Restaurant Field Monitoring

Final Report

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Disclaimer

Executive Summary

Hot water is a critical resource in commercial kitchens, primarily used for sanitation purposes. Across 85,500 facilities, the estimated fuel gas demand for domestic hot water is 340 million therms per year (CalNext. 2023), making it a high-energy intensity end-use. Decarbonizing this sector is essential for achieving state-level greenhouse gas reduction goals. However, significant barriers exist, including added complexity of heat pumps for design, added installation complexity, space and electrical capacity limitations, high retrofit costs, potentially increased operating costs, and water heater sizing guidelines imposed by California health departments that lack heat-pump-specific guidance. This field demonstration project aimed to address these challenges by implementing and analyzing a heat pump assist water heating system in a full-service restaurant.

Project Overview

The intent of this project was to retrofit an existing gas-fired water heating system with an in-series heat pump water heater and replace a door-type dish machine with a high-efficiency heat recovery dish machine, thereby offsetting the potentially increased operating costs of the heat pump water heater. The project team aimed to recruit a site with a pumped recirculation distribution system that would maintain hot water temperatures. Finally, in addition to the heat recovery dish machine, the project aimed to further reduce the heat pump water heater operating cost by shifting the heat pump electrical load out of the peak use period, reduce the distribution energy losses by lowering the water temperature with a master mixing valve, and by implementing hot water saving devices such as low flow fixtures.

The research team conducted a rigorous site screening process, evaluating 97 restaurants to identify suitable candidates for a full heat pump assist water heating system retrofit. Approximately 80 percent of screened sites had tank-type water heaters, making them viable candidates for this approach. However, the limited prevalence of recirculation systems and high-temperature dish machines reduced opportunities for efficiency measures. Although it did not meet all the original criteria, as it lacked a recirculation system and typical door-type dish machine, the selected site provided a representative hot water system infrastructure for the heat pump assist water heating demonstration.

The heat pump assist water heating system integrates a single-pass air-source heat pump water heater with one storage tank upstream and in series with an existing natural gas storage water heater. This retrofit approach retains the gas system as a backup, avoiding regulatory hurdles while reducing carbon emissions. The project objectives included characterizing baseline and post-retrofit performance, identifying energy efficiency measures to offset operating cost increases, and analyzing retrofit system data that supported updates to the state and municipal health department guidelines to add sizing for heat pump water heaters.

Key Findings

1. **Energy Performance:** The heat pump water heater system demonstrated a high coefficient of performance of 4.1 during the post-retrofit period, reducing natural gas consumption by 93 percent on days the restaurant was open. Overall energy savings averaged 76.5 percent on days the restaurant was open and showed improved hot water temperature stability—effectively eliminating hot water runouts.

2. **Cost Impacts:** Despite energy savings, the retrofit resulted in a very slight increase in overall energy costs, approximately $215 annually, due to higher electricity rates for heat pump water heater operation, despite the heat pump's decent coefficient of performance. Load shifting potential was limited by insufficient storage capacity, but additional storage tanks could reduce energy cost increases.
3. **Regulatory and Market Barriers:** Significant obstacles to heat pump water heater adoption included permitting challenges, existing water heater located in the attic, and space constraints. Findings from site recruitment highlighted the need for energy program incentives to overcome market and regulatory barriers in the food service sector.
4. **Operational Insights:** Hot water runouts during peak dinner service and continuous operation of dish machine wash heaters indicate opportunities for retro-commissioning programs. The existing dish machines consumed more energy than the heat pump water heaters, suggesting that efficiency measures targeting dish machines may yield significant benefits, as originally intended with the project.
5. **Site Characterization:** The research team found that restaurants in the San Francisco Bay Area—where recruitment was most successful—tend to be smaller and older, with lower prevalence of recirculation systems. The team identified owner concerns about dishwashing processes as a key barrier to adopting high-efficiency dish machines.

Recommendations

- **Energy Efficiency Measures:** Although this study was unable to implement them, a high-efficiency heat recovery dish machine or recirculation loop controls could offset energy cost increases from heat pump water heater installations. The data collected from the dish machine, along with other concurrent studies, indicate these systems often waste significant amounts of energy. In this study, the dish machine consumed roughly twice as much energy daily than the heat pump water heater and many recirculation system losses account for nearly a third of water heating energy.
- **Storage Capacity:** Adding storage tanks in series would enhance load shifting potential and improve system performance during peak periods.
- **Policy and Program Support:** Streamlining permitting processes, updating health department guidelines, and providing incentives for heat pump water heater adoption are critical to overcoming regulatory and market barriers.

Conclusion

The heat pump assist water heating system demonstrated promising energy savings and hot water delivery performance improvements in a restaurant setting, with potential for broader adoption in the food service sector. While challenges remain, the viability of heat pump water heater systems as a decarbonization solution could be further enhanced through targeted energy efficiency measures, increased storage capacity, and updated regulatory guidelines. Findings from this project underscore the need for energy programs to support the adoption of heat pump technology and other efficiency measures simultaneously in commercial kitchens.

Abbreviations and Acronyms

Acronym	Meaning
Btu	British thermal units
CF	Cubic foot
COP	Coefficient of performance
CVRMSE	Coefficient of Variance Root Mean Squared Error
DHW	Domestic hot water
GPM	Gallons per minute
HP	Heat pump
HPaWH	Heat pump assist water heating
HPWH	Heat pump water heater
IOU	Investor-owned utility
kWh	Kilowatt-hour
kBtuh	Thousand Btus per hour

Contents

Tables

Figures

Equations

Introduction

Restaurants consume a significant amount of natural gas, much of which is used for water heating. While there are heat pump water heaters (HPWH) on the market that could decarbonize these systems, there has been no known field demonstration of their performance in this application, and there are significant regulatory barriers. This field demonstration project analyzed the performance of an HPWH system installed in a full-service restaurant and documented the associated regulatory barriers, with the goal of improving pathways to decarbonization adoption.

To achieve the project objectives, the research team installed a single-pass air-source HPWH as part of a heat pump assist water heating system (HPaWH), where the existing gas water heating system was retained to handle a much lower heat load and serve as a backup. This plan helped avoid a health department review. Positioning this project as a retrofit add-on had some benefits, since the HPWH and storage tank did not have to be sized to meet the winter design day load and handle the high variability in daily hot water use at the site. These benefits have the potential to allow for much broader adoption than replacing the natural gas water heater and would result in a net carbon reduction.

Project challenges included extended site recruitment, slow permitting review, additional structural assessment while determining HPWH storage tank location, an atypical cylindrical dish machine, and lower-than-desired hot water use for a small fine dining establishment that only served dinner. Additionally, in California, electric HPWHs can cost more to operate than natural gas water heaters. The team planned to offset these anticipated cost increases by implementing load shifting measures via controls to reduce operation between 4:00 p.m. and 9:00 p.m.; however, site limitations restricted the team's ability to do so. Site characteristics are further outlined in the Retrofit Equipment Selection, Sizing, and Methods section.

Background

Hot water is primarily used for sanitation purposes in commercial kitchens. The 2013 study, CEC-500-2013-050, by Fisher-Nickel Inc. estimated gas-load for domestic hot water (DHW) in foodservice at 340 million therms per year across 85,500 facilities. Prior CalNEXT research documents the market barriers and opportunities for HPWH adoption in the food service sector, including unique regulatory barriers (CalNext. 2023). The HPaWH concept this project demonstrates is expected to overcome key existing regulatory decarbonization barriers—primarily health and safety—related to hot water system sizing in food service facilities. This concept is also expected to enable benefits, such as load flexibility and curtailment, if grid-connected controls are installed. Furthermore, the concept overcomes possible technical challenges that limit a site's electrical capacity to support a full-sized HPWH.

Figure 1 below illustrates how the HPaWH concept was implemented at the project site.

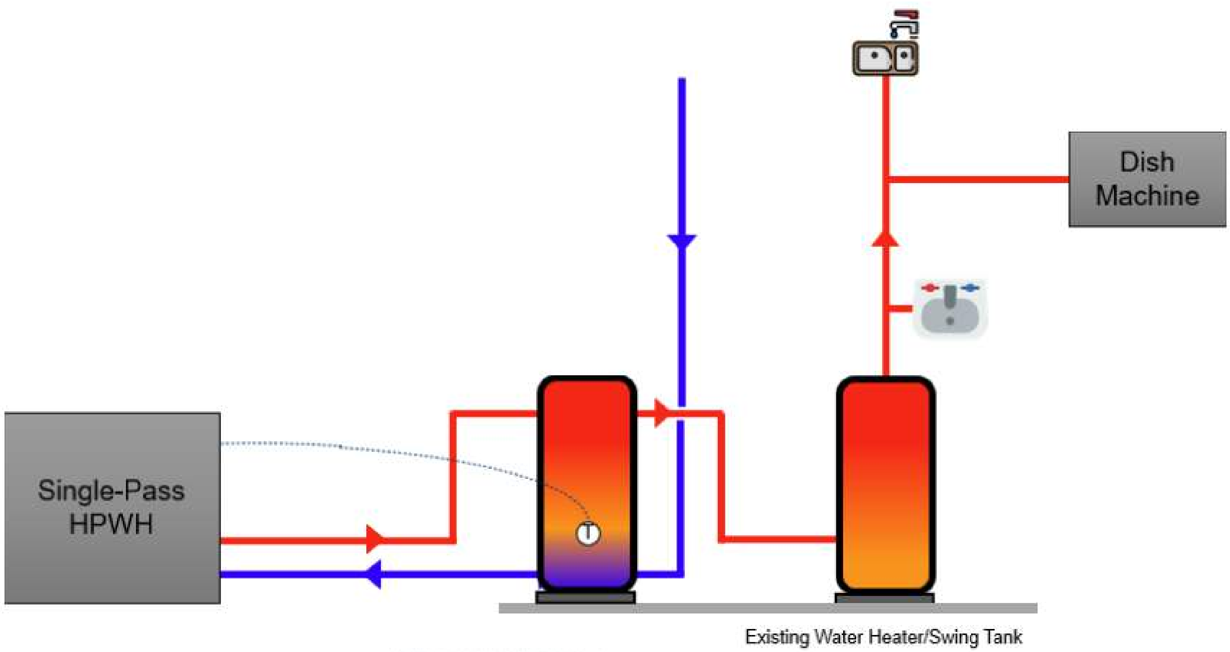


Figure 1: Project site HPaWH schematic diagram.

Methodology and Approach

The primary objective for this project was to demonstrate the HPaWH approach in a full-service restaurant and document hot water delivery performance, energy performance, first costs, operating cost impacts, and technical barriers to implementation, including permitting challenges. The secondary objective was to quantify energy costs and reduce potential energy cost increases from the retrofit.

This section of the report documents the methodology for activities completed, as outlined below.

1. Identified a suitable test site.
2. Developed a field monitoring and Measurement and Verification plan.
3. Installed baseline monitoring equipment.
4. Performed analysis of the baseline system.
5. Selected the HPWH system.
6. Submitted for a permit.
7. Procured structural analysis and other items to address plan checker comments.
8. Received a permit.
9. Installed the HPWH system.
10. Installed post-retrofit metering.
11. Analyzed and characterized the retrofit system performance.

Site Selection Process

The research team conducted site selection activities over the course of one year. Frontier Energy led site selection activities and logged key high-level site data, such as:

- Dish machine throughput, as reported by the restaurant owner.
- Water heater type (tank or tankless).
- Whether the dish machine was a door-type machine.
- Whether the dish machine was a high-temperature machine.
- Whether the site had a hot water recirculation system.

Specifically, a full-service restaurant offering the greatest opportunity for energy savings via a HPaWH system retrofit would have the following characteristics:

- Tank-type water heater.
- Door-type high-temperature dish machine with condensing-type heat recovery.
- Hot water recirculation loop that could benefit from a digital master mixing valve.
- Greater than 250 racks washed per day.

Finding a full-service restaurant that met all these criteria proved to be a challenge. Accordingly, the project team selected a site that met most of the desired criteria and installed and evaluated the best-suited HPaWH retrofit.

The recruitment challenges faced by the research team highlight structural barriers to deploying targeted energy efficiency incentive program measures at scale in the food-service sector. This sector experiences historically rapid business turnover—which was only accelerated by the COVID-19 pandemic—and faced associated economic pressure, including inflation, during the recruitment period. Two promising project sites closed for business while evaluating participation in the project. However, the research team gained valuable market insights from hundreds of phone screening calls and 97 site visits before finding the eventual project site. We were able to get a high number of responses for all screening criteria except number of dish machine racks per day, which are summarized in Table 1.

Table 1: Site characterization results.

Criteria	Number of Responses	Percentage That Met Criteria
Has a tank type water heater	93 (of 97)	80%
Has a door type high temperature dish machine	85 (of 97)	21%
Has a hot water recirculation loop	77 (of 97)	13%
Greater than 250 racks washed per day	30 (of 97)	10%

Based on the data in Table 1, the team filtered the list of sites by the essential criteria of having a tank-type water heater and a door-type high-temperature dish machine.

We engaged with six interested full-service restaurants that satisfied or nearly satisfied the criteria and performed a simple energy and utility bill analysis to identify the best candidates based on anticipated reduced cost. Two sites were expected to have reduced costs, although one of the sites had process-related concerns with the plan to replace their existing dish machine. The project team moved forward with the remaining site for this field demonstration project.

Selected Site Profile

The selected site is open from 5:30 p.m. to 8:00 p.m. Tuesday through Friday, 5:00 p.m. to 8:00 p.m. on Saturdays, and is closed on Sunday and Mondays. The selected restaurant profile details are outlined in

Table 2, and hot water fixtures are noted in Table 3.

Table 2: Selected restaurant profile.

Category	Details
Site type	Full-service restaurant
Location	San Mateo
Average monthly covers[1]	~500
Operating days	Tuesday to Saturday (typically closed Sunday and Monday)
Service hours	Dinner only, ~9-12 hours of hot water use, including prep and clean-up
Building type	Converted single-family building with first floor and attic
Existing water heater location	Attic
Existing water heater type	50-gallon natural gas tank water heater
Existing water heater input rate	38 kBtu/h (considered low for the application)
Dish machine type/model	Jackson Faspray 10AB
Recirculation loop	None

[1] One cover is a single meal for a single guest, so a party of four served one meal is four covers.

Table 3: Hot water fixtures.

Fixture	Quantity
Dish machine	1
Comp sink	1
Pre-rinse sprayer (over two comp sink)	1
Prep sinks	2
Lavatory sinks	2

The dish machine is a high-temperature Jackson Faspray systems Model 10AB Round Door-Type dish machine, with an owner-reported throughput of 150 racks per day, or about 80 cycles (two racks per cycle). The dish machine is rated for 220-volt single-phase power, with a rated wash temperature of 150°F to 165°F, and a rated final rinse temperature of 180°F to 195°F. The dish machine nameplate power data for each powered component is listed in Table 4; these specifications are used to understand the dish machine operations.

Table 4: Dish machine component power.

Sub-Component	Rated Power
Wash motor	1/2 HP
Rinse motor	N/A
Wash heater	750 W
Rinse heater	6,500 W

Field Monitoring Plan

The research team designed the field metering approach to quantify the natural gas savings, using a diaphragm gas meter and added electrical power consumption metering during the HPWH installation. Additionally, the field metering approach allowed the research team to characterize the system efficiency, hot water demands, and dish machine operations, including water use, power, number of cycles, hot water runout time, and any savings from retrofit efficiency measures. The baseline monitoring period was about seven and a half months, while the post-retrofit period was a few days shy of five months.

The baseline field metering is illustrated conceptually in Figure 2, while the post-retrofit field metering plan appears in Figure 3. The field metering points and specifications for baseline and post-retrofit are tabulated in Table 5. The research team collected weather data from the nearest high-quality National Oceanic and Atmospheric Administration weather station, which is less than five miles away at San Francisco International Airport. In addition to the measured physical parameters, the research team collected cover data from the restaurant and performed an analysis to show the relationship between daily covers and hot water use.

