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FINAL PROJECT REPORT

Demonstrating Natural Gas Heat Pumps for Integrated Water Heating and Air Conditioning in Restaurants

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Demonstrating Natural Gas Heat Pumps for Integrated Water Heating and Air-Conditioning in Restaurants is the final report for Contract Number PIR-16-001 conducted by GTI. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

This project demonstrated, measured, and verified an integrated gas commercial hot water and air conditioning prototype in two full-service restaurants in the Los Angeles Basin.

The team built two pre-commercial integrated gas heat pump systems for installation and commissioning at two full-service restaurants, undergoing ultra-low oxides of nitrogen certification in the process. The researchers monitored the two systems for 12 months and analyzed the resulting data with the integrated gas heat pump system sized as-installed at the two sites, using the performance of the gas heat pump to estimate a case where the gas heat pump component alone was sized properly to meet the total hot water load as a hypothetical and performance ceiling.

As California moves toward a decarbonized landscape over the next 20 years, this research will help reduce natural gas consumption and create a path towards technologies that will achieve these goals. For restaurants and other similar settings that struggle with electrification, the technology showed that NO_x and GHG emissions were decreased by as much as half. The gas savings were 16 percent to 26 percent for the sites as-installed, with up to an estimated 44 percent to 46 percent savings if the gas heat pump system were “right-sized” for the individual sites. Both sites demonstrated a 14 percent reduction in total site electricity consumption due to supplemental cooling from the heat pump water heater. The gas heat pump prototypes received an “ultra low” NO_x certification. The demonstrated heat pump used a natural refrigerant/absorbent, ammonia-water, which has both zero ozone depletion potential and zero global warming potential.

The research team solicited feedback from host sites and contractors and engaged in national market research to explore market barriers to adoption. Data analysis and modeling were done to estimate statewide potential for savings in energy, water, emissions, and operating costs. The team developed a simplified model of the low-cost gas heat pump system for commercial water heating and air conditioning. This model was incorporated into an informational water heater design guide for restaurants. In addition, the team developed a life-cycle/energy cost calculator tool for restaurants to determine both energy consumption and savings potential. Stakeholder outreach included educating prospective consumers, installation contractors, and other affected stakeholders; introducing the gas heat pump technology; and summarizing project findings.

Keywords: low-cost gas heat pump, integrated commercial air conditioning and water heating, ammonia-water, reduced emissions, natural gas reduction

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Background

California's energy policies focus on more efficient use of energy as a primary tool to reduce both energy consumption and greenhouse gas emissions. The escalating impacts from climate change have driven a growing sense of urgency to identify, demonstrate, and use energy-efficient technologies and strategies while overcoming barriers for new and emerging technologies.

The Department of Energy's Energy Star program reports that restaurants use about five to seven times more energy per square foot compared to other commercial buildings. Restaurants that offer high-volume, quick-service may even use up to 10 times more energy per square foot than other commercial buildings. As a result, the restaurant sector is a priority target for high-efficiency water heating technologies. Similar to residential water heating in California, restaurants are predominately served by gas water heaters. Gas-fired water heating in the California food service industry consumes 340 million therms of natural gas per year. Most new, standard water heaters have an efficiency factor of 60 percent. Although a high efficiency water heater typically has an efficiency of 90 percent to 95 percent, there are drawbacks to conventional high-efficiency gas water heaters. One disadvantage is the energy usage that is required to keep the water hot at all times, known as "standby losses."

Project Purpose

The purpose of this project was to evaluate and demonstrate an innovative technology: a low-cost gas heat pump for integrated commercial water heating and air-conditioning at two restaurants in the Los Angeles basin. The gas heat pumps were sized to simultaneously provide 80,000 British thermal units per hour (Btu/hr) of hot water and up to 2.5 tons of cooling. Cooling from the gas heat pump saves energy by consistently operating at high levels of efficiency and can offset energy use by existing air conditioning. The gas heat pump was designed by Stone Mountain Technologies, Inc., a startup company specializing in gas-fired heat pumps, with technical support from GTI and A.O. Smith.

The project team expanded the purpose of the project into the following goals and objectives to serve as a roadmap for overcoming the challenges of conventional, high-efficiency gas water heaters to:

- Understand the interaction between the gas heat pump and other system components such as storage tanks, conventional water heaters, and building air conditioning, to better optimize system controls.
- Assess the energy, water, and operating cost savings of a novel integrated gas heat pump system by demonstrating this technology.

- Develop analytical tools to prepare a new technology class to include in critical frameworks such as utility incentive programs, energy efficiency codes, and building energy models.
- Share findings broadly to introduce the technology and solicit feedback from business owners, distributors, installation contractors, code officials, and other stakeholders.
- Understand barriers to market entry through stakeholder surveys and seek feedback from industry interviews and focus groups.

Project Approach

Two restaurant sites were selected (1) a national casual dining chain and (2) a Southern California local 24/7 diner chain.

To advance this integrated gas heat pump system to certification and commercialization, the project team accomplished:

- A Prototype Field Demonstration
- Data Analysis and Modeling
- Greater Understanding of Market Barriers
- Stakeholder Outreach

The project team formed a technical advisory committee comprised of representatives from the Consortium for Energy Efficiency, Energy Solutions, Northwest Energy Efficiency Alliance, San Diego Gas & Electric Company, Pacific Gas and Electric Company, Southern California Gas, A.O. Smith, Frontier Energy, and the California Energy Commission (CEC). By executing a detailed and robust research plan, the research team characterized technology performance, costs, market barriers and drivers, and savings potential for full-service restaurants and other light commercial businesses. GTI and its project team, Stone Mountain Technologies, Inc., A.O. Smith, J.C. Mechanical, and ADM Associates, completed the integrated gas heat pump system. After extensively monitoring existing water heating and space heating, ventilation, and air conditioning equipment and receiving ultra-low oxides of nitrogen certification from the South Coast Air Quality Management District, the installation was finalized.

The project team wirelessly monitored 12 months of the water heating performance, which included more than 9,000 hours of gas heat pump operation that often exceeded 3,000 gallons per day at both restaurants. Measurements included the heat output of the gas heat pump unit, gigawatt-hours consumed (the equivalent of one million kilowatt hours), and overall measurement of the complete system. After decommissioning the integrated gas heat pump systems in March 2020 at both sites, the second baseline period focused on traditional gas heat pump equipment.

Because the two sites offered diverse energy load characteristics, the project team further examined the impact of gas heat pump sizing, modulation, and system losses. As a prototype air-source heat pump, the team also examined both gas heat pump efficiency (a reduction of 14 percent of electricity consumed) and demonstrated its effective operation as a "hybrid" system. For more detail refer to Appendix D.

Project Results

Overall gas savings were estimated at 16 percent to 26 percent compared with standard gas tank water heaters. From the demonstration, the system provided estimated average energy savings of 2,057 therms, with $3,144 in annual cost savings across the two restaurants. The savings were based on measured performance, but due to a dysfunctional gas meter the consumption of one gas water heater had to be modeled for 4.5 months. When utilizing "right-sizing", where the gas heat pump component alone was sized to meet the total service hot water load as a hypothetical performance ceiling, the modeled GHP coefficient of performance gas was between 1.40 and 1.70. The extrapolated savings were estimated at 44 percent to 46 percent savings with GHP "right-sizing" of the systems, with 49 percent CO_2 emissions savings, and 63 percent combined operating cost savings for the two restaurants.

The average service hot water load differed from the load measured during the baseline monitoring period, so results were scaled using input/output curves to the load measured during the monitoring period. The baseline gas and electricity inputs were therefore scaled to the same normalized curves. The project team extrapolated energy input, emissions, and economics from daily averages to meet the total service hot water load as a hypothetical and performance ceiling, using the input/output curves as baselines. This uses California-specific assumptions for source energy factors, electricity grid greenhouse gas intensity, and commercial utility rates (without including either demand charges or time-of-use rates). Cooling is assumed to be useful year-round and, based on predicted output from input/output curves, with its estimated avoided electricity consumption from existing heating, ventilation, and air conditioning rooftop equipment is deducted from the incremental power consumption of the gas heat pump or integrated gas heat pump system. The demonstrated heat pump uses a natural refrigerant/absorbent, ammonia-water, which has both zero ozone depletion and zero global warming. Nitrogen oxides and greenhouse gas emissions decreased by as much as half. Similar magnitudes of savings are also estimated for annual operating costs.

Technology, Knowledge, and Market Transfer

Robust and effective knowledge transfer (through outreach, information sharing, and publication of data and findings) is critical for research to build on previous work and guide future study. Because the two restaurants were national and local chains, there is strong potential for technology transfer in other locations. Additional transfer activities are discussed in the following sections.

Educational Outreach

As outlined in the technology and knowledge transfer plan, GTI intended to hold two in-person educational outreach events for this project – one hosted by Southern California Gas and one hosted by Frontier Energy at Pacific Gas and Electric Company's Food Service Technology Center. The goal of these events was to educate and familiarize prospective consumers, installation contractors, utilities, and other stakeholders with this integrated gas heat pump technology. Unfortunately, due to the COVID-19 pandemic, it was impossible to host any in-person events in 2020. Instead, the project team held a virtual session at the 2020 ACEEE Hot

Water Forum focusing exclusively on commercial applications for gas heat pump technology, where GTI presented this project in detail. Positive feedback and questions were discussed with forum participants. Additionally, Stone Mountain Technologies, Inc., one of the manufacturing partners for this project, provided information to a group of utility and affiliated stakeholders at a series of presentations from manufacturers active in commercial gas heat pump development. A second outreach event was the project team's presentation and paper delivered at the 2021 ASHRAE Winter Conference in Chicago, Illinois, by Paul Glanville of GTI, who gave a presentation on "Demonstrating an Integrated Thermal Heat Pump System for Hot Water and Air-Conditioning at Full Service Restaurants." An identically titled conference paper was submitted, reviewed, and distributed at the conference.

Online Outreach and Information Dissemination

The project team prepared several deliverables that will be hosted online to further enhance the availability of information to interested stakeholders. These are listed below and described in further detail in Chapter 5, along with published documents, fact sheets, and press releases.

1. Updated Water Heater Design Guide for Commercial Food Service
2. Integrated Gas Heat Pump Life-Cycle Cost Calculator
3. Codes and Standards Impact Analysis
4. Market Impact Analysis of Low-Cost Gas Heat Pumps in California
5. Educational content and training materials for future use with contractors and with utility ratepayers
6. Press releases, presentations, and conference papers

Benefits to California

This research project demonstrated energy and cost savings to California ratepayers and environmental improvements by reducing greenhouse gas and nitrogen oxides emissions. Although high efficiency water heating products are available, market updates have been limited by high upfront costs and low natural gas prices. The integrated gas heat pump prototype demonstrated in this project offers a high efficiency system with the added benefits of supplemental air conditioning, which together yield substantial energy and cost savings for commercial restaurants. This new technology class could potentially increase adoption of higher efficiency commercial water heating options in California.

The commercialization and adoption of a high efficiency integrated gas heat pump system in California full-service restaurants would provide several benefits. The system provided an average energy savings of 2,057 therms at the two restaurants and reduced greenhouse emissions by 28,411 lbs per year. Though there are significant variations in hot water use at restaurants, the annual operating cost savings of the two restaurants were $617 and $2,527 for a total annual cost savings of $3,144, with a simple payback of about 7.3 years.

Based on the current distribution of gas water heating product types in California and their respective efficiencies, a 10 percent market penetration of the integrated gas heat pump could provide annual natural gas savings of 13.6 million therms and a reduction of 0.08 million metric tonnes of carbon dioxide equivalent (CO_2e). In a more aggressive scenario of 50 percent market penetration, annual natural gas savings and greenhouse emissions reductions were 68 million therms and 0.38 million metric tonnes CO_2e, respectively.

California Investor Owned Utility Savings Estimate

Table ES-1 summarizes potential investor-owned utilities' savings for therms, costs, greenhouse gas, and nitrogen oxides of the integrated systems technology at restaurants under various market adoption rates.

Table ES-1: Summary of California Investor-Owned Utility-Wide Savings With Various Market Adoption Scenarios of the Integrated Gas Heat Pump at Restaurants

Integrated Gas Heat Pump System Market Penetration	Annual Therm Savings (Therms/yr)	Annual Operating Cost Savings ($/yr)	Annual GHG Reduction ($MMTCO_2e$/yr)	Annual NO_x Reduction (lbs/yr)
10%	13,600,000	$14,700,000	0.08	41,200
50%	68,000,000	$73,700,000	0.38	205,800
100%	136,000,000	$147,400,000	0.76	411,600

Source: GTI

Zero Emission Appliances

This research project occurred prior to recent state and local government policies focused on minimizing or eliminating fossil gas combustion from water heating systems. Consistent with its 2022 Scoping Plan, the California Air Resources Board is in the process of designing and developing zero-emission appliance standards for new space and water heaters sold in California. This potential regulation would not limit use or repair of existing fossil gas space or water heaters but would affect the purchase of new space or water heaters purchased after 2030. Zero-emission standards will be focused on zero greenhouse gas emissions, which may largely mean no combustion-based emissions, such as carbon dioxide, nitrogen oxide and methane. In addition, complementary local air district efforts are focused on use of low or zero nitrogen oxides technologies for water heating systems by 2027-2029. Gas-fired water and space heating appliances such as gas-fired heat pumps, could be affected by these zero-emission appliance standards.

CHAPTER 1: Introduction

Background

In California, the restaurant market is predominately served by gas water heaters. Because restaurants consume the most natural gas of any commercial building type, they are an important target for emerging high-efficiency gas water heating technologies. The condensing-efficiency gas water heater has an increased operating efficiency from 80 percent to 90 percent to 95 percent. However, barriers include the relatively inexpensive prices of natural gas and the higher installed cost of the equipment.

This project evaluated and demonstrated an innovative low-cost gas heat pump (GHP) for integrated commercial water heating and air conditioning (A/C) at two restaurant sites in Southern California. This technology addresses the issues highlighted here by delivering hot water more efficiently, with coefficients of performance (COP)[1] between 1.4 and 1.9, yielding a targeted annual fuel utilization efficiency (AFUE)[2] of 140 percent or greater and simultaneously providing space cooling. The integrated GHP system can operate more consistently at high COPs and is relatively independent of outdoor temperatures. Space cooling from the GHP can yield energy savings by offsetting energy use by existing air conditioning (A/C). This project aimed to verify these benefits and energy savings at two restaurants located in the Los Angeles Basin; develop guidance and sizing tools for business owners; analyze the benefits and cost-effectiveness in preparation for inclusion within efficiency codes; and survey business owners, contractors, and distributors to assess the new technology's barriers to entry in the California market.

Project Motivation

In the water heating industry, considerable attention has been given during the past decade to developing and deploying high-efficiency water heating products for residential buildings. Much of this attention has concerned the widespread deployment of gas-fired tankless water heater products (Kosar 2013), development and deployment of electric heat pump water heaters (Glanville 2012 and Sparn 2014), and even the development of gas-fired heat pump water heaters (Glanville 2020), each with significant potential for energy savings and changing how hot water is both generated and consumed. With an average life expectancy of up to 12 years, 41 million water heaters in the United States in operation for more than 10 years, and 82 percent sold as replacements (U.S. EPA 2016), the opportunity for market transformation to high-efficiency products is clear. However, the market and energy efficiency programs have struggled with the value proposition of more efficient residential water heating solutions

[1] The coefficient of performance (COP) is the ratio of useful heating or cooling provided compared to the work required. Higher COPs translate into lower operating costs.

[2] Annual fuel utilization efficiency the amount of heat actually delivered compared to the amount of fuel used to produce that heat.

because increases in retrofit costs of 50 percent or more are challenging to consumers, who typically spend $250-$300/year on electricity and gas for hot water (Kosar 2013).

In contrast, water heating in commercial buildings has not received similar levels of attention. Despite greater numbers of residential water heaters sold per year, and with approximately 36 times as many residential storage water heaters sold as commercial storage water heaters (AHRI 2020), commercial buildings can consume 10-100 times the hot water as a typical home (Hiller 2015).

In this project, the team focused on the restaurant industry as a target for commercial hot water savings, using GHP technologies. The restaurant sector consumes more natural gas per square foot than any other commercial building type, with water heating behind cooking equipment as the largest thermal load. Additionally, while single family and low-rise multi-family buildings are commonly serviced by individual water heaters, commercial buildings are more commonly served by multiple commercial water heaters or water heating systems that are more challenging to spread across the sector. Gas-fired commercial water heaters represent the majority of the non-residential "duty" commercial water heating market with approximately 77 percent of storage type; 14 percent are boilers coupled with indirect storage tanks (IST), and 9 percent are tankless (DOE 2016), shown in Figure 1.

Figure 1: Typical Commercial Water Heating Installations — Storage, Boiler, Indirect Storage Tank, and Tankless Equipment (Left to Right)

Photo examples from prior GTI field studies.

Source: GTI

As a result of greater hot water demand, and with purchase decisions driven by expectations of financial payback, commercial water heaters are generally much more efficient. Over the decade from 2009-2019, high-efficiency commercial gas-fired water heaters, with a rated thermal efficiency of 90 percent or greater, have increased from 29 percent of shipments to 47 percent, a shift in population-efficiency not seen for residential products (A.O. Smith 2020). As a result, end users and energy efficiency stakeholders are looking beyond "condensing efficiency" and seeking to leverage advances in heat pump technology. For electric options in 2019, a major U.S. water heater manufacturer introduced a commercial integrated electric heat pump water heater, with a rated COP of 4.2 on a site basis and a heat pump output capacity of approximately 40 kilo-British thermal units per hour (kBtu/h). For gas-fired options that often serve much larger commercial hot-water loads, several active demonstrations of heat pump systems have been performed at multiple building types including schools, senior care facilities, hospitality, and other commercial buildings in Oregon, Michigan, British Columbia, and Ontario (GTI 2019). In these studies, commonly involving one or multiple GHPs with an output capacity of 124 kBtu/h and employing the ammonia-water vapor absorption cycle, demonstrations have shown reduced gas consumption by baseline equipment ranging from 18 percent to 50 percent when serving commercial water heating loads (TAF 2018 and Pratt 2020).

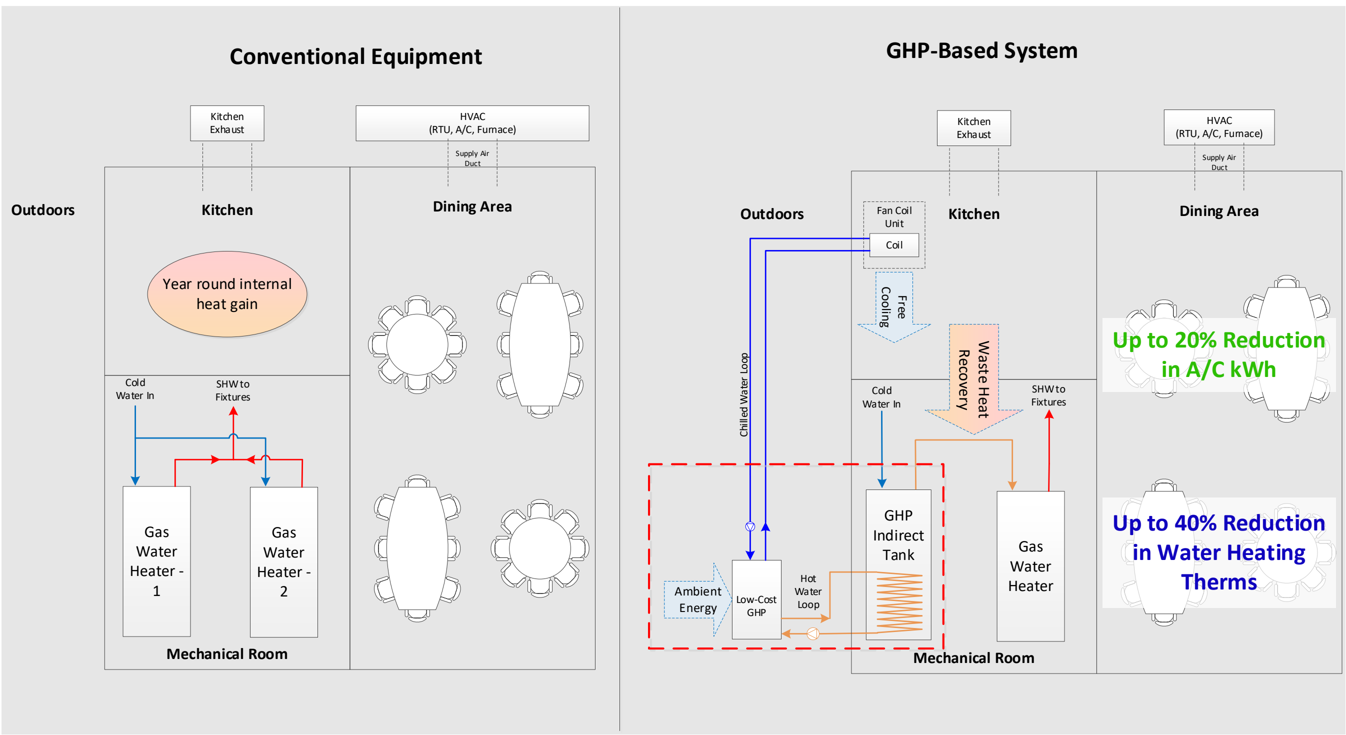
In California, restaurants consume more than 340 million therms of gas to heat hot water, and approximately 90,000 restaurants consume more gas for water heating than the total gas consumption of one million homes (Delagah 2013). Opportunities remain for reducing the energy input and emissions associated with this thermal load, with significant savings possible with conservation measures like efficient, demand-based recirculation pumps and integrated heat recovery in dish machines (the term commonly used for commercial dishwashers) (Delagah 2018). However, the limit of "condensing efficiency" must be addressed. With an estimated increase in operating efficiency to 140 percent or greater for hot water production, broad use of thermally driven heat pumps could reduce natural gas consumption for commercial water heating in restaurants by 43 percent (Glanville 2019); displacing up to 20 percent of electricity demand for A/C provides further energy and operating cost reductions.

Technology Overview

Restaurants commonly have one or two water heaters (depending on service hot water [SHW] loads and needs for redundancy, and rooftop or grade-level heating, ventilation, and air conditioning (HVAC) equipment, with quantity and type of HVAC equipment varying by restaurant type, size, and climate zone. Depending on requirements from local health codes, either the water heaters will be set to deliver the required temperature to all fixtures or deliver a lower temperature to most fixtures (for example, 140°F [60°C]) while some equipment may have small "booster" heaters to raise the temperature at a fixture or piece of equipment (such as raising the temperature to 180°F (82°C) at a dish machine). Also, restaurants commonly employ hot water recirculation loops that usually operate "always on" but are increasingly demand-based. Common HVAC equipment includes heat pumps, commercial furnaces, rooftop units (RTUs), evaporative cooling equipment, and exhaust fans (with and without heat recovery). HVAC equipment must be the proper size to handle high ventilation loads and the large internal and year-round heat gain that can result in restaurant HVAC, which consumes 5-7 times more energy than other commercial building types such as office buildings.

The integrated GHP system deployed at the demonstration sites is a hybrid system in the sense that the GHP provides hot water with conventional gas-fired water heaters and A/C supplemental to the building's existing A/C equipment. The GHP system consists of three major components: a low-cost GHP to provide high-efficiency heating and supplemental cooling to separate hydronic/chilled water loops, an indirect storage tank to provide hot water with the conventional gas-fired water heater, and an indoor cooling coil installed either as a standalone cooling coil within the kitchen or within the existing ductwork. The GHP is designed as a water-to-water heat pump with a "four-pipe" design, shifting heat from a chilled water loop (for A/C) to a hot water loop (for SHW), simultaneously providing both hot water and A/C. The GHP is also designed to operate in a SHW-only mode, where the chilled water loop absorbs heat from an integrated outdoor coil completely within the GHP cabinet, so it can operate as an air-to-water GHP as well during periods when cooling is not needed. The overall system is shown in Figure 2, illustrating a typical installation and how the GHP component integrates with the balance of the system, with the GHP upgrading heat drawn from the restaurant via the chilled water loop (supplemental cooling), or as an air-to-water GHP, drawing heat from the outdoor air. It was advantageous for the project team to place the GHP, the GHP indirect tank, and the associated hardware on a factory-assembled skid (highlighted in red dashed box).

Figure 2: Simplified Diagram of Integrated Gas Heat Pump System for Hot Water and Air-Conditioning



Source: GTI

Gas Heat Pump Component

The GHP is a direct-fired, single-effect absorption heat pump with an operating heating COP of 1.5 or greater, an estimated AFUE of 140 percent or greater, and a project unit cost of around 40 percent of an equivalent GHP available today (GTI 2019). The GHP yields 40 percent or greater therm savings when deployed to provide hot water, as demonstrated in prior laboratory and field testing of earlier GHP generations and is anticipated to have a total installed cost of approximately half that of comparable GHP equipment (Glanville 2019). The GHP in this system is sized to simultaneously provide 80,000 Btu/hr of hot water and 2.5 tons of cooling. This GHP was designed by a startup company specializing in thermally driven heat pumps, Stone Mountain Technologies, Inc., (SMTI) with technical support from GTI and A.O. Smith. As described, the integrated GHP system installed at two restaurants for this project is a hybrid system consisting of three major components:

1. A low-cost GHP providing high efficiency heating and supplemental cooling to separate hydronic/chilled water loops.
2. An indirect storage tank (IST) to provide hot water in series with the conventional gas-fired water heater.
3. An indoor fan coil unit (FCU) installed either as a standalone cooling coil within the kitchen or within the existing ductwork.

The GHP is based on the vapor absorption refrigeration cycle, using the ammonia-water working fluid pair where an absorbent (water) is used as a carrier for the refrigerant (ammonia). Most commonly, for air-source GHPs this refrigeration moves heat from ambient air at the evaporator to the recirculating hydronic loop at the condenser. For this integrated GHP for hot water and A/C, the evaporator is hydronically coupled. Rather than drawing heat from ambient air, this advanced system draws heat from a chilled water loop connected to the indoor space and "pumps" this heat to the hot water loop. This GHP design and system arrangement allows simultaneous heating and cooling, providing hot water and A/C at the same time. When A/C is not required, the GHP will draw heat to the evaporator from outdoors using an air-coupled hydronic heat exchanger (HX). For this project, this water-to-water GHP with this air-coupled HX is a first of its kind, adapted from a previously developed air-to-water GHP design. As intended, the integrated GHP system is sized and controlled to be hot water-led, meaning the GHP will cycle on to meet a call for hot water (a thermostat call). If, when the GHP cycles on there is also an open call for space cooling at the indoor cooling coil, the GHP will direct chilled water to this coil for supplemental A/C. If there is no call for space cooling, the GHP will instead use the outdoor heat exchanger.

Within the GHP the compression of the liquid refrigerant/absorbent solution is performed by the solution pump, which requires only about 2 percent of the total energy input to the heat pump. The thermal energy from the modulating, 55,000 Btu/hr gas burner is required to drive the refrigerant vapor from its absorbed state in the desorber (or "generator"). This desorption process occurs at an elevated temperature (250°F-300°F [121°C-149°C]) so exiting flue gases still have useful heat, which is recovered in a separate condensing heat exchanger (CHX), integrated within the hot water loop. As the ammonia/water pair has significant heat absorption, this is recovered at the absorber as well by the same hydronic loop as the condenser. Thus, the GHP heats the hydronic loop via three inputs: condenser heat from the heat pump effect, the recovered heat of absorption in the absorber, and the heat recovery of the flue gases via the CHX. Because only a fraction of the heat to the hot water loop is from the condenser, the A/C capacity is roughly 40 percent of the hot water capacity, which is well suited to hot water-intensive operations like restaurants.

Integrated System Considerations

Concerning system controls, the integrated thermally driven heat pump (THP) system was sized and controlled to be hot water-led; the THP will cycle on to meet a call for hot water (a thermostat call). When the THP cycles on, if there is also a call for space cooling at the indoor cooling coil, the THP will direct chilled water to this coil for supplemental A/C. If there is no call for space cooling, the THP will instead use the outdoor-coupled HX integrated within its cabinet. The indirect storage tank is used as a buffer between the SHW demand and the operation of the GHP to prevent unwanted GHP short-cycling and meet the "double-wall" HX requirement between a refrigerant (NH_3) and potable water.

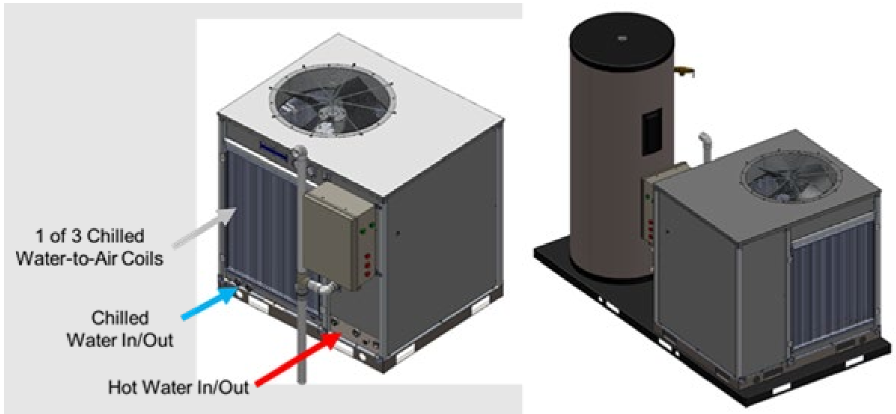
On component sizing: when used as an integrated system for hot water and supplemental A/C, the THP is sized only to carry a portion of the peak SHW load. SHW loads can vary by factors of two or greater from day-to-day, and large portions of a restaurant's 2,000-plus gal/day consumption for SHW can occur in a few hours each day (for example, kitchen clean-up) (Delagah 2013). It was therefore expected to be most cost-effective for the GHP to carry most of the SHW load, most of the time, with a "peaking" and "baseload" relationship between the conventional water heater(s) and the THP, borrowing the electricity generation analogy. The balance is important because too much or too little GHP is undesirable. With undersizing, if not enough of the load is carried by the THP this can offer only a minimal improvement over the baseline case. Conversely, if the THP is over-sized relative to the load and conventional water heaters, the value of the THP will not be realized when operating at partial load much of the time.

Concerning the additional cooling output, it was assumed that the added 0.5 ton to 2.5 tons of cooling[3] will be useful in all instances, with the range depending on THP modulation. In the mild Los Angeles climate, the internal loads within the kitchen are expected to demand year-round cooling. Prior studies of thermal comfort in commercial kitchens revealed that restaurant cooking staffs were equally uncomfortable during winter and summer months (Stoops 2013). It is therefore anticipated that cooling from the GHP will be useful, particularly during peak business hours.

Finally, as a concern for the physical layout of the GHP system, it is convenient to install the GHP component, the IST, and associated outdoor piping, instrumentation, and controls on a skid. While primarily motivated by the temporary nature of this installation and the difficulty in locating additional space within mechanical rooms for the indirect storage tanks, the additional benefit of this system is a compact and reliable factory installation of plumbing connections and components, reducing both the effort and potential for errors during installation. Figure 3 shows a preliminary image of the GHP system outdoor skid without showing the enclosures and connections. A more detailed overview of the integrated GHP system design is provided in Appendix A.

[3] A ton of cooling refers to a unit of power used to describe the heat-extraction capacity of refrigeration and air conditioning equipment.

Figure 3: Rendering of Gas Heat Pump Component (left) and Skid Assembly (right)



Source: Stone Mountain Technologies, Inc.

CHAPTER 2: Project Approach

This project team sought to accomplish these tasks to advance this GHP technology towards commercialization:

- Field demonstration: Demonstrate that the projected delivered efficiencies of 140 percent or greater are valid, robust, and are not achieved at the expense of user comfort or performance. Estimate annual energy, operating cost, and emissions savings, and solicit feedback from host sites and installation contractors through pre/post surveying.
- Development of analytical tools: Expand results through modeling and simulation from these restaurants to other restaurant types and sizes, light commercial businesses, California climate zones, and system configurations to determine the total market impact potential of the technology.
- Assessment of market barriers: Understand barriers to market entry through outreach with stakeholder surveys, in-depth interviews, and focus groups to determine the strengths, weaknesses, opportunities, and threats to the commercialization of this new technology.
- Stakeholder outreach: Share findings broadly to introduce the technology and solicit feedback from business owners, distributors, installation contractors, code officials, and other stakeholders.

Description of Host Sites

The process of finding two restaurant sites that met project requirements is outlined further in Appendix C. To briefly summarize, the screening criteria for the restaurant sites were:

1. Space for temporary equipment installations
    a. At least a 4' x 4' space for the GHP installation, preferably ground-mount on concrete pad rather than rooftop. If rooftop needed, ease of install with crane would be a priority.
    b. Room for auxiliary hot water tank, indoors for adjacent to GHP (where permitted)
    c. Wall space for the data acquisition system (DAS) in proximity to 120 VAC
2. Access for installation, servicing, data collection
    a. Adequate exposed piping for instrumentation
    b. Options for indoor cooling coil locations

3. Adequate loads and other considerations
    a. Hot water demand estimated as >1,500 gallons/day, represented directly or as >625 meals/day or >$7,500/day of restaurant revenue
    b. Need for auxiliary A/C
    c. Appearance of well-maintained facility and code compliance during inspection

During the project proposal, two restaurant sites provided letters of commitment as host sites. Unfortunately, following site inspections neither site was determined to meet the above criteria (full details in Appendix C). Site recruitment re-started and several more restaurants were visited. The project team performed a second round of site recruitment with a focus on local and national full-service restaurant changes, which increased the candidate pool in a short period of time. Ultimately, the team successfully recruited two restaurant chains well-established in the Southern California region:

- Site #1: A local chain of 24-hour diner full-service restaurants ("24-hour diner" to distinguish from second site), with 18 locations in Los Angeles and Orange counties. The restaurants are well known for their breakfasts and the nostalgic architecture of their buildings. At the time of recruitment, the site had an estimated hot water demand of up to 3,400 gallons per day, with a peak of 1,400 meals per day served on weekends and between 900-1,200 meals per day on weekdays.

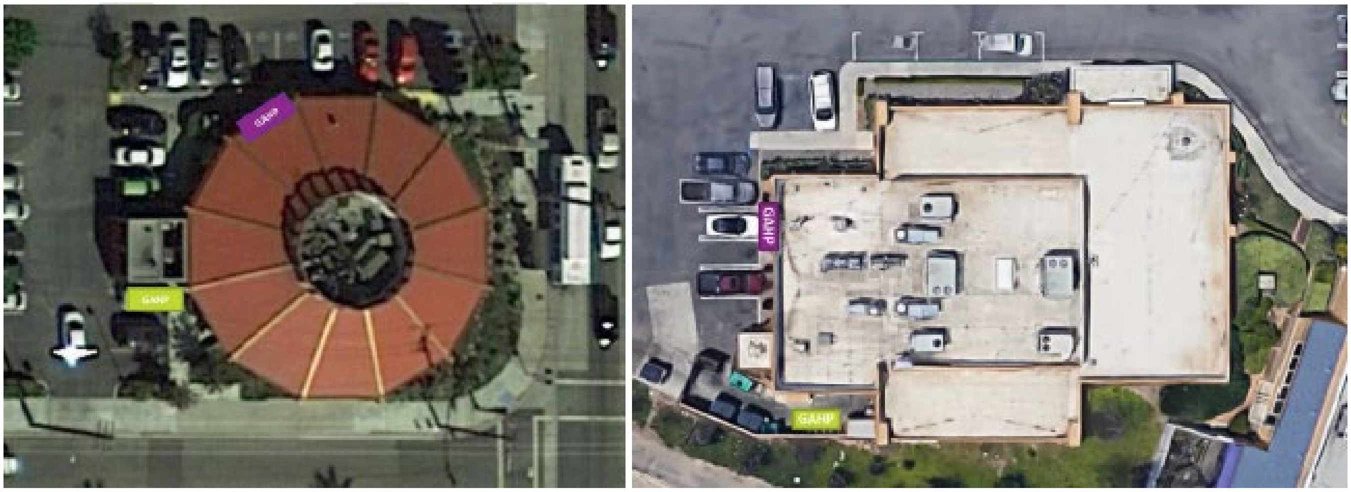
  This host site opportunity was provided by SoCalGas. The location of this diner is in West Covina, California, within California Climate Zone 9. The restaurant has a circular footprint and a screened off area in the center of the rooftop for HVAC equipment. Concerning siting of the GHP and indirect storage tank, three options were available a) the rooftop has little available space for the GHP on a skid, b) with a detached enclosure adjacent to the restaurant (there is available space next to or within parking spaces that could accommodate a ground-level installation of the GHP or GHP skid), or c) the existing water heaters are located within a small mechanical closet with exterior access with no additional space for equipment. If the IST is not located on a skid it will need to be placed within the kitchen area. Option B was selected.

- Site #2: A national chain of full-service restaurants, with 23 locations in Los Angeles and Orange counties, with approximately 860 locations in North America and well known for its Italian-American cuisine. This site is referred to as "FSR" in this report. At the time of recruitment, the site had an estimated hot water demand of up to 6,700 gallons per day and served between 1,260 and 2,800 meals per day.

  This host site was provided by A.O. Smith. The location of the national chain is Chatsworth in Los Angeles, California, within California Climate Zone 9. The relatively large restaurant has ample rooftop space and ground-level options for the GHP or GHP skid, including a partially enclosed area for storage and waste collection. There is ample indoor space compared to other restaurants inspected for additional equipment and, if needed, the IST.

Aerial photos of both sites are shown in Figure 4.

Figure 4: Overview of Sites #1 (Left)and #2 (Right) With Proposed (Green) and Final (Purple) Locations of Gas Heat Pump Skids



Source: GTI

It is important to note that the decision to package the GHP, indirect storage tank, and associated plumbing, mechanical, and electrical equipment as a skid was made during this recruitment phase. Therefore, while sites were initially screened for separate GHP and indirect storage tanks, rooftop or ground-mounts (for the former and indoors for the latter), the sites were also screened for adequate outdoor space for the complete skid package. Details regarding the decision to and layout of this skid are provided in Appendix C.

Existing equipment for the two sites is summarized in Table 1 and Table 2, focusing on equipment and fixtures associated with hot water consumption and mechanical HVAC equipment serving A/C loads. As noted in Appendix A, the delivered water temperature from these water heaters is 140°F (60°C) in all cases, which is comparable with the GHP system. Regarding the lifetime of the water heating products, the water heaters at Site #1 were built in 2015 and at Site #2 were installed in 2014.

Table 1: Existing Hot Water Equipment at Two Restaurant Host Sites

Category	Equipment	Site #1 – 24-Hour Diner	Site #2 – FSR
Water Heater	Water Heater #1	Make: Bradford White; Model: UCG100H2703N; 100 Gal. Storage, 270 kBtu/h input, 82% TE	Make: A.O. Smith; Model: BTH 199, 100 Gal. Storage, 199 kBtu/h input, 97% TE
Water Heater	Water Heater #2	Make: Bradford White; Model: UCG100H2703N; 100 Gal. Storage, 270 kBtu/h input, 82% TE	Make: A.O. Smith; Model: BTH 199, 100 Gal. Storage, 199 kBtu/h input, 97% TE

Category	Equipment	Site #1 – 24-Hour Diner	Site #2 – FSR
Indoor Fixture	Restroom Sinks	Four	Five
Indoor Fixture	Hand Sinks	Four	Five
Indoor Fixture	Underbar Sink	N/A	Two
Indoor Fixture	Three-Compartment Sink	N/A	One
Indoor Fixture	Pre-Rinse Valve	One	One
Indoor Fixture	Mop Sink	One	One
Indoor Fixture	Utility/Prep/Pre-Soak Sinks	Two	Six
Indoor Fixture	Dishwashing Machine	One; conveyor type (CMA-44)	One; conveyor type (Hobart – C44A)
Indoor Fixture	Other SHW Equipment	Two; Ice cream dipper well	N/A

Source: GTI

Table 2: Rooftop Heating, Ventilation, and Air Conditioning Equipment at Restaurant Host Sites

Site #1 – 24-Hour Diner	Site #2 – FSR
Heat Pump #1; Carrier Model 25HCB3; 5-ton Capacity; Rated SEER 13, EER 10.2-10.8	RTU #1; Trane Model YHD180F; 15-ton Capacity; Rated EER 12.1
Heat Pump #2; Carrier Model 25HCB3; 5-ton Capacity; Rated SEER 13, EER 10.2-10.8	RTU #2; Lennox Model LGA090H2BS2Y; 7.5-ton Capacity; Rated EER 11.3
Heat Pump #3; Carrier Model 25HCB3; 5-ton Capacity; Rated SEER 13, EER 10.2-10.8	RTU #3*; Trane Model YHC092E; 7.5-ton Capacity; Rated EER 12.6 *RTU model, capacity based on site plans, due to damaged nameplate
Heat Pump #4; Carrier Model 38QRR060; 5-ton Capacity; Rated SEER 13.5, EER 11.5	RTU #4; Trane Model YHD180F; 15-ton Capacity; Rated EER 12.1

Site #1 – 24-Hour Diner	Site #2 – FSR
Heat Pump #4; Carrier Model 38QRR060; 5-ton Capacity; Rated SEER 13.5, EER 11.5	RTU #5; Trane Model YHC120E; 10-ton Capacity; Rated EER 12.5
RTU #1; Trane Model YCH151C3L0BB; 12.5-ton Capacity; Rated EER 11.5	

Source: GTI

Field Data Acquisition System

Following the selection of the two restaurant host sites, baseline monitoring was initially planned for a 2-3-month period, followed by installation and commissioning of the GHP system for 12-months of monitoring. As an air-source heat pump, the low-cost GHP component is influenced by seasonality since its operating efficiency depends on ambient air and water temperatures; during colder months the operating efficiency and capacity can diminish. Seasonality can also impact system performance like in warmer months, where: ambient conditions increase the GHP component's efficiency and capacity; higher inlet water mains temperatures will effectively diminish hot water loads, shortening on-cycles and/or operating a lower modulation points; and warmer months will also drive supplemental A/C loads, effectively decoupling the GHP component from the ambient environment. Due to integration with the building HVAC via supplemental A/C, the shoulder months (spring and fall) were of particular interest as GHP on-cycles may frequently switch between providing or not providing supplemental A/C, with alternate cycles impacted by indoor-versus-outdoor conditions. Thus, it was important to capture GHP system performance over a range of annual operating conditions. At the close of the GHP system monitoring period, the GHP component was expected to be removed from the sites and the team would install a replacement, high-efficiency gas water heater for a second baseline monitoring period, also lasting 2-3 months.

As detailed extensively in the Field Demonstration Execution and Monitoring Plan (Appendix B), data were collected using the Logic Beach Intellilogger IL-80 datalogger, connecting to project implementers and evaluators via a cellular modem on Verizon's network. All clocks will be synchronized to the NIST clock available on the web. The Intellilogger will send datasets to ADM Associates and GTI via file transfer protocol (FTP) on a weekly basis, backing up data on their respective servers, and also storing data onto its 128 MB onboard memory card. To prevent data loss due to power surges or temporary power loss, the datalogger will be powered via surge protection and an uninterrupted power supply (UPS) with provisions for remote power cycling. With this datalogging platform, to quantify the mentioned performance metrics, the data in Table 3 were continuously collected. Figure 5 shows a diagram of measurements used during these planned field evaluations of the GHP systems. Note that the diagram includes measurement points, while other installation features required at the installation (such as valves) are omitted for clarity. Further details about the field data acquisition system can be found in the *Field Demonstration Execution and Monitoring Plan* included in Appendix B of this report.

Special Considerations for the Second Baseline

The first baseline monitoring period began in July 2018, with some delays while waiting for "ultra low" NO_x certification of the prototype GHP by the South Coast Air Quality Management District. The GHP system was installed and fully commissioned in March 2019. As a result, the second baseline period began when decommissioning the integrated GHP system in March 2020 (and ran through June 2020). During this time, the COVID-19 global pandemic ramped up in California and throughout the U.S. In Los Angeles County, where the two test sites are located, restaurants were forced to discontinue dining operations and shift to serving takeout and delivery orders beginning on March 18, 2020. While restaurants in Southern California were permitted to re-open dining (with explicit limitations) on May 29, 2020, this re-opening was later rescinded in mid-summer as COVID-19 cases in Southern California surged.

Since the entirety of the second baseline period was impacted by COVID-19-related restaurant closures and partial re-openings, it is difficult to draw conclusions from this period when compared with "business as usual" measurements in both the first baseline and integrated GHP system monitoring periods. As a result, while some data is reported from the second baseline measurements, they are not used as a basis of comparison or assessment of GHP performance.

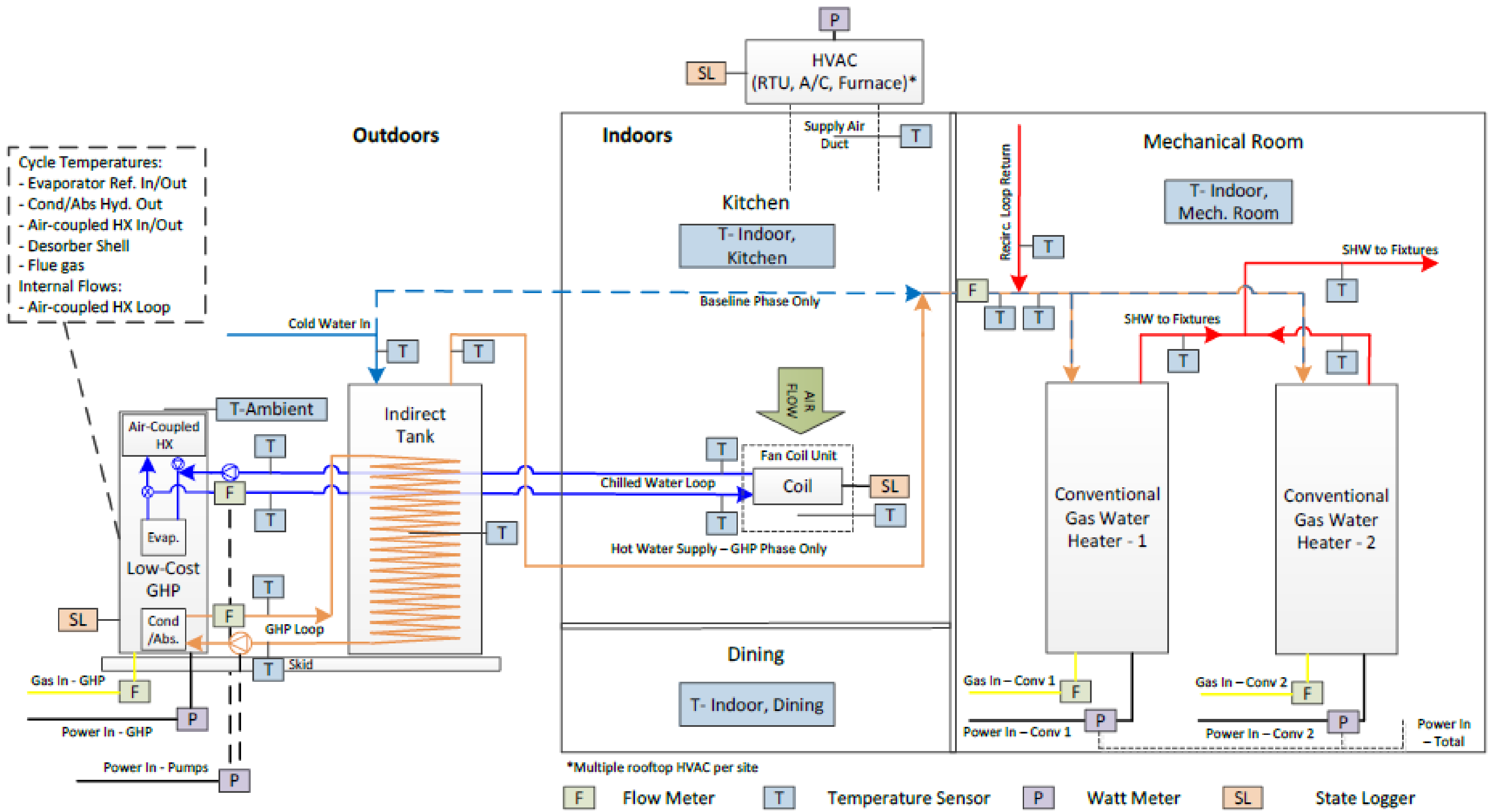
Table 3: Data Acquisition Continuous Measurement Points - Overview

Measurement	Method	Accuracy	Measurement Point – Baseline	Measurement Point – Integrated GHP System
Natural Gas Input	Positive displacement diaphragm meter with integrated pulser	±1%, Temperature Compensated	– Conv. Gas Water Heater(s)	– Conv. Gas Water Heater(s) – GHP
Electricity Input	True root mean square (RMS) power transducer with split core current transformers (CT)	±0.5% (Meter), ±0.75% (CT)	– Conv. Gas Water Heater(s) – Existing HVAC	– Con. Gas Water Heater(s) – Existing HVAC – GHP Skid/Pump
Water Flow	In-line turbine flow meter with pulse output	Resolution of 0.025 gallons	– Service hot water output	– Service hot water output
Recirculating Loop Flow	Vortex-shedding flow meter, magnetic-inductive flow meter, or in-line turbine flow meter	±2% of range or better, effectively ±0.5 GPM or better	N/A	– Chilled water loop – GHP loop
Water Temperature (Hot/Cold)	Thermocouple Type T	±0.9°F	– Inlet/outlet to Conv. Gas Water Heater(s)	– Inlet/outlet to Conv. Gas Water Heater(s) and Indirect Tank – Chilled Water Loop Supply/Return @ Indoor Cooling Coil
Water Temperature (Hot/Cold)	RTD sensor	±0.81°F	N/A	– GHP Loop Supply/Return, two per loop – Chilled Water Loop Supply/Return @ GHP
Air Temperature	Thermocouple Type T	±1.5°F	– Indoors – Kitchen, Mechanical Room – HVAC Supply	– Indoors – Kitchen, Mechanical Room – HVAC Supply

Measurement	Method	Accuracy	Measurement Point – Baseline	Measurement Point – Integrated GHP System
				– Indoor Cooling Coil Supply – Ambient at GHP
Ambient Weather Condition	Publicly Accessible Weather Station	N/A	– Outdoors	– Outdoors
Equipment Runtime	Dry contact	N/A	– Existing HVAC	– Existing HVAC – Indoor Cooling Coil – GHP

Source: GTI

Figure 5: Diagram of Instrumentation during Baseline and Gas Heat Pump System Monitoring



Source: GTI

CHAPTER 3: Project Field Evaluation Results

Baseline Water Heating Systems and Performance

Baseline equipment was installed in July 2018, with measurements through February 2019. GTI and its measurement and validation contractor, ADM Associates, experienced no issues with collecting data from indoor dataloggers, with a focus on measurements on water heating equipment. Regarding wireless measurements from rooftop HVAC equipment, GTI and ADM experienced several challenges related to datalogging, installation, and commissioning measurements; some issues were attributed to environmental causes while others were preventable installation errors. These are summarized in Table 4 and detailed further in Appendix B.

Baseline Data Analysis – Water Heating

Beginning on July 29, 2018, and running through January 31, 2019 (Site #1), and February 11, 2019 (Site #2), data were collected on the indoor water heating equipment at both sites. This first baseline monitoring period was extended through the point where onsite preparations were being made for both the integrated GHP system installation and commissioning.

Table 4 highlights the results tracking daily hot water consumption and the estimated delivered energy factor (gas-only) for both sites. For Site #1, the average of 2,720 gallons per day of SHW consumed is consistent with prior estimates based on meals served. Similarly, Site #2's average of 4,820 gallons of SHW per day is also roughly in line with the prior estimate. Both are highlighted in figures 6, 7, 8, and 9, which show the daily hot water draw cycles and maximum draws in gallons per minute (GPM). In both cases, the loads are above 1,500 gallons per day and therefore appropriate for integrated GHP system installation.

- Concerning daily consumption patterns, the Site #1 24-hour diner had steady hot water consumption throughout the day. By contrast, the Site #2 FSR had a steady rise each day in hot water consumption, with a peak approaching between 10 p.m. and 12 a.m., an indication of a well-defined cleaning routine. Charting the expected future performances of the two sites' integrated GHP systems will be interesting.
    - With the smaller overall consumption additionally spread over a 24-hour period at Site #1, the GHP will more likely cover a majority of the SHW load, while continuously modulating.
    - By contrast, the larger overall consumption and steady daily ramp-up at Site #2 will provide an excellent test case to understand how the "baseloaded" GHP impacts outputs from the indoor gas-fired water heaters.
- Concerning estimated delivered energy factors of the water heaters, treated collectively since they operate in parallel, Site #1 has a steady performance of ~70 percent (below the rated 82 percent thermal efficiency [TE]), and Site #2 shows an average of ~81

percent, which is also below the rated 96 percent-97 percent TE. The early lower estimated delivered energy factor (DEF) at Site #2 concerned equipment servicing at that site. The estimated delivered energy factor differs from rated efficiencies due to cycling and standby losses not captured by the equipment rating test, which is commonly seen in field demonstrations of this nature. Site #2 showed a slightly larger difference in rated TE versus measured DEF due to the draw pattern, indicating that standby losses are a larger fraction of output when compared with Site #1.

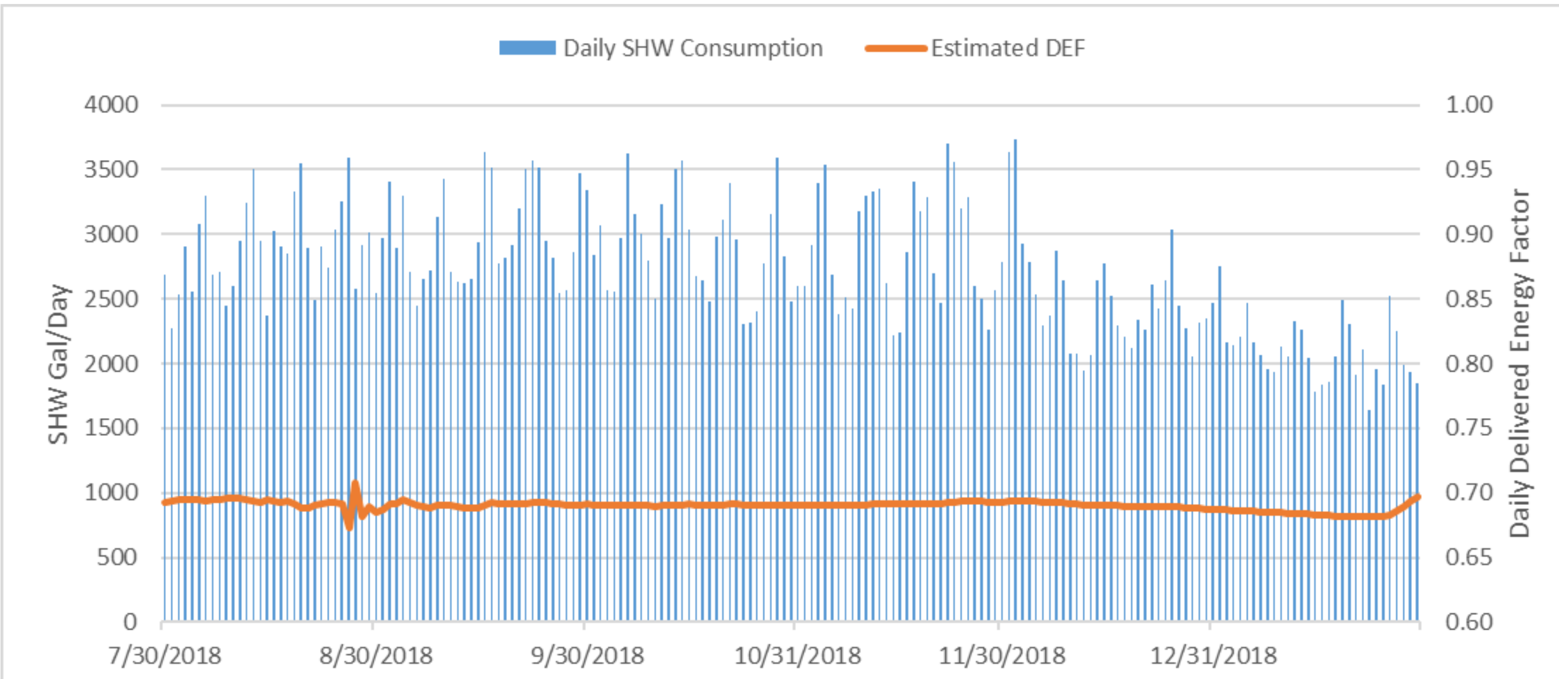
Table 4: Baseline Monitoring Challenges - Overview

Category	Issue	Description	Solution
Wireless Barriers	Interference/Line of Sight	– Operates in the ultra-high frequency (UHF) range, propagating mainly by line of sight meaning that physical interference, such as building structures, was responsible for much of the issue. Interference from other systems operating on the same frequency, such as TV broadcasting, GPS, Wi-Fi, Bluetooth, etc. may have contributed as well.	– Where possible, sensor locations were adjusted to remove physical interference. – Measurements were "doubled up" by installing Onset HOBO loggers as a back-up for each of the sensors. – Future possible solutions also include the use of wireless repeaters or a different type of antenna.
Wireless Barriers	Wireless Sensor Configuration Settings	– Each wireless sensor was run off a single Li-ion battery. The battery's lifetime is directly tied to the frequency of data transmission and other sensor operations. One sensor's settings were configured to increase the reporting frequency to address the above-mentioned radio interference. The frequency was set too high, and the battery's charge was depleted more quickly than expected.	– The field team replaced the batteries, relocated the sensor, and added more appropriate settings.
Wireless Barriers	Software Issues	– Remotely configuring the sensors was difficult as the configuration software contained an error in the MODBUS testing utility.	– The field team worked with the logger manufacturer to resolve the error and was able to use the testing utility to configure the sensor gateway.
Wireless Barriers	Accidental Damage	– Damage occurred to one of the sensors after the field installation accidentally disconnected one of the battery's contacts.	– Sensor was repaired and brought back online for the duration of the field monitoring.

Category	Issue	Description	Solution
Sensor Installation Errors	Current Transducers (CTs)	– A couple of CTs on one of the heat pumps were installed backward.	– Field team corrected the installed CTs to be facing the right direction.
Sensor Installation Errors	WattNodes	– An optional measure for improving readings using shorting jumpers across unused phase CT connections was suggested by the M&V team.	– Shorting jumpers were installed during the post-commissioning visits.

