrastructure (AMI) electricity data at 15-minute intervals
- AMI gas data at daily intervals
- Monthly electricity and gas billing data

Following the system installation, TRC field-verified Harvest Thermal's trends through spot measurements.

3.1.1.2 TRC-Installed Metering

At each site, TRC installed an eGauge true RMS power meter to collect the following data:

- Energy use for heat pump
- Energy use for air handler

3.1.1.3 Customer Experience

TRC conducted customer surveys at each of the four sites. The primary purpose was to gather customer feedback. We collected input on the use and satisfaction of the customer's Harvest Thermal system, as well as how it compared to their previous system and how it compared to their expectations for space heating and water heating.

TRC conducted surveys on three separate occasions during the M&V period:

1. The first survey captured customer feedback on their existing gas appliances around the time of the Harvest Thermal system installation (*pre-retrofit customer survey*).
2. The second survey, three months after system installation, captured early customer feedback on the Harvest Thermal system (*post-retrofit customer survey*).
3. The third survey, at the conclusion of the study, contained identical questions as the second survey conducted (*post-retrofit customer survey*).

TRC designed the survey to take the customers 5–10 minutes to complete and was administered online.

3.1.2 TRC-Installed Data Collection Equipment

3.1.2.1 Overview

TRC installed eGauge true RMS power meters to collect high-resolution electric power data at each demonstration site. At each site, the team installed an eGauge Core power meter to monitor the total electrical demand and energy of the heat pump and air handler separately. TRC installed the meters in the electrical panel housing or in a separate enclosure near the electrical panel. For each piece of equipment, TRC measured power, power factor, voltage, and current. We recorded measurements at 5-minute intervals.

TRC connected the eGauge meter to the home Wi-Fi through an eGauge Nano Wi-Fi Router at each demonstration site. By doing this, TRC was able to view the live and stored power trends throughout the monitoring period.

3.1.2.2 Equipment Installation

On April 18 and 19, 2022, TRC completed the meter installations at three of the demonstration sites (Daly City, South San Francisco, and Redwood City). TRC completed the meter installation at the fourth site (Menlo Park) on September 2, 2022. Refer to Figure 2 for a summary of the timeline. At each of the four sites, TRC installed power metering in the electrical panel housing or adjacent to the electrical panel housing. Figure 4 shows the eGauge meter TRC installed at the Daly City site, which serves as an example of the installations at the other sites. The figure shows the eGauge power meter and the eGauge Nano Wi-Fi Router installed within the electrical panel housing, which is used for both the heat pump and air handler power monitoring, and the current transducers (CTs), one around the heat pump wiring and one around the air handler wiring.

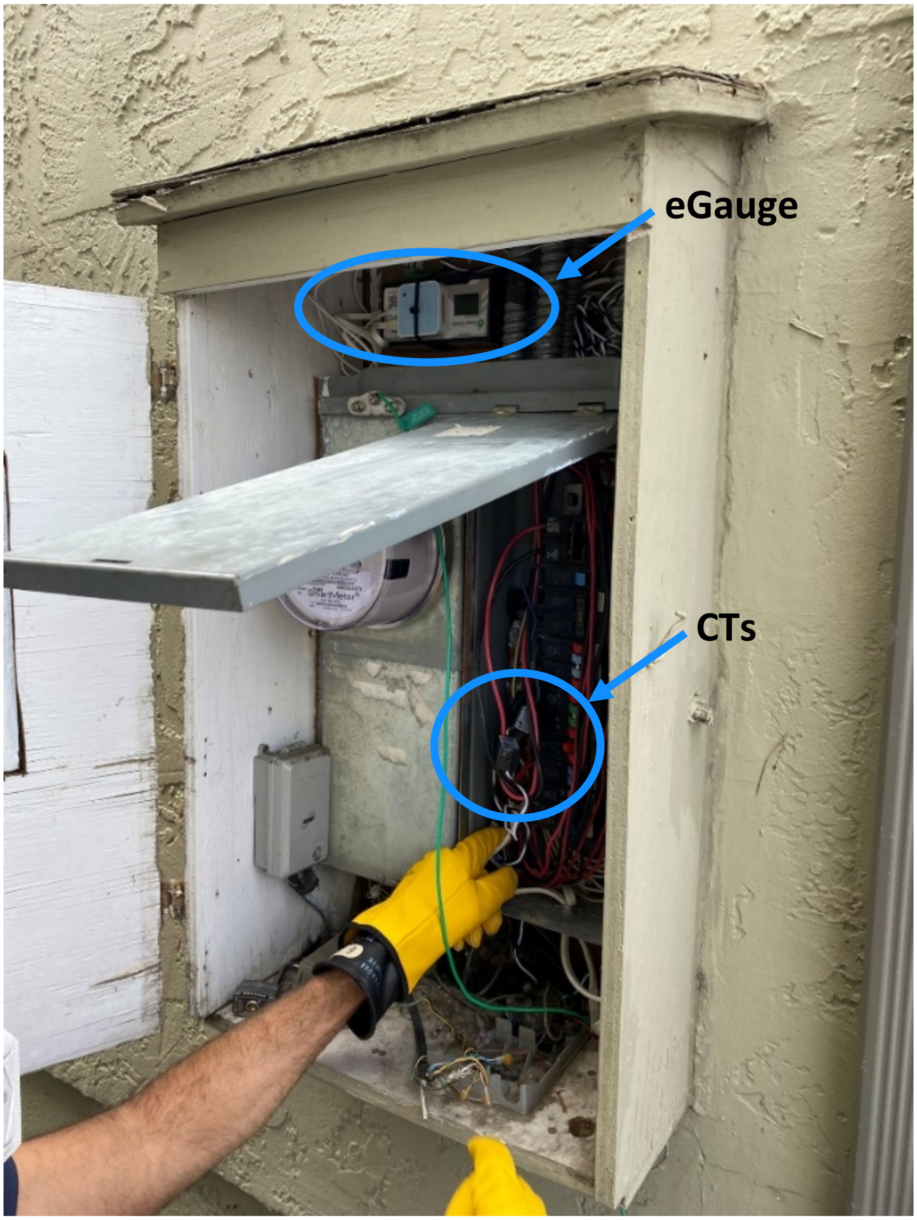


Figure 4. Power meter installation at Daly City site

3.1.3 Data Collection Equipment by Others

For data provided by Harvest Thermal, TRC field-verified Harvest Thermal's trends through spot measurements, as described below. Because the Harvest Thermal measurements were primarily used to determine heating and hot water loads, we validated the meters used to calculate these loads.

3.1.3.1Space Heating Load

TRC calculated the space heating load during the monitoring period based on waterside data collection by Harvest Thermal. TRC used the following points to calculate the space heating load:

- AHU coil inlet water temperature (delivered hot water temperature, T1),
- AHU coil outlet water temperature (water back from AHU temperature, T3),
- and AHU coil water flow rate (water back from AHU flow, F2).

In the field, we measured the space heating load on the airside and used that to validate the Harvest Thermal waterside load.

TRC measured the space heating load on the airside during the power meter deployment. We measured the supply air temperature at the first accessible supply air grille using a thermistor. We measured the airflow rate at the AHU return air inlet. We did this using a flow hood over the last return air register that feeds into the unit. We also measured the return air temperature using a thermistor at this location.

We increased the zone space temperature setpoint so that the space heating came on and allowed the system to reach a steady state. We then took measurements for a period of five minutes, during which time we took measurements once per second.

During the five minutes of steady state operation, we calculated the waterside load using the data collected by Harvest Thermal and the airside load using the data collected by TRC. We compared these two results and determined that the loads matched sufficiently to validate all three points that we use to calculate the waterside load. Appendix A gives an example of these calculations for the Daly City site.

3.1.3.2 Water Heating Load

TRC used the following points to calculate the water heating load: delivered hot water temperature (T1), utility water temperature (T2), and hot water into DHW pre-mix flow (F1).

TRC validated F1 using the procedure suggested by Harvest Thermal, provided in Appendix B. TRC also took spot measurements to validate T1 and T2.

3.1.4 Data Point Summary

Table 2 gives a summary of the data points that the team used.

Table 2. Data Points Summary

Parameter	Provided By	Location *	Meter Manufacturer/Model	Unit	Sampling Interval
Heat pump electric	TRC	Electric panel (metering enclosure)	eGauge - Core (4015)	kW, PF	5 min
AHU electric	TRC	Electric panel (metering enclosure)	eGauge - Core (4015)	kW, PF	5 min
Hot water into DHW pre-mix	Harvest Thermal	F1	Kamstrup 02U-23-C07-8EP CONFIG 23533	Gallons	64 seconds
Water back from AHU	Harvest Thermal	F2	Kamstrup 02U-23-C07-8EP CONFIG 23533	Gallons	64 seconds
Cold water into heat pump	Harvest Thermal	F3	Kamstrup 02U-23-C07-8EP CONFIG 23533	Gallons	64 seconds
Delivered hot water (to the DHW mixing valve and to the AHU)	Harvest Thermal	T1	Littel Fuse USP20466	°F	64 seconds
Utility water	Harvest Thermal	T2	Littel Fuse USP20466	°F	64 seconds
Water back from AHU	Harvest Thermal	T3	Littel Fuse USP20466	°F	64 seconds
Tank sensor	Harvest Thermal	T4	ECO2 Systems 91101-45190	°F	64 seconds
Heat pump cold	Harvest Thermal	T5	Littel Fuse USP20466	°F	64 seconds
Heat pump hot	Harvest Thermal	T6	Littel Fuse USP20466	°F	64 seconds
Indoor air temperature	Harvest Thermal	T7	Dwyer TE-DFN-B0644-00	°F	64 seconds

*Refer to Figure 3 for meter locations

After installation of the power meter and initial sensor validation, TRC continued monitoring to ensure data quality.

TRC monitored incoming data on a biweekly basis to ensure the quality of the data and identify potential issues with the metering system.

3.2 Data Processing

TRC reviewed the metered data on a biweekly basis for dropped or inaccurate data. The TRC-installed power meters trended power during the entire monitoring period without any data gaps or data quality issues.

We also observed the data for non-routine events and did not find any, so we did not make any related non-routine adjustments.

The system data from Harvest Thermal, which was used to determine space heating and water heating loads, had periodic data gaps. If the data gap was shorter than 2 hours, then TRC filled in the missing data. Because the flow meters report cumulative water flow (rather than instantaneous flow rate), for data gaps, we are still able to determine the average water flow rate during the period of the data gap. We averaged the temperatures adjacent to the data gap, applied that to the water flow rate to determine the average load during the gap, and used that in the analysis. Note that during many of the data gaps, the water flow was zero, and therefore there was no load.

For data gaps longer than 2 hours, TRC dropped the data at that time step (including the monitored power data) and considered it missing data. In the measured energy usage reporting in Section 4.1, we reported both the total monitored energy as well as just the energy that is coincident with the Harvest Thermal load data. The coincident energy is used in the subsequent analysis.

With the power and Harvest Thermal system data, TRC constructed the energy profiles described in the subsections below.

3.2.1 Space Heating Load

TRC used the following inputs to calculate the space heating load trend ($Q_{space\ heat}$):

AHU coil inlet water temperature (delivered hot water temperature, T1) [°F]

AHU coil outlet water temperature (water back from AHU temperature, T3) [°F]

AHU coil water flow rate (water back from AHU flow, F2) [gpm]

We calculated the space heating load trend using the following equation:

$$Q_{space\ heat} = 500 \times F2 * (T1 - T3) \text{ [Btu/h]}$$

TRC used the load measured in the post-retrofit to determine the pre-retrofit space heating gas usage. The baseline space heating system, a furnace, did have a fan with used electricity, but the methodology did not account for electricity use in the baseline.

3.2.2 Water Heating Load

TRC used the following inputs to calculate the DHW heating load trend ($Q_{DHW\ heat}$):

Delivered hot water temperature (T1) [°F]

Utility water temperature (T2) [°F]

Hot water into DHW pre-mix flow (F1)

We calculated the water heating load trend using the following equation:

$$Q_{DHW\ heat} = 500 \times F1 * (T1 - T2) \text{ [Btu/h]}$$

TRC used the load measured in the post-retrofit to determine the pre-retrofit water heating gas usage.

3.2.3 Electricity Consumption

TRC determined the post-retrofit space heating and water heating combined electrical energy use by adding together the measured heat pump and AHU electrical power collected from the TRC-installed power meters.

The AHU measured power includes the thermostat power. TRC conducted spot measurements of the thermostat power at the Daly City site and determined that the total thermostat power was around 2 watts. TRC assumes that the thermostats at the other sites have similar power. TRC subtracted these 2 watts of power from all AHU power measurements at all sites.

At the start of the monitoring period at the Daly City site until May 17, 2022, the AHU was on the same electrical circuit as the garage door opener. During this time, there were periodic 2-minute spikes around 800 watts that were not part of the Harvest Thermal system. In post-processing, from the start of the monitoring until May 17, 2022, TRC removed these spikes from the AHU power meter data.

In mid-May 2022, Harvest Thermal noted that the TRC power monitoring equipment showed heat pump standby power at the South San Francisco site as higher than expected. TRC investigated the issue on May 18, 2022, and TRC determined the issue to be electrical noise, which caused the heat pump standby power draw to be between 5 and 8 watts instead of the expected 1 watt. TRC reconfigured the metering cables on May 18, 2022, after which the power monitoring equipment showed the expected 1 watt of standby power. In post-processing, from the start of the monitoring period until May 18, 2022, TRC changed the heat pump standby power at this site (anything greater than 1 watt and less than 10 watts) to 1 watt.

3.2.4 AMI Data

In addition to electricity consumption measured for the Harvest System, TRC processed advanced metering infrastructure (AMI) data provided by Peninsula Clean Energy to summarize actual electricity and gas consumption observed in each pilot home in the 12-months before installation and 12-months after installation. Although this data is included in this report, AMI data is not the basis for the Energy Savings and Utility Cost analyses due to this data not being disaggregated for water and space heating only, usage pattern differences between the pre- and post-retrofit periods, and variations in weather during these periods.

3.3 Baseline

TRC used data collected during the post-retrofit period to simulate a baseline based on the specifications for the pre-retrofit gas furnace and water heater at the time of installation. Note that we do not assume any performance degradation over time. We used space heating and water heating loads as measured by Harvest Thermal during the post-retrofit period. TRC assumed that hot water and space heating loads during the post-retrofit period would be representative of the pre-retrofit period.

TRC determined the baseline space heating and water heating energy use as described in the subsections below. TRC created a model of the space heating load and a model of the water heating load, as described in Section 4. The team uses these models to determine the gas energy use of the pre-retrofit equipment.

3.3.1 Space Heating

TRC estimated the gas energy used for the baseline gas furnace based on the space heating load during the post-retrofit period and the pre-retrofit gas furnace specifications. TRC assumed that the baseline electricity use of the furnace fan is the same as the Harvest Thermal AHU fan. Table 3 gives a summary of the pre-retrofit gas furnace at each site, including the annual fuel utilization efficiency (AFUE) of each furnace based on manufacturer published literature. Where TRC could not determine the furnace AFUE, the team estimated an AFUE based on the federal efficiency standard at the time the furnace was installed.

Table 3. Pre-Retrofit Gas Furnace Summary

	Home 187	Home 267	Home 296	Home 81
City	Redwood City	Daly City	South San Francisco	Menlo Park
Manufacturer	Payne Heating and Cooling	Rheem	York	Trane
Model	PG8JAA024045	RCAC – 04EA	TG9S120D16M P11A	XR80 TUD080C936K4
Year installed	2011	1980	2010	2003
AFUE	80%[3]	Assumed: 76%[4]	95%[5]	80%[6]

The team determined the daily space heating load from the models described in Section 4. The team divided the daily space heating load (in Btu) by the AFUE to determine the total daily energy input (in Btu) for the baseline period.

3.3.2 Water Heating

TRC estimated the energy used for the baseline gas water heater based on the water heating load during the post-retrofit period and the pre-retrofit gas water heater. Table 4 gives a summary of the pre-retrofit gas water heater at each site, including the efficiency in Uniform Energy Factor (UEF) of each water heater based on manufacturer-published literature.

[3] https://www.payne.com/en/us/products/gas-furnaces/pg8maa/
[4] We could not find manufacturer literature on this product and instead assumed an efficiency based on the age of the product. The first federal efficiency standard for furnace was in 1987 and set minimum efficiency at 78 percent AFUE. Based on this, we assume 76 percent AFUE for a furnace from 1980.
[5] http://www.usair-eng.com/pdfs/Furnace%20TG9S.pdf
[6] https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/unitary/split-systems/Small%20Splits/Furnaces/22-1671-14_06012016.pdf

Water heater field efficiency is a function of the hot water draw pattern, and the federal water heater standard has different efficiency requirements for different draw patterns, with higher draw patterns requiring higher efficiency. If the manufacturer-reported UEF does not specify a draw pattern at which it was achieved, TRC assumes that it was at a 'high' draw pattern. Recognizing that homes may consume less hot water than what the high draw pattern represents, TRC estimated the average hot water consumption at each home and used that to adjust the manufacturer-reported efficiency to a water heater 'field efficiency'. The manufacturer-reported efficiency and the field efficiency are both given in Table 4.

Table 4. Pre-Retrofit Gas Water Heater Summary

	Home 187	Home 267	Home 296	Home 81
City	Redwood City	Daly City	South San Francisco	Menlo Park
Manufacturer	Rheem	Rheem	Rheem	Bradford White
Model	XG40T09EN38U0	642062	Prestige Tankless	URG150T6N
Year installed	2017	2015	~2011	2013
Manufacturer-reported efficiency	UEF 0.58[7]	UEF 0.64[8]	UEF 0.94[9]	UEF 0.63[10]
Field efficiency	0.51	0.51	0.94	0.52

TRC determined the daily water heating load from the models described in Section 4. TRC used the UEF and the daily water heating load (in Btu) to determine the total daily energy input (in Btu) for the baseline period.

[7] https://images.thdstatic.com/catalog/pdfImages/63/63f0c3ad-30f8-4f23-8f10-1f81d4d1b065.pdf
[8] https://www.rheem.com/product/professional-classic-atmospheric-1-gallon-propane-gas-water-heater-with-6-year-limited-warranty-prog50-36p-rh60
[9] https://www.rheem.com/product/condensing-tankless-gas-water-heaters-with-built-in-recirculation-rtgh-rh11dvln
[10] https://s3.amazonaws.com/bradfordwhitecorp/wp-content/uploads/residential_gas_ultra_low_nox_atmospheric_vent_naeca_compliant_specsheet_1113.pdf

4 Energy Usage Reporting

The research team used IPMVP Option B (Retrofit Isolation with All Parameter Measurement) to quantify energy savings resulting from the Harvest Thermal system. Differences in energy were wholly attributable to the retrofit.

We determined energy savings for electricity (in kWh), for natural gas (in therms), and for total energy by combining electricity and natural gas savings (in Btu). We determined two sets of energy usage results, as described in the following subsections:

1. **Measured energy usage**: In this approach, we compared the monitored Harvest Thermal system energy use to the estimated energy use for the pre-retrofit gas equipment under the same conditions. This approach utilizes the space and water heating loads measured during the post-retrofit period to simulate the pre-retrofit gas equipment's energy use that would have occurred under the same space and water heating loads (the baseline).
2. **Normalized energy usage**: In this approach, we also used the space and water heating energy use of the Harvest Thermal system and of the baseline (generated in the step above) and created models for both the pre-retrofit and post-retrofit timeframes based on time of week and outside air temperature. We apply the models to typical weather data over a year to determine energy use and savings during a typical year.

See the following subsections for more details.

4.1 Measured Energy Usage

TRC analyzed the measured energy use and estimated savings at each demonstration site. During the monitoring period, we recorded the following energy data at each demonstration site:

- The outdoor heat pump unit and AHU electricity usage, using TRC-installed power meters.
- The baseline space heating and water heating natural gas energy use, calculated from the hourly space heating and water heating loads as described in Section 3.1.
- The estimated energy savings, (the baseline energy usage minus the total measured electricity usage over the monitoring period).

According to our measurements across the three sites with a full year of data, the annual electricity usage increase ranges from 1,442 to 3,847 kWh, while the gas reduction ranges from 249 to 453 therms.

TRC collected customer feedback through customer surveys, as described in Section 3.1.1.3. In addition to asking about feedback, the survey also asked several questions to capture potential changes in water heating or space heating energy use. The responses showed that, compared to the twelve months prior to the retrofit, there were no changes in household occupancy. Two homes (the Daly City and Redwood City homes) stated that they were heating their home about the same as the previous year, and two homes (South San Francisco and Menlo Park) stated that they were heating their home slightly more than the previous year. Because the analysis methodology uses the post-retrofit energy use to calculate the baseline gas energy use, the baseline gas energy use may be underestimated.

The analysis may underestimate baseline gas water heater usage. To estimate the baseline gas water heater usage, TRC used the methodology described in Section 3.3.2, which uses the published UEF values of the actual pre-retrofit gas water heater. TRC notes that these published efficiencies may be higher than the actual annual field efficiency and therefore underestimate baseline heating energy usage.

See the subsections below for details.

4.1.1 Daly City

Table 5 presents the monthly measured energy use, the calculated baseline energy use, and the energy savings.

Table 5. Daly City Measured Energy Use and Savings

	Monitored Post-retrofit Energy Use			Calculated Baseline Energy Use		Energy Savings		
	Space Heating & Water Heating			Space Heating & Water Heating	Fan Energy	Space Heating & Water Heating		
Period	Electricity full TRC data (kWh)	Electricity Coincident with load data (kWh)	% of time missing HT load data	Gas (therms)	Electricity (kWh)	Electricity (kWh)	Gas (therms)	Electricity + Gas (kWh)
May-22	76	76	9%	13	4	-73	13	312
Jun-22	59	59	6%	10	5	-53	10	245
Jul-22	89	85	13%	12	29	-56	12	293
Aug-22	54	54	6%	10	6	-48	10	249
Sep-22	54	50	18%	9	6	-44	9	235
Oct-22	108	108	10%	17	10	-98	17	408
Nov-22	210	154	29%	23	19	-135	23	533
Dec-22	289	288	8%	41	24	-264	41	946
Jan-23	233	233	6%	36	19	-214	36	828
Feb-23	204	204	7%	30	15	-189	30	686
Mar-23	188	188	8%	30	14	-174	30	696
Apr-23	101	101	6%	18	7	-94	18	420
Year	**1,665**	**1,600**		**249**	**158**	**-1,442**	**249**	**5,850**

Energy Savings Figures

Figure 5 depicts the monthly energy use of the post-retrofit and the baseline, which shows that in terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use, with the peak energy use in both cases being in December 2022.

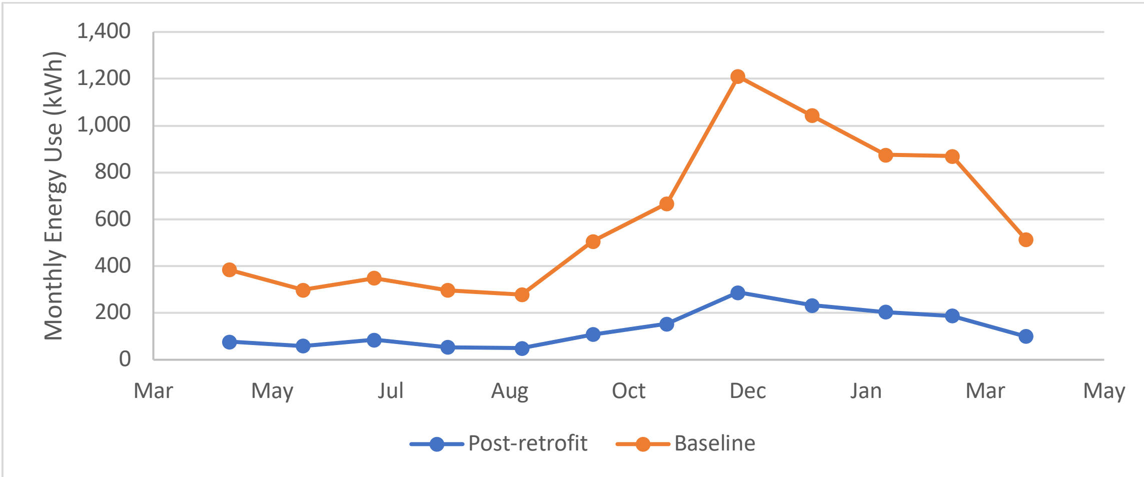


Figure 5. Post-retrofit and baseline monthly energy use

Measured Energy Use Figures

Figure 6 is a boxplot of the hourly outdoor unit monitored power, which shows that outdoor unit energy use is highest in the early afternoon and is very low during the morning, evening, and overnight hours.