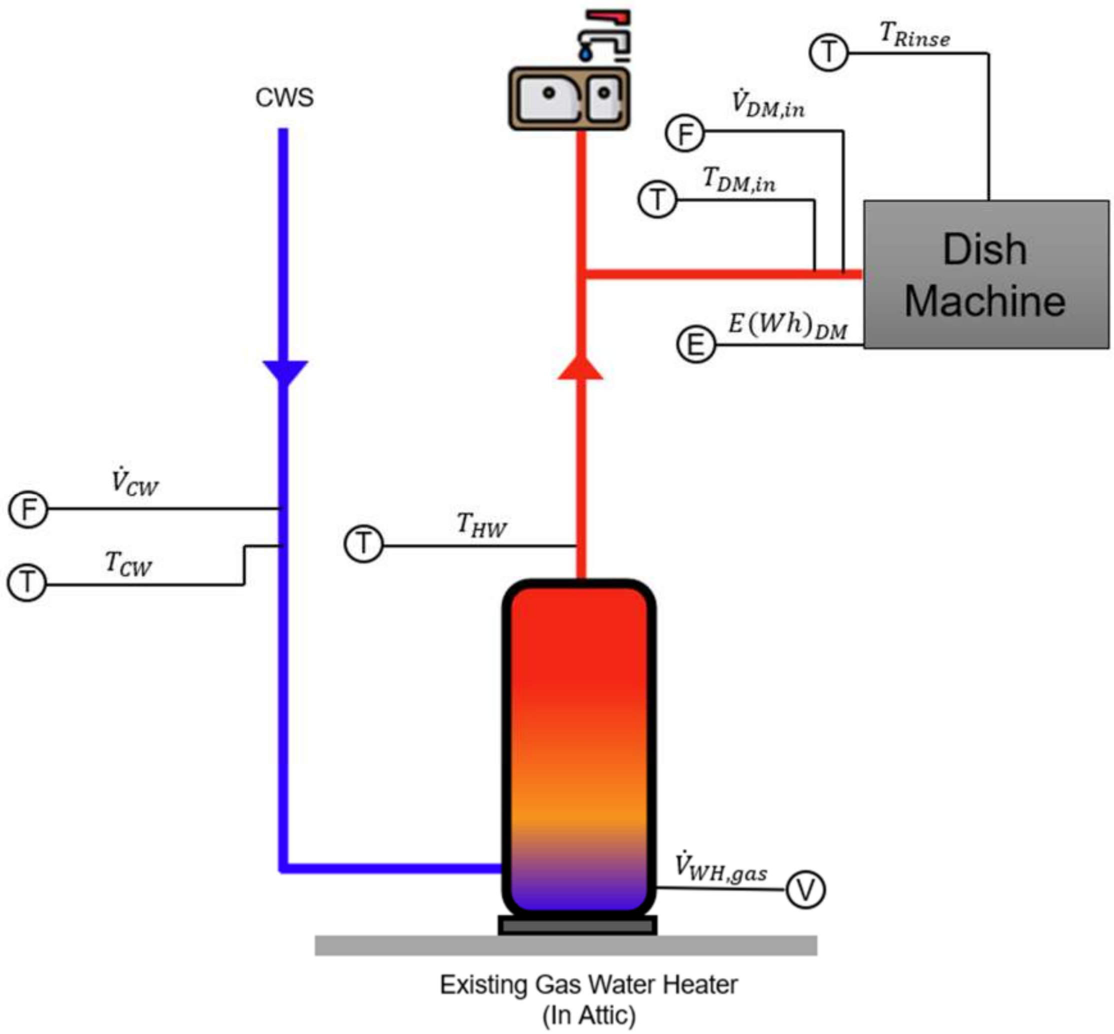


Figure 2: Baseline field metering schematic.

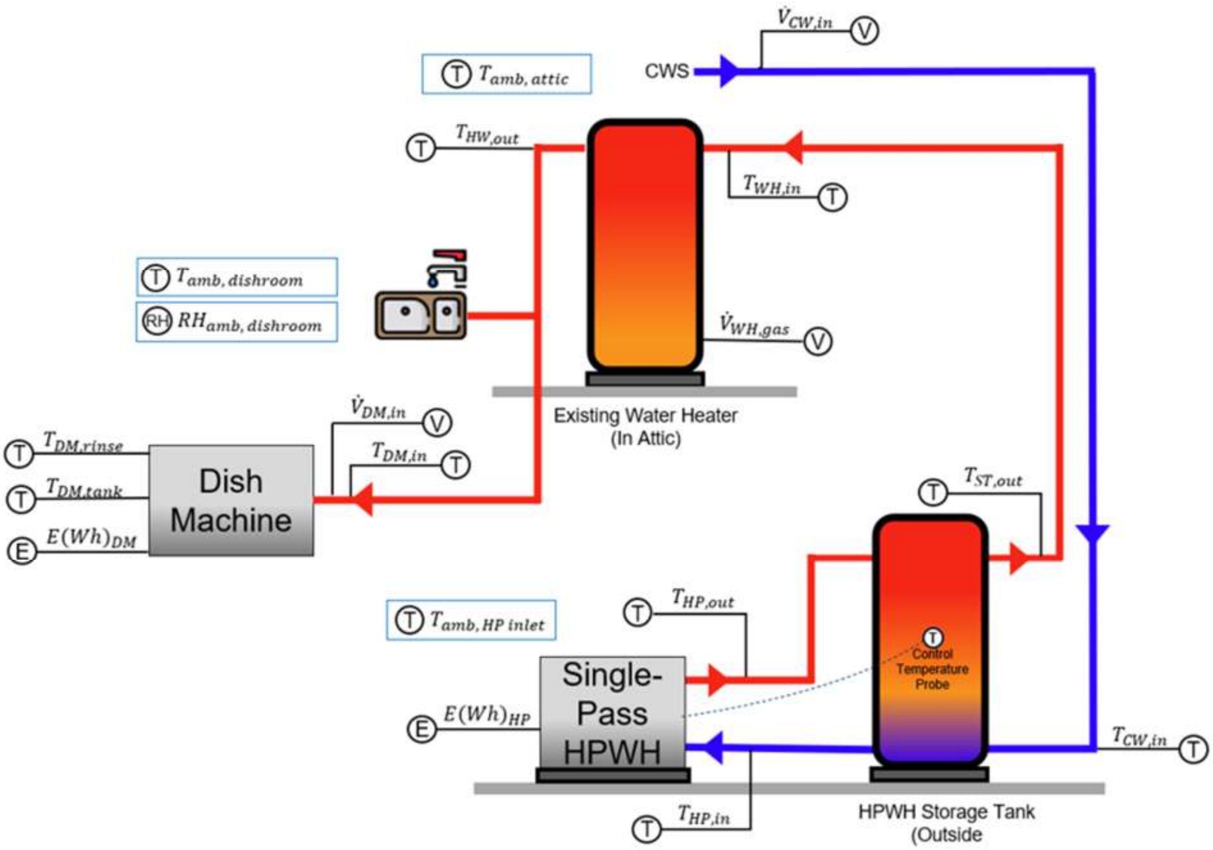


Figure 3: Post-retrofit field metering schematic.

Table 5: Field metering points and specifications.

Parameter	Diagram Label	Type	Make/Model	Unit	Sampling Interval
Cold water flow Rate	$\dot{V}_{CW}$	Volumetric Flow Rate	Badger RCDL 25	GPM	5 second
Cold water temperature	T_{CW}	Temperature	Omega TT-K-24-SLE	°F	5 second
Hot water supply temperature	T_{HW}	Temperature	Omega TT-K-24-SLE	°F	5 second

Parameter	Diagram Label	Type	Make/Model	Unit	Sampling Interval
Gas water heater gas use	$\dot{V}_{WH,gas}$	Volumetric Flow Rate	American Meter BK-G4	SCFM	5 second
Dish machine hot water use	$\dot{V}_{DM,In}$	Volumetric Flow Rate	Badger RCDL 25	GPM	5 second
Dish machine water inlet temperature	$T_{DM,In}$	Temperature	Omega TT-K-24-SLE	°F	5 second
Dish machine rinse water temperature	T_{Rinse}	Temperature	Omega TT-K-24-SLE	°F	5 second
Dish machine power	E_{DM}	Electrical Power	Continental Control Systems WNB-3Y-208-P	kW	5 second
HPWH power (post-retrofit only)	E_{HP}	Electrical Power	Continental Control Systems WNB-3Y-240-P	kW	5 second
HPWH inlet temperature	$T_{HP,In}$	Temperature	Omega TT-K-24-SLE	°F	5 second
HPWH outlet temperature	$T_{HP,Out}$	Temperature	Omega TT-K-24-SLE	°F	5 second
HPWH storage tank cold water inlet temperature	T_{CWin}	Temperature	Omega TT-K-24-SLE	°F	5 second
HPWH storage tank outlet temperature	$T_{ST,Out}$	Temperature	Omega TT-K-24-SLE	°F	5 second

Parameter	Diagram Label	Type	Make/Model	Unit	Sampling Interval
Existing water heater inlet temperature (post-retrofit)	$T_{WH,in}$	Temperature	Omega	°F	5 second
Dish room ambient temperature	Not Illustrated	Temperature	HOBO MX temp/RH logger	°F	1 minute
Dish room ambient RH%	Not Illustrated	Relative Humidity	HOBO MX temp/RH logger	%RH	1 minute
Outdoor air ambient wet bulb temperature	Not Illustrated	Temperature	Local Weather Station[2]	°F	1 hour

Retrofit Equipment Selection, Sizing, and Methods

Heat Pump Water Heating System

The research team evaluated the existing system performance to select the best system and configuration. Based on the low hot water use at the site, the setpoint requirements, and wide availability, the research team selected the SanCO2 GS5-45HPC HPWH. The selected equipment is lightweight and has a relatively small footprint, which are preferred characteristics for retrofit in a space-constrained application. After considering all possible HPWH and storage tank locations, performing building structural analysis, talking with the site owner, and receiving plans review comments from the city, the team selected an exterior-ground-mounted location at the back of the building. Importantly, the selected site had sufficient electrical capacity to support the installation of one HPWH.

After installing baseline monitoring, the research team calculated that the 15,400 British thermal units (Btu) per hour capacity of one HPWH was theoretically sufficient to meet the maximum observed hot water demand of 333 gallons per day, at an average temperature rise of 85°F with just over 16 hours of operation. This translates to roughly 21 gallons of hot water recovery per hour. On an average day, the HPWH would run less than 11 hours. When paired with the proper storage

[2] https://www.ncdc.noaa.gov/cdo-web/datasets/LCD/stations/WBAN:23234/detail

volume, this means that one HPWH could theoretically meet 100 percent of the facility's load without operating during the peak times of 4:00 p.m. to 9:00 p.m.

The research team assessed the options for storage tanks, including the manufacturer's 83-gallon and 119-gallon tanks. After consulting with the manufacturer to understand internal piping geometries that may affect useful storage volume—and considering the structural impacts of the 119-gallon tanks—the team planned on installing two of the manufacturer's ECO-83SSAQB 83-gallon stainless steel storage tanks. Upon receiving plan check review comments and feedback from the site owner, a second storage tank in the only feasible installation location would have taken up more space than was available, blocked a window, and displaced an exterior refrigerator. The increased height and diameter of a 119-gallon tank posed similar installation issues as two 83-gallon tanks would have. The team was forced to use a single 83-gallon tank, which effectively removed load shifting potential. An analysis of the installed system related to load shifting can be found in the Load Shifting Potential section.

Permitting and Structural Analysis

Even though the project team avoided a health department review by using the HPaWH method, the permitting process highlighted the significant implementation barriers associated with electrification of full-service restaurants. Much of the issue came from needing to add new tanks—a challenge that applies generally to the HPaWH concept and would also typically apply to properly installed HPWHs in this sector, as they often have lower recovery rates. The addition of just one 83-gallon tank in the attic at the demonstration site triggered a structural review, since the tanks weighed more than 400 pounds and would have been located on a framed floor. While the research team hoped to install two 83-gallon tanks, we were restricted to installing only one tank, and also had to install both the outdoor compressor and the storage tank outside. Although locating equipment outside resolved the structural challenges, it triggered an onerous review process that required approval by the planning and building departments, as detailed in Appendix A: Permit Application Process Summary.

The requirement to perform structural analysis added significant time and expense to the HPaWH retrofit, above and beyond the costs to perform any structural retrofits that may be required. The research team contracted a market-rate structural engineer to perform structural documentation services and create construction documents. This structural analysis revealed that significant improvements would be required to locate any additional hot water storage in the attic space. The costs of these structural upgrades were too extensive and expensive for the project and would also be prohibitive in a real-world scenario.

The added time and expense of structural assessments and upgrades may push project costs well beyond the typical cost of replacement; it would likely lead to like-for-like replacement or unpermitted replacements to HPWHs that might not meet a facility's demand. Although the selected site had some atypical characteristics—i.e., an attic—many sites are expected to require structural analysis due to a lack of on-grade space for a new tank. This highlights the pressing need for utility and technical support to connect building owners to structural engineers, financial support via energy programs, and advocacy for streamlined permitting reviews.

A detailed timeline of the permitting process can be found in Appendix A: Permit Application Process Summary. The San Mateo city permitting fee was $1,254, not including the project team labor of navigating the submittal process.

Installation and Commissioning

The installation of the HPWH spanned two days, April 21 and April 28, 2025, with Frontier orchestrating the work and adding metering equipment for the newly installed system while TRC provided oversight and documented the installation, which is shown in Figure 4 through Figure 8.

Day One site work included:

- HPWH location grade preparation.
- Pouring concrete for the HPWH and storage tank pad.
- Pouring and setting posts for protection and fencing to conceal the HPWH from sight.
- Placing HPWH and storage tank and installing earthquake strapping for the storage tank.
- Installation of valved tie-in plumbing.
- TRC spot-checked that thermistor readings hadn't drifted substantially since installation with a NIST-calibrated temperature sensor.

Day Two site work included:

- Plumbing between the HPWH and storage tank, and from the storage tank to the tie-in plumbing that was installed on Day One.
- Installing an expansion tank with the appropriate check valves, as the existing system did not have an expansion tank.
- Running electrical from the panel to HPWH location, with required breakers and disconnect, as well as installing an in-line power meter.
- Insulating plumbing.
- Installing fencing between posts.
- Filling and pressurizing HPWH system.
- Checking HPWH system operation.
- Adding or re-deploying metering, as needed and verified.

Additional installation details can be found in the Installation Overview section of Appendix A: Permit Application Process Summary.

Figure 4: Wide angle of partially installed HPWH system.

Figure 5: Close-up of partially installed HPWH system.

Figure 6: Fully installed HPWH system.

Figure 7: Customer view of installed HPWH.

Figure 8: Water heating data acquisition system and HPWH tie-in plumbing.

The total contractor cost of installation and HPWH equipment was $24,805, which does not include permitting fees or labor done by the project team. Although the contractor did not provide an itemized bill, the online price of the HPWH outdoor compressor, including an 83-gallon storage tank, is between $6,250 and $7,500 with tax.

Analysis Methodology

The research team analyzed the data to characterize energy use, hot water system operating efficiency, dish machine performance, and key performance metrics that affect efficiency, such as number of water heater and dish machine cycles. This section defines the methods used in that analysis. Table 6 includes additional variable nomenclature unique to the analysis; please refer to Table 5 in the Field Monitoring Plan section for field metering point nomenclature.

Table 6: Additional variable nomenclature.

Variable Symbol	Variable	Variable Units
q	Thermal energy	$kBtu$
ρ	Density	lbm/ft^3
V	Volume (water or fuel)	$gal\ or\ ft^3$
c_p	Specific heat for constant pressure process	$BTU/lbm * °F$
E_{In}	Energy input	$kBtu$
E_{sa}	Energy savings	$kBtu/Day$
E_{CW}	HPaWH energy cost summer	$\$/Day$
E_{CS}	HPaWH energy cost summer	$\$/Day$
E_{CA}	HPaWH energy cost annual	$\$/Year$
$Volts$	Voltage	$Volts$
I	Current	$Amps$
PF	Power factor	kW/kVA
n_{phases}	Number of electrical phases	[-]
η	Efficiency	$kBtu/kBtu$
T_{CW}	Mass weighted temperature of cold water	°F

Variable Symbol	Variable	Variable Units
T_{HW}	Mass weighted temperature of hot water	°F
D_{ElOPW}	Electricity cost rate off-peak winter	$/kWH
D_{ElOPS}	Electricity cost rate off-peak summer	$/kWH
D_{ElPW}	Electricity cost rate off-peak winter	$/kWH
D_{ElPS}	Electricity cost rate on-peak Summer	$/kWH
R_P	Percent energy used on-peak	%
R_{OP}	Percent energy used off-peak	%
M_i	Model Y intercept	Constant
M_s	Model slope	Constant
S_S	Summer season days	Days
S_W	Winter season days	Days
E_{CLSW}	Winter load shifting energy cost savings potential	$/Day
E_{CLSS}	Summer load shifting energy cost savings potential	$/Day

A number of minor conversions and assumptions are required to convert the measured data for analysis, which include:

- The specific heat of water for constant pressure processes is approximated as 1 Btu per (pound-mass*°F).