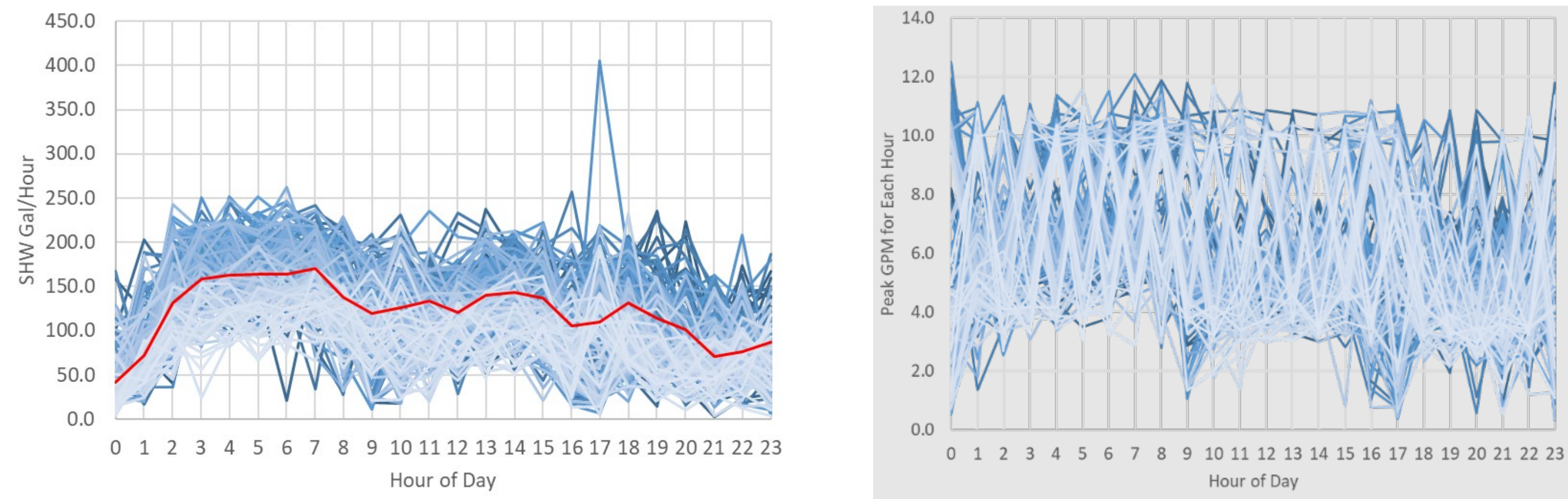
Source: GTI

Figure 6: Daily Hot Water Consumption and Estimated Delivered Energy Factor – Site #1



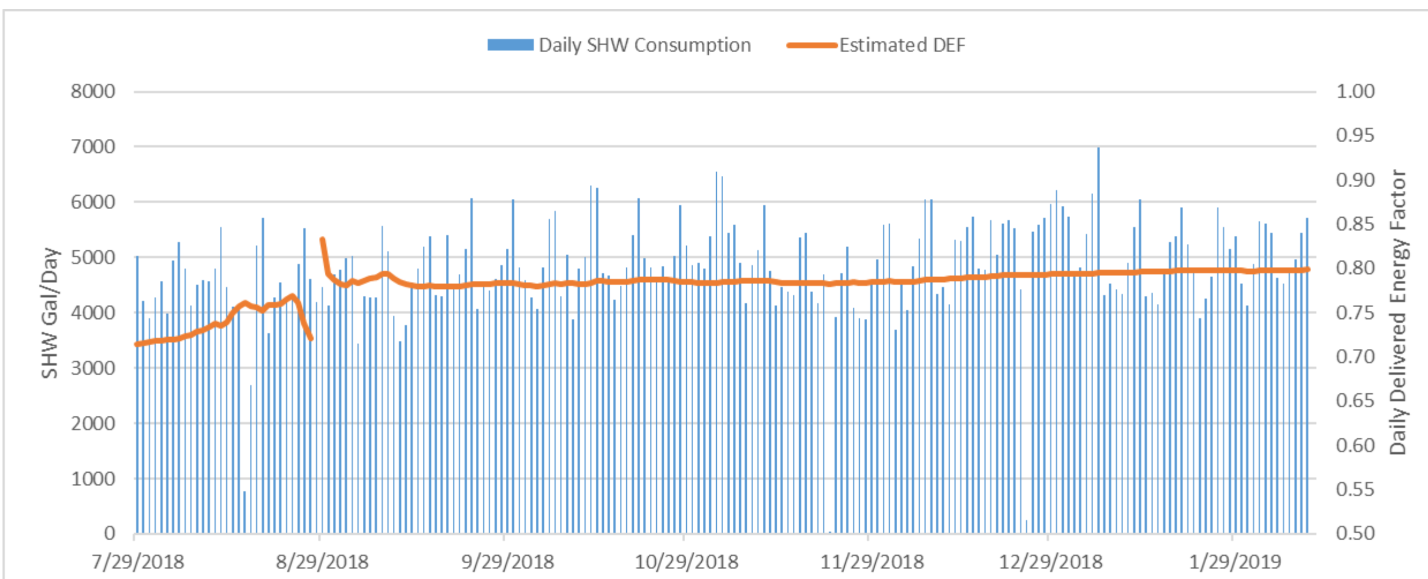
Source: GTI

Figure 7: Daily Hot Water Draw Pattern and Maximum (Gallons per Minute) – Site #1



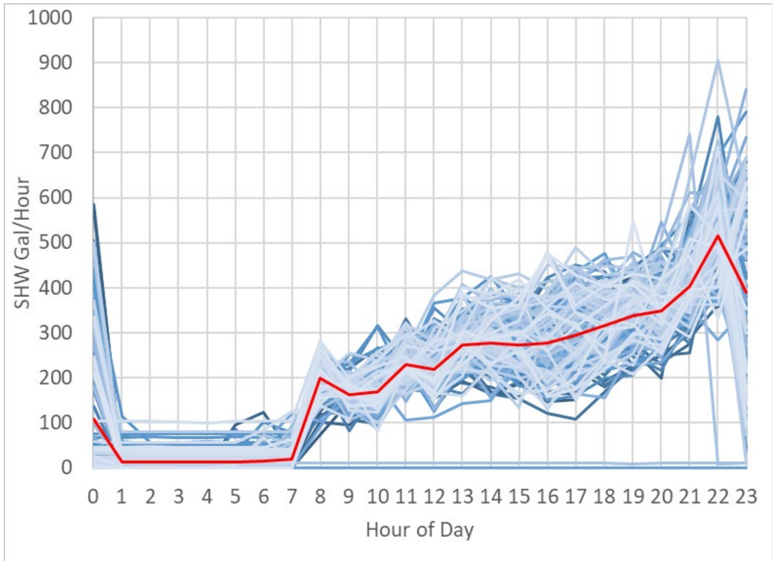
Source: GTI

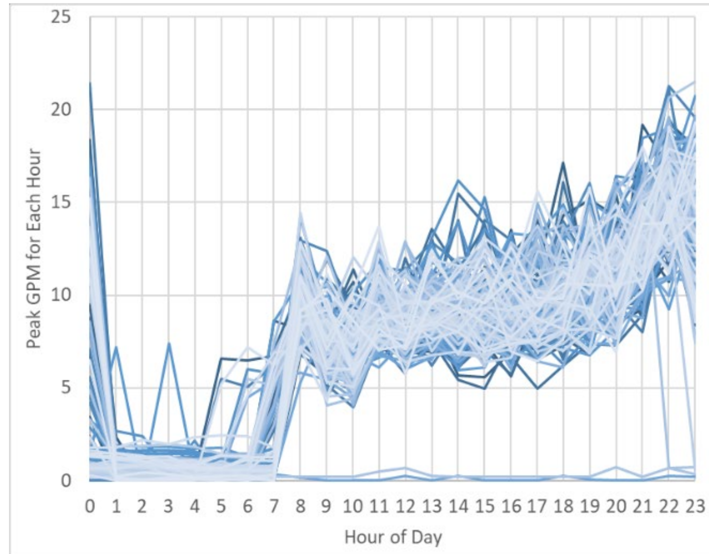
Figure 8: Daily Hot Water Consumption and Estimated Delivered Energy Factor – Site #2



Source: GTI

Figure 9: Daily Hot Water Draw Pattern and Maximum (Gallons per Minute) – Site #2





Source: GTI

The primary energy input and output characteristics of the two sites are summarized in Table 5. Each site shows a significant opportunity for savings focusing on the water heating alone, with a potential 40 percent reduction in natural gas consumption leading to $3,062 or $4,831 in annual savings for Sites #1 and #2 respectively. Both sites were observed to have 24/7 hot water recirculation in their facility, with the average return temperature. As far as ambient temperatures, the range of indoor temperatures was quite steady in both sites, with a 15-20°F (–9 to –7°C) range throughout the day and a decline into the heating season trailing outdoor measurements.

Table 5: Summary of Baseline Energy Inputs/Outputs – Water Heating

Metric	Site #1	Site #2
Service Hot Water Load (avg.)	2,722	4,821
Service Hot Water Load (peak)	3,736	6,995
Average Gas Consumption (CF/day)	2,206	3,488
Average Electricity Consumption (kWh/day)	2.0	2.6
Average Delivered Temperature (F)	141.7	143.2
Recirculation Return Temperature (F)	128.5	130.0
Estimated Delivered Energy Factor	70.0%	79.1%
Peak Flow Measured (GPM)	11.9	19.7
Normalized Output (Gallons SHW/CF Input)	1.23	1.38

Source: GTI

Table 6 summarizes baseline annualized estimates, with energy use estimates extrapolated from daily averages. Electric grid GHG emissions factors were assumed to be 144.2 lb CO_2e/ MMBtu of gas, 613.8 lb CO_2e/MWh baseline electricity, and 1,178.7 lb CO_2e/MWh non-baseline electricity for eGRID CAMX subregion for 2018. All-in commercial utility rates of $0.91/therm and $0.15/kWh were used; demand charges and time-of-use rates were not considered.

Table 6: Summary of Baseline Annualized Estimates

Estimate	Metric	Site #1	Site #2
Annualized Energy Estimate	Gas Consumption (therms)	8,293	13,112
Annualized Energy Estimate	Electricity Consumption (kWh)	716.0	966.3
Annualized Energy Estimate	Total Source Energy Input (MMBtu, gas & electricity)	908.9	1,435.9
Annual GHG Emissions Estimate	Baseline Electric Grid (lbs/yr)	120,025	189,668
Annual GHG Emissions Estimate	Non-Baseline Electric Grid (lbs/yr)	120,429	190,214
	Annual Operating Cost	**$7,654**	**$12,077**

Source: GTI

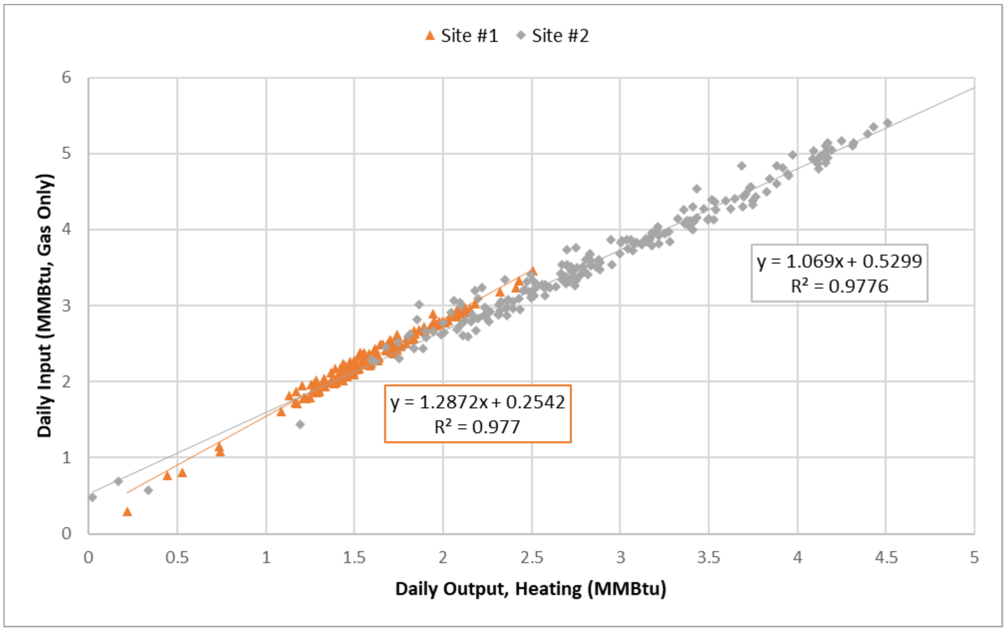
For future comparison with the integrated GHP system on a normalized basis, normalizing for hot water demand and inlet/outlet temperature conditions, the "Input/Output" chart following shows remarkable linearity for both sites. This method will be used to extrapolate energy savings to the general case and compare the integrated GHP system versus baseline performance across multiple laboratory and field studies. As outlined in the monitoring plan, this method posits that the daily energy input versus output of a heating system can yield a delivered efficiency from their linear relationship of the transient energy input to the energy output (Bohac 2010; Butcher 2011). When plotted on an I/O chart the slope and y-intercept can estimate the delivered efficiency (DE), as follows:

$$Input = m * Output + b; \frac{Output}{Input} = DE = \left(m + \frac{b}{Output}\right)^{-1}$$

Figure 10 shows the linear fits are nearly overlaid and:

- The lower slope of Site #2, 1.069 versus 1.2872, reflects the greater efficiency of the condensing-type water heaters, which deliver more output for a given input.
- The slightly lower intercept of Site #1, 0.2542 vs. 0.5299, indicates a reduced level of standby losses (energy input with no output), a reflection more of the 24-hour demand pattern than the insulation level of the storage tanks themselves. Conversely it is much more common at Site #2 for no demand for the first 6-8 hours of the day, during which standby losses are more readily captured by this method.

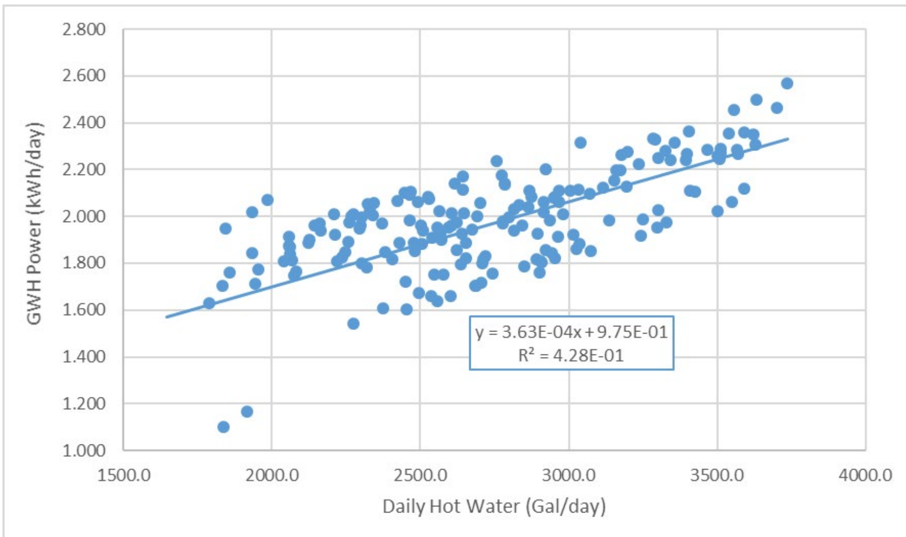
Figure 10: Input/Output Chart – Baseline Monitoring



Source: GTI

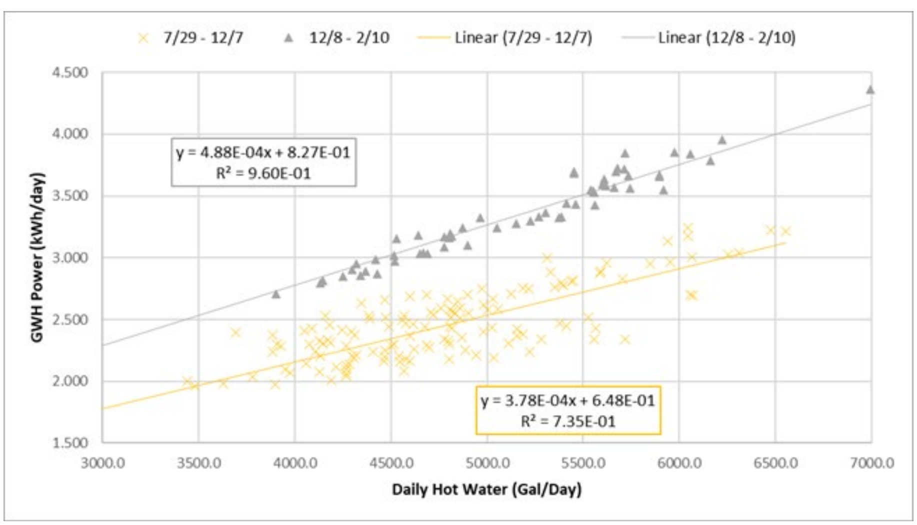
Finally, on normalized power consumption of the gas water heaters, it is challenging to precisely normalize the two gas-fired water heaters operating in parallel. While steady operation offers predictable power consumption, it is water heater modulation and cycling rates that introduce scatter. This can be seen in the scatter in Figure 11 and Figure 12 and can be further examined for Site #2. When normalizing to daily hot water volume delivered, the normalized power consumption will shift with time as the inlet water temperature varies. As they are temperature controlled, the two water heaters will vary cycling rates and split duty between water heaters as the required water temperature rise varies. However, in early December 2018, Site #2 raised the thermostat setting, increasing the average delivered temperature from the water heaters from 141.8°F (61°C) to 152.8°F (67.1°C). Segmenting the normalized power draw before and after this thermostat change, seen in Figure 13, results in a distinct shift in the linear fit independent of the gradual scattering from cold water changes.

Figure 11: Normalized Water Heater Power Consumption – Site #1



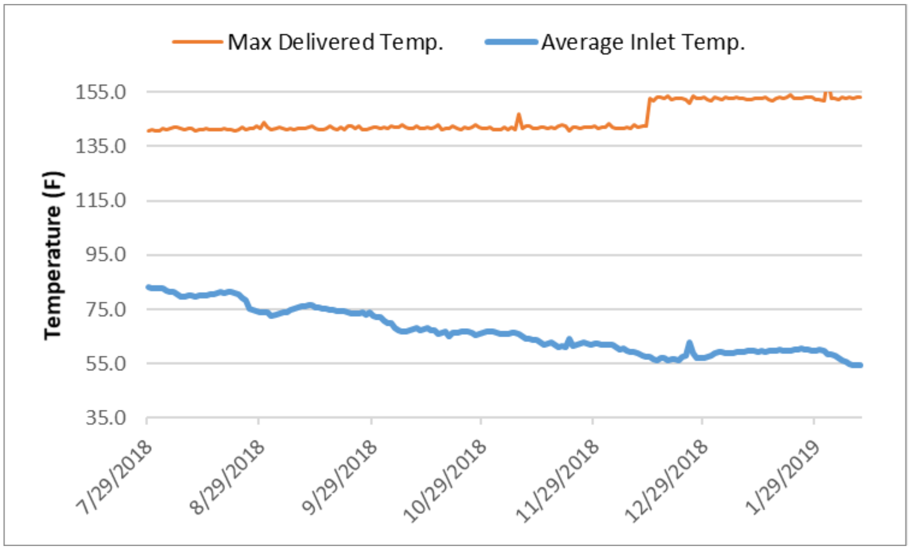
Source: GTI

Figure 12: Normalized Water Heater Power Consumption – Site #2



Source: GTI

Figure 13: Site #2 Inlet and Outlet Water Temperatures



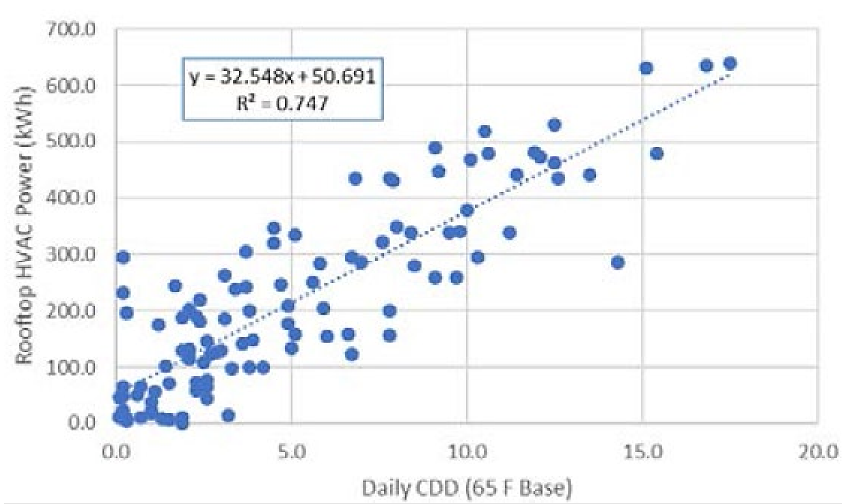
Source: GTI

Baseline Data Analysis – Rooftop Heating, Ventilation, and Air-Conditioning

Site #1 – 24-Hour Diner

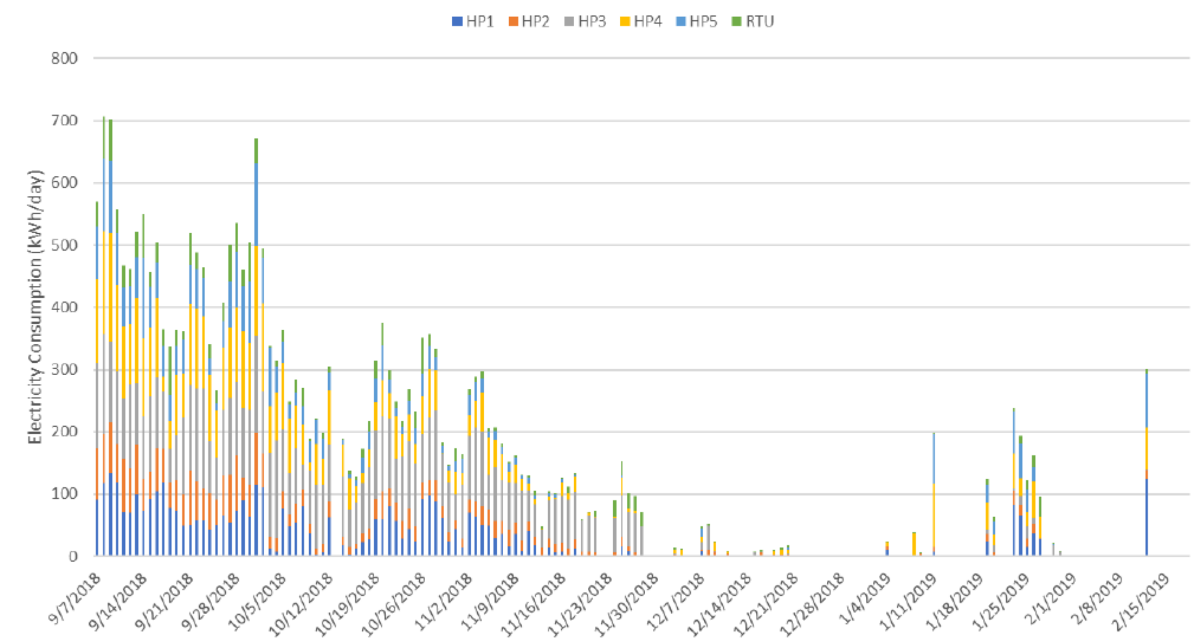
Using the data collected from the five heat pumps, when cooling (per monitoring of reversing valve) and the RTU, the normalized daily electricity consumption to daily cooling degree days (CDD) is shown in Figure 14. More scatter is seen at Site #2, possibly due to the 24-hour nature of the site and that the A/C equipment has active demands for cooling over the full diurnal variation in outdoor temperature. The distribution of electricity demand across equipment is shown in Figure 15 with some calls for cooling corresponding to daily CDDs in the winter as well. Generally, an even distribution of demand is seen across equipment. When extrapolated to the 2019 cooling season, using actual CDDs from 4/1 to 11/30, this extrapolates to 79.0 MWh/year for cooling.

Figure 14: Normalized Air-Conditioning Electricity Use – Site #1



Source: GTI

Figure 15: Distribution of Daily Electricity Demand – Site #1 Rooftop

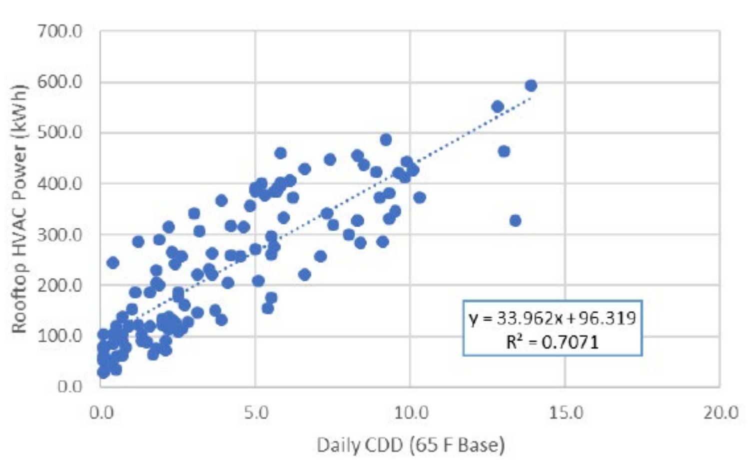


Source: GTI

Site #2 – Full-Service Restaurant

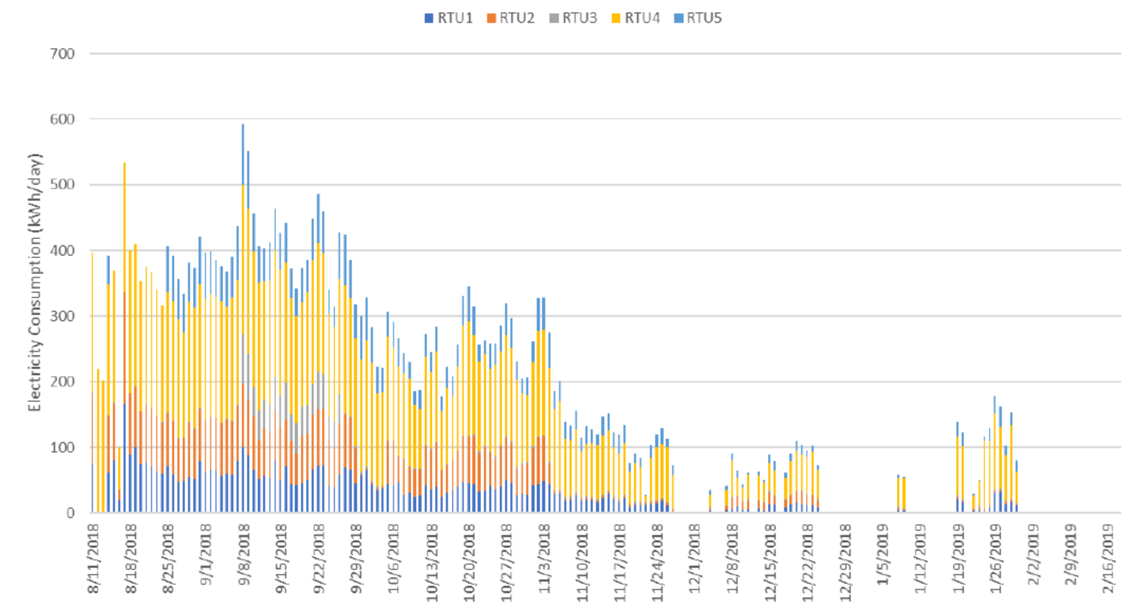
Using the data collected on the five RTUs, the normalized electricity consumption to daily cooling degree days (CDD) is shown in Figure 16. The distribution of electricity demand across equipment is shown in Figure 17, with some calls for cooling corresponding to daily CDDs in the winter as seen in Site #1. RTU #4, located in the center of the rooftop and closest to the cookline, carries the majority of the cooling load on most days. When extrapolated to the 2019 cooling season, using actual CDDs from April 1 to November 30, 2019, this extrapolates to 71.0 MWh/year for cooling, lower than at Site #2 due to the milder climate (closer to coast). Generally, the equipment at this site is more oversized and more often operates at low part-load ratios.

Figure 16: Normalized Air-Conditioning Electricity Use – Site #2



Source: GTI

Figure 17: Distribution of Daily Electricity Demand – Site #2 Rooftop



Source: GTI

Second Baseline Performance

Interestingly, during the integrated GHP system monitoring period, the existing gas-fired water heaters failed at both sites and required early replacement. As a result, the high-efficiency retrofit water heaters originally to be installed upon integrated GHP system decommissioning to initiate the second baseline monitoring period, were installed early. For Site #1, the original water heaters were replaced with condensing storage water heaters in June 2019 (Figure 18, A.O. Smith model BTH 250, with rated 96 percent TE). For Site #2, the original water heaters were also replaced with condensing storage water heaters in September 2019 (Figure 19, A.O. Smith model BTH 400, with rated 95 percent TE).

Figure 18: Replacement Water Heaters at Site #1

Source: GTI

Figure 19: Replacement Water Heaters at Site #2

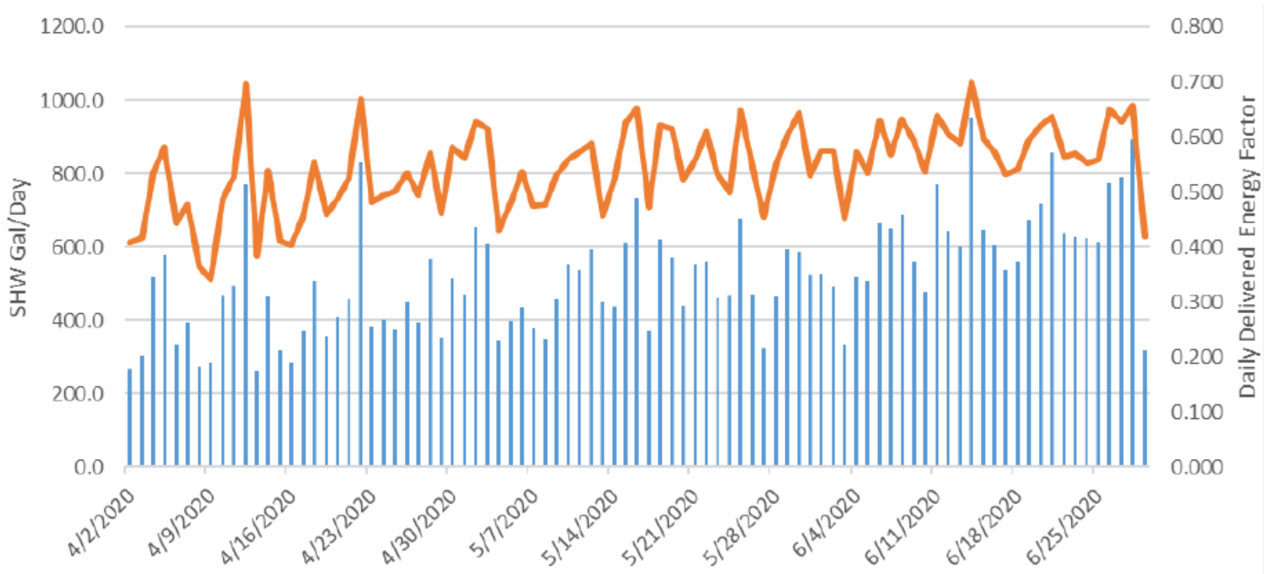
Source: GTI

While it would be expected to see an increase in efficiency for the second baseline gas-fired water heaters, this was not seen due to the significant reduction in demand due to COVID-19 related closures discussed previously. Shown in the subsequent data charts, Site #1 had a reduction in hot water consumption by nearly an order of magnitude while Site #2, which presumably had a more robust takeout order business, had only about a 50 percent reduction in demand. Similarly, how the sites managed this period differed as well with implications towards efficiency:

- Site #1 maintained typical operation, with both water heaters active and 24/7 recirculation pump active as well. Due to the sharp reduction in demand, this led to an increase in standby heat loss by 29 percent. This, and a more on/off demand pattern per charts below led to a larger reduction in DEF when compared to rated efficiency
- By contrast, Site #2 disabled one of the two water heaters and disabled the recirculation pump during this same period. This led to an 82 percent reduction in standby head loss for the overall water heating system, significantly closing the gap between rated efficiency and DEF as estimated in Figure 20, Figure 21, and Figure 22.

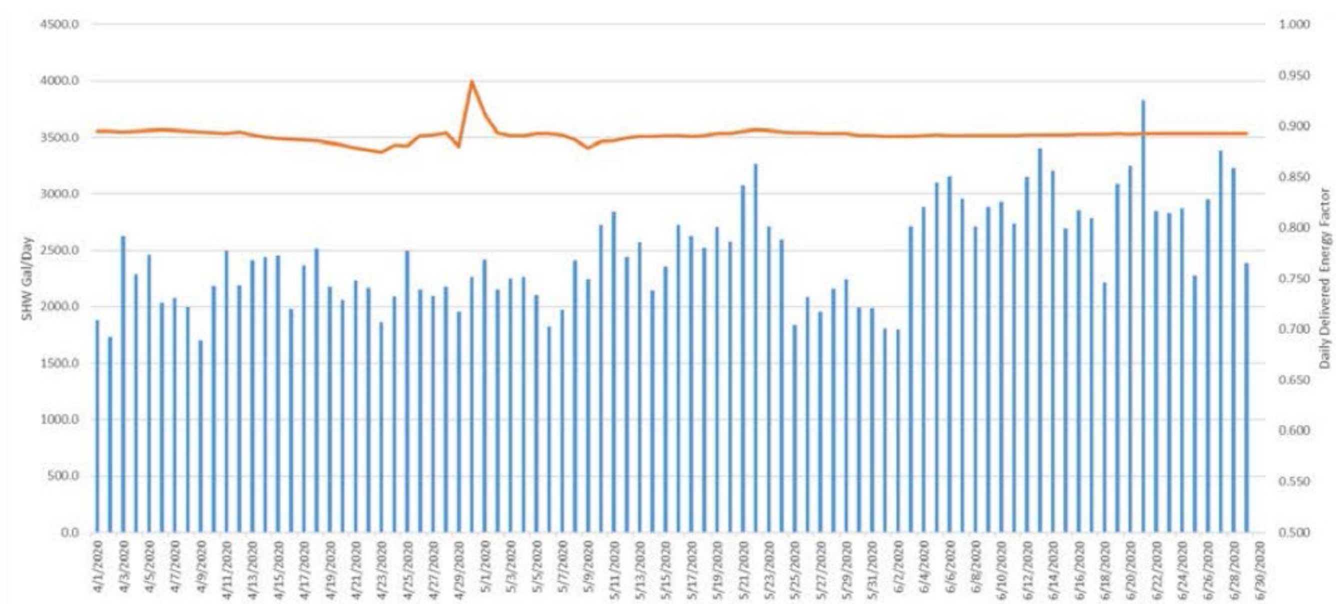
Due to the unique nature of this operating period, the project team decided that it does not offer a useful comparison to either the original baseline or the integrated GHP system monitoring periods; they are therefore not be considered in energy savings extrapolations.

Figure 20: Daily Service Hot Water Consumption and Estimated Delivered Energy Factor – Site #1 (Second Baseline)



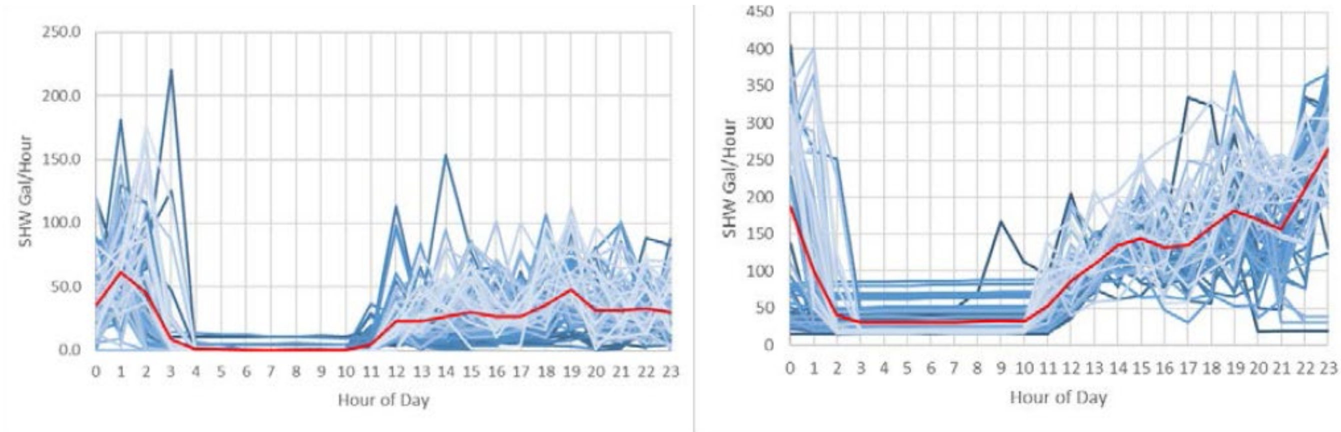
Source: GTI

Figure 21: Daily Service Hot Water Consumption and Estimated Delivered Energy Factor – Site #2 (Second Baseline)



Source: GTI

Figure 22: Second Baseline Site #1 (Left) and Site #2 (Right) Daily Service Hot Water Draw Patterns (COVID-Impacted)



Source: GTI

Heat Pump Water Heater Installation and Commissioning

Pre-Shipment Preparations

As discussed in detail in Appendix C, the project team opted to affix the outdoor GHP components, the indirect storage tank, the closed hydronic loop, and associated controls and instrumentation outdoors on an easily installed and removable 4′ x 8′ skid. The skidding of these elements was intended to ease installing and removing this temporary equipment, with the added benefit of performing a portion of the overall integrated GHP system plumbing, electrical, and instrumentation installation offsite. The integrated GHP systems act as a pre-heater for the existing Gas Water Heater (GWH) installed for this demonstration. The skids as assembled, pre-shipment, are shown in the following photographs. The GHP has a firing rate of 55 kBtu/h with a nominal output of 80 kBtu/h, the indirect storage tank has 113 gallons of storage, and the indoor fan coil unit was sized for 1070 CFM with up to 32 kBtu/h output capacity, requiring 450 W and a pressure drop of 14′ of head.

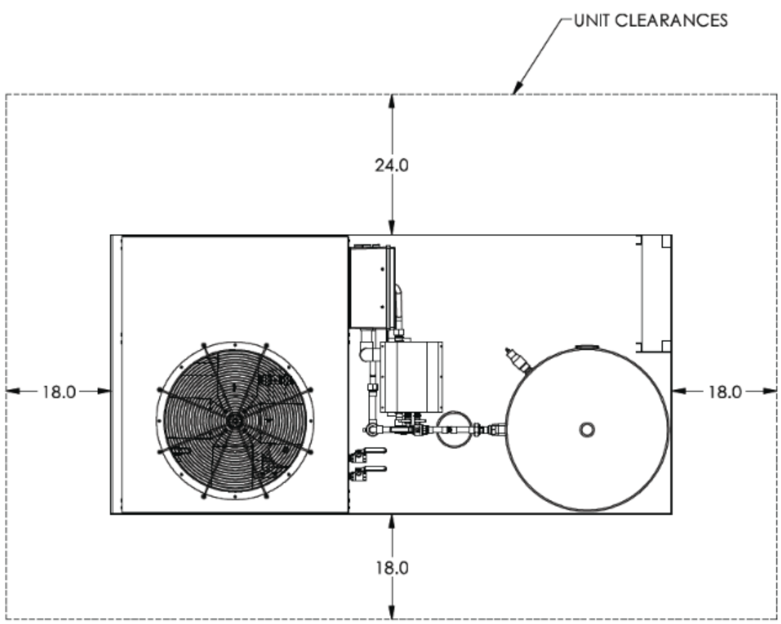
The skids as assembled pre-shipment are shown in Figure 23.

During this period of skid assembly and pre-shipment preparation, GTI worked with SMTI to develop contractor training materials to assure a smooth installation and commissioning period, including information concerning the location and nature of connections for the water, gas, electrical, and other service lines (for example condensate). Documentation was developed and provided to ensure correct installation of the integrated GHP system components and field-installed instruments, with site-specific notes based on prior walk-throughs (needed clearances shown in Figure 24). Additionally, SMTI prepared and issued an operational manual, as documentation for site staff, the installation contractor, local inspection authorities, and the rest of the project team.

Figure 23: Fully Assembled Gas Heat Pump Skid Pre-Shipment

Source: GTI

Figure 24: Installation Clearances for Outdoor Skid



Source: SMTI

Ultra Low NO_x Certification

As was the case with a parallel project to demonstrate prototype residential-sized gas-fired heat pump water heaters, this prototype was initially believed to be exempt from ultra low NO_x requirements for similar reasons: the project concerns a temporary research-driven demonstration project with CEC support, and the project team published previously that the GHP component was ultra low NO_x capable (Garrabrant 2015). Additionally, it was unclear whether this GHP component would fall under Rule 1146.2 or Rule 1121, certifying to 14 ng NO_x/J or 10 ng NO_x/J respectively, with very different test procedures. Ultimately, the

SCAQMD, with jurisdiction over the two demonstration sites, determined that the GHP skid must be certified to the 1146.2 standard,[4] demonstrating compliance with the 14 ng NO_x/J emission rate using the applicable SCAQMD test standard.

Unfortunately, the team was unable to meet this requirement by supplying GTI test data of prototypes, receiving a research waiver for compliance, or by meeting requirements with an onsite source test. The GHP instead needed to be certified to the Rule 1146.2 requirement using the traditional method: using a pre-approved third-party certification laboratory. GTI and SMTI shipped one GHP skid first to BR Laboratories (Huntington Beach, California), that provided the necessary services to certify these GHP prototypes as ultra low NO_x. Documentation associated with this certification is available upon request. When certified to Rule 1146.2, these GHPs will meet SCAQMD requirements in future efforts provided they are substantially similar to the certified prototypes.

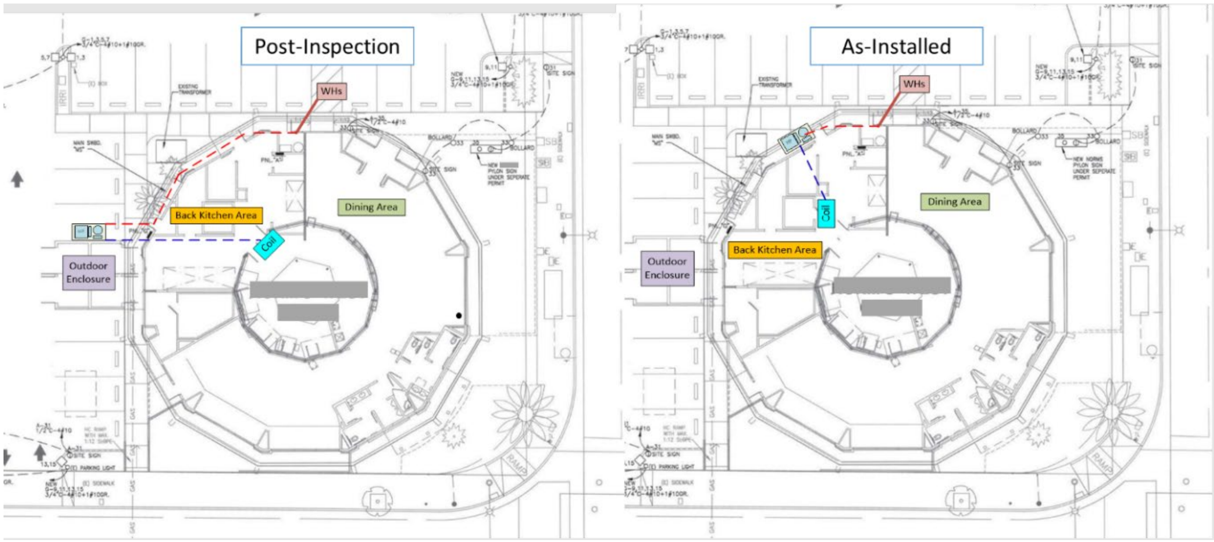
Site Preparation for Installation

The skidding procedure reduced onsite challenges associated with plumbing the GHP unit to its indirect tank, so SMTI prepared several aspects of the GHP system wiring and controls. However, much of the integrated GHP system was installed and configured on a custom basis. This was largely driven by the relative location of the three primary components: the GHP skid, the indoor gas-fired water heater(s), and the fan coil unit (FCU) for indoor cooling. Both sites obliged by providing the project team with full sets of architectural plans to facilitate pre-installation planning. With the indoor water heaters fixed, as described in the baseline reporting, the two primary concerns were the placement of the GHP skid and the indoor FCU, described in sequence.

- For Site #1, as shown in Figure 25 and Figure 26, the original intent was to either place the GHP skid adjacent to the outdoor enclosure and a parking space or, as a backup, on the rooftop of the enclosure. During installation preparations, the project and host site agreed that a location closer to the water heater mechanical closet and the preferred location of the indoor FCU (facing the interior cooking area) would be optimal, to minimize the hot water piping from the GHP indirect tank on the skid to the water heaters (red dashed line) and the closed chilled water loop (blue dashed line) between the GHP and the indoor FCU. The site agreed to place the skid in a lightly landscaped area along the exterior wall as shown in the diagram, reducing the length of both lines. For the FCU, access through drop ceilings and placement of other utilities prevented installation in the preferred location. Rather, the FCU was placed within the back kitchen area.

[4] Rule 1121 covers residential gas-fired water heaters, with a firing rate of less than 75 kBtu/hr, with a water heater understood to be a closed vessel. While the GHP component technically had firing rate in this range, a maximum input of 55 kBtu/hr, it was not configured as a closed vessel and the GHP was more akin to a process heater or commercial water heater subject to Rule 1146.2, which covers all commercial water heaters with inputs below 2,000 kBtu/h that are not subject to Rule 1121. Ultimately, SCAQMD directed the project team to certify to Rule 1146.2 in this instance.

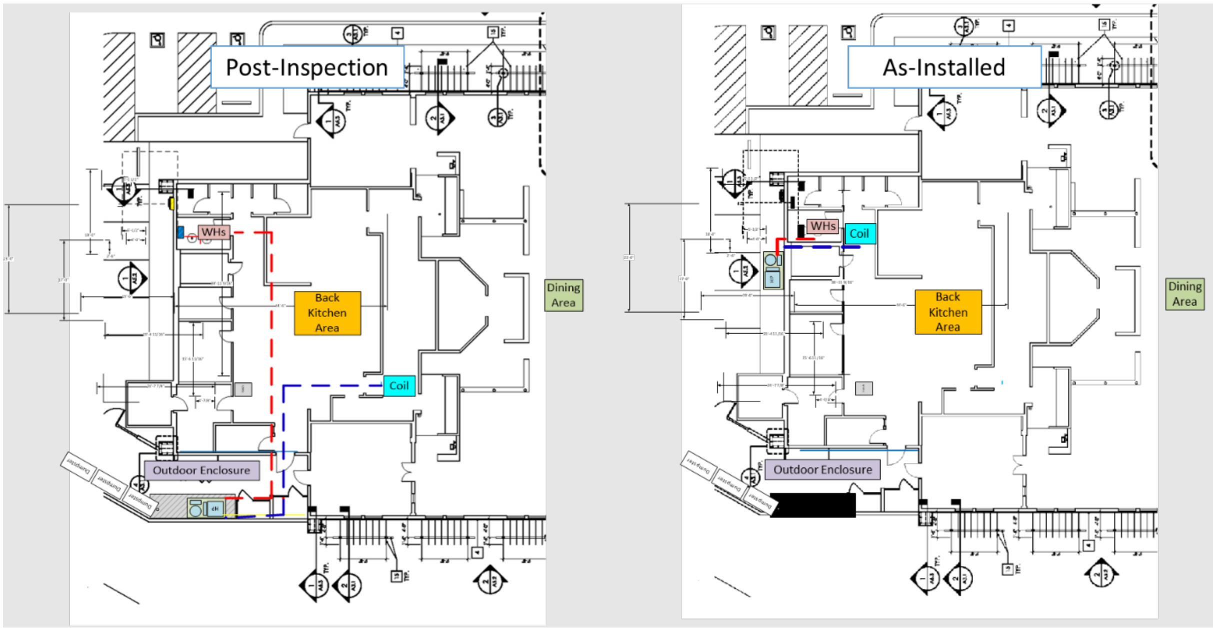
Figure 25: Original Post-Inspection and Final As-Installed Components (Site #1)



Source: GTI

- For Site #2, the project team had similarly intended to place the GHP skid near an outdoor enclosure, though specifically within the enclosure in this case. Also similarly, this created longer hot-water and chilled-water lines to the mechanical room water heaters and the intended FCU location facing the main cook line. With host site approval, the skid was instead placed on gravel between the exterior wall and a parking lot curb, much closer to the indoor water heaters and eventual FCU placement. With the same challenge of existing utilities and other barriers obstructing the installation of a chilled water loop within a drop ceiling, the FCU was necessarily installed in a hallway in the back kitchen area, mainly providing cooling to the primary dishwashing area.

Figure 26: Original Post-Inspection and Final As-Installed Components (Site #2)



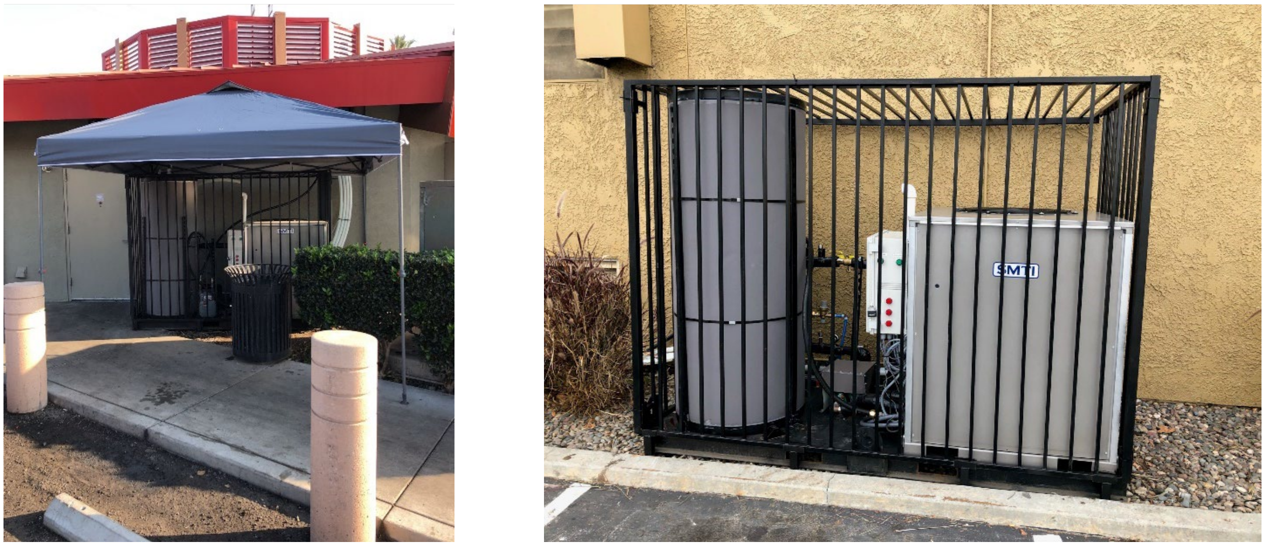
Source: GTI

The GHP skid and FCU placement were both necessary compromises, impacted by site-specific constraints and the temporary nature of their installation. While the hot-water connection and chilled-water loops were shorter than expected, reducing the impact of system standby losses and required pumping energy, the compromises on performance follow.

- The GHP skid did not have the manufacturer-required setbacks at each site due to the proximity to the exterior wall and the encroachment on a sidewalk (Site #1) and parking lot (Site #2). As a result, the bottom of the "U" evaporator coil was not installed with the required 18" setback, limiting air flow within this portion and creating sub-optimal performance for the GHP. With efforts to maximize this gap between the wall, the net distance was 8" for Site #1 and 7" for Site #2, well below requirements. Initial placement of GHP skids is shown in Figure 27, with additional efforts to maximize this distance as permitted by the sites. The example of Site #2 is shown in Figure 28, where the skid was sitting on the curb, which was permitted with the addition of parking bollards in the adjacent parking space to prevent damage to vehicles.
- The FCUs were not directed at portions of the cook line and food preparation areas. In addition to embedded utilities and other barriers blocking the team from running chilled water lines, both sites expressed concern with the water/glycol mixture being so close to cooking areas. This concern, brought on by the potential for leaks of water glycol, was in part perceived (even though food-grade propylene glycol was used as antifreeze) that leaks could cause concerns with customers and health officials. As a result, there was lower comfort running these chilled water and glycol lines near or above cooking areas. Ultimate placement of the FCUs was potentially less useful for improving the thermal comfort of restaurant employees, though this would only be reflected in qualitative data collections.
- The chilled water flow rates were below manufacturer requirements. At both sites, challenges associated with the length of and restrictions within the chilled water loops prevented the installed and commissioned systems from reaching the design chilled water flow rates recommended by the manufacturer. Additional issues were observed with effective air removal from these loops. The team made efforts to mitigate this issue, which had the effect of reducing the supplemental A/C effectiveness from the GHP (lower flow rate increased loop temperatures overall), including up-sizing circulation pumps and removing restrictive piping segments. However, the best each site could get was within 65 percent and 75 percent of target for Site #1 and 55 percent of target for Site #2, the latter impacted by a damaged FCU. Further details on this issue are outlined in Appendix C.

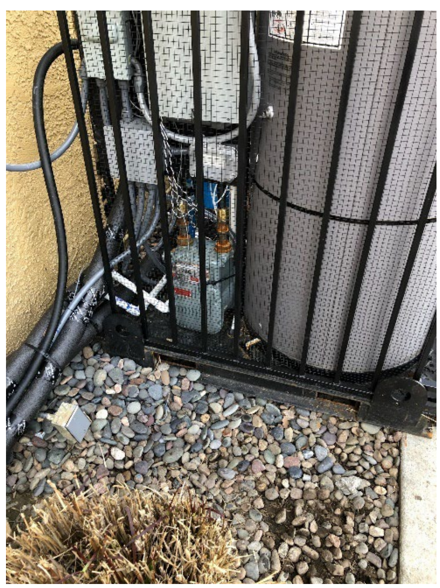
Finally, in an apt recommendation from the manufacturing partner, an anti-vandalism cage was specified at a late time for the outdoor skid. The intent was both to protect the prototype equipment and associated instrumentation, but also to protect individuals from any potential harm due to the experimental equipment. While the GHP equipment was expected to be safe, from experience with prior demonstrations it was determined that aggressive tampering could create unsafe operating conditions. As a result, custom anti-vandalism cages were built for the two GHP skids and affixed at each site, which ultimately proved useful at Site #2, which late in the demonstration period suffered tampering by individual(s) reaching between the skid and the exterior wall. (See Figure 28 for an image of the site wall gap before vandalism.)

Figure 27: Photos of Initial GHP Skid Placements Including Anti-Vandalism Cages at Site #1 (Left) and Site #2 (Right)



Source: GTI

Figure 28: Wall Gap at Site #2



Source: GTI

Installation, Commissioning, and Servicing

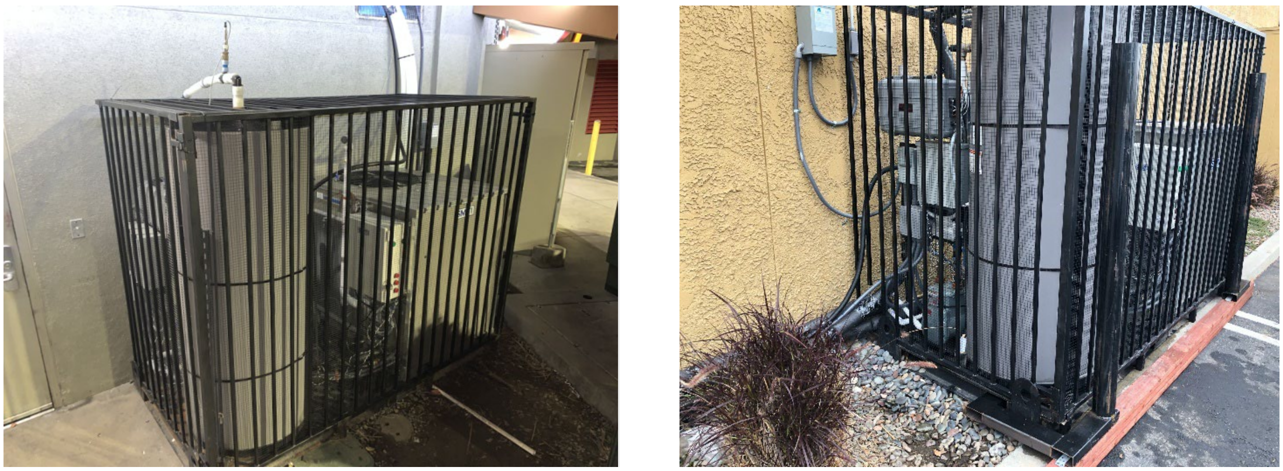
Upon receiving certification from SCAQMD in late 2018 and finalizing installation plans after the holiday period,[5] the project team scheduled installation and commissioning of the two sites from late January to late February 2019. GTI and its project team, including extensive support

[5] Both sites limited on-site activity and major physical changes to the sites between November 15^{th} and December 31^{st} to accommodate the busy holiday season.

from SMTI, A.O. Smith, J.C. Mechanical, and ADM Associates, completed the integrated GHP system and DAS commissioning in late February with the formal beginning of the integrated GHP system monitoring period in the first full week of March 2019. Key commissioning photos from the two sites follow, including:

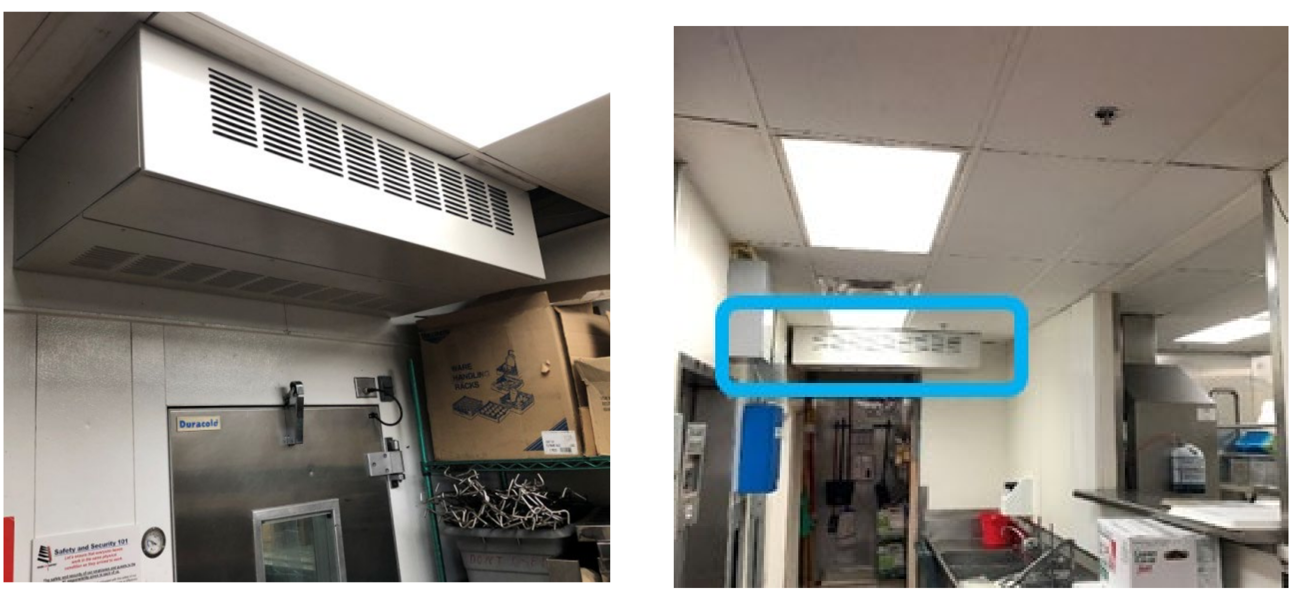
- Photos of the outdoor GHP skids at both sites (Figure 29).
- Photos of the indoor FCU units (Figure 30).
- With Site #2 as an example, the indoor plumbing modifications at the water heaters before and after integrated GHP system commissioning, highlighting the hot water inlet and bypass from the outdoor skid upstream from the installed water meter (Figure 31).