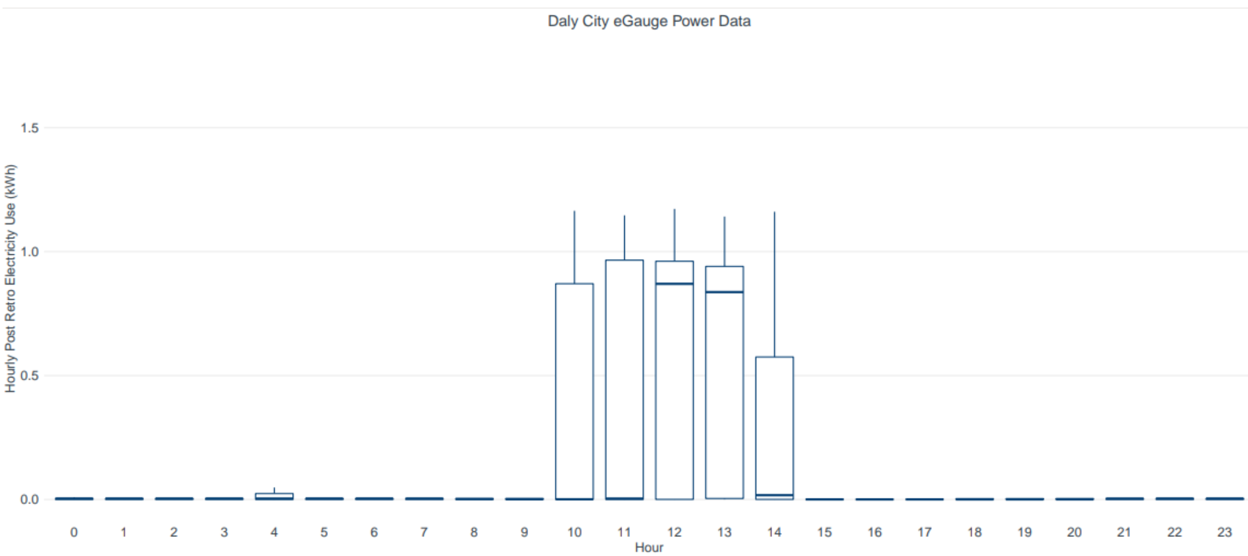


Figure 6. Boxplot of hourly outdoor unit monitored power

Figure 7 is a density plot of the hourly outdoor unit monitored power, separated by month, which shows that energy use is higher during the winter months than the summer months.

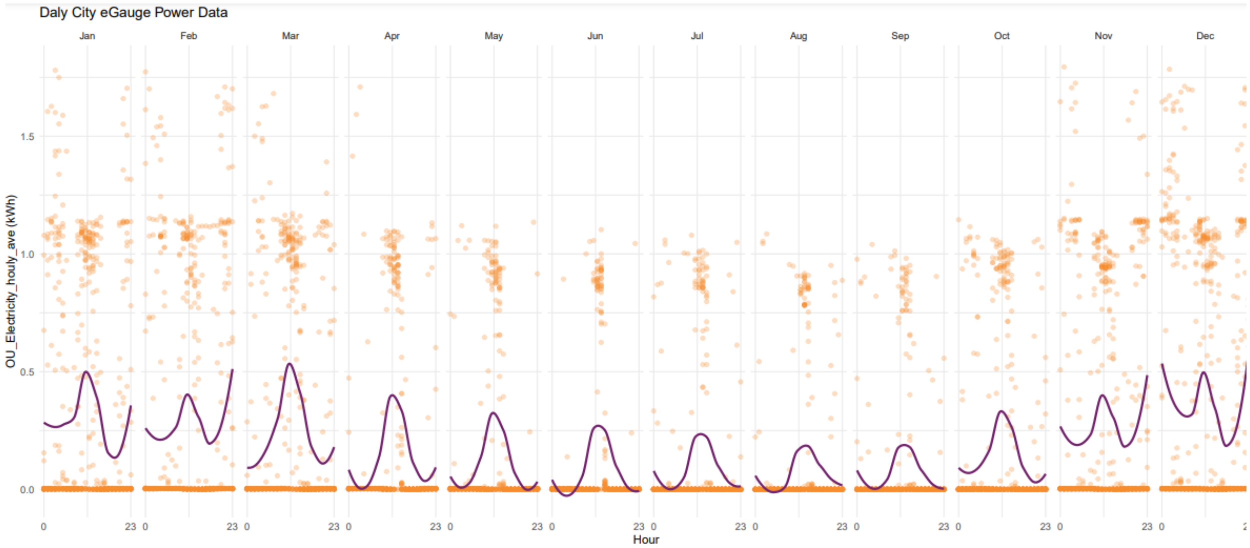


Figure 7. Density plot of hourly outdoor unit monitored power, separated by month

Figure 8 is a density plot of the outdoor unit monitored power, separated by day of week and season, which shows that the energy use is highest in winter, with no significant trends based on day of the week.

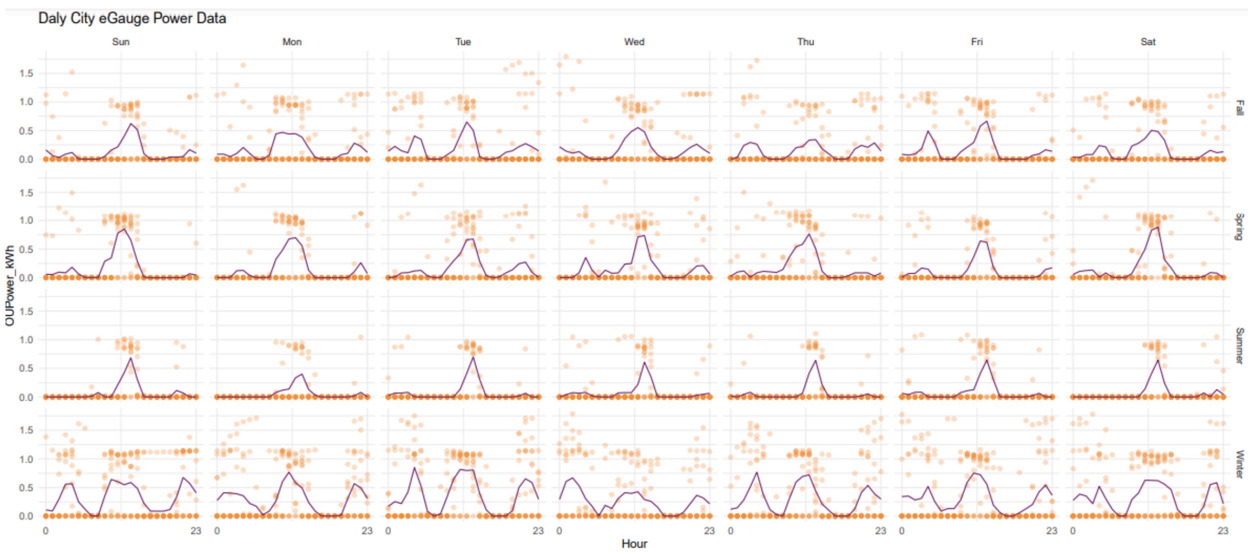


Figure 8. Density plot of hourly outdoor unit monitored power, separated by day of week and season

Figure 9 is a boxplot of the hourly air handling unit monitored power, which shows that outdoor unit energy use is highest in the morning from 8 a.m. to 9 a.m. and at night from 6 p.m. to 10 p.m.

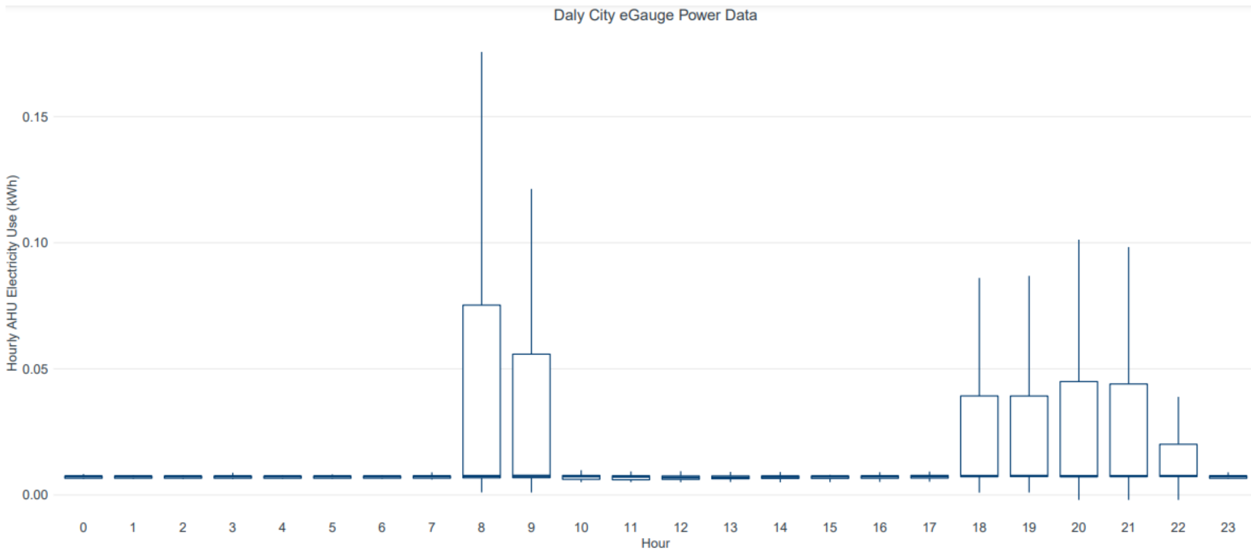


Figure 9. Boxplot of hourly air handling unit monitored power

Figure 10 is a density plot of the hourly air handling unit monitored power, separated by month, which shows that energy use is significantly higher during the winter months than the summer months. From April through September, there is not much energy use, except for during July, during which it appears that the air handler runs for much of the month.

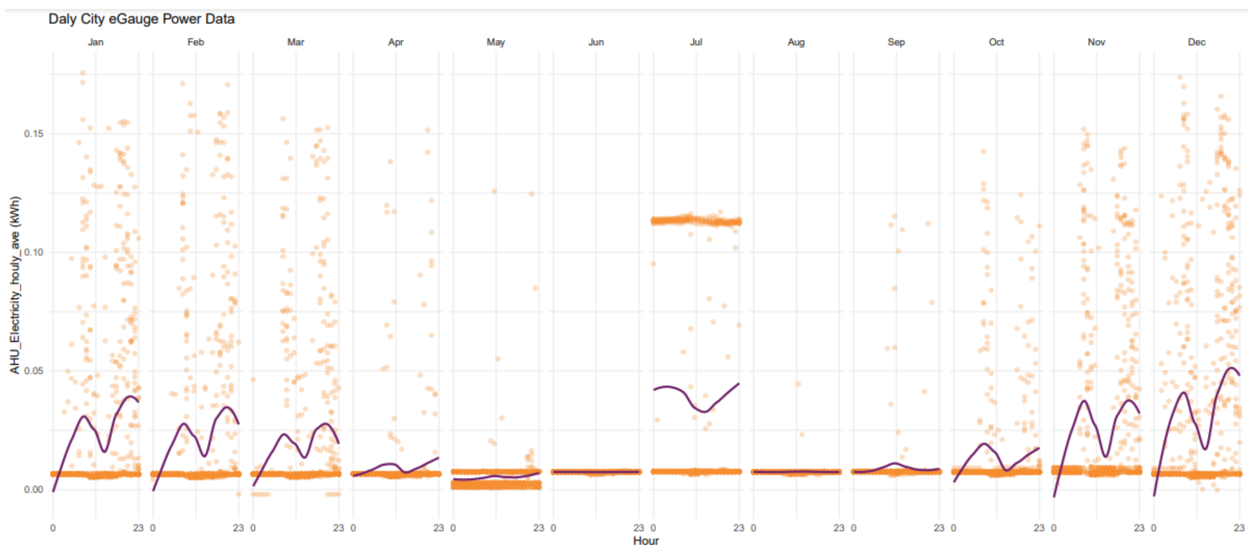


Figure 10. Density plot of hourly air handling unit monitored power, separated by month

Figure 11 is a density plot of the air handling unit monitored power, separated by the day of the week and season, which shows that the energy use is highest in the winter and fall, with some energy use in the spring and summer.

Figure 11. Density plot of hourly air handling unit monitored power, separated by day of week and season

4.1.2 Redwood City

Table 6 presents the monthly measured energy use, the calculated baseline energy use, and the energy savings.

Table 6. Redwood City Measured Energy Use and Savings

	Monitored Post-retrofit Energy Use			Calculated Baseline Energy Use		Energy Savings		
	Space Heating & Water Heating			Space Heating & Water Heating	Fan Energy	Space Heating & Water Heating		
Period	Electricity full TRC data (kWh)	Electricity Coincident with load data (kWh)	% of time missing HT load data	Gas (therms)	Electricity (kWh)	Electricity (kWh)	Gas (therms)	Electricity + Gas (kWh)
May-22	65	65	7%	12	5	-60	12	306
Jun-22	45	45	17%	8	5	-39	8	203
Jul-22	45	45	11%	8	6	-39	8	195
Aug-22	44	44	6%	8	5	-39	8	197
Sep-22	42	39	12%	7	5	-34	7	176
Oct-22	62	62	7%	10	5	-57	10	235
Nov-22	270	270	7%	35	18	-252	35	761
Dec-22	361	361	6%	46	24	-338	46	1,018
Jan-23	316	316	6%	42	21	-295	42	941
Feb-23	344	332	10%	37	23	-309	37	762
Mar-23	286	286	7%	39	18	-267	39	866
Apr-23	143	142	7%	20	9	-133	20	461
Year	**2,024**	**2,008**		**272**	**146**	**-1,862**	**272**	**6,121**

Energy Savings Figures

Figure 12 depicts the monthly energy use of the post-retrofit and the baseline, which shows that in terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use, with the peak energy use in both cases being in December 2022.

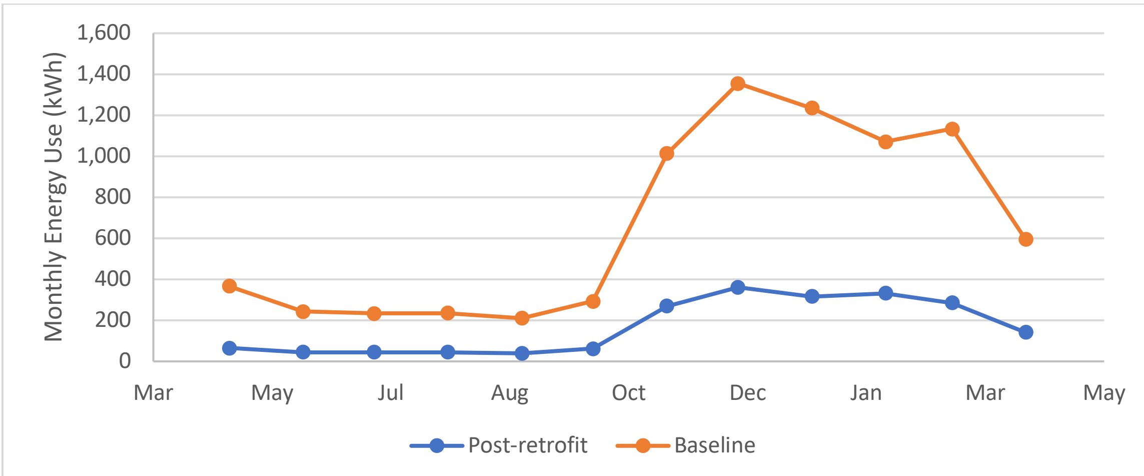


Figure 12. Post-retrofit and baseline monthly energy use

Figure 13 is a boxplot of the hourly energy use using data from the entire monitoring period, both post-retrofit and baseline.

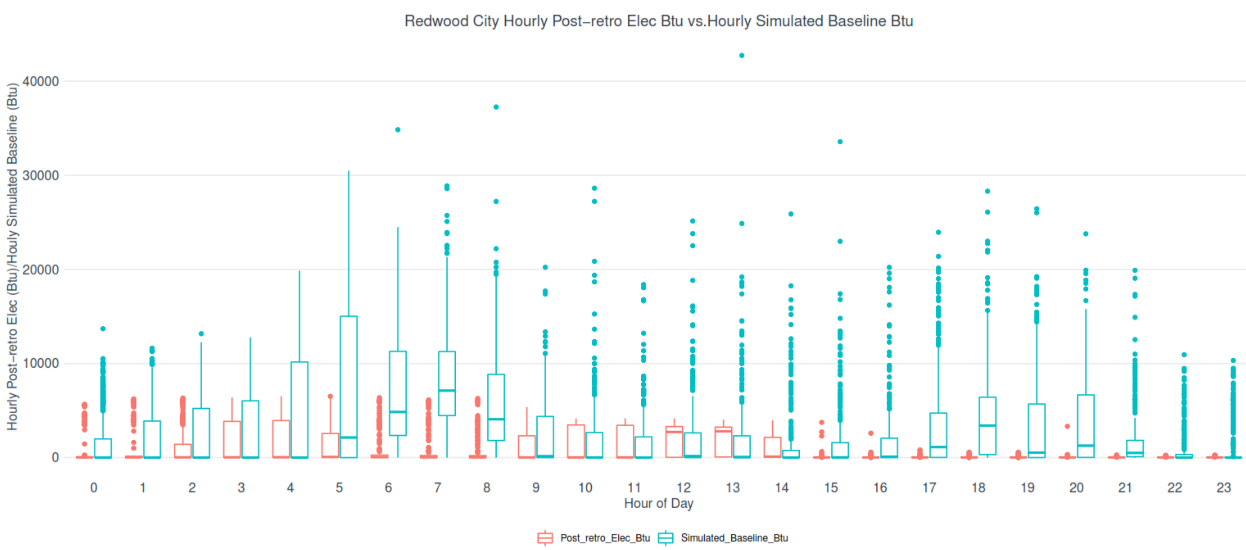


Figure 13. Boxplot of hourly post-retrofit and baseline energy use

Measured Energy Use Figures

Figure 14 is a boxplot of the hourly outdoor unit monitored power, which shows that outdoor unit energy use is highest overnight (2 a.m. to 5 a.m.) and in the early part of the day (9 a.m. to 2 p.m.), and is very low during the late morning, late afternoon, and evening hours.

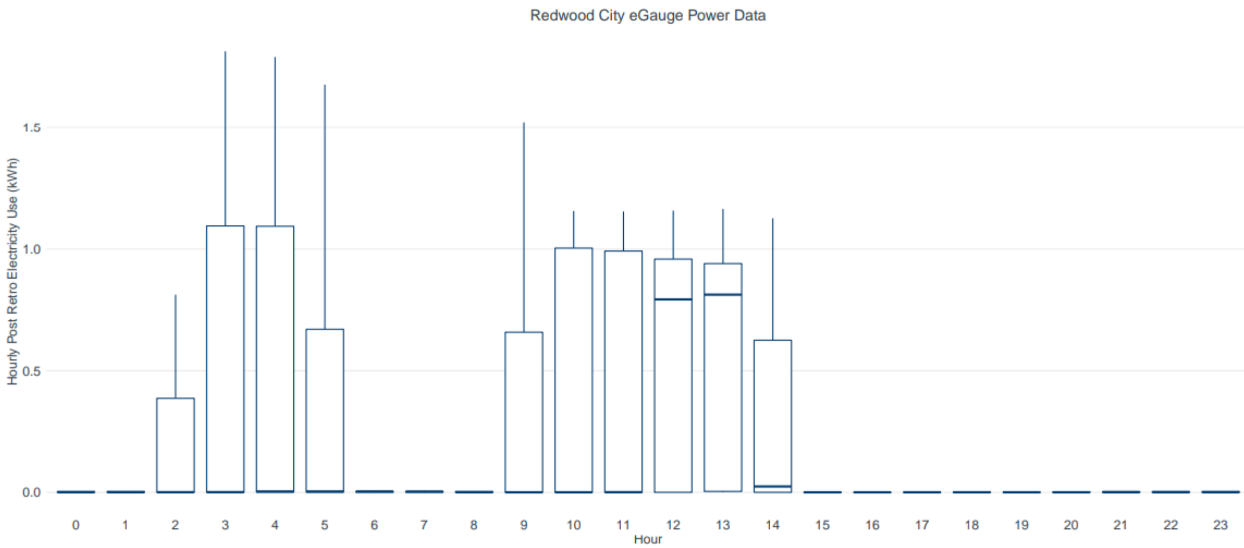


Figure 14. Boxplot of hourly outdoor unit monitored power

Figure 15 is a density plot of the hourly outdoor unit monitored power, separated by month, which shows that energy use is higher during the winter months than the summer months.

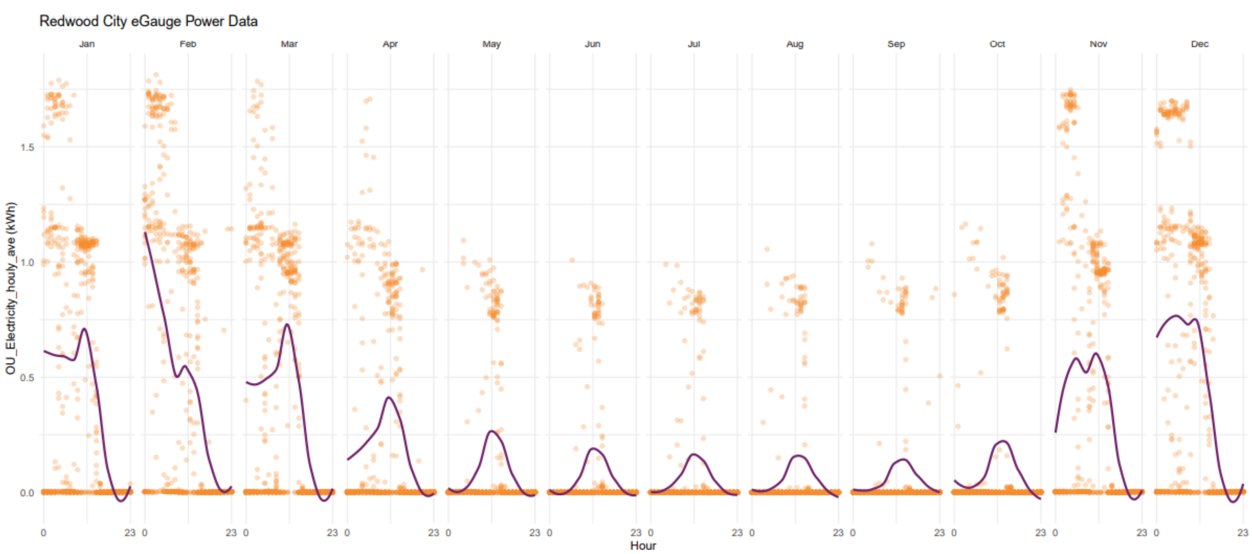


Figure 15. Density plot of hourly outdoor unit monitored power, separated by month

Figure 16 is a density plot of the outdoor unit monitored power, separated by day of week and season, which shows that the energy use is highest in winter, with no significant trends based on day of the week.