- The density of water is calculated as a temperature-dependent value; a unique value for density is assigned for each 1°F via linear interpolation between the United States Geological Survey published values (United States Geological Survey 2024).
- The team used 1,041 Btu per cubic foot heating value of natural gas, calculated by averaging that data found on the site's April and May 2025 bills.
- The measured cold water flow rate is the same as hot water demand based on the flow meter location.
- The natural gas meter installed on the existing tanked water heater has a resolution of 1 cubic foot (CF). Although the readings are quite accurate, it can take time for the water heater to consume 1 CF of natural gas, thus leading to a lag between gas consumption and the associated pulse output. The gas meter is observed to pulse—indicating 1 CF consumed—every 105 seconds when the gas water is firing. Using this information, the team created a rolling sum function to interpolate between pulses, which better depicted presumed continuous combustion periods in plots.

Because hot water system performance is a function of mass flow rate and temperature rise of water through the water heater, the team implemented a mass weighting function that weights the measurement of the water temperatures by the mass flow rate. All water temperature data presented in tables in this report follow this method and are mass weighted average, as opposed to the arithmetic average, unless noted otherwise.

The project team calculated the heating energy delivered to the hot water distribution system at each time step according to Equation 1. The reported water heater efficiency for this site, which is calculated via Equation 2, is lower than the equipment-rated steady state thermal efficiency due to water heater tank losses, but higher than the system efficiency of providing hot water to the fixtures. This is because our measurement did not account for pipe heat losses from the outlet of the water heater to the fixture outlet.

Equation 1: Delivered hot water energy to distribution system for baseline natural gas water heater and post-retrofit HPWH.

$$q_{HW}\ [kBTU] = \frac{(\rho * V) * c_p * (T_{HW} - T_{CW})}{1000}$$

Equation 2: Water heater efficiency.

$$\eta = q_{HW}/E_{In}$$

The team obtained site utility bill information for April and May of 2025 to determine the restaurant's natural gas and electrical rate schedules. The site is on a G-NR1 natural gas rate and a Business Low Use Alternative (B6) electric rate schedule offered by Pacific Gas & Electric, which is presented in Table 7. Natural gas rates are highly variable, so the team procured the monthly natural gas rate data directly from the utility provider and applied the rates for the gas consumed during the baseline and the counterfactual baseline when calculating energy cost savings impacts. Winter months span from October 1 to May 31, and summer is inversely May 31 to October 1. Super off-peak costs were utilized in the analysis, which ran from March 1 to May 31; however, because HPWH operation typically starts around 2:00 p.m., this had a minimal impact on results.

Table 7: Site energy costs.

Period	Time of Day Applicable	Electricity Cost ($/kWh)	Average Natural Gas Cost ($/Therm)	Average Percent HP Energy During Peak Periods
Winter On-Peak	4:00 p.m. – 9:00 p.m.	0.43545	2.05744	64.5%
Winter Off-Peak	9:00 p.m. – 4:00 p.m.	0.39186	2.05744	64.5%
Super Off-Peak	Winter 9:00 a.m.– 2:00 p.m.	0.35578	2.05744	64.5%
Summer On-Peak	4:00 p.m. – 9:00 p.m.	0.68214	1.810422	64.5%
Summer Off-Peak	9:00 a.m. – 4:00 p.m.	0.42452	1.810422	64.5%

The research team performed a multivariable regression analysis to determine the best model for predicting water heating energy use. Table 8 and Table 9 present the linear model statistics the team selected for creating the counterfactual baseline used to calculate energy savings. With the high R-squared value and low Coefficient of Variance Root Mean Squared Error (CVRMSE), the team determined the water use model to be the best at predicting energy consumption without overfitting. All the models we considered and the associated statistics can be found in Appendix C: Modeling Results Tables. The team applied the water use model when creating the counterfactual baseline, using the formula values included in Table 8.

Table 8: Water heating system linear models used.

Model	Intercept	Water Use Slope
Daily Water Use	14.03	0.84

Table 9: Statistics of water heating system linear models used.

Model	R Squared	R ~ Squared	CVRMSE	Influence	Dependent Variable Mean	Residual Standard Error
Daily Water Use	0.99	0.99	0.07	0.58	150.80	10.13

To calculate total savings as presented in Table 16 in the Water Heating Savings Results section, the team subtracted all post-retrofit existing water heater gas consumption and all HPWH electrical energy consumption, both in kBtu, from the counterfactual baseline as defined in Equation 3. Equation 4 and Equation 7 define the methods for calculating cost saving.

Equation 3: Energy savings.

$$E_{sa}[kBTU] = \left((M_s * V_{HW}) + M_i\right) - E_{InNG} - E_{InHP}$$

Equation 4: Winter HPaWH energy cost.

$$E_{CW}[\$] = \left(\left((M_s * V_{HW}) + M_i\right) - E_{InNG}\right) * D_{NG} - (E_{InHP} * D_{ElOPW} * R_{OP}) - (E_{InHP} * D_{ElPW} * R_P)$$

Note: Equation 4 was performed for both open and closed days and presented independently.

Equation 5: Summer HPaWH energy cost.

$$E_{CS}[\$] = \left(\left((M_s * V_{HW}) + M_i\right) - E_{InNG}\right) * D_{NG} - (E_{InHP} * D_{ElOPS} * R_{OP}) - (E_{InHP} * D_{ElPS} * R_P)$$

Note: Equation 5 was performed for both open and closed days and presented independently.

Equation 6: Annual HPaWH energy cost.

$$E_{CA}[\$] = E_{CW} * S_W + E_{CS} * S_S$$

Note: Although not shown here, annual savings accounted for five open days a week and two closed days a week, using the corresponding daily energy cost values.

Equation 7: Winter HPWH load shifting potential cost savings.

$$E_{CLSW}[\$] = abs(E_{CW}) - (E_{InHP} * D_{ElOPW})$$

Note: Equation 7 was performed for both open and closed days and presented independently.

Equation 8: Summer HPWH load shifting potential cost savings.

$$E_{CLSS}[\$] = abs(E_{CW}) - (E_{InHP} * D_{ElOPW})$$

Note:

Equation 8 was performed for both open and closed days and presented independently.

Findings

Overview

The Water Heater Operation and Dish Machine Operation sections present detailed results addressing the primary objectives on system performance, while the Water Heating Savings Results and Load Shifting Potential sections explore secondary project objectives related to operational costs. Additionally, the impact of a hot water savings measure is analyzed and presented in the Hot Water Savings Measure Analysis section.

The baseline analysis date range is August 24, 2024, through April 21, 2025, and the post-retrofit period date range is April 29, 2025, through September 15th, 2025.

Water Heater Operation

Figure 9 illustrates the system's operations over the entire monitoring period, including total hot water use, dish machine hot water use, and the average number of covers per day. The vertical dashed red lines indicate a pause in data collection, when the HPWH was being installed, while the vertical yellow dashed line indicates when a low flow rinse spray head was installed as a hot water savings measure. The figure illustrates fairly steady operations, with some slight changes in the number of covers and hot water demand.

It should be noted that some of the reduction in hot water demand can be attributed to the installation of the low-flow rinse spray head, and could potentially also be due to a slight increase in the cold water main's temperature. Additionally, Figure 9 shows that the restaurant was closed over Thanksgiving week, which the research team confirmed with the site. Graphically, the dish machine hot water usage is about one quarter of the total hot water usage; this is confirmed by Table 10, which shows that dish machine use accounts for about 28 percent of the total hot water demand during operational days.

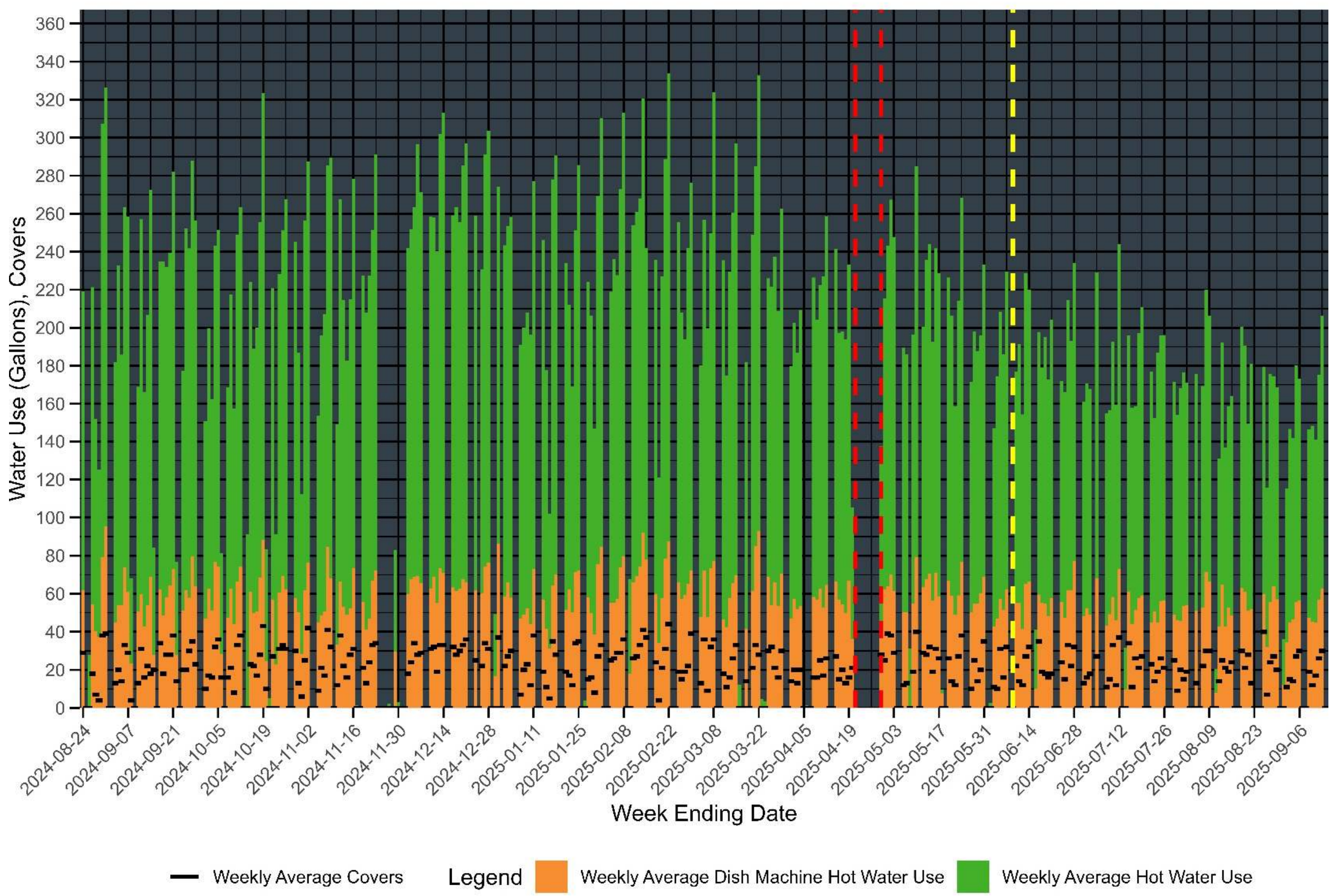


Figure 9: Daily total hot and dish machine water use profiles with covers.

Figure 10 illustrates the average daily hot water flow in gallons per minute (GPM) during the baseline and post-retrofit periods for days in which the restaurant had one or more covers. The vertical dashed red lines represent the typical electrical on-peak time of use tariff period of 4:00 p.m. to 9:00 p.m. The average water use profiles remained similar between the baseline and the retrofit periods, but there are visually significant differences in the average hot water supply temperatures between the two periods, especially starting just before 9:00 p.m. In the baseline period, hot water supply temperatures were maintained at 140ºF (green line), but began to slump to the 120ºF outlet temperature just before 9:00 p.m. The temperatures then further declined to 110ºF when the staff was wrapping up kitchen sanitations at closing time or after-dinner service, as the natural gas tanked water heater struggled to maintain temperatures during high use.

Note: All values in Figure 10 and Figure 11 are the arithmetic mean of the data at the corresponding timestamp, including temperatures—which are not mass weighted.

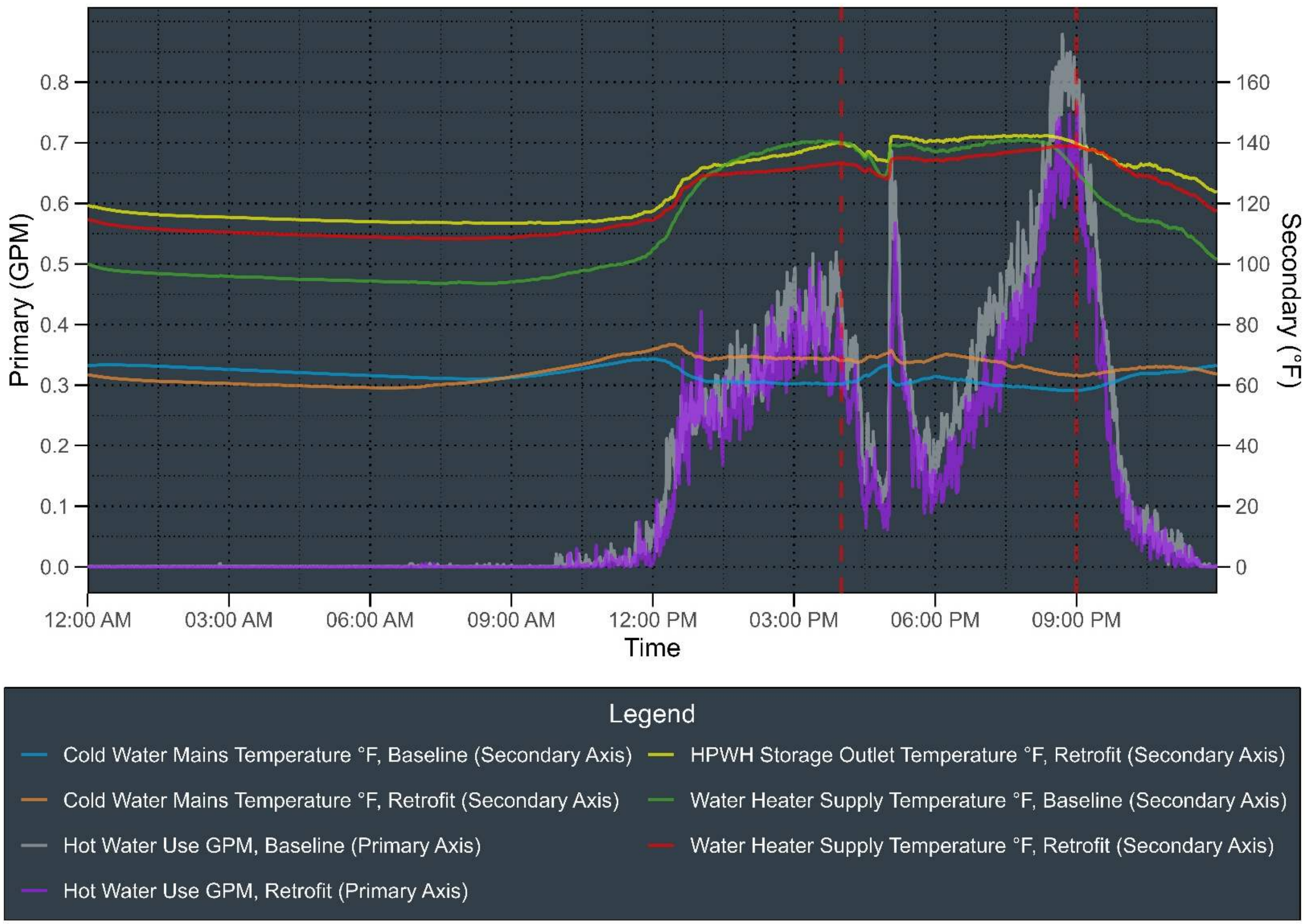


Figure 10: Average daily hot water flow and water heating system temperatures baseline and post-retrofit.