Figure 29: Gas Heat Pump Skid Operating at Sites #1 (Left) and #2 (Right)



Source: GTI

Figure 30: Location of Fan Coil Unit at Site #1 (Left) and #2 (Right, Highlighted)



Source: GTI

Figure 31: Before and After Integrated Gas Heat Pump System Commissioning at Site #2

Source: GTI

Regarding primary concerns with integrated GHP system infrastructure needs and other commissioning requirements, the following items are noteworthy:

- **Inlet Gas:** Taken by the plumbing contractor, the inlet gas pressure at the meter ranged from 8.0" WC to 10.0" WC at the two sites. Adjustments were made during initial firing of the GHP to 5.0 percent O2 dry. Per the local gas utility, the inlet fuel HHV ranged from 1,020 to 1,040 Btu/SCF over the course of the study, with site-specific monthly values used in analysis.
- **Closed Hydronic/Chilled Water Loops:** In the case of the chilled water loops, the glycol mixture was monitored with periodic visits to meet the intended target of 35 percent glycol by volume and to adjust the calculated loop thermo-physical properties, though lower concentrations were later tolerated due to observed operating conditions. To maintain desired loop pressure, auto-fill assemblies were applied at both sites to automatically maintain pressure through small, controlled additions of city water. On occasion, the project team struggled with removing air from these loops when the system was serviced, which led to lower-than-required flow rates.
- **Electrical Service:** At both sites, adequate electrical service was available for the outdoor GHP skid; however, infrequent interruption of power did require onsite service visits as noted in the following section, and in several cases the GHP servicing was triggered by site electrical faults, such as a power surges.
- **Venting and Condensate Disposal:** Condensate disposal and venting were consistent between the sites as local conditions permitted, with sites disposing

condensate into a gravel pit and venting flue products directly above the GHP unit, as is typical for these types of equipment.

In addition to those challenges outlined in the baseline monitoring period, the project team overcame several more datalogging, installation, and complete commissioning challenges that are outlined here following the initial commissioning of the system in March 2019. Issues such as environmental (site-specific, outside of project team’s control) and others were preventable errors that the project team learned from extensive observations and data review. These issues are outlined in detail in Appendix B.

Integrated Gas Heat Pump System Performance

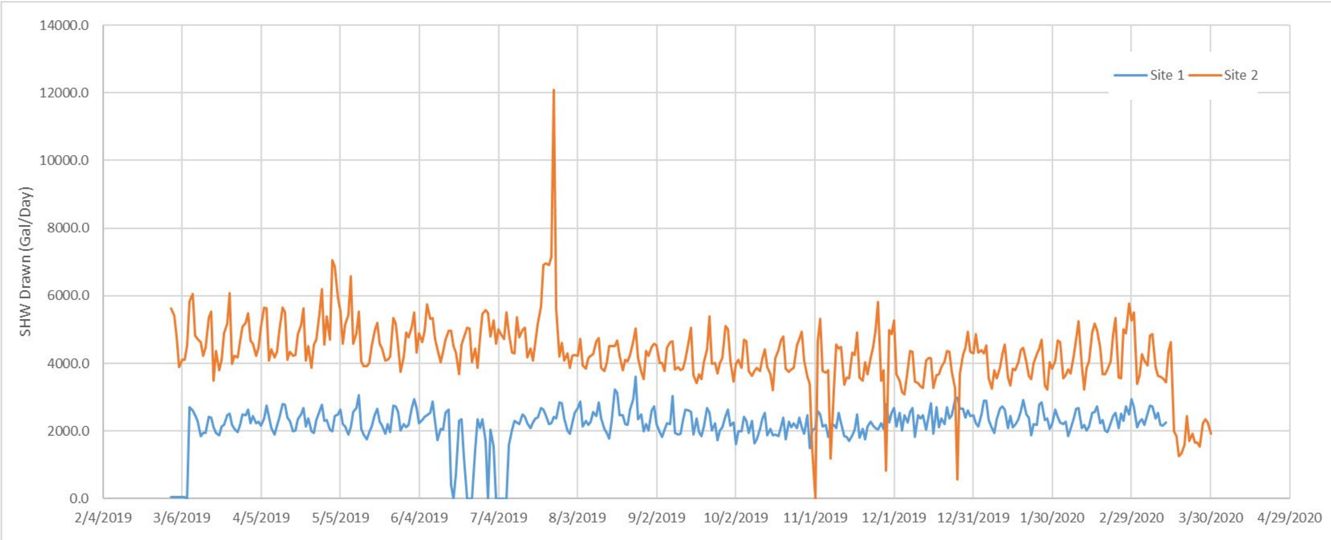
Water Heating Results

With the issues addressed identified in the prior section, including calibration of select RTD sensors and modeling of the gas consumption of Site #2 GWH #2 for a limited duration the project team monitored the water heating performance of the integrated GHP system from March 2, 2019, to March 12, 2020 (Site #1) or March 30, 2020 (Site #2) per the monitoring plan. This included the thermal output of the GHP unit, the indoor GWHs, and the complete system at both sites. Upon de-commissioning of the integrated GHP system in March 2020 for both sites, the second baseline period initiated focusing back on the indoor GWHs only, as previously described. Performance of the integrated GHP system for delivered hot water is compared primarily to the original baseline period, due to the impact of COVID-19 on normal restaurant operations during the second baseline.

With data summarized in the following charts, the project team made the following observation:

- **Service Hot Water (SHW) Consumption:** There was no major change in SHW consumption for the two sites upon commissioning of the integrated GHP system. Shown in Figure 32, the two sites had typical week-to-week variations of 2,000 to 2,500 gallons per day (Site #1) and 4,000 to 6,000 gallons per day (Site #2). Daily outliers include water heater servicing periods and restaurant closures, in early Summer 2019 at Site #1 and late Fall 2019 at Site #2. Addressing an observed GWH water leak at Site #2 led to an observed spike in consumption in late July. The primary structural change in SHW consumption was brought about by the COVID-19-related reduction in operations, which occurred after decommissioning Site #1 but did impact the last two weeks of operation at Site #2. This SHW consumption impact is further discussed in the baseline data reporting.

Figure 32: Daily Service Hot Water Consumption for Site #1 and Site #2 During Integrated Gas Heat Pump System Period



Source: GTI

- **GHP Activity:** Highlighted in Table 7, this 12-month monitoring period, coupled with high SHW demand at both sites produced significant GHP operation: over 9,000 hours collectively. Due to the 4:1 modulation functionality of the GHP, in the case of the 24-hour diner Site #1, the GHP would commonly remain active continuously for several days at a time. As a result, the number of GHP individual on-cycles is much lower than anticipated. This is further reflected in Figure D-14, which tracks the total daily run times and durations of the longest daily GHP on-cycle for each site over the monitoring period. Where gaps in GHP operation are seen lasting multiple days, the primary operational issue is noted. In total, the two sites had 72 percent and 65 percent up-time of the GHP, impacted by both operational issues of the GHP system and DAS, site-specific issues (for example, electrical faults), and the scheduling and coordination of resources.

Table 7: Summary Table of Integrated Gas Heat Pump System Activity

	Site #1	Site #2
GHP Cycles (On/Off) [Avg. per day]	1,157 [4.6]	597 [2.6]
GHP Runtime (Hours)	4,792	4,224
Days GHP Operational (Days) [%]	274 [72%]	258 [65%]
Average SHW (Gal/day)	2,226	4,396
Avg. System Temperature Rise (F)	66.1	70.7
Average SHW Load Fraction	73.7%	43.2%

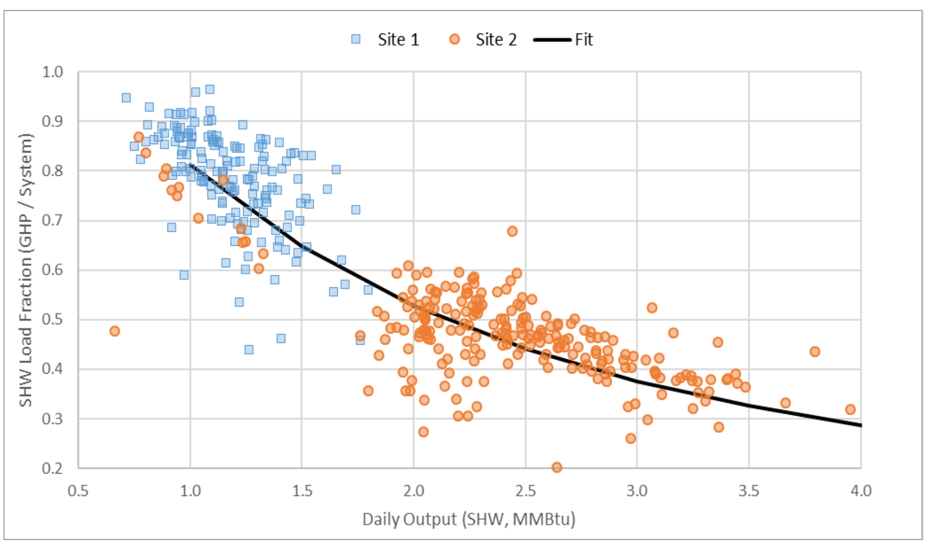
Source: GTI

- **SHW Load Fraction:** Defined as the fraction of daily hot water output supplied by the GHP unit relative to the complete integrated system (GHP + indoor GWHs that it is preheating), the SHW load fraction is a means of measuring the degree to which the GHP is "baseloaded". Higher values of load fraction indicate the GHP is meeting most or 100 percent of the load, and likely the GHP is operated at a lower modulation point to "load follow".

- Site #1: Due to the lower overall SHW consumption at Site #1, and that the 24-hour operations spread out this consumption throughout the day, the GHP at Site #1 covers most of the SHW load most of the time, with load fractions typically between 70 percent and 95 percent, as shown in Figure 33. Also shown are the daily average delivered temperatures from the GHP skid to the indoor GWHs and the final delivered temperature from the overall integrated GHP system. Note that some of the days where the apparent SHW load fraction is 100 percent are very low or no-load days.
- Site #2: By contrast, the larger SHW draw, often by two times or greater and a steadily rising peak in SHW consumption each day towards the evening results in a much lower load fraction at Site #2, on average. The GHP commonly carries 30 percent to 60 percent of the overall SHW load, which is more of a baseloaded state, as seen in Figure D-14.

Comparing load fraction across the sites, where the GHP component is identically sized and controlled, offers additional insight. A distinct curve forms across the sites when considering daily SHW load fraction as a function of total SHW output (from the whole system). In other words, the observed lower load fractions at Site #2 are predominantly a function of daily SHW demand.

Figure 33: Service Hot Water Load Fraction as Function of Daily Load



Source: GTI

The energy inputs highlight the daily gas and electricity inputs into the integrated GHP system. For gas inputs, the daily consumption by the GHP and the two indoor GWH units is shown, including notation of when the GWHs are replaced. One can see the rotation of duty amongst the components over the monitoring period, with times that one or both of the GWHs are functionally offline. This flexibility and inherent redundancy of this integrated system are clear, given the high SHW demand and the frequency of servicing needs previously noted. In fact, at Site #1, upon replacing the indoor GWHs there was a period of several weeks where an electrical issue with the GWH installation prevented their operation and the GHP unit carried the full SHW restaurant load. On electricity, the demand of the GWHs, the GHP unit and the two circulation pumps (hydronic and chilled water) are shown in Appendix D, highlighting between 20-25 kWh/day for the complete system, across sites. Given that the largest component of the system consumption is the GHP (and for it, the evaporator fan), improvements were made to reduce the nominal power consumption of the GHP from 300 W to 600 W by using more efficient components.

Summary of Integrated GHP System Phase Results – Water Heating

Table 8 summarizes the key metrics from a water heating perspective, with the weather conditions shown in Appendix D which have an impact on GHP performance when it is operating in an air-source mode and not providing indoor supplemental A/C. As noted, both sites were observed to have continuous recirculation during the integrated GHP system monitoring period.

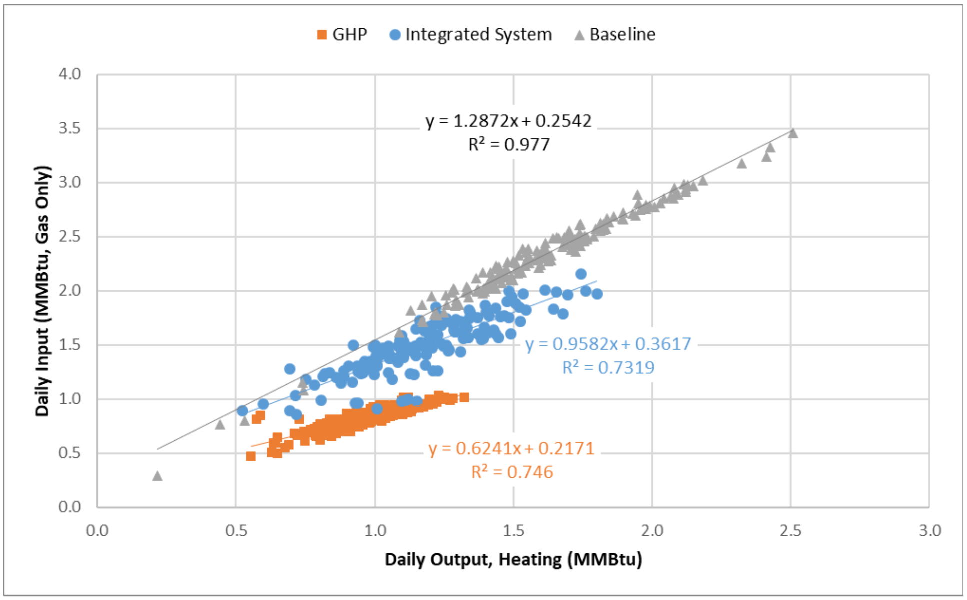
Table 8: Summary of Key Metrics – Water Heating

Metric	Site #1	Site #2
SHW Load (Gal/Day) – Average	2,225	4,396
SHW Load (Gal/Day) – Peak	3,605	7,152
Average Gas Consumption (CF/day)	1,488	2,429
Average Electricity Consumption (kWh/day)	22.1	23.4
Average Delivered Temperature from System (°F)	132.6	135.5
Average Delivered Temperature from Skid (°F)	112.9	94.4

Source: GTI

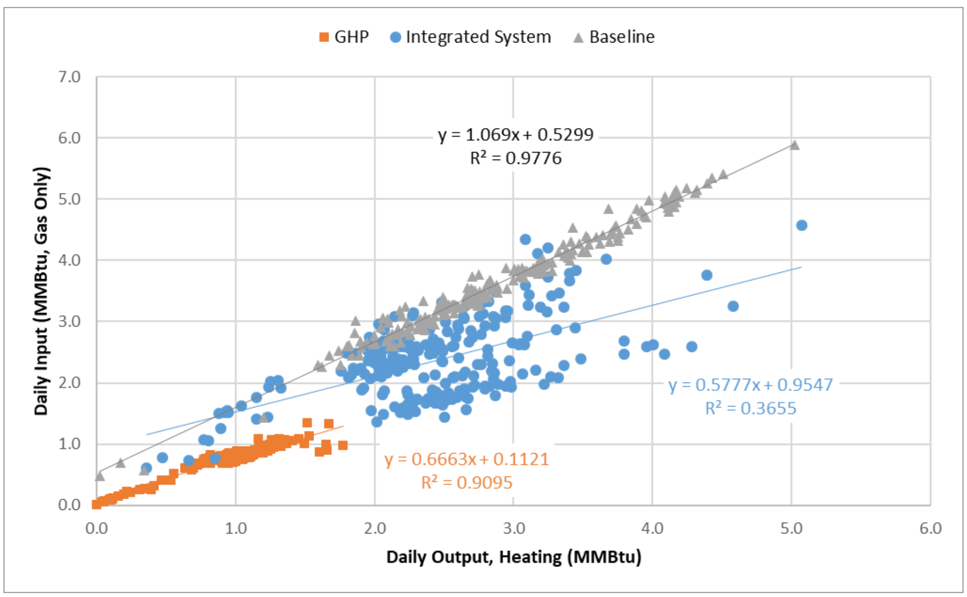
As outlined in the baseline monitoring, the extrapolation and comparison with the integrated GHP system are performed using the normalization afforded by the "Input/Output" method, accounting for hot water demand and inlet/outlet water temperatures. Per Figure 34 and Figure 35, which highlight the input/output curves for the two sites, the input is counted on a gas input only basis and two curves are presented for each site: the GHP itself (input/output of the unit alone as a subcomponent), and the overall integrated GHP system (including indoor GWHs). The scatter is greatest for the integrated GHP system when observing the diversity of GWH versus GHP runtimes at the two sites. As noted in the baseline monitoring period, a lower slope indicates a greater steady state efficiency, and a lower intercept relates to a reduced level of standby losses. For example, when focused on heating output alone, Site #1 appears to have lower system standby losses and Site #2 appears to have higher system efficiencies, which follow from the SHW consumption patterns at both sites. Normalization of electric power consumption for water heating equipment and an examination of GHP performance is also provided in Appendix D.

Figure 34: Input/Output Chart – Integrated Gas Heat Pump System at Site #1 for Water Heating Only



Source: GTI

Figure 35: Input/Output Chart – Integrated GHP System at Site #2 for Water Heating Only

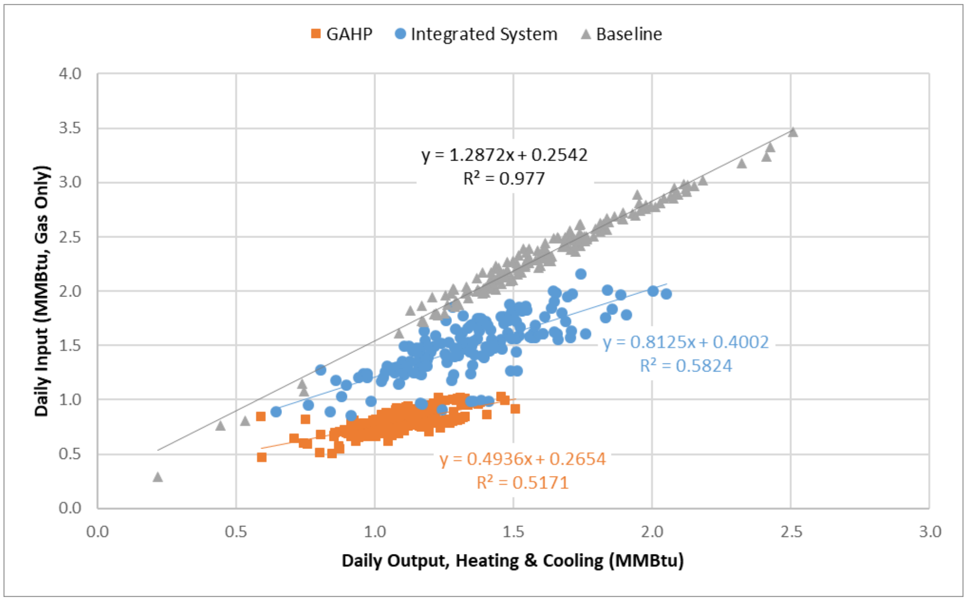


Source: GTI

GHP-Phase Rooftop HVAC and Supplemental A/C

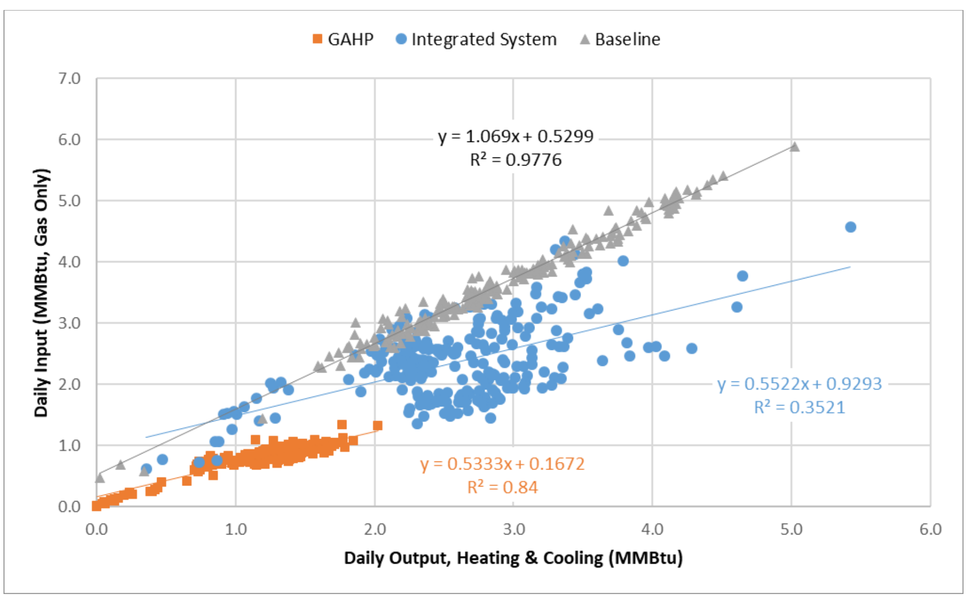
Using the conservative assumption that all supplemental cooling is useful, the prior analysis includes supplemental GHP cooling as an output. Augmenting the prior input/output charts in the previous section, Figure 36 and Figure 37 show useful cooling measured at the FCU as an output combined with the SHW output, for both GHP and the integrated system. When converting these linear fits to delivered efficiency (gas only), the curves in Figure 38 show the estimated efficiency of the GHP and the integrated system, for both SHW only and with supplemental A/C, all as a function of SHW load.

Figure 36: Input/Output Chart – Integrated Gas Heat Pump System at Site #1 for Heating and Cooling



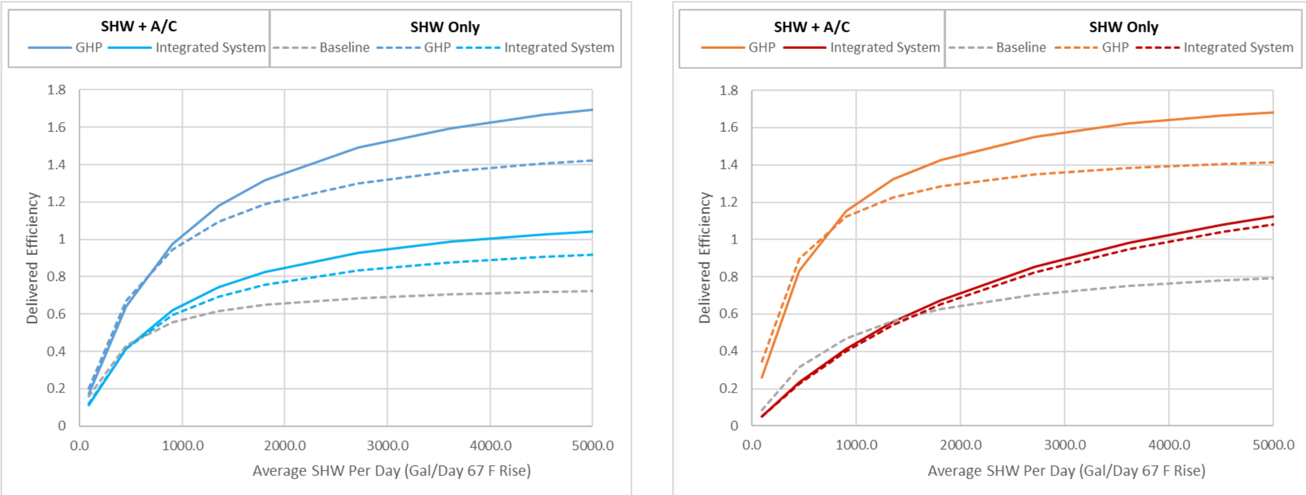
Source: GTI

Figure 37: Input/Output Chart – Integrated Gas Heat Pump System at Site #2 for Water Heating Only



Source: GTI

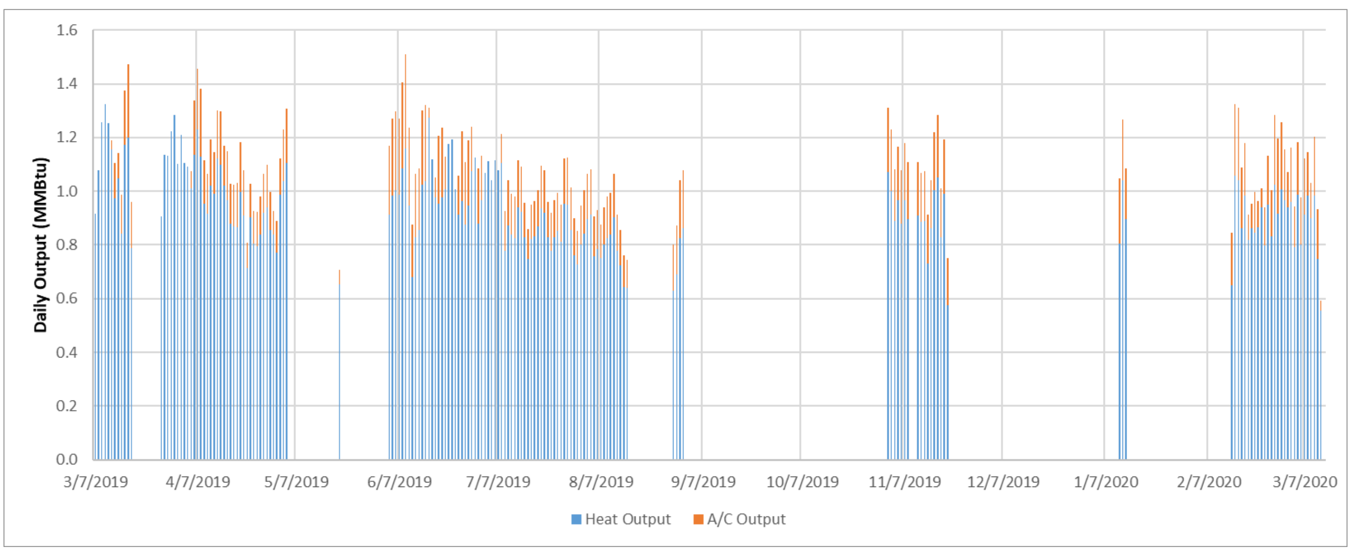
Figure 38: Delivered Efficiency of Gas Heat Pump Unit and Integrated System Normalized to Load at Site #1 (Left) and Site #2 (Right)



Source: GTI

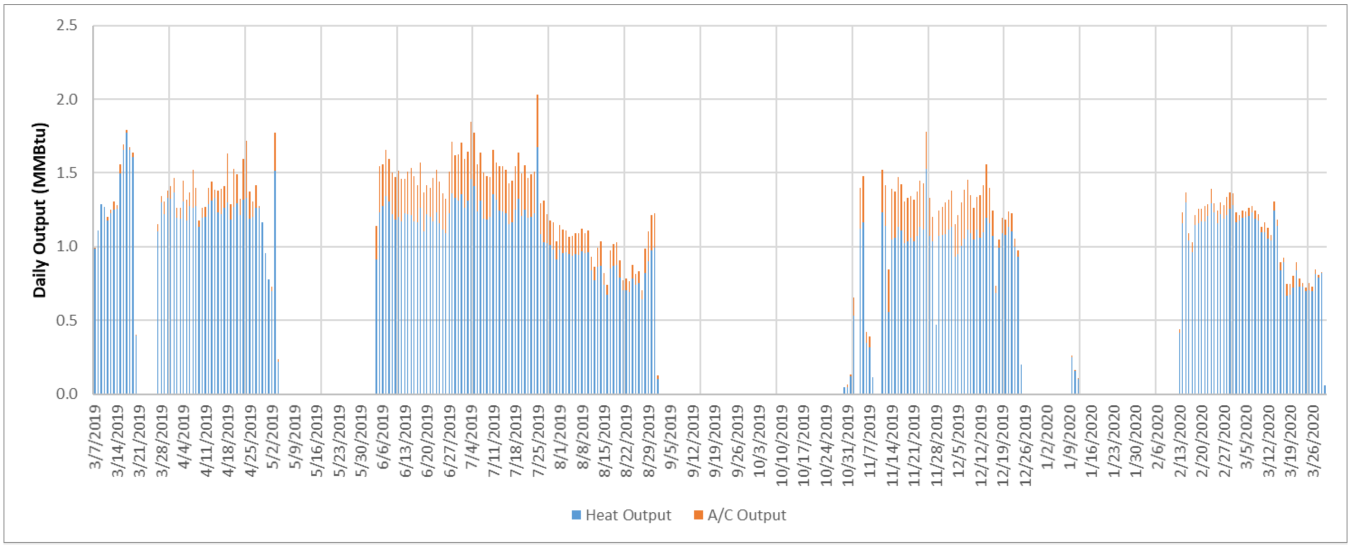
There was observed year-round demand for supplemental A/C from the integrated GHP system. While the original site selection assumed the added 0.5-2.2 tons of cooling would be useful during an extended cooling season, perhaps from April to November in the mild Los Angeles climate, with only 1,200 heating degree days per year on average (2017-2019). However, the internal loads within the kitchen did demand year-round cooling. This is in line with prior studies of thermal comfort in commercial kitchens, which revealed that restaurant cooking staff were equally uncomfortable during winter and summer months (Stoops 2013). As shown in Figure 39 and Figure 40, when there was a call for hot water from the GHP and it was operational, the majority of days at both sites also received up to 0.39 MMBtu/day of cooling.

Figure 39: Daily Heat and Cooling Output from Gas Heat Pump at Site #1



Source: GTI

Figure 40: Daily Heat and Cooling Output from Gas Heat Pump at Site #1

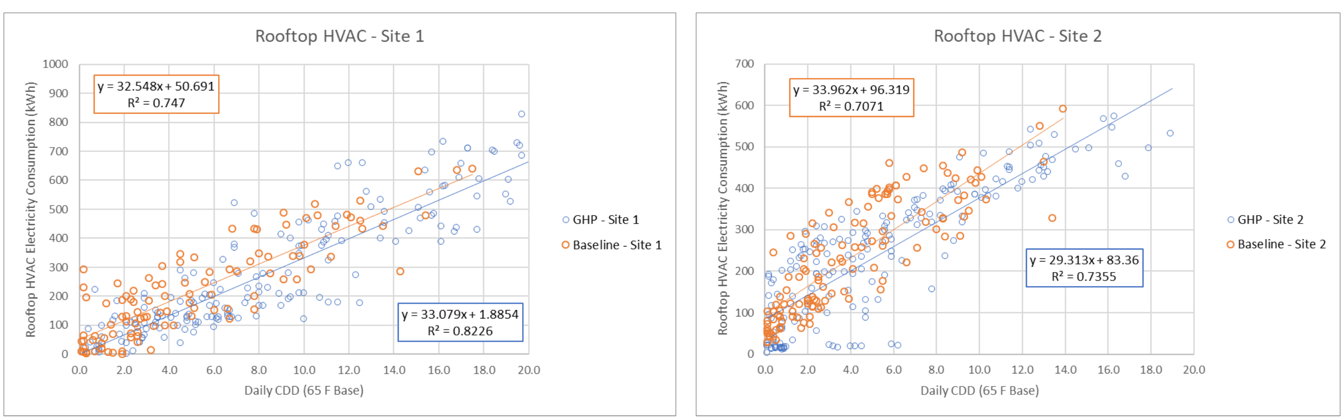


Source: GTI

Displaced A/C – As Measured

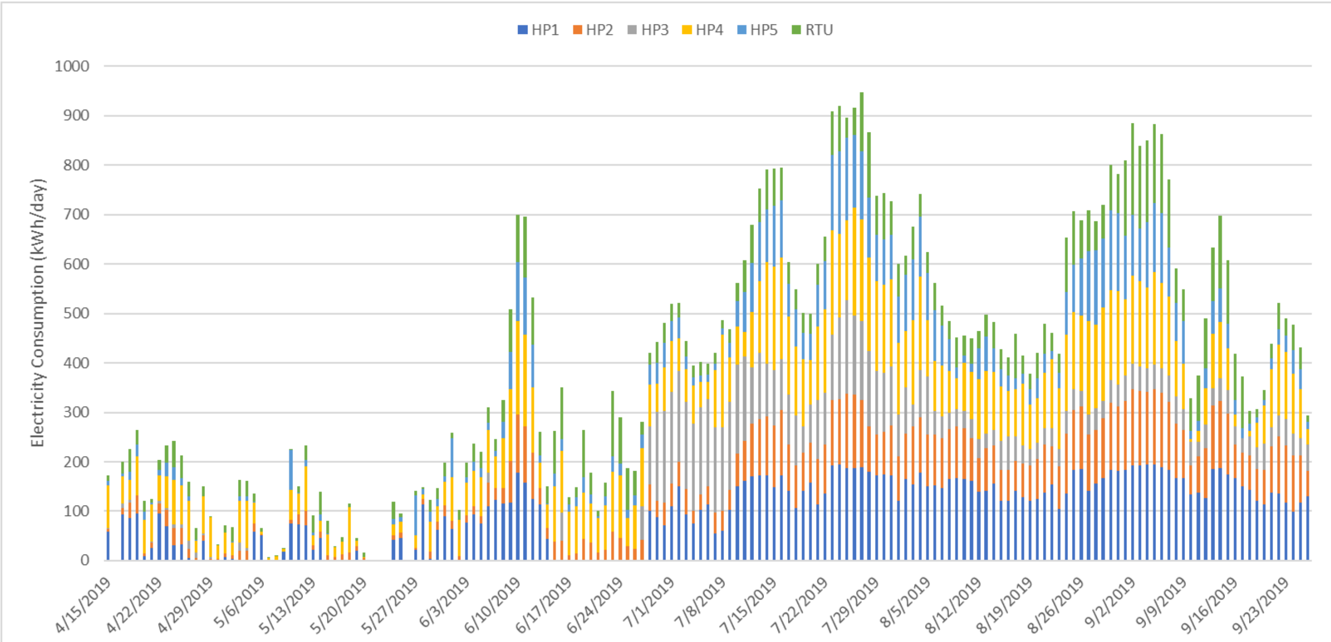
With the same instrumentation in place from the baseline period on the rooftop HVAC equipment at both sites, five heat pumps and an RTU at Site #1 and five RTUs at Site #2, daily electricity consumption of this equipment (as a function of daily cooling degree day [CDD]) is shown in Figure 41. Note that for the GHP phase, data points are screened from the charts when the GHP unit is not operating and providing supplemental cooling. In both cases, a measurable weather-adjusted reduction in HVAC equipment electricity consumption is seen, generally reducing offsets consistent with the addition of near-constant supplemental cooling. For Sites #1 and #2, the reduction in electricity consumption is 13.7 percent and 13.6 percent respectively, amounting to annual reductions of 10,821 kWh/year or 9,663 kWh/year using observed cooling degree days in 2019 from 4/1 to 11/30. As was analyzed in the baseline period, the distribution of power consumption of rooftop HVAC equipment is examined in Figure 42 and Figure 43.

Figure 41: Normalized Air-Conditioning Electricity Use at Sites #1 (Left) and #2 (Right) for Baseline and Integrated Gas Heat Pump System Phase



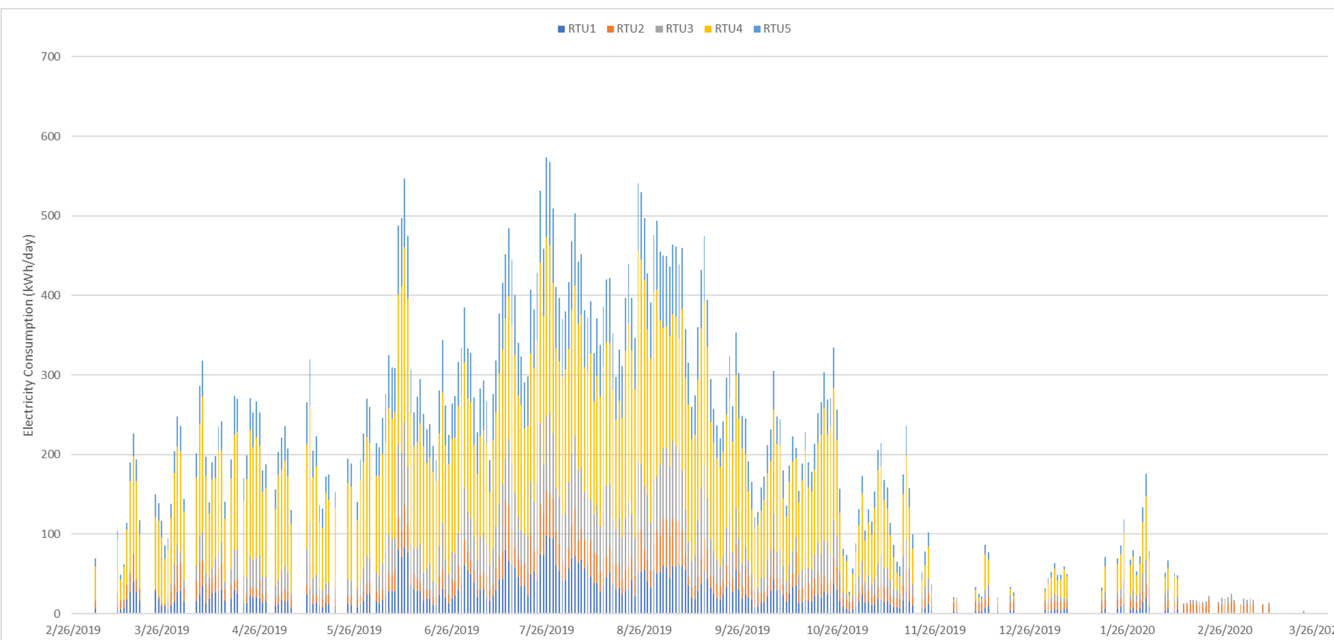
Source: GTI

Figure 42: Distribution of Daily Electricity Demand – Site #1 Rooftop



Source: GTI

Figure 43: Distribution of Daily Electricity Demand – Site #2 Rooftop



Source: GTI

Extrapolations of Integrated GHP System Energy, Emissions, and Economic Savings

Using the input/output curves for baseline, Site #1, and Site #2 integrated GHP system equipment, the natural gas and electric consumption, emissions, and economics are extrapolated from daily averages.[6] This uses the same assumptions as in the baseline monitoring section for source energy factors, gas/electricity grid GHG intensity, and commercial utility rates (ignoring demand charges or TOU rates). Cooling is assumed to be useful year-round and, based on predicted output from input/output curves; the estimated avoided electricity consumption from existing HVAC is deducted from the incremental power consumption. This is reflected in "net electricity" consumption for the GHP and integrated GHP system scenarios, where increased electrical demand for the GHP itself and the additional components (for example circulation pumps) is reduced by the site electricity savings associated with displaced A/C demand. For this estimation, an assumed aggregate HVAC EER of 11.0 (Site #1) and 12.0 (Site #2), consistent with existing rooftop HVAC equipment, is used in conjunction with estimated displaced cooling output from the integrated GHP system input/output performance curves.

Two scenarios are presented in Table 9, one with the integrated GHP system as sized at the two sites (see SHW load fraction), and the other as a "GHP only" system using the performance of the GHP to estimate the GHP component alone and sized properly to meet the total SHW load as a hypothetical and performance ceiling. Overall, the gas savings are substantial, 16 percent-26 percent for the sites as installed, with up to 44 percent to 46 percent savings with GHP "right-sizing." Similar magnitudes of savings are also estimated for annual operating costs and GHG emissions.

Table 9: Extrapolated Integrated GHP System Energy, Emissions, and Economic Savings

	Site #1: GHP Only System	Site #1: Integrated GHP System***	Site #2: GHP Only System	Site #2: Integrated GHP System***
Average SHW Load – GHP Period (Gal/day)	2,225	2,225	4,396	4,396
Average Temperature Rise (°F)	66	66	71	71
SHW Load Fraction (%)	100%	73.7%	100%	43.2%
Baseline* Gas (Therms/year)	6,626	6,626	11,945	11,945
Baseline* Electricity (kWh/year)	651	651	843	843
Baseline* Source Energy (MMBtu/year)	727	727	1,308	1,308
Baseline* GHG Emissions - Baseload (Lbs/year)	95,944	95,944	172,758	172,758
Baseline* GHG Emissions - Non-baseload (Lbs/year)	96,312	96,312	173,234	173,234
Baseline* Annual Utility Cost ($/year)	$6,123	$6,123	$10,990	$10,990
GHP/System Natural Gas (Therms/year)	3,555	5,562	6,649	8,894
GHP/System Net Electricity Less A/C Savings (kWh/year)	757	3,691	-8,028**	3,374
GHP/System Source Energy (MMBtu/year)	388	627	663	987

[6] Note that the average SHW load differs from the load measured during the baseline monitoring period. Thus, the results here are scaled using the input/output curves to the load measured during the GHP monitoring period. With this, the baseline gas and electricity inputs are scaled using the same normalized curves.

	Site #1: GHP Only System	Site #1: Integrated GHP System***	Site #2: GHP Only System	Site #2: Integrated GHP System***
GHP/System GHG Emissions - Baseload (Lbs/year)	51,334	82,071	90,428	129,809
GHP/System GHG Emissions - Non-baseload (Lbs/year)	51,394	83,788	85,417	131,238
GHP/System Annual Utility Cost ($/year)	$3,250	$5,506	$4,745	$8,463
GHP/System Natural Gas Savings (%)	46%	16%	44%	26%
GHP/System Natural Gas Savings (Therms/year)	3,070	1,064	5,296	3,050
Increased Elec. Consumption (kWh/year)	106	3,040	-8,871**	2,531
GHP/System GHG Savings - Baseload (%)	46%	14%	48%	25%
GHP/System GHG Savings - Baseload (Lbs/year)	44,610	13,873	82,330	42,949
GHP/System Operating Cost Savings (%)	47%	10%	57%	23%
GHP/System Utility Cost Savings ($/year)	$2,873	$617	$6,245	$2,527

*Note that baseline figures are scaled to this SHW load, as measured during the GHP period.
**Net electricity savings at Site #2 for the "GHP Only System" are high due to the large SHW load and the model assumes all A/C is useful, which will depend on the cooling needs of the building.
***Integrated GHP System reflects the performance of the integrated GHP system as paired with the existing gas water heaters on site for pre-heating.

Source: GTI

Contractor and Restaurant Staff Interviews

In addition to quantitative data collections, GTI and its partner ADM Associates developed and executed surveys for the host sites and installation contractor to gather qualitative data on the performance of the integrated GHP system. With a two-site demonstration of an experimental technology, it was difficult to separate the experience of the demonstration project (such as installation of complex data collection system) from the technology itself since this was a hands-on demonstration. While the survey results reflect the experience of both the project and the technology, the manufacturing partners noted that a commercialized solution will have some or all the following features:

- **Simplified Installation:** To install and commission such an integrated GHP system, as either a retrofit or as new construction, will take less time than shown in this project. In addition to eliminating the instrumentation needs (such as temperature sensors within heating/cooling loops) the installation may be further simplified by installing the GHP component on the roof, which is common with commercially available GHP equipment. This was avoided to accommodate GHP removal at the close of the project, but in practice this has the net effect of reducing siting barriers and simplifying integration with indoor equipment.
- **Product Reliability:** The GHP component demonstrated in this effort was a first-of-its-kind prototype, a water-to-water version of an emerging GHP technology. The

manufacturing partner claims that product reliability will be improved with commercialized products.

- **Installer Training:** Installer training was performed by the project team in parallel with system design and site engineering tasks. A refined installer and operator training program will greatly improve the efficiency and effectiveness of integrated GHP system installation, operation, and maintenance.

Information Provided by M&V Contractor ADM Associates

This section summarizes staff perspectives on the gas heat pump units developed from interviews with the contractor and restaurant general managers.

ADM interviewed the installing contractor about the equipment and the installation process in January 2020. The interview lasted 25 minutes. The installing contractor stated that his company installs about 30 water heaters in restaurants each year, all of which are emergency repairs.

ADM completed an interview with a general manager at each of the installation sites during March 2020. The interviews lasted about 15 minutes and involved a discussion of the respondents' experience with the installation of the water heater and its use.

Restaurant Manager Perspectives

- **Unit Installation Location:** The general manager of a restaurant and the contractor noted costs and other considerations such as risks of water damage in the event of a leak, to a roof installation. The contractor also noted that installing the unit outside the building may be problematic because of space concerns or aesthetic requirements of local jurisdictions. Neither general manager had significant concerns about the location of the unit on a skid pad outside the restaurant or that there was a better location for the cooling unit. Nevertheless, one mentioned installing it on the line in the kitchen as an alternative, but the other did not think that would be a good location. The contractor believed that the cooling unit needed to be installed in the kitchen because that was where the cooling load was greatest.
- **Installation Time and Process:** The contractor reported that installing the unit took significantly longer than a conventional water heater and believed that with additional experience, the time would be less but that it would still take considerably longer than a conventional water heater. The contractor favored new construction applications for the unit so that the building is designed to accommodate the various components of the unit. However, the general manager was present for the installation and said the installation did not interrupt the business and did not have concerns about the installation process.
- **Unit Reliability:** The contractor indicated that there were several failures during the pilot period and believed that additional development and testing time were needed before the unit was ready for a larger market. However, neither restaurant manager cited concerns about the reliability of the unit.

- **Unit Performance:** Neither general manager had concerns about the unit performance in supplying hot water, and one general manager thought that the time for water to get hot may have decreased as compared with the old unit.
- **Factors Affecting the Choice of a Water Heater:** The main considerations cited when evaluating a water heater were the unit's performance and reliability (hot water must be available to serve customers) and the energy efficiency of the unit. Both general managers thought that the unit's ability to provide cooling was a benefit and would influence their decision when choosing a water heater.

Additional findings from the interviews are presented.

Contractor Perspective

The main findings of the contractor interview were that:

- While the installer thinks the technology is a good concept, the installation was challenging and time consuming.
- The technology, as currently designed, would work better for a new construction project where space can be allocated for the mechanical systems and the roof can be engineered to hold the weight of the equipment if a rooftop installation is preferred.
- The new components had multiple incidences of failure, and getting the components fixed by the manufacturer was a slow process. Overall, the contractor thought that additional design and testing work were needed before the equipment was ready for future installations.

The contractor noted that there were multiple special needs for installation. The demonstration units were installed on a cement pad outside of the restaurant. For that type of installation, he noted that special approval needed from the jurisdictions for the visual impacts and that additional space requirements can be difficult to meet in densely populated areas of Southern California. A key consideration for a rooftop unit is verifying that the roof can handle the weight of the unit and its components. Additionally, the installer noted that a water leak with a unit installed on a rooftop creates greater risks of damage.

The contractor estimated that a conventional water heater can be replaced in about a day, where the installation of this system took approximately three weeks. The contractor believed that even with additional experience installing the unit, the time required will remain considerably longer than with a conventional system. He noted that it is not a cookie cutter unit; there is a lot of custom installation work needed to install it as a retrofit, including additional water lines. As much as the installing contractor supports the technology and its benefits, he compared the installation of the unit to installing a pool and hot tub in your backyard instead of putting in a pond. He stated that multiple issues were discovered during the installation process, which were resolved by working closely with the manufacturer and GTI.

The cooling unit was installed to provide supplemental cooling to the kitchen. The installing contractor's view was that the unit must be installed in that location because that is where the cooling load is greatest. He did not believe that there would be a benefit to installing it in the dining area, and that installing it in a dining room would not ease the installation process.

Restaurant staff did not ask many questions about the unit but did raise some concerns about the disruption; the longer installation time was perceived as an inconvenience. He additionally noted that owners might have a more favorable view of the unit because of the cost savings.

Several failures occurred with the new components of the technology post-installation, which caused some level of disruption. The installer noted that the manufacturer had some difficulty providing service and indicated that one repair took 14 weeks.

Restaurant Perspectives

Overall, both respondents provided positive feedback about the water heater and its installation. The key findings are summarized here.

- The general manager present during the installation stated that the installation process was smooth and did not disrupt business operations. This respondent noted that they would have appreciated more information about the expected benefits and energy savings during the installation process, but that otherwise his information needs were met.
- Neither respondent raised concerns about the aesthetics of the external components of the system. While one respondent noted that it was not particularly attractive, he expressed a lack of concern about the aesthetics. Furthermore, neither stated that the placement of the external unit prevented them from using the space for another purpose. Additionally, neither respondent raised concerns about noise coming from the external equipment. Neither respondent indicated a strong preference for a rooftop installation, but one noted that a rooftop installation would make more sense even though the cost would be greater.
- Both respondents stated that the cooling provided by the internal fan unit was noticeable. One characterized the cooling functionality as "quite amazing." Neither respondent indicated that they had heard comments from kitchen staff about the cooling unit. One of the respondents thought that it might be better if the cooling unit were installed in a location where it could provide cooling to the line area, though the other stated that this would not be a good location. Neither respondent stated a preference for installing the cooling unit in the dining area. Both respondents thought the cooling capacity was a benefit that would affect a decision about purchasing a water heater.
- Both respondents stated that the unit performed well in delivering in hot water. One indicated that if anything, it took less time to get hot water at the points where they checked the temperature. The one respondent who was not employed until after the unit was installed did state that he had heard there were some performance issues after the unit was first installed but was not sure of the details.
- The respondents indicated that overall, the unit was reliable. One respondent stated that there were a few minor issues. Both respondents stated that reliability of the unit is a major factor in deciding which unit to purchase, and both reported that the gas heat pump water unit reliability was satisfactory.

- One respondent thought there might be slight cost savings from the unit but noted that it is difficult to identify utility cost changes amongst other factors. The other respondent was not employed during the period the replaced conventional water heater was installed.
- The respondent who had been employed at the restaurant when the unit was installed noted that the technical team was very good to work with and that they were respectful of their time and professional in the execution of the project.

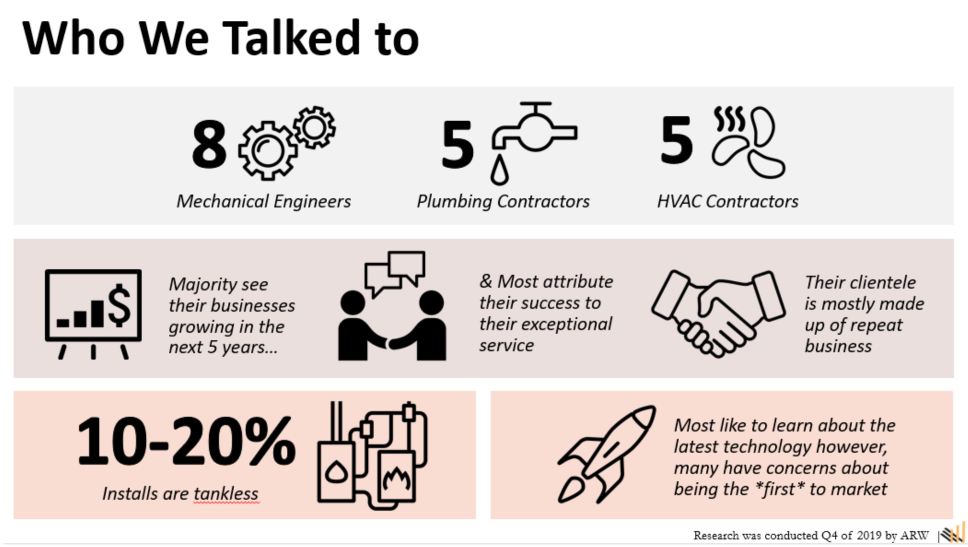
CHAPTER 4: Assessment of Market Barriers

The team surveyed and quantified market barriers to adopting the GHP both in California and nationally. Barriers included real and perceived obstacles to restaurant adoption and contractor recommendations (plumbing and HVAC contractors included). To assess these barriers, a market research plan was developed using a two-step approach: an initial qualitative step, comprising in-depth interviews and focus groups, and a second quantitative step, comprising a larger-scale online survey. Subcontractor Applied Research-West, ARW, led the design and implementation of this effort.

Qualitative Assessment Approach and Results

ARW conducted a 90-minute online video, in-depth interviews with 18 mechanical engineers, plumbing contractors, and HVAC contractors between October and December 2019. Prior to the interview, participants watched a brief video presentation describing the new GHP technology. Each interviewee was identified and invited to participate due to their role as a decision maker or key influencer regarding equipment offered by the contracting business (such as owners or managers). Screening criteria also included that at least half of their business was providing services to commercial buildings, with a focus on restaurants, nursing homes, laundromats, hotels, and resorts, and that the contractors installed at least 15 commercial water heaters per year (Figure 44).

Figure 44: Overview of In-Depth Interviews With Contractors and Engineers for Qualitative Market Assessment



Source: GTI

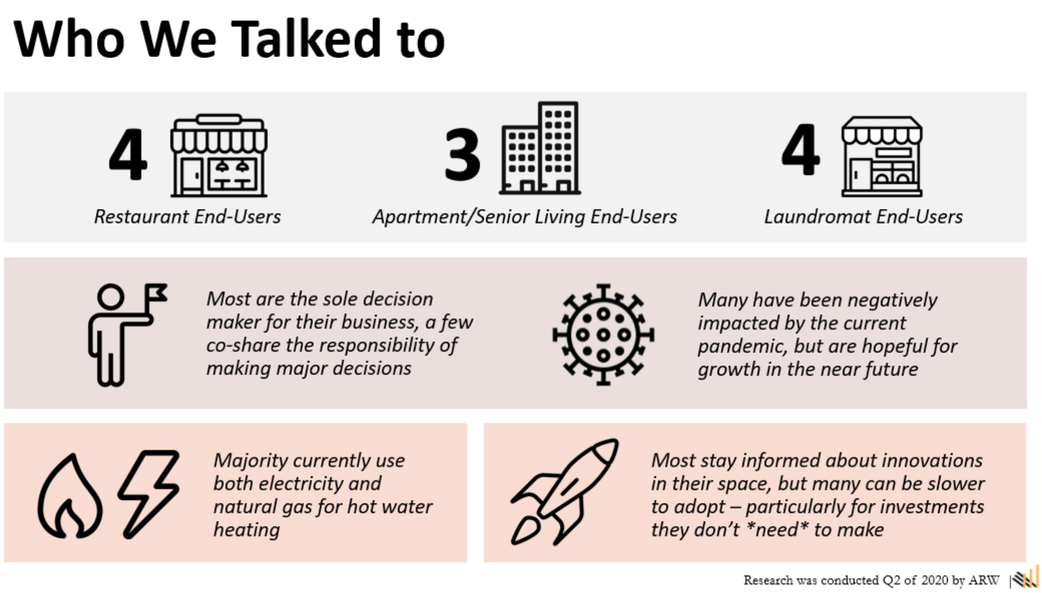
Contractors emphasized that customer needs varied significantly by industry. For example, small, independent restaurants seek installation cost savings where larger chain restaurants have enough longevity to allocate cost savings over time. Other industries have entirely different sets of priorities. In government buildings, energy savings and American-made equipment are key, and in multifamily buildings the speed of installation and replacement is the most important.

Generally, contractors had favorable first impressions of the integrated GPH technology, but with some hesitation. After being introduced to the system, respondents were initially impressed overall, and many saw it as applicable for most clients. Some respondents were hesitant and brought up concerns with unit complexity and project cost, use of ammonia with regard to unit safety, and that the unit's water heating capacity might not be sufficient for some larger users' needs. Contractors liked the flexibility of installing outside, or on the roof, but were concerned about space issues at some facilities. Respondents also cited a fear of lack of support as a key point of potential failure: difficulty accessing the parts they need for a repair or for guidance in maintenance requirements.

Ultimately, the take-away is that if these questions and concerns are addressed, many contractors are interested in a keeping an eye on and learning more about the product. Some respondents mentioned that they would at least have to see the product installed and "get to know it" for their comfort, while others said they would only feel confident if the product had a proven track record.

In addition to in-depth interviews, ARW performed three virtual focus groups with business owners in the restaurant, laundromat/laundry, and multifamily/senior living industries in late May 2020 (Figure 45). Owners and general managers indicated they made concerted efforts to stay on top of technological developments applicable to their industries.

Figure 45: Overview of Focus Groups With Business Owners for Qualitative Market Assessment



Source: GTI

Respondents indicated that with tight profit margins, adoption of new technology can be slow, with laundromats most likely to consider early adoption, with more flexibility. When exploring innovations, owners and general managers are most frequently looking for technologies with greater efficiency and an attractive ROI, saving both time and money. Restaurant end users specifically noted that they find it harder to decide where to invest their capital because of ever-changing trends and landscapes in their industries.