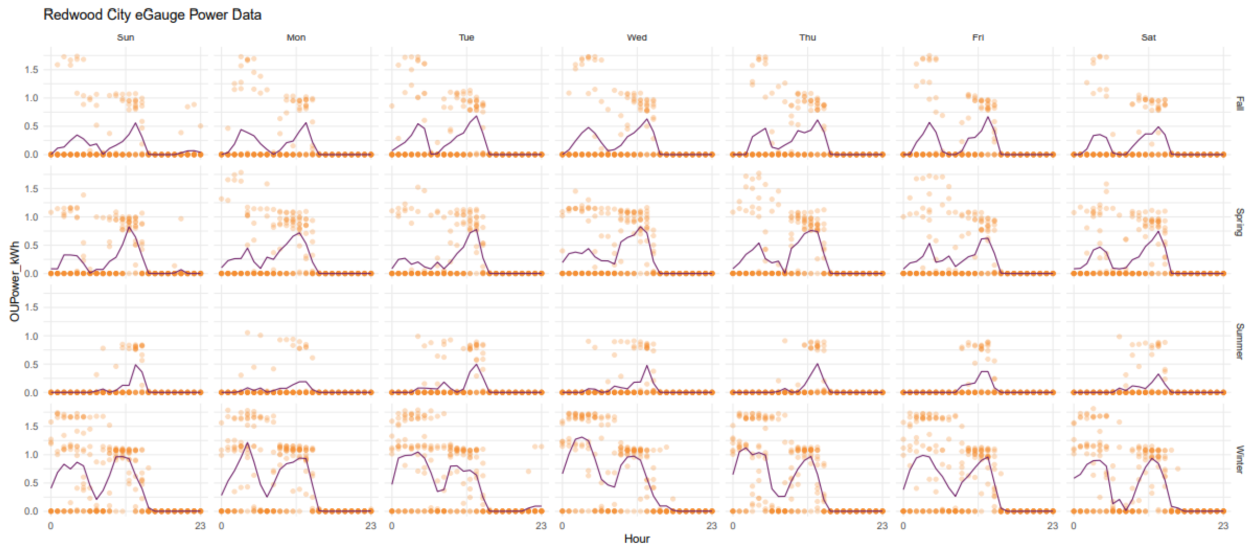


Figure 16. Density plot of hourly outdoor unit monitored power, separated by day of week and season

Figure 17 is a boxplot of the hourly air handling unit monitored power, which shows that outdoor unit energy use is highest in the morning, starting to ramp up around 12 a.m., peaking around 5 a.m., after which it decreases then tapers down by around 10 a.m.

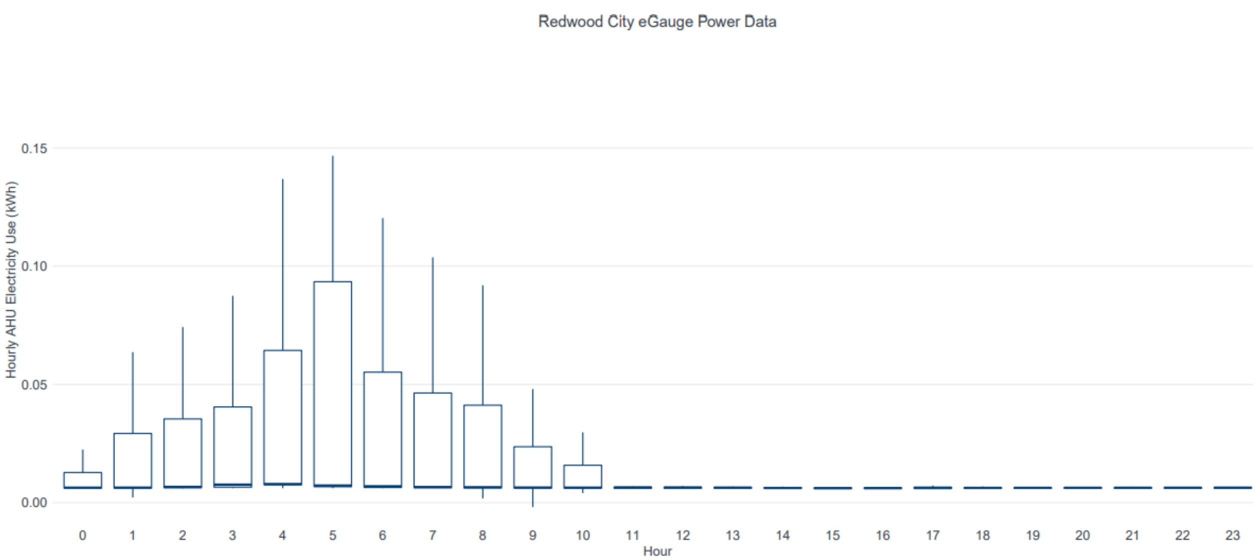


Figure 17. Boxplot of hourly air handling unit monitored power

Figure 18 is a density plot of the hourly air handling unit monitored power, separated by month, which shows that energy use is significantly higher during the winter months than the summer months.

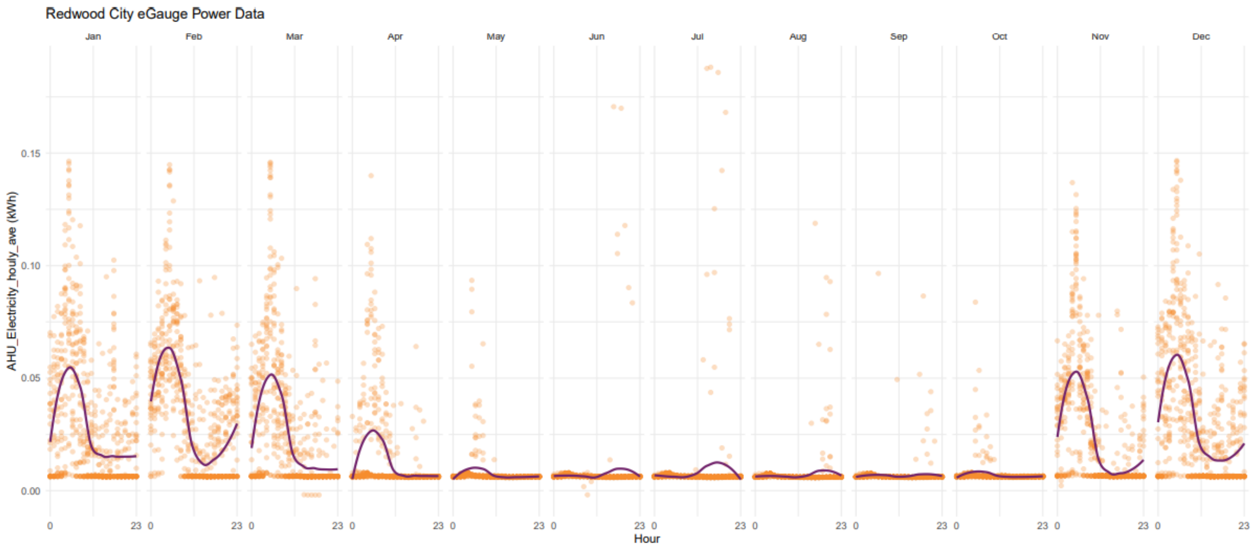


Figure 18. Density plot of hourly air handling unit monitored power, separated by month

Figure 19 is a density plot of the air handling unit monitored power, separated by day of week and season, which shows that the energy use is highest in the winter, with still some energy use in the spring and fall, and very little energy use in the summer.

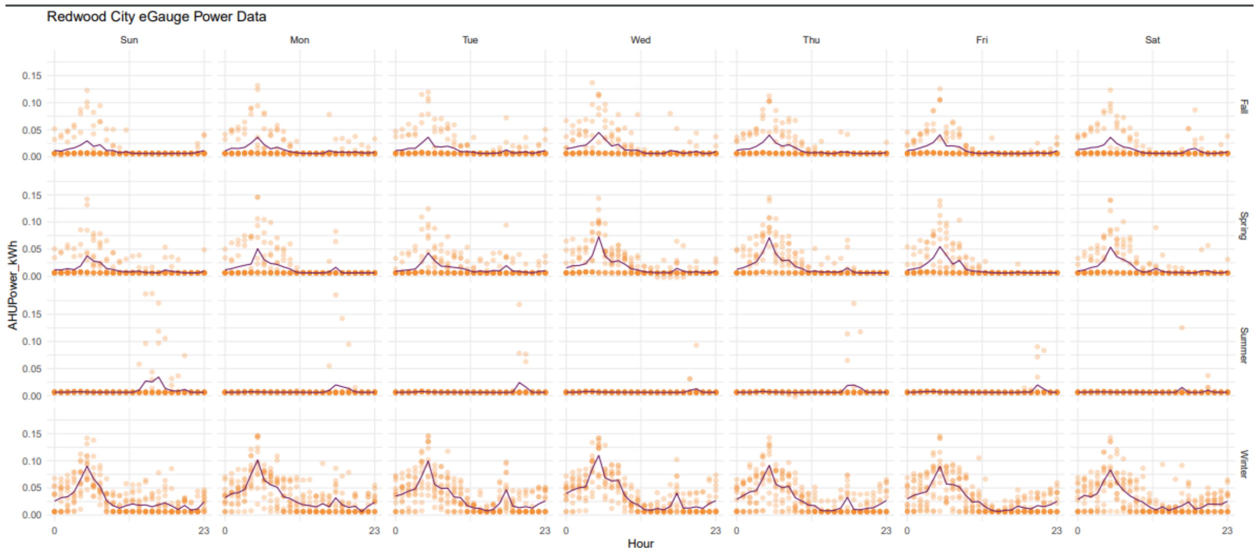


Figure 19. Density plot of hourly air handling unit monitored power, separated by day of week and season

4.1.3 South San Francisco

Table 7 presents the monthly measured energy use, the calculated baseline energy use, and the energy savings.

Table 7. South San Francisco Measured Energy Use and Savings

	Monitored Post-retrofit Energy Use			Calculated Baseline Energy Use		Energy Savings		
	Space Heating & Water Heating			Space Heating & Water Heating	Fan Energy	Space Heating & Water Heating		
Period	Electricity full TRC data (kWh)	Electricity Coincident with load data (kWh)	% of time missing HT load data	Gas (therms)	Electricity (kWh)	Electricity (kWh)	Gas (therms)	Electricity + Gas (kWh)
May-22	316	316	7%	33	31	-285	33	680
Jun-22	154	154	7%	16	16	-138	16	323
Jul-22	185	183	8%	19	19	-163	19	383
Aug-22	77	77	6%	7	9	-68	7	143
Sep-22	62	62	12%	6	8	-54	6	117
Oct-22	222	222	7%	23	25	-197	23	486
Nov-22	426	420	8%	44	42	-378	44	925
Dec-22	597	597	6%	65	56	-541	65	1,351
Jan-23	574	574	6%	62	55	-519	62	1,298
Feb-23	595	595	7%	63	55	-540	63	1,301
Mar-23	612	612	7%	67	57	-554	67	1,398
Apr-23	452	452	6%	49	43	-409	49	1,019
Year	**4,271**	**4,261**		**453**	**414**	**-3,847**	**453**	**9,423**

Energy Savings Figures

Figure 20 depicts the monthly energy use of the post-retrofit and the baseline, which shows that in terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use, with the peak energy use in both cases being in March 2023.

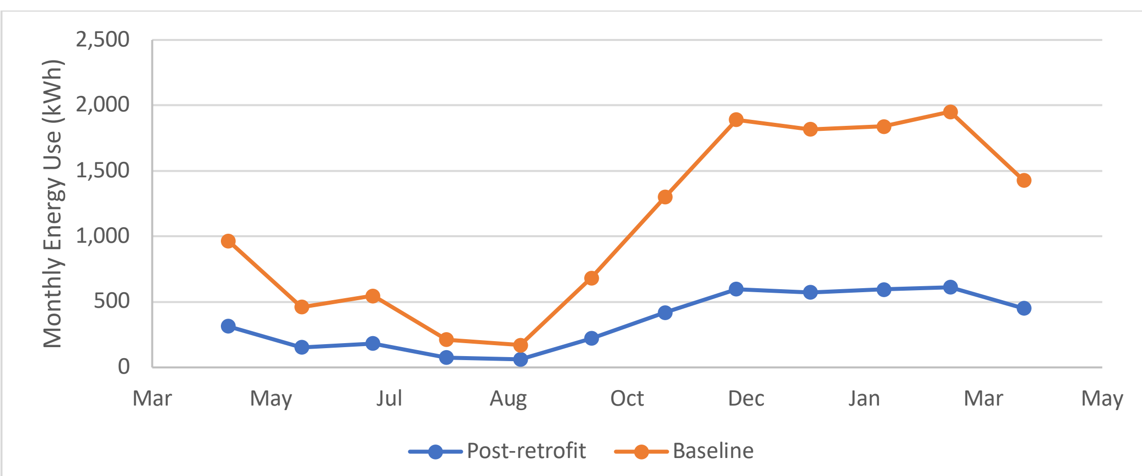


Figure 20. Post-retrofit and baseline monthly energy use

Figure 21 is a boxplot of the hourly energy use using data from the entire monitoring period, both post-retrofit and baseline.

Figure 21. Boxplot of hourly post-retrofit and baseline energy use

Measured Energy Use Figures

Figure 22 is a boxplot of the hourly outdoor unit monitored power, which shows that outdoor unit energy use is highest in the early morning and early afternoon and is very low during the late afternoon and evening hours.

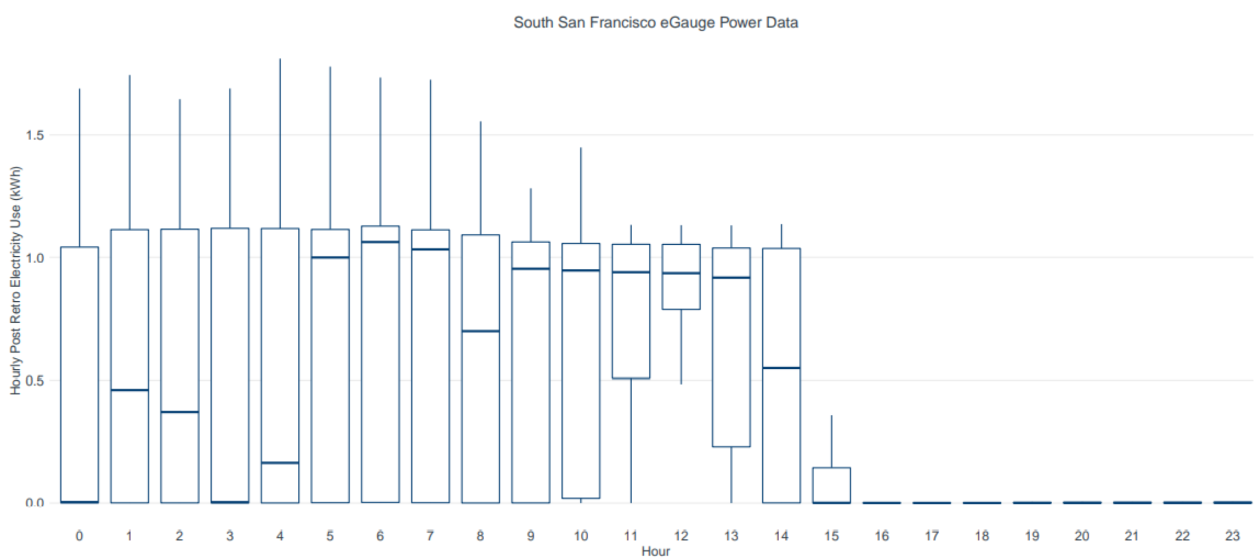


Figure 22. Boxplot of hourly outdoor unit monitored power

Figure 23 is a density plot of the hourly outdoor unit monitored power, separated by month, which shows that energy use is higher during the winter months than the summer months.

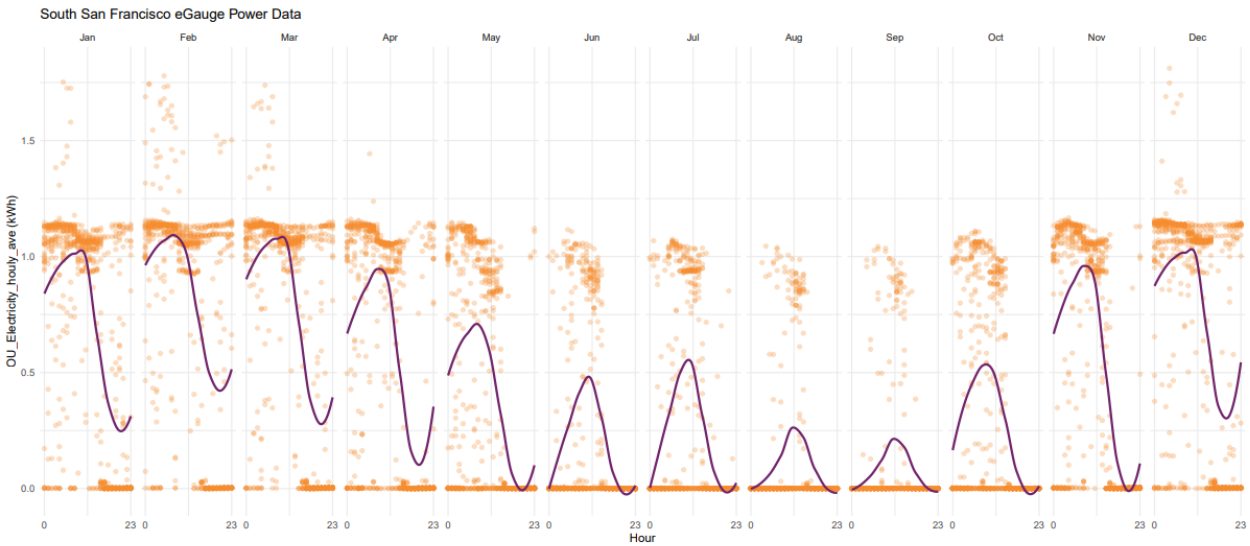


Figure 23. Density plot of hourly outdoor unit monitored power, separated by month

Figure 24 is a density plot of the outdoor unit monitored power, separated by day of week and season, which shows that the energy use is highest in winter and spring, with no significant trends based on day of the week.

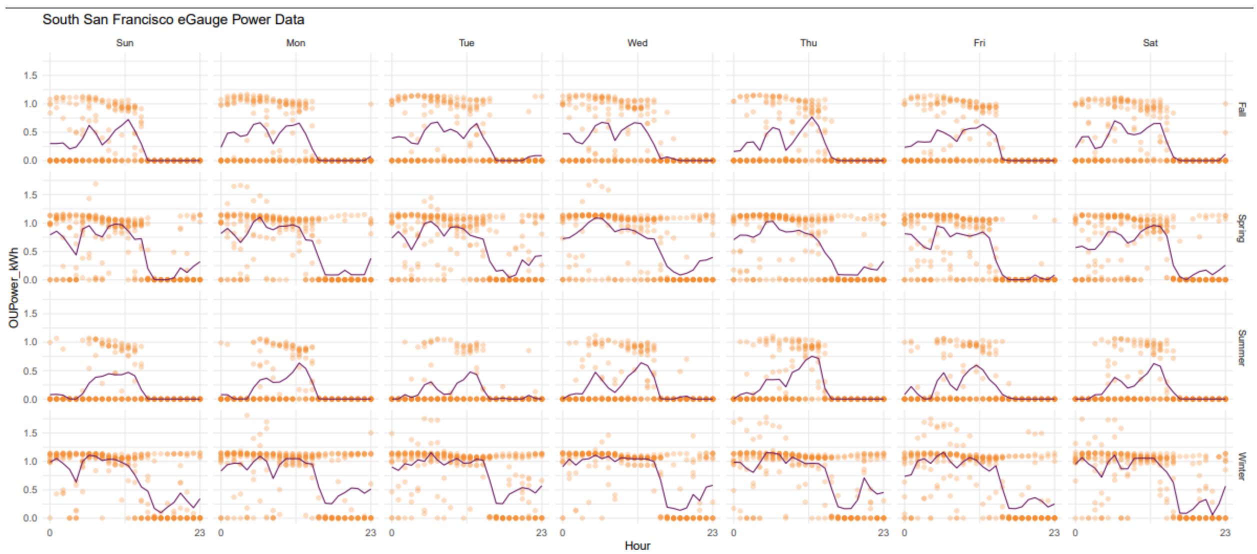


Figure 24. Density plot of hourly outdoor unit monitored power, separated by day of week and season

Figure 25 is a boxplot of the hourly air handling unit monitored power, which shows that outdoor unit energy use is highest in the morning, starting to ramp up around 3 a.m., peaking around 6 a.m., after which it decreases then tapers down by around 12 p.m.

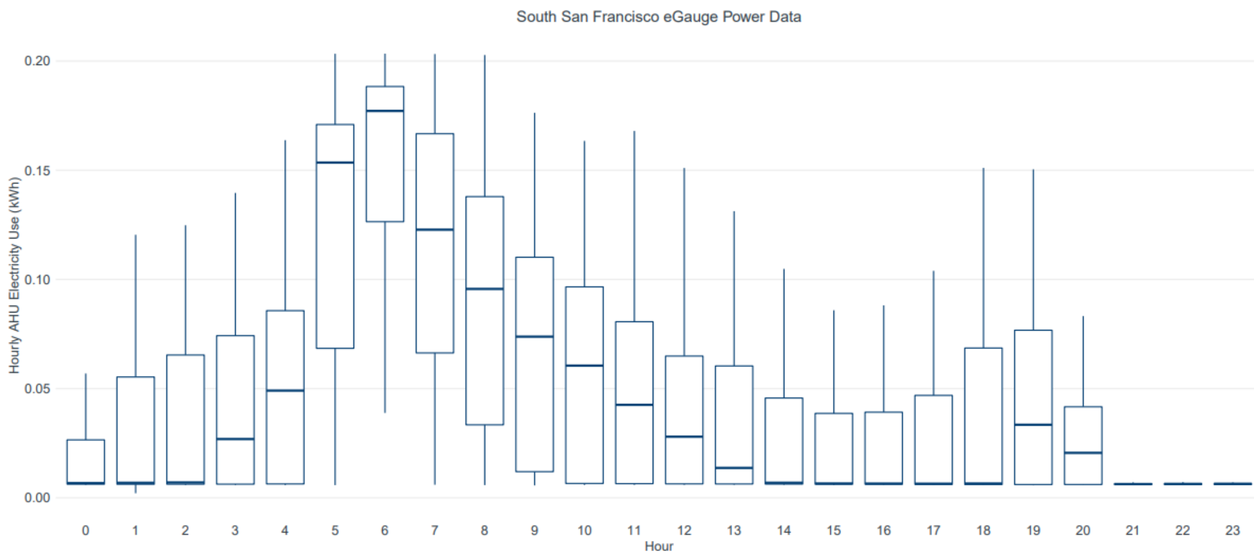


Figure 25. Boxplot of hourly air handling unit monitored power

Figure 26 is a density plot of the hourly air handling unit monitored power, separated by month, which shows that energy use is significantly higher during the winter months than the summer months.