During the post-retrofit period, where both the HPWH and the natural gas water heater were combined (as represented by red line), the supplied hot water temperature was better maintained through this period, as expected. It is also worth noting that the hot water temperature in the post-retrofit period remained within a tighter range on average than in the baseline period. The team believes this is primarily attributed to poor temperature control of the natural gas water heater—which occurred due to a large deadband in activation and deactivation temperature setpoint—and that the typically more stable water temperature provided by the HPWH reduced the slight temperature creep.

The natural gas water heater's temperature creep is illustrated by the green line from 1:30 p.m. to 3:00 p.m. and 7:00 p.m. to 8:30 p.m. This phenomenon is also visible later in this section when a single day is presented. The average HPWH outlet temperature, shown via the yellow line, indicates that the HPWH occasionally struggled to meet the entire hot water demand of the site during the evening peak use, which starts just before 9:00 p.m. This effect would be significantly improved or eliminated if the site had space for more HPWH storage.

Figure 11 takes a closer look at the time periods during which the restaurant used hot water, which spans from 12:00 p.m. to just before midnight

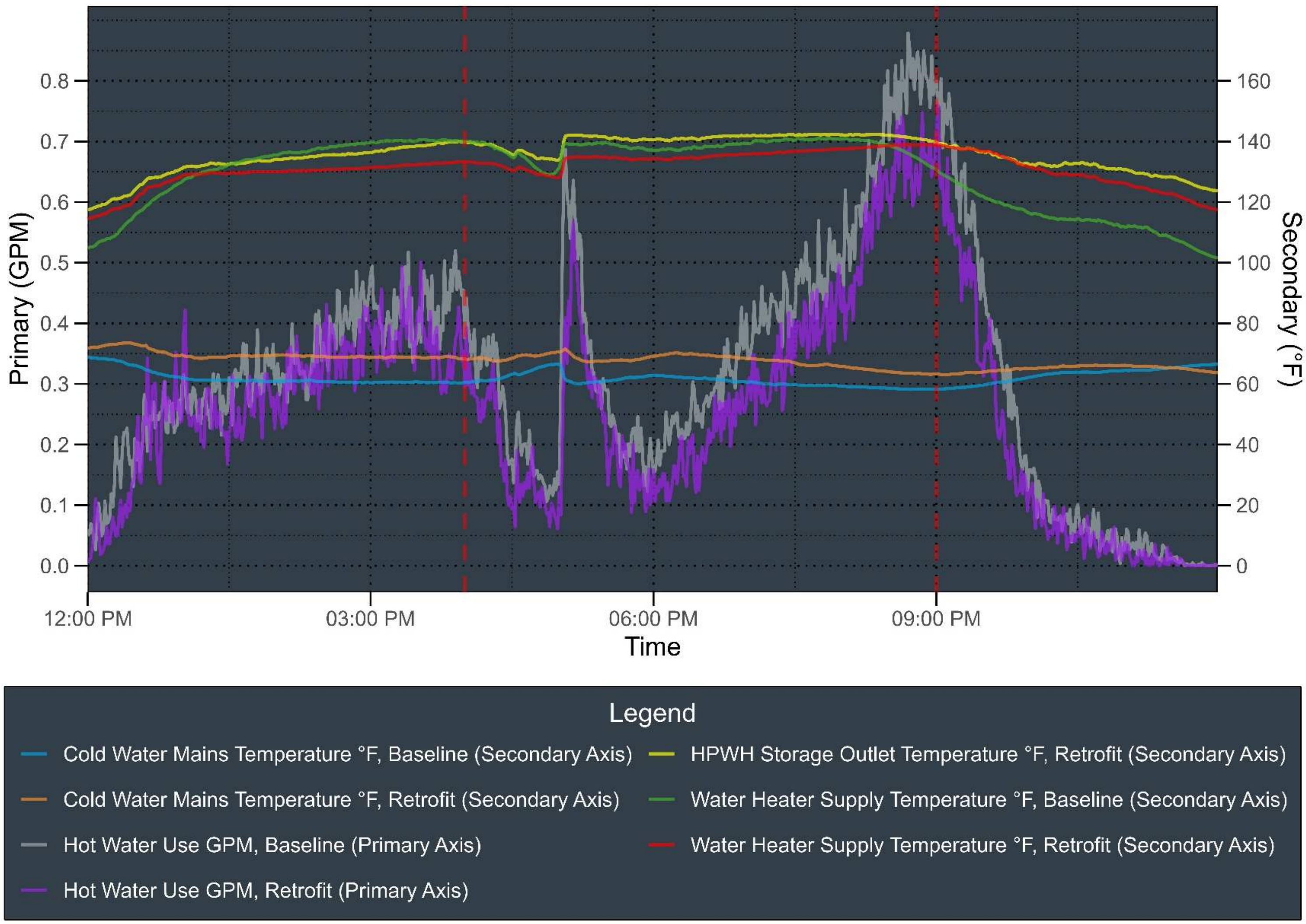


Figure 11: Average daily operational period hot water flow and water heating system temperatures baseline and post-retrofit.

Figure 12 characterizes average daily water heating system energy input relative to hot water flows for both the baseline period and the post-retrofit period. The vertical dashed red lines represent the typical electrical on-peak time-of-use tariff period of 4:00 p.m. to 9:00 p.m. It is important to note that the team converted the electrical input of the HPWH from kW to kBtuh so that it could be directly compared to the natural gas water heater. As seen in Figure 10 and Figure 11, the average hot water flows remain similar between the baseline and retrofit periods; however, there are significant differences in energy input.

The average daily baseline natural gas input, as shown via the light orange line, is significantly elevated during operational periods, reaching up to an average of 33 kBtuh at 9:00 p.m. The energy consumption of the natural gas water heater during the post-retrofit period is much lower and nearly matches the standby—mostly pilot light energy—of the baseline period during times of low or no hot water consumption. This indicates that the natural gas water heater very seldom fired during the post-retrofit period, except during peak use days, when it ran mostly during after-hours clean up. The HPWH electrical use, as shown via the green line in kBtuh, maintained a much lower relative consumption for a similar duration, only shifted slightly later. This overall reduction in energy consumption is attributed to the impressive coefficient of performance (COP) of the selected HPWH system.

Figure 13 takes a closer look at the time periods during which the restaurant used hot water, which spans from roughly 12:00 p.m. to just before midnight.

Note: All values in Figure 12 and Figure 13 are the arithmetic mean of the data at the corresponding timestamp.

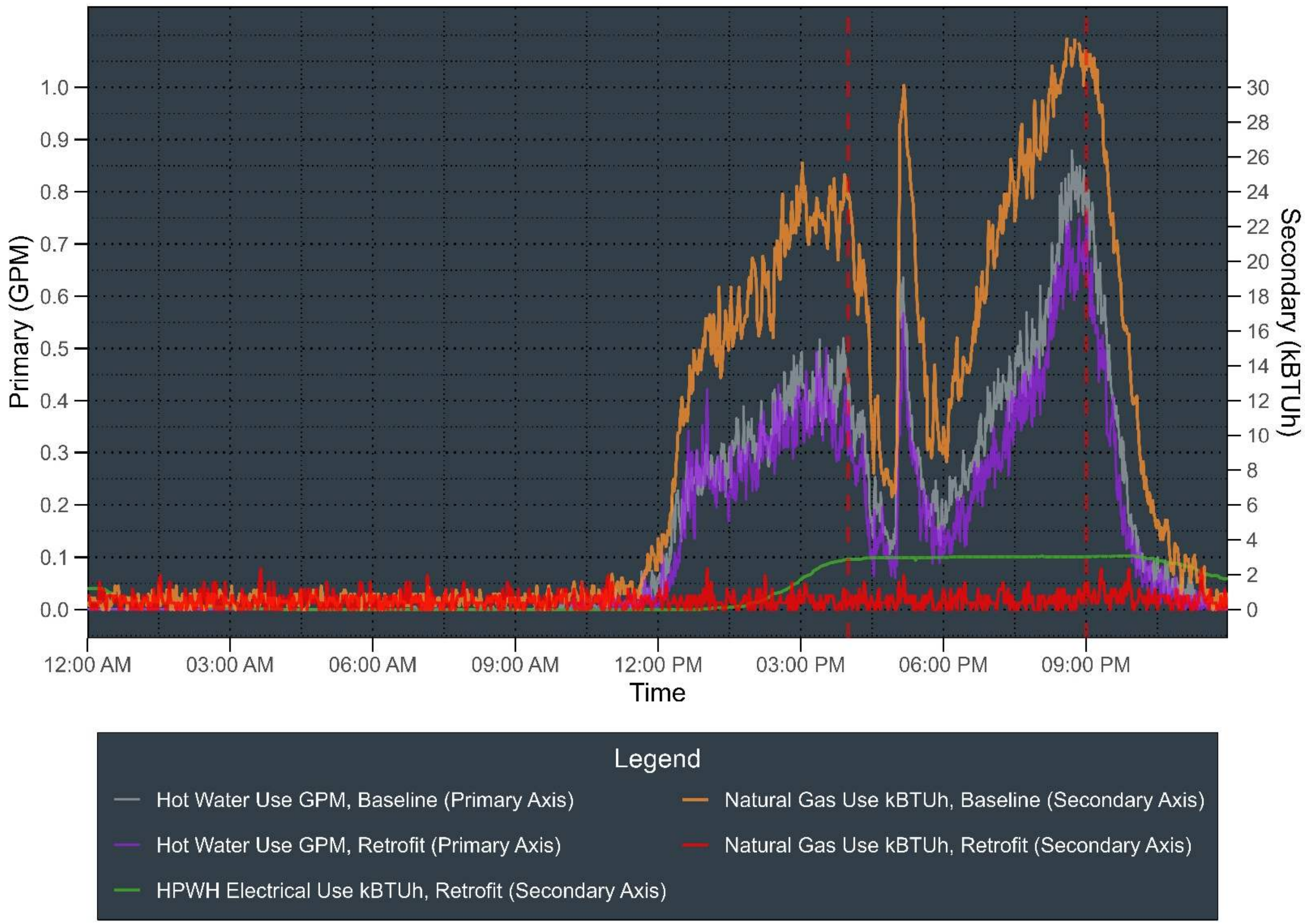


Figure 12: Average daily hot water flow and water heating system energy inputs baseline and post-retrofit.

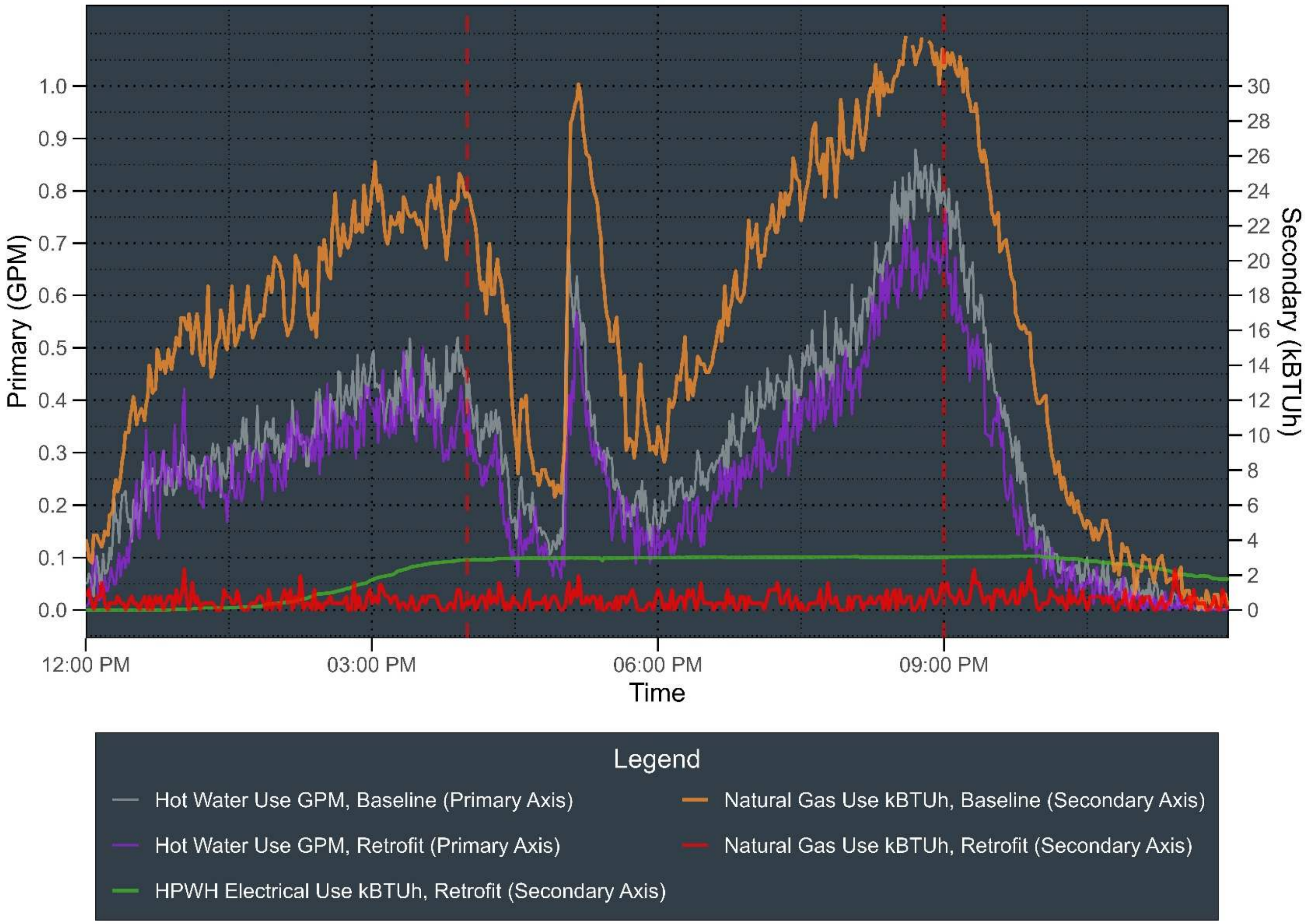


Figure 13: Average daily operational period hot water flow and water heating system energy inputs baseline and post-retrofit.

The HPWH and natural gas water heater system performance is independently summarized in Table 10, Table 11, and Table 12, characterized by baseline versus post-retrofit for days when the restaurant was closed, as well as by day of the week. Average values are the arithmetic mean of all days in the sample period unless otherwise indicated. The restaurant is defined as closed when there were zero covers, and open when there were covers, with the restaurant open about 70 percent of the observed days for both the baseline and post-retrofit periods. Even when the restaurant was closed, there were days when hot water use was non-zero, indicating some level of food preparation or heavy kitchen sanitization on closed days.

The post-retrofit HPWH COP was calculated to be 4.1 for days when the restaurant was open. The mean and median COP values for Sunday and Monday were outside of the typically expected range of 1 to 5—due to both very low hot water and energy consumption—and can be ignored. For open days, the HPWH covered nearly 95 percent of the total hot water energy consumption, on average.

The existing natural gas water heater efficiency was calculated as 72 percent when the restaurant was open during the baseline period, with a much lower efficiency when the restaurant was closed due to thermal losses. Calculating post-retrofit efficiency of the natural gas water system proved challenging due to a higher tank inlet temperature than tank outlet temperature; therefore, the numbers presented should only be compared to the other post-retrofit numbers. This resulted from high temperature HPWH water entering the existing natural gas water heater and mixing down with lower temperature water in the tank. Note that the natural gas water heater had a pilot light that consumed gas and got registered as a “cycle” between 10 and 14 times a day if there was no full fire cycle, which was a result of the natural gas meter’s resolution. Days with this number of “cycles” should be considered as standby pilot natural gas consumption only.

Table 10: Baseline and post-water heater system energy performance characterized by operational status.