Respondents generally indicated that they will do their best to fix things in-house to save money and time, and that regular maintenance is key to keeping equipment running smoothly. When there is a larger issue, respondents usually have a list of pre-selected, trusted contractors that they call on, and said they rely heavily on contractors' expertise and recommendations. Respondents were generally impressed and interested in the integrated GHP technology, particularly the payback and savings over time, and the energy savings. Many cited no faults with the system, though a few respondents brought up concerns with ammonia regarding unit safety, unit size, upfront cost (particularly for businesses that may not last the duration of the unit's life), and the maximum water heating output, which some larger users felt might be too low. When a leasing option was presented, nearly all respondents were excited about the technology. Many found that the leasing option came with benefits that solved their water heating needs and addressed any initial concerns they had about upfront and maintenance costs. Additionally, they cited other advantages with the leasing option, including:

- Ability to upgrade more frequently as newer technology comes out.
- Maintenance broken down into a monthly payment, which improves their P&L.
- Potential to use it in conjunction with their current water heater to gain efficiencies.

Quantitative Assessment Approach and Results

The results and insights gained from the qualitative research phase served as the foundation for the survey design of the quantitative phase, which included the development, launch, and analysis of results from a national survey exploring the perceptions and opinions of business owners in the restaurant, laundromat/laundry, and apartment/senior living sectors. The goals of this survey were to:

- Understand the important of key features of the new integrated GHP.
- Discover the interest level of the target audience in the new integrated GHP versus existing products.
- Define which of the audience segments (restaurants, laundromats, apartment/senior living) are most likely to adopt the new integrated GHP technology.

ARW collected 200 responses in total (66 each from restaurants and laundromats68 from apartment/senior living) for this process. Figure 46 provides a summary of the selection criteria for survey respondents.

Figure 46: Summary of Quantitative Survey Respondent Screening Criteria for Restaurants, Laundromats, and Apartments/Senior Living Facilities

Restaurants:

- 66 conjoint surveys among restaurant owners/key personnel responsible for equipment purchases
- Focused on full-service restaurants that served at least 100 meals daily (pre-pandemic) on washable dishes
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

Laundromats:

- 66 conjoint surveys among laundromat owners/key personnel responsible for equipment purchases
- Focused on laundromats or large laundries that operated at least 20 washers
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

Apartments/Senior Living

- 68 conjoint surveys among apartment/senior living owners or key personnel responsible for equipment purchases
- Focused on apartment buildings/senior living with at least 100 units with no one building with more than 50 units
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

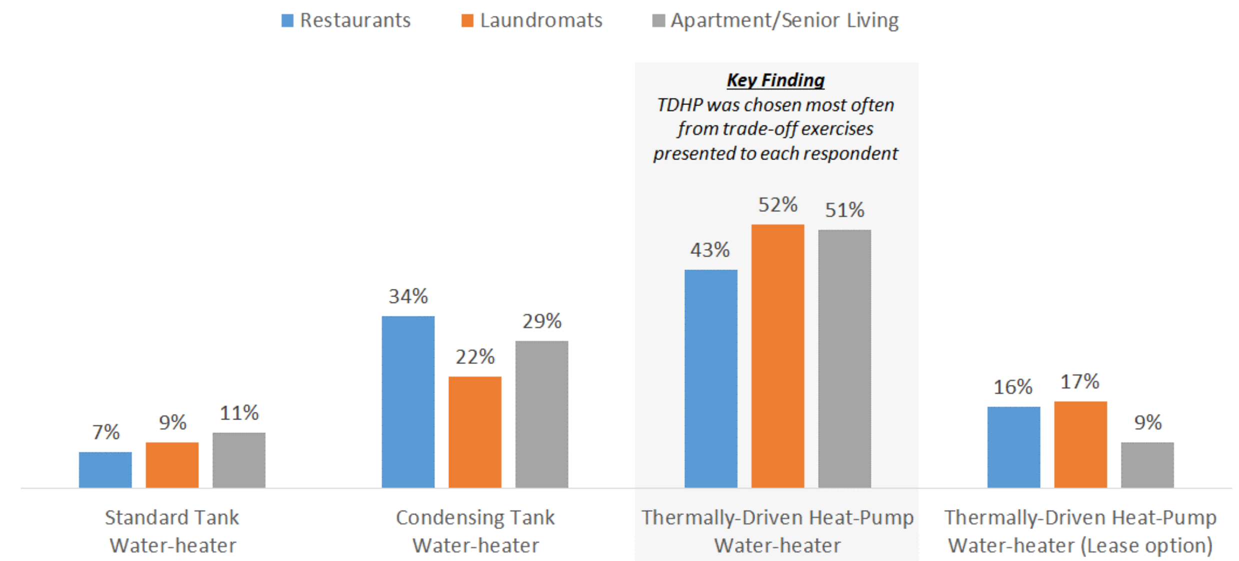
Source: GTI

Respondents identified key business influences and priorities, which overlapped in some cases and varied in others, depending upon their sector.

- Business Influences:
    - Restaurants and apartments/senior living facilities tend to pay more for high energy using appliances, look for new products to better their businesses, and view environmental concerns as overly restrictive.
    - Laundromats tend to pay more for high energy using appliances and are very cost conscious.
- Priorities:
    - Restaurant respondents indicated they almost always purchase top-quality equipment that is available and were the most interested of all three groups in leasing equipment.
    - Laundromat respondents indicated they will purchase refurbished equipment when available and will also purchase top-quality equipment that is available.
    - Apartments/senior living respondents indicated they purchase top-quality equipment that is available and will purchase refurbished equipment if available.

Respondents were also asked to rank their preferences across four gas water heater options: a standard tank unit, a condensing tank unit, the integrated GHP, and the integrated GHP (lease option). Given the rare nature of electric water heating in these high-usage commercial applications, it was not included as a potential option. These technologies were outlined at price points that varied each time, but still within pre-determined, bounded amounts. The respondents were asked to rank their preferred choice of water heater, weighing the trade-offs of each one (Figure 47).

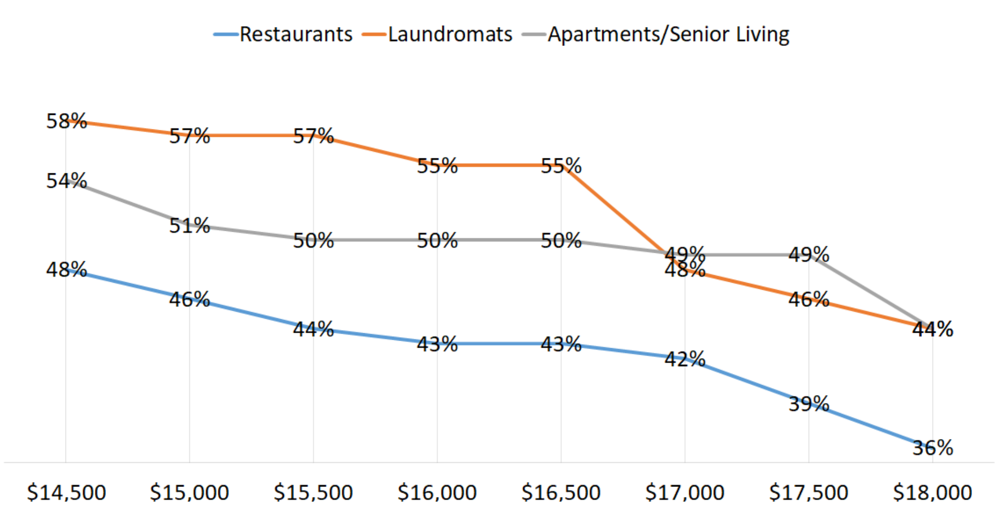
Figure 47: Preliminary Results of the Preferred Choice of Water Heater Based on Quantitative Survey Trade-Offs



Source: GTI

They were then asked to make a theoretical purchase option based on the information presented. This enabled ARW to create a preference curve showing what portion of respondents selected the GHP system at different price points (Figure 48). At the lowest presented price point, laundromat respondents had the highest rate of preference for the GHP system (58 percent), followed by apartments/senior living (54 percent), and restaurants (48 percent). The rates descend as the price point increases, with the biggest drop occurring in laundromat preferences.

Figure 48: Price Elasticity for Preference of Gas Heat Pump System Purchase, by Respondent Type



Source: GTI

CHAPTER 5: Technology/Knowledge/Market Transfer Activities

Robust and effective knowledge transfer through outreach, information sharing, and publication of data and findings, is critical for the research to build on previous work and guide future efforts. In addition to the details following, further information on technology/knowledge transfer activities can be found in the Technology and Knowledge Transfer Report (Appendix F), including:

- List of published documents.
- Copies of journal articles, press releases, and other documents prepared for public presentation.
- Websites where project materials are posted or shared, including the number of downloads.

Educational Outreach Events

As outlined in the Technology and Knowledge Transfer Plan developed in July 2017, GTI intended to plan two in-person educational outreach events for this project – one to be hosted by Southern California Gas and a second to be hosted by Frontier Energy at the PG&E Food Service Technology Center. The goal of these events was to educate and familiarize prospective integrated GHP consumers, installation contractors, utilities, and other affected stakeholders. Unfortunately, due to the COVID-19 global pandemic, hosting an in-person event was not possible in 2020. Alternate approaches were identified. A virtually-held and moderated session focusing exclusively on commercial applications for gas heat pump technology was held at the 2020 ACEEE Hot Water Forum. GTI presented this project in detail at that session. Additionally, one of the manufacturing partners for this project, SMTI, presented to a group of utility and affiliated stakeholders through a CEE-coordinated series of presentations from manufacturers active in commercial GHP development.

The second outreach event was the project team's presentation at the 2021 ASHRAE Winter Conference in Chicago, Illinois. Paul Glanville, PE, gave a presentation entitled Demonstrating an Integrated Thermal Heat Pump System for Hot Water and Air-Conditioning at Full-Service Restaurants. The same titled conference paper was also submitted, reviewed, and distributed at the conference.

Online Outreach and Information Dissemination

Under this project effort, several deliverables were prepared and hosted online to further enhance the availability of information to interested stakeholders. These included:

1. **Updated Water Heater Design Guide for Food Service:** Frontier Energy worked with GTI to develop a simplified model of the low-cost gas heat pump system for central hot water and air-conditioning for incorporation into an updated Water Heater

Design Guide for food service. The project team is currently determining the most appropriate location for sharing this design guide.

2. **Integrated Gas Heat Pump Life-Cycle Cost Calculator:** Also available for public use, this life-cycle cost calculator was developed based on data from this project as well as prior data analyses. The project team is currently determining the most appropriate vehicles for sharing this calculator.
3. **Codes and Standards Impact Analysis:** Frontier Energy conducted a survey of codes and standards, including energy efficiency standards relevant to the GHP system. This analysis specifically looked at the system as deployed in light commercial facilities, with a focus on restaurants, including a review of California's building energy-efficiency code requirements.
4. **Market Impact Analysis of Low-Cost Gas Heat Pumps in California:** Applied Research-West, with guidance from GTI, SMTI, and A.O. Smith, developed surveys and questionnaires to qualify and quantify market barriers to low-cost GHP adoption in California, once commercialized. This included input from business owners, installation contractors, and mechanical engineers. Potential barriers considered may include profit potential, training/education, safety, and incentive management, as well as other market concerns. A final summary of the results of a nationwide survey, in-depth interviews and focus groups can be requested from GTI.
5. **Education and Training Materials:** With support from SMTI and A.O. Smith, GTI prepared educational content and training materials for contractors and utility ratepayers. The project team is determining the most suitable avenues to share this information.
6. **Press Release:** Southern California Gas issued a press release highlighting this project on March 12, 2019. https://www.prnewswire.com/news-releases/socalgas-joins-the-california-energy-commission-in-the-demonstration-of-a-new-ultra-efficient-water-heater-and-space-cooler-developed-by-stone-mountain-technologies-300811110.html.

Presentations and Papers

GTI has developed and delivered multiple presentations regarding this project, in addition to a conference paper. These efforts follow.

- Presentations:
  - 2018 ACEEE Hot Water Forum, March 21, 2018
  - 2019 ACEEE Hot Water Forum, March 11-13, 2019
  - 2019 GTI Emerging Technology Program, Spring Meeting, April 24-25, 2019
  - 2020 CEE Winter Program, January 23, 2020
  - 2020 ACEEE Hot Water Forum (held virtually), July 21, 22, 28, & 29, 2020
- Papers:
  - ASHRAE 2021 Winter Conference Paper

CHAPTER 6: Conclusions and Recommendations

The project was successful in meeting all the research goals and objectives identified at the outset of this effort. The goals and objectives were closely intertwined and included the following:

- **Field Test Planning and Preparation:** The project team was successful in securing two full-service restaurant field host sites and developed design and controls specifications for the integrated GHP system components based on site characteristics, and prepared data collection hardware and GHP prototypes for field testing.
- **Integrated GHP System Field Demonstration:** The project team successfully monitored the performance of the original and replacement baseline equipment, installed and commissioned the integrated GHP system, and monitored its performance for 12 months.
- **Data Analysis and Modeling:** The project team was successful in analyzing the data to quantify integrated GHP system energy efficiency, emissions, and reliability through the extended field dataset, while generalizing results with a user-friendly modeling tool and engaging host sites and contractors with surveys.
- **Market Impact and Outreach:** The project team successfully developed stakeholder-facing materials including a design guide, codes and standards survey, and a white paper concerning Zero-Net-Energy food service, while additionally completing an in-depth market research study concerning this emerging product category and engaging key partners through targeted outreach.

Installed as a new-construction or as a retrofit to an existing commercial water heating system, the integrated GHP system shows high potential for cost-effective energy savings and emissions reductions. While site-specific variables of each installation must be considered, as described in-depth in the body of this report, system performance was impressive considering its prototype nature, with over 9,000 GHP operating hours between the two sites and measured reductions of natural gas use for hot water of 44 percent to 46 percent and 14 percent reductions in electricity for A/C from supplemental cooling (demanded year-round).

Key accomplishments in this effort include:

- Monitoring first and second baseline conditions at two full-service restaurants in the Los Angeles Basin.
- Receiving ultra low NO_x certification for the GHP prototype.
- The construction, installation, and commissioning of two integrated GHP systems at test sites.
- Operation of those systems over a 12-month period generating more than 1.4 million gallons of hot water while simultaneously providing more than 5,490 ton-hours of

supplemental cooling, and demonstrating effective operation as a hybrid system for restaurant hot water and A/C services maintained.

- Demonstrating the Integrated GHP System potential, of an estimated GHP COP of 1.40 - 1.70 for typical SHW loads of 2,000 to 5,000 gal/day, up to 46 percent therms savings, 49 percent CO_2 emissions savings, and 63 percent operating cost savings between the test sites.

Additionally, the project team sought to extensively document lessons learned with site recruitment, installation, and commissioning, de-mystifying the complexity of this integrated system while outlining methodologies for system controls. Through contractor and installer surveys, the participants noted the increased effort associated with integrated GHP system installation, but also noted the system's reliability in maintaining hot water demand and its supplemental cooling, noted by one participant as "quite amazing."

Through the preliminary system design and the development of the simplified modeling tool, the project team explored the impact of GHP sizing relative to the estimated SHW load and gas water heater(s) installed in series, highlighting challenges with under-/over-sizing while identifying a 30 percent-60 percent sweet spot for GHP sizing relative to the estimated peak SHW load. Surprisingly, the two demonstration sites provided a wide diversity of operational characteristics, with the GHP component covering 30 percent to 95 percent of the daily SHW load, on average, providing design guidance to what is likely in most cases to be a site-engineered system. An assessment of the market opportunities and barriers explored both contractor and food service industry perspectives about the technology, while also widening the net of potential applicable markets by surveying the laundromat/commercial laundry, multifamily, and senior living sectors for both their interest in and impressions of the technology. This helped identify more likely early adopters and consolidated common findings and concerns across groups that should be addressed before commercialization.

Through the lessons learned in this study, the project team outlined several future research areas to realize the energy savings potential of this innovative integrated GHP system in advance of broader product development and rollout of GHP-based commercial water heating systems.

- Developing a Refined Approach to Installation and Commissioning
    - With integrated GHP system components installed outdoors, in the mechanical room with existing water heater(s), and within the kitchen or dining space, connected by pumped loops and sensors, further development of installation kits, optimized components (for example FCU), and installation best practices will further improve the ease of installation and commissioning.
    - From tuning GHP combustion systems to maintaining proper GHP and FCU air flows to detecting and addressing issues with hydronic loops (such as restrictions, air to bleed, proper anti-freeze protection), refined approaches to system commissioning and ongoing fault detection are necessary and leverage innovations elsewhere in the energy industry.

    - Sizing the GHP component has a significant impact on operating economics and system efficiency, with standard industry sizing approaches not suitable for this hybrid system, so further development of sizing guidance is needed, informed by subsequent integrated GHP system demonstrations in food service and other commercial building applications.
- Optimize GHP System Design and Controls:
    - As found in this study and noted by the manufacturer, the operating efficiency and reliability of certain components, ranging from the nuisance (for example. ignitor) to the substantial (such as solution pump) of the GHP units were slightly below that of similar heating-only GHP units deployed in other applications. As the first prototypes designed for simultaneous heating/cooling, findings from this effort have led to GHP design improvements in several areas.
    - While the benefit of supplemental cooling from the integrated GHP system is clear, from improved comfort to reduced electricity consumption observed, further reduction of electrical power consumption from the system itself is needed, from the GHP, FCU, associated pumps, and controls.
- Addressing Non-Technical Barriers:
    - Hampered by the onset of the COVID-19 pandemic, further outreach and socialization of the integrated GHP system is needed for key stakeholders including business owners, installers, and regulatory authorities. In the last group, while improvements in coverage of GHP technologies by existing codes and standards are underway, continued refinement is for these commercial GHP water heating systems is necessary, ranging from properly crediting both the supplemental cooling and total system efficiency to the health code implications of indoor closed-loop installations.

CHAPTER 7: Benefits to Ratepayers

The commercialization and adoption of a low-cost, integrated GHP system for water heating and air-conditioning in California would provide several benefits to ratepayers. The following is a detailed outline of assumptions, supporting data, references, and methods used to calculate the estimated annual energy, cost, and GHG emissions savings of an individual integrated GHP at a restaurant in California.

Individual Savings Estimate

The simple payback is 7.27 years. As previously noted, the baseline equipment (standard gas water heater) can have shorter lifetimes, but this is a strong function of usage and water quality. The estimated useful life of the prototype installed in this project is assumed to have a standard useful life comparable to standard equipment.

Integrated GHP Prototype Performance

- **Operating Efficiency:** 140 percent AFUE for heating, projected based on laboratory and field research (Garrabrant, et. al., 2016)
- **Baseline Efficiency:** 80 percent AFUE/TE, most common commercial gas water heating efficiency in food service (Delagah and Fisher 2013)
- **Energy Savings versus Baseline:** 40 percent or greater for SHW, directly measured at field sites (Garrabrant et. al., 2016). Also, 20 percent or greater displacement of electricity for site A/C
- **GHG Savings versus Baseline:** For heating, 49 percent or greater for CHW, directly proportional to reductions in natural gas consumption (Garrabrant et. al., 2016). Also, through 20 percent or greater reduction in GHG emissions from electricity site use.

Integrated GHP Prototype Benefits Calculation

- (2,500 gallons of hot water per day2)*(498 Btu/gallon[7])*(365 days/year) = 1.25 MMBtu CHW used per day, with 80 percent efficiency baseline, 15.6 therms consumed per day baseline
- For the GHP system, if 85 percent of natural gas consumed to produce SHW is consumed by the GHP and 15 percent is consumed by the 80 percent efficiency conventional water heater, this represents an aggregate system efficiency of 131 percent, so 1.25 MMBtu output SHW/day requires 9.5 therms input for the integrated GHP system.
- At a price of $0.95/therm, this yields $2,100 saved per year from therm savings.
- To consume 85 percent of 9.5 therms per day (8.07 therms), with an input of 55,000 Btu/hr, the GHP will run for 14.7 hours per day. Assuming that 10 hours per day

[7] Assumes specific heat = 1 Btu/lb*°F; density = 8.3 lb/gal; 60°F (33°C) temperature rise

provide useful A/C delivering 2.5 tons of cooling, this displaces (10 hours/day)*(2.5 tons)*(12,000 Btu/hr per ton) = (300,000 Btu/day of cooling).

- The electricity consumed by a 14 EER A/C system would be (300,000 Btu/day of cooling)/(14,000 Btu/hr per kWh input)*(5 months)*(30.3 days/month) = 3,245 kWh saved/year.
- At $0.1564/kWh, this yields an additional $507.70 per year in savings.
- Total savings are $2,610/year when rounding to the nearest $10.
- With 2,211 therms and 3,245 kWh saved per year per site, using 11.7 lbs CO_2e/therm saved and 0.73 lbs CO_2e/kWh saved, these combine to yield 28,200 lbs CO_2e saved per year, per site.
- Also, with 4.64 gallons of water consumed per kWh generated in California (Torcellini et. al., 2003), 3,245 kWh saved per year also yields 15,060 gallons of water saved per year.

Considering this individual savings estimate and scaling it up to the cumulative impact of widespread market adoption across California, IOU service territories were studied in the following calculations.

California IOU Savings Estimate

- Total natural gas consumed by California restaurants for water heating: 340 million therms in 2015 (Delagah and Fisher 2013), and 585 GWh consumed for A/C based on data provided by the CEC in the solicitation for this project
- Total GHG from restaurant SHW and A/C: (340,000,000 therms) *(11.7 lbs CO_2e/therm consumed)*(MMTCO_2e/2,204 lbs CO_2e) + (585,000,000 kWh)*(0.73 lbs CO_2e/kWh consumed)*(MMTCO_2e/2,204 lbs CO_2e) = 2.0 MMTCO_2e per year
- 585 GWh consumed with 4.64 gallons of water per kWh generated (Torcellini 2003) yields 2.7 billion gallons of water consumed by electricity generation.
- GHG emissions from Aliso Canyon natural gas leak: 2.4 MMTCO_2e (CARB 2016)

Integrated GHP system GHG reduction from restaurant SHW and A/C with 40 percent reduction in natural gas for SHW and 20% reduction in A/C electricity: (340,000,000 therms)*(40 percent)*(11.7 lbs CO_2e/therm consumed)*(MMTCO_2e/2,204 lbs CO_2e) + (585,000,000 kWh)*(20%)*(0.73 lbs CO_2e/kWh consumed)*(MMTCO_2e/2,204 lbs CO_2e) = 0.76 MMTCO_2e reduction per year.

Calculation: (2.4 MMTCO_2e from Aliso Canyon leak)/(0.76 MMTCO_2e saved per year by GHP system) = 3.16 years = 38 months of integrated GHP system GHG savings to equal the Aliso Canyon natural gas leak GHG impact.

Also, (585,000,000 kWh per year for restaurant A/C)*(20 percent reduction from GHP system)*(4.64 gallons of water per kWh generated in CA5)*(3.16 years of operation) = 1.7 billion gallons of water saved.

Calculations assume 40 percent therm savings and 20 percent electricity savings with the integrated GHP system, 11.7 lbs CO_2e/therm saved and 0.73 lbs CO_2e/kWh saved, $0.95/ therm and $0.1564/kWh, and a reduction in NO_x from 14 ng/J output (Baseline) to 7.5 ng/J output (GHP), an emission rate demonstrated in prior peer-reviewed research (Garrabrant 2015).

Calculation Example: (340 million therms/year consumed by baseline for SHW)*(10 percent are replaced with GHP system)*(40 percent therm savings per GHP system) = 13.6 million therms saved/year; (585 GWh/year consumed by baseline for A/C)*(10% are replaced with GHP system)*(20 percent reduction in consumption) = 11.7 million kWh saved/year.; (13.6 million therms saved)*($0.95/therm) + (11.7 million kWh saved/year)*($0.1564 kWh) = $14.7 million saved; [(13.6 million therms saved/year)(11.7 lbs CO_2e/therm saved) + (11.7 million kWh saved/year)*(0.73 lbs CO_2e/kWh saved)]*($MMTCO_2e$/2,204 lbs CO_2e) = 0.08 $MMTCO_2e$ saved.

For NO_x savings, output is calculated as (340 million therms input for restaurant SHW)*(10 percent of market)*(0.1 MMBtu/therm)*(80 percent baseline efficiency) = 2,720,000 MMBtu output; (2,720,000 MMBtu/output)*(2.33e-3 lb/MMBtu per ng/J)*(14 ng NO_x/J output baseline – 7.5 ng NO_x/J output GHPWH) = 41,200 lb NO_x saved/year. Cumulative savings across all California IOUs at different market adoption levels are outlined in Table 10.

Table 10: Summary of California IOU-Wide Savings with Various Market Adoption Scenarios of the Integrated Gas Heat Pump at Restaurants

Integrated GHP System Market Penetration	Annual Therm Savings (Therms/yr.)	Annual Operating Cost Savings ($/yr.)	Annual GHG Reduction ($MMTCO_2e$/yr.)	Annual NO_x Reduction (lbs./yr.)
10%	13,600,000	$14,700,000	0.08	41,200
50%	68,000,000	$73,700,000	0.38	205,800
100%	136,000,000	$147,400,000	0.76	411,600

Source: GTI

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AFUE	Annual fuel utilization efficiency
CARB	California Air Resources Board
CDD	Cooling Degree Day
COP	Coefficient of Performance
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
GHG	Greenhouse gases
GHP	Gas heat pump
GHPWH	Gas heat pump water heater
HDD	Heating Degree Day
HVAC	Heating, ventilation, and air-conditioning
HX	Heat exchanger
IST	Indirect storage tank
IOU	Investor-owned utilities
kWh	Kilowatt-hour
MMT	Million metric ton
M&V	Measurement and verification
NO_x	Nitrogen oxides
PG&E	Pacific Gas & Electric
RMS	Root mean square
SCAQMD	South Coast Air Quality Management District
SCG	Southern California Gas
SDG&E	San Diego Gas & Electric
SHW	Service hot water
SMTI	Stone Mountain Technologies, Inc.
TE	Thermal efficiency
THP	Thermally-driven heat pump
UEF	Uniform Energy Factor
UPS	Uninterrupted power supply
ZNE	Zero Net Energy

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CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A: Integrated GHP System Design – Further Details

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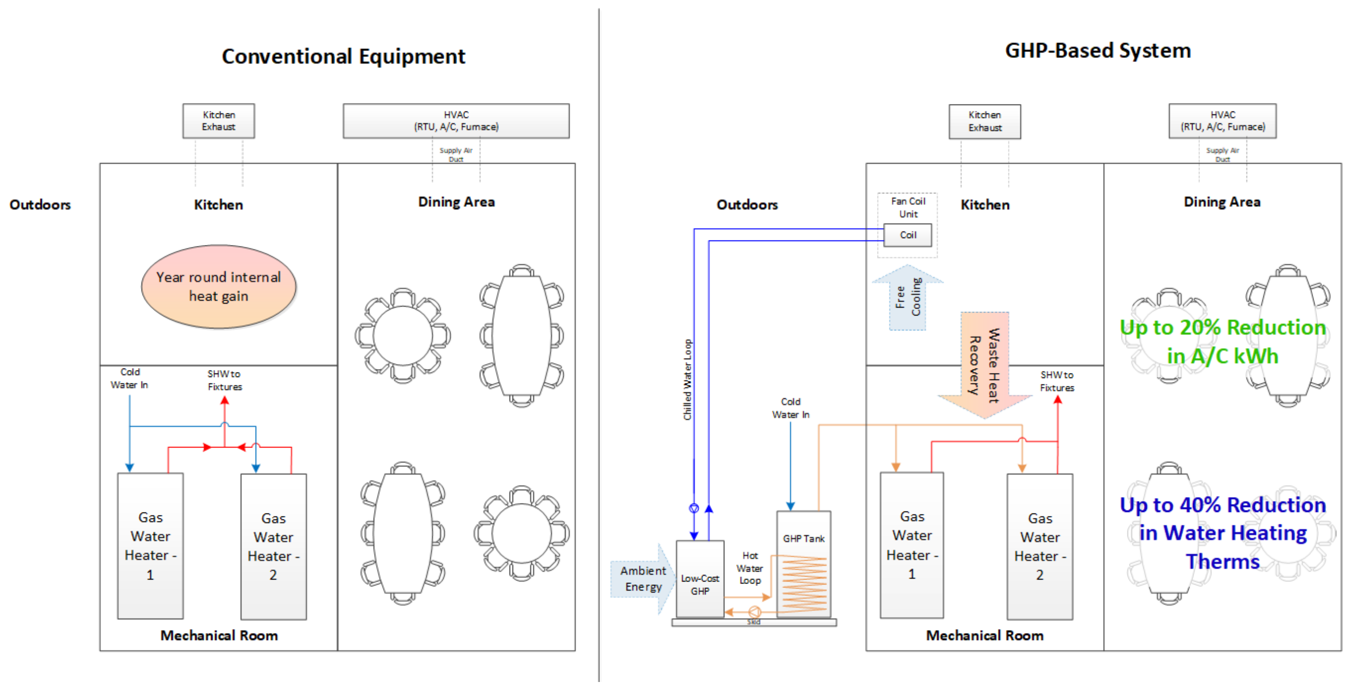
APPENDIX A:
Integrated GHP System Design – Further Details

The subject of this field demonstration is the Integrated Gas Heat Pump System for Commercial Hot Water and A/C, a "hybrid" system in the sense that the GHP will (a) provide hot water in series with conventional gas-fired water heater(s), and (b) A/C supplemental to the building's existing A/C equipment, described in the main body of the report. This integrated GHP system is pictured in Figure A-1 and is further described in this appendix.

Figure A-1: Simplified Diagram of GHP-Based SHW & A/C System – As-Installed

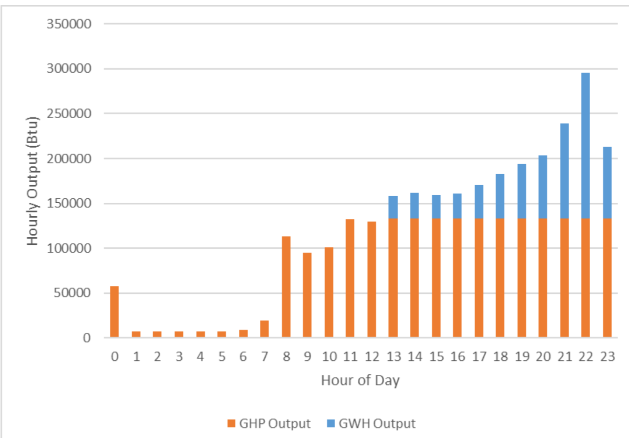


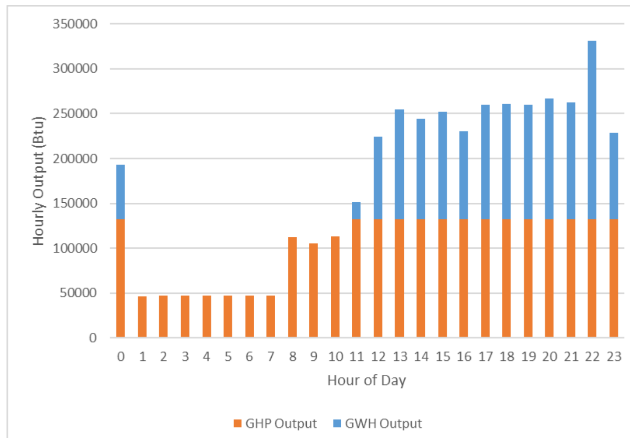
Source: GTI

Relative Sizing of the GHP

The optimal fraction for the best operating economics depends on the nature of the SHW load at each site (and volume of on-site storage); however, the project team estimates that the optimal size of GHP output relative to total output is between 30 percent and 60 percent. This can be illustrated by the following example below. Using SHW loading patterns from one of the restaurant sites, the average and peak daily hourly load pattern (4,850 and 7,000 gal/day respectively) were used to compare the impact of relative GHP sizing, assuming a 70°F (39°C) rise. Assuming 140 percent and 80 percent delivered efficiency from GHP and backup gas water heating (GWH) components respectively, a simple parametric analysis was performed. For example, Figure A-2 highlights the output from GHP/GWH for a system designed for the GHP to carry 40 percent of the peak daily load (132,500 output, in this case). For low hourly demand, the GHP can carry the load, but during the evening rush and cleaning period, the GWH carries half or more of the load. Assuming the peak daily hourly load pattern occurs throughout the year and with an assumed equipment cost of $62.50/kBtu/h (GHP) and $28.25/kBtu/h (GWH) nominal output installed and $1.15/therm for gas-only operating economics, the simple payback for systems with increasing capacity of GHP relative to GWH is shown in Figure A-3. As the GHP component gets larger with the intent of carrying most of the peak hourly load, it doesn't deliver a proportionate increase in overall annual output, and so the simple system payback advantage (equipment cost only) of increasing GHP capacity decreases. For this case, a system with the GHP component sized to handle 40 percent -50 percent of the peak hourly load is "good enough", as the incremental equipment cost is less and less offset by the operating cost savings.

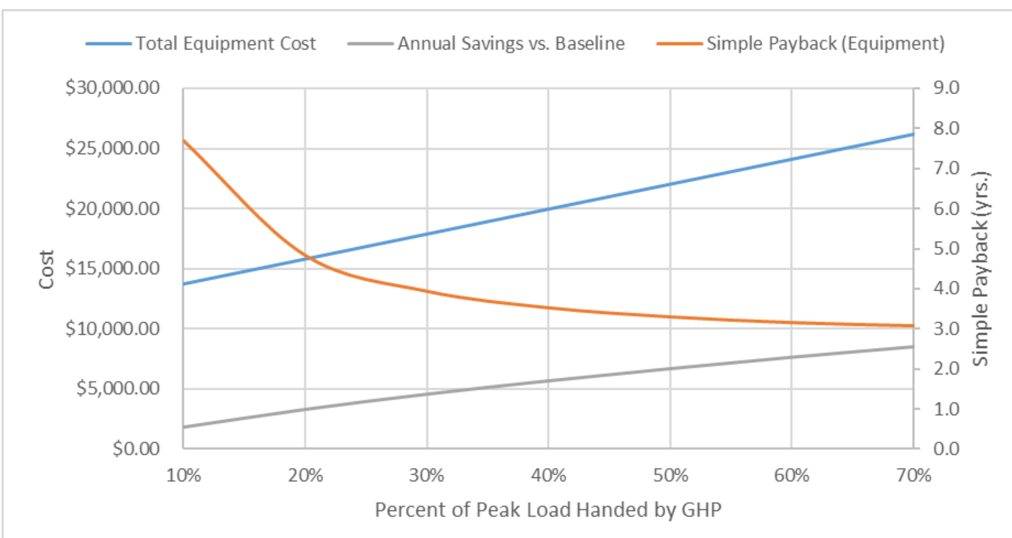
Figure A-2: Hourly SHW Output from GHP and Gas Water Heater (GWH) Component for Peak (Right) and Average (Left) Pattern – 40% Output from GHP





Source: GTI

Figure A-3: Simple Payback Analysis for Peak Daily Load Pattern

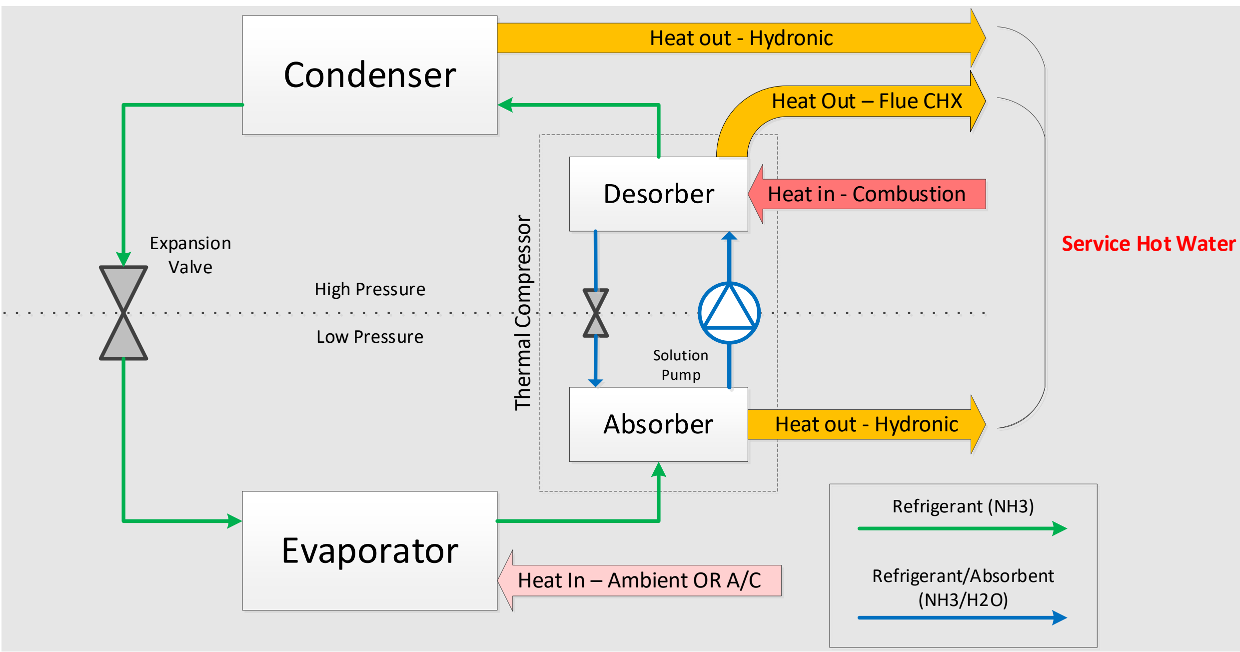


Source: GTI

Gas Heat Pump Component – Further Details

The low-cost GHP is based on the vapor absorption refrigeration cycle (Figure A-4), using the ammonia-water working fluid pair, in which an absorbent (water) is used as a carrier for the refrigerant (ammonia). Commonly, for air-source gas heat pumps, this refrigeration moves heat from ambient air at the evaporator to the recirculating hydronic loop at the condenser. For this integrated GHP for hot water and A/C, the evaporator is hydronically-coupled, and rather than drawing heat from ambient air, this advanced system draws heat from a chilled water loop connected to the indoor space and "pumps" this heat to the hot water loop. This GHP design and system arrangement is what allows simultaneous heating and cooling, providing hot water and A/C at the same time. When A/C is not required, the GHP will draw heat to the evaporator from outdoors using an air-coupled hydronic heat exchanger (HX).

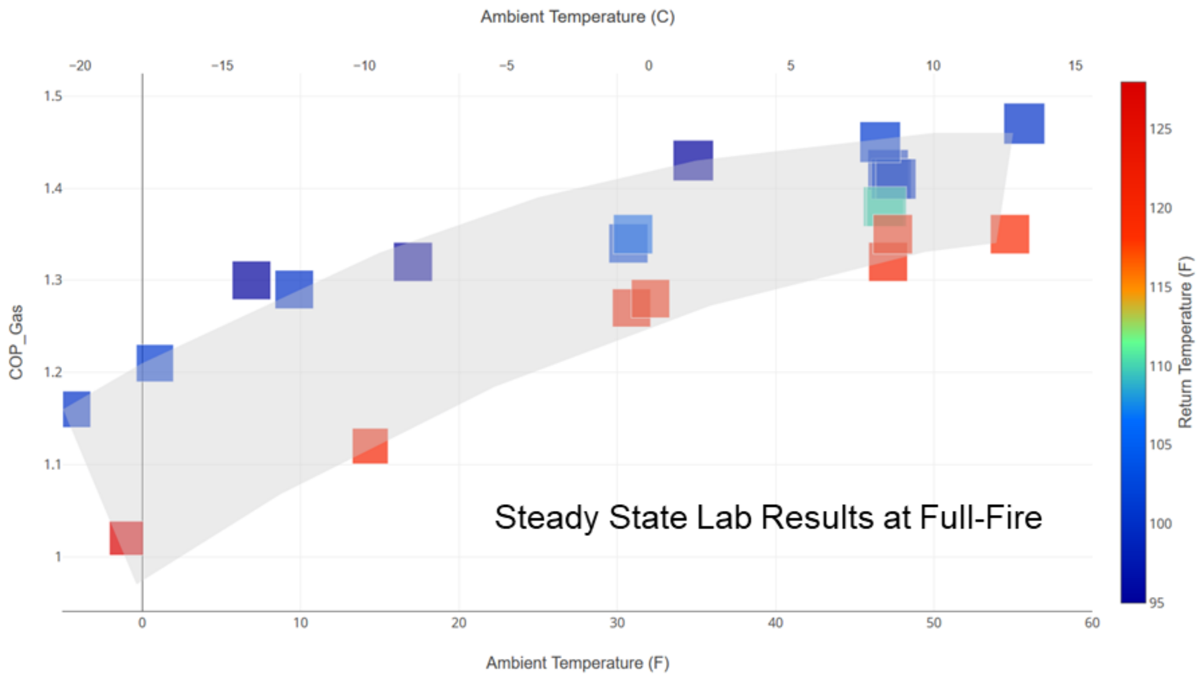
Figure A-4: Simplified Diagram of Single-Effect Absorption Cycle



Source: GTI

The core GHP is based on a prototype low-cost design developed and demonstrated in prior R&D efforts, targeting whole-house space/water heating. This GHP development is described in greater detail in prior papers (Glanville 2017 and Glanville 2018) and has a nominal 80,000 Btu/hr (23 kW) heating output, and full modulation of 4:1, a peak delivered temperature of 165°F, and active defrost. Through prior efforts, GTI and SMTI have demonstrated that this GHP operates with a projected 140 percent AFUE, with operating efficiency at or better than existing GHPs and cold climate electric heat pumps (Garrabrant 2016). After a laboratory evaluation from –13°F (–25°C) to 50°F (10°C) ambient conditions, the team monitored GHP performance supplying heat to a commercial warehouse and space heat and domestic hot water (DHW) to a residence over several years, both using standard hydronic air coils for forced-air heating (Figure A-5). Like existing residential-scaled GHPs, available in Europe, this GHP is similar to a boiler, in that it is an air-to-water/brine heat pump supplying heat to a closed hydronic loop, which can independently supply hydronic air coils, indirect tanks for DHW, and other zones (such as radiant) as the site requires.

Figure A-5: Performance Mapping of GHP Component in Prior GTI Testing



Source: GTI

Parallel demonstrations to those in this project paper at single-family homes are (photographs in Figure A-6):

- Tennessee (Climate Zone 4A): Installed in early 2016 at a residence in Eastern Tennessee, the residence is an 1,800 sf single-family home with 4 occupants (three full-time, one intermittent). The GAHP has continuously delivered domestic hot water and space heating since installation and continues operation at time of writing.
- Wisconsin (Climate Zone 6A): In 2018, three GHP systems (updated designs) were installed as combination space/water heating systems in Western Wisconsin. These units included design improvements to increase reliability, active defrost mode, and controls as designed by the HVAC industry partner.

Figure A-6: Photos of Low-Cost Gas Heat Pumps Operating in Prior/Concurrent Residential Heating Demonstrations

Source: GTI

For this project, the major change to the GHP as designed in prior efforts is replacing the original evaporator (refrigerant-to-air) with a chilled water coil tied to a hydronically-coupled evaporator. The internal chilled water circuit moves water from the evaporator to the chilled water coil or the indoor fan coil unit (FCU), depending on the call-for-cooling status. Thus, the prior GHPs are "two-pipe" with only a hydronic supply/return connection while the GHPs installed as part of this field demonstration are "four-pipe", with the additional chilled water supply/return. Additionally, as required by the South Coast Air Quality Management District (SCAQMD), this GHP component was certified as "Ultra Low NO_x" with an emission rate in compliance with Rule 1146.2 (14 ng NO_x/J output).

System Design

During initial site assessments, the project team encountered numerous site-specific constraints as illustrated in the following examples:

- Siting the GHP itself: Due to the temporary nature of the field demonstration, the fact that the GHP is an air-source heat pump (at times), and the refrigerant charge, the GHP had to be sited outdoors, which meant either a rooftop installation or a ground-level installation. Ground-level installations were preferred for several reasons, including a) to permit easy access throughout the demonstration phase, b) to avoid the costs associated with installing/removing the GHP via crane, and c) to avoid making multiple, temporary penetrations through the restaurant roof. Several restaurants inspected that were interested host sites did not have sufficient clearance around the periphery of the property for a ground-level installation with two examples shown in Figure A-7, indicating a location with only public sidewalks and alleys at the building periphery and a "strip mall" type location located on a sloping hill. While not preferred, several sites did not have available rooftop space for the GHP installation (approximately 4' x 4' footprint with 18" clearance) as shown in Figure A-8 while some sites did have sufficient space as shown in Figure A-9. With multiple rounds of site recruitment and inspection, the team was able to identify sites with suitable ground-level GHP installation options.

Figure A-7: Sites Requiring Rooftop Installations with Insufficient Clearance for Ground-Level Installation

Source: GTI

Figure A-8: Examples of Sites Inspected with Insufficient Rooftop Space for Gas Heat Pump

Source: GTI

Figure A-9: Examples of Inspected Restaurants with Available Space for Gas Heat Pump

Source: GTI

- Siting the Indirect Storage Tank (IST): Ideally, the IST would be located as close to the GHP as possible to minimize the standby and pumping losses associated with a long, closed hydronic loop linking the two. Additionally, the IST would also be as close to the existing gas water heaters (GWH) as possible too, to minimize the same losses associated with the SHW (potable water) connections, wherein the IST provides pre-heated water to the GWH(s). The best-case scenario would be a site that a) has space for an IST in proximity with the existing GWH(s) and b) this IST location would be close to the outdoor GHP location. Note that this requirement of additional space is a feature of this demonstration project, where in typical installations the IST would replace an existing water heater in most instances. With few exceptions, the former was not possible due to the crowded and, sometimes cluttered, nature of commercial kitchens. With GWHs up against ice machines, cooking/prep space (Figure A-10) or other equipment, there is limited open space for an indoor IST installation. As with the temporary GHP installation for this project, the IST is similarly temporary, and this matter was resolved by locating the IST on a skid with the GHP and mounting the skid outdoors. To match the 80 kBtu/h GHP component, a 113-gallon IST was selected.

Figure A-10: GWHs at Inspected Sites Without Space for Adjacent Indirect Storage Tank

Source: GTI

- Siting the Fan Coil Unit (FCU): For the FCU, from which the GHP provides supplemental cooling to the indoor space, the same applies as the IST wherein proximity to the GHP is critical to minimize the standby and pumping losses associated with long runs in the chilled water loop. Most restaurants had ample space for the typically low-profile FCUs (Figure A-11), but concerns were raised with a) ability to run chilled water lines to/from FCUs with potential leakage and interference with existing electrical/refrigerant lines and ductwork and b) the appearance/noise of the FCU and test instrumentation in high-traffic areas. While the latter was a valid concern from several prospective sites, it is not likely an issue with future permanent FCU installations with this system as recessed or in-duct cooling coils will be no more visible than other similar HVAC distribution equipment.

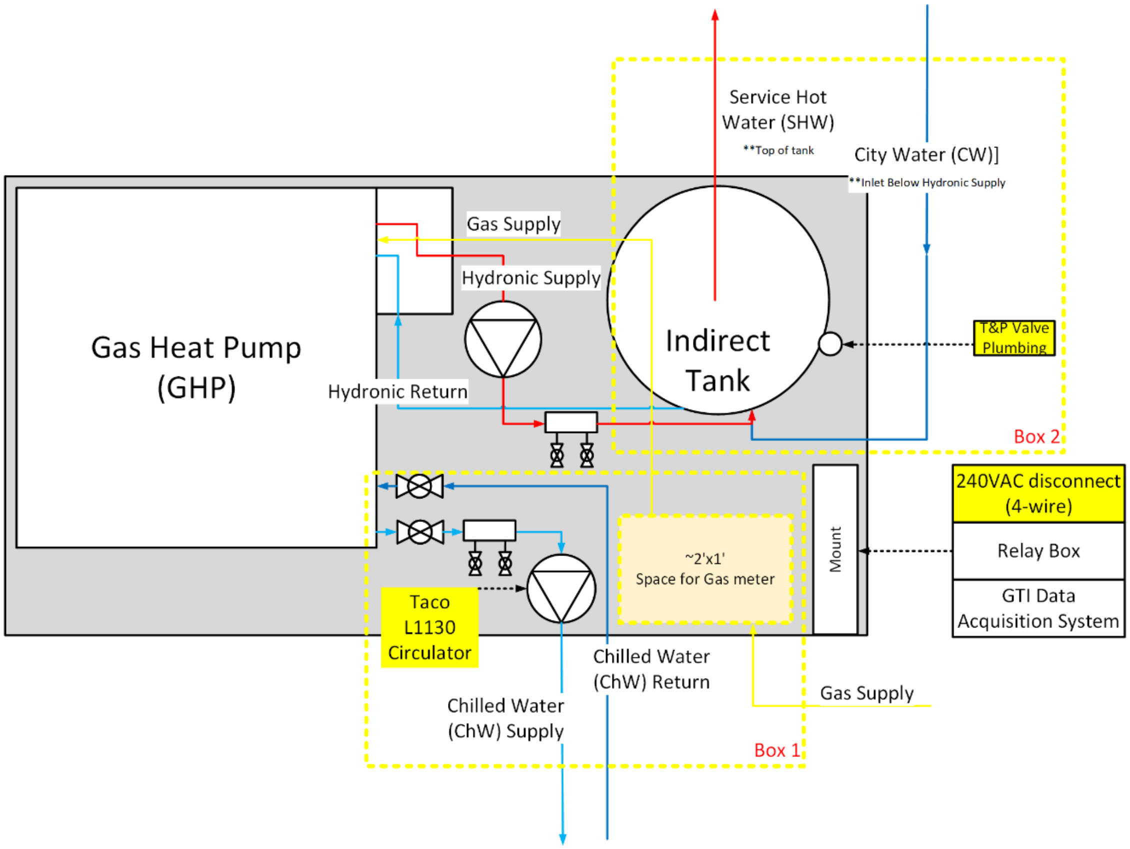
Figure A-11: Example Fan Coil Units

Source: Williams

"Skidding" the Outdoor Equipment

With previously noted considerations for a) ease of installation/removal for temporary demonstration project and b) assuring proximity of GHP and IST while limiting requirement for indoor installation space, the project team elected to "skid" the GHP and IST, along with associated hardware. Figure A-12 highlights the initial skid design, including relative placement of GHP, IST, connections and controls. Overall skid dimensions are 48" W x 96" L x 74" H, with the skid assembled off-site and shipped to the demonstration sites in completed condition. Note that due to concerns raised by the manufacturing partners, the skids will be outfitted with custom anti-vandalism enclosures, with an example shown in Figure A-13. The SHW outlet will be plumbed directly to the inlet of the indoor GWH(s).

Figure A-12: Initial Schematic for Gas Heat Pump "Skid"



Source: GTI

Figure A-13: Security Cage Example

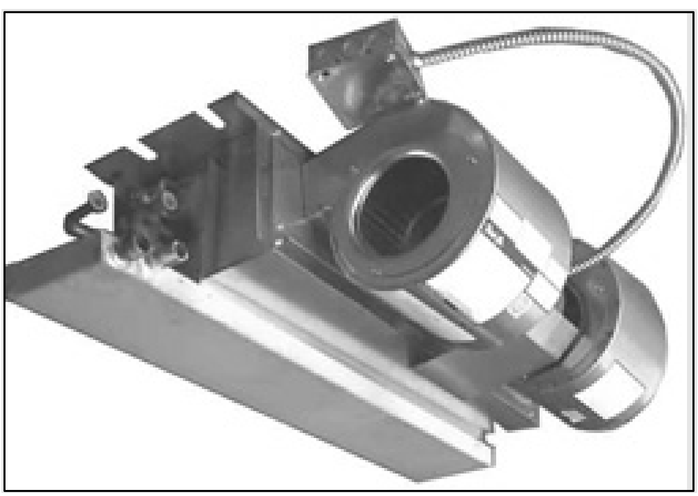
Source: MetalWorks

Indoor Fan Coil Unit

For the indoor FCU, the project team identified an off-the-shelf option that is designed for fully concealed applications (Figure A-14). This 10” high space saving unit provides easy access for service and maintenance. This FCU is sized for 1070 CFM with up to 32 kBtu/h output capacity, requiring 450 W and with a pressure drop of 14’ of head. Features of this FCU include:

- Basic Unit - All fan coils are manufactured with heavy gauge galvanized steel to resist corrosion. All models are approved for installation with “0” clearance to combustible material.
- Insulation - Plenums and cabinets are insulated with dual density fiberglass blanket insulation with an anti-microbial agent.
- Ceiling Panels - Hinged access/return panels are manufactured with heavy gauge galvanized steel with captive mounting screws and an attractive white baked powder finish.
- Condensate Pans - Positive sloped drain pans are galvanized steel, coated on the inside surface with a U.L. Listed closed cell, fire retardant, foam insulation. Pan includes both primary and secondary drain connections.
- Return Air Plenums - Return air plenums are manufactured from galvanized steel insulated with Tuf-Skin dual density fiber glass blanket insulation and a 1” TA fiber glass filter.
- Coils - Constructed with seamless copper tubes and headers. The tubes are mechanically expanded into corrugated aluminum fin material for a permanent primary to secondary surface bond. Coils are tested under water at 350 PSI for operation at 300 PSI. Coils include manual air vents.

Figure A-14: Selected Fan Coil Unit for Installations



Source: GTI

The FCU is controlled by the project's data-logging equipment with the following initial strategy:

1. Chilled Water Circulator control
    a. The circulator pump is controlled by the GHP controls via a relay (24V)
    b. The relay will open/close the circuit that powers the circulator pump.
2. Fan Coil Unit Fan Control
    a. Chilled water (ChW) flow is not controlled by valves on fan coil unit (FCU) as there are none. The circulator pump modulates flow.
    b. 24V thermostat wire (2-conductors) via the data-logging equipment relay controls FCU's fan.
        - 24V AC transformer on the FCU control board is connected through a relay to the high-speed fan input terminal. This is analogous to the "G" wire of a typical thermostat.
3. Cooling Call from GHP
    a. Indoor air temperature reading is compared to a set point. If the temperature reaches (> 68 °F [20°C]) a call for cooling condition is met.
    b. Call for cooling provided from data-logger to GHP controls via dry contact.
    c. A 2°F (–17°C) dead-band is used for the cooling call.
    d. FCU fan activated by GTI DAS when ChW at FCU drops to (< 65 °F [18°C]).
    e. Thermostat set point and dead band are remotely adjustable.
4. Control Logic
    a. If there is a call for cooling and the GHP is cycling on for SHW then:
        - GHP turns on ChW pump
    b. If ChW Pump is on, then:
        - If ChW in FCU drops below 65°F (18°C)
            - Then data-logger control turns fan on
        - Else If ChW in FCU drifts above 65°F (18°C)
            - Then data-logger control turns fan off
            - Implicit to switch over to outdoor HXs
        - If thermostat signal from data-logger control stops cooling in the middle of GHP cycle, then the GHP switches over to the hydronically-coupled evaporator (ambient source).

c. If data-logger control reads indoor temperature less than (set point – 2°F [–17°C])

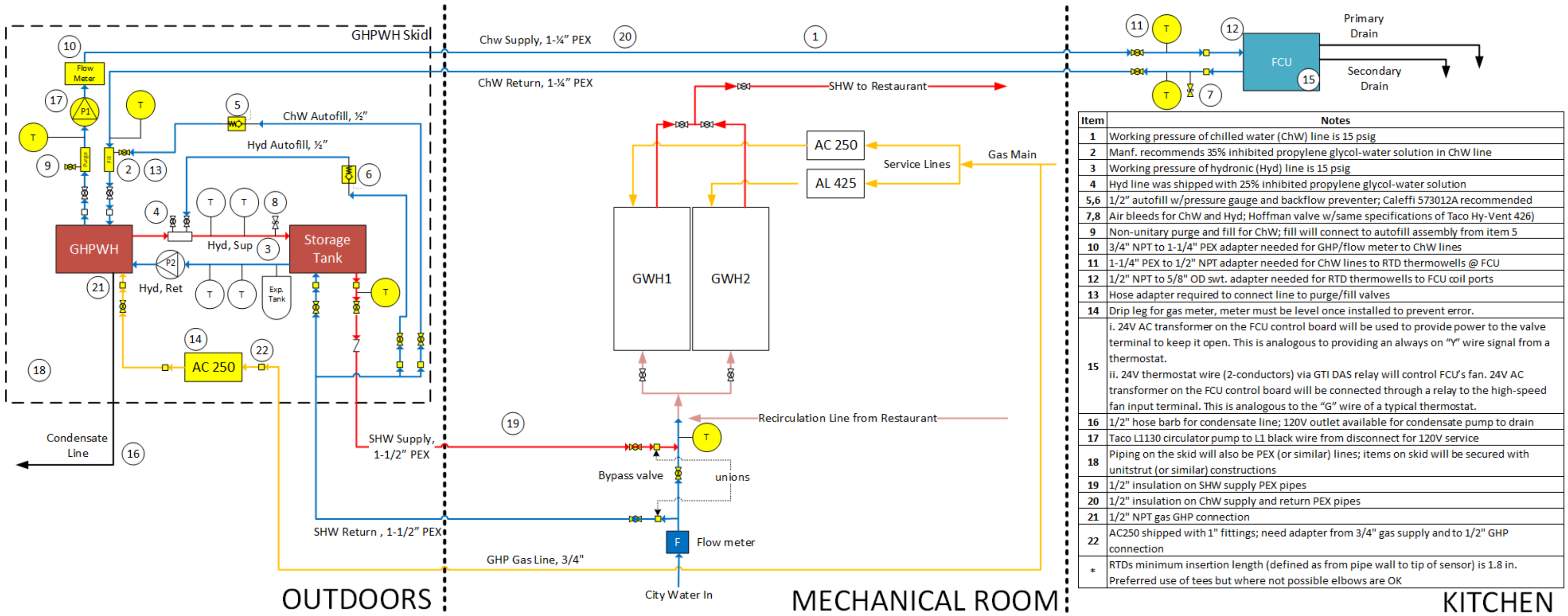
- Call for cooling satisfied and a dry contact signal "open" sent to GHP controls.