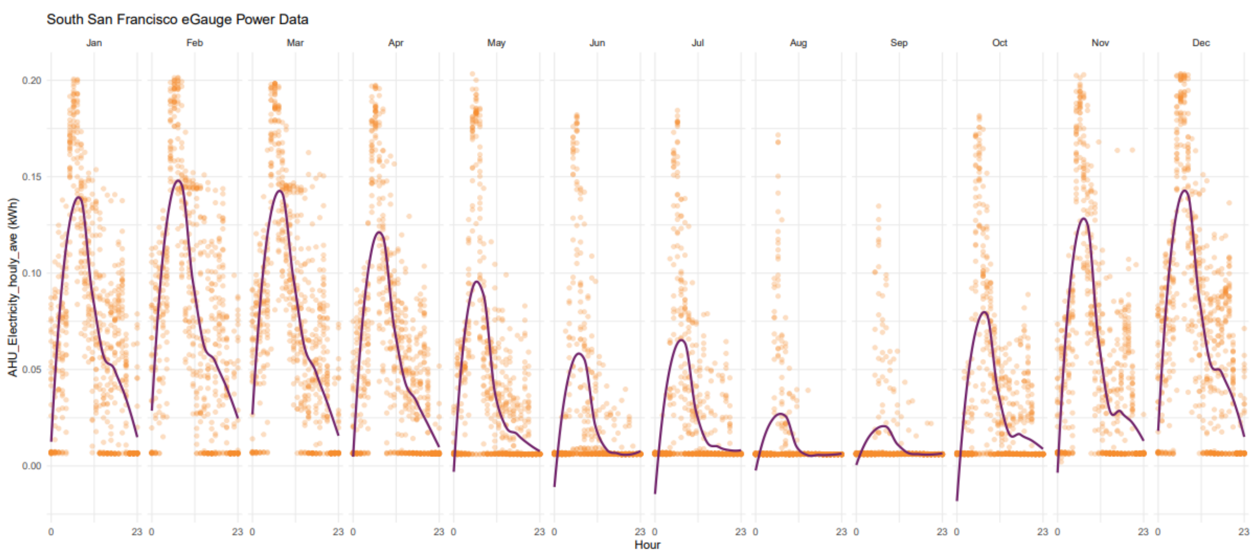


Figure 26. Density plot of hourly air handling unit monitored power, separated by month

Figure 27 is a density plot of the air handling unit monitored power, separated by day of week and season, which shows that the energy use is highest in the winter and spring, with still some energy use in the summer and fall.

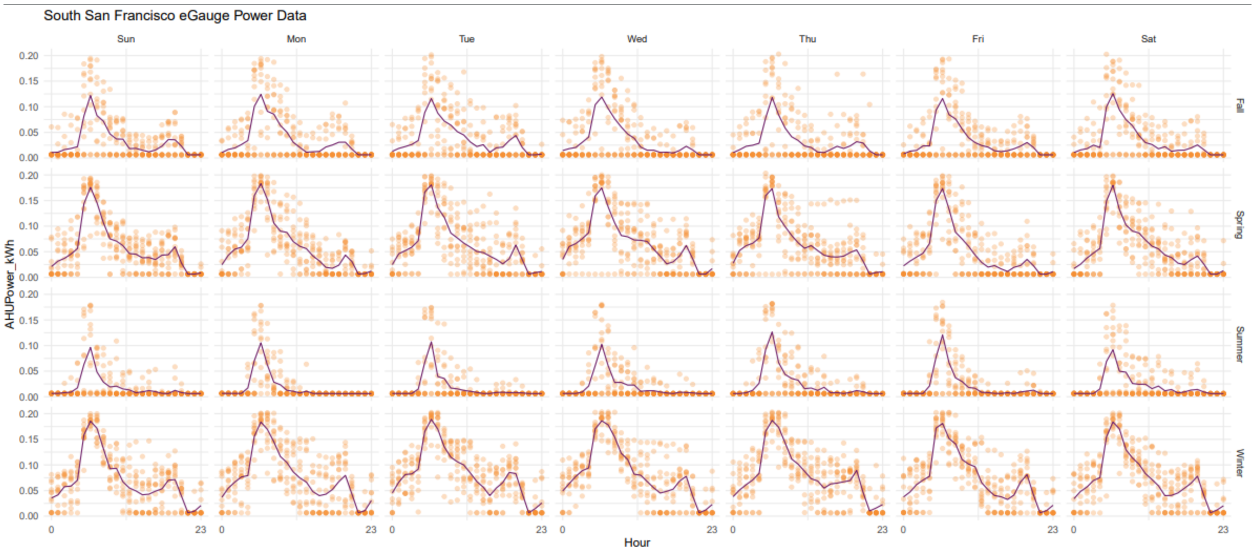


Figure 27. Density plot of hourly air handling unit monitored power, separated by day of week and season

4.1.4 Menlo Park

Table 8 presents the monthly measured energy use, the calculated baseline energy use, and the energy savings.

Table 8. Menlo Park Measured Energy Use and Savings (7 months)

	Monitored Post-retrofit Energy Use			Calculated Baseline Energy Use		Energy Savings		
	Space Heating & Water Heating			Space Heating & Water Heating	Fan Energy	Space Heating & Water Heating		
Period	Electricity full TRC data (kWh)	Electricity - Coincident with load data (kWh)	% of time missing HT load data	Gas (therms)	Electricity (kWh)	Electricity (kWh)	Gas (therms)	Electricity + Gas (kWh)
Oct-22	197	196	9%	29	26	-169	29	668
Nov-22	752	752	7%	88	46	-706	88	1,875
Dec-22	859	855	8%	101	55	-800	101	2,166
Jan-23	668	665	7%	78	43	-622	78	1,652
Feb-23	630	559	16%	62	37	-522	62	1,308
Mar-23	499	468	12%	56	31	-438	56	1,208
Apr-23	239	238	7%	32	20	-218	32	713
Partial Year	**3,844**	**3,733**		**446**	**258**	**-3,475**	**N/A**	**9,590**

Energy Savings Figures

Figure 28 depicts the monthly energy use of the post-retrofit and the baseline, which shows that in terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use, with the peak energy use in both cases being in December 2022.

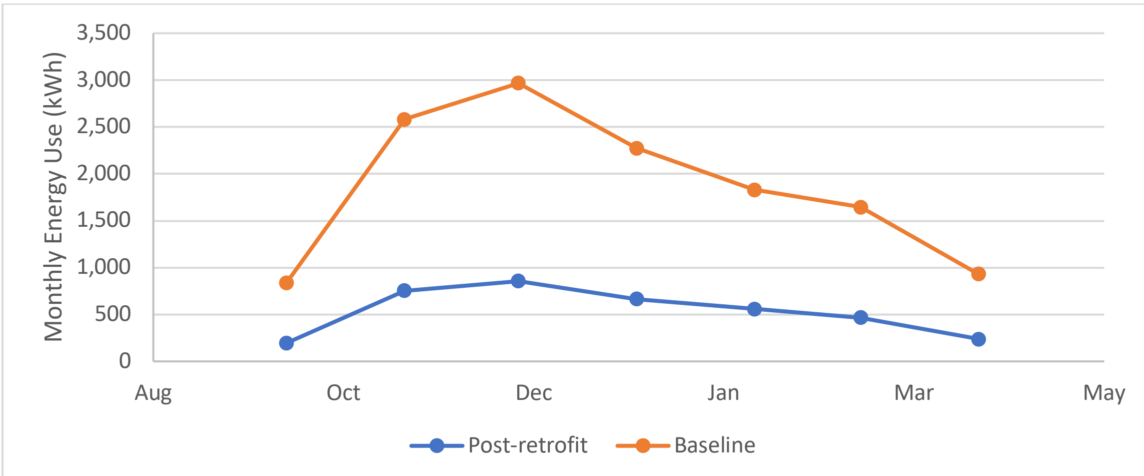


Figure 28. Post-retrofit and baseline monthly energy use (7 months)

Figure 29 is a boxplot of the hourly energy use, using data from the entire monitoring period, in the post-retrofit and the baseline.

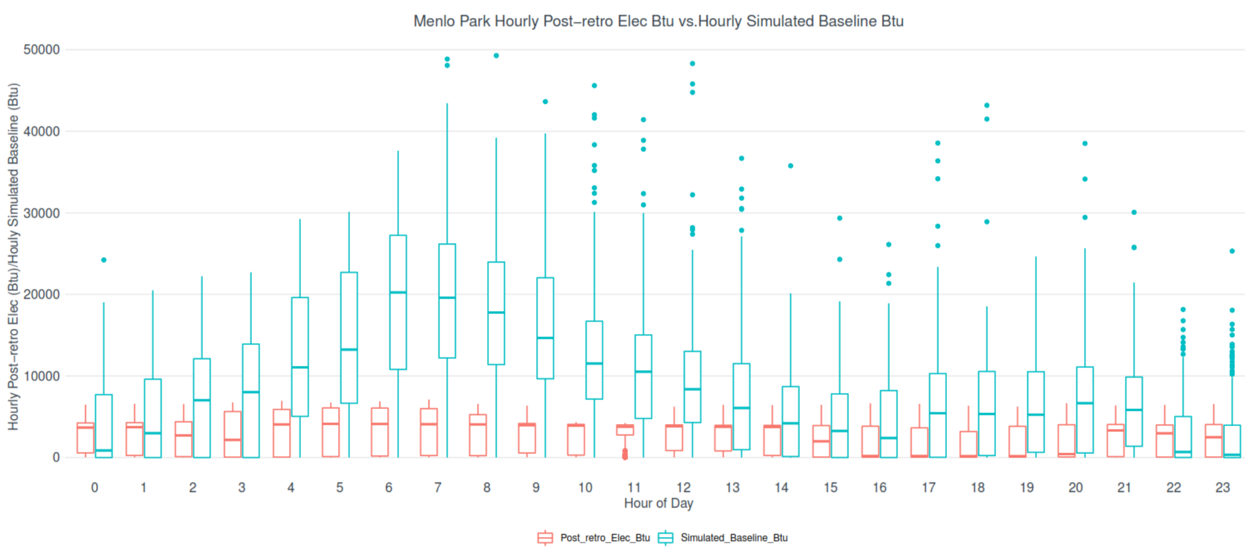


Figure 29. Boxplot of hourly post-retrofit and baseline energy use (based on 7 months of monitored data)

Measured Energy Use Figures

Figure 30 is a boxplot of the hourly outdoor unit monitored power, which shows outdoor unit energy use throughout the day, with lowest usage from 4 p.m. to 9 p.m.

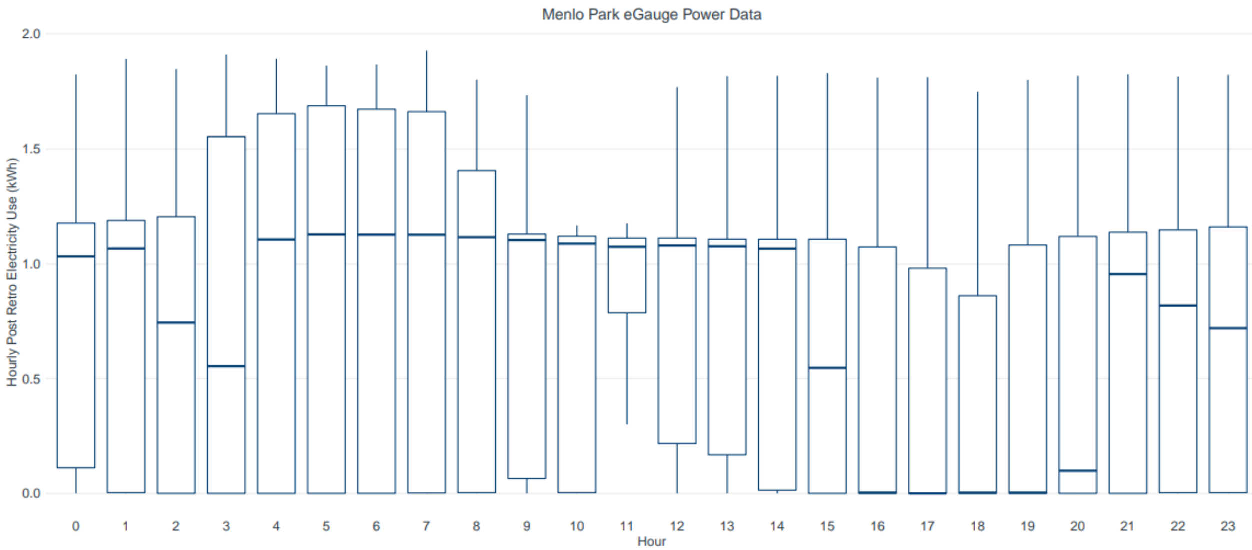


Figure 30. Boxplot of hourly outdoor unit monitored power (based on 7 months of monitored data)

Figure 31 is a density plot of the hourly outdoor unit monitored power, separated by month.

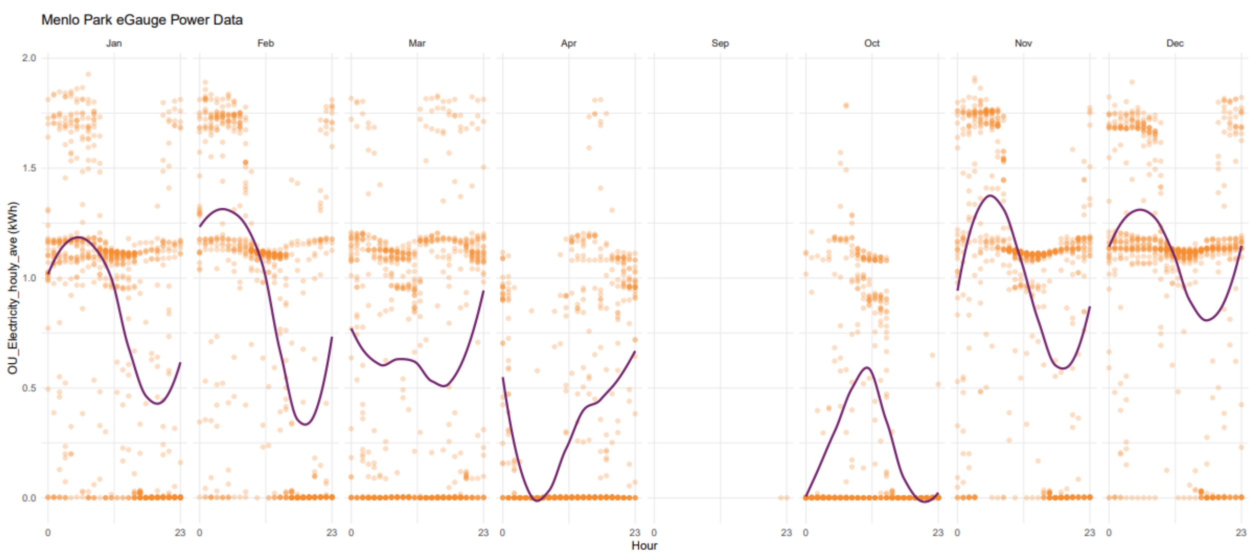


Figure 31. Density plot of hourly outdoor unit monitored power, separated by month

Figure 32 is a density plot of the outdoor unit monitored power, separated by day of week and season, which shows that the energy use is highest in the winter, with no significant trends based on day of week.

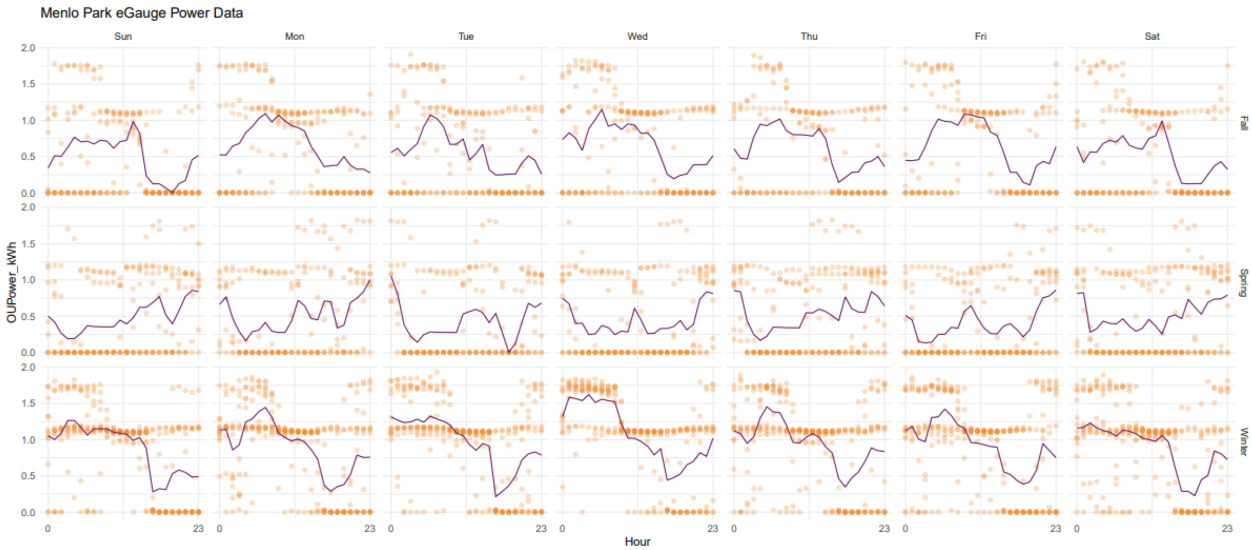


Figure 32. Density plot of hourly outdoor unit monitored power, separated by day of week and season (based on 7 months of monitored data)

Figure 33 is a boxplot of the hourly air handling unit monitored power between October and April, showing outdoor unit energy use throughout the day, with the peak being in the morning around 6 a.m. to 7 a.m.

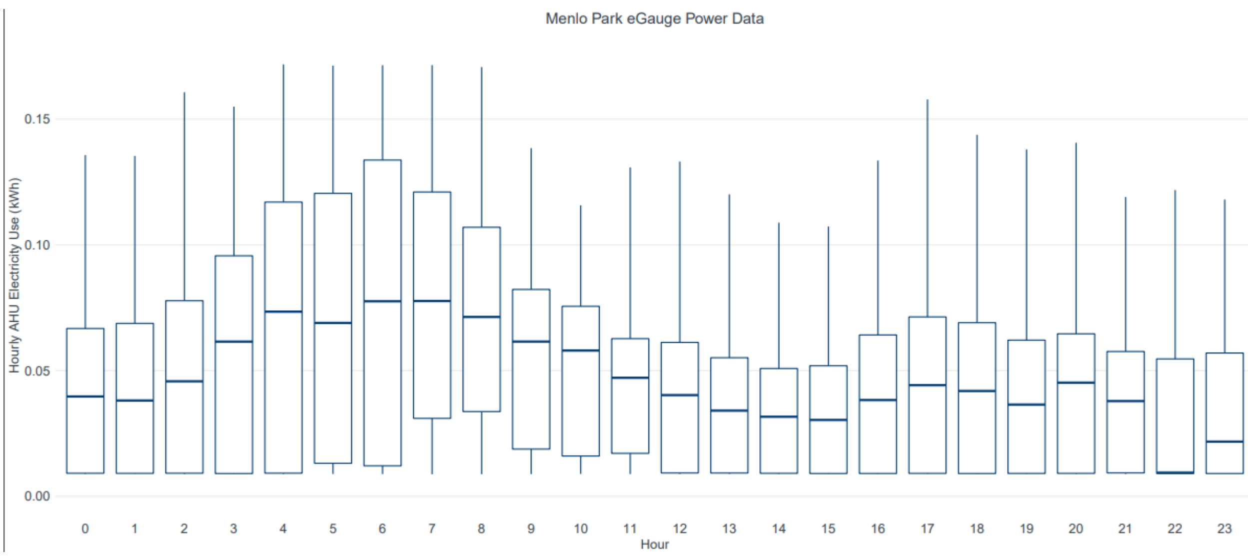


Figure 33. Boxplot of hourly air handling unit monitored power (based on 7 months of monitored data)

Figure 34 is a density plot of the hourly air handling unit monitored power, separated by month, showing energy use is higher during the winter months than the summer months.

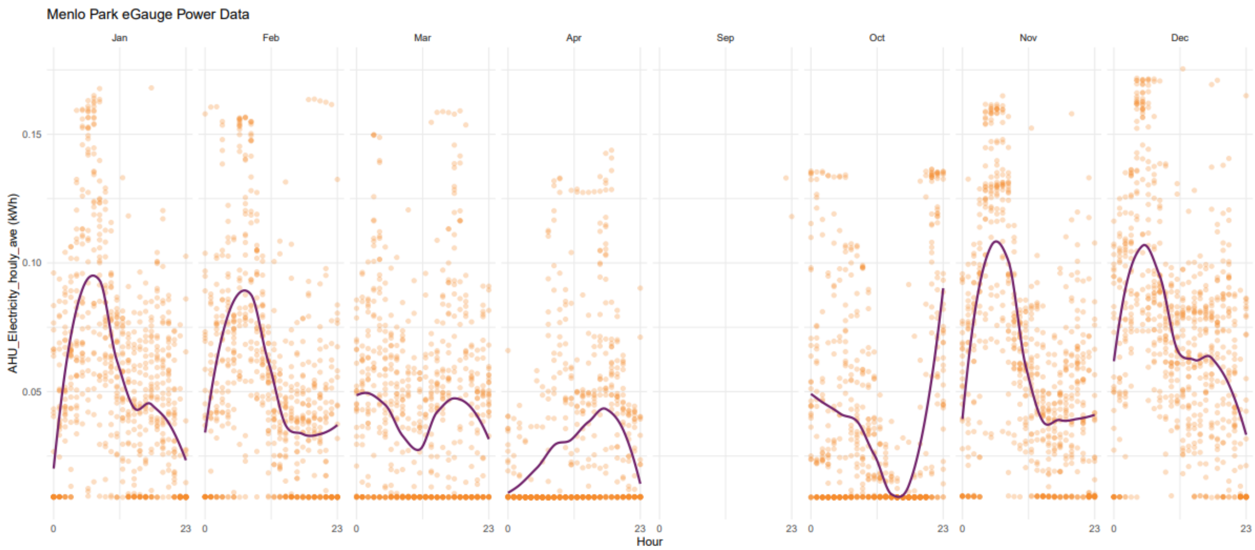


Figure 34. Density plot of hourly air handling unit monitored power, separated by month

Figure 35 is a density plot of the air handling unit's monitored power, separated by day of week and season, showing energy use is highest in the winter, with still some energy use in the spring and fall.

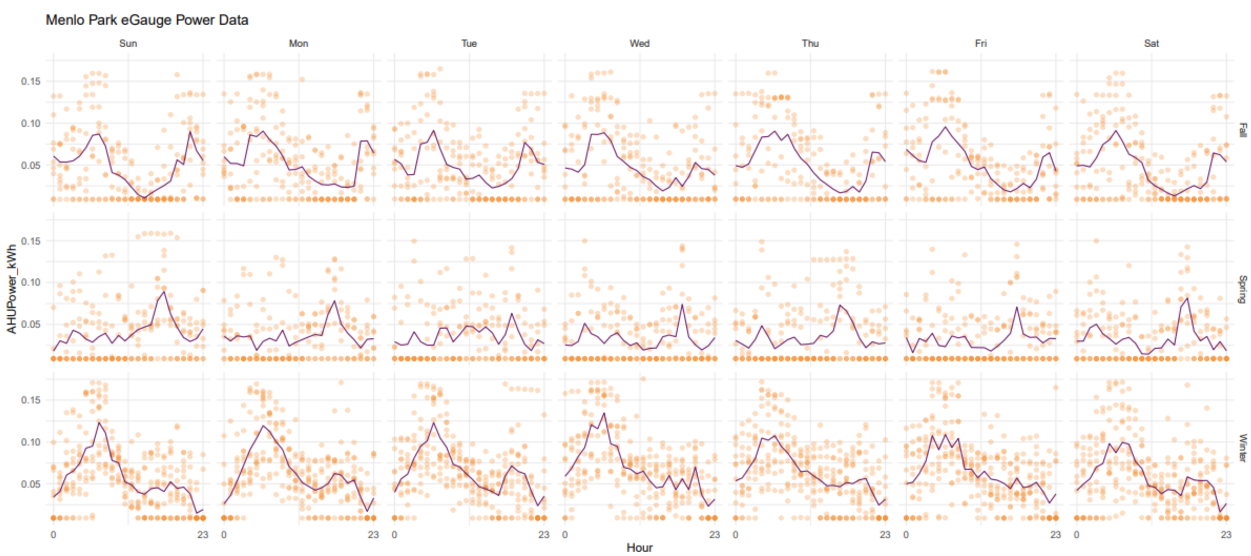


Figure 35. Density plot of hourly air handling unit monitored power, separated by day of week and season (based on 7 months of monitored data)

4.2 Normalized Energy Usage

TRC characterized the annual savings in terms of normalized energy use at each demonstration site. This approach normalizes for both the time of week and the outside air temperature. Normalized savings are more reliable predictions of future energy savings compared to the measured energy savings approach.