Restaurant Operation	Units	Open (Pre)	Open (Post)	Closed (Pre)	Closed (Post)
Number of Days	Days	168	97	72	42
Average Number of Covers	Covers/Day	24.0	22.4	0.00	0.00
Average Outdoor Wet Bulb Temperature	°F	49.7	55.2	50.0	55.4
Average Hot Water Demand	Gallons/Day	230	188	6	4
Average Hot Water Per Cover	Gallons/Daily Covers	10.81	9.33	NA	NA
Max Hot Water Demand	Gallons/Day	334	285	91	41

Restaurant Operation	Units	Open (Pre)	Open (Post)	Closed (Pre)	Closed (Post)
Min Hot Water Demand	Gallons/Day	68	115	0	0
Average Mass Weighted Hot Water Supply Temperature	°F	137.4	135.6	105.0	115.3
Average Mass Weighted Cold Water Mains Temperature	°F	59.2	66.8	65.9	66.8
Average Natural Gas Energy Input	kBtu/day	207	12	19	12
Average HPWH Energy Input	kWh/day	NA	8.2	NA	0.8
Average Natural Gas Water Heater Cycles	Cycles/Day	49	11	14	11
Average HPWH Cycles	Cycles/Day	NA	2	NA	0
Average Natural Gas Energy Input per Cycle	kBtu/Cycle	4.3	1.1	1.4	1.0
Average Natural Gas Water Heater Efficiency	%	72.0	92.9	6.0	11.6
Average HPWH Efficiency	COP	NA	4.1	NA	190.4
Median HPWH Efficiency	COP	NA	4.1	NA	2.7
Average Percent of Hot Water Energy Supplied by HPWH	%	NA	94.5	NA	10.5

Restaurant Operation	Units	Open (Pre)	Open (Post)	Closed (Pre)	Closed (Post)
Average Percent Hot Water Used by Dish Machine	%	26.3	29.8	1.7	0

Table 11 and Table 12 provide additional useful context by presenting data for each day of the week. For example, the water heater efficiency was consistent in the baseline among the open days, which increases confidence in the calculated efficiency. Additionally, Table 11 shows that Friday and Saturday were the days of highest hot water use. In the baseline period, the research team observed that the original gas water heater was undersized, and the average hot water supply temperature dropped by about 2.5°F on Saturday, the day of highest hot water use, indicating increased hot water runout as the restaurant used more hot water.

Table 11: Baseline water heater system energy performance characterized by day of week.

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Typical Operation	Open/Closed	Closed	Closed	Open	Open	Open	Open	Open
Number of Days	Days	35	34	34	34	34	34	35
Number of Open Days	Days	6	1	33	29	33	33	33
Average Number of Covers	Covers/Day	2	0	21	17	18	28	31
Average Outdoor Wet Bulb Temperature	°F	50.2	50.1	49.4	49.0	50.0	50.1	49.7
Average Hot Water Demand	Gallons/Day	15	12	214	185	198	252	267
Average Hot Water Per Cover	Gallons/Daily Covers	7.5	12.4	11.6	12.3	12.6	9.4	9.0
Max Hot Water Demand	Gallons/Day	105	149	274	263	268	321	334
Min Hot Water Demand	Gallons/Day	0	0	0	0	0	83	0

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average Mass Weighted Hot Water Supply Temperature	°F	106.7	106.6	137.6	134.5	137.5	137.2	134.2
Average Mass Weighted Cold Water Mains Temperature	°F	65.4	67.3	59.4	59.3	59.2	58.6	59.1
Average Natural Gas Energy Input	kBtu/day	25	24	198	170	183	226	232
Average Natural Gas Water Heater Cycles	Cycles/Day	15	15	49	44	46	51	48
Average Natural Gas Energy Input per Cycle	kBtu/Cycle	1.7	1.6	4.0	3.9	4.0	4.4	4.9
Average Natural Gas Water Heater Efficiency	%	12.2	9.6	69.4	64.0	69.6	73.0	70.3
Average Percent Hot Water Used by Dish Machine	%	5.8	2.4	25.1	22.7	25.6	26.7	24.3

Table 12: Post-Retrofit Water Heater System Energy Performance Characterized by Day of Week

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Number of Days	Days	20	19	20	20	20	20	20
Number of Open Days	Days	0	1	20	19	19	19	19
Average Number of Covers	Covers/Day	0	2	21	16	21	22	27
Average Outdoor Wet Bulb Temperature	°F	54.9	55.5	55.3	55.2	55.2	55.2	55.2
Average Hot Water Demand	Gallons/Day	0	18	173	167	169	186	206
Average Hot Water Per Cover	Gallons/Daily Covers	0	6.9	9.4	11.8	8.7	9.2	7.7
Max Hot Water Demand	Gallons/Day	10	200	236	244	243	267	285
Min Hot Water Demand	Gallons/Day	0	0	115	0	31	0	0
Average Mass Weighted Hot Water Supply Temperature	°F	112.4	119.2	133.3	134.6	135.6	135.1	135.5

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average Mass Weighted Cold Water Mains Temperature	°F	64.3	70.0	66.8	66.6	67.3	66.6	66.0
Average Natural Gas Energy Input	kBtu/day	12	12	12	12	12	12	14
Average HPWH Energy Input	kWh/day	1.3	0.7	8.1	7.6	7.3	8.0	8.4
Average Natural Gas Water Heater Cycles	Cycles/Day	11	12	11	11	11	11	12
Average HPWH Cycles	Cycles/Day	0	0	2	2	2	2	2
Average Natural Gas Energy Input per Cycle	kBtu/Cycle	1.0	1.0	1.1	1.0	1.0	1.1	1.2
Average Natural Gas Water Heater Efficiency	%	2.7	23.8	92.0	87.9	91.7	88.8	89.2
Average HPWH Efficiency	COP	2.0	420.2	3.7	3.8	4.3	4.4	4.2
Median HPWH Efficiency	COP	0.0	13.1	3.6	4.0	4.2	4.1	4.4

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average Percent of Hot Water Energy Supplied by HPWH	%	2.7	21.8	94.2	89.7	93.2	90.1	90.1
Average Percent Hot Water Used by Dish Machine	%	0	0	29.9	28.2	28.1	28.5	28.1

To take a closer look at baseline and retrofit system performance, the team selected the day from the post-retrofit period with the highest hot water usage over the day, which was 284 gallons, and selected the day in the baseline period that had the closest daily water use—also 284 gallons. The data from these two days is plotted in Figure 14 and Figure 15. It is clear from Figure 14 that water use and water use profile had a similar baseline to post-retrofit; however, the temperatures deviated. In the post-retrofit period, shown via the red line, the supplied hot water temperature was very well maintained throughout the day, even during the peak hot water demand period starting just after 9:00 p.m. This anticipated result is attributed to the overall added heating capacity and storage that resulted from installing the HPWH and storage tank.

During the baseline period, the supplied hot water temperature, shown via green line, was not well maintained, falling to roughly 110°F during peak demand due to a runout event. In the post-retrofit period, the HPWH storage tank outlet temperature—shown via yellow line—began to drop as the HPWH experienced a similar hot water runout event, which required heating input from the natural gas-fired water heater to maintain appropriate hot water supply temperatures. Figure 15 illustrates the corresponding increase in natural gas consumption, shown via the purple line, during this period.

The selected site closed at 8:00 p.m. on all its open days, with patrons likely fully vacated by 9:00 p.m., meaning that the observed hot water runouts occurred during post-service cleaning operations. Additionally, the selected days were at the upper limit of hot water demand and hot water runouts were limited, allowing the HPWH to typically cover the entire load.

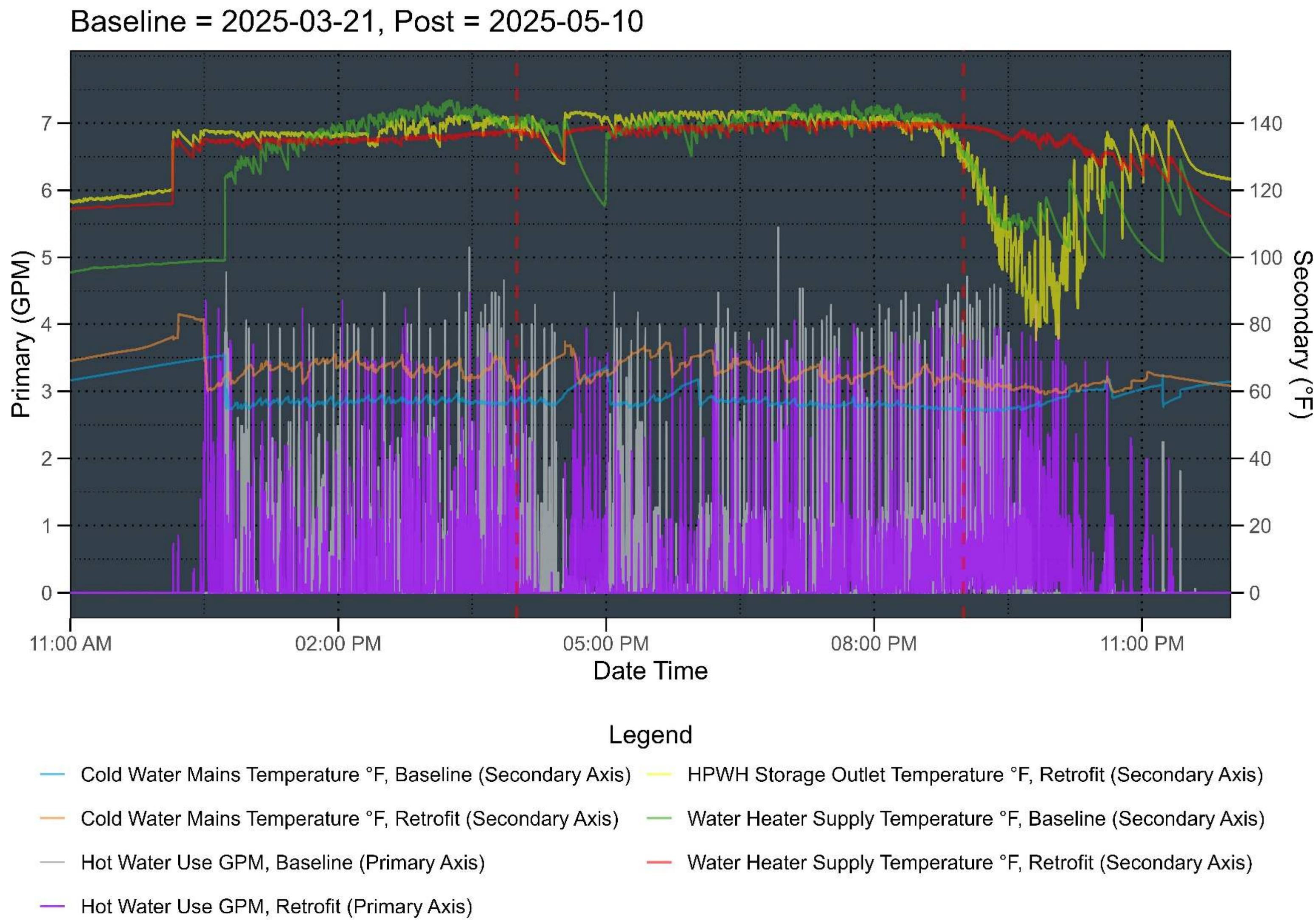


Figure 14: Representative days of HPaWH system temperatures and flows.

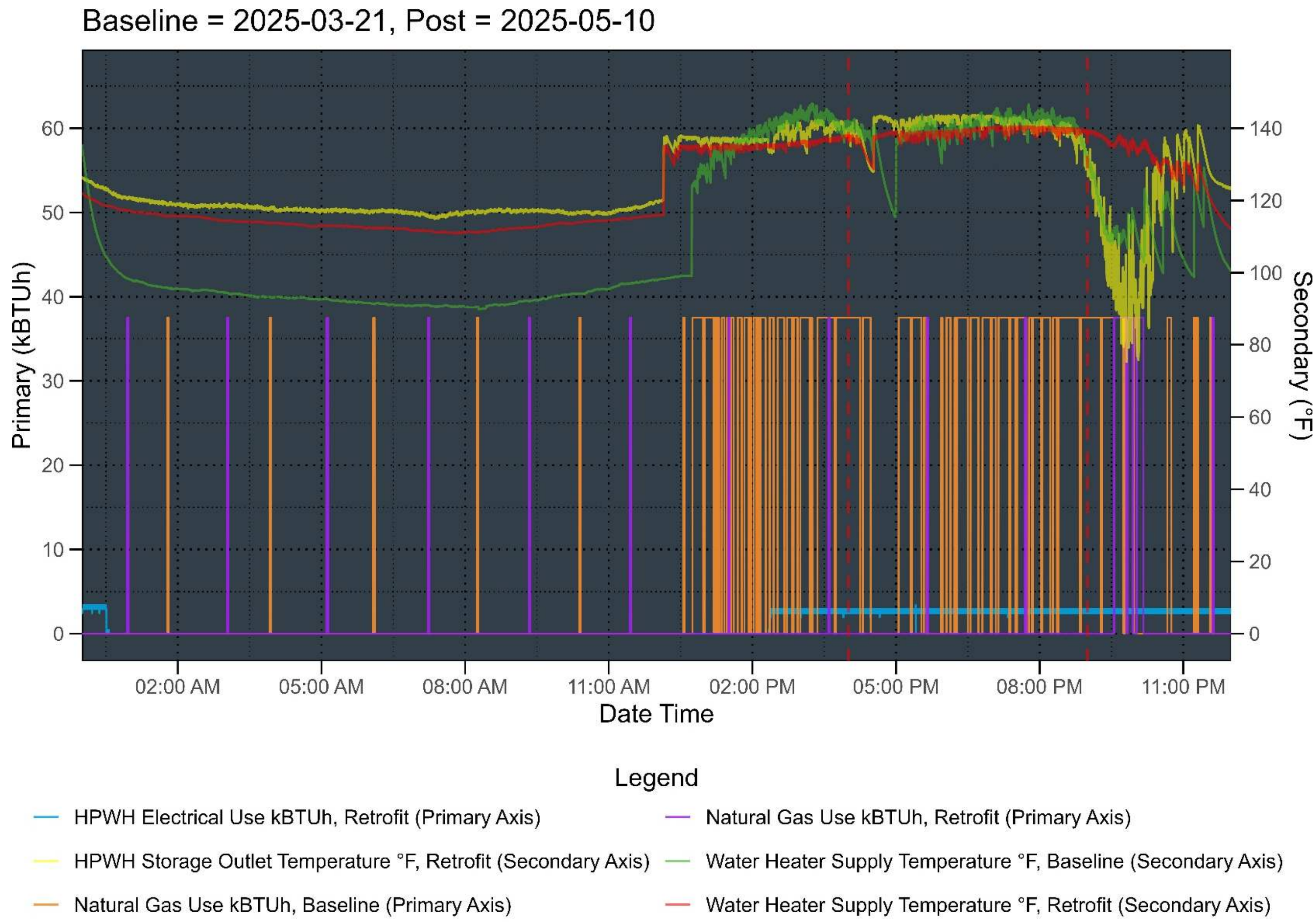


Figure 15: Representative days of HPaWH system temperatures and energy inputs.

Note that in Figure 15, the team converted HPWH energy input to kBtuh to allow for a better comparison to the existing natural gas water heater.

Dish Machine Operation

Although the dish machine could not be replaced as an energy savings measure as planned, it is still important to characterize the existing dish machine's energy consumption and its hot water consumption, as well as its relation to the water heating system.

Table 13 shows that overall operation and performance remained consistent between the two periods across all variables, with only slight changes due to supplied water temperatures.

For context, the average daily electrical energy consumption of the HPWH was 9.1 kWh on days that the restaurant was open, while the dish machine consumes an average of 19.8 kWh of electrical energy. This equates to over twice as much energy as the HPWH consumes, while the dish machine only consumes about one quarter of the total hot water—indicating that dish machine efficiency measures may be more beneficial than load shifting the HPWH.

Table 13: Baseline and post-HPWH installation dish machine energy performance characterized by operational status.

Restaurant Operation	Units	Open (Pre)	Open (Post)	Closed (Pre)	Closed (Post)
Number of Days	Days	168	97	72	42
Average Number of Covers	Covers/Day	24.0	22.4	0.0	0.0
Days With No Dish Machine Use	Days	0	0	68	37
Average Hot Water Demand In	Gallons/Day	60	56	0	0
Average Hot Water Per Cover	Gallons/Daily Covers	2.8	2.8	0	0
Max Hot Water Demand In	Gallons/Day	95	79	30	12
Min Hot Water Demand In	Gallons/Day	23	32	0	0
Average Mass Weighted Water In Temperature	°F	128.8	127.4	120.0	118.4

Restaurant Operation	Units	Open (Pre)	Open (Post)	Closed (Pre)	Closed (Post)
Average Mass Weighted Rinse Water Temperature	°F	171.3	174.3	154.5	131.8
Average Mass Weighted Tank Water Temperature	°F	132.7	133.9	NA	106.5
Average Energy Consumption	kWh/day	19.4	18.8	0.7	0.7
Average Dish Machine Energy Cost	$/Day	8.6	9.8	0.3	0.4
Average Dish Machine Cycles	Racks/Day	78	79	2	2

Table 14: Baseline dish machine energy performance characterized by day of week.