Overall Design

Working closely with the GHP and GWH manufacturing partners, the plumbing/HVAC contractor, and the host sites, the project team finalized the overall integrated GHP system design, including preliminary control strategy, specification of key components (GHP, IST, FCU), and procurement of associated system components (such as circulation pumps, control valves). While the temporary nature of the demonstration project influenced the site selection and component siting, wherein the GHP/IST/FCU must be removed at the close of the project, the team sought compromises between satisfying host site requirements, conforming to existing constraints, and minimizing adverse system design considerations (for example distance between key components).

With this design finalized, the project team "skidded" the GHP and IST for outdoor installation, with associated controls and instrumentation conforming to the demonstration execution plan. At both host sites and to minimize impact to site business operations, the integrated GHP system will be set up so the existing A/C and conventional gas water heater can be fully operable and isolated from the GHP prototype, with 100 percent redundancy. As noted in prior documentation, this allows the project team to perform any needed GHP servicing over the 12-month period without impacting the host site business operations. Drawings and photos of the GHP skid are provided in the main body of the report, with a system detail diagram for one of the two sites shown in Figure A-15 as an example.

Figure A-15: Integrated Gas Heat Pump System Detail



Item	Notes
1	Working pressure of chilled water (ChW) line is 15 psig
2	Manf. recommends 35% inhibited propylene glycol-water solution in ChW line
3	Working pressure of hydronic (Hyd) line is 15 psig
4	Hyd line was shipped with 25% inhibited propylene glycol-water solution
5,6	1/2" autofill w/pressure gauge and backflow preventer; Caleffi 573012A recommended
7,8	Air bleeds for ChW and Hyd; Hoffman valve w/same specifications of Taco Hy-Vent 426)
9	Non-unitary purge and fill for ChW; fill will connect to autofill assembly from item 5
10	3/4" NPT to 1-1/4" PEX adapter needed for GHP/flow meter to ChW lines
11	1-1/4" PEX to 1/2" NPT adapter needed for ChW lines to RTD thermowells @ FCU
12	1/2" NPT to 5/8" OD swt. adapter needed for RTD thermowells to FCU coil ports
13	Hose adapter required to connect line to purge/fill valves
14	Drip leg for gas meter, meter must be level once installed to prevent error.
15	i. 24V AC transformer on the FCU control board will be used to provide power to the valve terminal to keep it open. This is analogous to providing an always on "Y" wire signal from a thermostat. ii. 24V thermostat wire (2-conductors) via GTI DAS relay will control FCU's fan. 24V AC transformer on the FCU control board will be connected through a relay to the high-speed fan input terminal. This is analogous to the "G" wire of a typical thermostat.
16	1/2" hose barb for condensate line; 120V outlet available for condensate pump to drain
17	Taco L1130 circulator pump to L1 black wire from disconnect for 120V service
18	Piping on the skid will also be PEX (or similar) lines; items on skid will be secured with unitstrut (or similar) constructions
19	1/2" insulation on SHW supply PEX pipes
20	1/2" insulation on ChW supply and return PEX pipes
21	1/2" NPT gas GHP connection
22	AC250 shipped with 1" fittings; need adapter from 3/4" gas supply and to 1/2" GHP connection
*	RTDs minimum insertion length (defined as from pipe wall to tip of sensor) is 1.8 in. Preferred use of tees but where not possible elbows are OK

Source: GTI

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix B: Field Demonstration Monitoring Plan Details

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APPENDIX B: Field Demonstration Monitoring Plan Details

In this field demonstration of a pre-commercial integrated GHP system, the project team sought to quantify the performance and efficiency of the system in a "real world" application while providing market insight into the challenges and barriers for adoption of this advanced technology during its late stage development. Specifically, the goals of these two project tasks are to accomplish the following, in four distinct phases:

Field Test Planning and Preparation

- Finalize selection of two restaurant host sites, following interviews and site inspections.
- Develop a data acquisition specification to meet the parallel goals of M&V of energy savings and other benefits and prototype fault detection and diagnosis.
- Using site characteristics and performance data from prior low-cost gas heat pump field and laboratory studies, develop engineering specification for the integrated system, including indirect storage tank, hydronic cooling coil, conventional backup gas water heater, and system controls. Solicit past utility bills from host sites to support analysis. Prepare and issue an Integrated Low-Cost Gas Heat Pump for Commercial Hot Water and Air-Conditioning System Design, including site characteristics, system performance data, and engineering specifications for the integrated system, and annual energy consumption for each host site to support design analysis.
- Based upon this Field Demonstration Execution and Monitoring Plan, procure data acquisition hardware, package, test, and prepare for shipment to host sites. Prepare an end user and installation contractor survey instrument for pre/post prototype installation.
- Build two low-cost GHP prototypes, conduct field-worthiness with limited laboratory testing to verify performance, and prepare for shipment to host sites.

Initial Baseline Monitoring Period

- Commission data acquisition system for monitoring of baseline (existing) water heating systems and A/C for a period of several months.
- Collect and summarize data during the baseline monitoring phase and collect the pre-installation survey responses from end users and installation contractors. Summarize the results in a *Baseline Field Demonstration Monitoring Report*.

Prototype System Field Demonstration

- Ship two GHP prototypes to site and/or contractor warehouse in the Los Angeles Basin. Install prototypes on-site, following inspection of prototypes with repairs as needed.

- Install the balance of the integrated system (e.g., indirect storage tank). Modify site instrumentation as needed and shift to prototype monitoring phase. Commission integrated system and test fault detection and diagnostic system.
- Initiate prototype system monitoring period, collecting data for 12 months. Trouble-shoot system remotely, and, on an as-needed basis, perform site repairs to prototype system and/or data acquisition hardware.

Second Baseline Period and Reporting

- De-commission the integrated systems and associated equipment and ship the equipment back to the manufacturer for teardown analysis. Collect post-installation survey responses from end users and installation contractors.
- Set up second baseline monitoring for the site water heating with the high-efficiency water heaters and original A/C equipment, and monitor energy usage for up to three months. Collect and summarize data during second baseline monitoring phase to compare to baseline and prototype energy data.

Monitoring Goals and Methodologies

The project team built on the prior success with field data collection of GHP technologies to perform independent M&V of the integrated GHP system, verify energy savings, track performance and fault detection and diagnostics, and facilitate rapid assessment and treatment of prototype GHP servicing needs. Independent assessment of M&V was performed by ADM Associates, Inc. (ADM) and performance tracking and fault detection and diagnostics was performed by GTI, with support from SMTI and A.O. Smith, as needed, using remote monitoring and data collection via data loggers with cellular modems.

To properly size integrated GHP system components (the indirect storage tank, the conventional gas water heater, and the cooling coil), and refine the system controls, the project team began by monitoring the original gas water heater and A/C equipment for two months or more. This established a site-specific baseline of energy consumption and hot water consumption. To minimize impact to the host site business operations, the integrated GHP system was set up so the existing A/C and conventional gas water heater will be able to be fully operable and isolated from the GHP prototype, with 100% redundancy. This allowed the project team to perform any needed GHP servicing over the 12-month period without impacting the host site business operations. As the GHP is integrated with the A/C system and at the ambient environment, it is influenced by seasonality, as its operating efficiency depends on process temperatures (air, water). Additionally, higher demand may trigger greater usage of the low-efficiency conventional gas water heater. Thus, it was important to capture system performance over the range of annual operating conditions.

Broad research questions addressed by the project team during this demonstration task include:

1. Under installed conditions in the Los Angeles Basin, how do the low-cost GHP-delivered efficiencies and system COPs vary with hot water usage patterns, A/C

loading, operating conditions, and installation type? How do they differ from prior GHP testing in different installation contexts (e.g., space heating)?

2. Compared to the baseline water heater delivered efficiency as measured in the baseline field monitoring and from other published data, what therm savings can California IOUs anticipate from this new technology?
3. Through displacing site A/C loads, what operating cost and electricity savings can customers expect from the system? How do these electricity savings translate to statewide emissions and water reductions? Is this a technology supportive of peak load shaving?
4. Using data gathered in this task and modeling tools developed under subsequent Task 4, extrapolating results further:
    a. How do these savings and benefits compare to competing gas and electric commercial water heating technologies, and for heat pumps with and without supplemental cooling?
    b. How do the aforementioned savings and benefits depend on hot water usage patterns and ambient temperature/humidity? How does the performance of the GHP unit differ from prior generation GHP units in laboratory testing and field demonstrations?
5. Through extended field demonstrations, how reliable is the low-cost GHP design? Is the GHP capable of extended operation with high performance and minimal maintenance?
6. Based on survey results from installation contractors and host end users, what knowledge gaps exist concerning this absorption heat pump technology that may require resolution through education prior to market introduction? What gaps exist in the regulatory framework for this GHP technology introduction?
7. Based on the experience of the system installation and commissioning, what retrofit installation issues present barriers to market adoption and what are the benefits over existing high-efficiency gas-fired water and HVAC equipment?

As a field demonstration of a pre-commercial technology—specifically a new product in this novel product category—the goals of this project fell into two groups, which are described below.

A. Independent M&V of Energy Savings and Other Benefits

Using data collected during baseline and GHP system monitoring periods, ADM Associates and GTI quantified gas savings and electrical energy savings associated with the GHP system, from improved efficiency of hot water production and displaced A/C. In addition, the end users were surveyed. Energy savings was analyzed for the two case studies and served as the basis for addressing research questions #2 and #3. The survey results used to address research question #6 included satisfaction, motivation, quality control, and comments about the GHP system operation and performance, and the experience of the team in the equipment installation and commissioning was used to address research question #7.

Analysis of the monitored data by ADM and GTI was used to measure key operational characteristics of the GHP system, such as efficiency and capacity of the GHP component as a function of ambient air temperature, incoming water temperature, and hot water demand, intended to normalize the efficiency projections as addressed by research question #1.

B. Tracking the Performance of GHP System for Model Development and Fault Detection & Diagnosis

As a pre-commercial technology integrating with existing components in a novel way, the secondary goals were to (a) generalize the performance, efficiency, and capacity to extrapolate to other applications through model development (research question #4); and (b) to assure the proper and reliable performance of the low-cost GHP component by tracking its "health" (research question #5). In the case of the latter, the "health" of the GHP unit was monitored through the internal heat pump cycle, observing system dynamics and the impact of operating conditions. Key metrics measured and estimated over time to assess system performance, used for generalization and extrapolation through model development, and assessment of "health" were:

- Heat Pump Coefficient of Performance;
- System Coefficient of Performance;
- Heat Pump Capacity;
- Evaporator Superheat as a function of cycle conditions;
- Desorber Shell Temperature as a function of cycle conditions; and
- Other cycle properties.

Working with manufacturing partners, the project team sought to develop methods to track these metrics over time and identify abnormal operational conditions in real time to improve FD&D and minimize prototype downtime, in the event servicing is required.

Measurement Methodology and Hardware Specification

This measurement methodology and hardware specification was intended to reliability collect data in support of answering the aforementioned research questions, while generating high quality datasets for future analysis. This built on GTI's previous experience with GHP demonstrations in other applications and ADM's long experience with independent M&V programs. Over the first/second baseline and GHPWH monitoring periods, the following was quantified:

Independent M&V

- Energy consumption of original and high-efficiency baseline gas water heaters, measured during initial and second baseline monitoring periods, respectively.
- Energy consumption of the HVAC equipment for A/C during initial and second baseline periods.

- Energy consumption of the GHP system, as-installed, for the 12-month monitoring period, including energy consumption of conventional gas-fired water heater component and original HVAC equipment for A/C (all as part of the system).
- Projected energy savings from the GHP system as compared to original and high-efficiency baseline gas water heaters, including displaced electricity for supplemental A/C, unadjusted and accounting for inlet/outlet water temperatures, hot water usage, local weather conditions, and other factors.
- Track end-user interaction through adjustment of thermostat settings (hot water and A/C, if any).
- Disaggregate natural gas from electricity inputs.

Prototype Performance, Model Development, and FD&D

- Coefficient of Performance (COP) of the GHP (as system and just absorption heat pump portion) over the course of a recovery cycle as a function of ambient air temperature and humidity, inlet water mains temperature, and other installation factors.
- Chart and quantify robustness of absorption cycle startups, as a function of hot water demand and ambient conditions. Tracking cycle temperatures versus loading/ambient conditions to identify periods of abnormal operation.
- Interactions between GHP, its modulation, other system elements—including conventional water heater and original HVAC equipment—and effectiveness of system controls to maximize GHP runtime and successful use of "free cooling."

Baseline and GHP System Monitoring Methodology

Following the selection of the two restaurant host sites, baseline monitoring was performed. This was followed by installation and commissioning of the GHP system for a 12-month monitoring period. As an air-source heat pump, the low-cost GHP component is influenced by seasonality, as its operating efficiency depends on ambient air and water mains temperatures and during colder months the operating efficiency and capacity can diminish. Additionally, seasonality can impact system performance as during warmer months, (a) ambient conditions will increase the GHP component's efficiency and capacity, (b) higher inlet water mains temperatures will effectively diminish hot water loads, shortening on-cycles and/or operating a lower modulation points, and (c) warmer months will also drive supplemental A/C loads effectively decoupling the GHP component from the ambient environment. Due to integration with the building HVAC via supplemental A/C, shoulder months (spring and fall) was also of particular interest as GHP on-cycles may frequently switch between providing or not providing supplemental A/C, with alternate cycles impacted by indoor versus outdoor conditions. Thus, it was important to capture GHP system performance over the range of annual operating conditions. At the close of the GHP system monitoring period, the GHP component was removed from the sites and the team installed a replacement, high-efficiency gas water heater for a second baseline monitoring period.

During these monitoring periods, for continuously monitored data points, the Logic Beach *Intellilogger* datalogger platform was used, connecting to project implementers and evaluators via a cellular modem on Verizon's network. All clocks will be synchronized to the NIST clock available on the web. The *Intellilogger* sent datasets to ADM and GTI via FTP on a weekly basis, backing up data on their respective servers, and also storing data onto its 128 MB onboard memory card. To prevent data loss due to power surge and/or temporary power loss, the datalogger was powered via surge protection and an Uninterrupted Power Supply (UPS) with provisions for remote power cycling. With this datalogging platform, to quantify the aforementioned performance metrics, the data summarized in the main body of the report were measured on a continuous basis, measuring water heater energy input, energy output, and environmental conditions continuously using the remotely connected datalogger package. The frequency of data records was no longer than one minute, with shorter duration events and site conditions requiring more frequent data sampling.

As the Independent M&V Contractor, ADM Associates planned to do the following in the two-site demo:

- Site Oversight: For M&V, ADM will confirm that the GTI-specified monitoring equipment and instrumentation met the accuracy and fidelity requirements for independent M&V and ensure that proper calibration is performed where necessary, being present during the initial installation of the data acquisition system (DAS) and instrumentation prior to the baseline monitoring phase, to be present at each site for supervision, calibration, and commissioning.
- Data Collection and Analysis: With data transferred by GTI via FTP on a weekly basis, ADM will monitor the existing/replacement gas water heaters (GWH), HVAC system, and the integrated GHP system for the duration of the monitoring periods. Data was viewed weekly to ensure data quality is maintained. If for any reason the data review identifies an issue with a sensor or the system, a site visit was scheduled to address the issue and resume data collection. At the close of the GHP monitoring period and after site decommissioning, ADM will execute the post-monitoring period survey with installation contractors and host site. At the close of the monitoring tasks, the monitored data was analyzed for energy savings, other benefits, and operational performance. The installer and customer surveys were analyzed to provide additional evaluation criteria for the performance of the integrated GHP system.

Monitoring Points for GHP System Performance and FD&D

Concerning GHP system performance and FD&D, GTI continuously monitored the following data points in addition to those used for M&V (with SMTI support) to track system performance, identify off-design operation, and troubleshoot the GHP system for automated fault detection and diagnosis:

- Refrigerant temperature into and out of the evaporator;
- Chilled water temperature into and out of the air-coupled heat exchanger (HX);
- Chilled water flow rate within the air-coupled HX;
- Ambient air temperature at air-coupled HX;

- Chilled water temperature into and out of the indoor cooling coil;
- Chilled water flow rate within the indoor cooling coil;
- Internal hydronic temperatures exiting the absorber and condenser;
- Hydronic supply/return temperatures between GHP and indirect tank;
- Hydronic flow rate between GHP and indirect tank;
- Thermostat temperature of the indirect tank;
- Temperature of the desorber shell;
- Internal flue gas temperatures; and
- State of the GHP unit and indoor cooling coil (on/off).

In total, these measurements have proven useful in monitoring and modeling GHP system performance, detecting/diagnosing off-design operation, and through custom programmed automation (for example auto-emails to project team), issues can be identified and addressed in near real-time. Additionally, during site visits and soliciting from project partners, GTI made batch measurements of the following, to be used in model development and analysis:

- True RMS power measurements was made on operating existing HVAC equipment and the indoor fan cooling coil.
- Natural gas heating value and inlet natural gas pressure (at meters).
- Excess air level in flue gases for GHP and conventional water heaters, as measured using a portable combustion analyzer.

During the installation of instrumentation and datalogging equipment, the following requirements were met:

- Water meters was installed with recommended lengths of straight pipe upstream/ downstream and with correct orientation.
- Immersed thermocouples for leaving/enter water temperatures were installed at locations as close to those required by the standard method of test as allowable. Associated piping was insulated to minimize heat loss/gain between the equipment and the points of measurement.
- Ambient air temperature sensors were wall-mounted in a location representative of local conditions.
- The *Wattnode* power meters must be powered by the same circuit as the devices being measured.
- The 12” cellular modem antennas were installed to maximize signal quality as verified during commissioning.

Baseline Instrumentation – Measurement Points and Hardware Specification

Figure B-1 shows the baseline dataloggers that monitored the baseline measurement points. One was installed in the mechanical closet/room at both of the field sites. The datalogger measured the conventional water heaters’ energy consumption and the HVAC energy consumption. These measurement points provided data for third-party verification and helped establish a model of baseline cooling energy.

The majority of the indoor monitoring points were related to existing water heater monitoring near the data acquisition system (DAS) in the mechanical room (that is, city water temperature, service hot water (SHW) supplied as well as gas and water flow).

The remaining baseline indoor and outdoor points were geared toward monitoring the rooftop equipment and zone data for the indoor cooling coil (that is, kitchen temperature, kitchen relative humidity, rooftop equipment power consumption, rooftop equipment operating parameters (cooling/heating stage, reversal valves, unit power, etc.)). These points were farther away from the DAS and connected wirelessly. All wireless devices selected are capable of transmitting signals up to 250 feet through typical building materials.

Figure B-1: Monnit Wireless Sensors

Source: Monnit

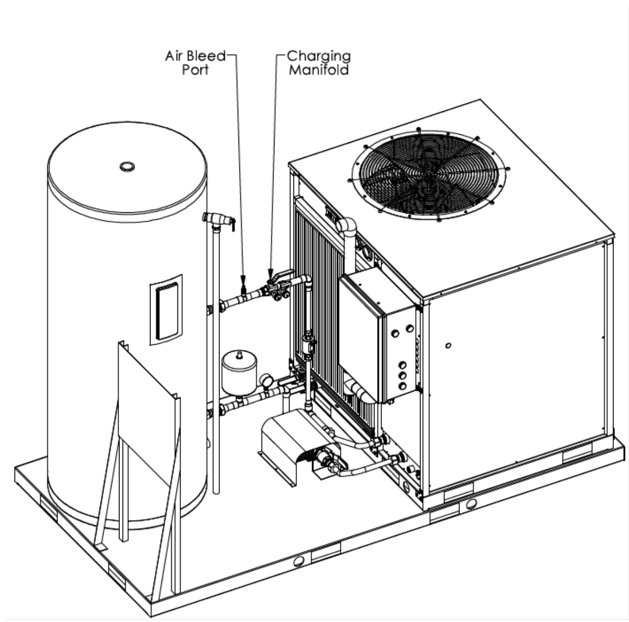
GHP Instrumentation – Measurement Points and Hardware Specification

During commissioning of the GHP, a second datalogger was added to monitor gas-fired heat pump water heater (GHP) and indoor cooling coil (ICC) points. These measurement points are outlined in Table B-2.

Similarly to the baseline DAS setup, the GHP datalogger was installed nearby where the majority of the physical connections was made—proximal to the GHP. The measurement points for the GHP are under the "OUTDOOR – GHP" section and should not require any wireless transmission of data. Data from the GHP will serve both M&V as well as FDD purposes. More detail is shown in the *Data Analysis* section of this document.

The dimensions of the GHP skid are L8'xW4'xH6' and the equipment secured to it was protected by a custom-ordered standard utility enclosure as the GHP was housed outdoors. Figure B-2 shows the GHP/tank skid assembly but not the aforementioned utility enclosure. As seen, the GHP/tank skid provides a stand for mounting the DAS. The stand is shown as being adjacent to the hot water storage tank and demonstrates that there is ample space to make the necessary connections to the GHP's outputs on the manufacturer's PLC board. The PLC is located within the enclosure mounted onto the GHP and is directly across from the DAS stand.

Figure B-2: Gas Heat Pump Skid Schematic



Source: GTI

The combined measurement points are shown in Table B-1 and Table B-2 highlights the measurement name, signal/units, which DAS systems are used, project phase, and whether measurements are purely for Baseline and/or M&V monitoring. Dataloggers #1 (baseline) and #2 (GHP) was based on the mentioned IL-80, with an expansion in the case of the outdoor DAS hardware. The remaining measurement points are reserved for monitoring the indoor cooling coil (ICC) are listed in Table B-3 under the "INDOOR – ICC" section. Table B-4 displays the outdoor measurement of the collected data.

Table B-1: Indoor Continuous Measurement Points – Outline of Baseline Data Collection

Indoor Measurement Point	Signal Type/Units	Manufacturer / Model	Accuracy	Req. M&V?
Natural Gas Flow – Conventional GWH 1	Pulse / CF	Elster American Meter / AC-250	<0.5%[8]	Yes
Natural Gas Flow – Conventional GWH 2	Pulse / CF	Elster American Meter / AC-250	<0.5%[9]	Yes
Power In – Conventional GWH 1	Pulse / kWh	WattNode / WNB-3Y-208-P CCS[10] / ACTL-0750 Series	±0.5% of reading[11]	Yes
Power In – Conventional GWH 2	Pulse / kWh	WattNode / WNB-3Y-208-P CCS[12] / ACTL-0750 Series	±0.5% of reading[13]	Yes
Service Hot Water (SHW) Flow	Pulse / Gal	EKM / SPWM-150-CF	± 2%/±5%[14]	Yes
City Water Inlet – Conventional WH 1 & 2	Temperature / °F	ProSense RTD	±0.81 °F	Yes
Hot Water Outlet – Conventional GWH 1	Temperature / °F	ProSense RTD	±0.81 °F	Yes
Hot Water Outlet – Conventional GWH 2	Temperature / °F	ProSense RTD	±0.81 °F	Yes
Hot Water Outlet – Conventional GWH 1 & 2 Service Hot Water (SHW) to Fixtures	Temperature / °F	ProSense RTD	±0.81 °F	Yes
Hot Water Recirculation Return and Mixed Temperatures (Inlet to GWHs)	Temperature / °F	Surface Thermocouple	±1.5 °F	Yes
Indoor Air Temperature – Kitchen [nearby where fan coil (FCU) is expected]	Temperature / °F	Monnit / MNS-9-IN-TS-ST-L03	±1.5 °F (±0.45°F calibrated)	Yes
Indoor Rel. Humidity – Kitchen	Rel. Humidity / %	Monnit / MNS-9-IN-HU-RH-L03	±3%	No

Source: GTI

[8] Less than 0.5% deltas for proof curve over the unit's rated range.

[9] Less than 0.5% deltas for proof curve over the unit's rated range.

[10] Continental Control Systems current transformers. Each CT will be selected in base of the circuit measured.

[11] At normal operating conditions: -20% to 15% of nominal line voltage, 1.0 power factor, 48-62 Hz, 23°C±5°C, and CT 5%-100% of rated current.

[12] Continental Control Systems current transformers. Each CT will be selected in base of the circuit measured.

[13] At normal operating conditions: -20% to 15% of nominal line voltage, 1.0 power factor, 48-62 Hz, 23°C±5°C, and CT 5%-100% of rated current.

[14] Accuracy changes based on flow regime.

Table B-2: Outdoor Continuous Measurement Points – Outline of Baseline Data Collection

Outdoor Measurement Point	Signal Type/Units	Manufacturer / Model	Accuracy	Req. M&V?
Total Power In – HVAC Unit X[15]	Pulse / kWh	WattNode / WNB-3Y-208-P CCS[7] / ACTL-0750 Series	±0.5% of reading[8]	Yes
State Logger – HVAC Unit X: Cmpsr. Stages	Dry Contact	Monnit / MNS-9-IN-DC-CF-L03 Setra / CSCGFN015NN	N/A	Yes
State Logger – HVAC Unit X: Gas Heat Stages	Dry Contact	Monnit / MNS-9-IN-DC-CF-L03 Setra / CSCGFN015NN	N/A	Yes

Source: GTI

Table B-3: Indoor Cooling Coil Continuous Measurement Points – Outline of Gas Heat Pump Data Collection

Indoor ICC Measurement Point	Signal Type/Units	Manufacturer / Model	Accuracy	Req. M&V?
Supply Air Temperature – Indoor Cooling Coil	Temperature / °F	Omega / SCPSS-125E-6	±0.9 °F	Yes
ChW Supply Temperature – Indoor Cooling Coil	Temperature / °F	ProSense RTD	±0.81 °F	No
ChW Return Temperature – Indoor Cooling Coil	Temperature / °F	ProSense RTD	±0.81 °F	No
FCU State– Indoor Cooling Coil	Dry Contact	N/A	N/A	Yes

Source: GTI

Table B-4: Outdoor Gas Heat Pump Continuous Measurement Points – Outline of Gas Heat Pump Data Collection

Outdoor GHP Measurement Point	Signal Type/Units	Manufacturer / Model	Accuracy	Req. M&V?
GHP Runtime – State Logger	Dry Contact	Monnit / MNS-9-IN-DC-CF-L03 Setra / CSCGFN015NN	N/A	No
Natural Gas Flow – GHP	Pulse / CF	Elster American Meter / AC-250	<0.5%	Yes

[15] Energy consumption for rooftop appliances may be calculated with nameplate data and recorded state data instead of being measured.

Outdoor GHP Measurement Point	Signal Type/Units	Manufacturer / Model	Accuracy	Req. M&V?
Power In – GHP	Pulse / kWh	WattNode / WNB-3Y-208-P CCS[7] / ACTL-0750 Series	±0.5% of reading[8]	Yes
Power In – Loop Pumps	Pulse / kWh	WattNode / WNB-3Y-208-P CCS[7] / ACTL-0750 Series	±0.5% of reading[8]	Yes
GHP NH3 Temp. – Evaporator In	Temperature / °F	N/A, GHP output	TBD	No
GHP NH3 Temp. – Evaporator Out	Temperature / °F	N/A, GHP output	TBD	No
GHP ChW Temp. - Air-coupled HX In	Temperature / °F	N/A, GHP output	TBD	No
GHP ChW Temp. - Air-coupled HX Out	Temperature / °F	N/A, GHP output	TBD	No
GHP Desorber Temp. – Shell	Temperature / °F	N/A, GHP output	TBD	No
GHP Flue Exit	Temperature / °F	Omega / SCPSS-125E-6	±0.9 °F	No
GHP ChW Flow – To Indoor Cooling Coil	Analog / GPM	IFM / SM7604	TBD	Yes
GHP ChW Flow – Air-coupled HX	Analog / GPM	N/A, GHP output	TBD	No
GHP Skid Hydronic Flow – Indirect Tank Loop	Analog / GPM	IFM / SM7604	TBD	No
GHP Skid ChW Temp. – Loop Return	Temperature / °F	ProSense RTD	±0.81 °F	No
GHP Skid ChW Temp. – Loop Supply	Temperature / °F	ProSense RTD	±0.81 °F	No
GHP Skid Hydronic Temp. – Loop Return (X2)	Temperature / °F	ProSense RTD	± 0.81 F	No
GHP Skid Hydronic Temp. – Loop Supply (X2)	Temperature / °F	ProSense RTD	± 0.81 F	No
GHP Skid Tank Temperature – Cold Water Inlet	Temperature / °F	ProSense RTD	±0.81 °F	Yes
GHP Skid Tank Temperature – Hot Water Outlet	Temperature / °F	ProSense RTD	±0.81 °F	No
GHP Skid Tank Temperature – Tank Thermostat	Temperature / °F	N/A, GHP output	TBD	No
b	Temperature / °F	Omega / SCPSS-125E-6	±0.9 °F	Yes

Source: GTI

Displaced Cooling Measurement Approach

Based on preliminary simulations, the team expected the peak cooling load to range from 20 to 40 tons for full-service restaurants meeting the study criteria. The maximum capacity of the indoor cooling coil can reach 2.0-2.5 tons when the heat pump is active, which in a full-service restaurant is expected to be most of the time. Presenting the displaced cooling with respect to the total capacity of the HVAC system is misleading, as it does not reflect part-load factors and therefore would underestimate the percentage of the cooling load that was displaced. Since it would be difficult to perform an accurate cooling load analysis without knowing the installed equivalent full load hours (EFLH) for each individual piece of HVAC equipment, the team needed to directly monitor energy consumption.

Two options are used, which represent two ends of a spectrum, a conservative and non-conservative approach to crediting the displaced cooling supplied by the gas heat pump. Over the course of the field trial, the team will perform both options *simultaneously* to cover this range, referring to these as Method A and Method B, which are summarized as follows:

- Method A will give full credit to cooling energy delivered at the indoor cooling coil (ICC), assuming that all cooling measured as chilled water is useful and displaces A/C provided by the building HVAC. This non-conservative approach assumes that all cooling delivered at the FCU is (a) useful and (b) would otherwise be provided by building HVAC equipment.
- Method B is a conservative approach which measures total power consumption by building HVAC during baseline and gas heat pump monitoring periods and, when adjusting for weather and other factors, quantifies avoided power consumption for A/C while FCU provides cooling.

Method A requires that the team partially measure key parameters for analyzing the energy conservation measure (ECM). In our case this means being able to: 1) measure the cooling delivered, and 2) calculate the amount of energy used by an installed A/C condenser to deliver the same cooling. To quantify the cooling energy delivered at the FCU, measured parameters include chilled water (ChW) supply temperature and return temperature as well as flow rate and runtime. As previously mentioned, electricity consumption by the FCU was quantified directly with a power meter or inferred from runtime supplemented with manual measurements. The delivered cooling is calculated an energy balance, which is used to credit the cooling output of the GHP unit, as a combined thermal efficiency. If the data collection from the rooftop equipment is insufficient to make a conservative assumption, then a modeled approach from this measured FCU load can be used to calculate the displaced cooling energy.

Method B is used to credit the electricity savings of the integrated GHP system from displaced cooling. Some disadvantages exist when using Method B to measure the displaced cooling energy. While expensive in terms of monitoring resources, this approach includes all interactive effects when a sufficiently long baseline monitoring period is used.

Data Quality Control and Safety Precautions

Using automated data quality control during weekly data file transfers, GTI and ADM sought to identify and resolve issues with data collection and GTI will swiftly resolve GHP system operation to minimizing data loss. Data from each site was downloaded, analyzed, and reviewed on a weekly basis to spot issues, trends, and identify needs for field servicing of datalogging equipment or the GHP systems.

As the GHP is a pre-commercial prototype and as such, is not a certified product, during this field demonstration the datalogger sent out automated warning emails to key staff from the project team to prompt action and, if necessary, field servicing if the following conditions are observed, however unlikely:

- *Low refrigerant temperatures* – If the evaporator inlet temperatures drop below 10°F (–18°C), this represents an off-design operating condition resulting in frosting of the evaporator. The pre-commercial GHP is equipped with a defrosting system; however, it is not expected to be used in the Los Angeles-area climate. Staff will remotely power down the GHP system and contact the host site to arrange for a servicing visit.
- *Excessive heating* – If the hydronic supply temperature exceeds 150°F (66°C) or if the desorber shell temperature exceeds 350°F (177°C), this represents an off-design operating condition which could result in a GHP system automatic shutdown due to excessive high-side pressures. The GHP controls can recover from this event; however, following email notification, staff may arrange for a site visit to investigate this overheating event.
- *Thermostat temperature too low* – If the indirect mid-tank temperature is at 105°F (41°C) or less for more than six consecutive hours, this may indicate that the GHP is locked out on an error which will not interrupt hot water service (conventional water heaters will carry load) but will require servicing. Staff will contact the host site to assure that the GHP wasn't otherwise shutdown for other reasons and, if necessary, arrange for field servicing the unit.

In the event of a loss of GHP system functionality, the restaurant sites have 100 percent redundancy through the operational conventional water heaters, thus the project team will need to respond quickly but with minimal impact to business operations. Local contractors and on-site personnel received training from the project team members to detect, and if possible, rectify GHP system issues during the demonstration. Depending on the nature of the issue, GTI staff, or GTI subcontractors traveled to the sites for assistance.

Concerning host site safety, beyond the email alert system to identify and diagnose system operational issues, an ambient ammonia sensor and alarm - able to detect ambient ammonia and alert the host site in the event of an ammonia leak - was used in the vicinity of the GHP. The ammonia alarm is well below the 8-hour federal workplace exposure limits (50 ppm for OSHA / 25 ppm for NIOSH). Host sites were trained to recognize this alarm and what to do in the event it is heard.

Data Analysis

Continuously monitored data was sampled at the frequency of at most, every 10 seconds during activity (hot water draws or recovery cycles of GHP and/or conventional heating equipment) and otherwise at least every 1 minute during standby. Datasets were downloaded on a weekly basis and analyzed with custom programming, yielding the following data as summarized in reporting:

Baseline and GHP System Periods

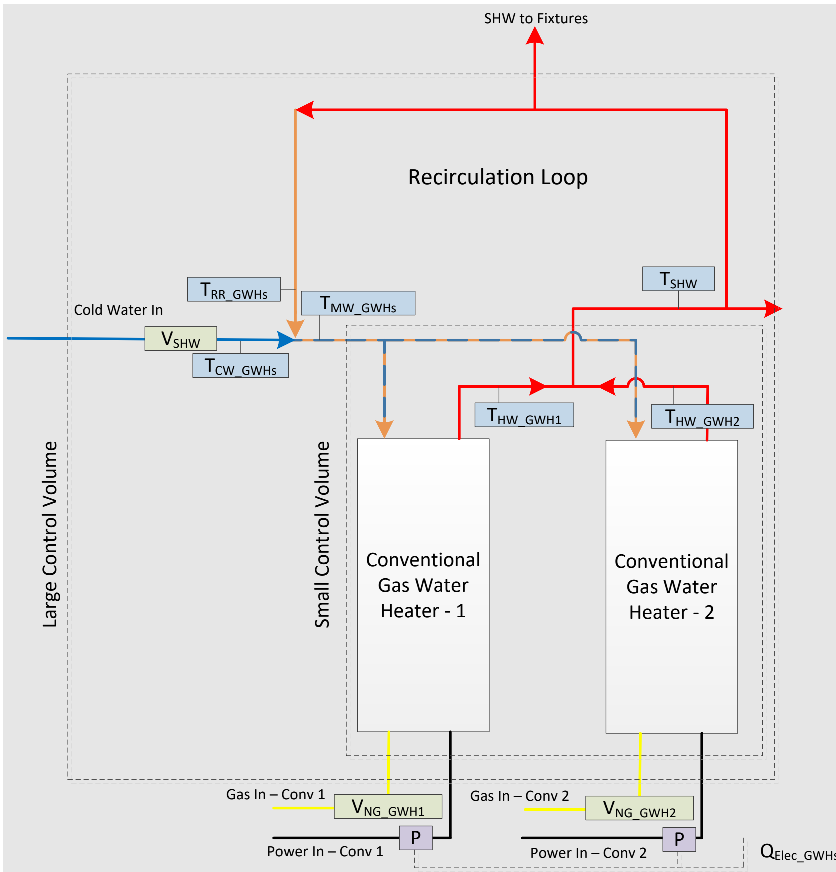
- Operating conditions: Outdoor temperature/humidity, indoor temperatures in kitchen, mechanical room, and dining area, inlet water mains temperature.
- Hot water consumption statistics: daily draw volumes, draw rates, draw durations, draws per day, delivered hot water temperature, delivered energy of hot water.
- Water heater recovery cycling: Cycles per day/week, cycle duration, hot water consumed between cycles.
- Existing HVAC equipment: RTU, Heat Pump, and A/C equipment cycling, power/gas consumption (direct or indirectly measured).
- Energy input to all water heating equipment: daily/weekly natural gas consumption, daily/weekly electricity consumption, power draw in both "standby" and "active" modes, average firing rate for modulating gas equipment, HVAC equipment input as measured and weather-normalized.
- Energy efficiency: daily/weekly "Delivered Energy Factor" for water heating equipment.

GHP System Period Only

- GHP component operating conditions:
    - *Heating:* GHP loop hydronic return/supply temperatures, condenser/absorber outlet temperatures, desorber shell and flue gas temperatures.
    - *Cooling:* Evaporator inlet/outlet temperatures.
    - Hydronic return/supply temperatures, evaporator inlet/outlet temperatures, desorber shell and flue gas outlet temperatures.
    - GHP cycle startup health, observed operational issues, and service calls.
- GHP system output and cycling:
    - *Heating:* GHP system cycling, utilization, indirect tank mid-tank temperatures at cycle cut-in/cut-out, SHW output capacity (BTU/hr), Heating COP, GHP system COP, "Delivered Energy Factor" for water heating output of skid and entire system.
    - *Cooling:* Combined cooling/heating GHP COP, cooling coil cycling, chilled water loop and cooling coil output capacity (BTU/hr), cooling coil supplied air temperatures.

- System/Skid energy inputs (gas/electricity) and energy balance, estimated heat losses.
- Figure B-3 displays a simplified gas water heater and recirculation loop diagram.

Figure B-3: Simplified Diagram of Gas Water Heaters with Recirculation Loop



Source: GTI

Measurement and Verification

Outputs:

- Hot water energy: for hot water generated by the conventional GWHs as a system (Large Control Volume), $Q_{SHW,GWHSYS} = V_{SHW,}C_P\rho\left(T_{SHW} - T_{CW,GWHs}\right)$ [=] Btus; for $C_P\rho$ evaluated at $T_{CW,GWHs}$; to estimate flow rate of the recirculation loop return, the ratio of measured temperatures are used, $V_{RR} = V_{SHW}C_P\rho\left(T_{MW,GWHs} - T_{CW,GWHs}\right)/\left[C_P\rho\left(T_{RR,GWHs} - T_{MW,GWHs}\right)\right]$ for $C_P\rho$ evaluated at local temperatures; for individual GWHs (Small Control Volume in Figure B-3), $Q_{SHW,GWH} = (V_{SHW} + V_{RR})C_P\rho\left(T_{SHW} - T_{MW,GWHs}\right)$ [=] Btus; for $C_P\rho$ evaluated at $T_{MW,GWHs}$; for hot water generated by the GHP skid, $Q_{SHW,GHP} = V_{SHW,}C_P\rho\left(T_{HW,Skid} - T_{CW,Skid}\right)$ [=] Btus; for $C_P\rho$ evaluated at $T_{HW,Skid}$, and during the GHP system monitoring phase overall $Q_{SHW,GHPSys} = V_{SHW,}C_P\rho\left(T_{SHW} - T_{CW,Skid}\right)$ [=] Btus; for $C_P\rho$ evaluated at $T_{HW,Skid}$

- HVAC Output: Concerning the baseline HVAC rooftop equipment, the cooling/heating output will not be directly measured, but rather inferred by equipment runtime and, if measured, power consumption. Concerning the GHP indoor cooling coil, delivered cooling will be estimated as $\dot{Q}_{ICC} = \dot{V}_{ICC,}C_P\rho\left(T_{CHW,ICCRtn} - T_{CHW,ICCSup}\right)$ [=] Btu/hr; $C_P\rho$ evaluated at $T_{CHW,ICCSup}$

Inputs:

Natural gas input: $Q_{NG,GWHs} = \left(V_{NG_{GWH_1}} + V_{NG_{GWH_1}}\right) \cdot HHV$ [=] Btus, $Q_{NG,GHP} = \left(V_{NG_{GHP}}\right) \cdot HHV$ [=] Btus, and $Q_{NG,HVAC} = \left(V_{NG_{HVAC}}\right) \cdot HHV$ [=] Btus; evaluated for each cycle with the fuel value (HHV) adjusted to local barometric/line pressures and as supplied by local utility, and converted to a firing rate as a rolling average over each cycle, $\dot{Q}_{NG}$. Note that $V_{NG_{HVAC}}$ may be approximated using runtime, state loggers, and nameplate firing rates.

- Power consumption: Power consumption is directly measured in Q_{Elec_GWHs}, Q_{Elec_HVAC}, Q_{Elec_ICC}, Q_{Elec_GHP}, and Q_{Elec_Skid}, noting that in the case of Q_{Elec_HVAC} and Q_{Elec_ICC} these may be estimated based on runtime, state loggers, and a combination of nameplate and field measurements of power consumption.

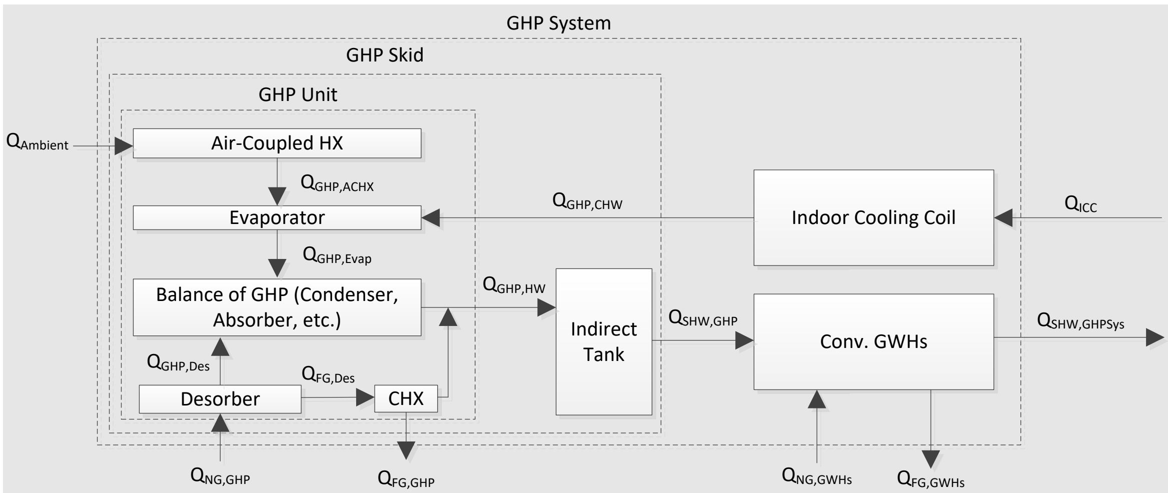
Prototype Performance of and FD&D on GHP System

- Hot Water Delivered Energy Factor: Comparing baseline to GHP system skid will include three calculations of DEF, determined on a daily and weekly basis and on a gas input only or combined gas & electricity input basis, as noted:
  - $DEF_{Baseline} = \sum Q_{SHW} \Big/ \sum\left(Q_{NG,GWHs} + Q_{Elec,GWHs} * 3.412\right)$
  - $DEF_{GHPskid} = \sum Q_{SHW,GHP} \Big/ \sum\left(Q_{NG,GHP} + Q_{Elec,GHP} * 3.412\right)$
  - $DEF_{GHPsys} = \sum Q_{SHW,GHPSys} \Big/ \sum\left(Q_{NG,GWHs} + Q_{NG,GHP} + 〚(Q〛_{Elec,GWHs} + Q_{Elec,GHP}\right) * 3.412)$
- GHP Utilization: Defined as the ratio of GHP skid output to total daily output, defined as $GHP\ Utilization = \sum Q_{SHW,GHP} \Big/ \sum Q_{SHW,GHPSys}$
- GHP output capacity will be determined at the GHP unit, as: $\dot{Q}_{GHP,HW} = 60 \cdot \dot{V}_{HW}C_P\rho\left(T_{HW,GHPSup} - T_{HW,GHPRtn}\right)$ [=] Btu/hr; for $C_P\rho$ evaluated at $T_{HW,GHPSup}$ and $\dot{Q}_{GHP,CHW} = 60 \cdot \dot{V}_{ICC}C_P\rho\left(T_{CHW,GHPRtn} - T_{CHW,GHPSup}\right)$ [=] Btu/hr; for $C_P\rho$ evaluated at $T_{CHW,GHPSup}$. Additionally, when operating in a hot water-only mode, the GHP air-coupled HX load will be estimated as $\dot{Q}_{GHP,ACHX} = 60 \cdot \dot{V}_{ACHX}C_P\rho\left(T_{ACHX,out} - T_{ACHX,in}\right)$ [=] Btu/hr; for $C_P\rho$ evaluated at the average of the two temperatures.
- Combustion Efficiency (CE):
  - Desorber CE: Using a curve fit generated by prior GTI test data, $\eta_{CE,DES} = \frac{91.66 - 0.27n_{O2} - 0.0254T_{FG,Des} + 0.0000016T_{FG,Des}^2}{100}$; $\eta_{CE,DES} \frac{= \dot{Q}_{GHP,DES}}{\dot{Q}_{NG,GHP}}$, noting that this curve fit may be updated during pre-shipment testing of the GHP units.

- Overall GHP CE: Defined as $\eta_{CE,GHP}=\frac{\dot{Q}_{FG,GHP}}{\dot{Q}_{NG,GHP}}$, $\dot{Q}_{FG,GHP}$ will be estimated using portable combustion analyzer equipment (n_{O2}, T_{FG}), during commissioning, using standard methods and as a function of $T_{FG,Des}$ and $T_{HW,GHPRtn}$.

Figure B-4 shows a diagram of the heat flow of a gas heat pump system.

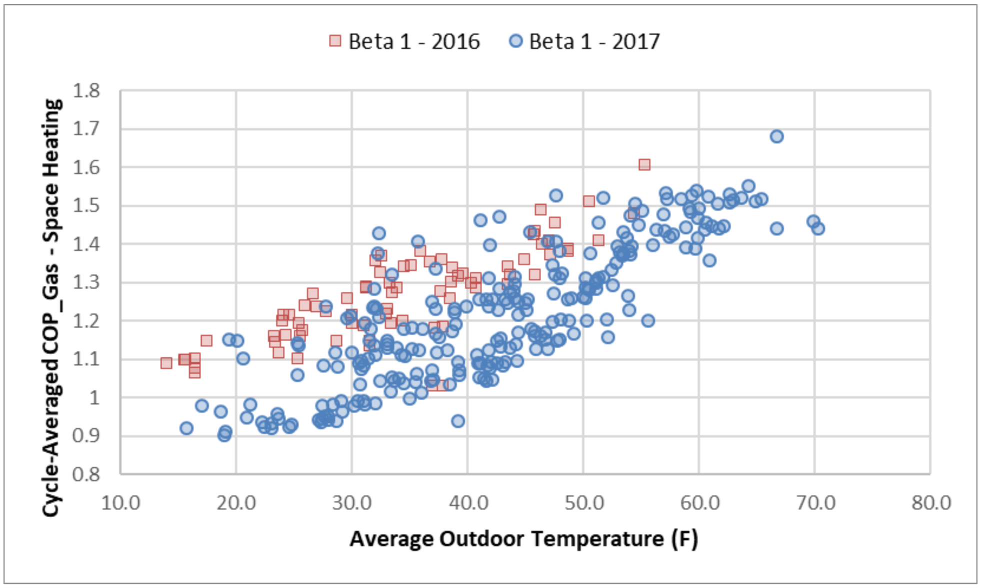
Figure B-4: Simplified Gas Heat Pump System Heat Flow Diagram



Source: GTI

- GHP COPs, focusing on just the inputs/outputs to the GHP on a gas-input basis:
  - Heating COP: $COP_{GHP,H}=\frac{\dot{Q}_{GHP,HW}}{\dot{Q}_{NG,GHP}}$; estimated and reported as, both time and cycle-averaged. Time-averaged permits comparison to instantaneous operating conditions (COP vs. ambient temperature, Figure B-5), while cycle-averaged is a better assessment of energy efficiency.
    - Time-averaged: For each heating on-cycle, the instantaneous COP_{GHP} using 5-minute averaged firing rates (GHP is modulating), the time-averaged COP_{GHP} will be reported.
    - Cycle-averaged: For each complete heating on-cycle, the total useful heating output measured at each time step, through the 'wind-down' stage, is compared to the total gas input over the complete cycle, $Q_{GHP,HW}$ [=] Btus.
  - Combined Heating/Cooling COP: Crediting the 'supplemental cooling', when operational, as $COP_{GHP,H/C}=\frac{\dot{Q}_{GHP,HW}+\dot{Q}_{GHP,CHW}}{\dot{Q}_{NG,GHP}}$. As with COP_H, $COP_{H/C}$ will be defined as time-averaged and cycle-averaged.
- Heat Pump COP, focusing on the health of the heat pump itself and does not include combustion losses or electricity consumption, defined as $COP_{HP}=\frac{\dot{Q}_{GHP,HW}}{\eta_{CE,DES}\dot{Q}_{NG,GHP}}$ and only reported on a time-averaged basis.

Figure B-5: Example of Gas Heat Pump Coefficient of Performance Data for Prior Field Test



Source: GTI

- To compare to prior GHP testing, the "Input/Output" method will be used, which posits that the daily energy input vs. output of a heating system can yield a delivered efficiency from their linear relationship of the transient energy input to the energy output (Bohac 2010 and Butcher 2011). When plotted on an "I/O" chart the slope and y-intercept can be used to estimate the DEF_{IO}, as follows:

$$Input = m \cdot Output + b; \frac{Output}{Input} = DEF_{I/O} = \left(m + \frac{b}{Output}\right)^{-1}$$

  With a known Output (on a skid and system basis) and the linear fit parameters, the $DEF_{I/O}$ is readily estimated, which can be compared to those from laboratory tests and for baseline equipment, the rated efficiency.

- Displaced Cooling: In addition to quantifying delivered cooling as $\dot{Q}_{ICC}$, the displaced cooling will be estimated as the difference in HVAC power consumed for A/C during baseline and GHP system monitoring periods, normalizing for weather, (CDD) and, if possible, restaurant revenue as a proxy for occupancy.
- Table B-5 displays the analysis of the data recorded by measurement points and their variables.

Table B-5: Measurement Points and Variables

Measurement Type	Measurement Category	Measured Quantity	Measurement Point(s) and Variable(s)	Units
Continuous Measurement	Natural Gas Flow	Natural Gas Flow	Conventional GWH 1 [V_{NG_GWH1}], Conventional GWH 2 [V_{NG_GWH2}], HVAC* [V_{NG_HVAC}], GHP [V_{GHP}]	ft^3
Continuous Measurement	Power Consumption	Power Consumption	Conventional GWH Total [Q_{Elec_GWH}], HVAC* [Q_{Elec_HVAC}], Indoor Cooling Coil* [Q_{Elec_ICC}], GHP [Q_{Elec_GHP}], GHP Skid Pumps [Q_{Elec_Skid}]	Wh
Continuous Measurement	Service Hot Water (SHW)	Water Flow	SHW [V_{SHW}]	gal.
Continuous Measurement	SHW	Temperature	Hot Water Outlet Conventional GWH 1 [T_{HW_GWH1}], Hot Water Outlet Conventional GWH 2 [T_{HW_GWH2}], Hot Water Outlet – SHW to Fixtures [T_{SHW}], Cold Water Inlet to Conventional GWHs [T_{CW_GWHs}], Recirc. Return to Conventional GWHs [T_{RR_GWHs}], Mixed Water Inlet to Conventional GWHs [T_{MW_GWHs}], Cold Water Inlet to GHP Skid [T_{CW_Skid}], Hot Water Outlet from GHP Skid [T_{HW_Skid}], GHP Skid Tank Mid-Tank Temperature [T_{Tank_Skid}]	°F
Continuous Measurement	Ambient/Indoor Air	Temperature	Indoor Kitchen [T_{Air_K}], Indoor Mechanical Room [T_{Air_Mech}], Indoor Dining Room [T_{Air_Dining}], Outdoor GHP Air-Coupled HX [T_{Air_GHP}], HVAC Supply Air [T_{SupAir_HVAC}], Indoor Cooling Coil Supply Air [T_{SupAir_ICC}]	°F
Continuous Measurement	GHP System Loops	Temperature	*Chilled Water:* Indoor Cooling Coil Supply [T_{CHW_ICCSup}], Indoor Cooling Coil Return [T_{CHW_ICCRtn}], GHP Supply [T_{CHW_GHPRtn}], GHP Return [T_{CHW_GHPRtn}] *Hot Water:* GHP Supply [T_{HW_GHPRtn}], GHP Return [T_{HW_GHPRtn}]	
Continuous Measurement	GHP System Loops	Flow Rate	GHP Hot Water Loop [$\dot{V}_{HW}$], GHP Chilled Water – Indoor Cooling Coil [$\dot{V}_{ICC}$], GHP Chilled Water – Air-Coupled HX [$\dot{V}_{ACHX}$]	GPM
Continuous Measurement	GHP Internal	Temperature	Evaporator NH_3 Inlet [T_{NH3_In}], Evaporator NH_3 Outlet [T_{NH3_Out}], Desorber Shell [T_{Des}], Desorber Flue Gas Outlet [T_{FG_Des}], Air-Coupled HX Inlet [T_{ACHX_In}], Air-Coupled HX Outlet [T_{ACHX_Out}]	°F
Batch Measurement	-	Inlet Fuel Pressure	At GHP and Conventional GWH gas inlet [P_{NG}]	in. WC
Batch Measurement	-	GHP Skid Operating Noise	Measured 1.0 m from GHP Skid	dB
Batch Measurement	-	Excess air level, as dry stack O_2	GHP Stack [n_{O2}]	%, dry
Batch Measurement	-	GHP Flue Gas Outlet	GHP Stack [T_{FG}]	°F

Measurement Type	Measurement Category	Measured Quantity	Measurement Point(s) and Variable(s)	Units
3rd Party Data	-	Tank storage volume	Conventional GWH 1 [V_{Tank_GWH1}], Conventional GWH 2 [V_{Tank_GWH2}], Skid Tank [V_{Tank_Skid}]	gal.
3rd Party Data	-	Outdoor Temperature	Ambient Weather [$T_{Outdoor}$]	°F
3rd Party Data	-	Outdoor Humidity	Ambient Weather [$RH_{Outdoor}$]	%
3rd Party Data	-	Barometric Pressure	Ambient Weather [P_{Baro}]	in. Hg
3rd Party Data	-	Natural Gas HHV	From Utility [*HHV*]	Btu/scf

* Note that gas and power consumption may be approximated using state loggers here, as noted previously

Source: GTI

CALIFORNIA ENERGY COMMISSION

CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix C: Site Screening and Selection Details

June 2024 | CEC-500-2024-058

APPENDIX C:
Site Screening and Selection Details

Host Site Recruitment and Selection

Screening Criteria

As noted in the main body of the report, the team's first goal was to find two qualified host sites that suitably meet the project requirements while sufficiently representing typical restaurant applications of this integrated GHP system. In order to assure the sites were suitable for project goals and to better understand performance and installation barriers, the following screening criteria for the two restaurant sites were as follows:

Space for Temporary Equipment Installations:

- At least a 4' x 4' space for GHP installation, preferably ground-mount on concrete pad rather than rooftop. If rooftop needed, ease of install with crane would be a priority
- Room for auxiliary hot water tank, indoors or adjacent to GHP (where permitted)
- Wall space for the data acquisition system (DAS) in proximity to 120 VAC

Access for Installation, Servicing, Data Collection:

- Adequate exposed piping for instrumentation
- Options for indoor cooling coil locations

Adequate Loads & Other Considerations:

- Hot water demand estimated as >1,500 gallons/day
    - Represented directly or as >625 meals served/day or >$7,500/day of restaurant revenue
- Need for auxiliary air-conditioning
- Appearance of well-maintained facility and code compliance during inspection

Regarding estimating loads, industry sizing suggests that a full-service restaurant consumes 2.4 gallons of hot water/meal/day on average (Source: ASHRAE) from which the approximately >625 meals/day target comes. In discussing the integrated GHP system design, concerning relative sizing of the GHP component, in general there are risks of both under- and over-sizing. If undersized, not enough of the load is carried by the GHP and this can offer only a minimal improvement over the baseline no-GHP case. If oversized relative to the load and conventional water heaters, the full value of the GHP(s) will not be realized as they will be operating at part-load most of the time. In this project's specific case, the GHP size was fixed by the manufacturing partners with a nominal 80 kBtu/hr output at 47°F (8°C) outdoor temperature. When aiming for a GHP output fraction of 30%-60% of peak load, a wide range of sites are possible with peak loads ranging from approximately 375-600 GPH or with "right-sized" existing water heaters with combined inputs of 250 to 450 kBtu/hr, as additional criteria to the total daily service hot water (SHW) load. Worth noting for this study, the indoor water heater(s) are left in place following the GHP retrofit, with the GHP pre-heating the incoming water to the indoor water heater(s). With these existing water heater(s) presumably oversized for the site SHW load as is (*N+1* redundancy is common in full-service restaurants), it is most important to assure the GHP will not be oversized for the purposes of site screening.

Concerning the additional cooling output, sites were screened to best take advantage of the supplemental cooling. Generally, it is assumed that the added 0.5-2.2 tons of cooling will be useful in all instances as noted previously, the internal loads within the kitchen are expected to demand year-round cooling. Prior studies of thermal comfort in commercial kitchens revealed that restaurant cooking staff were equally uncomfortable during winter and summer months (Stoops 2013), so it is anticipated that cooling from the GHP will be useful, particularly during peak business hours. The utility of the cooling will depend more on the location of the indoor Fan Coil Unit (FCU) relative to the outdoor GHP, with longer chilled water loops incurring greater thermal losses and pumping energy penalties. Similarly, the cost versus benefit of said cooling must be weighed in terms of *net electricity benefit*, where avoided cooling energy benefit is adjusted by the additional electrical load. As an example, a rough estimate for a chilled water loop with 160 ft of 1" PEX tubing[16] and standard FCU would reduce the avoided cooling energy benefit by 10% (pump) and 17% (FCU fan), highlighting the importance of both minimizing pressure loss in the chilled water loop and specifying low-power pump and FCU equipment.