We developed regression models using the Time-of-Week and Temperature (TOWT) approach, a piecewise linear regression-based model developed by Lawrence Berkeley National Lab that uses both time of week and outdoor air temperature.[11, 12] We developed time-of-week and temperature-dependent change point regression models from the monitored Harvest Thermal system's energy use and the baseline energy use developed in Section 4.1. TRC applied those models to an annual typical meteorological year (TMY3) weather file to determine typical annual energy use profiles for both the baseline and the post-retrofit cases. TRC also applied those models to the actual outside air temperature profile at each site to determine the normalized energy use, which fills in any data gaps present from the measured energy use reported in Section 4.1. We determined energy savings by subtracting the post-retrofit energy use from the baseline energy use for both the TMY3 weather analysis and the modeled actual weather analysis. We reported the savings separately for electricity (in kWh) and natural gas (in therms), as well as total energy (in Btu). We reported energy savings by month and for the full year.

TRC followed modeling best practices and sought to collect a dataset that included the maximum range of energy and independent variable values by collecting a full year of data where possible. We evaluated model fit accuracy using the R-squared value, the Coefficient of Variation of the Root Mean Square Error (CVRMSE), and the Net Determination Bias Error (NDBE). The R-squared value indicates the model's ability to capture the variability of the data. CVRMSE indicates the model's predictive accuracy. NDBE indicates how the model's predictions of training period total energy use are different from the actual energy use. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 14 indicates in the Whole Building Prescriptive Path that the CVRMSE and NDBE should have maximum values of 25% and 0.005%, respectively. The ASHRAE CVRMSE recommendation is applicable to the evaluation of whole-building energy modeling results, while the fitted model in this project is evaluating the load of a single appliance. The energy usage of an individual appliance is more sensitive to noise such as individual resident behavior and preferences, which cannot be captured by the independent variables used in the model.

Table 9 summarizes the daily energy use modeling results. The energy models have relatively high R-squared values, ranging from 0.52 to 0.88. The CVRMSE is between 25% and 49%, which is higher than what is recommended within ASHRAE guidelines. Despite the elevated CVRMSE, the model can predict daily energy profiles and energy use with sufficient accuracy for energy savings evaluation purposes. We observed lower model fit statistics for the Menlo Park home, which had a shorter monitoring period compared to the other sites.

Table 9. Model Fit Parameters

	Post-retrofit Daily Electricity Use			Calculated Baseline Daily Gas Use		
	R2	CVRMSE	NDBE	R2	CVRMSE	NDBE
Daly City	0.61	49%	0.000%	0.68	37%	0.000%
Redwood City	0.81	42%	0.000%	0.81	35%	0.000%
South San Francisco	0.87	25%	0.000%	0.88	25%	0.000%
Menlo Park	0.52	39%	0.000%	0.54	34%	0.000%

Figure 36 and Figure 37 depict variations between the monitored energy use and the model for the Daly City home in time series (Figure 36) and compared to outside air temperature (Figure 37). Overall, the

[11] https://www.osti.gov/servlets/purl/1048308
[12] https://eta-publications.lbl.gov/sites/default/files/LBNL-4944E.pdf

model shows a tighter correlation with outside air temperature than the actual monitored energy use, which is expected. Similarly, the time-series data generally shows more dramatic peaks and valleys for the monitored data compared to the model, which is also expected.

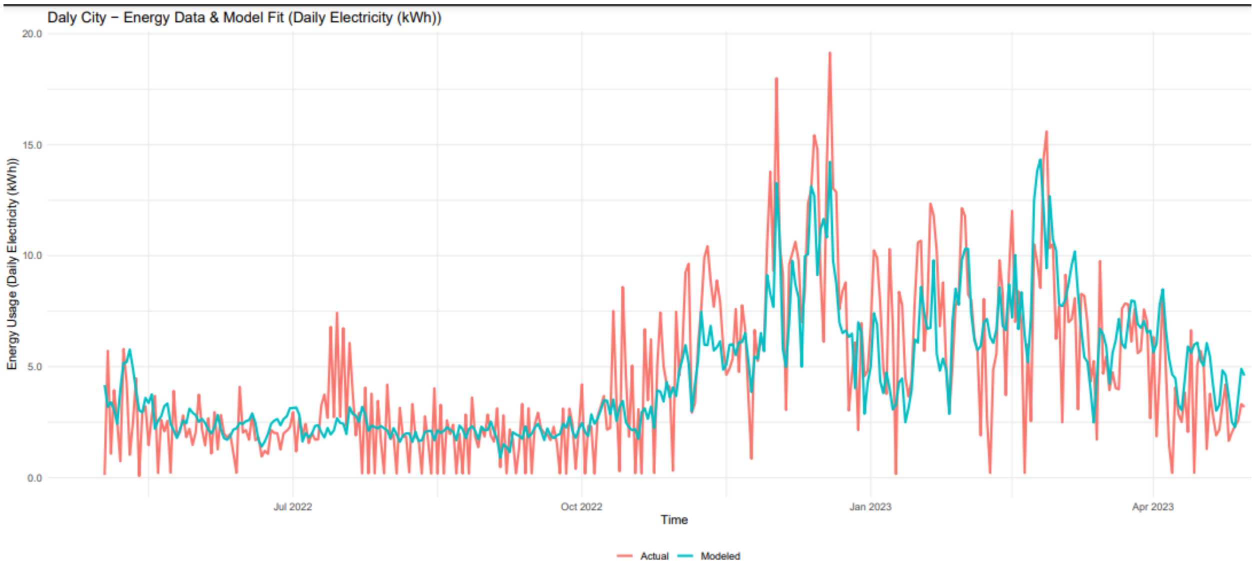


Figure 36. Electricity Use Model Fit, Daly City

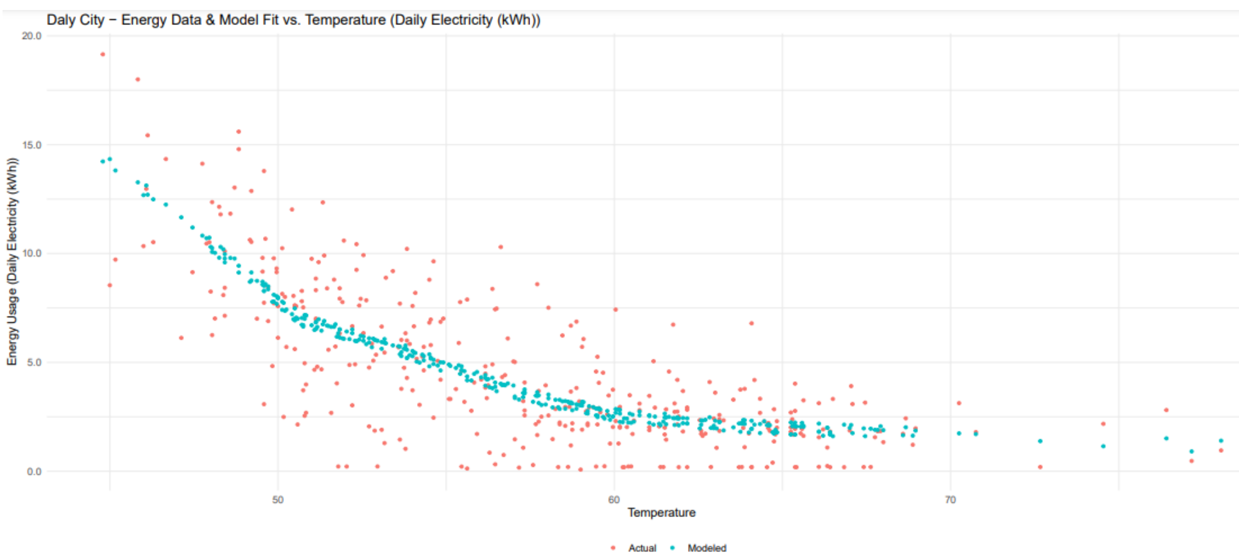


Figure 37. Electricity Use Model Fit, Daly City

Across all four sites, the normalized energy use with TMY weather data shows the annual energy savings range from 5,950 to 12,615 kWh across the four sites. See the subsections below for details.

4.2.1 Daly City

Table 10 presents the normalized post-retrofit and baseline monthly energy use. The post-retrofit energy use based on monitored data, normalized with actual outside air temperature results, and

normalized with TMY results all show consistent trends, with energy use being higher in the winter months and lower in the summer months.

Table 10. Daly City Normalized Energy Use and Savings

	Post-retrofit Energy Use (kWh)		Baseline Energy Use (kWh)		Energy Savings (kWh)
Period	Monitored (2022-2023)	Normalized, TMY	Normalized, space heating & water heating TMY	Normalized, fan electricity TMY	Normalized, TMY
January	233	297	1,177	10	890
February	204	179	808	9	637
March	188	157	721	7	572
April	101	126	588	7	469
May	76	106	505	7	406
June	59	94	453	9	369
July	89	80	379	13	312
August	54	74	358	19	302
September	54	71	334	23	287
October	108	97	468	15	386
November	210	148	682	13	548
December	289	231	993	11	774
Annual	**1,665**	**1,658**	**7,465**	**143**	**5,950**

Figure 38 shows the post-retrofit and baseline monthly energy use. In terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use.

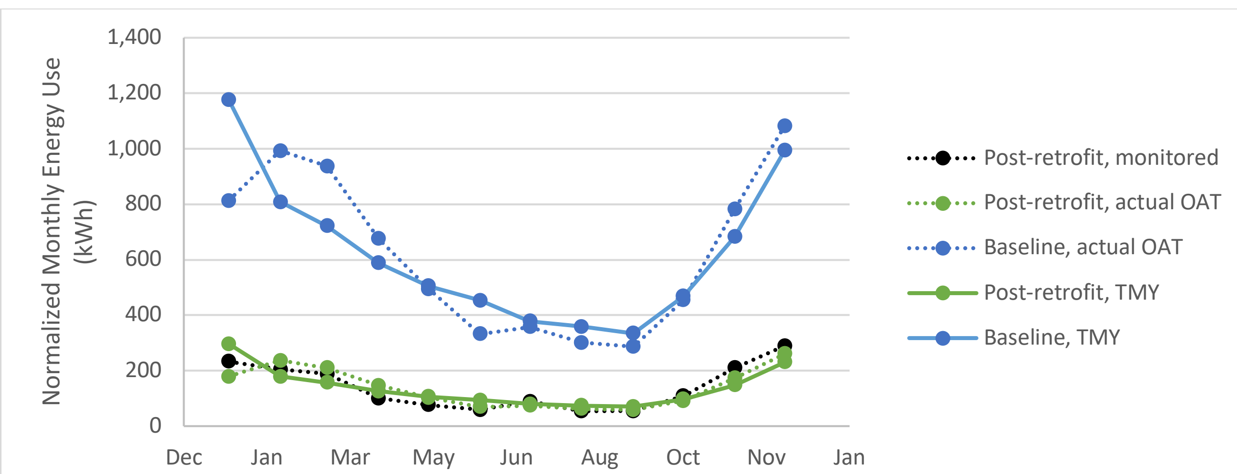


Figure 38. Post-retrofit and baseline monthly energy use, Daly City

4.2.2 Redwood City

Table 11 presents the normalized post-retrofit and baseline monthly energy use. The post-retrofit energy use based on monitored data, normalized with actual outside air temperature results, and

normalized with TMY results all show consistent trends, with energy use being higher in the winter months and lower in the summer months.

Table 11. Redwood City Normalized Energy Use and Savings

	Post-retrofit Energy Use (kWh)		Baseline Energy Use (kWh)		Energy Savings (kWh)
Period	Monitored (2022-2023)	Normalized, TMY	Normalized, space heating & water heating TMY	Normalized, fan electricity TMY	Normalized, TMY
January	316	412	1,405	15	1,009
February	344	256	967	13	724
March	286	196	782	10	595
April	143	141	589	9	457
May	65	99	451	9	360
June	45	79	374	13	309
July	45	55	283	24	251
August	44	50	267	41	258
September	42	49	253	48	253
October	62	79	378	33	333
November	270	172	698	27	553
December	361	330	1,200	20	890
Annual	**2,024**	**1,917**	**7,647**	**261**	**5,991**

Figure 39 shows the post-retrofit and baseline monthly energy use. In terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use.

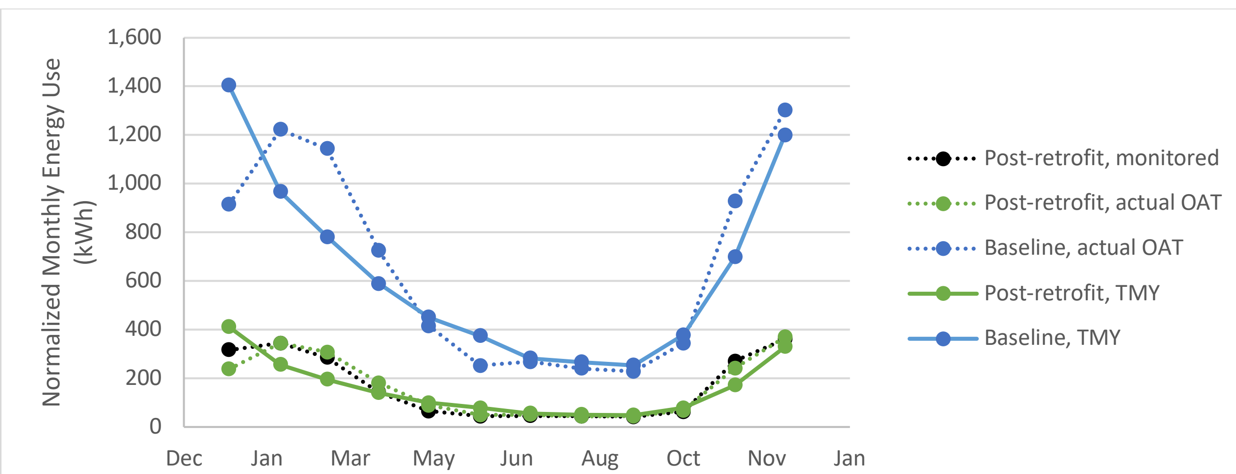


Figure 39. Post-retrofit and baseline monthly energy use, Redwood City

4.2.3 South San Francisco

Table 12 presents the normalized post-retrofit and baseline monthly energy use. The post-retrofit energy use based on monitored data, normalized with actual outside air temperature results, and

normalized with TMY results all show consistent trends, with energy use being higher in the winter months and lower in the summer months.

Table 12. South San Francisco Normalized Energy Use and Savings

	Post-retrofit Energy Use (kWh)		Baseline Energy Use (kWh)		Energy Savings (kWh)
Period	Monitored (2022-2023)	Normalized, TMY	Normalized, space heating & water heating TMY	Normalized, fan electricity TMY	Normalized, TMY
January	574	716	2,165	29	1,478
February	595	488	1,564	27	1,102
March	612	440	1,397	22	978
April	452	362	1,135	18	791
May	316	283	881	17	615
June	154	262	808	28	574
July	185	216	620	41	445
August	77	174	500	56	382
September	62	166	466	64	365
October	222	273	840	47	613
November	426	421	1,335	43	957
December	597	602	1,899	36	1,334
Annual	**4,271**	**4,403**	**13,610**	**427**	**9,634**

Figure 40 shows the post-retrofit and baseline monthly energy use. In terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use.

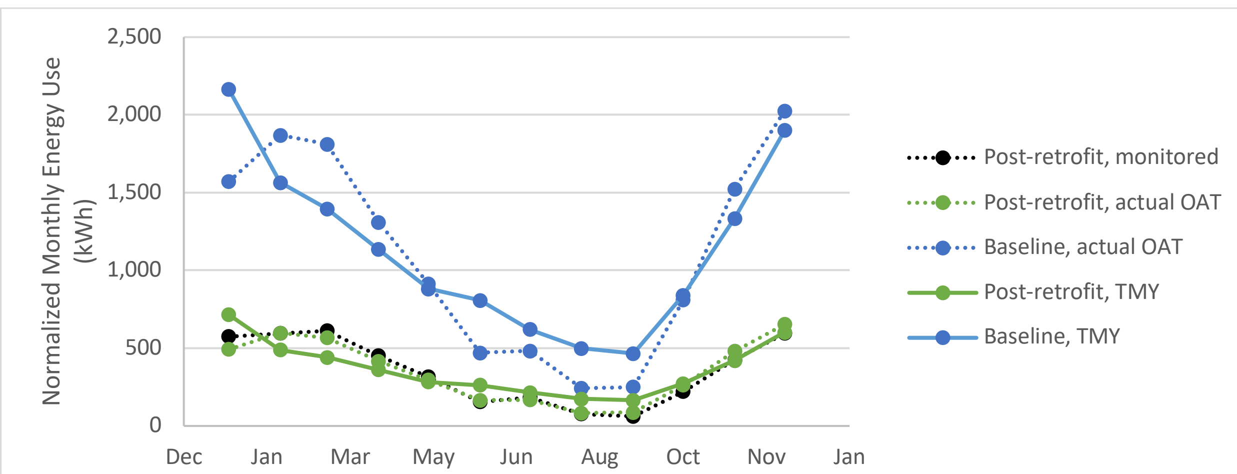


Figure 40. Post-retrofit and baseline monthly energy use, South San Francisco

4.2.4 Menlo Park

Table 13 presents the normalized post-retrofit and baseline monthly energy use. The post-retrofit energy use based on monitored data, normalized with actual outside air temperature results, and normalized with TMY results all show consistent trends, with energy use being higher in the winter months and lower in the summer months.

Table 13. Menlo Park Normalized Energy Use and Savings (based on 7 months of monitored data)

	Post-retrofit Energy Use (kWh)		Baseline Energy Use (kWh)		Energy Savings (kWh)
Period	Monitored (2022-2023)	Normalized, TMY	Normalized, space heating & water heating TMY	Normalized, fan electricity TMY	Normalized, TMY
January	668	797	2,644	29	1,876
February	630	554	1,921	27	1,395
March	499	486	1,745	26	1,285
April	239	386	1,420	28	1,061
May	-	304	1,140	27	862
June	-	257	961	27	731
July	-	216	808	31	623
August	-	198	745	42	589
September	-	188	711	49	572
October	197	268	998	35	765
November	752	442	1,588	34	1,180
December	859	676	2,321	30	1,675
Annual	**-**	**4,772**	**17,001**	**386**	**12,615**

Figure 41 shows the post-retrofit and baseline monthly energy use. In terms of kWh, the baseline energy use is higher each month than the post-retrofit energy use.

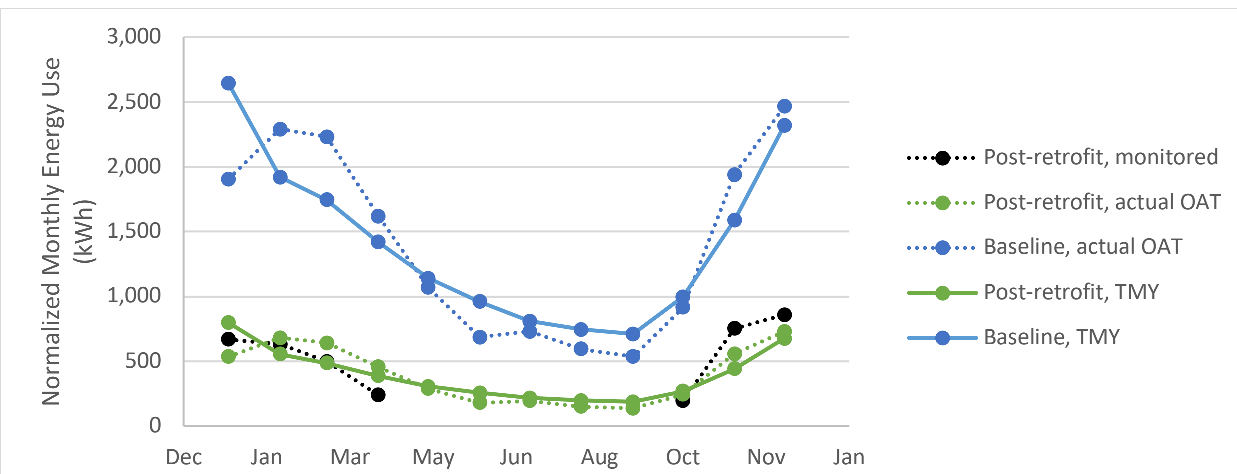


Figure 41. Post-retrofit and baseline monthly energy use, Menlo Park (based on 7 months of monitored data)

4.3 Energy Cost Analysis

TRC analyzed the energy cost of the post-retrofit Harvest Thermal system as well as the calculated baseline. To determine the energy cost of the Harvest Thermal system, TRC determined the hourly electricity usage for the Harvest Thermal system and the applicable rate for each hour. TRC analyzed the electricity cost for all homes using the following three time of use (TOU) utility rates: TOU-C, EV2, and E-

ELEC.[13] In these TOU rate plans, the utility charges a fixed price per kWh based on the time of day and time of year, with the late afternoon and evening periods having a higher rate than other times of day and the summer season rates being higher than the winter season rates.[14] TRC used the simulated gas usage for the baseline and used the applicable rate for each month to calculate costs, summarized monthly and annually.

Table 14 summarizes the total volumetric energy rate (including generation, distribution, transmission, public purpose programs, reliability services, etc.) for E-TOU C, EV2, and E-ELEC rate structures. The E-TOUC structure has peak (4 p.m. to 9 p.m.) and off-peak time-of-use-based rates, while EV2 and E-ELEC has peak (4 p.m. to 9 p.m.), partial peak (9 p.m. to midnight), and off-peak-based rates for the summer (June–Sep) and the winter (Oct.–May) months.

Table 14. Electricity rate breakdown for three rate structures by time of use and season

(Electricity $/kWh)	Peak (4 p.m. to 9 p.m.)			Partial Peak (9 p.m. to midnight)			Off Peak		
	E-TOU C	EV2	E-ELEC	E-TOU C	EV2	E-ELEC	E-TOU C	EV2	E-ELEC
Summer (June–Sept.)	0.50	0.55	0.52	N/A	0.44	0.37	0.42	0.24	0.31
Winter (Oct. –May)	0.40	0.43	0.30	N/A	0.41	0.28	0.37	0.24	0.27

In calculating the baseline gas energy cost, TRC determined the baseline allocation for each home and applied the Tier 1 rate ($2.18 per therm) for usage below the allocation and the Tier 2 rate ($2.62 per therm) for usage above the allocation. This resulted in the average annual gas cost rates shown in Table 15.

[13] The following is the actual customer utility rates, provided by Peninsula Clean Energy:

- Redwood City: H2EV2AN - this is an EV rate and a solar rate
- Daly City: HETOUC - standard TOU rate that most residential customers are on since the TOU migration
- South SF: NEM2PS - a solar and battery storage rate
- Menlo Park: HEV2A - standard EV rate. Rate that Harvest Thermal recommends people with their system have

[14] https://www.peninsulacleanenergy.com/for-residents/

Table 15. Average annual gas cost rate

	Average Gas Rate ($/therm)
Daly City	$2.28
Redwood City	$2.31
South SF	$2.38
Menlo Park	$2.52

Table 16 shows the calculated space heating and water heating annual costs in the baseline gas scenario and the Harvest Thermal scenario for three different electricity tariff structures. A positive value for Energy Cost Savings indicates that the Harvest Thermal system had a lower energy cost than the Calculated Baseline Gas System cost. The results show that the Harvest Thermal system saves energy cost compared to the baseline gas system. The EV2 rate provides the lowest cost, and provides between 8 and 36 percent annual energy cost savings compared to the baseline gas system.