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Typical Operation	Open/Closed	Closed	Closed	Open	Open	Open	Open	Open
Number of Days	Days	35	34	34	34	34	34	35
Number of Open Days	Days	6	1	33	29	33	33	33
Average Number of Covers	Covers/Day	2	0	21	17	18	28	31
Days With No Dish Machine Use	Days	29	31	1	4	1	0	2
Average Hot Water Demand In	Gallons/Day	5	2	55	47	52	67	69
Average Hot Water Per Cover	Gallons/Daily Covers	2.5	2.8	3.0	3.2	3.4	2.5	2.3
Max Hot Water Demand In	Gallons/Day	36	33	86	72	74	92	95

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Min Hot Water Demand In	Gallons/Day	0	0	0	0	0	30	0
Average Mass Weighted Water In Temperature	°F	125.0	118.6	129.0	129.2	128.7	129.0	128.8
Average Mass Weighted Rinse Water Temperature	°F	158.4	150.1	174.2	168.5	170.4	174.2	171.3
Average Mass Weighted Tank Water Temperature	°F	131.4	NA	134.3	131.6	132.4	132.5	132.8
Average Energy Consumption	kWh/day	1.8	1.2	18.5	15.9	17.4	21.0	20.8
Average Dish Machine Energy Cost	$/Day	0.7	0.5	8.2	7.2	7.8	9.3	9.3
Average Dish Machine Cycles	Cycles/Day	6	3	71	61	66	88	91

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average Water Use Per Cycle	Gallons/Cycle	0.7	0.6	0.8	0.8	0.8	0.8	0.8

Table 15: Post-retrofit dish machine energy performance characterized by day of week.

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Typical Operation	Open/Closed	Closed	Closed	Open	Open	Open	Open	Open
Number of Days	Days	20	19	20	20	20	20	20
Number of Open Days	Days	0	1	20	19	19	19	19
Average Number of Covers	Covers/Day	0	2	21	16	21	22	27
Days With No Dish Machine Use	Days	19	14	0	1	1	1	1
Average Hot Water Demand In	Gallons/Day	0	5	52	50	49	55	60
Average Hot Water Per Cover	Gallons/Daily Covers	NA	2.2	2.8	3.5	2.6	2.7	2.3
Max Hot Water Demand In	Gallons/Day	8	63	68	71	64	71	79

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Min Hot Water Demand In	Gallons/Day	0	0	34	0	0	0	0
Average Mass Weighted Water In Temperature	°F	119.1	119.5	125.4	127.5	127.2	128.3	129.1
Average Mass Weighted Rinse Water Temperature	°F	125.4	140.4	178.5	176.1	175.4	171.5	169.9
Average Mass Weighted Tank Water Temperature	°F	93.7	114.2	135.1	133.4	133.5	134.6	133.0
Average Energy Consumption	kWh/day	0.2	2.4	18.2	17.0	17.3	18.5	19.3
Average Dish Machine Energy Cost	$/Day	0.1	1.3	9.7	8.9	9.2	9.6	9.9
Average Dish Machine Cycles	Cycles/Day	1	8	75	70	69	79	86

Parameter	Units	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Average Water Use Per Cycle	Gallons/Cycle	0.3	0.7	0.7	0.7	0.7	0.7	0.7

Figure 16 presents dish machine operation as the average of all open days disaggregated by the baseline and post-retrofit periods, highlighting any changes between the periods. In addition to dish machine operation data, the figure also shows the water heating system supply temperature. As already established, there is a significant difference in the water heating supply temperature between the baseline and the post-retrofit periods starting just before 9:00 p.m. This can be seen to a slightly lesser extent at the dish machine inlet temperature, indicating a slight improvement. The dish machine rinse temperature was typically consistent during this time, indicating that the dish machine was usually able to maintain sufficient sanitation temperatures despite the difference in incoming hot water temperature. There was very little variation in water and electrical use patterns or magnitudes.

Figure 16 also illustrates a consistent minimum of roughly 720 watts during the restaurant's operational period, which is due to the wash heater. The team suspects that much of this energy is lost to the ambient kitchen air and could pose a significant opportunity for energy savings. Though there did not appear to be large impacts to the kitchen's ambient air temperature from the waste heat—likely because of high ventilation rates—there may still be some potential for improved employee comfort near the dish machine if the wash heater was better controlled.

Note: All values in Figure 16 are the arithmetic means of the data at the corresponding timestamp. The vertical dashed red lines indicate the on-peak time of use tariff period from 4:00 p.m. to 9:00 p.m.

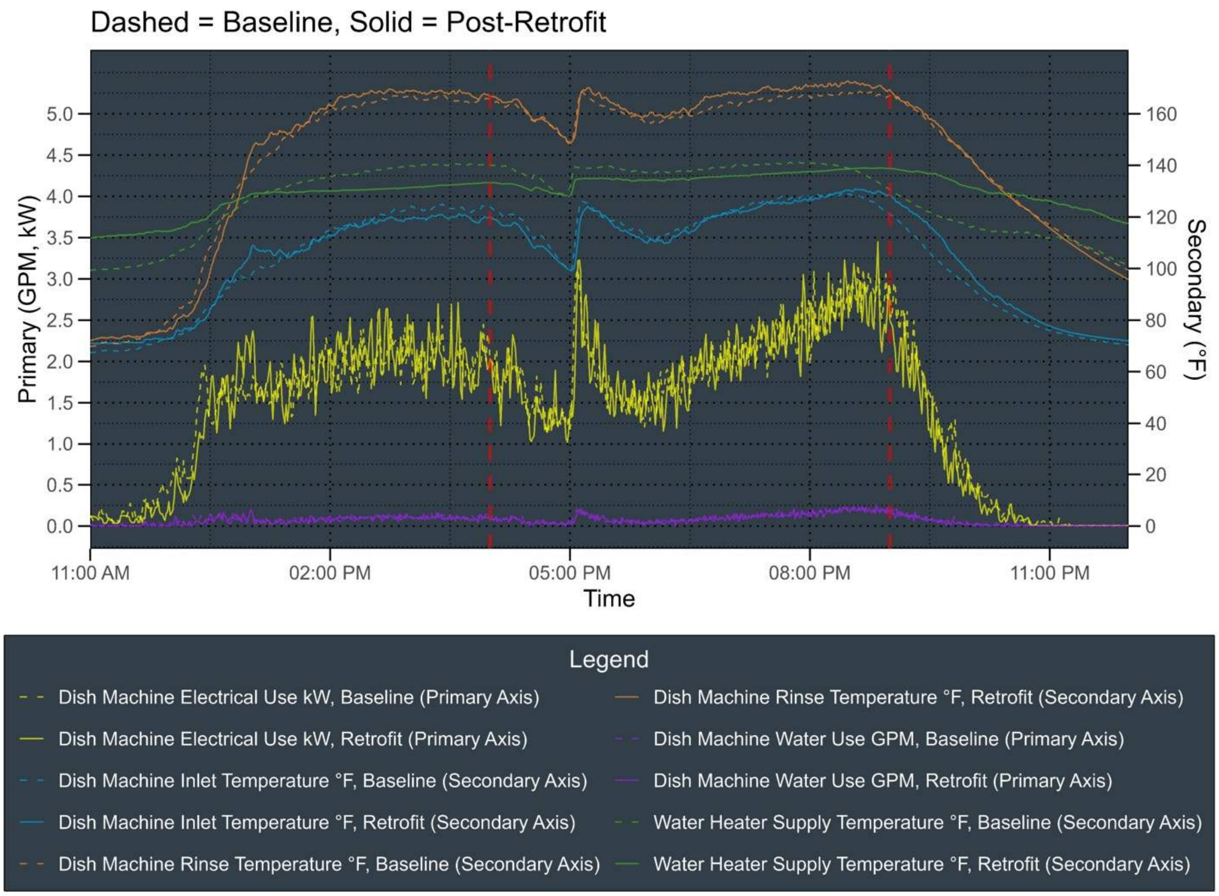


Figure 16: Average daily dish machine operation during baseline and post-retrofit.

Figure 17 illustrates typical dish machine operation by selecting a baseline day with an average number of covers—in this case, November 1, 2024. The figure shows that the lowest dish machine power was 720 watts; based on the component power specifications previously shown in Table 4, the research team deduced that the wash heater was on during the entire operational period each day that the restaurant was open. The research team confirmed with the site that the staff turned the dish machine on manually each morning and then left it on all day to avoid heat-up delays. The team also confirmed that the door was typically left open, allowing the heat to dissipate without overheating the dish machine. The data show that the dish machine power was zero outside of operating hours, which the research team found to be unexpected; we believe this may present an opportunity to reduce daily dish machine energy use by up to 7 kWh, which is more than one-third of the average energy use associated with the dish machine.

After the initial fill, the power spiked to about 8,300 watts, which is higher than the rated power, but which the research team inferred was due to the wash heater and rinse heater operating at the same time. The wash heater remained on for the entire shift, while the rinse heater activated again 20 minutes after the fill operation.

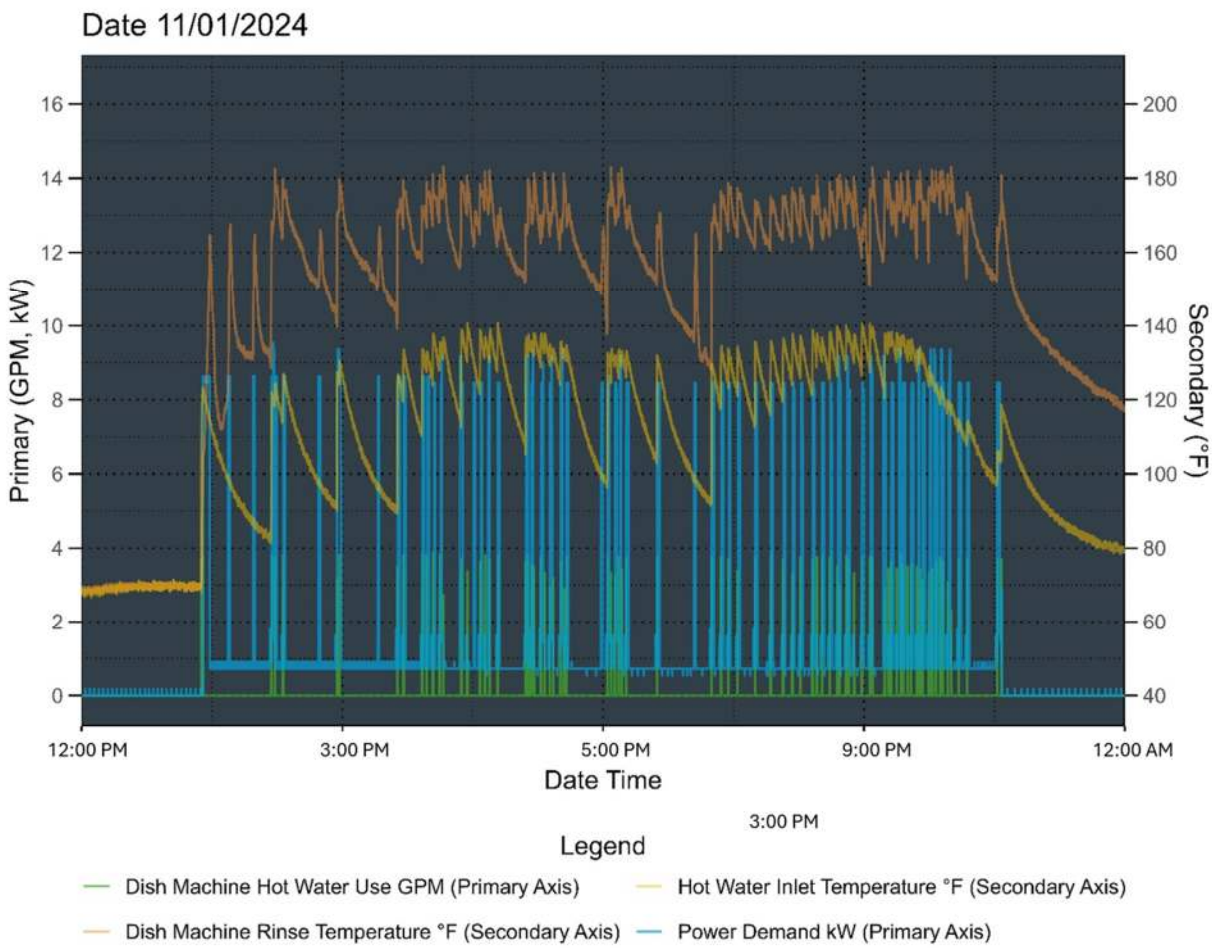


Figure 17: Representative day dish machine operation.

Figure 18 shows the relationship of the dish machine energy consumption to hot water consumption over the entire monitoring period. There is a strong linear relationship, with an R-squared value of 0.99, a y-intercept of 0.85, and a slope of 0.31. This shows that there was almost a 1 kWh average base use and a cluster around 20 kWh, indicating high savings potential.

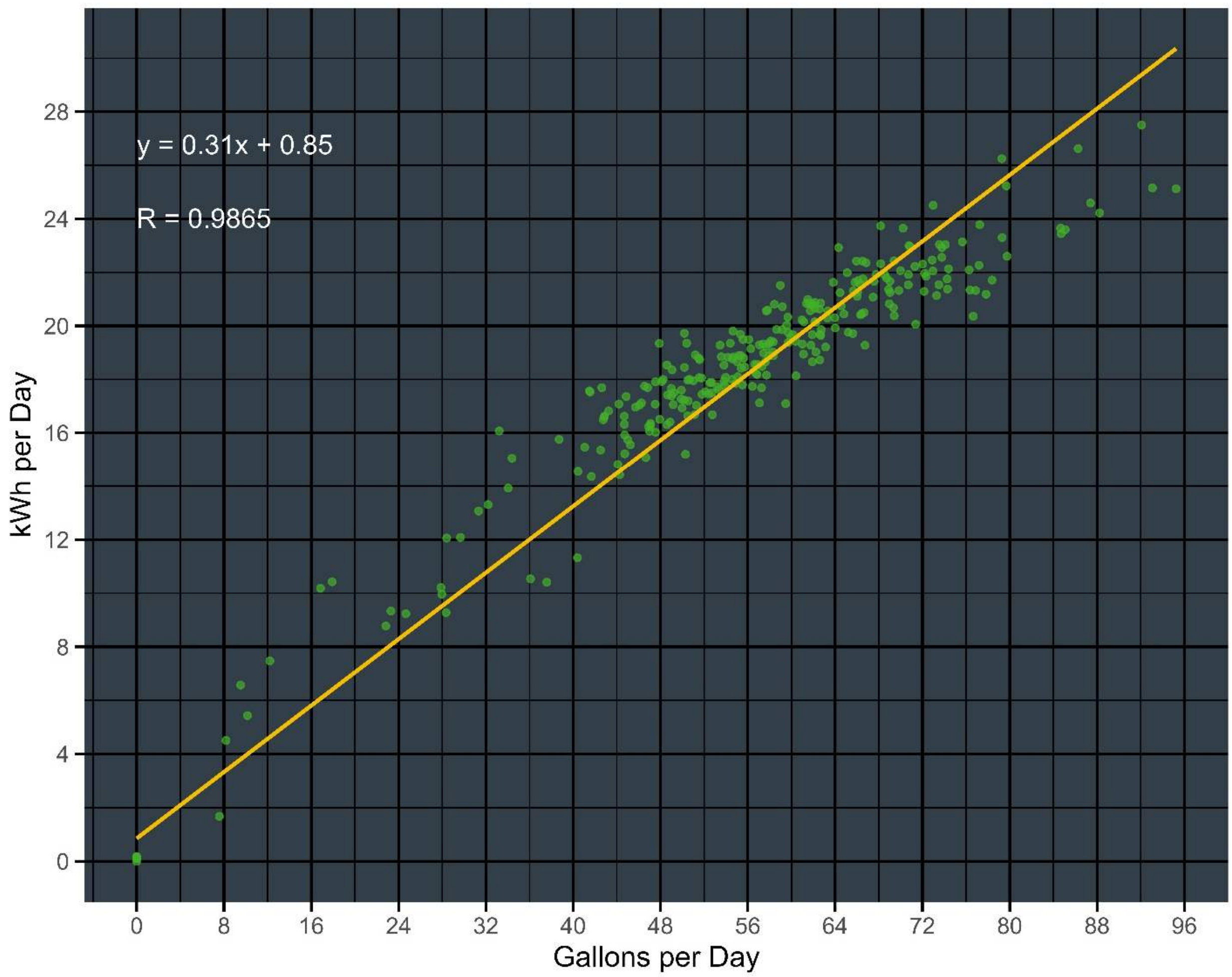


Figure 18: Dish machine daily energy use as a function of daily hot water consumption for open days.