Site Screening Details – First Round

Outlined in detail in the *Baseline Field Monitoring Report* submitted as part of this study and summarized here, while building on the summary provided in Appendix A regarding integrated GHP system design, the project team performed an initial screening of potential restaurant sites recruited during the proposal phase. GTI visited three potential restaurant sites in the Los Angeles-area, out of a six-site small chain of "gastropubs". Two of the sites in Pasadena and Anaheim Hills had significant challenges to hosting for this project, so a third suitable option was explored in Rancho Cucamonga, but was not accepted due to its location outside of Los Angeles and Orange Counties. In mid-2017, GTI visited three potential restaurant sites in Southern California and the three sites were all from the small chain of casual dining restaurants identified during the proposal stage, with six total locations in Southern California. The three locations visited were:

- Pasadena – One of the two sites identified by the chain during the proposal phase as a good option, located in Los Angeles County.
- Anaheim Hills – The second of two sites identified by the chain during the proposal phase, located in Orange County.
- Rancho Cucamonga – Knowing that the Pasadena site may present logistical issues and that their Huntington Beach site will move locations within the next year, the chain

[16] Includes nominal quantity of fittings, pressure loss of GHP and FCU, in addition to tubing.

offered up an alternative site and GTI inspected the Rancho Cucamonga site as well despite the fact that it is located in San Bernardino County.

Based on site inspections, including considerations for access for equipment installations, space for additional equipment, and anticipated loads at the sites, GTI recommended the following:

1. Use Rancho Cucamonga Site – This is the most suitable site for this demonstration. There is room for a second tank and the gas absorption heat pump (GHP) can be installed on a pad adjacent to the property. This site is technically not within the "Los Angeles Basin", as required by the original Grant Funding Opportunity (GFO) paperwork, however it is within the South Coast Air Basin (governed by AQMD) and served by SoCalGas.
2. Consider Anaheim Hills Site – This site is not optimal, but a demonstration here may be feasible. The GHP will have to be mounted onto the roof, to which access is feasible. Currently, there is no space for the additional indirect tank. There are three options, in order of preference: a) the existing water heater is replaced by the indirect tank and the conventional water heater is replaced by a wall-mounted tankless water heater,[17] b) the site makes space within the kitchen for the additional tank, which may not be possible, and c) the indirect storage tank is placed on the roof with the appropriate considerations for weight. As part of the original proposal, this site presents no issue with sponsor approval.
3. Drop the Pasadena Site – While the Pasadena location may be suitable concerning space within the kitchen and mechanical room, logistically installing equipment on the rooftop of a historic building and running hydronic lines down to the first story will exceed project resources. To operate a demonstration at this site is not impossible, but GTI would be better off soliciting new sites that better fit the project.
4. Solicit New Sites as Contingency – GTI solicited new sites that are within the Los Angeles Basin as backups, if needed.

Site Inspection Details: Pasadena Location

The Pasadena location in the historic downtown Pasadena ("Old Pasadena"). The three-story building's last major renovation was in 1968 and the building is 130′ x 107′. The building has multiple tenants, 38,500 ft^2 overall, with the restaurant as the ground floor tenant for the south half of the building (Figure C-1).

Access: The south and east sides of the building are busy streets, while the north side of the building abuts a neighboring building, and the west side has an approximately 16′ wide alley. There is one door leading from the alley to the kitchen, which is 36″ wide, shown in Figure C-2. This ramp shown leads to a 90-turn and directly to the mechanical room. The roof is accessible via a main building elevator and stairwell as shown in Figure C-3.

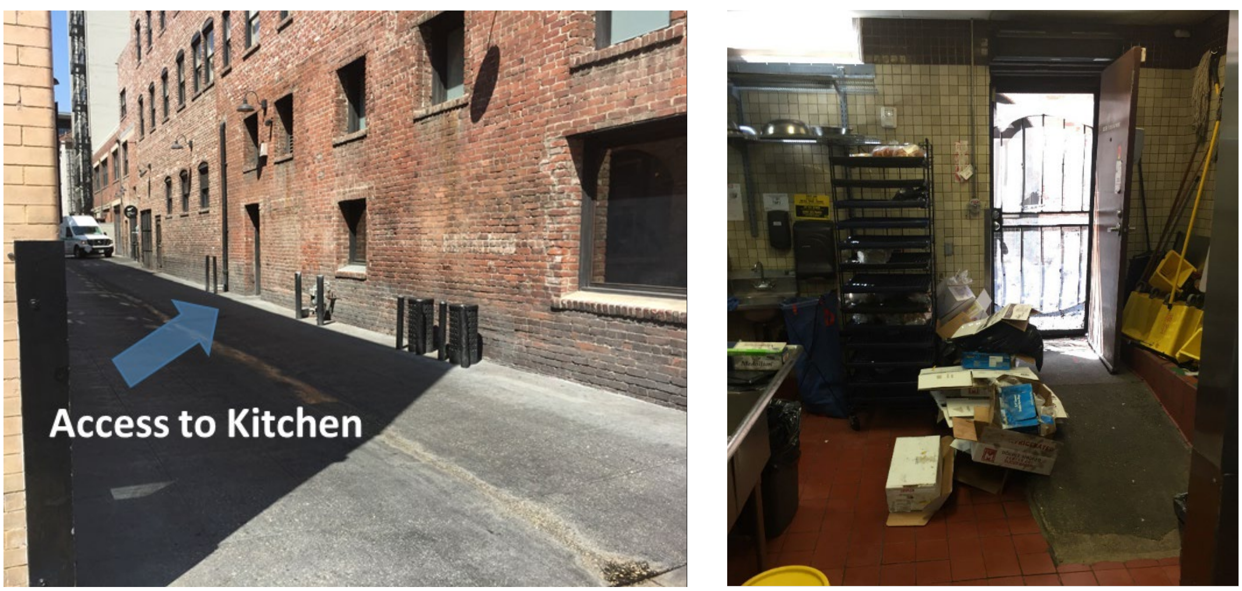
[17] The site is served by an 85 kBtu/hr input, natural draft, 100-gallon commercial storage water heater. It is likely that a standard 199 kBtu/h or if necessary, 250 kBtu/h, commercial tankless water heater can effectively replace baseline unit.

Business: The restaurant manager estimates at peak the site serves 500 meals/day. The restaurant is open 11 am-11 pm on weekdays and 11 am to midnight on Fridays and Saturdays. At peak activity, the restaurant will have up to nine servers active and the occupancy of the restaurant is estimated as 100 guests. The site does not have on-site maintenance staff present.

Figure C-1: Photo of Pasadena Site

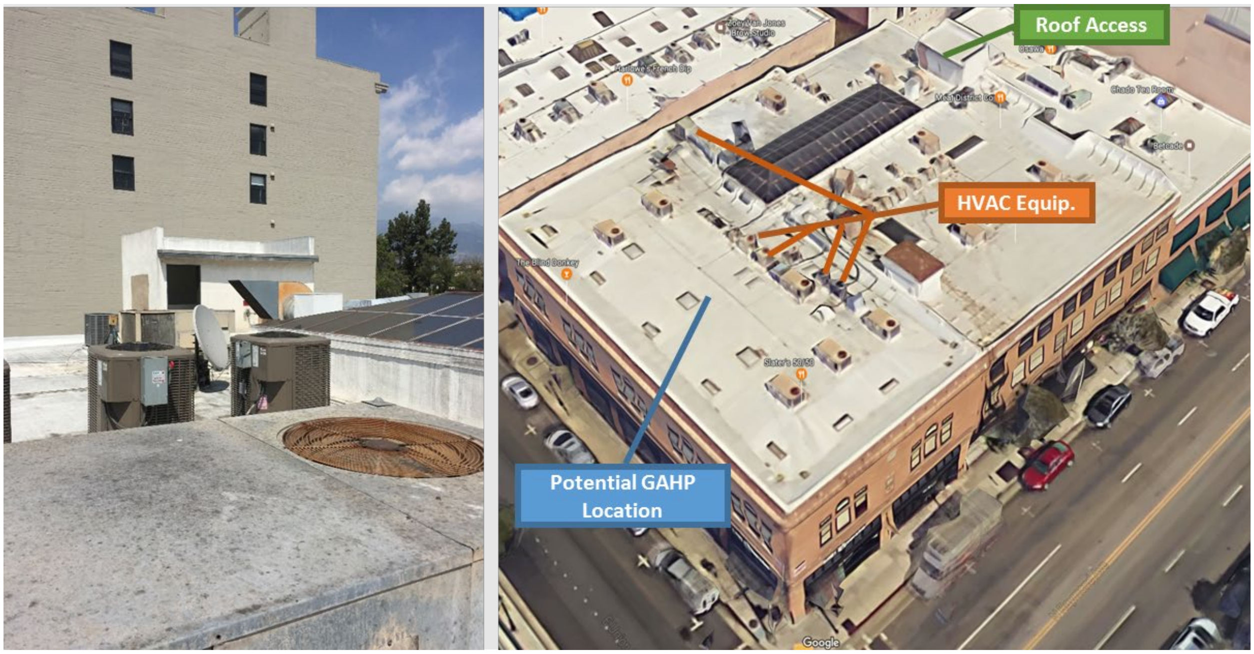
Source: GTI

Figure C-2: Alley on East Side of Building Highlighting External Access to Kitchen



Source: GTI

Figure C-3: Photo of Roof Access (via elevator) with Location Relative to Heating, Ventilation, and Air-Conditioning/Gas Heat Pump Siting



Source: GTI

Existing Equipment

Water Heater: The building is served by one water heater, a Bradford White gas storage water heater, Model: UCG100H1993N, 199,999 Btu/hr input and 100 gallons of storage. The water heater has a thermostat setting of 140°F (60°C). The water heater is located in a small room 80″ x 104″, with the water heater in a corner next to an ice machine and the gas cylinders for carbonation. The unit is plumbed with 1″ copper piping and the site appears to have a traditional main/branch-type plumbing. Plumbing is uninsulated in the mechanical room. The entrance to the mechanical room is a 36″ doorway. Above the gas cylinders is sufficient wall space for the data collection equipment as shown in Figure C-4 (to left of water heater). There are no visible electrical outlets within the mechanical room. The closest outlet is opposite the entrance to the mechanical room.

Based on the estimate of 500 meals served per day and guidance from the ASHRAE handbook indicating restaurants consume an average of 2.4 gallons of hot water/day-meal, this results in an estimated 1,200 gallons/day. For a more refined estimate, the number of fixtures can be used with industry calculators:

- A door-type dishwasher
- Two restroom sinks (men/women)
- Two hand sinks (incl. bar)
- One under-bar sink
- Two three-compartment sinks (incl. bar)
- Two pre-rinse valves

- Two utility sinks (kitchen and coffee prep)
- One mop sink

Figure C-4: Views in Mechanical Room to Right and Left of Water Heater

Source: GTI

HVAC: All HVAC equipment servicing the building are on the rooftop, where the restaurant RTUs are amongst others that serve the rest of the building (Table C-1). HVAC units serving the restaurant are marked by stickers. There are four heat pump and A/C units serving the restaurant, they are as follows below. Note that the site is also served by two evaporative air coolers (Figure C-5).

Table C-1: Existing HVAC at Pasadena Site

Unit #	Manufacturer	Model	Type
1	York	E1HB060S46A	Heat Pump
2	York	E1HB060S46A	Heat Pump
3	Carrier	25HBR360A0060010	Heat Pump
4	Carrier	25HBR360A0060010	Heat Pump

Source: GTI

Distribution from these HVAC equipment into the main dining area is by round overhead ducts running west to east. Makeup air and space conditioning to the kitchen is supplied by two diffusers over the main cooking area and counter per Figure C-6.

Figure C-5: Location of Heating, Ventilation, and Air-Conditioning Equipment with Nameplate

Source: GTI

Figure C-6: Location of Two Supply Air Diffusers in Kitchen

Source: GTI

Siting of GHP/Tank/Cooling Coil/DAS:

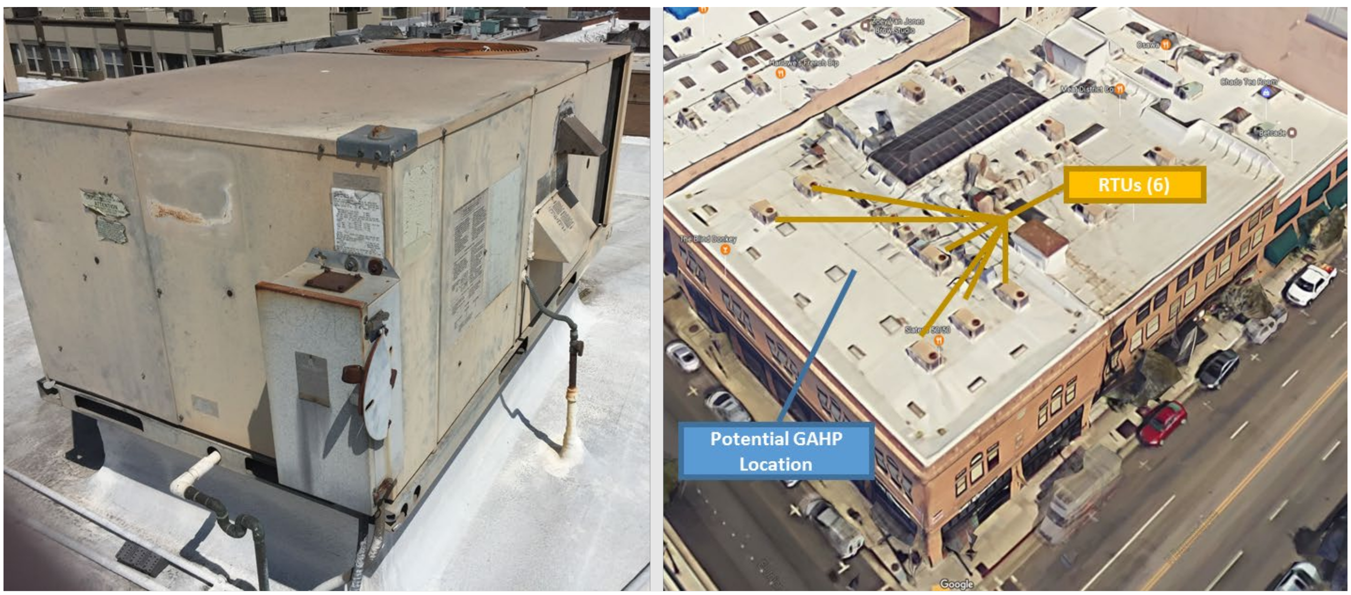
GHP: The GHP must be installed on the building's roof as there is no available space adjacent to the building due to its location. The rooftop does have natural gas service, with six RTUs operating that serve other parts of the building (Figure C-7). There is a roughly 20' by 50' space where the GHP may be installed.

Indirect Tank: Presently, there isn't sufficient space in the mechanical room for an indirect tank, however it may be possible to shift gas cylinders or move the ice machine forward to permit installation of the additional tank within the mechanical room, assuming it is 24-28" in diameter. The room's ceiling is not prohibitively low). Alternatively, there is a partially filled storage room that shares a common wall with the mechanical room.

Cooling Coil: The greatest need for supplemental cooling within the kitchen would be near the cooking line. The best location may be just above the pre-rinse valve/compartment sink. This location would face the entrance cooking line, arranged as a "cul-de-sac" in the kitchen, and would be mounted near the outside wall facing the alley. This would permit running hydronic lines down the building exterior and into the kitchen.

DAS Package: With such a large distance between the rooftop and the mechanical room, it is likely that two separate DAS packages will be necessary. The roof-mounted DAS package with the GHP can be affixed to the prototype. For measurements within the kitchen, the DAS package can be mounted on the tile wall above the gas cylinders or in the adjacent storage room, with the latter preferred. Instrument wiring will need to round a corner over a refrigerator to run from this storage room to the mechanical room.

Figure C-7: Location of Rooftop Units on Rooftop with Gas Service



Source: GTI

Site Inspection Details: Anaheim Hills Location

The Anaheim Hills location is along the Santa Ana river and the 91 Freeway. The restaurant is located within an "L" shaped small strip mall development, with the restaurant located at the bend in the "L" as shown in Figure C-8. The building was built in 1985 and this restaurant space was first occupied by the restaurant in 2009. The full building has 67,528 ft2 overall, and Figure C-9 has a red box highlighting the portion of the footprint occupied by the restaurant.

Access: The entrance to the restaurant is accessed through the main parking lot as shown. As the restaurant is situated on a hill, the rear of the building is atypical, running along a residential access road. The building directly abuts this road with a wood fence and a security gate as shown in Figure C-9. Along the back of the building, it directly abuts the hill with no space behind the building. Access to the roof is gained through two means:

- *Through Kitchen:* Ascending a stairwell from the back of the kitchen leads to a landing which to the left leads to a hatch opening to the roof and to the right an exit door leading to the aforementioned security gate and residential access road. This hatch is shown in Figure C-10 and is 29” wide and 35” tall at the opening.
- *From Residential Access Road:* Through the security gate, leads directly to the exit door and roof hatch.

The main entrance of the restaurant and this exit door are the only two points of access to the restaurant.

Business: The restaurant manager estimates that weekday sales are $3000-$3500/day and weekend sales are $9000-11000/day. If one assumes $20/meal (the average at other major FSRs), this translates to 150-175 meals/day on weekdays and 450-550 meals/day on the weekends. The restaurant is open 11 am-11 pm on weekdays and 11 am to midnight on Fridays and Saturdays. At peak activity, the restaurant will have up to six servers active and the occupancy of the restaurant is estimated as high as 150 guests. The site does not have on-site maintenance staff present.

Figure C-8: Photo of Restaurant Entrance (L) with Google Maps Satellite (R) Imagery

Source: GTI

Figure C-9: Photo of Rear Access to Kitchen Roof

Source: GTI

Figure C-10: Looking Through Roof Hatch to Exit Door (Left) and Other Side of Roof Hatch (Right)

Source: GTI

Existing Equipment:

Water Heater: The building is served by one water heater, a Bradford White gas storage water heater, with 85,000 Btu/hr input and 100 gallons of storage. The water heater has a thermostat setting of 135°F (57°C). It is located in the corner of a corridor within the back kitchen area and is directly adjacent to a prep counter in a narrow corridor with dishwashing and compartment sinks. There is also a dry storage room and a small alcove where cleaning supplies are stored next to the heater. Access to this back kitchen area is through one of two 36″ wide hallways. The unit is plumbed with flex lines and 3/4″ copper piping and the site appears to have a traditional main/branch-type plumbing and the plumbing is uninsulated.

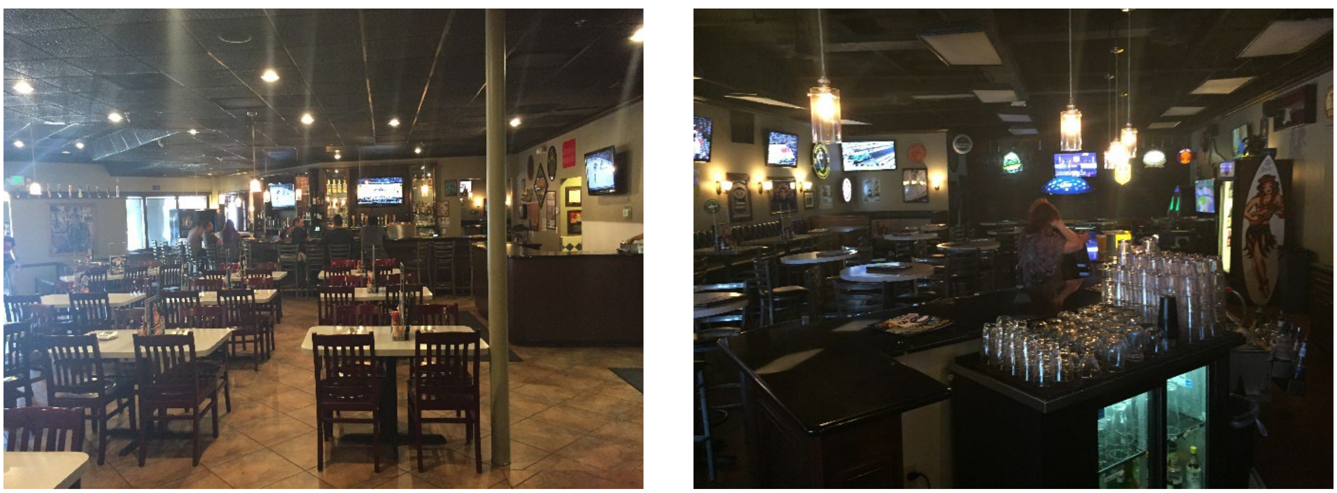
Note that this back kitchen area is framed by the back wall of the building, housing the water heater vents as shown previously. There are no visible electrical outlets within this back kitchen area. The closest outlet is in the area marked "cleaning storage".

Based on the estimate of up to 550 meals served per day and guidance from the ASHRAE handbook indicating restaurants consume an average of 2.4 gallons of hot water/day-meal, this results in an estimated 1,320 gallons/day. For a more refined estimate, the number of fixtures can be used with industry calculators:

- A door-type dishwasher
- Two restroom sinks (men/women)
- Two hand sinks (incl. bar)
- Two under-bar sinks (two bars)
- Three three-compartment sinks (two bars and back kitchen area)
- One pre-rinse valve
- One utility sink (kitchen)

Figure C-11 shows the inside of both of the restaurant's dining area and bars. The main dining room is on the left and the secondary dining area and bar can be seen on the right.

Figure C-11: Main Dining Area and Bar (Left) and Secondary Dining Area and Bar (Right)



Source: GTI

HVAC: All HVACs servicing the building are on the rooftop, where the restaurant RTUs are among others serving the rest of the building. HVAC units serving the restaurant are marked by labels. There are six heat pump and A/C units serving the restaurant, as outlined in the following table. Towards the northwest portion of the rooftop, there are several old, disconnected HVAC equipment and what appears to be a new heat pump and a small refrigeration condenser. These two items and the #1-#6 HVAC units are summarized in Table C-2.

Table C-2: Existing HVAC at Anaheim Hills Site

Unit #	Manufacturer	Model	Type
1	Rheem	RJNL-A060CM	Heat Pump
2	Rheem	RPKA-0375AZ	Heat Pump
3	Rheem	RJMB-A120CM	Heat Pump
4	Rheem	RJNL-A060CM	Heat Pump
5	Goodman	CK30-18	A/C
6	Goodman	CPRT 48-1	A/C

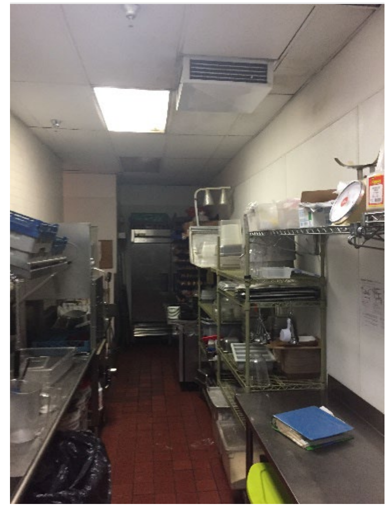
Source: GTI

Figure C-12 shows a photograph of the rooftop exhaust equipment. The distribution from the HVAC equipment into the main dining area is by standard recessed ceiling grilles. Makeup air and space conditioning to the kitchen is supplied by two diffusers over the main cooking area and counter and one diffuser over the back kitchen area, per Figure C-13.

Figure C-12: From Left to Right – Units #6, #3, and #4 with Exhaust Equipment and Roof Hatch

Source: GTI

Figure C-13: Distribution in Kitchen Area above Cook Line (Left) and Back Kitchen Area (Right)

Source: GTI

Siting of GHP/Tank/Cooling Coil/DAS

GHP: Like the Pasadena site, the GHP must be installed on the building's roof as there is no available space adjacent to the building due to the nature of the rear of the building. The rooftop does not appear to have natural gas service. There is an open space framed by HVAC equipment immediately outside of the roof hatch, as shown in Figure C-14. Inspection indicates there is sufficient room for a 4' by 4' GHP with 18" clearance all around. If this is not feasible, there is a very large open space northwest as shown in prior overviews, however this will require a longer gas line run and longer hydronic piping runs.

Figure C-14: Panorama Photo of Potential Gas Heat Pump Location

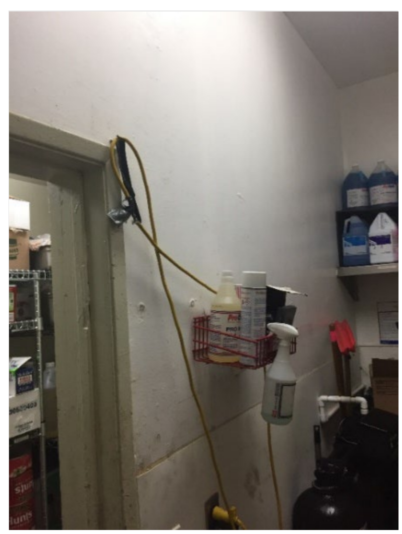
Source: GTI

Indirect Tank: Presently, there isn't sufficient space in the back kitchen area for an indirect tank and the site would need to rearrange supplies and materials to make space for the tank. As noted in the summary, there are three options, in order of preference: a) the existing water heater is replaced by the indirect tank and the conventional water heater is replaced by a wall-mounted tankless water heater, b) the site makes space within the kitchen for the additional tank, which may not be possible, and c) the indirect storage tank is placed on the roof with the appropriate considerations for weight.

Cooling Coil: Like the Pasadena site, the need for supplemental cooling within the kitchen would be near the cooking line. The best location may be in the corridor between the cook line, walk-in cooler, and the back kitchen area close to the water heater, as shown in Figure C-15. The coil would face the cook line and would minimize the distance from the potential DAS package location, indirect tank, and back wall.

DAS Package: While not as extreme as the Pasadena site, there may still be a large distance between the rooftop GHP location and the indirect tank/indoor measurements, and as a result, it is likely that two separate DAS packages will be necessary. Like Pasadena, the roof-mounted DAS package with the GHP can be affixed to the prototype. For measurements within the kitchen, the DAS package can be mounted on the wall above the outlet in the cleaning storage area as shown in Figure C-15. Instrument wiring to the water heater/tank can be run along the high wall or ceiling to be out of the way. Alternatively, the DAS may be mounted on the upper wall near the water heater or an inner wall within the dry storage area. Neither alternative is preferred as the upper wall is above a busy prep work area and the dry storage wall space is limited, with both farther away from the nearest outlet.

Figure C-15: Potential Coil Location (Left) and Open Wall Space in Cleaning Storage above Outlet



Source: GTI

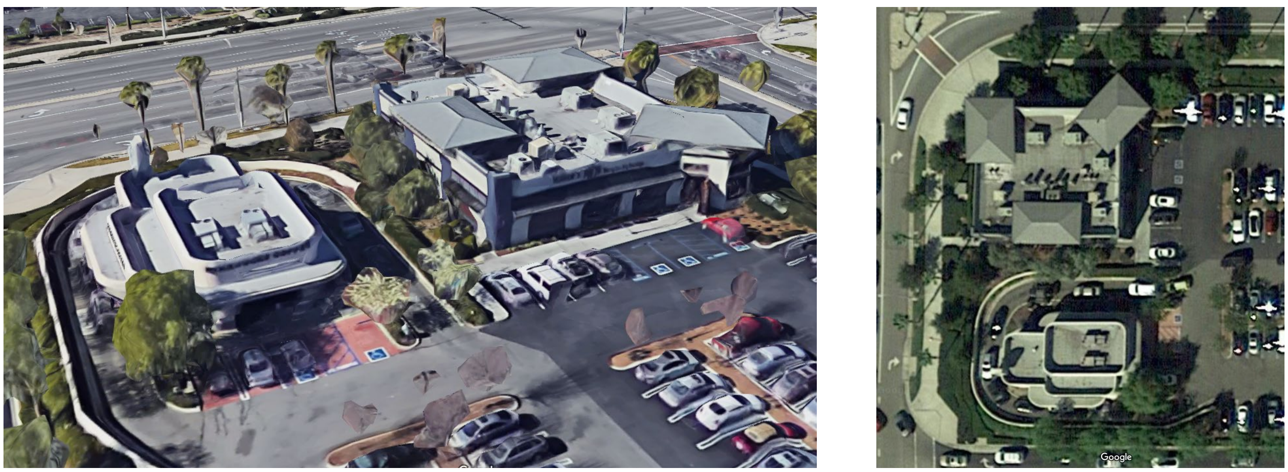
Site Inspection Details: Rancho Cucamonga Location

The Rancho Cucamonga location near the "Victoria Gardens" outdoor shopping mall and the I-15 freeway. Unlike the Pasadena and Anaheim Hills locations, the Rancho Cucamonga site is a standalone building. The building is approximately 6,000 ft^2 overall and was built in 2006. Figure C-16 shows rendered and satellite imagery of the building, with the adjacent coffee shop drive-thru shown for reference.

Access: The main entrance of the building is in the northeast corner facing the parking lot. The kitchen runs along the southern portion of the building and has an exit door along this south wall (Figure C-17). The "L" shaped mechanical room is physically separate from the kitchen and has access from the exterior along the southwest corner with a double-door on the south wall (70" total width) and a side door along the west (34" width). The roof is accessed by a ladder from the kitchen, leading to a hatch opening to the roof.

Business: The restaurant manager estimates the site serves 200-300 meals/day on average and a prior A.O. Smith/SoCal Gas survey (different project) found the site had a peak of 680 meals/day. The restaurant is open 11 am -11 pm on weekdays and 11 am to midnight on Fridays and Saturdays. At peak activity, the restaurant will have up to eight servers active and the occupancy of the restaurant is estimated as 210 guests. The site does not have on-site maintenance staff present.

Figure C-16: Rancho Cucamonga Location (with Neighboring Starbucks to the Left) Rendered from the East (Left) and Satellite (Right) Imagery



Source: GTI

Figure C-17: Entrance to Kitchen and Mechanical Room along South Wall (Left) and Additional Access to Mechanical Room around Corner on West Wall

Source: GTI

Existing Equipment:

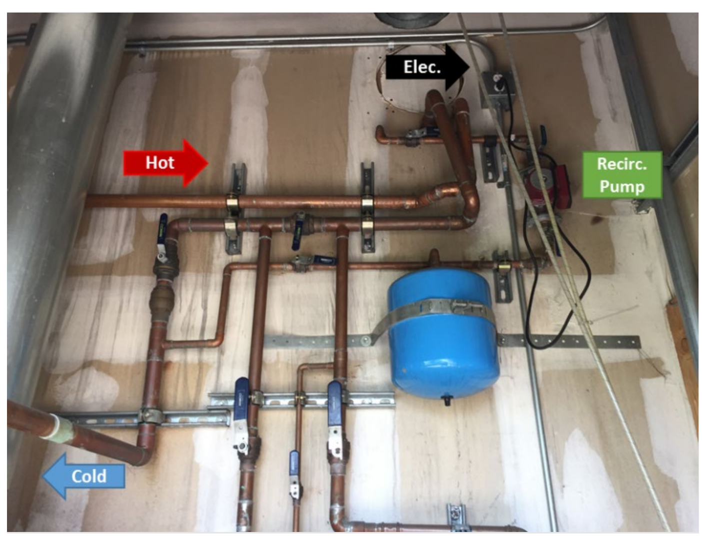
Water Heater: The building is served by one water heater, an American Standard gas storage water heater, Model: ULN80-399AS, 399,000 Btu/hr input and 81 gallons of storage. The water heater's thermostat setting is unknown. The water heater is located in an "L" shaped mechanical room at the southwest corner of the building with external access only. From the south the heater can be accessed by a 70" wide double door. The heater is to the left of a bank of gas cylinders (Figure C-18) in a space that is 56" deep. The unit is plumbed with 1" copper piping, and the site appears to have a recirculation loop as evidenced by a recirculation pump. Plumbing is uninsulated in the mechanical room. The closest electrical outlet is serving the recirculation pump and is located on the upper wall next to the pump and hot/cold supply line wall penetrations.

The bend in the "L" shaped mechanical room to the west leads to a separate door for access to the fire sprinkler riser. The open space is currently used as storage for a large rolling bin for soiled floor mats. The space is 43" deep and accessed by a 34" wide door as shown in Figure C-19. The fire sprinkler riser is located in the bend of the "L". Overall, the room has high ceilings, which run up to near the roof line, which creates a lot of open wall space for data logging equipment and may allow for simpler runs of hydronic/instrumentation lines.

Based on the estimate of 680 meals served per day and guidance from the ASHRAE handbook indicating restaurants consume an average of 2.4 gallons of hot water/day-meal, this results in an estimated 1,632 gallons/day. For a more refined estimate, the number of fixtures can be used with industry calculators:

- A door-type dishwasher
- Three restroom sinks (men/women/employee restrooms)
- Three hand sinks (incl. bar)
- Two three-compartment sinks (incl. bar)
- One pre-rinse valves
- Four utility sinks (kitchen and coffee prep)
- One mop sink

Figure C-18: Water Heater Located in Mechanical Room (Left) and Closeup of Plumbing (Right)



Source: GTI

Figure C-19: Open Space Viewed from South over Heater (Left) and From West Entrance (Right)

Source: GTI

HVAC: All HVAC equipment servicing the building are on the rooftop, and as a standalone building, all units serve the restaurant. There are five RTUs total, manufactured by Trane and are outlined in Table C-3. Note that the site is also served by two evaporative air coolers. These units are relative to potential GHP locations with site access shown in Figure C-20.

Table C-3: Existing HVAC at Rancho Cucamonga Site

Unit #	Manufacturer	Model	Type
AC-1	Trane	YCD151C3LABB	RTU
AC-2	Trane	YCD151C3LABB	RTU
AC-3	Trane	YCD151C3LABB	RTU
AC-4	Trane	YHC120A3 ELA2KC	RTU
AC-5	Trane	YHC120A3 ELA2KC	RTU

Source: GTI

Distribution from these HVAC units into the main dining area is by recessed supply air grilles and makeup air and space conditioning to the kitchen is similarly supplied over the main cooking area and counter per Figure C-21.

Figure C-20: Location of Heating, Ventilation, and Air-Conditioning Equipment on Rooftop and Potential Gas Heat Pump Locations

Source: GTI

Figure C-21: Distribution in Main Dining Area (Left) and Over Kitchen Cook Line (Right)

Source: GTI

Siting of GHP/Tank/Cooling Coil/DAS

GHP: As shown in Figure C-20, the GHP can be installed on the building's roof or on a pad adjacent to the building. The rooftop has natural gas service, with five RTUs serving the building. There is a roughly 19′ by 39′ space where the GHP may be installed close to RTUs AC-1 and AC-2 as shown in Figure C-22. Alternatively, and perhaps preferably, the GHP could be located on a pad adjacent to the mechanical room double doors. This location is favorable as it does not require locating the GHP on the roof and is very close to both the kitchen and the backup water heater/indirect tank. Electrical, gas, and hydronic lines will likely have to be buried underneath the sidewalk. An alternate outdoor location is along the west side of the restaurant and next to the west door to the mechanical room/fire sprinkler riser. In this location, while farther away from the kitchen, the unit would be closer to the indirect tank and may be installed without burying utilities. Note that in both ground-mounted cases, the GHP will need to be secured against theft/vandalism.

Indirect Tank: As previously noted, there is space for an indirect tank within the mechanical room around the corner from the baseline water heater, in front of the west access door. There is sufficient headroom above this location for water lines to connect to building plumbing. This would only require that the restaurant find an alternate location for the rolling bin.

Cooling Coil: As with other sites, the greatest need for supplemental cooling within the kitchen would be near the cooking line. The best location may be near the back cook line that runs parallel to the main cook line. Along this corridor are prep stations, a convection oven, additional cooktops, and other equipment (both lines share a common exhaust hood). This coil location could also cool the manager's office and the back region close to the dishwashing area. The location is close to the south exit door as shown in Figure C-23.

DAS Package: As noted previously, there is ample wall space within the mechanical room, particularly near the west access door where the indirect tank may be placed. Power can be supplied by an outlet serving the circulation pump, around the corner on the upper wall.

Figure C-22: Panorama of Rooftop Location for Gas Heat Pump, South of Rooftop Units AC-1 and AC-2

Source: GTI

Figure C-23: Potential Location of Supplemental Cooling Coil near Office and Exit Door (Left) and Looking Down Second Cook Line (East) from Directly Below Coil Location (Right)

Source: GTI

Second Round of Recruitment – Site Selection

After the initial screening and site inspections, the project team performed a second recruitment phase. This phase focused on local and national full-service restaurant chains. Figure C-25 displays a map of prospective sites. Through a combination of stakeholder outreach (including an updated recruitment flyer in Figure C-26), cold-calling, and leveraging team partnerships. A significant number of opportunities were screened out due to:

- Size of the restaurant, with quick service restaurants, delis, and other smaller establishments perceived to be well below < 1,500 gallons/day consumption.
- Location outside of the key regions of Los Angeles and Orange Counties.
- Expectations of space availability for rooftop or ground-mounted equipment, screened out with satellite, street-level imagery (see example below).

Figure C-24: Potential Site for Demonstration Screened Out with Satellite Imagery

Source: GTI

Ultimately, the team had success establishing interest with two restaurant chains well-established in the Southern California region:[18]

- A local chain of 24-hour diners, with 18 locations in Los Angeles and Orange Counties, well known for breakfast and the nostalgic architecture of their buildings. This host site opportunity was brought to the team by SoCalGas.
- A national chain of full-service restaurants, with 23 locations in Los Angeles and Orange Counties, with approximately 860 locations in North America and well known for its Italian-American cuisine. This host site opportunity was brought to the team by A.O. Smith.
- This section summarizes the detailed screening, inspecting, and selection process by the project team, further highlighting some challenges with retrofit projects of this nature.

Candidate Pool #1: Local Chain of 24-Hour Diners

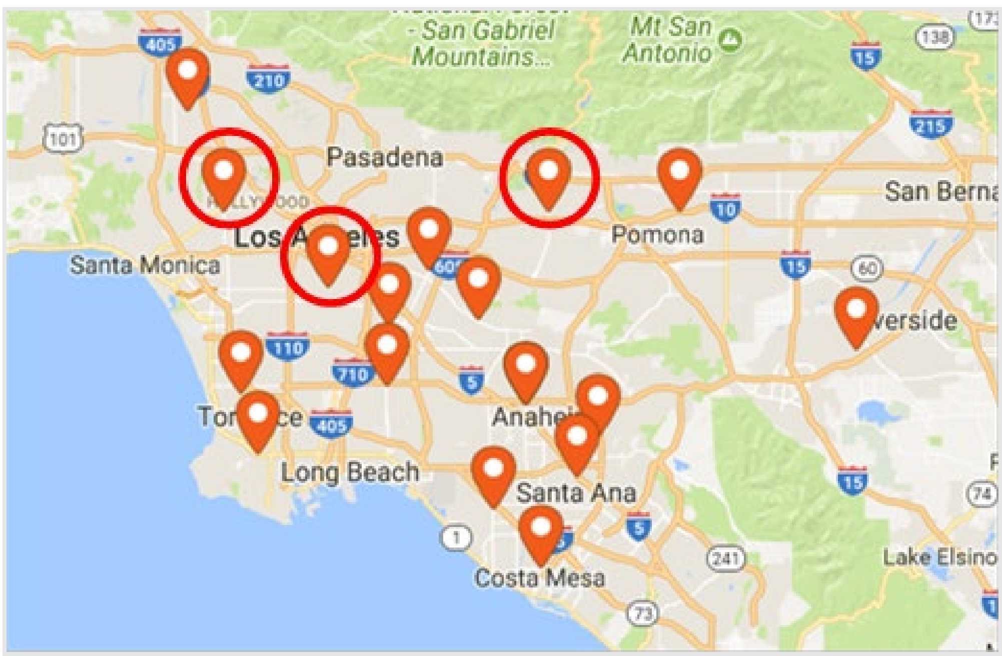
With strong interest from the general management of the 24-hour diner chain, introductory teleconferences with the team outlined the preferences and constraints for this demonstration

[18] These numbers do not reflect closures due to the 2020 COVID-19 pandemic.

project. For the one site this chain was willing to offer for this project, they noted the following key points:

- All sites were 24 hour/day operations, with the requirement that major disruptions to site operations, such as temporary interruption of hot water, occur between the hours of 10 pm and 3 am.
- All sites also use 140°F (60°C) hot water and, in some cases, have integrated boost heaters at dish machines bringing the temperature up to 180°F (82°C).
- While the chain did not have a preferred location in mind, they did recommend three sites based on expected hot water demand (as sales volume) and the age of the existing water heating equipment.

Figure C-25: Prospective Sites for 24-Hour Diner Option



Source: GTI

Figure C-26: Project Site Recruitment Flyer

gti · AO Smith. Innovation has a name. · SMTI

Commercial Gas-Fired Absorption Heat Pump Water Heating-Space Cooling Demonstration

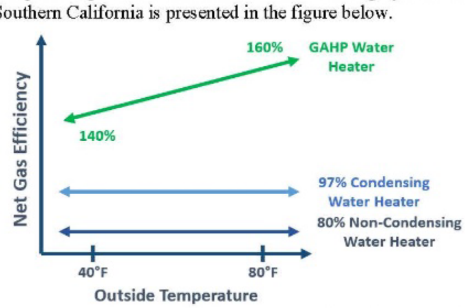
GTI, AO Smith and SMTI are seeking two host sites to demonstrate a gas-fired heat pump technology for commercial water heating and space cooling in the Los Angeles and Orange Counties as part of a study funded by the California Energy Commission and SoCal Gas. A brief baseline monitoring period will be conducted to evaluate the performance of the existing water heating system. GTI will then install and monitor the performance of the Gas-Fired Absorption Heat Pump - Water Heater/Space Cooling (GAHP-WH/SC) unit. The heat pump will be installed outdoors and will be coupled via a closed water loop to an indoor tank that is installed in series with the existing water heating system. The heat pump will also be coupled via a closed water loop to an air handler in the building and provide space cooling when there is a demand and the GAHP is providing water heating. The figure to the right presents the expected installation layout of the commercial water heating system.

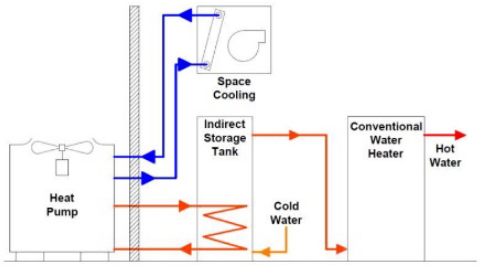
The pre-commercial GAHP-WH delivers hot water while saving up to half of the energy required by standard gas water heaters. Space cooling provided by the unit, when needed, reduces the cooling load of the building A/C. The energy savings goals for this project are:

- 40% reduction in therms used for service hot water
- 20% reduction in electricity by displaced A/C load

The system will achieve this by 'pumping' low temperature heat from the ambient or indoor space to a usable domestic hot water temperature. The high level of performance offered by this system will result in a significant reduction in energy usage and lower operating costs when compared to conventional water heating equipment.

Specific to Southern California, the GAHPWH is able to outperform conventional technologies because it receives 0.4 to 0.6 units of energy from the ambient air for every 1.0 unit of energy it receives from the combustion of natural gas. This allows the system to provide 1.4 to 1.6 units of heat for every 1.0 unit of natural gas energy used. A performance comparison plot with conventional water heating systems for Southern California is presented in the figure below.





System Specifications

- Heating output: **20-80 kBtu/hr**
- Cooling output: **6-26 kBtu/hr**
- Natural gas input: **14-54 kBtu/hr**
- Electric input: **300 -500 W**
- **Installation: Outdoors**
- Unit dimensions (ft): **3.9 x 3.2 x 3.9 (L x W x H)**
- Thermal Efficiency: **115-160%**

Field Test Summary

Objective: Evaluate the performance of a GAHP-WH/SC and identify market barriers via deployment of two field trial systems in Southern California.

Team: Gas Technologies Institute (Project Lead)
AO Smith (Technical Contributor)
Stone Mountain Technologies Inc. (Technical Lead)

Expected Outcome:

- Performance evaluation of the GAHP-WH/SC
- Identify and simplify installation and maintenance

Demonstration Site Requirements

Region: Los Angeles and Orange Counties, CA
Buildings: Full Service Restaurant
Site Preference: >1500 gal/day hot water usage
Footprint needed: 30-40 ft² with accessible electric, natural gas and water
Access:

- Regular onsite monitoring and periodic maintenance
- Monitored by GTI and maintained by SMTI during test

At the end of the project:

- GAHP System and auxiliary equipment will be removed
- The site will be returned to its original state
- The site will receive new high-efficiency gas water heaters at no cost to the host site

Previous and Ongoing Parallel Efforts

- **2017-2018** - SMTI-ORNL-AO Smith to install a field demonstration of 41 kW GAHPWH in the East TN area.
- **2015-2017** – SMTI field demonstration of two prototypes at a residence and warehouse in the Johnson City TN area. Two second generation prototypes developed and performance 3rd party verified.

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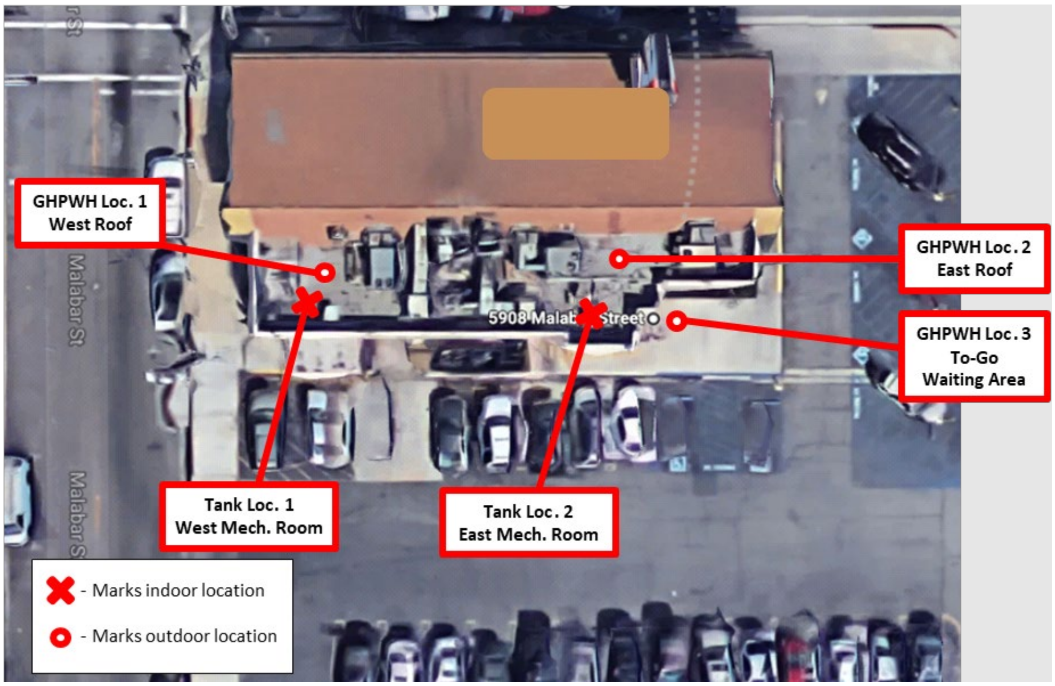
Source: GTI

Of the chain's 17 sites in the Los Angeles Air Basin (one added during the project), the general management identified three preferred sites in West Hollywood, Huntington Park, and West Covina. Ultimately the West Covina site was selected, but each site was deemed feasible and the individual site constraints are discussed here as illustrative examples.

Option #1A – Not Selected

Siting Test Equipment: Originally determined to be the preferred site of the 24-hour diner chain, this site had several options for siting new test equipment, the outdoor GHP and indoor/ outdoor storage tank. The site had three options for siting the outdoor GHP (alternatively GHPWH), two locations on the rooftop and on ground-level installation adjacent to a waiting area for picking up to-go orders (Figures C-27 and Figure C-28). Similarly, there was flexibility in the installation of indoor equipment (namely storage tank), with two mechanical rooms to choose from.

Figure C-27: Siting Options for Test Equipment at Option #1A



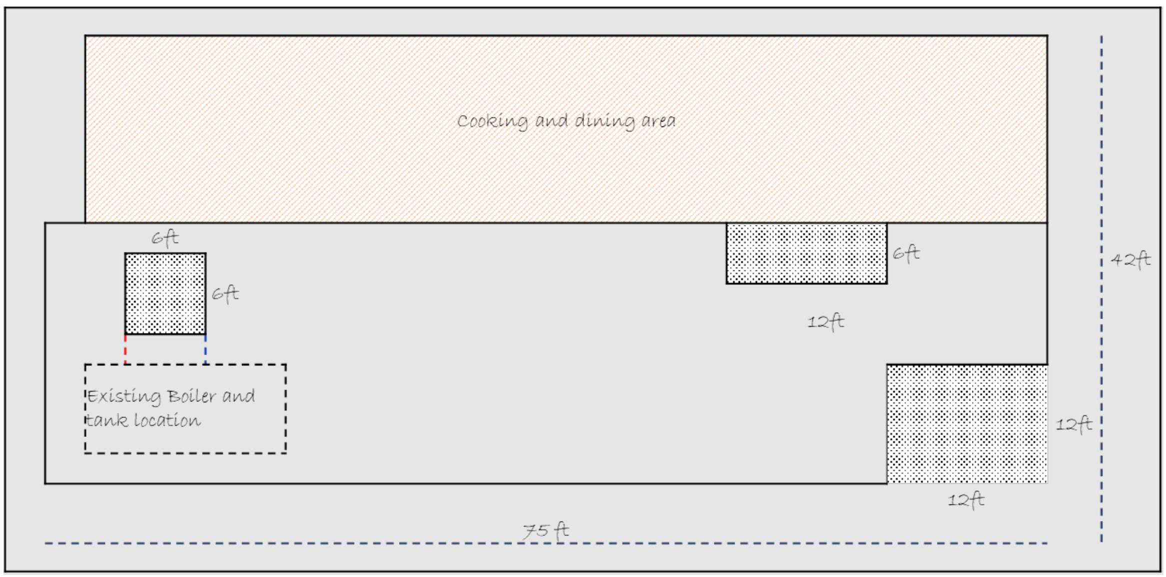
Source: GTI

Figure C-28: Potential Locations of Gas Heat Pump on Ground-Level (Left) and Rooftop Options at Site #1A

Source: GTI

Upon the team decision that the GHP and storage tank would have to be packaged as a removable skid, for ease of installation/removal primarily, the Site #1A presented challenges for siting shown in Figure C-29. For the 4′ x 8′ skid, the available space on the roof coupled with required setbacks for the GHP (18″ from wall) are challenging, and for the larger of two options the platform creates logistical challenges. Piping runs for the former will be preferably short; however, for the latter will be > 120 ft. The ground-mounted position is possible for the skid; however, a) the skid is clear on the opposite side of the building as the existing heating equipment, piping run for chilled water and hot water lines > 120 ft., and b) the skid will be exposed in what is described as a high-traffic area.

Figure C-29: Rough Layout of Space Options for Site #1A



Source: GTI

Indoor Equipment and Load Conditions: This restaurant is served by two boilers, located in a rather tight mechanical room (West of building Figure C-30)), with each boiler tied to an individual storage tank.

- Larger boiler, Ray-Pak H3-0401 (375 kBtu/h input, 82 percent TE), tied to 120-gallon tank kept at 140°F (60°C). It has "hand sinks + pot sinks" written on it.
- Smaller boiler, Ray-Pak (250-400 kBtu/hr input), tied to 80-gallon tank kept at 180°F (82°C), likely dedicated to dishwasher, identified as a CMA 44H dish machine.

While this site was anticipated to have an adequate hot water load with ~9,000 meals served per week, well over the 600 meals/day target on average, the logistics of this mechanical room presented challenges. Given that the storage tanks are plumbed in series, that means the boilers are most likely operated in a booster arrangement. With the GHP's inability to serve 180°F (82°C) loads, that would require that the boost boiler remain in place to serve the dishwashing machine. However, the other boiler would also have to remain to serve as backup for the 140°F (60°C) SHW loads. The team determined that two options to proceed would be to a) eliminate the high-temperature boiler and replace with a dish washing machine boost heater, a common feature of other locations of this same chain, or b) leave the boiler alone and verify that the non-dishwashing machine plumbing circuit had a sufficient SHW load for the GHP to serve. Neither option was ideal, and the team opted to review other sites before revisiting these issues.

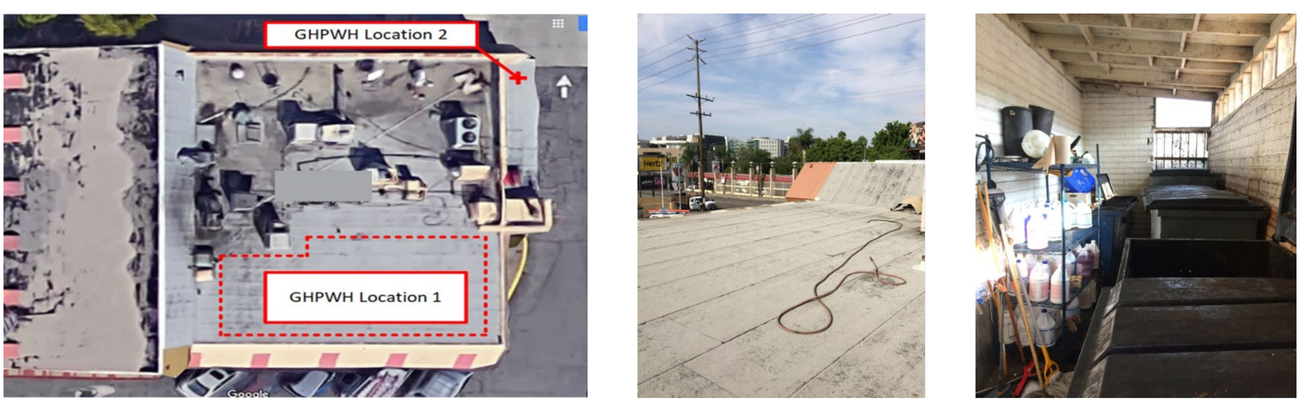
Figure C-30: West Mechanical Room at Site #1A

Source: GTI

Option #1B – Not Selected

Siting Test Equipment: Fewer options were available at a second site, a smaller location of the 24-hour diner chain as shown in Figure C-31. The two GHP siting options were identified. The first is located on the southeast corner of the roof. The other is in a mechanical room adjacent to a parking lot. In the case of the rooftop installation, this would require running gas and water lines to this vacant portion of the rooftop and space would be required indoors for the storage tank. Within the mechanical room, dumpsters would need to be moved to open space for the GHP and storage tank. In both cases, the site is more space constrained than the prior option and presents additional challenges with assuring proper clearances of equipment for servicing access, airflow, and safety.

Figure C-31: Siting Options at Site #1B



Source: GTI

Indoor Equipment and Load Conditions: Like the prior option, the restaurant manager estimates sufficient demand with an estimate of 1,350 meals/day served on weekends and 1,050 meals/day on weekdays, both well above the 600 meals/day threshold. The restaurant is served by a single, large hot water boiler tied to an indirect storage tank. The boiler is a Ray-Pak make, approximately 900 kBtu/hr output with three-stage input and an estimated 82% thermal efficiency (Figure C-32). Despite inspection, it is unclear what the target SHW temperature is, though all plumbing circuits appear to be supplied with 140°F (60°C) water. Additionally, noted during inspection was what appeared to be active water leaks from the storage tank and circulation pump. Within each mechanical room, a lack of available power outlets was also noted.

Figure C-32: Boiler at Site #1B

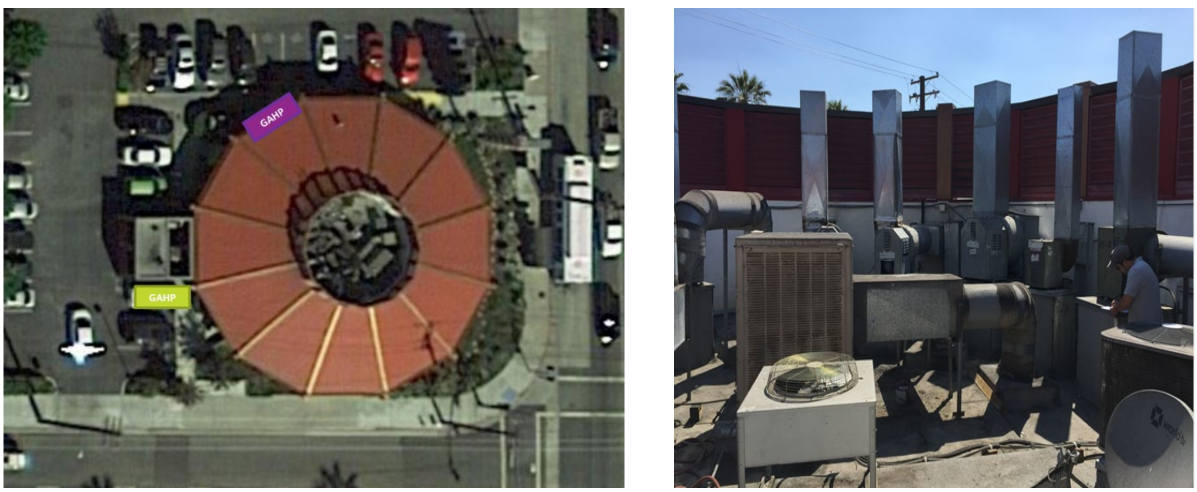
Source: GTI

Option #1C – Selected

Siting Test Equipment: Unlike many of the diner chain's location, this site has a circular footprint with a semi-conical roofline rising with a vertical visual barrier concealing the rooftop equipment in an interior circular space, somewhat reminiscent of a large tent. This creates two challenges for siting the GHP equipment, as a) the interior roof area is already quite crowded with HVAC and refrigeration equipment, offering no space available for a rooftop GHP installation, and b) the circular perimeter of the building makes ground-level installations somewhat awkward. This can be seen in Figure C-33, showing the very crowded rooftop from the air and within this space.