Table 16. Calculated space heating and water heating annual energy cost

Site	E-Tariff structure	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Energy Cost Savings	% Savings
Daly City	TOU-C	$706	$610	$96	14%
	EV2A	$705	$453	$252	36%
	E-ELEC	$794	$628	$166	21%
Redwood City	TOU-C	$765	$755	$10	1%
	EV2A	$765	$501	$264	35%
	E-ELEC	$850	$726	$124	15%
South SF	TOU-C	$1,263	$1,612	($349)	-28%
	EV2A	$1,234	$1,134	$100	8%
	E-ELEC	$1,374	$1,352	$22	2%
Menlo Park (7 months)	TOU-C	$1,222	$1,398	($177)	-14%
	EV2A	$1,208	$1,088	$120	10%
	E-ELEC	$1,295	$1,123	$172	13%

Table 17 through Table 20 show the calculated monthly space heating and water heating costs at each site.

Table 17. Calculated space heating and water heating monthly energy cost, Daly City

	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost
	TOU-C		EV2A		E-ELEC	
May-22	$37.48	$28.40	$37.48	$19.43	$42.16	$35.73
Jun-22	$31.87	$24.68	$31.87	$15.17	$37.33	$33.55
Jul-22	$37.23	$36.37	$36.24	$24.88	$50.54	$44.07
Aug-22	$31.69	$22.71	$31.69	$15.27	$37.34	$33.07
Sep-22	$31.84	$21.13	$31.84	$13.52	$37.43	$31.09
Oct-22	$51.38	$40.31	$51.38	$28.73	$57.64	$44.40
Nov-22	$63.71	$57.54	$63.71	$43.00	$71.05	$56.53
Dec-22	$108.31	$107.68	$108.31	$85.46	$118.71	$93.79
Jan-23	$106.88	$86.94	$106.88	$66.06	$115.77	$78.43
Feb-23	$92.69	$76.47	$92.69	$62.23	$100.22	$69.70
Mar-23	$74.22	$70.22	$74.22	$52.75	$81.79	$66.24
Apr-23	$38.83	$37.41	$38.83	$26.74	$44.19	$41.82
TOTAL	**$706.14**	**$609.87**	**$705.15**	**$453.23**	**$794.18**	**$628.42**

Table 18. Calculated space heating and water heating monthly energy cost, Redwood City

	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost
	TOU-C		EV2A		E-ELEC	
May-22	$36.21	$24.25	$36.21	$16.28	$41.33	$32.72
Jun-22	$28.01	$18.83	$28.01	$11.60	$33.58	$29.17
Jul-22	$28.14	$19.07	$28.14	$11.86	$34.16	$29.89
Aug-22	$27.56	$18.66	$27.56	$11.66	$33.23	$29.53
Sep-22	$26.81	$16.48	$26.81	$11.28	$32.04	$27.33
Oct-22	$34.21	$23.13	$34.21	$15.57	$39.24	$31.91
Nov-22	$90.83	$100.42	$90.83	$66.72	$99.18	$86.95
Dec-22	$119.93	$134.24	$119.93	$89.57	$129.94	$111.77
Jan-23	$124.49	$117.52	$124.49	$78.31	$133.96	$99.75
Feb-23	$111.04	$123.32	$111.04	$82.45	$120.31	$102.46
Mar-23	$93.22	$106.19	$93.22	$70.53	$101.80	$91.58
Apr-23	$44.93	$52.81	$44.93	$35.32	$51.00	$52.76
TOTAL	**$765.40**	**$754.91**	**$765.40**	**$501.17**	**$849.77**	**$725.83**

Table 19. Calculated space heating and water heating monthly energy cost, South San Francisco

	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost
	TOU-C		EV2A		E-ELEC	
May-22	$83.53	$117.38	$83.53	$79.09	$95.38	$99.71
Jun-22	$43.78	$64.73	$43.78	$38.30	$52.66	$63.44
Jul-22	$50.72	$76.69	$50.72	$46.43	$60.74	$73.37
Aug-22	$25.92	$32.14	$25.92	$19.39	$32.55	$39.57
Sep-22	$23.92	$25.93	$23.92	$16.04	$29.92	$34.60
Oct-22	$67.10	$82.41	$67.10	$55.05	$77.39	$74.52
Nov-22	$120.13	$156.11	$116.09	$105.81	$130.68	$127.14
Dec-22	$177.85	$222.71	$172.63	$164.63	$187.41	$176.69
Jan-23	$190.38	$214.53	$185.25	$156.11	$200.03	$170.59
Feb-23	$203.61	$222.85	$198.50	$167.56	$211.76	$175.59
Mar-23	$172.01	$228.36	$166.47	$167.01	$181.38	$180.65
Apr-23	$104.17	$168.12	$99.87	$118.51	$114.53	$136.15
TOTAL	**$1,263.13**	**$1,611.96**	**$1,233.79**	**$1,133.91**	**$1,374.43**	**$1,352.03**

Table 20. Calculated space heating and water heating monthly energy cost, Menlo Park (based on 7 months of monitored data)

	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost	Calculated Baseline Gas System Cost	Calculated Harvest Thermal Electricity Cost
	TOU-C		EV2A		E-ELEC	
Oct-22	$82.51	$72.70	$82.51	$49.91	$93.35	$67.65
Nov-22	$240.31	$281.48	$236.24	$215.84	$250.38	$219.46
Dec-22	$275.90	$321.01	$271.38	$254.49	$285.60	$249.41
Jan-23	$229.68	$248.52	$226.14	$186.94	$240.64	$195.69
Feb-23	$191.89	$208.33	$190.54	$152.08	$202.44	$164.62
Mar-23	$134.02	$175.82	$134.02	$144.90	$145.68	$144.14
Apr-23	$67.26	$90.29	$67.26	$83.60	$76.46	$81.79
TOTAL	**$1,221.58**	**$1,398.15**	**$1,208.10**	**$1,087.77**	**$1,294.55**	**$1,122.75**

5 Pre-retrofit and Post-retrofit Bill Comparison

In addition to the energy cost analysis for the retrofit described in Section 3.4, TRC compared the customers' gas and electric utility bills, provided by Peninsula Clean Energy, in the 12-month monitoring period (post-retrofit) with the 12-month period before the retrofit (pre-retrofit) with a direct bill comparison, where we compared the actual energy use and costs during the pre-retrofit and post-retrofit periods.

These utility bill comparisons do not account for any change in utility rates during the pre-retrofit or post-retrofit periods, do not disaggregate the space and water heating energy use from the total home's energy use, and do not account for usage pattern changes or changes in temperature. For both electricity and gas, there were instances where monthly data wasn't available for certain months. In some cases, it was indicative that the usage reported for the month following these missing periods included the missing period usage. For all such missing periods, TRC assumed that the next available usage data included the missing periods hence usage equally apportioned the usage. For these reasons, the energy cost analysis described in Section 3.4 more accurately characterizes the utility bill impact of the Harvest Thermal retrofit.

Table 21 through Table 24 show the pre-retrofit and post-retrofit monthly utility bill comparisons at each site. Figure 42 through Figure 45 show the monthly utility bill before and after the retrofit at each site.

Table 21. Pre-retrofit and post-retrofit monthly whole home utility bill comparison, Daly City

	Pre-retrofit (2021-2022)		Post-retrofit (2022-2023)	
	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)
March	$152	$42	-	-
April	$94	$40	-	-
May	$129	$40	$96	$4
June	$101	$36	$118	$4
July	$102	$33	$113	$4
August	$97	$34	$110	$4
September	$98	$37	$85	$4
October	$83	$79	$195	$5
November	$131	$79	$228	$5
December	$177	$80	$214	$5
January	$189	$0	$135	$4
February	$201	$50	$193	$4
March	-	-	$156	$4
April	-	-	$36	$4
Total	**$1,555**	**$550**	**$1,677**	**$50**
Total (electricity + gas)	**$2,104**		**$1,728**	
Difference	**$377**			

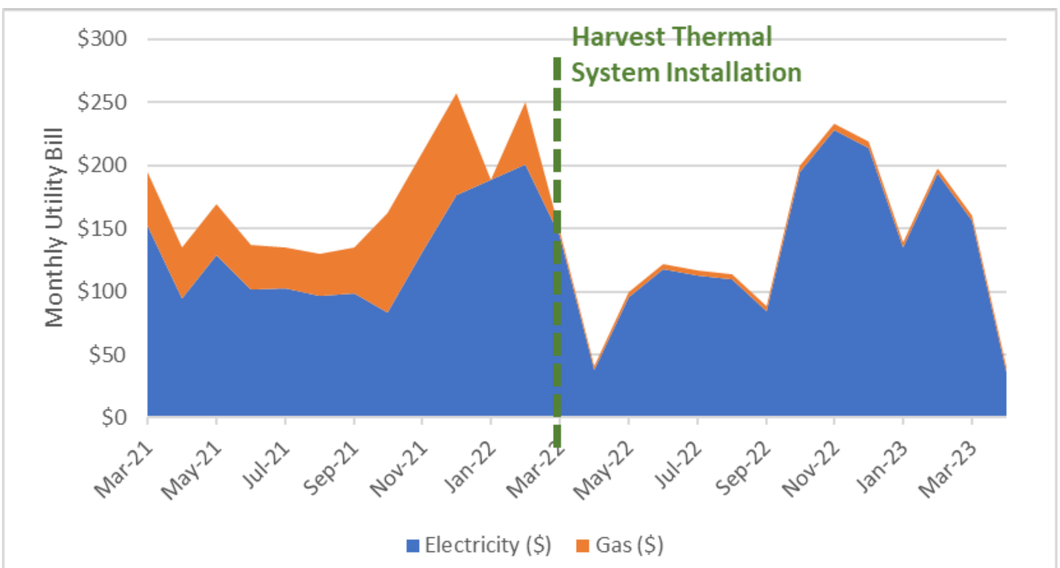


Figure 42. Monthly Utility Bill Before and After Retrofit, Daly City

Table 22. Pre-retrofit and post-retrofit monthly whole home utility bill comparison, Redwood City

	Pre-retrofit (2021-2022)		Post-retrofit (2022-2023)	
	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)
March	$64	$34	-	-
April	$6	$20	-	-
May	$32	$21	$30	$4
June	$34	$18	$33	$4
July	$31	$15	$30	$4
August	$27	$16	$33	$4
September	$37	$23	$57	$4
October	$424	$24	$620	$5
November	$94	$42	$72	$4
December	$104	$63	$106	$5
January	$91	$55	$130	$5
February	$68	$39	$102	$4
March	-	-	-$1	$4
April	-	-	$68	$4
Total	**$1,013**	**$371**	**$1,279**	**$51**
Total (electricity + gas)	**$1,384**		**$1,330**	
Difference	**$54**			

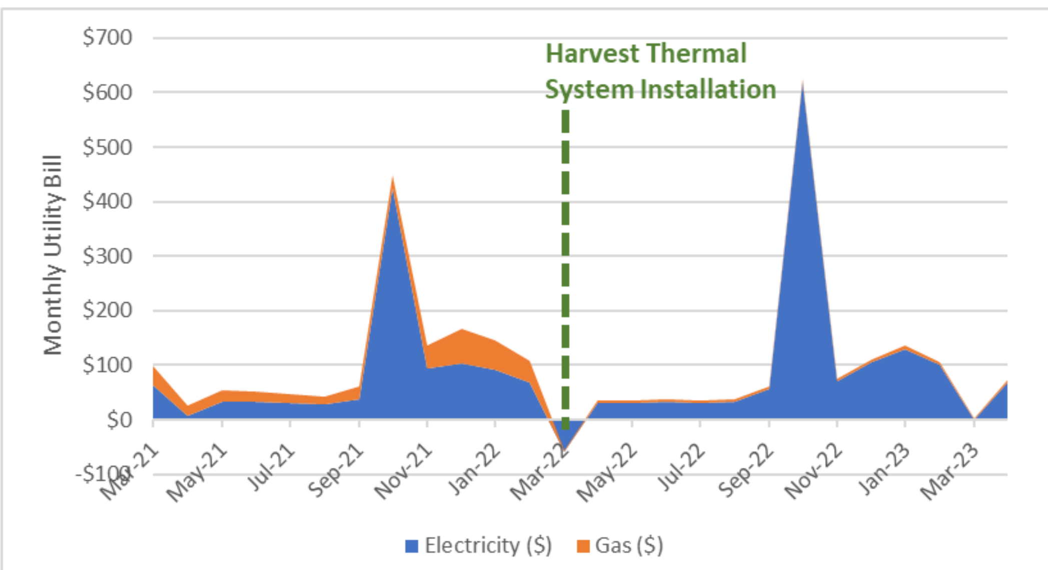


Figure 43. Monthly Utility Bill Before and After Retrofit, Redwood City

Table 23. Pre-retrofit and post-retrofit monthly whole home utility bill comparison, South SF

	Pre-retrofit (2021-2022)		Post-retrofit (2022-2023)	
	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)
March	$222	$77	-	-
April	$175	$91	-	-
May	$218	$63	$16	$10
June	$229	$26	$16	$6
July	$198	$37	$18	$6
August	$183	$17	$17	$8
September	$179	$23	$20	$4
October	$154	$37	-$23	$6
November	$174	$181	$18	$6
December	$226	$103	$16	$5
January	$245	$0	$18	$5
February	$125	$92	$8	$6
March	-	-	$17	$4
April	-	-	$17	$4
Total	**$2,327**	**$746**	**$157**	**$69**
Total (electricity + gas)	**$3,074**		**$226**	
Difference	**$2,848**			

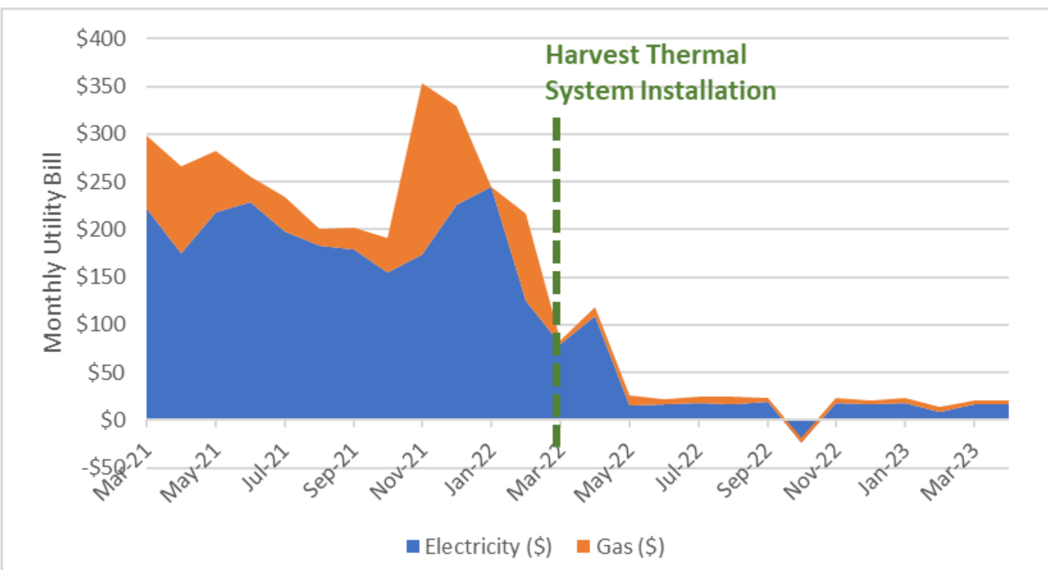


Figure 44. Monthly Utility Bill Before and After Retrofit, South SF

Table 24. Pre-retrofit and post-retrofit monthly whole home utility bill comparison, Menlo Park

	Pre-retrofit (2021-2022)		Post-retrofit (2022-2023)	
	Electricity ($)	Gas ($)	Electricity ($)	Gas ($)
August	$189	$29	-	-
September	$200	$50	-	-
October	$214	$68	$321	$5
November	$315	$131	$321	$7
December	$376	$176	$321	$7
January	$370	$158	$321	$8
February	$294	$130	$330	$6
March	$173	$82	$223	$6
April	$191	$91	$273	$5
May	$257	$39	Not available	Not available
June	$213	$40	Not available	Not available
July	$228	$43	Not available	Not available
August	-	-	Not available	Not available
September	-	-	Not available	Not available
Total	**$3,019**	**$1,039**	**$2,109**	**$43**
Total (electricity + gas)	**$4,058 (12 months)**		**$2,152 (7 months)**	
Difference	**$1,906**			

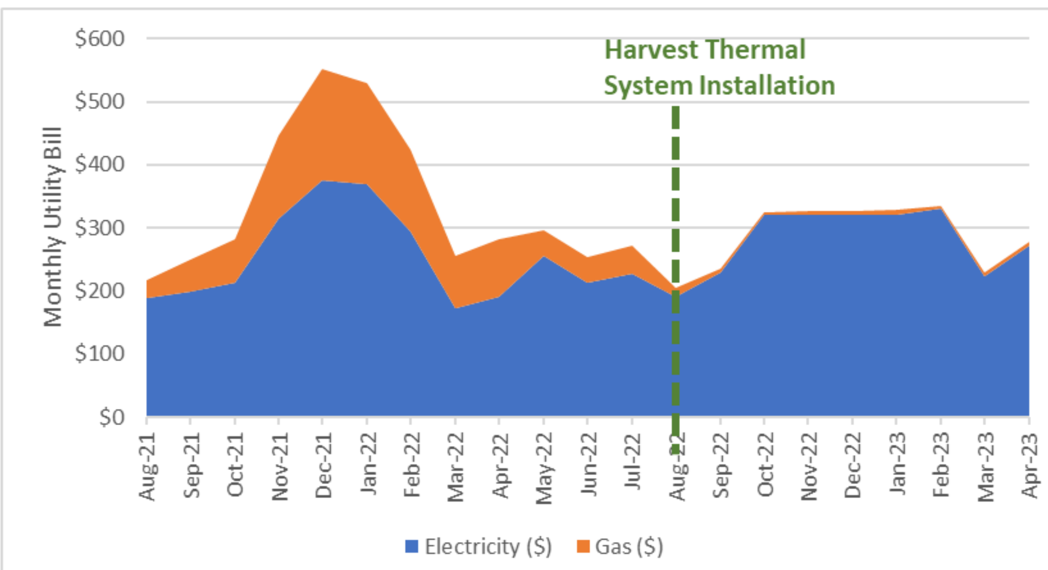


Figure 45. Monthly Utility Bill Before and After Retrofit, Menlo Park

Figure 46 gives a summary of the annual energy cost based on the billing data, pre and post retrofit, for each site.

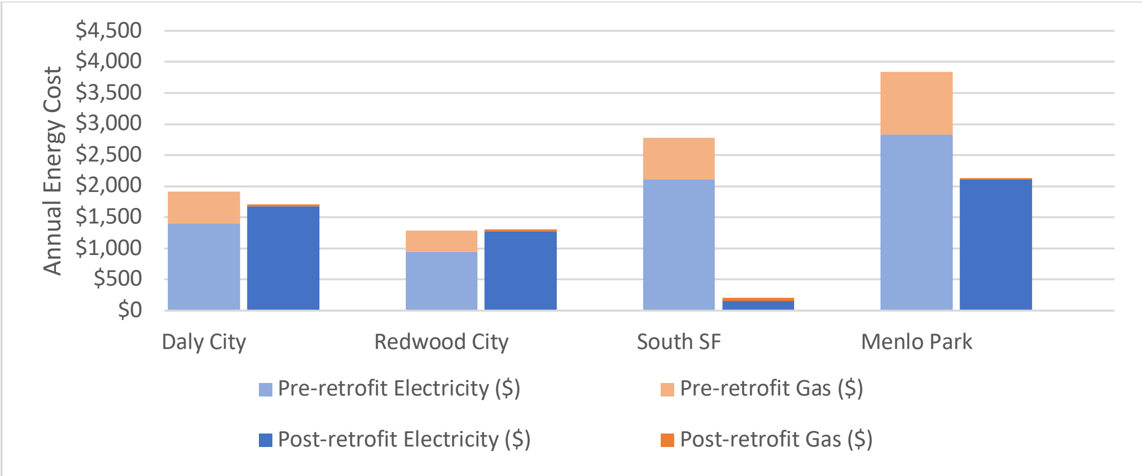


Figure 46. Annual Energy Cost from Whole Home Billing Data

6 Load Shift Impact

Grid-integrated buildings are becoming more important as we move to a future with 100% renewable electricity that depends on available wind, solar, geothermal, and hydroelectric resources. The ability to flex loads in our homes helps reduce the amount of battery storage needed on the grid.

TRC characterized the impact of using the Harvest Thermal system as a thermal battery by shifting energy use away from peak and part-peak hours. Peak hours are defined as 4 p.m. to 9 p.m. in the summer season (June–Sept.) and 4 p.m. to 9 p.m. in the winter season (Oct.–May). Combining peak and part-peak hours, the hours are 3 p.m. to 11 p.m. We assessed the load shift impact of the system by comparing the space and hot water load profiles to the Harvest Thermal system's electricity load profiles.

For the monitored period, we determined the heating load during the peak period that is satisfied by using water from the charged tank. We did this by determining the space and water heating loads during the peak periods that were not coincident with outdoor unit electrical energy use. We considered those loads to have been shifted by the Harvest Thermal system.

Table 25 presents the shifted space and water heating loads and the shifted hours across all four sites. The shifted hours represent the time during the peak hours when the outdoor unit is not running or is on standby and the space heating and water heating loads are greater than zero. This analysis was completed on a per-minute basis. On average across the sites, the load shifted from 4 p.m. to 9 p.m. is 4.4 to 11.6 kWh per day, and the load shifted from 3 p.m. to 11 p.m. is slightly more at 5.1 to 12.7 kWh per day. We also determined the average demand shift per site to be 1070 watts.

Table 25. Load Shift Summary

	Utility Peak 4 p.m. to 9 p.m.		Utility Peak 3 p.m. to 11 p.m.	
	Shifted kWh	Shifted Hours	Shifted kWh	Shifted Hours
Daly City				
Annual total	4,260	518	4,658	572
Monthly average	355	43	388	48
Daily average	11.6	1.4	12.7	1.6
Menlo Park				
Annual total	1,677	224	1,928	280
Monthly average	240	32	275	40
Daily average	7.9	1.1	9.0	1.3
Redwood City				
Annual total	1,943	289	2,318	366
Monthly average	162	24	193	30
Daily average	5.3	0.8	6.3	1.0
South San Francisco				
Annual total	1,621	364	1,857	429
Monthly average	135	30	155	36
Daily average	4.4	1.0	5.1	1.2

The primary sources of the Harvest Thermal system's electricity energy use are the outdoor unit and the air handler. The majority of the energy use and the majority of the load shifting is with the outdoor unit's electricity use, which, in conjunction with the hot water tank, effectively decouples the time of energy use from the time of the load because the outdoor unit can run and fill up the tank with hot water that can then be used later. There are limitations to how much the load can be shifted because the tank can only provide a fixed volume of hot water once charged and because the tank cools overtime even if well-insulated, but the space heating and water heating energy use can both still be effectively shifted in this way. However, even though the bulk of the space heating energy can be shifted, there is still some fan energy use at the air handler that would happen at the time of the load, which is generally not shifted.

Table 26 through Table 29 present the monthly load shift at each site.