Water Heating Savings Results

Table 16 and Table 17 present the average energy and cost savings of the post-retrofit HPaWH system. The team calculated the results using daily hot water use as the independent variable; we used the linear model outlined in Table 8 and Table 9 to calculate the counterfactual baseline as presented in Table 16 and illustrated in Figure 19. HPWH energy and the minimal post-retrofit natural gas use of the existing water heater were subtracted from the counterfactual baseline for energy savings, where positive values represent savings and negative values represent an overall increase.

Negative energy savings were seen on days with little to no hot water demand, likely resulting from HPWH standby power and/or an imperfect model fit. Overall energy savings were positive, which indicates substantial potential in the market for energy use and greenhouse gas reduction.

The team calculated cost savings using the utility cost data presented in Table 7 and the methods outlined in Analysis Methodology. Despite overall energy savings, there was an overall energy cost increase from baseline to post-retrofit period of $0.96 on open days and a savings of $0.34 per closed day. This equates to about $215 per year increase, or roughly 1 percent of the site's annual energy costs.

Table 16: Average water heating energy and cost savings and modeling results by restaurant operation.

	Units	Open	Closed
Average Energy Savings	**kBtu/day**	**131.00**	**2.97**
Min Energy Savings	kBtu/day	79.20	-8.87
Max Energy Savings	kBtu/day	194.52	29.18
Average Counterfactual Baseline	kBtu/day	171.30	17.55
Average HPWH Energy Cost	$/Day	4.18	0.19
Average Percent Electricity During Peak-Period	%	64.50	55.24
Average Peak-Period Electricity Cost	$/Day	2.70	0.05
Average Natural Gas Water Heater Cost	%	0.23	0.22
Average Cost Savings	**$/Day**	**-0.96**	**0.34**

Table 17: Average water heating energy and cost savings and modeling results by day of the week.

	Units	Sunday	Monday	Tuesday	Thursday	Friday	Saturday
Typical Operation	Open/Closed	Closed	Closed	Open	Open	Open	Open
Average Energy Savings	kBtu/day	-1.6	14.4	119.6	116.4	118.6	130.3
Min Energy Savings	kBtu/day	-8.9	1.6	79.2	-0.6	25.7	2.6
Max Energy Savings	kBtu/day	5.0	143.4	163.7	170.8	173.7	177.3
Average Counterfactual Baseline	kBtu/day	14.5	28.8	159.2	154.4	155.6	169.8
Average HPWH Cost	$/Day	0.2	0.3	4.3	3.9	3.8	4.0
Average Percent Electricity During Peak-Period	%	30.2	84.3	62.6	64.3	64.4	66.0
Average Peak-Period Electricity Cost	$/Day	0.0	0.2	2.7	2.6	2.6	2.6
Average Natural Gas Water Heater Cost Baseline	%	0.2	0.2	0.2	0.2	0.2	0.2
Average Cost Savings	$/Day	0.3	0.4	-1.0	-0.7	-0.7	-0.6

Figure 19 illustrates the characterized baseline and retrofit system energy performance over the entire monitoring period. The figure demonstrates that energy use can be characterized as a linear function, with flow as the independent variable for both the baseline and retrofit systems, further supporting using water flow for modeling. The y-intercept of the characterized linear performance model is non-zero but low, at 14.03 kBtu per day for the baseline and only 0.76 kWh per day (or 2.6 kBtu per day) for the post-retrofit HPWH. This aligns with expectations for standby thermal losses to the ambient environment on days with no hot water demand for a system without recirculation.

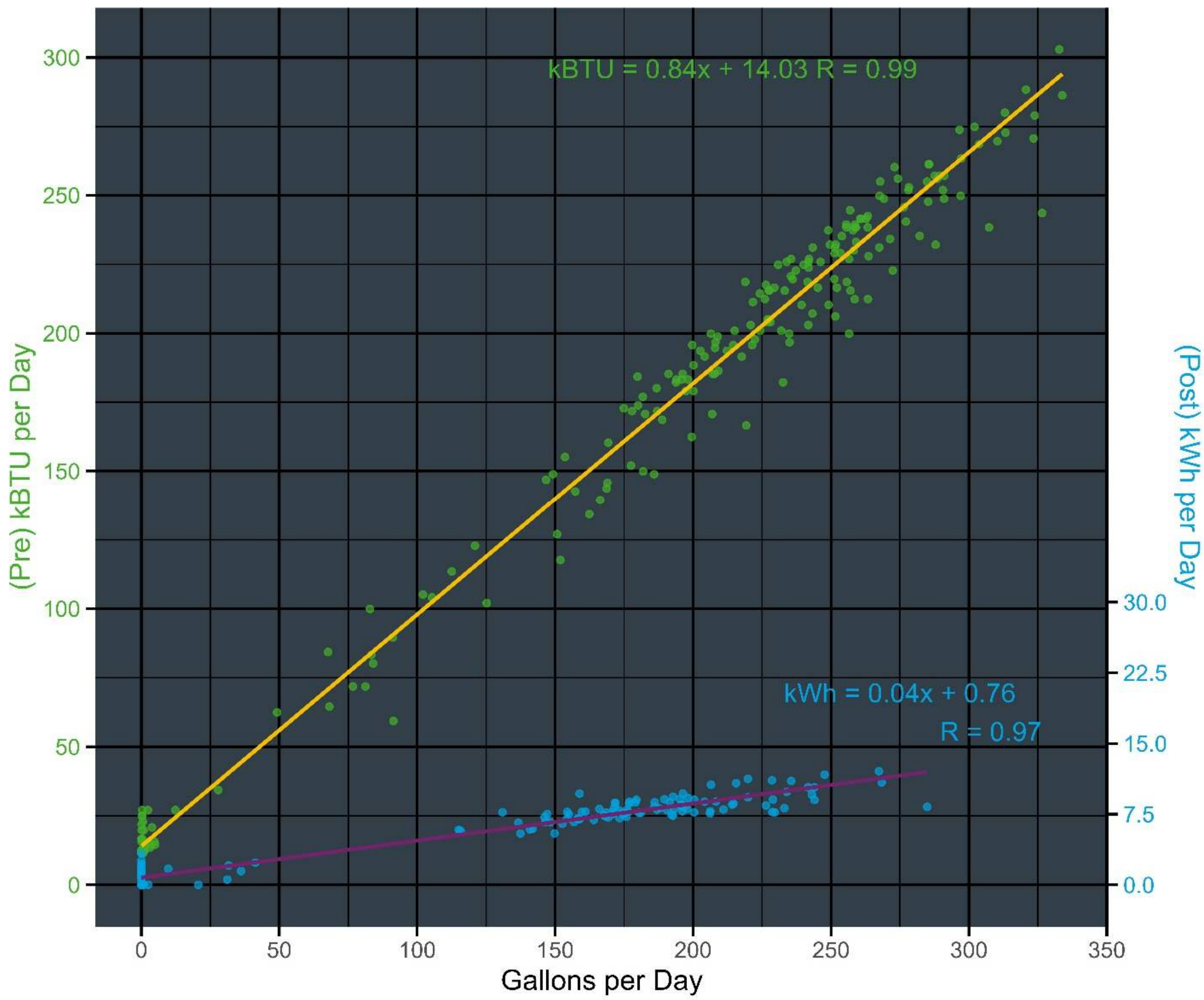


Figure 19: Daily hot water use vs. daily natural gas and electrical energy use during the pre- and post-periods

Note: The secondary axis is scaled to the primary axis using the conversion of kWh to kBtu of 3.412. Additionally, although there is some natural gas usage in the post period, this data was removed from the plot and fit statistics as it largely represents a horizontal line at the baseline y-intercept.

Load Shifting Potential

The final installed 83-gallon storage volume was much lower than the originally intended 186 gallons, which great diminished the potential for load shifting. To estimate the load shifting potential, it is important to note that the heat pump is deactivated when hot water in the tank is heated. Warm water reaches the lower cold water heat pump port and travels to the heat pump inlet, where the temperature sensor is located. Because there is no recirculation system and the tank geometry is a simple cylinder, the useful volume of the tank can be calculated based on the lower port height of 8.75 inches versus total tank height of 60.87 inches.

The team calculated the useful tank volume as 85 percent of the total volume of 83 gallons, which translates to about 70 gallons. Assuming the unit activated at 2:00 p.m. and operated through the 4:00 p.m. to 9:00 p.m. peak period, the maximum hot water generated at 20 gallons of hot water generated per hour was 140 gallons, with 210 gallons available in total. The heat pump covered a majority of the hot water load on an average day of about 200 gallons, but the unit had to operate during most of the peak period, thus eliminating the load shift potential.

While the team could not install additional storage volume, if another tank was used in series with an additional 83 gallons of usable storage volume, then there would be potential to shift five hours of the heat pump operating time during the peak period. If there was room to install two 120-gallon storage tanks in series, then the system would be capable of fully load shifting the primary heat pump system on most operating days.

Using the values from Table 7, Table 18 presents the estimated load shifting potential if adequate storage had been installed, which equates to about $200 annually. With a single 83-gallon SanCo2 storage tank retailing for roughly $3,000 with tax, the return on investment—ignoring controls implementation, installation labor, and additional plumbing hardware—would be about 15 years. If all these additional costs were included, the return on investment could reach upwards of 25 years.

Table 18: Load shifting potential by season and operation.

Restaurant Operation	Units	Open	Open	Closed	Closed
Season	Summer/Winter	Summer	Winter	Summer	Winter
Actual Energy Cost	$/Day	4.35	3.71	0.18	0.26
Cost if Load Shifted	$/Day	3.23	3.47	0.16	0.26
Load Shifting Savings	$/Day	1.12	0.24	0.02	0

Hot Water Savings Measure Analysis

The team was able to replace the shower head style pre-rinse sprayer at the site, bringing the fixtures flow rate from 1.5 GPM to 0.75 GPM on June 9, 2025. Table 19 presents water use for days when the site was open and had at least one cover, normalized by the number of covers. The hot water use per cover during the baseline was greatest, while after the low flow pre-rinse sprayer installation, water use was 1.6 gallons less per cover. Interestingly, after the HPWH was installed, but before the low flow pre-rinse sprayer was installed, there was also a water use reduction despite the dish machine use per cover remaining consistent across all three periods. Based on the data, it is likely that the installation of the low-flow pre-rinse spray nozzle reduced the site's hot water consumption to a measurable degree; however, there may also be other factors that the team is unable to account for.

Table 19: Water saving measure impacts for open days.

Restaurant Operation	Units	Baseline	Post HPWH, Pre Spray	Post Spray
Number of Days	Days	168	30	67
Average WH Hot Water Per Cover	Gallons/Cover/Day	10.8	9.9	9.1
Average DM Hot Water Per Cover	Days	2.8	2.8	2.7

Conclusion and Recommendations

The heat pump assist water heating (HPaWH) system demonstrates significant promise for restaurant applications, offering a pathway to decarbonize water heating while maintaining operational reliability. This study confirms that integrating a heat pump water heater (HPWH) with an existing natural gas system can deliver substantial energy savings, improved temperature stability, and only modest impacts on overall energy costs—even under higher electricity rates—thanks to the selected system's high coefficient of performance (COP) of 4.1.

This system nearly matched baseline energy costs and improved the baseline natural gas system hot water delivery temperatures. Larger facilities with a higher hot water load and room for additional storage stand to benefit even more, particularly when additional energy efficiency, load shifting, and demand reduction measures can be added to the retrofit.

The study highlighted several challenges that must be addressed for broader adoption. These include space constraints, extended permitting review timelines, and structural assessments that delayed installation. Streamlining permitting processes and offering clear technical guidance would help reduce these barriers.

The project illustrates the need to improve cost-effectiveness through complementary energy efficiency measures. High-efficiency heat recovery dish machines and recirculation loop controls offer practical ways to reduce overall energy use. Notably, the existing dish machine at the study site consumed more energy than the HPWH system, highlighting the importance of targeting other pieces of energy-intensive equipment in addition to reducing HPWH energy demand. On-site photovoltaic generation and battery storage may also help reduce HPWH operational costs.

To support adoption, targeted incentives will be necessary. These should prioritize sites that:

- have adequate space for heat pumps and storage tanks.
- do not require structural upgrades.
- have sufficient electrical capacity.
- can bundle additional efficiency, generation, and energy storage measures into the project.

In summary, the HPaWH method is a viable and effective decarbonization strategy for the food service sector. When paired with appropriate design, permitting support, and complementary efficiency upgrades, it can significantly reduce greenhouse gas emissions and improve system performance. Future deployment should focus on sites best positioned to benefit from the technology while encouraging policy and programmatic support to overcome current market barriers.

References

CalNEXT. 2023. "Market Potential for Heat Pump Assisted Hot Water Systems in Foodservice Facilities."

United States Geological Survey. 2024. *Water Density.* Accessed 2024. https://www.usgs.gov/special-topics/water-science-school/science/water-density.

Appendix A: Permit Application Process Summary

The permit application process for installing a heat pump water heater and storage tank at the selected restaurant—a two-story converted house located in San Mateo, California—progressed through multiple stages, as outlined below.

Initial Submission (Early November 2024)

Frontier Energy submitted an over-the-counter (OTC) permit application to the City of San Mateo, proposing a heat pump water heater split system to be installed in the selected site's second story attic, with the storage tank located adjacent to the existing gas water heater and the heat pump located on the attic balcony. The application included the filled-out building permit form and specification sheets for the heat pump and 83-gallon storage tank.

The City of San Mateo reviewed the application and provided the following comments:

- **Floor Plans and Framing Details:** Drawings of the floor plan and site plan, as well as framing details for the floor where the appliances would rest, were required.
- **Structural Calculations:** Due to the weight of the proposed storage tank (greater than 400 pounds), structural engineering calculations would have to be provided to show that the floor framing could adequately bear the extra loading.
- **Electrical Specifications:** Include the receptacle, main panel location, new breakers or disconnects, and service clearance space, per manufacturer specifications.
- **Seismic Anchorage:** If the operating weight exceeded 400 pounds, seismic anchoring requirements per California Building Code 1617A would need to be included, along with structural calculations.
- **Energy Forms:** Required submission of Nonresidential Certificates of Compliance (NRCC) energy forms from the California Energy Commission (CEC) website.

The application was subsequently canceled on November 15, 2024, as it did not qualify for OTC review.

Second Submission (November 21, 2024)

The team submitted a new application with included site plans, revising the proposed location to install the heat pump outside the building on the ground. The city provided comments on November 26, 2024, highlighting the following requirements:

- **Plan Set:** Combine all plan sheets into a single file signed by the designer, with a cover sheet including the building address and project information.
- **Site Plan and Elevation:** Provide a detailed site plan and elevation showing the exact location of the heat pump and water meter. Clarify whether the heat pump will be installed outdoors and whether it will have an enclosure or canopy.
- **Seismic Anchorage:** Specify details per the manufacturer's installation instructions and California Plumbing Code (CPC) 2022.
- **Safety Bollards:** Include safety bollards in front of the heat pump as per CPC 507.13.
- **Energy Forms:** Submit the missing CEC-NRCC-PLB-E form for domestic water heaters.

- **Piping Diagram:** Clarify the design and sizing of the heat pump system and its connection to the existing gas water heater, including all new piping dimensions and lengths.

Third Submission (December 2, 2024)

To address the city's comments, Frontier Energy resubmitted the application with updated plans and detailed responses, which included:

- Combining all plan sheets into a single file with a cover sheet.
- Providing enhanced site plans and marked photos showing the heat pump's proposed outdoor location, including bollards for protection.
- Clarifying that the heat pump and storage tank are separate units, to be bolted to a skid, and included the manufacturer's installation instructions.
- Submitting the completed CEC-NRCC-PLB-E form.
- Detailing the piping design and purpose of the gas water heater as a swing/temperature maintenance tank for system efficiency.