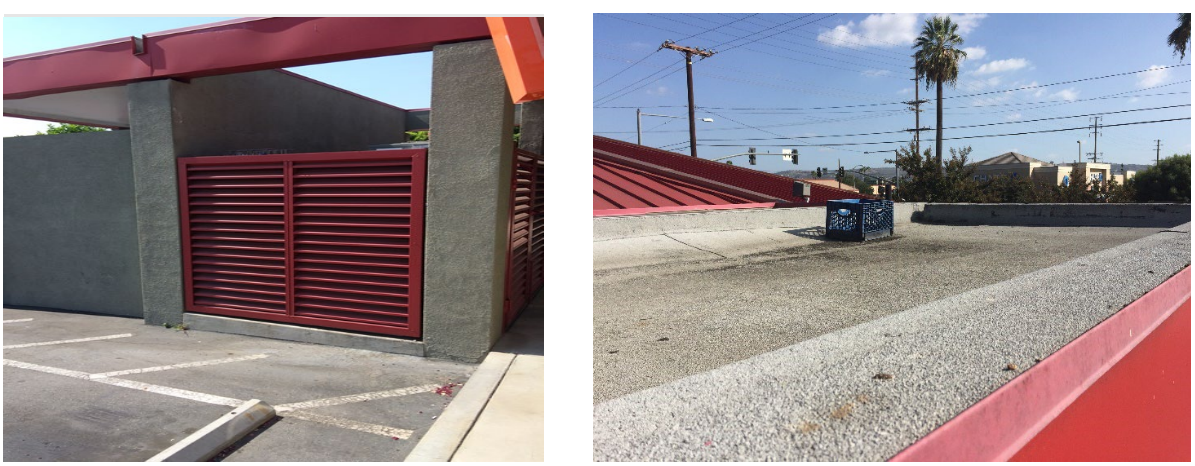
With only ground-level options for the GHP siting available, the site manager identified available parking lot space on either side of an external enclosure separated from the restaurant by a walkway. Regrettably, the enclosure itself, half filled with spare cooking equipment and overflow refrigeration equipment (that would otherwise be on a rooftop), and half filled by dumpsters and other disposal containers, did not have suitable space for the GHP itself. Both the north and south side of this enclosure had adequate space for a pavement-mounted skid, with the south side shown in Figure C-34, noting that the site was amenable to revise the spacing of adjacent parking spaces to accommodate the GHP and safety equipment (bollards, etc.). Due to the walkway between the enclosure and the restaurant, all piping (water, gas) and other utilities would need to be buried or, more likely, run over the walkway within a bridge. Additionally, if the ground mount wasn't feasible on either side of the enclosure, the site offered the roof of the enclosure as an option, which while open for equipment the enclosure would require an assessment by a structural engineer to understand the weight-bearing capacity of this roof. The proposed location of the GHP adjacent to the enclosure is shown in a green box. Ultimately, the site permitted the installation of the GHP skid partially on top of landscaped areas, which allowed the GHP to be much closer to the indoor gas water heaters (shown in magenta box).

Figure C-33: Overview of Location #1C (Left) and Crowded Rooftop (Right)



Source: GTI

Figure C-34: External Enclosure at Site #1C – Elevation (Left) and Roof (Right)



Source: GTI

Indoor Equipment and Load Conditions: For this site, the general manager estimates 1,400 meals per day on weekends and between 900-1,200 meals per day on weekdays, all above the target of 600 meals per day. The two gas-fired water heaters servicing the site are similar Bradford White models with 100 gallons of storage and 270 kBtu/hr input each. The water heaters were confirmed to both deliver 140°F (60°C) and the site uses a CMA-44 dish machine with an integrated boost heater. Figure C-35 shows the water heaters which are located in a cramped closet with exterior access, leaving limited room for data collection equipment or additional hardware. Generally, the site appeared quite suitable for the study with the primary compromise around the siting of the GHP unit outdoors. The site appeared to be the most up-to-date with equipment and installation practices, likely given the relative age of the restaurant, converted to a location of this chain approximately 12 years ago compared to the #1B location, an original location of the chain from the 1950's.

Figure C-35: Site #1C Water Heater Closet

Source: GTI

Site #1 – Overall Assessment

Among the three sites, Site #1C was selected when weighing the pros and cons, which are outlined below:

- Site #1A:
    - Pros: Three potential locations for GHP unit (two on roof) and two potential indirect storage tank locations, though in skidded arrangement only the ground-level location is an option.
    - Cons: Dual hot water circuits, with 140°F (60°C) provided by main boiler and 180°F (82°C) by a boost boiler. Either modification is required to accommodate the GHP or the GHP can only serve a portion of the SHW load.

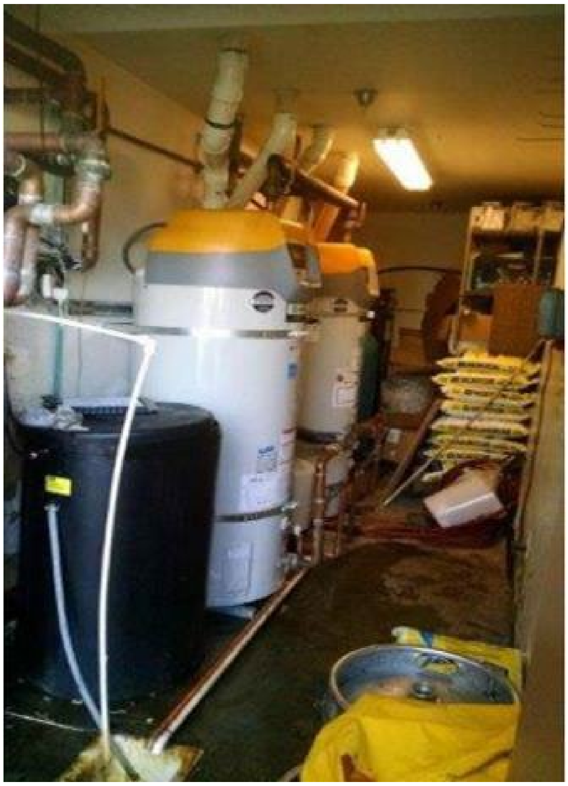
- Site #1B:
    - Pros: Available rooftop and mechanical room space for GHP and indirect tank, also site appears to only have a 140°F (60°C) plumbing circuit.
    - Cons: Existing equipment appears to be leaking and in need of repair or modification.
- Site #1C:
    - Pros: Hot water heaters appear most up to date, serving 140°F (60°C) circuit
    - Cons: No space on rooftop, limited outdoor space and requirement to run new utilities to GHP location.

Candidate Pool #2: National Chain of Full-Service Restaurants (FSR)

With the support of the manufacturing partner, GTI discussed the potential sites in Los Angeles and Orange Counties with the corporate office managing the national restaurant chain. Working with the site would require similar constraints as with the 24-hour diner sites. This would include limiting on-site work hours involving interruption of hot water service (10 pm to 10 am) with additional requirements for off-hours access, due to overnight closure of the facility. Due to the general uniformity across the Southern California locations, there were several options available, with selection proceeding as follows:

- Initially a large location in Huntington Beach was offered as a site, however on further discussion it was ruled out due to lack of available space in the mechanical room and the existence of solar hot water at the site, with the latter not a technical issue with the demonstration but less representative of restaurant installations of the GHP water heating system (Figure C-36).
- With the potential of 15 locations in Los Angeles County and an additional 8 locations in Orange County, the project team first ruled out the four locations that were attached to other structures (such as mall structures) and then screened sites for expected availability of rooftop space and peripheral ground-level space for the GHP or GHP skid installation.
- Eight potential sites were identified with approval from the corporate office, six in Los Angeles County and two in Orange County, however upon inspecting the first two sites in the San Fernando Valley area of Los Angeles, the project team determined that both sites were generally suitable, and no further inspections were necessary.

Figure C-36: Huntington Beach Mechanical Room

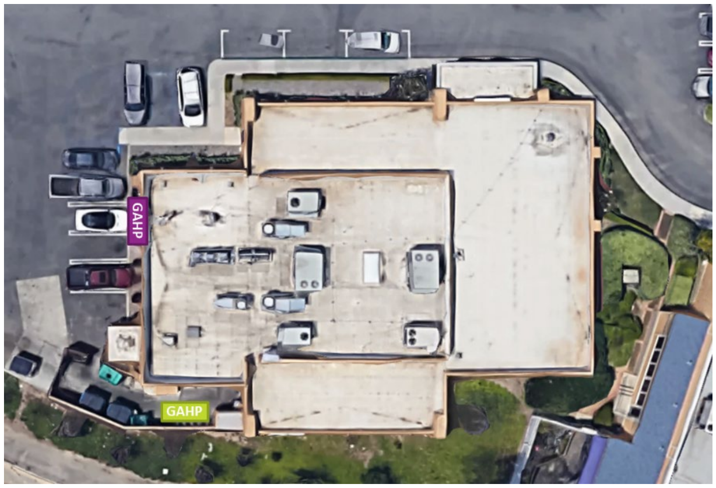


Source: GTI

Option #2A – Selected

Siting Test Equipment: The GHP was sited along this western wall adjacent to the indoor mechanical room, (Figure C-37). Projected from satellite view assessments and confirmed during inspections, this site has ample room for the GHP on the rooftop (Figure C-38) and adjacent to the restaurant in a partial enclosure (Figure C-39), for the latter dumpsters and outdoor storage would need to be moved but the site management was open to locating the GHP equipment there. With the option to avoid the added cost of a rooftop installation, the project team focused on the ground-level installation of the GHP though noting the disadvantage of distance from the indoor water heaters and likely location of the indoor cooling coil. Within said mechanical room, there is space for instrumentation, an additional storage tank (if needed), and adequate electrical service, though access to this room is through the kitchen (diagram in Figure C-40). Ultimately, note that concerning GHP siting the management expressed concern about the 3rd party waste collector possibly damaging the test equipment with rolling dumpsters around and discouraged the team from placing the GHP within the enclosure.

Figure C-37: Overview of Site #2A with Projected (Green) and Final (Magenta) Location of Gas Heat Pump



Source: GTI

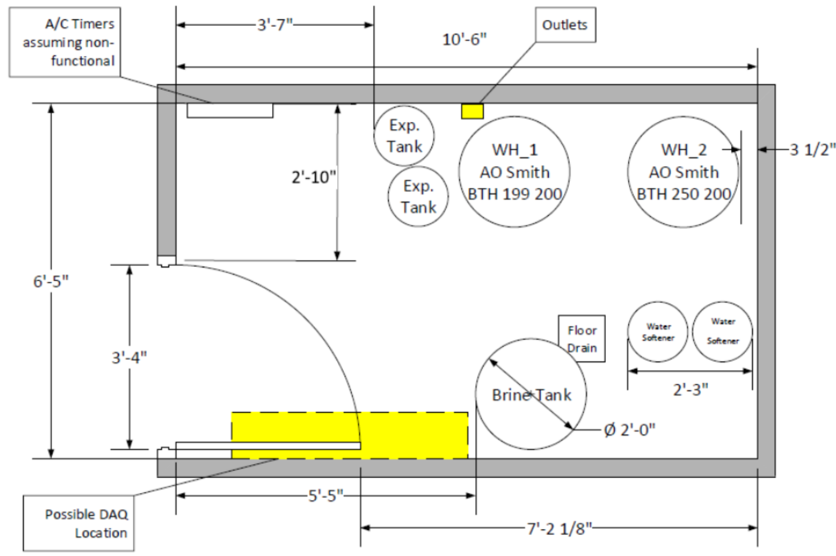
Figure C-38: Rooftop Options at Site #2A

Source: GTI

Figure C-39: Enclosure Ground-Level Options at Site #2A

Source: GTI

Figure C-40: Diagram of Site #2A Mechanical Room



Source: GTI

Indoor Equipment and Load Conditions: For this site, the general manager estimated a rather high 1,260 to 2,800 meals per day, well above the 600 meals per day target. Figure C-41 shows the indoor water heaters. Both were condensing storage-type with 100 gallons of storage, a 199 kBtu/hr input and 250 kBtu/hr input respectively, each providing 140°F (60°C) hot water. From an existing equipment standpoint, the site is suitable however the existing equipment are already high-efficiency.

Figure C-41: Indoor Water Heaters at Site #2A

Source: GTI

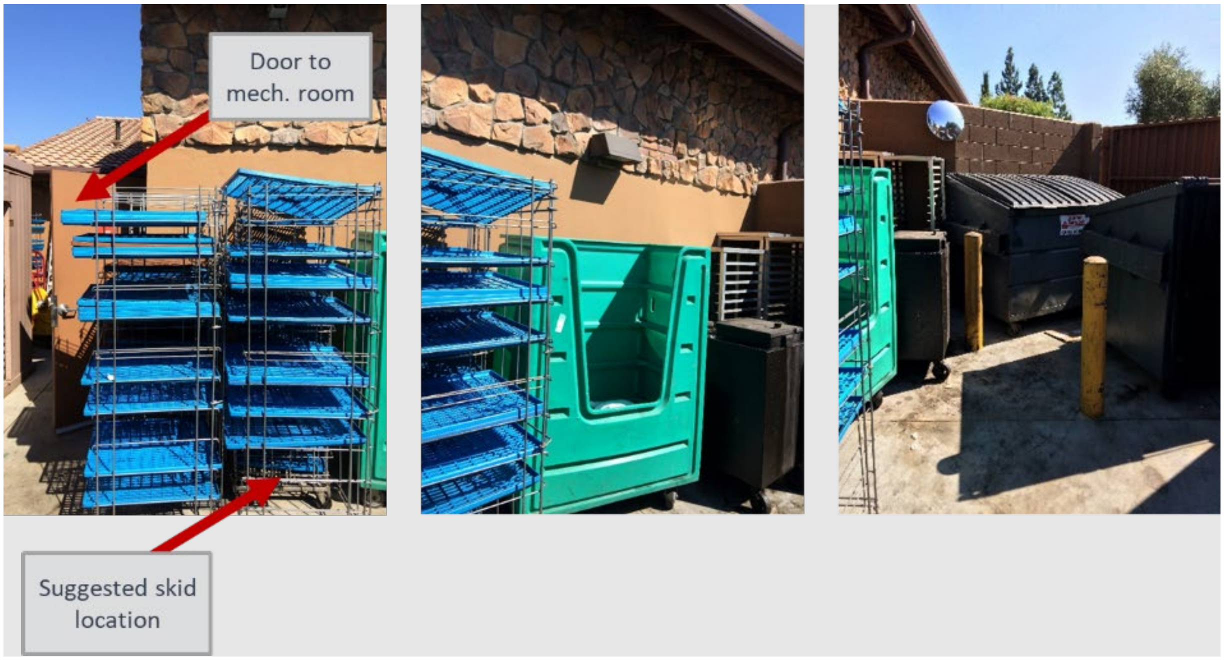
Option #2B – Not Selected

Siting Test Equipment: As seen in review of satellite imagery and confirmed during inspections, this site generally had fewer rooftop options for the GHP installation but similar options for ground-level installations. As seen in Figure C-42 and Figure C-43), the yellow and red markers represent the best options for a GHP installation with respect to proximity to available utilities and integration with indoor equipment. For the ground-level installation, a similar concern was raised regarding proximity to dumpsters that could, when moved, damage the GHP equipment. Regarding the indoor location of the cooling coil, interestingly the site manager requested siting it within a dining space. Within the mechanical room, there is limited room for an indirect storage tank, however it is possible to fit one as shown in Figure C-44 and Figure C-45. Generally, there are more siting constraints than Site #2A, though these are improvements over Site #1 options.

Figure C-42: Overview of Site #2B

Source: GTI

Figure C-43: Enclosure Ground-Level Options at Site #2B

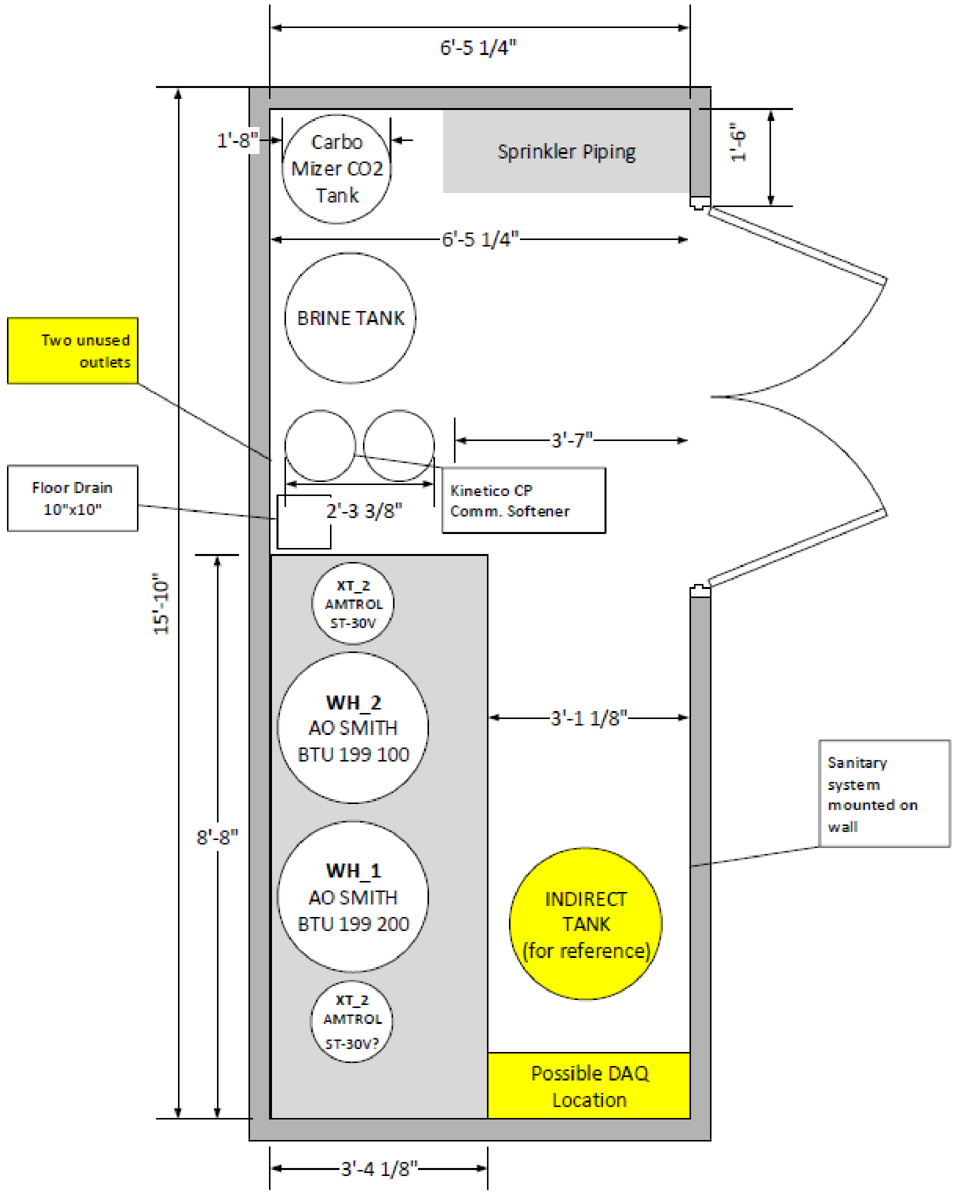


Source: GTI

Figure C-44: Mechanical Room at Site #2B

Source: GTI

Figure C-45: Diagram of Site #2B Mechanical Room



Source: GTI

Indoor Equipment and Load Conditions: For this site, the general manager estimated a that 400 to 700 guests are served per day, a significantly lower number than Site #2A and possibly close or below the 600 meals per day target. The indoor water heaters were both condensing storage-type water heaters with 100 gallons of storage, each with 199 kBtu/hr input and providing 140°F (60°C) hot water. From an existing equipment standpoint, this site is suitable but from a projected hot water demand standpoint this is much less favorable than Site #2A.

CALIFORNIA ENERGY COMMISSION

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix D: Project Field Evaluation Results – Details

June 2024 | CEC-500-2024-058

APPENDIX D:
Project Field Evaluation Results – Details

Baseline Monitoring

As summarized in the main report body, the following installation and commission challenges were overcome during the baseline monitoring periods.

Baseline Commissioning Challenges

The project team overcame several datalogging/installation problems with the wireless and wired sensors (Figure D-1). Some issues were attributed to environmental causes while others were preventable installation errors.

Figure D-1: Wireless Sensor

Source: GTI

Wireless Barriers

Wireless sensors were selected to minimize installation time and time spent on the rooftop. However, they also presented challenges of their own - troubleshooting physical and radio interference. Despite efforts to stress test the radio's range in advance of installation, the bulk of troubleshooting took place during installation/commissioning as well as during the early stages of the project after the GHP units had been commissioned.

Interference/Line of Sight

The operating frequency for our wireless sensors was within the 900 MHz band, which lies in the ultra-high frequency (UHF) range. Since UHF radio waves propagate mainly by line of sight it was likely that physical interference, such as by building structures, was responsible for much of the troubleshooting. For example, four sensors were not only located within an enclosed metal storage area but also out of sight from the gateway (Figure D-2). Physical interference on some of the sensors was resolved by relocation to a higher level in addition to relocating and reconfiguring the gateway.

The four sensors mentioned previously were not able to consistently connect regardless of configuration settings even when they were raised outside of the enclosure. As a solution for reliability concerns the decision was made to double up on measurements by installing Onset HOBO loggers (self-contained and battery operated) as a backup for each of the sensors

Figure D-2: Starting Gateway Location

Source: GTI

It should also be noted that the UHF range covers radio waves with frequencies of 300 MHz to 3 GHz and is used for television broadcasting, cellular communications, GPS, Wi-Fi, Bluetooth, walkie-talkies, cordless phones and many other applications. It is presumed that some of the interference at both sites was caused by nearby cell tower interference in addition to physical obstructions.

In retrospect, connectivity may have been improved with the use of wireless repeaters and use of a different type of antenna that would have reduced the impact that antenna height would have had on signal integrity. Newer versions of the sensors have an extended range which reaches about four times farther than the sensors used in this project. The manufacturer also claims improved non-line-of-sight connections and wall penetration.

Wireless Sensor Configuration Settings

Each wireless sensor was run off a single Li-ion battery, meaning that the lifetime of the battery would be directly tied to the frequency of data transmission and other sensor operations like searching for the gateway. One sensor's settings were configured to increase the gateway search and reporting frequency to help it connect more reliably due to the previously mentioned radio interference. The search/reporting frequency was set too high, and the battery's charge was depleted more quickly than expected. To account for this the field team replaced the batteries, relocated the sensor, and added more appropriate settings.

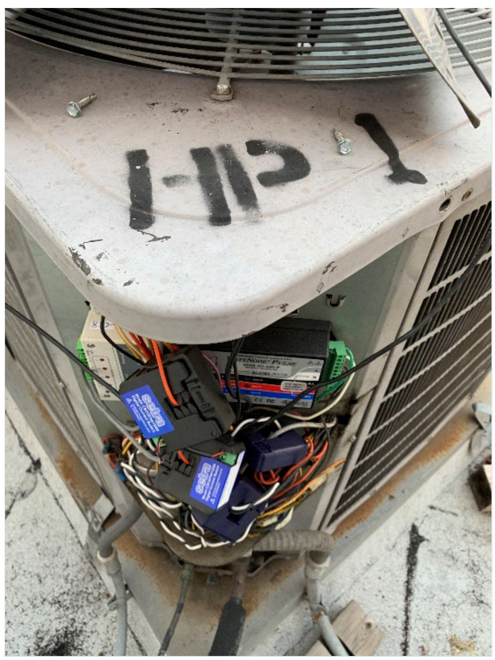
Software Issues

Remotely configuring the sensors was also difficult as the Hyperware-II software for configuring the IL-80 logger to work with the sensor gateway contained a software error in the MODBUS testing utility. The field team worked with the logger manufacturer to resolve the error and was able to use the testing utility to configure the sensor gateway. Prior to field installation, the sensors were not remotely configured but were instead directly configured by way of a serial connection and the sensor manufacturer’s configuration utility.

Accidental Damage

Figure D-3 shows the installed Watt-Node and switches on the heat pump. Damage occurred to one of the sensors after the field installation disconnected one of the battery’s contacts. As a result, the sensor was not powered and was unable to connect. The sensor was repaired and brought back online for the duration of the field monitoring. Damage was likely due to the position of the sensor on the electrical compartment door (that is, swinging open the panel may have sandwiched the sensor between the RTU and the door to the electrical compartment). Damage to the sensor may have been avoided by attaching the sensors to a non-moving component of the RTU.

Figure D-3: WattNode and Switches Installed on a Heat Pump (Cover Removed)



Source: GTI

Other types of accidental damage to sensors occurred when a few resistance temperature device (RTD) and thermocouple (TC) cables were cut during work in the mechanical room to replace the water heaters. The RTD cables were replaced, and the TC wire was repaired during a subsequent field visit which was organized to validate sensor readings after the installation of the new water heaters. Damage to the cabling may have been avoided by running cables away from the plumbing and by having a pre-installation visit to remove and set aside cables prior to any work in the mechanical room.

Sensor Installation Errors

Current Transducers (CTs)

The field team noted that no pulses were being registered at one of the heat pumps. Upon further investigation, it was noted that a couple CTs were installed backward. This error was easily corrected and could have also been easily prevented with a more thorough review of the installation to confirm the direction of the source current.

WattNodes

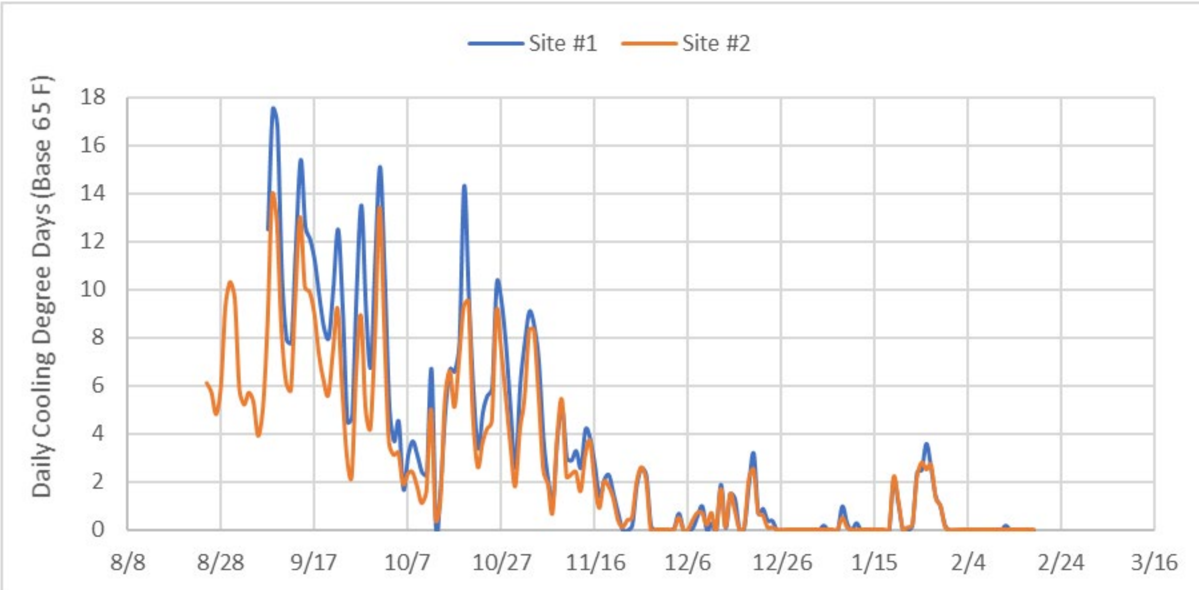
An optional measure for improving readings using shorting jumpers across unused phase CT connections was missed by the field team and suggested by the M&V team. Shorting jumpers were installed during post-commissioning visits.

Initially watt-hour readings were set to be recorded with 208Y WattNodes because the team had assumed the provided electrical service was 208V wye electrical service. Shortly after the WattNodes were replaced with the appropriate 240D model to reflect the service provided to the RTUs. The field team may have avoided this by connecting with the last mechanical contractors to service the units, however the contact information was difficult to track down and the service type was assumed.

Net Impact on Measurements

Initial data analysis suggests that the wireless measurements would periodically drop pulses for certain HVAC equipment, primarily due to the aforementioned "line-of-sight" issues with the gateway that impacted ground-level HVAC at Site #1 and intermittently other equipment. Therefore, preference was placed on limiting the data analysis period to when the stationary, wired measurements were made and thus overall, Site #1 had a monitoring period from 9/7/18 – 2/18/19 and Site #2 from 8/25/18 – 2/18/19. While not ideal, as this further cuts into the primary cooling season, it was necessary and per the figure below this still captures significant cooling degree days (CDD) from late summer into fall (Figure D-4). The outdoor air baseline temperatures were analyzed at Site #1 as shown in Figure D-5.

Figure D-4: Site #1 and #2 Cooling Degree Days

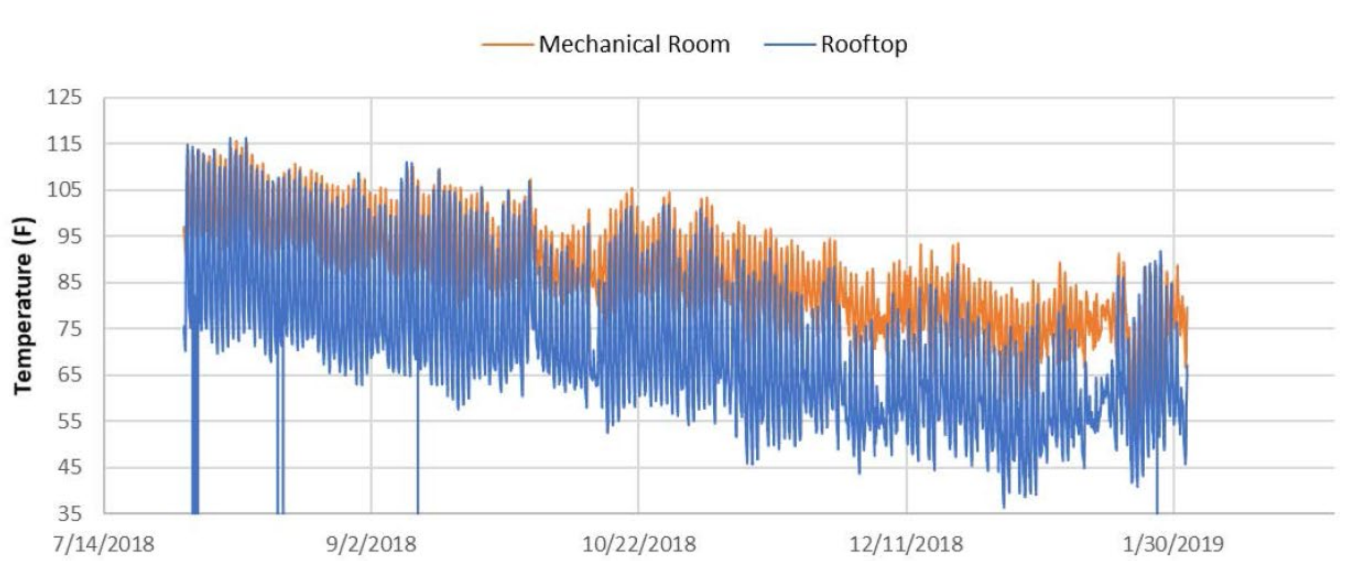


Source: GTI

Additional Baseline Analysis

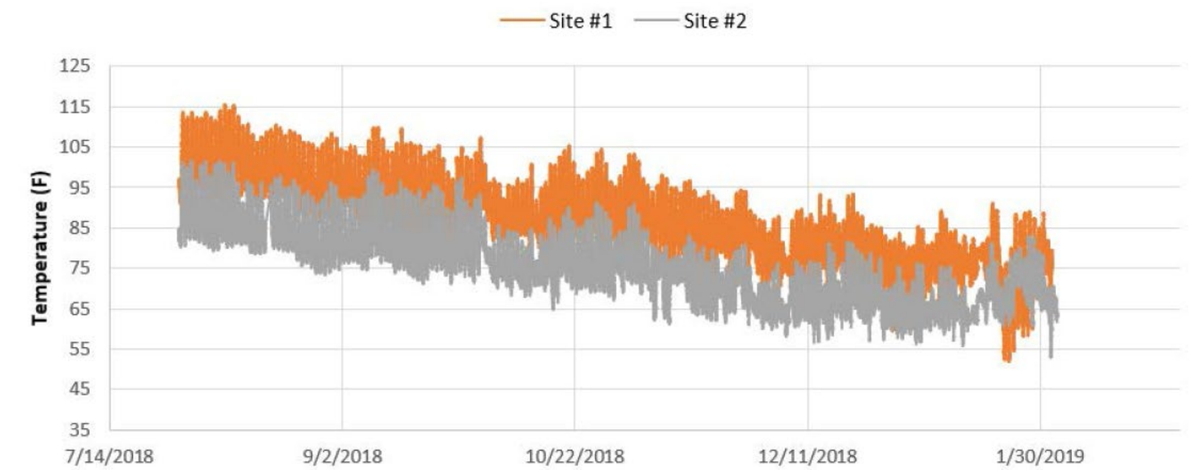
The following charts concern the first baseline period, as described in the main report body.

Figure D-5: Indoor and Outdoor Air Temperatures at Site #1



Source: GTI

Figure D-6: Comparing Indoor Mechanical Room Temperatures for Sites #1 and #2



Integrated GHP System Installation and Commissioning

Installation and Commissioning Lessons Learned

As noted in the main body of the report, the project team overcame several more datalogging, installation, and complete commissioning challenges that are outlined here following the initial commissioning of the system in March 2019. Issues were both environmental (site specific, outside of project team's control) and others were preventable errors that the project team learned from extensive observations and data review.

Instrumentation Issues

- Instrumentation Grounding: An installation error occurred when the additional datalogger was not properly grounded which caused erroneous RTD readings. This was corrected the same day during the installation by grounding the datalogger in question.
- Immersed RTDs: The field team did not consider the effect from incident sunlight on exposed areas of the thermowells. A diurnal heating effect called into question some of the RTD readings. To help mitigate the effect of the sun on temperature readings, additional insulation was added to the thermowell. To adjust for any measured offsets a dry well calibrator was used to create calibration curves for all outdoor RTDs to obtain a more accurate reading.

Prototype Faults, Operational *Issues*, and Maintenance

- The GHP unit was still a prototype and as a result, minor manufacturing defects and increased servicing were expected. In addition, other prototype hardware/software issues arose due to human error.
- Operational Issues with Key GHP Components: In one instance, at Site #2, the prototype went offline in conjunction with an overall loss of skid power. This was traced to a blown fuse, which upon replacement additional troubleshooting traced the issue back to the evaporator fan. The field team checked the resistance of the existing motor and

testing suggested that the startup capacitor was not functioning correctly. Figure D-7 shows the new fan motor installed and the unit was brought back online, though it was not ultimately determined whether a power surge led to the evaporator fan motor failure or vice versa. Similar issues arose with the solution pump, including a) a bearing showing excessive wear, leading to a pump replacement and b) replacement of the drive belt due to observed slippage from an older idler arm assembly. Each of these events resulted in several weeks of downtime for the unit, due in part to on-site coordination delays.

Figure D-7: Evaporator Fan Replacement

Source: GTI

- Hot Surface Ignitor: Based on several field visit results, a component that required servicing or replacement on multiple occasions was the GHP hot surface ignitor (Figure D-8). While limited investigation was performed to determine the root cause, it could potentially be a combination of overheating, electrical connection issues, or other component defects. The issue may be misdiagnosed in one instance at Site #1, where the sealing gasket at the ignitor fitting was found to be deteriorated.

Figure D-8: Hot Surface Ignitors

Source: GTI

- Evaporator Coil Fouling: Not anticipated as an issue over the course of this 12-month study, evaporator coil cleaning was required due to excessive dust/lint Site #1, due in part to landscape maintenance practices at the site and the location of the skid. Coil fouling was easily addressed by hosing down the evaporator coils as with other HVAC products.
- Refrigerant/Absorbent Adjustments: As an outcome of other servicing visits concerning the sealed system (components in contact with the refrigerant/absorbent), including removal of the solution pump for servicing or inspection and periodic removal of non-condensable gases, small adjustments to the refrigerant and/or absorbent charge were necessary at both sites.

Installation Issues and Human Factors

- Hydronic and Communication Connections: The hydronic line sprung a leak at both sites, at one site the O-ring was misshapen due to overtightening, which was easily corrected by removing, flattening, and reseating the oaring to provide a better seal for the hydronic line joint in question. Hose clamps in other areas of the system were also found to be a loose, possibly due in part to equipment vibration. Similarly addressed readily, data connection cables were found to be seated incorrectly after initial installation, causing a pressure limiting switch to trip. Reseating the cable connection allowed the GHP unit to function without errors.
- Software Problems: The GTI datalogger cellular modem was setup to also permit the GHP controller to receive firmware updates and provide additional GHP monitoring. Care was needed when updates were sent over a spotty connection and/or when IP addresses assigned by the modem's network were misaligned with said controller. The controller's connection was reestablished by configuring the logger's modem subnet to match the controller, at which point the correct settings were established and the modem's settings reset, allowing all devices internet access.
- Instrument Installations: During commissioning, it was found that both the gas and water meter were installed backwards at one site, which was readily resolved with a follow-up site visit.
- GHP Vent Termination: The vent termination on one of the units was initially tilted too far forward to allow the combustion condensate to flow properly, leading to dripping condensate onto the top of the unit. The solution was to tilt and brace the vent backward to allow any condensed combustion products to flow back into the flue to drain from the condensate drain, suggesting that future guidance on levelling the vent termination could be provided to avoid improper vent installation.
- FCU Damage and Chilled Water Loop Flow: Damage was discovered on one of the FCUs upon receipt of the unit, the FCU intended for Site #2 (see Figure D-9). Outwardly the damage seemed to be limited to the blower motor and blower motor supports. To avoid the expense and extensive delay of ordering a replacement FCU, the team determined replacing the blower and testing the coils for leaks was the best path forward. The coils

showed no leaks as well as allowed the passage of water and the new blower motor was received quickly.

Upon commissioning both sites, the data collection showed that chilled water flow rates were approximately 50% the required flow rate by the manufacturer. It was discovered that the incorrect circulation pump was ordered due to a clerical error and that several unnecessary restrictions were included in the cooling loop (that is small diameter sections, excessive elbows etc.). After installing the originally specified pump and straightening some sections of chilled water lines, the target flow rate was still not being met.

Later into the monitoring period, the project team opted to remove fittings that could cause unnecessary restrictions and up-size the circulation pumps a second time. Flow rates at Site #1 site improved, within 65-75% of the target flow rate, but stubbornly Site #2 showed marginal improvements to approximately 55% of the target flow rate. Upon measuring the pressure drop across the FCU, the pressure drop was three times the specification, suggesting that internal damage to the FCU coil did not cause leaks but did increase restrictions. Late into the project, the team opted to keep the FCU, but focus on reducing the restrictions in a complex section of chilled water tubing (Figure D-9). The installation contractor made an effort to straighten and simplify this section; however, the improvement was small, and the team opted not to replace the FCU or re-pipe the entire loop late into the monitoring period (also mid-winter). In retrospect, the team should have measured the FCU pressure drop during operation by plumbing in accessible taps at an earlier stage.

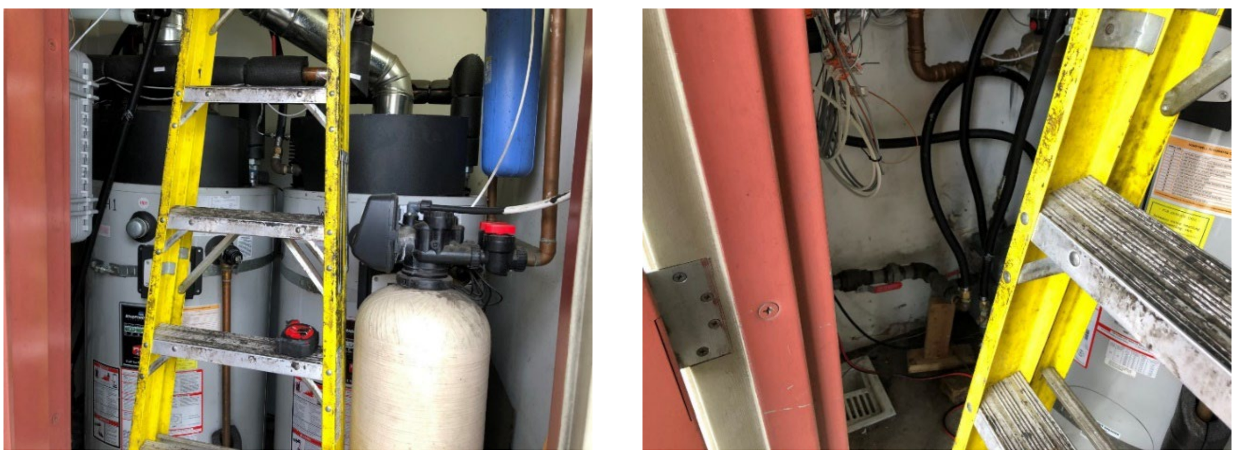
As a result, in addition to the GHP setback from the exterior wall less than was permissible by the manufacturer, similarly the chilled water loop flow rates were below specification for both sites throughout the monitoring period. Additionally, the project team struggled at times eliminating the air introduced into loops each time modifications were made, with observed shifts in flow rate consistent with air elimination occurring days after a servicing visit.

Figure D-9: Damaged Fan Coil Unit Upon Receipt (Left) and Targeted Restrictions at Site #2 (Right)


Source: GTI

- Early Replacement of Water Heaters: The indoor water heaters at both sites were replaced earlier than expected, originally intended to occur upon de-commissioning the integrated GHP system. Both host sites received high-efficiency, direct vent, condensing water heaters, as described in the baseline monitoring section. For Site #1, special care was necessary to accommodate the small installation space within the mechanical closet (as shown in Figure D-10), particularly in light of prior observed venting and barometric balancing issues leading to operational faults with the original water heaters (see below). During installation of the replacements at one host site, mistakenly RTD cables were cut and the datalogger's backup power supply (UPS) as well as the power distribution unit (PDU) were damaged. Due to the nature of the replacements, driven by installation contractors not directly associated with the project, better coordination on the part of the project team could have avoided these issues, though they were remedied shortly after discovery. For another site, after installation it was noted that the condensate drain line from one of the water heaters was not draining into the appropriate fixture and was instead draining onto the floor. The solution was to use PVC piping instead of vinyl tubing to ensure the condensate drain line would not be moved.

Figure D-10: Tight Installation Requirements Within Site #1's Mechanical Closet (Original Heaters Shown)



Source: GTI

Site-Specific Barriers

- Soft Lockouts of Water Heaters: One of the host sites experienced a soft lockout of the existing water heaters shortly after work was completed to integrate the GHP into the water heating system. Several visits from the host site's plumbing contractors did not yield any resolution to the lockout. The gas meter was investigated as a potential issue, due to potential increases in fuel line pressure loss, but this was ruled out upon further investigation. Later it was determined that the mechanical closet where the water heater was located was being depressurized by a combination of strong winds and the action of range hoods from the kitchen. The mechanical closet was within the pressure boundary of the kitchen, which was increased by additional penetrations to accommodate the integrated GHP system. As this issue was discovered at the same time as the failure of one of the two water heaters, believed to be unrelated and described above, the direct vent replacement water heaters did not have the same issue.

Additionally, shortly after the replacement of the water heaters at one site the water heaters stopped working. During a follow up visit, it was determined that the outlet had been replaced with a GFCI outlet. The manual for the water heater stated that the water heaters should not be operated on a GFCI outlet given that the in-shot current for the combustion blower motor would trip such outlets.

- Low Gas Pressure: Both existing water heaters (250 kBtu/hr and 199 kBtu/hr) at Site #2 were replaced with larger input water heaters (both 400 kBtu/hr). The existing water heaters were being metered with an AL425 and an AC250 respectively. The smaller meter, AC250, was no longer suitable for the new 400 kBtu/hr water heater and needed to be upgraded to an AL425. Upon installing the new, larger AL425, the new water heater would shut down on a low fuel pressure fault. While replacement and reinstallation of another AL425 did not resolve the issue, as specifications indicated a minimal pressure loss across the meter at full flow, the issue was ultimately traced to a damaged gas shutoff valve which was left in a partially closed position, with damage likely suffered with the removal of old heaters and installation of new heaters by the installation contractor outside of the project (recall both sites had emergency water heater replacements). While the valve was replaced by the project team out of an abundance of caution, ultimately it did not improve monitoring as the heater that meter served was already disabled by the host site due to the reduction in operations brought about by the onset of the COVID-19 outbreak.

  Unfortunately, the extended investigation and resolution of this issue had the net effect of interrupting gas flow measurement for one of the indoor water heaters at Site #2 for a duration of approximately four months at the end of the integrated GHP system monitoring period. As a result, the inlet gas flow to this replacement water heater ***is modeled*** for this duration, as described in the subsequent section.

Vandalism/Tampering

Upon arrival for a service visit, a field team member noted that someone had attempted to access to the 120 VAC outlet as well as several other electrical enclosures within the caged skid, presumably to look for some free electricity. Fortunately, the system was unpowered during this incident, by chance. Figure D-11 shows the opened enclosure, which will be improved in future, similar demonstration projects.

Figure D-11: Opened Enclosures from Tampering

Source: GTI

Data Analysis Commissioning Considerations

In-situ RTD Calibration

Finally, mid-monitoring period, GTI calibrated the four RTDs measuring hydronic supply and return temperatures at the GHP unit (measurements are doubled and averaged) using a Fluke dry well calibrator, Model 9102S. Calibration was performed for four temperatures per sensor on-site, at 75°F (24°C), 95°F (35°C), 120°F (49°C), and 150°F (66°C) under equilibrium conditions. Photos of these sensors in normal use and the calibration are shown in Figure D-12. The resulting linear calibration fits calculated and applied to all data analysis are shown in the table below, indicating stability of the measurements, but with minor offsets necessary in some cases.

Figure D-12: Installed RTDs at Site #1 (Left), Site #2 (Middle), and Calibration (Right)

Source: GTI

Table D-1: Calibration Fit Parameters for Hydronic Supply (X2) and Return (X2) at Both Sites

Site #1	Hyd Sup 1	Hyd Rtn 1	Site #2	Hyd Sup 1	Hyd Rtn 1
Slope - fit	1.001E+00	1.000E+00	Slope - fit	9.985E-01	9.943E-01
Intercept - fit	-5.120E-02	-2.099E-02	Intercept - fit	-3.663E-01	7.512E-02
	Hyd Sup 2	Hyd Rtn 2		Hyd Sup 2	Hyd Rtn 2
Slope - fit	1.001E+00	9.990E-01	Slope - fit	9.978E-01	9.984E-01
Intercept - fit	-1.310E-01	-3.200E-02	Intercept - fit	-9.773E-02	-1.836E-01

Source: GTI

Modeling Indoor Gas Water Heater at Site #2

As noted in the main report, upon the replacement of the indoor water heaters at Site #2, one of the gas water heaters (GWH #2) was tripping on faults of low fuel pressure, which occurred in October 2019. The installation contractor employed in the emergency replacement, unaffiliated with the project team, believed that the gas meter was the issue and bypassed the meter to get the water heater up and running. Further investigation, including replacing the meter, did not resolve the matter which was expected due to the low pressure drop of the 'revenue grade' diaphragm-type gas meters. During a subsequent site visit, a damaged gas shutoff valve feeding this gas meter was discovered, which appeared to be in a partially closed position. It is likely that this damage occurred during the removal of the original water heaters and replacement of the larger high-efficiency water heaters. Rather than attempt to operate the damaged valve, the project team installation contractor replaced the valve and re-installed the gas meter. While this did remedy the situation, delayed by the holiday season and other scheduling issues, it was ultimately not necessary as with the onset of COVID-19 related shutdowns, the host site opted to disable the water heater in question on March 20th, before the valve and meter were replaced. Two weeks after this, the integrated GHP system was decommissioned, and the second baseline period began.

Figure D-13: AL425 Gas Meter

Source: Elster

Regrettably, this sequence had the net effect that a) the GWH #2 at Site #2 did not have a functioning gas meter for the final 4.5 months of the integrated GHP system monitoring period and b) with the onset of this issue upon gas water heater replacement and resolution after it was disabled, the project team did not have a recorded gas flow data on this replacement GWH #2. As this gas flow data is critical to the outcome of this task, the project team opted to model this gas flow for this 4.5-month period as follows:[19]

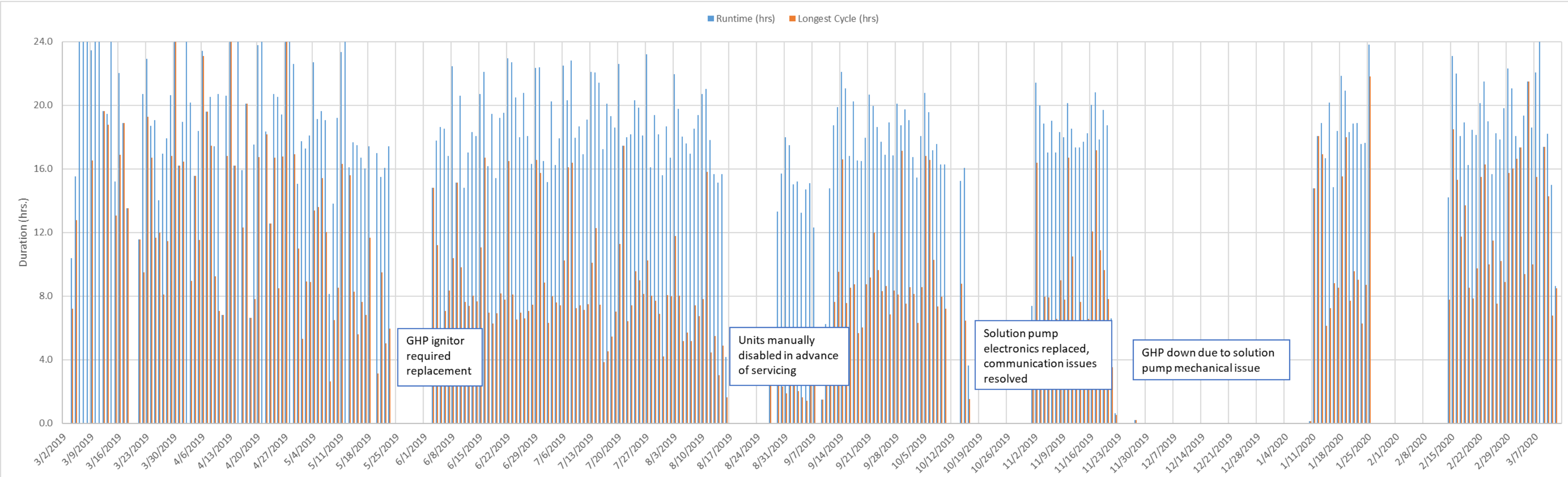
- Data on the pair of GWHs suggest that, with continuous recirculation, there is always water flow through both GWHs, which is assumed to be the case for this period. Fluctuations in outlet temperature data support this assumption.
- While the total flow rate through both water heaters is known at all times, the split between heaters is not. This is estimated using a continuous energy balance using the GWH #1 outlet temperature, GWH #2 outlet temperature, and the mixed measured temperature shown, per the measurement scheme in Figure 5 of the main report. This calculated split of flow through GWH #1 versus GWH #2 does vary with makeup water flow (SHW demand). This value, calculated for each time step in data analysis, has a mean value of 62%-65% of flow through GWH #1 on a weekly basis when screening for small (< 0.1°F) differences in the measured temperature difference between GWH #1 and GWH #2 outlet.
- To estimate the assumed SHW output split, as a means of smoothing the impact of fluctuating temperatures, the weekly average split is used to disaggregate the SHW output of GWH #1 versus GWH #2 (e.g., value used is 62.3% split for week of 2/15/20).
- Using this calculated GWH #1 output, the daily delivered efficiency is calculated as a ratio of measured gas input to GWH #1. This ratio of thermal energy input and output typically ranges from 82% to 92% for GWH #1 depending on the day, with values lower than 80% on occasion.
- The final assumption is that, on a daily basis, the estimated delivered efficiency of GWH #1 is equal to GWH #2, as the units are identical. This assumption permits calculating the daily GWH #2 input based on a measured output and assumed SHW split between GWHs. This calculated GWH #2 input would otherwise be measured by the gas meter. This final, and most consequential assumption is expected to be conservative by over-estimating the GWH #2 gas consumption by underestimating the GWH #2 efficiency. With an estimated ~40% of total water flow through the GWH #2 and with constant recirculation keeping inlet temperatures generally warm above 100°F (38°C), it is assumed that GWH #2 would be cycling its burner and/or operating more consistently in a lower modulation stage, both of which are expected to result in slightly higher operational efficiency versus GWH #1.

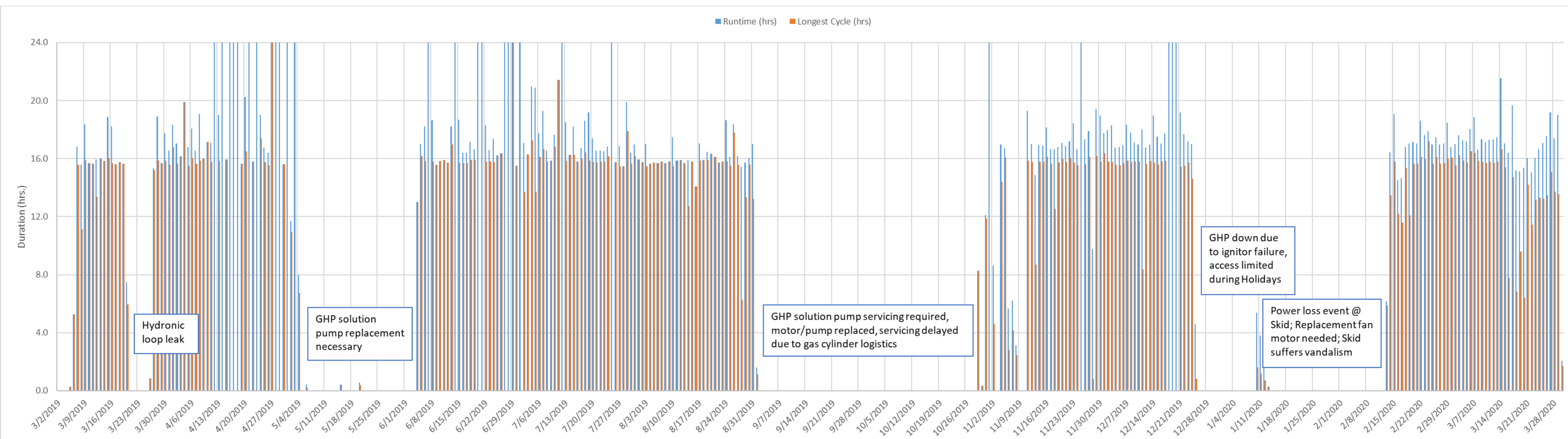
Integrated GHP System Performance - Details

The following charts are supplemental to the data analysis in the main section *Summary of Integrated GHP System Phase Results –Water Heating.*

[19] Note that modeling was not necessary for the second baseline period, as the GWH #2 was disabled for the duration.