Table 26. Monthly load shift, Daly City

	Utility Peak 4 p.m. to 9 p.m.		Utility Peak 3 p.m. to 11 p.m.	
	Shifted kWh	Shifted Hours	Shifted kWh	Shifted Hours
May-22	255	31	281	36
Jun-22	197	27	215	33
Jul-22	228	31	245	37
Aug-22	203	33	228	39
Sep-22	190	27	209	33
Oct-22	285	39	319	47
Nov-22	397	47	414	52
Dec-22	623	66	705	78
Jan-23	558	65	632	77
Feb-23	503	55	529	63
Mar-23	521	58	554	66
Apr-23	299	38	328	47
Annual total	4,260	518	4,658	572
Monthly average	355	43	388	48
Daily average	12	1.4	13	1.6

Table 27. Monthly load shift, Redwood City

	Utility Peak 4 p.m. to 9 p.m.		Utility Peak 3 p.m. to 11 p.m.	
	Shifted kWh	Shifted Hours	Shifted kWh	Shifted Hours
May-22	145	19	155	21
Jun-22	103	15	110	16
Jul-22	96	15	108	17
Aug-22	93	17	108	21
Sep-22	92	16	110	19
Oct-22	107	17	120	20
Nov-22	168	25	206	32
Dec-22	280	38	350	52
Jan-23	272	38	334	51
Feb-23	165	28	229	41
Mar-23	263	36	311	45
Apr-23	158	26	177	31
Annual total	1,943	289	2,318	366
Monthly average	162	24	193	30
Daily average	5	0.8	6	1.0

Table 28. Monthly load shift, South San Francisco

	Utility Peak 4 p.m. to 9 p.m.		Utility Peak 3 p.m. to 11 p.m.	
	Shifted kWh	Shifted Hours	Shifted kWh	Shifted Hours
May-22	84	24	98	30
Jun-22	33	12	48	15
Jul-22	70	21	80	25
Aug-22	35	12	39	14
Sep-22	25	10	40	13
Oct-22	90	27	100	30
Nov-22	183	45	195	51
Dec-22	259	50	285	57
Jan-23	257	49	295	58
Feb-23	207	32	247	37
Mar-23	216	43	255	50
Apr-23	162	40	176	50
Annual total	1,621	364	1,857	429
Monthly average	135	30	155	36
Daily average	4	1.0	5	1.2

Table 29. Monthly load shift, Menlo Park

	Utility Peak 4 p.m. to 9 p.m.		Utility Peak 3 p.m. to 11 p.m.	
	Shifted kWh	Shifted Hours	Shifted kWh	Shifted Hours
Oct-22	80	18	118	25
Nov-22	344	44	364	52
Dec-22	451	31	548	38
Jan-23	383	44	443	53
Feb-23	263	45	314	53
Mar-23	131	26	122	35
Apr-23	26	17	21	24
Annual total	1,677	224	1,928	280
Monthly average	240	32	275	40
Daily average	8	1.1	9	1.3

Figure 47 summarizes the monthly shifted energy use across all four sites.

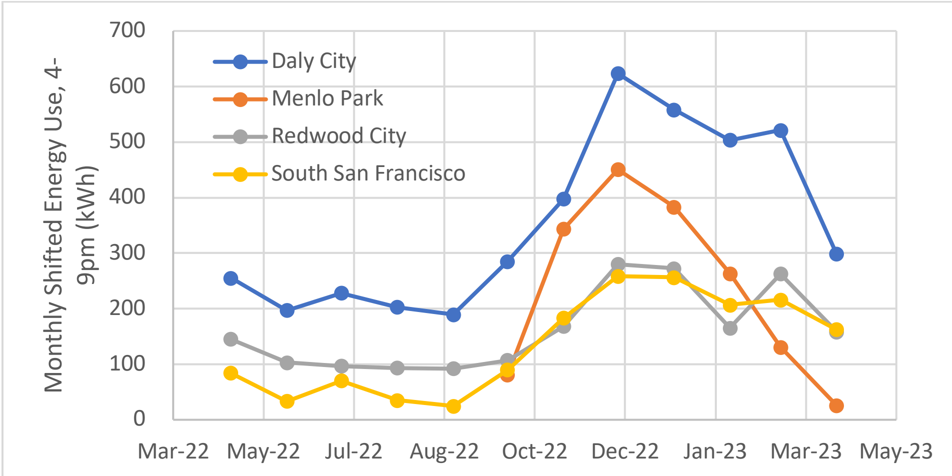


Figure 47. Monthly Shifted Energy Use, 4-9pm

7 GHG Emissions

TRC estimated the GHG emissions of the Harvest Thermal system and the baseline gas system during the monitored period using California statewide grid hourly emissions factors and a fixed emissions rate for methane gas using emissions factors from the California Energy Commission (CEC).[15]

The difference between the Harvest Thermal GHG emissions for the year and the gas baseline emissions for the year is deemed to be the GHG savings for the project. The emissions savings are shown in Table 30 and range from 83 to 90 percent across all of the sites.

Table 30. Site GHG emissions, CEC emissions factors

Site	Post-retrofit (MTCO2e)	Pre-retrofit (MTCO2e)	Savings (MTCO2e)	Savings (%)
Daly City	0.15	1.51	1.36	90%
Menlo Park	0.47	2.71	2.24	83%
Redwood City	0.20	1.65	1.45	88%
South San Francisco	0.40	2.76	2.36	85%

Peninsula Clean Energy also requested calculating the GHG emissions impact using factors from a memo they provided, which estimates the impact of fugitive emissions. [16] Table 31 shows the resulting GHG emissions, both including and not including fugitive emissions. Including fugitive emissions, the Harvest Thermal system saved 90 to 94 percent of emissions compared to the baseline across all of the sites.

Table 31. Site GHG emissions, PCE

		Including Fugitive Emissions			Not Including Fugitive Emissions		
Site	Post-retrofit (MTCO2e)	Pre-retrofit (MTCO2e)	Savings (MTCO2e)	Savings (%)	Pre-retrofit (MTCO2e)	Savings (MTCO2e)	Savings (%)
Daly City	0.15	2.67	2.52	94%	1.53	1.38	90%
Menlo Park	0.47	4.78	4.31	90%	2.75	2.28	83%
Redwood City	0.20	2.92	2.71	93%	1.68	1.47	88%
South San Francisco	0.40	4.86	4.46	92%	2.80	2.39	86%

Figure 48 through Figure 54 show the daily load, energy use, and electricity emissions factor based on the CEC emissions factors for each home during the summer and winter seasons separately. From the figures it is clear that the Harvest Thermal system energy use is offset from the space heating and hot

[15] https://www.energy.ca.gov/files/2025-energy-code-hourly-factors

[16] Memo received from Peninsula Clean Energy received on 10/4/2023, titled FINAL Fugitive Methane Emissions Memo_20211102.docx

water loads, and that the Harvest Thermal system primarily uses energy when the electricity emissions factor is low.

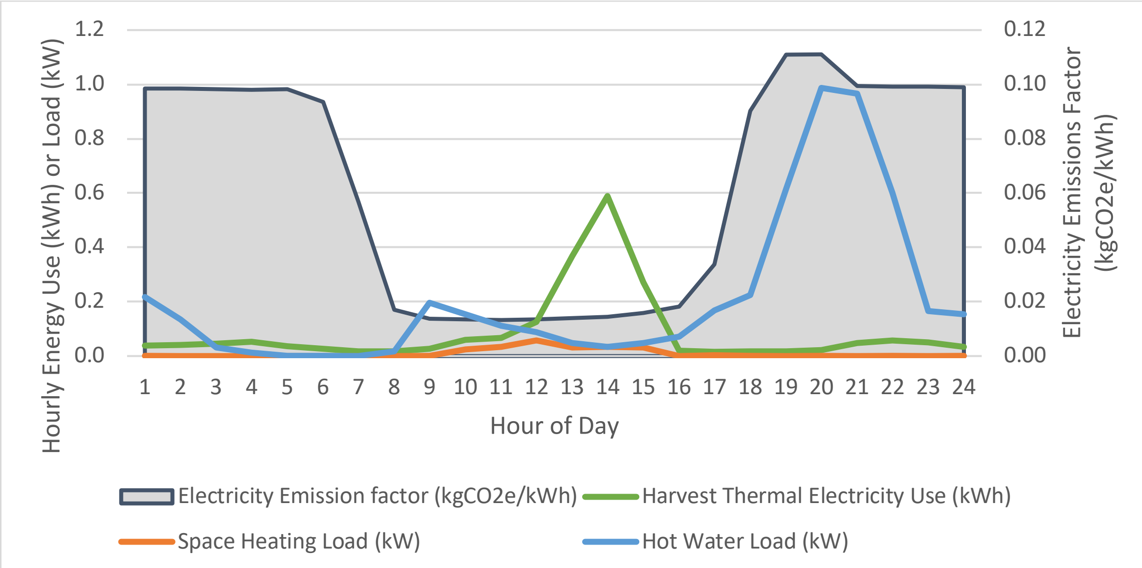


Figure 48. Summer Daily Load and Energy Use Profile, Daly City

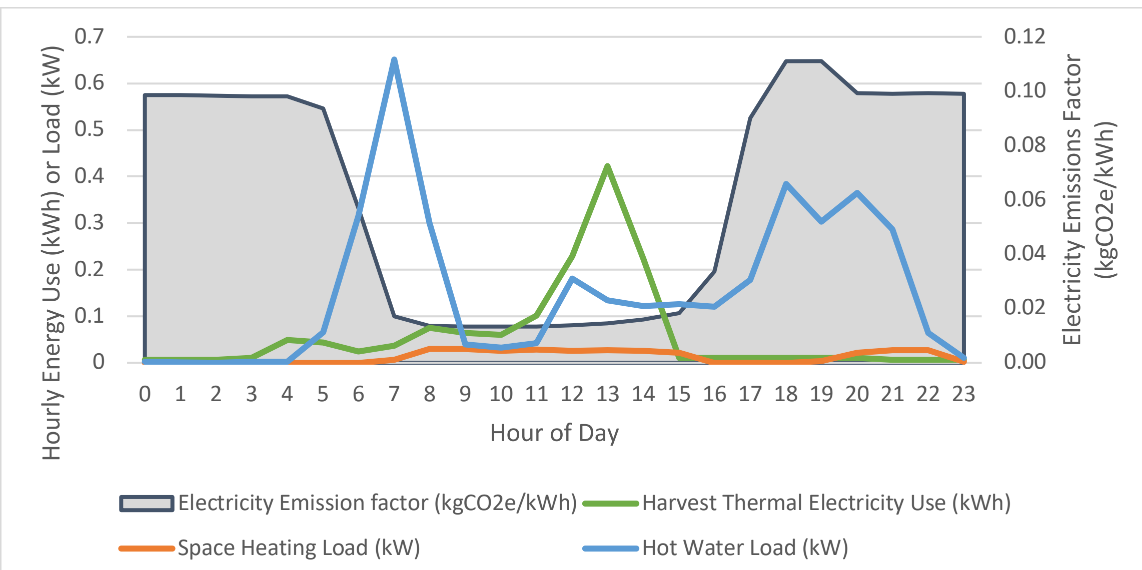


Figure 49. Summer Daily Load and Energy Use Profile, Redwood City

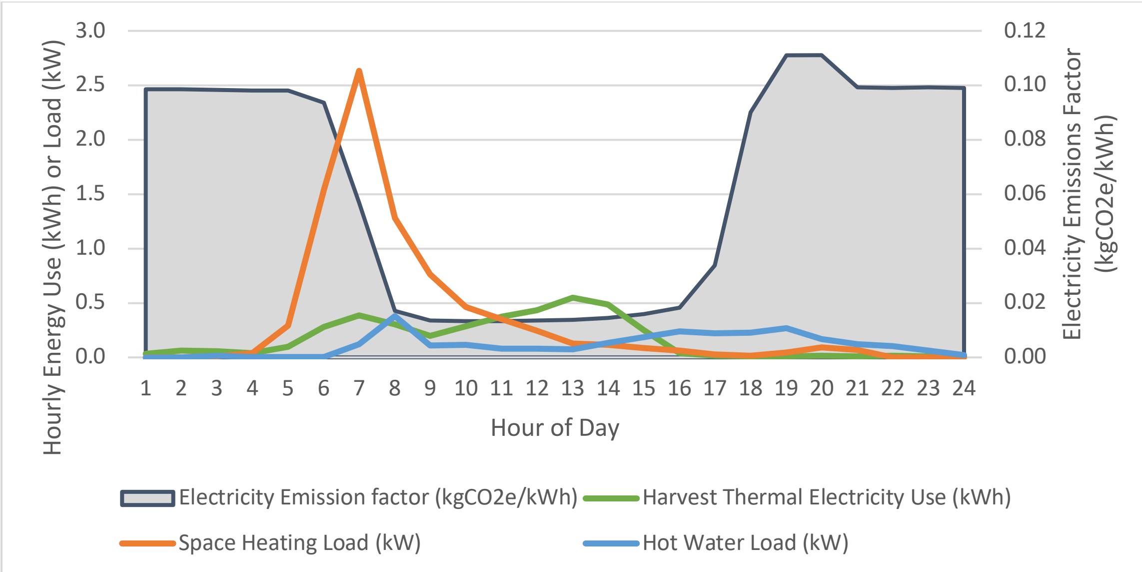


Figure 50. Summer Daily Load and Energy Use Profile, South San Francisco

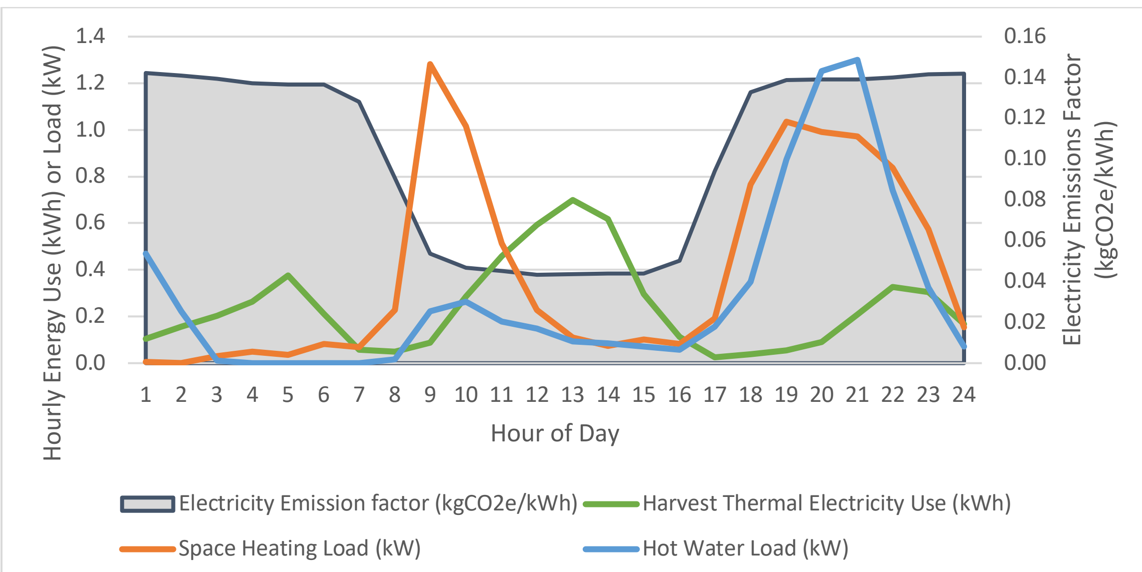


Figure 51. Winter Daily Load and Energy Use Profile, Daly City

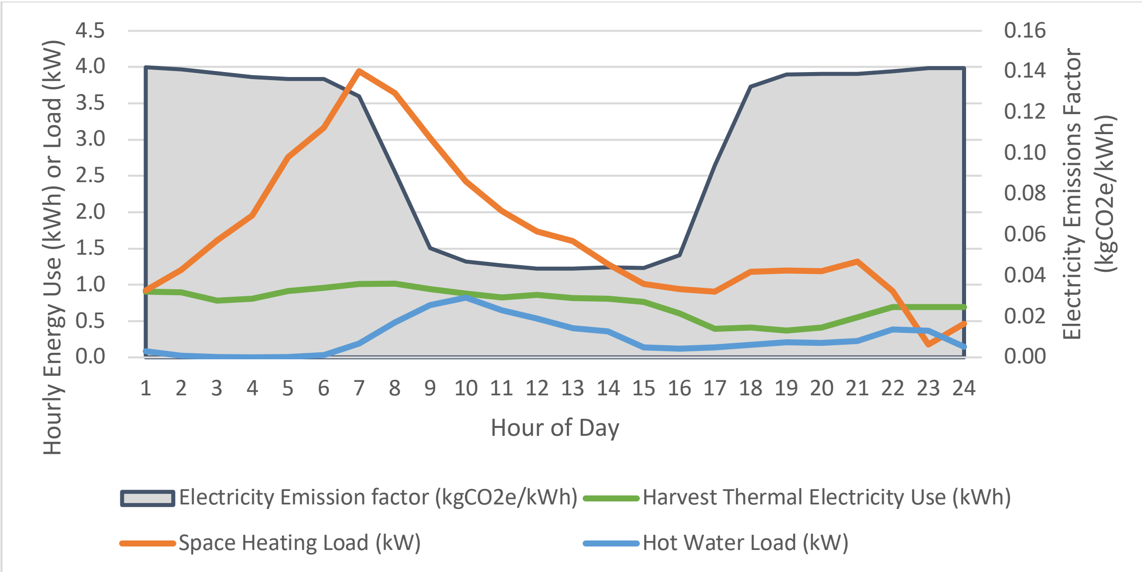


Figure 52. Winter Daily Load and Energy Use Profile, Menlo Park

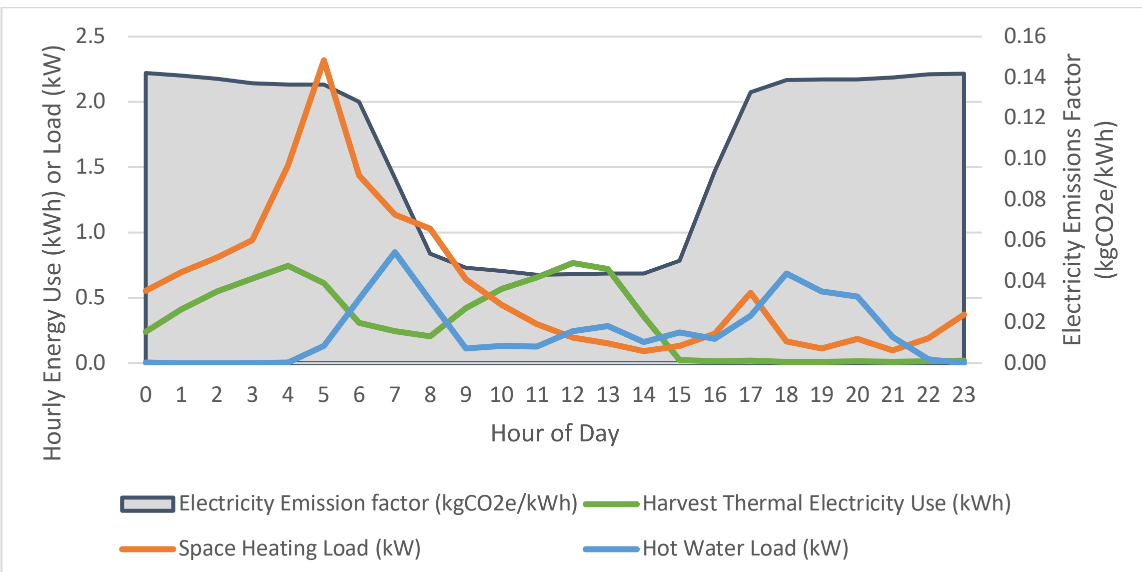


Figure 53. Winter Daily Load and Energy Use Profile, Redwood City

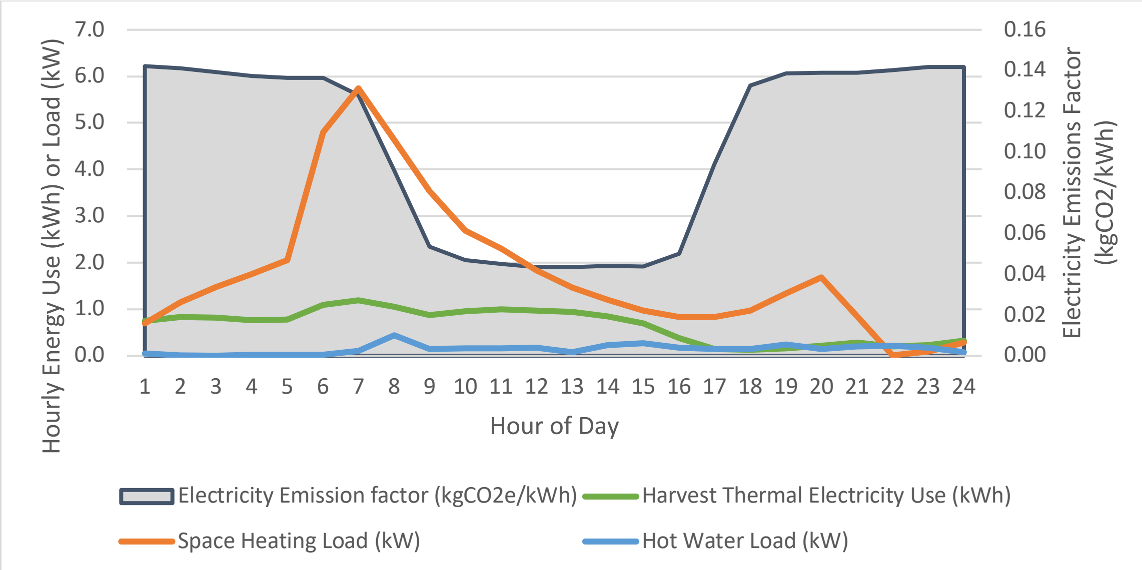


Figure 54. Winter Daily Load and Energy Use Profile, South San Francisco

8 Harvest Thermal Performance Characterization

TRC characterized the performance of the Harvest Thermal system using metered trends. In the post-retrofit case, TRC calculated the hourly coefficient of performance (COP) as the heating load divided by the unit electrical input. Table 32 presents the average COP as well as the total heating load and total energy use across the monitoring period at all sites. The average system COP ranges from 2.61 to 2.96 across the four sites.

Table 32. Average COP across Monitoring Period, all sites

	Total Heating Load (kBtu)	Total Energy Use (kWh)	System COP
Daly City	15,197	1,600	2.79
Menlo Park	33,227	3,733	2.61
Redwood City	18,208	2,008	2.66
South San Francisco	42,976	4,261	2.96

We would expect the Harvest Thermal system's performance to vary based on outside air conditions and heating load. Figure 55 through Figure 58 show the monthly average COP and the total monthly heating load as a function of the average monthly outside air temperature at each site. All sites show a trend that. As the monthly average outside air temperature increases, the total monthly heating load decreases, as expected. The figures show an inconsistent trend between the monthly average COP and the average monthly outside air temperature. In typical heat pump operation, the COP increases with increasing outside air temperature. That trend is seen at the Menlo Park and Redwood City sites. At the other two sites, we observed the opposite trend.

There are a number of factors that could explain the unexpected COP correlations.

- The first is due to load shifting. In a traditional heat pump system, the energy output and the electricity use occur at the same time, and there is often a very clear relationship between the outside air temperature, load, and COP. Because the Harvest Thermal system does load shifting, that clear relationship is not there. We attempted to see this relationship by calculating the COP at daily and monthly intervals, but the anticipated relationship did not emerge.
- In general, DHW load shifting performed by the Harvest Thermal system charges the tank (heats up the water in the hot water tank) in the morning and early afternoon hours, and any heating loads used later in the day would be from the hot water in the tank without the outdoor unit running. Therefore, it is likely that some days the tank is charged more than is needed, and the hot water is not fully used. In that case, there may be significant storage losses with significant electricity input and little energy output. Additionally, given the relatively mild climate on the peninsula, we do see some days with very low space and water heating loads. In very low load scenarios, the COP may be less predictable, with potential unit cycling or the possibility of meeting heating loads with hot water already in the tank from the previous day.
- Another reason for the unexpected trends may be the split between the domestic hot water load and the space heating load. The space heating load requires the air handler to run, so the COP of just the space heating side may be lower than the water heating side.