Second Review Comments (December 11, 2024)

After the third submission, the city provided the following additional comments:

- **Plan Set and Energy Report:** Submit a complete plan set with all working drawings and a signed energy report. Provide separate files for specifications and responses to plan review comments.
- **Site Plan and Rear Elevation:** The submitted rear elevation photo was insufficient. The proposed six-by-six-foot water heater skid overlaps with an adjacent window and encroaches into the driveway. Additional clarification is required.
- **Seismic Anchorage**: Include seismic anchorage details for the 83-gallon water heater.
- **Safety Bollards:** Plans must include safety bollard details with footing specifications.

Location Reconsideration

Due to added complications with the ground installation—including challenging piping routes and the need to obtain approval from the Planning and Public Works Departments—Frontier reconsidered the original attic-based installation. However, a two-month structural evaluation determined that the structural modifications necessary to support the 83-gallon storage tank exceeded the project's budget and schedule constraints. Frontier reverted to pursuing the outdoor installation with continued coordination with Planning and Public Works.

Fourth Submission (March 3, 2025)

Frontier submitted updated plans reflecting revised structural and anchorage details, added bollard footing specifications, and clarified installation layout in response to the previous round of comments.

Planning Department Comments (March 18, 2025):

- Relocate the heat pump and water heater to the side of the building or a landscaped area.
- All mechanical equipment must be screened from public view.

Public Works Department Comments (March 18, 2025):

- Add entrance and exit signage at driveway approaches.
- Include the required best management practices (BMP) construction plan sheet from FlowstoBay.org.

Fifth Submission (March 28, 2025)

Frontier Energy submitted a formal justification letter advocating for the proposed equipment location based on practicality and safety, and a revised plan set in response to the comments from Planning and Public Works comments. Revisions included removal of directional arrows, revised screening details using cedar fencing, and updates reflecting manufacturer guidance that outdoor installation does not require an enclosure.

Planning Department Comments (April 15, 2025):

- Screening materials must match the existing building.
- Screening must not obstruct adjacent windows.

Sixth Submission (April 15, 2025)

Frontier Energy submitted a final revision with updates to screening color and height. The team adjusted the elevation drawing to scale to confirm that the three-foot screening panel terminates below the windowsill. All screening panels will be painted to match the existing building with acrylic latex exterior paint.

Permit Approval (April 25, 2025)

Following these final revisions and the plumbing contractor obtaining a City of San Mateo business license, the city issued the permit, concluding the approval process.

Installation Overview

The heat pump assist system was installed on April 28, 2025. Installation was completed by Pipe It Up Plumbing, with the supervision of Frontier Energy. The scope included both mechanical and electrical work to support the SanCO2 GS5-45HPC heat pump water heater and 83-gallon ECO-83SSAQB storage tank, both of which were installed outdoors along the rear wall of the building.

On the electrical side, the electrician added a quad breaker to the main panel and installed an outdoor service disconnect adjacent to the heat pump to meet code requirements. The electrical supply circuit was routed using MC cable through the crawl space to the disconnect location.

For the mechanical installation, the contractor poured a single concrete pad to support both the heat pump and storage tank. The tank was strapped to the building using Unistrut and a metal strap to satisfy the seismic bracing requirement, and the heat pump was elevated on pressure-treated wood sleepers to allow for adequate drain valve access.

Piping from the new equipment to the existing 50-gallon gas water heater was installed using three-quarter-inch PEX, with transitions to copper along the exterior wall for durability and code compliance. All exposed lines were insulated with one-inch-thick insulation. An expansion tank and necessary check valves were installed, and a control cable was run between the heat pump and storage tank. Additionally, the accessible existing hot water pipe exiting the gas water heater (approximately eight feet) was also insulated.

To meet the Planning Department requirements for equipment screening, three six-inch-by-six-inch pressure-treated posts were installed in concrete footings in front of the heater and tank, and a fourth side two-inch-by-six-inch post was attached to the building. The six-inch-by-six-inch posts doubled as protective safety bollards. Then three cedar fence panels were mounted between the posts to provide visual shielding. All work was completed in accordance with the approved permit and is consistent with the scope outlined in the contractor's proposal.

Appendix B: HPWH System Specification

ECO2 Systems

SUBMITTAL : GS5-45HPC & ECO-83SSAQB 83 Gallon Tank

SANCO2

Job Name	Location				
Purchaser	Engineer				
Submitted to	Reference	☐	Approval ☐	Construction ☐	
Unit Designation	Schedule #				

Specifications	GS5-45HPC
Performance	
Uniform Energy Factor	3.80
Uniform First Hour Rating	121 Gallons
Nom Heating Capacity (Btu/h)	15,400 Btu/h
Nom Heating Capacity (kw)	4.5kw
Heating COP @ 80/47/17°F	5.5 / 4.2 / 2.8
Water Temperature Setting (°F)	145°F or 150°F
Refrigerant Type	R744 (CO_2)
Refrigerant Charge (Oz)	25.4oz (720g)
Power Voltage	208/230v-1Ph-60Hz
Breaker Size	15A
MCA (Amps)	7.2A
Compressor MRC (Amps)	5.0A
Fan Motor MOC/Watts	0.3A / 30W
Pump MOC/Watts	0.6A / 60W
Noise Level (DbA)	37
Weight (lbs)	108lbs
Storage Tank	**ECO-83SSAQB**
Nominal Volume	83 Gallons
Pressure Relief Valve (Psig & °F)	150 & 210°F
Temperature Sensor	Thermistor
Tank Weight (lbs)	115lbs
Standby Loss in 67°F Ambient	110 Btu/h
Tank Connection Sizes	
Cold Water Inlet	3/4" NPT
Hot Water Outlet	3/4" NPT
Cold Water to Heat Pump	3/4" NPT
Hot Water Return from HP	3/4" NPT
Pipe Size - Tank to Heat Pump	
Cold Water pipe - Tank to HP	1/2"
Hot Water pipe - HP to Tank	1/2"
Max Pipe Length inc	66ft
Max Vertical Separation of	23ft
Certifications	
Safety	ETL & ETLc
Performance	Energy Star
Warranty - System	3 Years Labor
Heat Pump	10 Years Parts
Tank	15Yrs Limited Lifetime

Construction
The Outdoor unit shall be galvanized steel with a baked on powder coated finish on all panels except for unit base

Heat Exchangers
Evaporator coil shall be mechanically bonded Aluminum fin to copper tube. Fins shall be coated to resist corrosion
The Refrigerant to Water HX (Gas Cooler) shall be a Double Wall type pressure tested to 6000 psi

Refrigerant System
Compressor shall be a hermetically sealed DC Inverter drive Rotary vane type
Refrigerant shall be R744 (CO_2).
Refrigerant flow shall be controlled by Electronic Expansion Valve

Fan & Motor
The outdoor unit fan shall be a propeller type, driven by a BLDC Motor

Water Pump
The pump shall be a BLDC Impellor type

Controls
The unit shall be operated using a temperature sensor mounted in the Storage tank
Control wiring shall require 16AWG shielded wire
Ambient operating range shall be -25°F to 114°F
A Modbus communication signal shall be accepted by the GS5 Heat Pump via a Controller that shall be supplied by ECO2 Systems as an accessory

Storage Tank
Storage tank shall be constructed from a blend of 316/444 Stainless Steel with R12 Insulation
Storage Tank connections shall be NPT
Connections shall be interchangeable as required

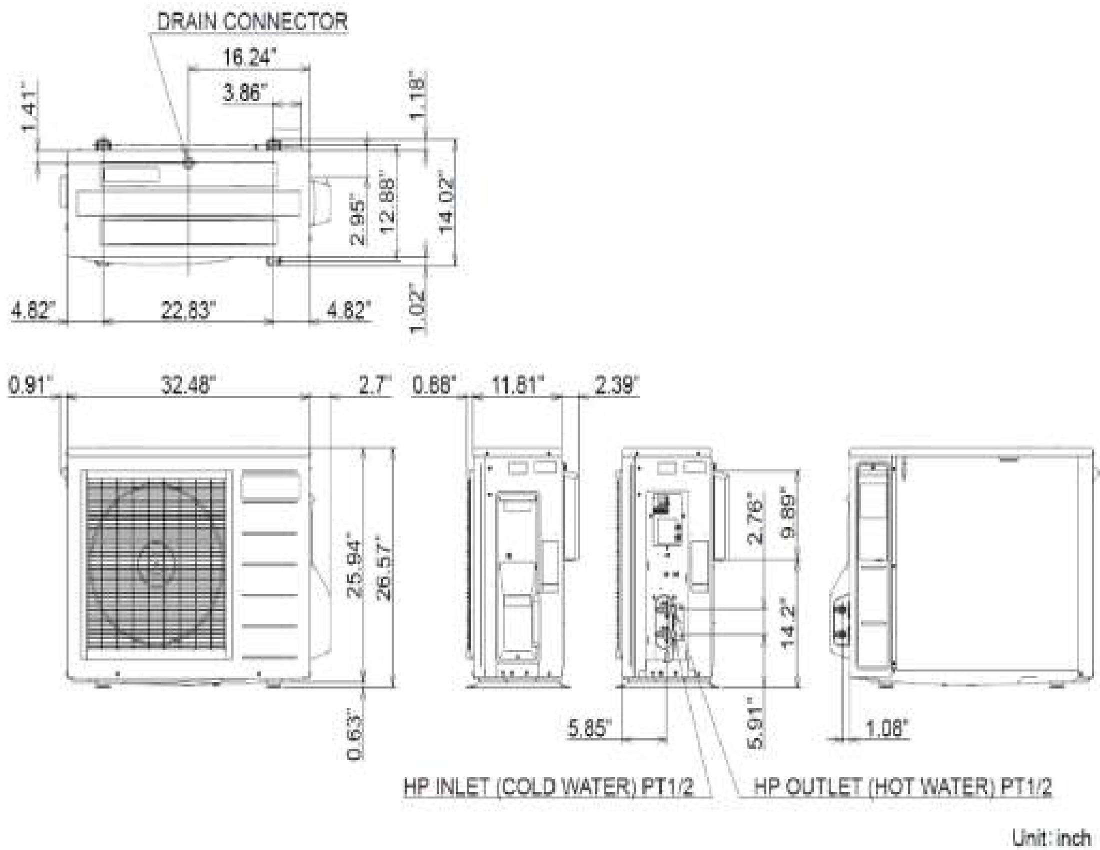
Interconnect Piping
Interconnect Piping shall be 1/2" copper or where permitted 1/2" PEX tubing
Both Cold and Hot piping should be insulated with min 3/4" closed cell foam and where required Heat Trace tape shall be used to prevent pipes from freezing

Eco2 Systems LLC PO Box 1358, Walled Lake MI 48390, Tel : 1-844 SAND CO2 (1-844 726 3262)
www.eco2waterheater.com

SUBMITTAL : GS5-45HPC & ECO-83SSAQB 83 Gallon Tank

Job Name	Location				
Purchaser	Engineer				
Submitted to	Reference	Approval		Construction	
Unit Designation	Schedule #				

GS5-45HPC Dimensions



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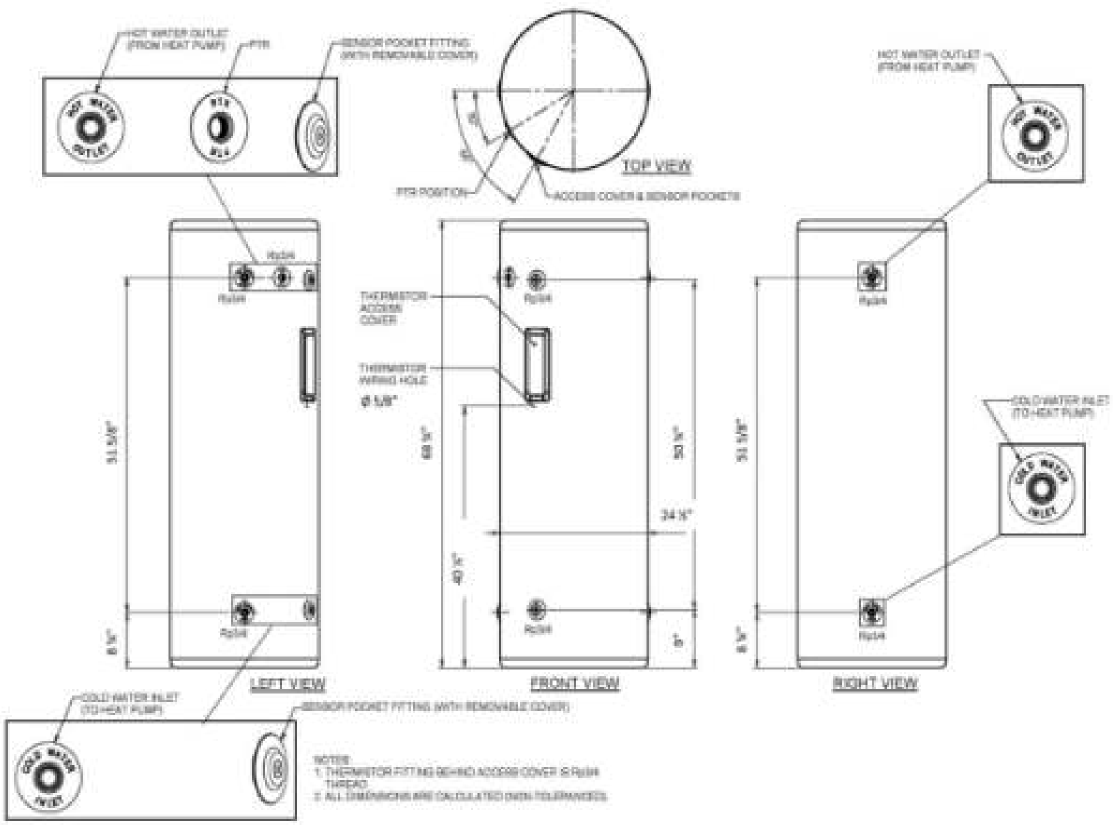
SUBMITTAL : GS5-45HPC & ECO-83SSAQB 83 Gallon Tank

Job Name	Location						
Purchaser	Engineer						
Submitted to	Reference	☐	Approval	☐	Construction	☐	
Unit Designation	Schedule #						

ECO-83SSAQB Stainless Steel Storage Tank Dimensions



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Due to Eco2 SystemsLLC's policy of on-going product development specifications are subject to change without notice SUB-ECO2-GS5+83-042024

Appendix C: Modeling Results Tables

Table 20: Water heating system linear models considered.

Model	Intercept	Water Use Slope	Delta T Slope	Wet Bulb T Slope	Water Use, Delta T Slope
Water Use	14.03	0.84	NA	NA	NA
Delta T	-118.51	NA	4.05	NA	NA
Wet bulb	226.72	NA	NA	-1.42	NA
Water Use + Delta T	-3.89	0.77	0.43	NA	NA
Water Use*Delta T	14.98	NA	NA	NA	0.01
Water Use + Water Use*Delta T	14.89	0.03	NA	NA	0.01
Delta T + Water Use *Delta T	7.68	NA	0.18	NA	0.01
Delta T + Water Use + Water Use*Delta T	7.11	0.06	0.19	NA	0.01

Table 21: Statistics of water heating system linear models considered.

Model	R Squared	R ~ Squared	CVRMSE	Influence	Dependent Variable Mean	Residual Standard Error	Prediction Standard Error
Water Use	0.99	0.99	0.07	0.58	150.81	10.13	10.16
Delta T	0.75	0.75	0.31	1.66	150.81	47.20	47.32
Wet bulb	0.00	-0.03	0.62	11.97	156.05	98.17	99.27
Water Use + Delta T	0.99	0.99	0.06	1.22	150.81	9.00	9.05
Water Use* Delta T	1.00	1.00	0.03	0.15	150.81	4.23	4.25

Model	R Squared	R ~ Squared	CVRMSE	Influence	Dependent Variable Mean	Residual Standard Error	Prediction Standard Error
Water Use + Water Use* Delta T	1.00	1.00	0.03	0.67	150.81	4.22	4.25
Delta T + W ater Use*D elta T	1.00	1.00	0.03	0.28	150.81	3.82	3.84
Delta T + W ater Use + Water Use* Delta T	1.00	1.00	0.02	0.67	150.81	3.77	3.80