- Lastly, we expect the homes located where there are temperature swings, with cooler mornings and warmer afternoons, may be in microclimates. In these scenarios, the average monthly outside air temperature may not be representative of the outside air conditions when the system runs.

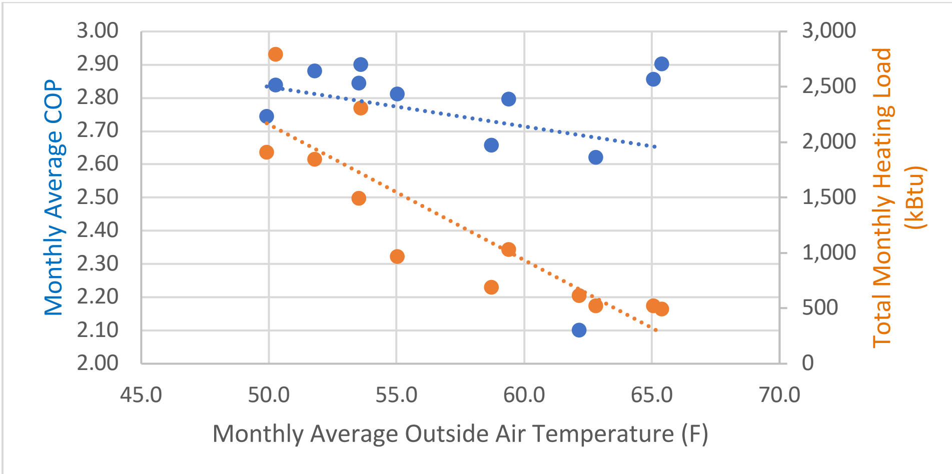


Figure 55. Monthly Average COP and Total Monthly Heating Load as a Function of Monthly Average Outside Air Temperature, Daly City

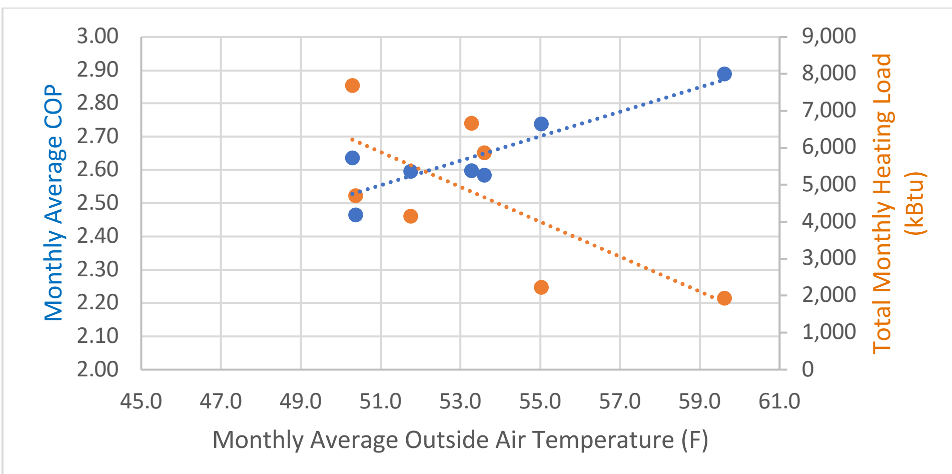


Figure 56. Monthly Average COP and Total Monthly Heating Load as a Function of Monthly Average Outside Air Temperature, Menlo Park

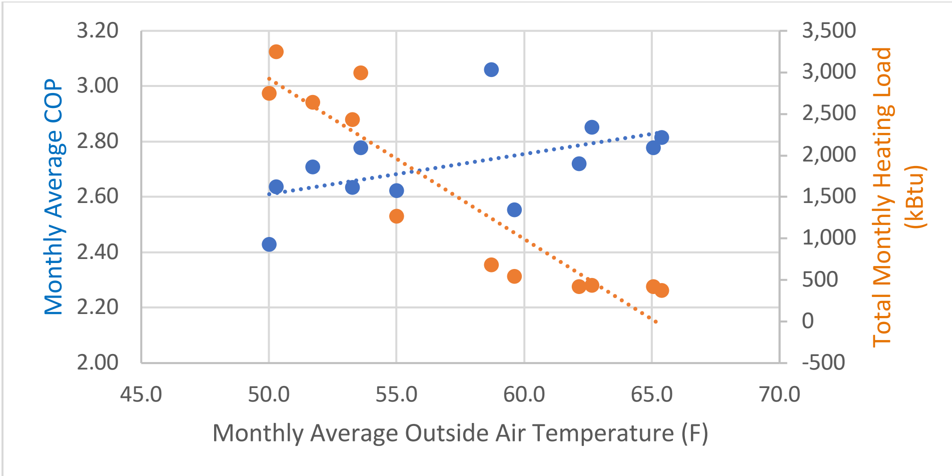


Figure 57. Monthly Average COP and Total Monthly Heating Load as a Function of Monthly Average Outside Air Temperature, Redwood City

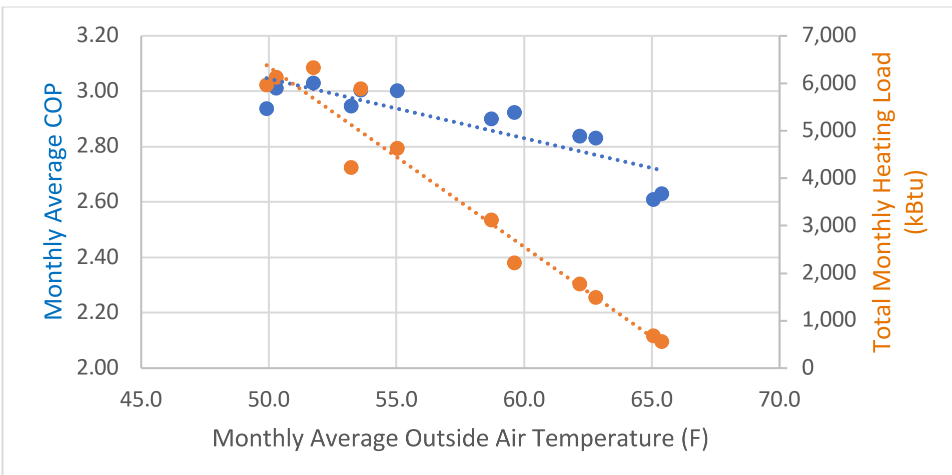


Figure 58. Monthly Average COP and Total Monthly Heating Load as a Function of Monthly Average Outside Air Temperature, South San Francisco

We compared our performance analysis results with those reported by Harvest Thermal, the results of which are shown in Table 33. Overall, the system COP calculated by TRC and calculated by Harvest Thermal generally agree but vary by up to five percent.

Table 33. Annual average COP calculated by TRC and by Harvest Thermal

	Calculated COP	System COP from Harvest Thermal	System COP % diff
Daly City	2.75	2.85	5%
Redwood City	2.72	2.70	0%
South San Francisco	2.89	2.92	1%
Menlo Park	2.64	2.65	0%

One main reason that the calculated COPs may be different between the Harvest Thermal analysis and the TRC analysis is the power metering. Figure 59 shows the hourly electricity reported by Harvest Thermal and the TRC-installed power meters in South San Francisco. From the chart, it is clear that the power recorded from the two sources follows the same trends and has the same magnitudes, but differs slightly. As described in Section 3.1.2, TRC installed true RMS power meters and has confidence in their readings.

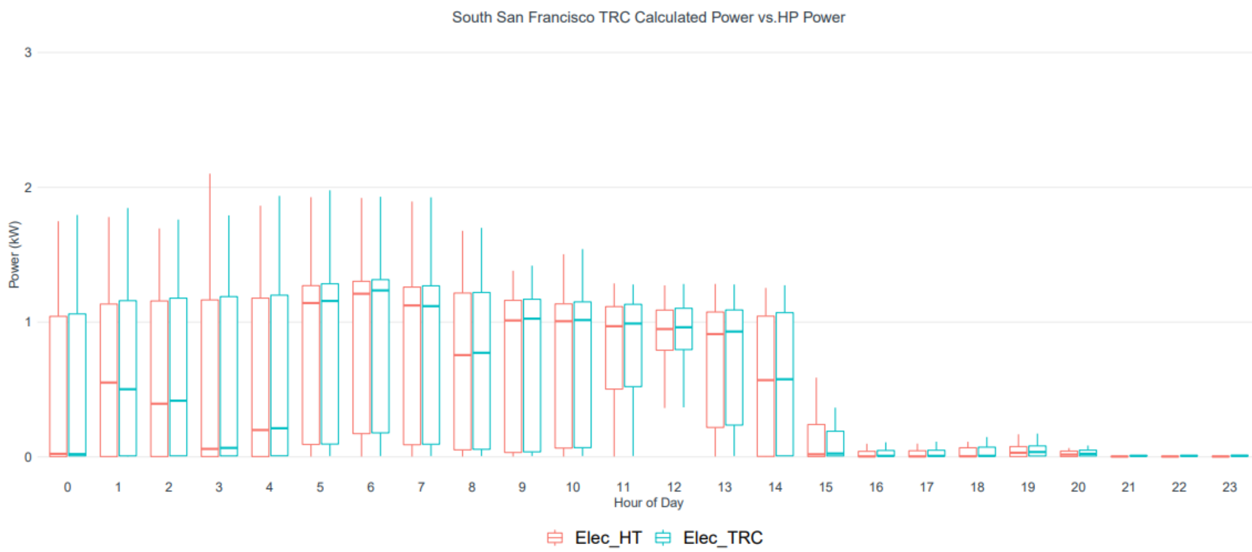


Figure 59. Box plot of hourly electricity reported by Harvest Thermal and by TRC-installed power meters, South San Francisco. Excludes outliers

9 Customer Satisfaction

TRC evaluated the pre-retrofit and post-retrofit survey results to determine customer satisfaction with the Harvest Thermal system. As described in Section 3.1.1.3, TRC conducted surveys on three separate occasions during the M&V period: a pre-retrofit survey, a three-month post-retrofit survey, and a final customer survey. In general, the responses between the three-month post-retrofit survey and the final survey were the same, and therefore below TRC reports on the final survey results and only reports the three-month survey results when they differ from the final survey results. Note that due to the compressed monitoring period, the Menlo Park home did not complete the three-month post-retrofit period.

In general, customers like the Harvest Thermal system better than their previous gas appliances, both for space heating and water heating, and were satisfied with the installation experience.

In general, customers were favorable toward the water heating aspect of the Harvest Thermal system. Three customers stated that they like the Harvest Thermal system a lot more than their gas water heater, with the fourth customer stating that they like the Harvest Thermal system about the same as their gas water heater. In terms of why customers like the Harvest Thermal system better, customers stated that the water gets hotter, the water heats up faster, the water stays hot for longer, and the system has a lower carbon footprint compared to a gas system. When asked if their household had taken any new actions to change how they use hot water since the Harvest Thermal system was installed (for example, timing the use of the dishwasher to not overlap with showers), one customer responded that they try to space out showers and baths for the kids, one customer responded that they try to take shorter showers, and two customers responded that they made no changes.

In general, customers were favorable about towards the space heating aspect of the Harvest Thermal system. Three customers stated that they like the Harvest Thermal system a lot more than their gas water heater, with the fourth customer stating that they like the Harvest Thermal system slightly less than their gas furnace. In terms of why customers like the Harvest Thermal system better, customers stated that their home's heat is more consistent over time, the home's heat is more balanced room to room, they like the MERV 13 air filtration, and that there is less risk of carbon monoxide poisoning compared to a gas system. The customer who stated they liked the Harvest Thermal system slightly less than the gas system stated their home now warms up slower than with their old furnace, the air coming out of the vents feels colder, and hot water can run out on the coldest days, leading to more heating. When asked if their household had taken any new actions to change how they heat their home post-Harvest Thermal system installation (for example, using space heaters more or less), one customer responded that they changed their nighttime temperature setting from 60°F to 66°F. The customer that reported liking the Harvest Thermal system slightly less stated that they don't let the house get too cold, but then that caused it to be too hot at night, so they installed a smart vent in the bedroom so that the bedroom space could drop to a lower temperature overnight. They also installed insulation to prevent heat loss.

When asked how satisfied the customers were with the Harvest Thermal system, all four stated that they were extremely satisfied and would likely or very likely recommend a Harvest Thermal system to a friend. When asked about challenges with the Harvest Thermal system, one customer commented that there were a few days when the home dropped below the set temperature due to unusually cold weather. A second customer commented that the capacity of the hot water tank for heating the house on the coldest days was a challenge. The other two customers commented that they had not had any challenges. When asked about any other comments regarding the Harvest Thermal system, the following are quotes from the customers:

- It's a great system and I hope more households will get the opportunity to experience it.
- I wish there is an app to show system statistics and to adjust hot water temperature.
- Love the positive impact on global warming.

TRC also used the monitored data to infer customer satisfaction with water heating post-retrofit. We estimated the number of hours, summarized for each site in Table 34, when the water heating load was not met by determining *unmet load hours*, which represent the time of hot water draw when the hot water supply temperature was less than 110°F. The unmet hours are low, representing less than one percent of time. These results are consistent with the customer's reported satisfaction with the water heating aspect of the Harvest Thermal system. Note that while the reported unmet hours is low, some of the unmet hours is simply due to the time associated with hot water flowing from the tank to the sensor location, and for the sensor and pipe to warm up.

Table 34. Unmet hours During Monitoring Period

	Unmet Hours During Monitoring Period (Hours)
Daly City	57
Menlo Park	31
Redwood City	92
South San Francisco	73

10 Total Installed Cost

By leveraging a single compressor to serve both water heating and space heating needs, there is a potential opportunity for cost reductions. However, the system is also a more complex installation. According to Peninsula Clean Energy and Harvest Thermal, the Harvest Thermal system total installed costs averaged $28,600 per home, and $22,500 after incentives. This is a similar cost to installing a unitary heat pump water heater and split system, ducted space heater in a single-family home in San Mateo County.[17]

[17] Based on cost information collected by TRC using a review of BayREN program cost data, TECH program cost data, and contractor interviews for a PCE / SVCE decarbonization market characterization study

11 Qualitative Comparison of Harvest Thermal to Other Retrofit Solutions

We qualitatively compared the Harvest Thermal system to several other retrofit solutions common in the residential retrofit market, as summarized in Table 35.

Table 35. Qualitative comparison of Harvest Thermal and other comparable options

	Monthly Energy Cost	GHG Emissions	Customer Lifecycle Cost	Overall Customer Satisfaction
Sources	Calculations presented in Section 4.3 Assumptions based on calculations of other scenarios	Calculations presented in Section 7 Assumptions based on calculations of other scenarios	2019 Cost-Effectiveness Study: Existing Single Family Residential Building Upgrades[18]	Customer surveys conducted as part of this study
Pre-retrofit gas system	**Low** Calculated	**High** Calculated	**Low**	**Medium** Customer surveys
New gas-fired equipment	**Low** Assumed	**High** Assumed	**Low**	**Medium** Interpreted based on Customer surveys
All-electric equipment: separate heat pump space heating and heat pump water heating	**High** Assumed	**Medium** Assumed	**High**	**High**
Harvest Thermal System	**Low** Calculated	**Low** Calculated	**Medium** due to first cost similar to other all-electric equipment and low monthly energy cost	**High** Customer survey

[18] https://localenergycodes.com/download/875/file_path/fieldList/2019%20V2-Residential%20Retrofit%20Cost-eff%20Report-2021-08-27.pdf

12 Conclusions

TRC evaluated the Harvest Thermal system in four homes. The main objectives of this Harvest Thermal Pilot M&V study were to:

1. Determine the overall energy savings and bill impacts of the Harvest Thermal system compared to the pre-retrofit gas appliances.
2. Characterize the Harvest Thermal system's performance in terms of load shifting.
3. Characterize the Harvest Thermal system's performance in terms of efficiency.
4. Determine customer satisfaction with the Harvest Thermal system.

According to our energy use data measurements across the three sites with a full year of data, the annual electricity increase ranges from 1,442 to 3,847 kWh, while the gas reduction ranges from 249 to 453 therms. Figure 60 shows the pre and post retrofit energy use in kWh across all four sites.

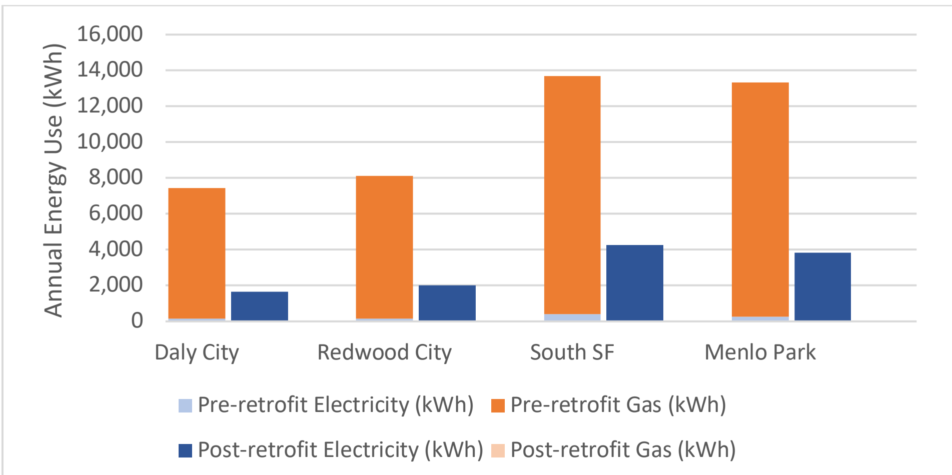


Figure 60. Pre and post retrofit energy use across all sites

TRC also fit a Time-of-Week and Temperature model to the metered data and estimated normalized energy use with TMY weather data. Across all four sites, the normalized energy use with TMY weather data shows the annual energy increase ranges from 5,950 to 12,615 kWh.

The energy cost analysis results show that the Harvest Thermal system saves energy cost compared to the baseline gas system. The EV2 rate provides the lowest cost, and provides between 8 and 36 percent annual energy cost savings compared to the baseline gas system.

On average across the sites, the load shifted from 4 p.m. to 9 p.m. is 4.4 to 11.6 kWh per day, and the load shifted from 3 p.m. to 11 p.m. is slightly more at 5.1 to 12.7 kWh. The average demand shift per site was 1070 watts. The Harvest Thermal system shows significant GHG emissions savings compared to the baseline gas savings, with 83 to 90 percent GHG emissions savings across all of the sites.

TRC characterized the performance of the Harvest Thermal system using metered trends. In the post-retrofit case, TRC calculated the hourly coefficient of performance (COP) as the heating load divided by the unit electrical input. The average system COP ranges from 2.61 to 2.96 across the four sites.

In general, customers like the Harvest Thermal system better than their previous gas appliances, both for space heating and water heating. They were generally very satisfied with the performance of the Harvest Thermal system and liked the positive environmental impact of the system compared to their pre-retrofit gas appliances.

Appendix A: Harvest Thermal System Space Heating Waterside Load Meter Validation

Space heating

Test times

pre-test	14:46pm	turned on heat
Test 1	16:53:00 AM	start test time
	16:58:00 AM	stop test time

Harvest Thermal Meter Data
Waterside calculation

Start time	4/18/22 16:53	
Stop time	4/18/22 16:58	
Monitoring period	0:05:00	hours:minutes:seconds

Waterside heating load (Btu/h)

Min	11,172	Btu/h
Max	12,870	Btu/h
Average	11,911	Btu/h

TRC Field Measurements
Airside BTU calculation

Parameter	**Average Value**	**Units**	**Measurement location**
Airflow	751	cfm	at return air register
Supply air temperature	83.2	°F	at first supply grille
Return air temperature	67.4	°F	at return air register
Airside heating load (Btu/h)	12,856	Btu/h	calculated

Compare waterside calculation with airside calculation

Difference from Average HT		
Btu/h difference	(945)	Btu/h
Error	-7.4%	%

Notes

Supply temperatures started to drop off at end, indicating that the system was no longer steady state. Removing that data improves the % difference.

During the meter verification procedure, HT noted that they had previously noted an issue with the T1 sensor, noting that it was reading ~5°F below what it should be.
TRC added a thermistor to the pipe surface just downstream of where the HT T1 sensor is.

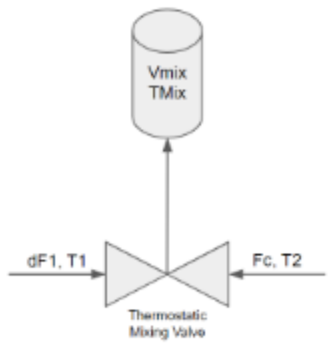
Using TRC's measured values for T1 in place of Harvest Thermal's measured values T1 results in the following:

Average waterside heating load	12,995	Btu/h
Btu/h difference	139	Btu/h
Error	1.1%	

Appendix B: Harvest Thermal System DHW Pre-mix Flow (F1) Validation Procedure

Testing Procedure for Validating F1

Goal: Validate the flow reading through Flow Meter 1 in the Harvest Pod without tampering with the preset thermostatic mixing valve or other components within the pod.



Approach:

- Measure the volume and temperature of mixed water over a steady 20-gallon draw test.
- Reconcile the measured values with T1, T2, and dF1 (the difference in Flow Meter 1 measurements over 1 minute periods).

Materials needed:

- Testing Bucket A and B - either two (2) five-gallon buckets or two (2) ten-gallon buckets
- Temperature probe - either a thermistor or an IR gun

Testing Procedure:

1. Ensure tank stage-of-charge < 150 gal, run hot water if needed to get it below 150 gal

2. Turn on the heat pump using the Harvest Setup web tool, and run the heat pump for at least one hour.
    a. This ensures there is plenty of hot water for tests and constant temperature readings

3. Turn on the testing faucet to hot and fill a testing bucket
    a. This will warm the DHW pipes and lessen thermal losses of warming pipes during testing

4. Perform a 20-gallon steady draw at medium flow (1-2 gpm) test:

    a. Fill Testing Bucket A with hot water from a faucet. Prepare bucket B for swapping after A is full.

    b. When A is full replace it with B under the faucet and continue the draw test.

c. Measure and record the temperature of bucket A with your temperature probe, then dispense of its contents.

d. Repeat steps 4, 5, and 6 until 20 gallons of water have been measured and recorded.

5. Calculate Vhot (see below) using HT data and compare against the volume of water measured by F1. Finally, compute the error in the measured and calculated values.

<u>Calculations & Assumptions:</u>

- Vmix = Volume of mixed water
- Tmix = Temperature of mixed water

- Vhot = Volume of hot water
- T1 = Temperature of hot water

- Vcold = Volume of cold water
- T2 = Temperature of cold water

1. Vmix = Vhot + Vcold = Vhot + Vcold
→ Vcold = Vmix - Vhot

2. Vmix * Tmix = Vhot * T1 + Vcold * T2
→ Vmix * Tmix = Vhot * T1 + (Vmix - Vhot) * T2
→ Vmix * Tmix = Vhot * (T1 - T2) + Vmix * T2
Vhot = Vmix * (Tmix - T2) / (T1 - T2)

Error = |(Σ(dF1) - Vhot) / Vhot|

*assumes that Tmix is constant over the testing period. If it isn't the test can be broken down into sub-periods and the calculation be run for each sub-period.

See the attached file for *F1 Validation Example Calculation*