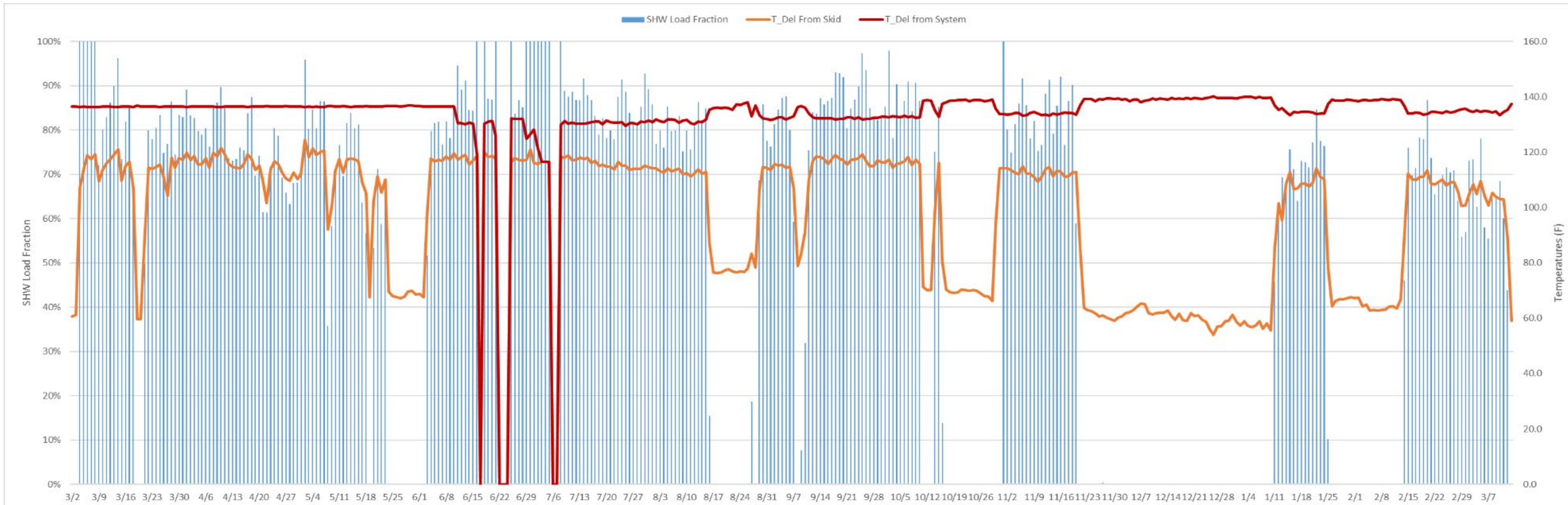
Figure D-14: Gas Heat Pump Runtime and Major Operational Interruptions for Site #1 (Top) and Site #2 (Bottom)

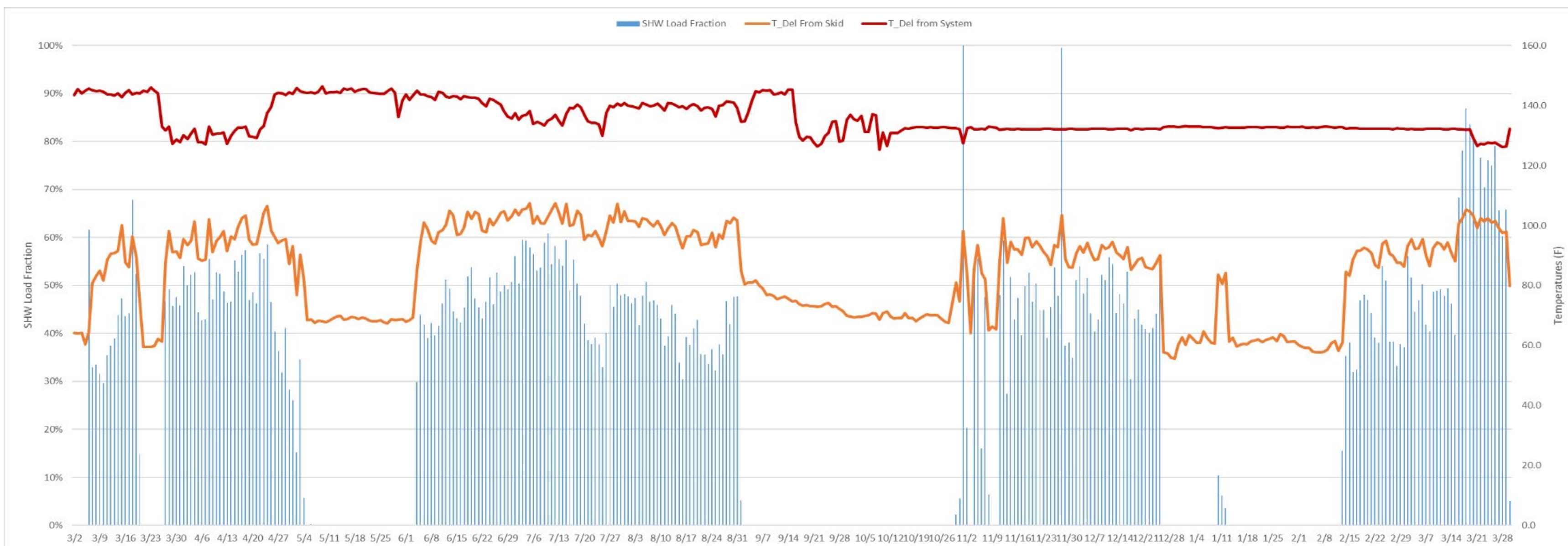




Source: GTI

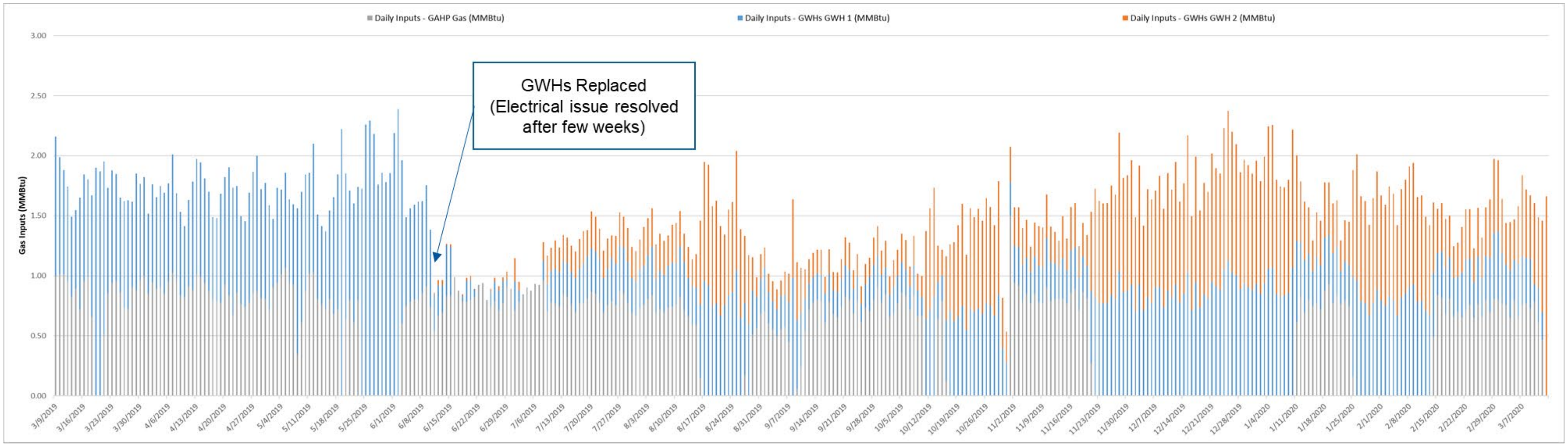
Figure D-15: Service Hot Water Load Fraction for Gas Heat Pump, with Delivered Temperature from Skid (to Gas Water Heaters) and from System for Site #1 (Top) & Site #2 (Bottom)

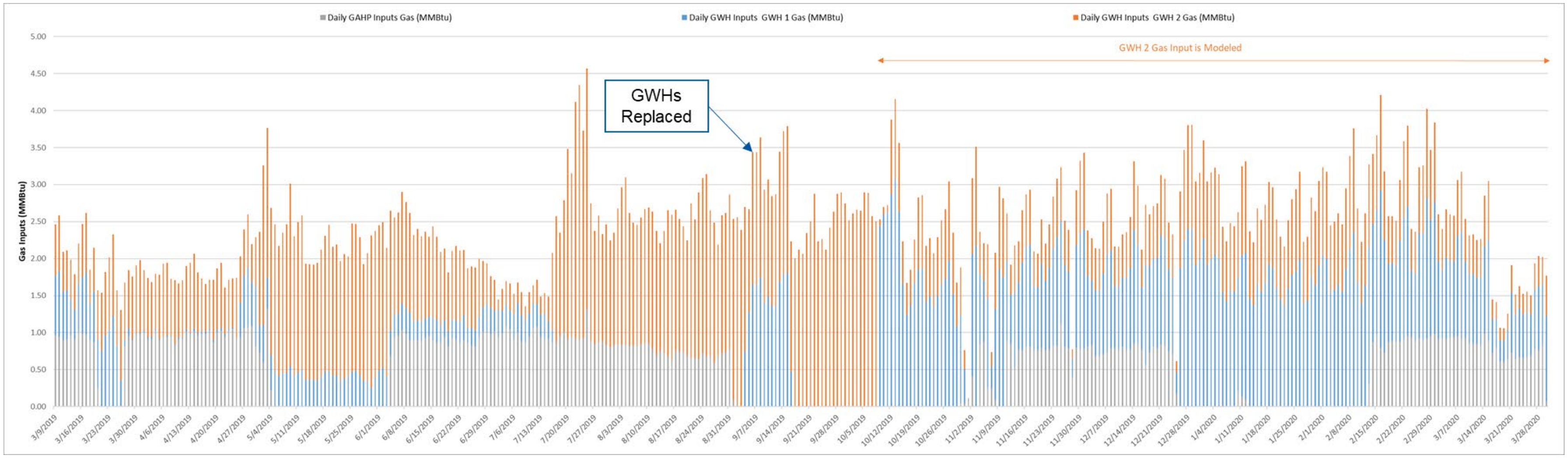




Source: GTI

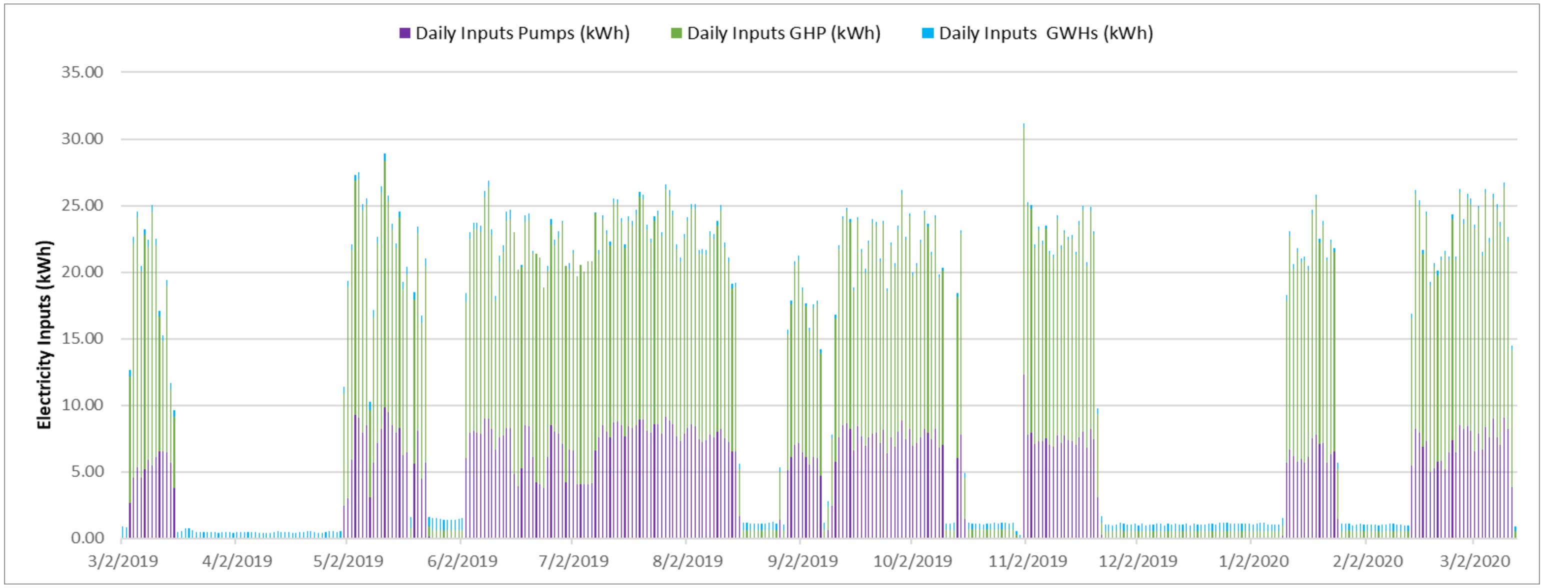
Figure D-16: Daily Gas Input to Gas Heat Pump and Indoor Gas Water Heaters at Site #1 (Top) and Site #2 (Bottom)

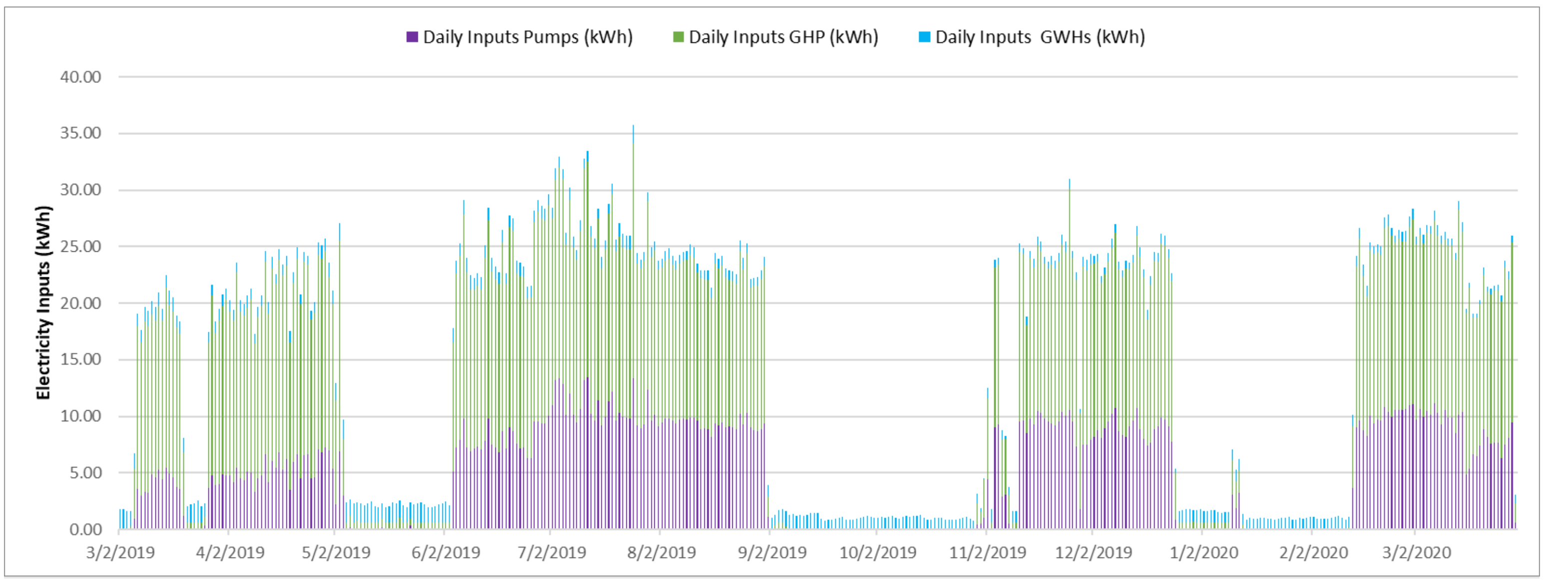




Source: GTI

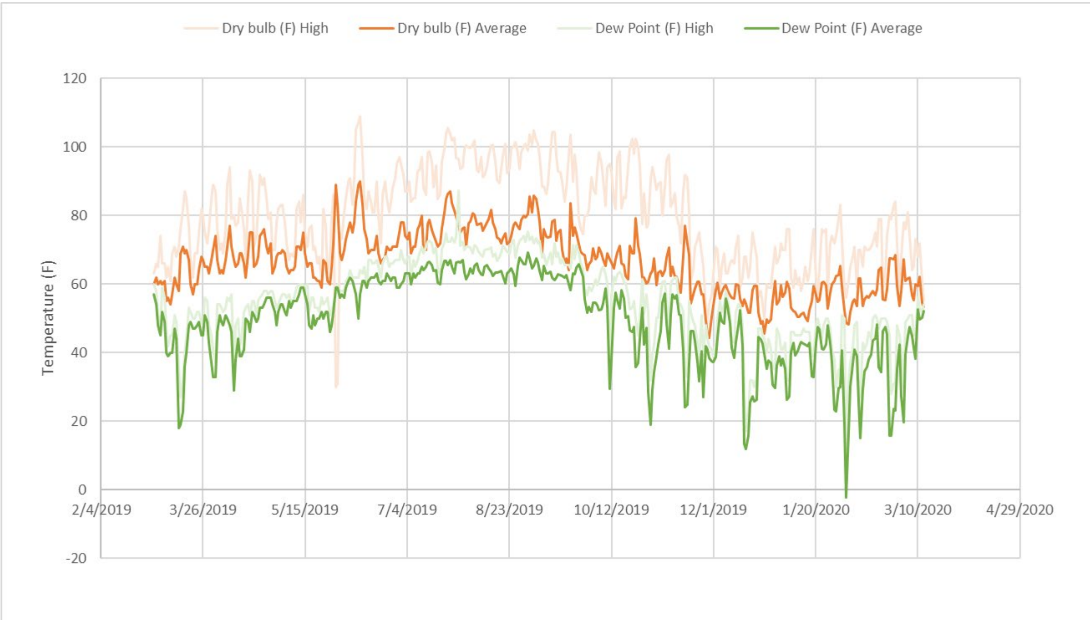
Figure D-17: Electricity Input to Gas Heat Pump System Components at Site #1 (Top) and Site #2 (Bottom)





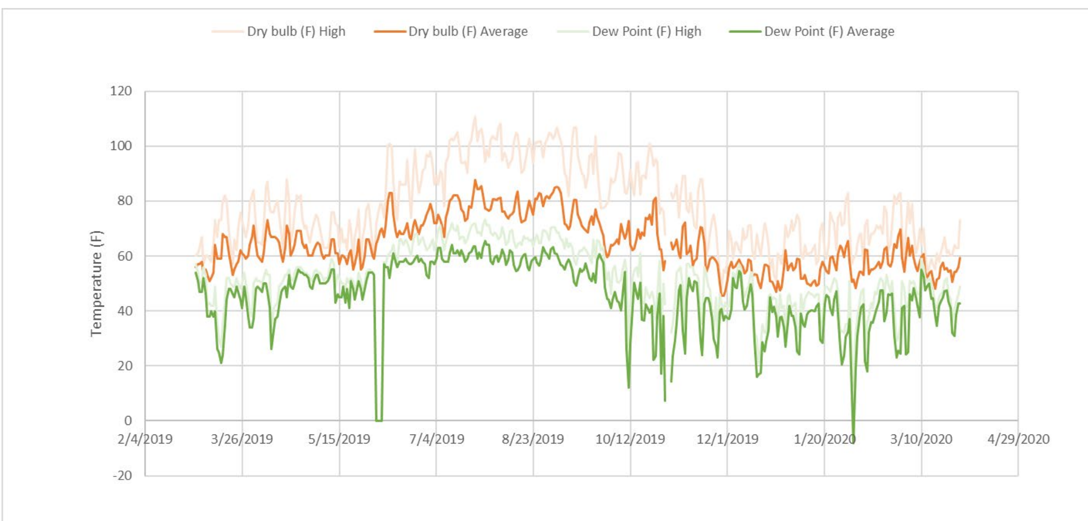
Source: GTI

Figure D-18: Weather Conditions at Site #1



Source: GTI

Figure D-19: Weather Conditions at Site #2

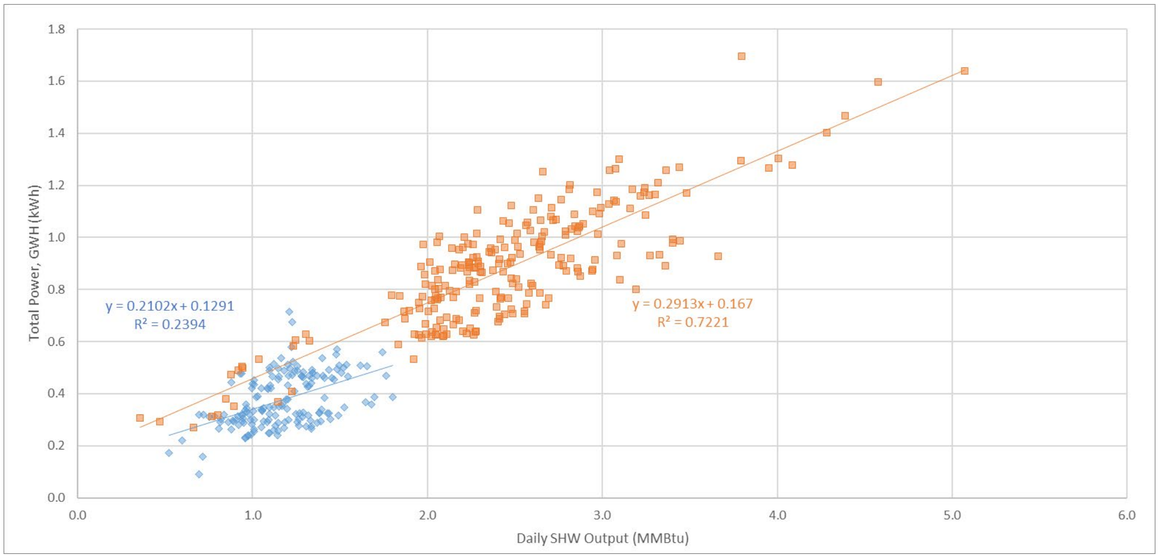


Source: GTI

Electric Power Consumption – Water Heating Equipment

On power consumption of the GWHs, it is challenging to precisely normalize the complete integrated GHP system, as compared to the pair of baseline GWHs collectively, with multiple components drawing electric power, as a function of not just hot water draw, but also cycling rates, SHW load fraction, and ambient temperature (impacting GHP performance and demands for supplemental A/C). While a model-based approach would be preferable in the future, as the prototype is refined into a product offering, in this case the data collected will be generalized in a manner similar to the baseline monitoring period though with a large increase in scatter as seen in the following figures, including the GWHs, the GHPs, and the complete system, including GWHs, GHPs, and circulation pumps (hydronic, chilled water).

Figure D-20: Normalized Water Heater Power Consumption – Site #1 and #2 Gas Water Heaters

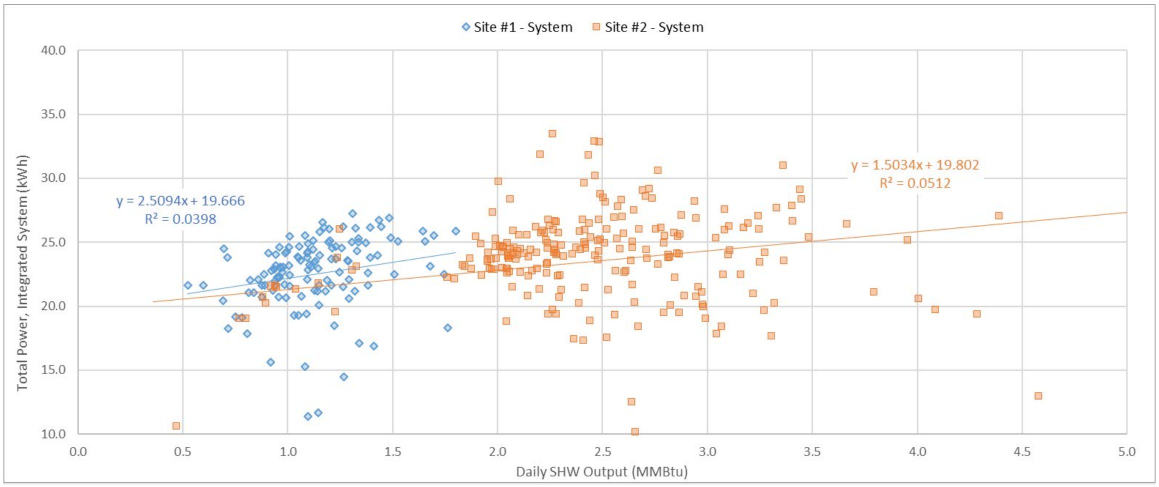


Source: GTI

Figure D-21: Normalized Water Heater Power Consumption – Site #1 and #2 Gas Heat Pumps

Source: GTI

Figure D-22: Normalized Water Heater Power Consumption – Site #1 and #2 Complete Integrated Systems



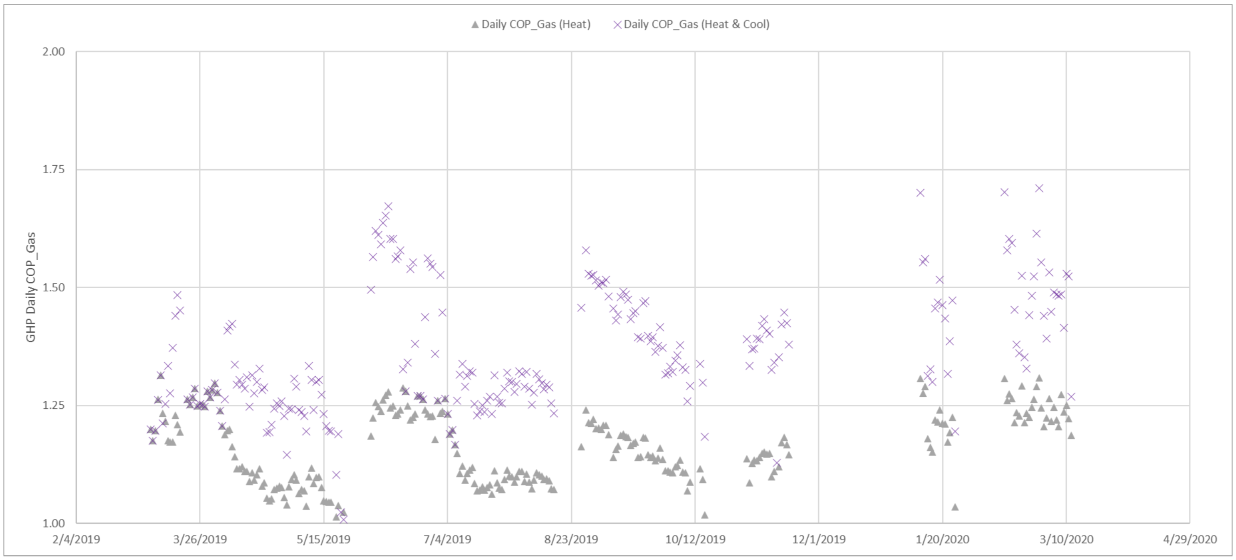
Source: GTI

Focus on GHP Performance

Focusing on the GHP component, where prior field demonstration studies have also examined performance from a cycle perspective (e.g., efficiency per on-cycle) in addition to a daily lens, this demonstration presents a challenge due to the extreme runtime of the GHP units. With average daily runtimes of 18.2 and 17.0 hours per day for Sites #1 and #2 respectively, and frequent cycle durations longer than 24 hours (see Figure D-14), averaging performance per cycle is akin to a daily basis. It is often difficult to generalize the variation in operating conditions over the course of an operating cycle, as both water-side and air-side (outdoor/indoor) vary constantly. Additionally, the GHP and other system components are cycling frequently and, in some cases, experience a range of operational issues noted previously. As a result, it is difficult to generalize much beyond daily performance when viewing individual cycles.

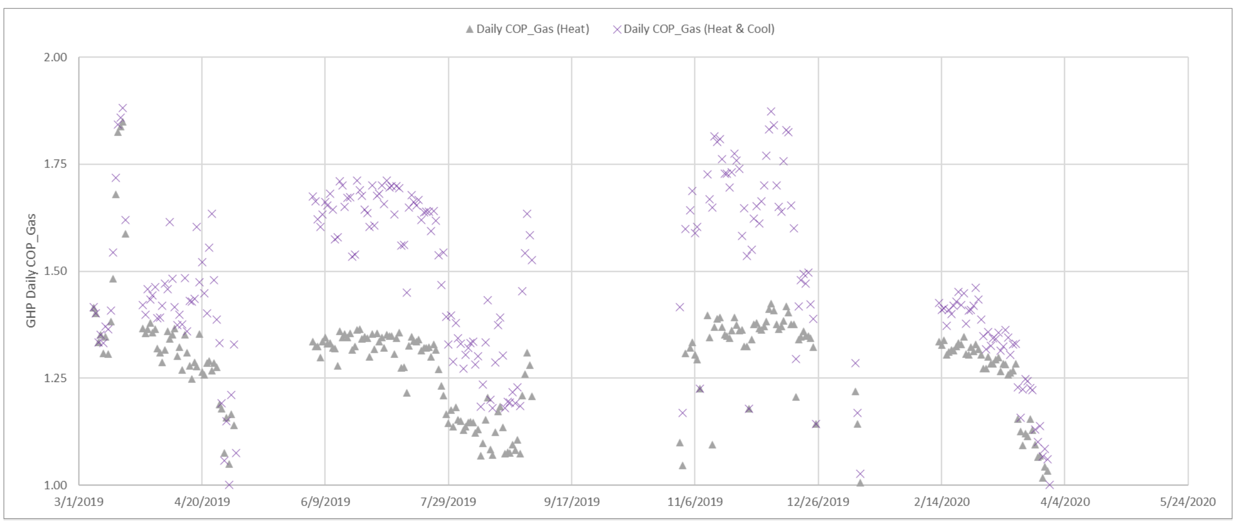
Figure D-23 and Figure D-24 highlight the daily COP_{Gas} for water heating and water heating + cooling output, using values accumulated over the 24-hour period as opposed to time-averaging an operational quasi-steady state COP. The primary observable trend is the impact of system maintenance, as periods of operation see a decline in COP_{Gas} followed by a servicing event for the GHP and/or system components (refer to Figure D-14). These include minor improvements, such as cleaning the evaporator coils, and major changes, such as replacing the GHP solution pump. Each system restart is followed by a jump in efficiency and, in most cases, the cycle repeats. While the operational issues and their impact on GHP efficiency are known, with improvements made during servicing and applied to future GHP units, it is difficult to generalize GHP efficiency as a function of other operational conditions, including ambient temperatures (Figure D-18 and Figure D-19), inlet water temperatures, or load conditions beyond the aforementioned input/output method.

Figure D-23: Daily COPGas of Gas Heat Pump for Water Heating and Water Heating plus Cooling Mode – Site #1



Source: GTI

Figure D-24: Daily COPGas of Gas Heat Pump for Water Heating and Water Heating plus Cooling Mode – Site #2



Source: GTI

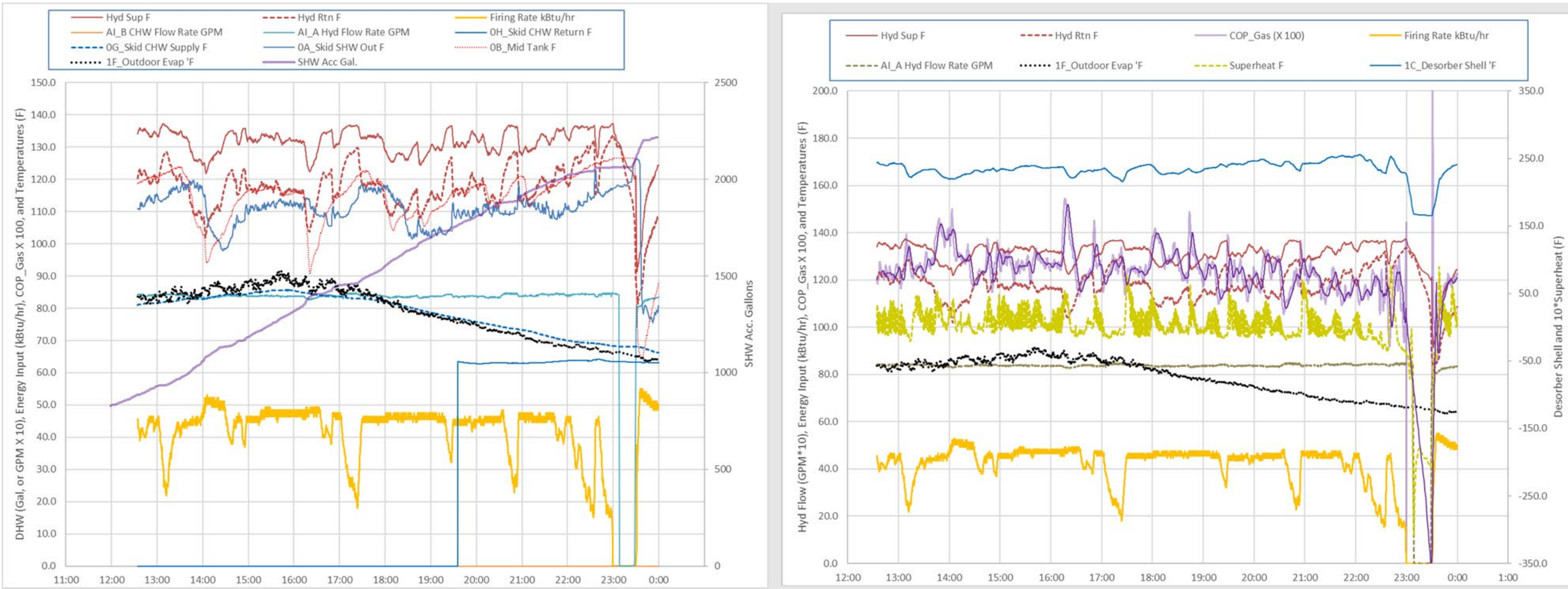
That is not to say that the performance of the GHP, as heating/cooling capacity and COP_{Gas}, is not a function of cold source (ambient air or chilled water loop) and hot sink (hydronic loop) temperatures, including minor variations with modulation. Prior and parallel laboratory and field studies of this GHP prototype have demonstrated this (Glanville 2019). This can be seen when observing quasi-steady state operating conditions. The subsequent charts highlight these dynamics as follows:

- At Site #1, shown in Figure D-25, the GHP unit is operating continuously once the unit cycles on at approximately 12:30. Due to the lower hourly SHW load at Site #1, the

GHP modulates frequently, observed by the reduced firing rate (orange-yellow trace). This modulation, coupled with the dynamic SHW load that it is a response to, leads to constantly fluctuating hydronic loop temperatures (red traces in left chart), ultimately resulting in a fluctuating COPGas for water heating only (purple trace in right chart, solid line is a moving average). Per the prior test data (Figure A-5), these conditions should yield ~1.35-1.40 COPGas, however these fluctuations limit the Site #1 GHP from reaching this.

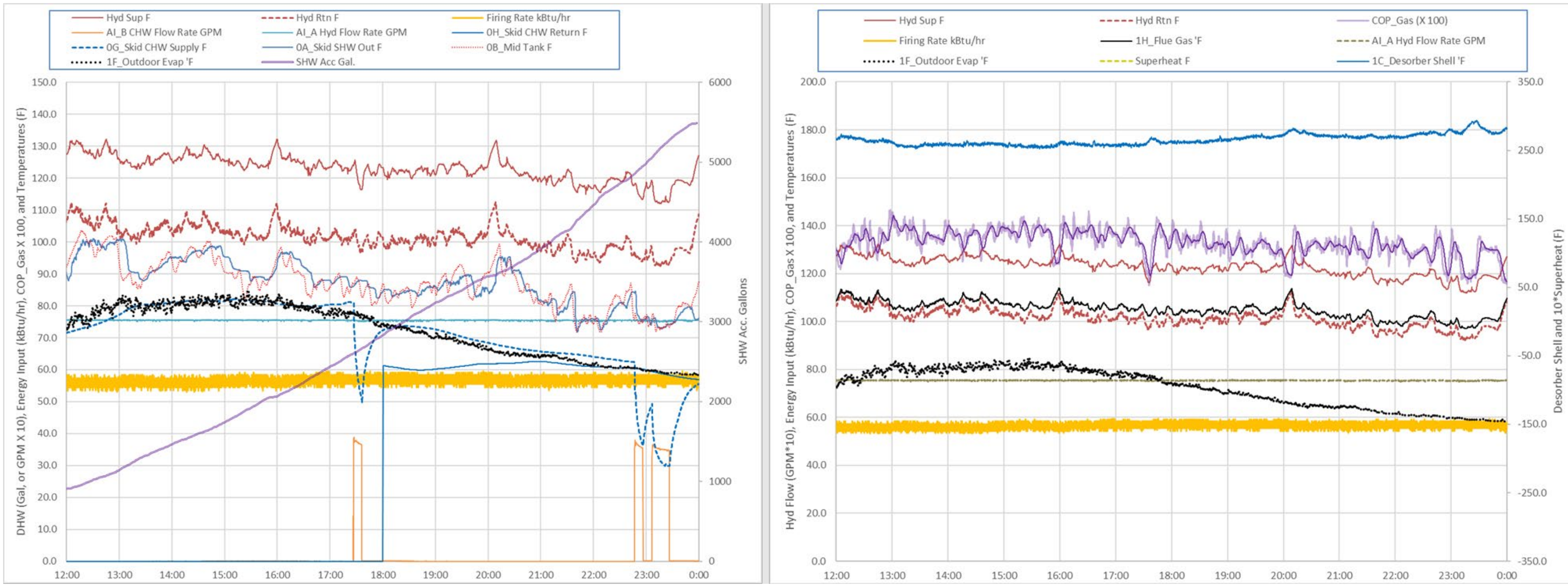
- At Site #2, shown in Figure D-26, the GHP is operating at full output continuously with the firing rate at maximum 55 kBtu/hr for the entire cycle. As a result, the GHP unit is only seeing fluctuations in capacity and COPGas brought about by fluctuations in loop temperature (load), and the operating efficiency is much closer to the steady-state target.

Figure D-25: Example Cycling Period at Site #1 – April 2019



Source: GTI

Figure D-26: Example Cycling Period at Site #2 – April 2019



Source: GTI

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix E: Additional Site Photos

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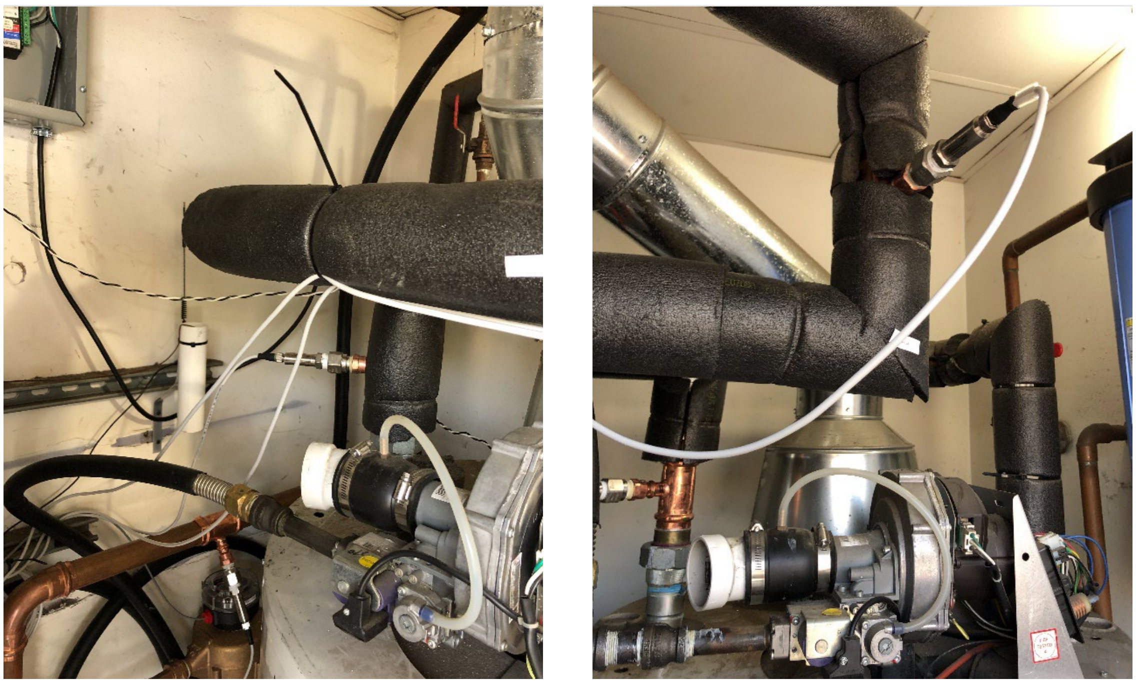
APPENDIX E:
Additional Site Photos

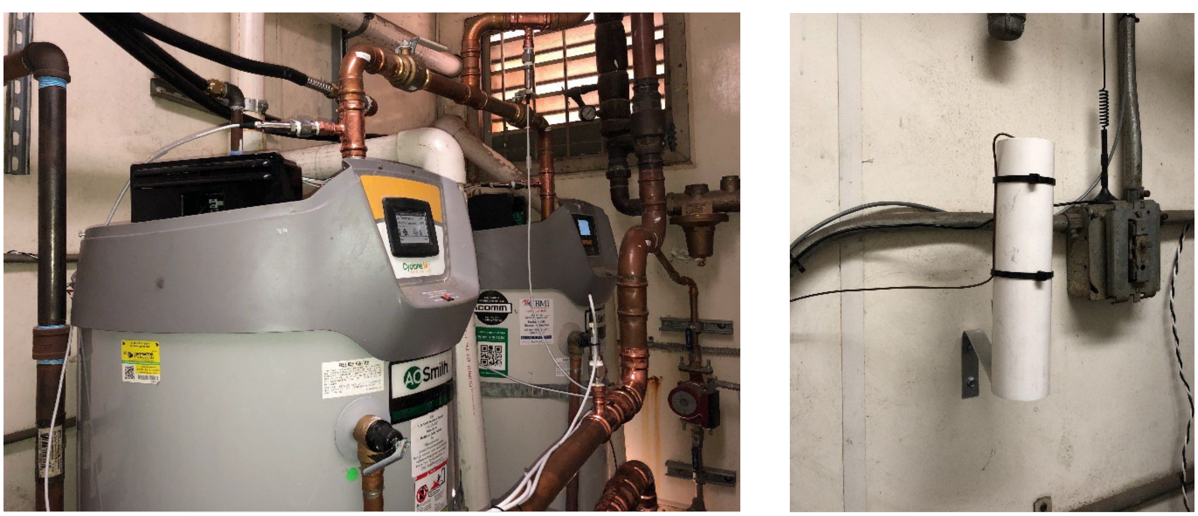
Baseline Monitoring Phase

Figure E-1: Hot/Cold Water and Mechanical Room Air Temperature Measurements at Site #1



Source: GTI

Figure E-2: Hot/Cold Water and Mechanical Room Air Temperature Measurements at Site #2

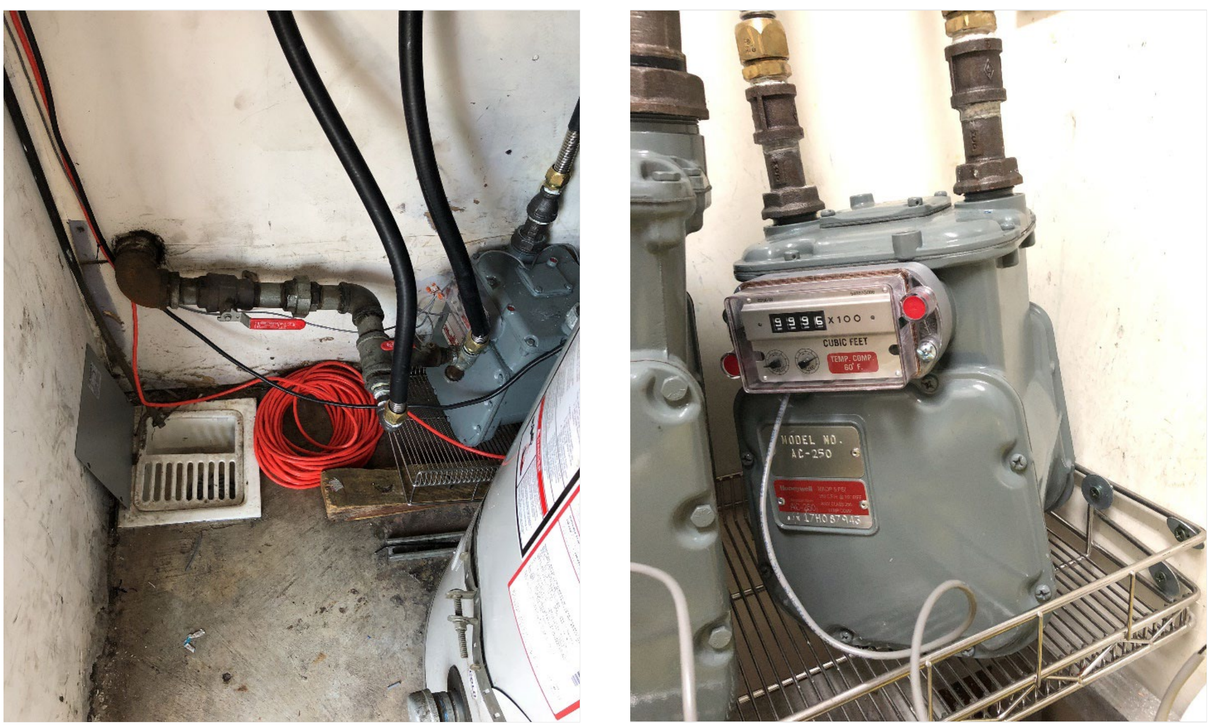


Source: GTI

Figure E-3: Water Meter Installed at Site #1 (Left) and Site #2 (Right)

Source: GTI

Figure E-4: Water Heater Gas Meters Installed at Site #1 (Left) and Site #2 (Right)

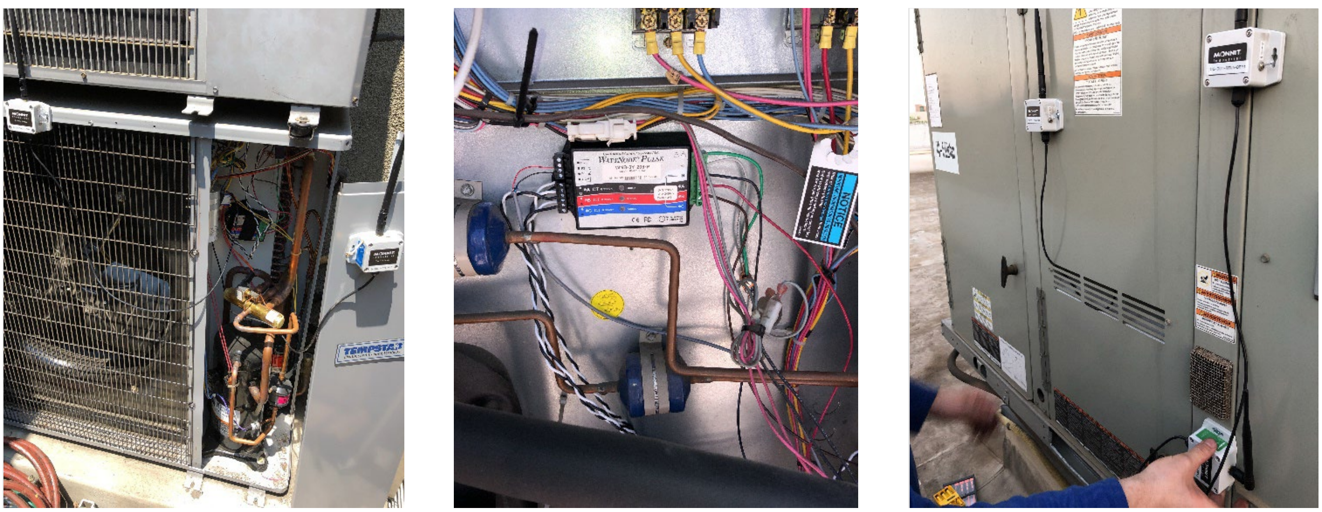


Source: GTI

Figure E-5: Water Heater Power Meters Installed at Site #1 (Left) and Site #2 (Right)

Source: GTI

Figure E-6: Wired and Wireless Rooftop Measurements at Site #1 (Left) and Site #2 (Middle, Right)



Source: GTI

Figure E-7: Baseline Water Heaters at Site #1 (Left) and Site #2 (Right)

Source: GTI

ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix F: Technology and Knowledge Transfer Report

June 2024 | CEC-500-2024-058

CALIFORNIA ENERGY COMMISSION

Energy Research and Development Division

Demonstrating Natural Gas Heat Pumps for Integrated Hot Water and Air-Conditioning in Restaurants: Technology/Knowledge Transfer Report

Final

Gavin Newsom, Governor
June 2024

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Natural Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Demonstration and Assessment of Residential Gas Heat Pump Water Heaters in the Los Angeles Basin Technology/Knowledge Transfer report is an interim report (PIR-16-003) conducted by GTI. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the CEC at 916-327-1551.

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CHAPTER 1: Background

A final technology/knowledge transfer plan was prepared and submitted to the California Energy Commission on July 3, 2017, which outlined the planned activities for supporting the sharing of knowledge gained, experimental results, and lessons learned through this project. The focus of these activities relied on disseminating information to the following target audiences:

- Contractors and installers
- Engineers
- Equipment manufacturers
- Equipment dealers and representatives
- Residential designers
- Professional/trade organizations, associations, and societies
- Codes and standards bodies/advocates
    - ACEEE
    - Consortium for Energy Efficiency (CEE)
    - California Energy Commission (CEC)
    - Department of Energy – Environmental Protection Agency (DOE EPA)
- Utilities – Energy Centers, CA statewide IOU advisory council meetings, codes & standards, incentives and emerging technologies groups
- Other research organizations

The goal of this outreach is to educate the target audiences on the availability, performance, and requirements of a commercial integrated gas-fired heat pump to provide water heating and air-conditioning while highlighting its increased energy efficiency and energy cost savings for customers.

CHAPTER 2:
Technology/Knowledge Transfer Activities

Stakeholder Outreach through Workshops

The 2017 Technology/Knowledge Transfer Plan prepared for this project included industry outreach through one Southern California Gas-hosted workshop at their Energy Research Center and a second outreach event hosted by Frontier Energy (formerly Fisher-Nickel, Inc.) at the PG&E Food Service Technology Center (FSTC). The intent was for the project team to lead workshops to familiarize IOUs, installation contractors, code officials, restaurant owners, and other interested parties with this new class of technology and solicit feedback. These workshops were envisioned to be in-person events to maximize participation and engagement and were tentatively scheduled for the first half of 2020. Unfortunately, as the COVID-19 global pandemic emerged the project team had to re-visit this original intention. It was decided that instead of an in-person workshop hosted at Southern California Gas, the project would be presented in detail at the 2020 ACEEE Hot Water Forum (HWF). The HWF transitioned from an in-person to a virtual event and was temporarily postponed from March to July 2020. The project was presented during a session titled 'Commercial Applications of Gas Heat Pump Technologies'. There was a positive reception with questions and discussion from the group. After the session, there was a further 20-minute Zoom-based discussion – a more casual format for follow-up questions and thoughts to be shared. This was well-attended with lots of good discussion.

The second outreach event will be the project team's presentation and paper to be delivered at the 2021 ASHRAE Winter Conference in Chicago, Illinois. Paul Glanville, PE will give a presentation titled "Demonstrating an Integrated Thermal Heat Pump System for Hot Water and Air-Conditioning at Full Service Restaurants". An identically titled conference paper was submitted, reviewed, and upon acceptance will be distributed at the conference.

Online Outreach and Information Dissemination

Under this project effort, several deliverables are being prepared that will be hosted online to further enhance the availability of information to interested stakeholders. These include:

1. Updated Water Heater Design Guide for Food Service: Frontier Energy worked with GTI to develop a simplified model of the low-cost gas heat pump system for central hot water and air-conditioning for incorporation into an updated Water Heater Design Guide for food service. The project team is currently determining the most appropriate location for sharing this design guide.
2. Integrated Gas Heat Pump Life-Cycle Cost Calculator: Also available for public use, this life-cycle cost calculator was developed based on data from this project as well as prior data analysis. The project team is currently determining the most appropriate location for sharing this calculator.
3. Codes and Standards Impact Analysis: Frontier Energy executed a survey of codes and standards, including energy efficiency standards, relevant to the GHP system. This analysis specifically looked at the system as deployed in light commercial facilities, with

a focus on restaurants, including a review of California building energy efficiency code requirements.

4. Market Impact Analysis of Low-Cost Gas Heat Pumps in California: Applied Research-West, with guidance from GTI, SMTI, and A.O. Smith, developed surveys and questionnaires to qualify and quantify market barriers to low-cost GHP adoption in California, once commercialized. This included input from business owners, installation contractors, and specifying mechanical engineers. Potential barriers considered may include profit potential, training/education, safety, and incentive management, as well as other market concerns. At this time, the in-depth interviews and focus group portions are complete, and ARW has launched a nationwide quantitative survey. As soon as the target number of responses are received, a final summary of results will be developed.
5. With support from SMTI and A.O. Smith, GTI will prepare educational content and training materials for future use with contractors and with utility ratepayers. The project team is determining the most suitable location to share this information, with the most likely candidate being it's incorporated into GTI's website.
6. Southern California Gas issued a press release highlighting this project on March 12, 2019. https://www.prnewswire.com/news-releases/socalgas-joins-the-california-energy-commission-in-the-demonstration-of-a-new-ultra-efficient-water-heater-and-space-cooler-developed-by-stone-mountain-technologies-300811110.html

Conference Outreach and Papers

GTI leveraged its role as a research and development (R&D) leader in the energy industry to relay the data gathered from this project to R&D memberships and technical organizations active in this space. Information outreach was delivered through various modes and venues, including in-person presentations, fact sheet summaries, and informal talks. These types of outreach activities provided a forum in which a group was given detailed information at various points in the project progression in a quick timeframe (typically 10-30 minutes), in several venues and most often by invitation.

GTI made presentations about the project on several occasions, outlined below.

Meeting Setting: 2018 ACEEE Hot Water Forum

Date: March 21, 2018

Location: Portland, Oregon

Presenter: Paul Glanville, GTI

Audience: Approximately 30 attendees, including manufacturers, utilities, plumbing contractors, researchers, and other stakeholders.

Meeting Setting: 2019 ACEEE Hot Water Forum

Date: March 11-13, 2019

Location: Nashville, Tennessee

Presenter: Isaac Mahderekal, GTI

Audience: Approximately 30 attendees, including manufacturers, utilities, plumbing contractors, researchers, and other stakeholders.

Meeting Setting: 2019 GTI Emerging Technology Program, Spring Meeting

Date: April 24-25, 2019

Location: Los Angeles, California

Presenter: Paul Glanville, GTI

Audience: Approximately 20-25 attendees, primarily utility program administrators and other affiliated staff.

Meeting Setting: CEE Winter Program

Date: January 23, 2020

Location: Long Beach, California

Presenter: Merry Sweeney, GTI

Audience: Presented in a Commercial Water Heating breakout session to over a dozen CEE members, primarily utility program administrators, energy efficiency organizations, industry stakeholders, and other affiliated staff. Several expressed interest in the project and preliminary findings and lessons learned.

Meeting Setting: 2020 ACEEE Hot Water Forum

Date: July 21, 22, 28, & 29, 2020

Location: Held virtually due to COVID-19 pandemic

Presenter: Paul Glanville, GTI

Audience: Presented the results in a session titled 'Commercial Applications of Gas Heat Pump Technologies'. There was a positive reception with questions and discussion from the group. After the session, there was a further 20-minute Zoom-based discussion – a more casual format for follow-up questions and thoughts to be shared. This was well-attended with lots of good discussion.

Paper Submission: GTI submitted an abstract to ASHRAE for consideration as a conference paper at the 2021 Winter Conference.

Status: Abstract was accepted, and a paper is during in the final stages of being drafted. When the paper is finalized by ASHRAE, it will be made available through ASHRAE's website.

Demonstrating an Integrated Thermal Heat Pump System for Hot Water and Air-Conditioning at Full Service Restaurants

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ABSTRACT

In this paper the authors summarize data and key findings from the demonstration of integrated thermal heat pump (THP) systems, which are innovative "hybrid" commercial water heating solutions installed such that the THP provides (a) hot water in series with conventional water heater(s), and (b) A/C supplemental to the building HVAC. Major components are the THP, providing high-efficiency heating and 'free cooling' to separate hydronic/chilled water loops, an indirect storage tank in series with conventional water heater (s), and an indoor cooling coil installed as standalone or within the ductwork. At its core is the THP, a direct-fired absorption heat pump providing hot water and A/C through a four-pipe design, with additional flexibility to operate as an air-source THP during periods of low or no A/C demand.

Of the estimated 340 million therms per year consumed for commercial hot water in California restaurants, most are consumed by low-efficiency water heaters with a thermal efficiency of ~80%. With an estimated improvement of operating efficiency to 140% or greater for hot water production, broad deployment of THPs could reduce natural gas consumption for commercial water heating in restaurants by 43%, while displacing up to 20% of electricity demand for A/C, providing further energy and operating cost reductions. This potential is assessed in a year-long demonstration of prototype integrated THP systems at two restaurants in Los Angeles, CA, summarizing system design and optimization, energy savings over a broad range of operating conditions, retrofit installation barriers, and interactive effects with other building systems.

INTRODUCTION

In the water heating industry, significant attention has been given over the past decade to the development and deployment of high-efficiency water heating products for residential buildings. Much of this attention has concerned the widespread deployment of gas-fired tankless water heater products [Kosar, 2013], development and deployment of electric heat pump water heaters [Glanville, 2012], and even the development of gas-fired heat pump water heaters [Glanville, 2020], each with significant potential for energy savings and changing how we generate and consume hot water. With an average life expectancy of up to 12 years and 41 million water heaters in the U.S. in operation for more than 10 years, with 82% sold as replacements [U.S. EPA, 2016], the opportunity for market transformation towards high-efficiency products is clear. However, the market and energy efficiency programs have struggled with this value

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proposition of more efficient residential water heating solutions, where increases in retrofit costs of 50% or greater are challenging to consumers who typically spend $250-$300/year on electricity and/or gas for hot water [Kosar, 2013].

By contrast water heating in commercial buildings has not received similar levels of attention, where despite greater numbers of residential water heaters sold per year, with approximately 36x as many residential storage water heaters sold as commercial storage water heaters [AHRI, 2020], commercial buildings can consume 10-100x the hot water as a typical home [Hiller, 2015]. Additionally, while single family and low-rise multifamily buildings are commonly serviced by individual water heaters, commercial buildings are more commonly served multiple commercial water heaters or water heating systems which are more challenging to generalize across the sector. For gas-fired commercial water heaters, which represent the majority of the non-"residential-duty" commercial water heating market, approximately 77% of shipments are storage type, 14% are boilers coupled with indirect storage tanks (IST), and 9% are tankless type [DOE, 2016], with examples from the author's field studies in the figure below.

Figure 1 Typical Commercial Water Heating Installations from Prior Field Studies, Storage-type, Boiler & Indirect Storage Tank, and Tankless-Type Equipment (Left to Right)

As a result of this greater hot water demand and with purchase decisions driven more by expectations of financial payback, commercial water heaters are much more efficient as a population. Over the period from 2009-19, high-efficiency commercial gas-fired water heaters, with a rated thermal efficiency of 90% or greater, have increased from 29% of shipments to 47%, a shift in population-efficiency not seen for residential products [A.O. Smith, 2020]. As a result, end users and energy efficiency stakeholders are looking beyond 'condensing efficiency' and seeking to leverage advances in heat pump technology. For electric options in 2019, a major U.S. water heater manufacturer introduced a commercial integrated electric heat pump water heater, with a rated coefficient of performance (COP) of 4.2 on a site basis and a heat pump output capacity of approximately 40 kBtu/h (11 kW). For gas-fired options, often serving much larger commercial hot water loads, several active demonstrations of heat pump systems have been performed at multiple building types, including schools, senior care facilities, hospitality, and other commercial buildings, in Oregon, Michigan, British Columbia, and Ontario [GTI, 2019]. In these studies, commonly involving one or multiple thermal heat pumps (THPs) with an output capacity of 124 kBtu/h (36 kW) and employing the ammonia-water vapor absorption cycle, demonstrations have shown a reduction of gas consumption by baseline equipment ranging from 18% to 50%, when serving commercial water heating loads [TAF, 2018 and Pratt, 2020].

Building on this potential for energy savings, the authors focused on the restaurant industry as a target for commercial hot water savings using THP technologies. As a sector, restaurants consume more natural gas per square foot than any other commercial building type, with water heating following cooking equipment as the largest thermal loads. In California, over 340 million therms are consumed to generate hot water in restaurants, wherein these approximately 90,000 restaurants consume more gas for water heating than the total gas consumption of one million homes [Delagah, 2013]. While opportunities remain for reducing the energy input and associated emissions with this thermal load, with significant savings possible with conservation measures like efficient, demand-based recirculation pumps and integrated heat recovery in dishmachines [Delagah, 2018], the limit of 'condensing efficiency' must be addressed. With an estimated improvement of operating efficiency to 140% or greater for hot water production, broad deployment of THPs could reduce natural gas consumption for commercial water heating in restaurants by 43% [Glanville, 2019], while displacing up to 20% of electricity demand for A/C, providing further energy and operating cost reductions. This potential is assessed in a year-long demonstration of prototype integrated THP systems at two restaurants in Los Angeles, CA, summarizing system design and optimization, energy savings over a broad range of operating conditions, retrofit installation barriers, and interactive effects with other building systems.

INTEGRATED THERMAL HEAT PUMP SYSTEM

Restaurants commonly have one or two water heaters, depending on service hot water (SHW) loads and needs for redundancy, and rooftop and/or grade-level HVAC equipment, with quantity and type of HVAC equipment varying by restaurant type, size, and climate zone. Depending on requirements from local health codes, either the water heaters will be set to deliver the required temperature to all fixtures or will deliver a lower temperature to most fixtures (e.g., 140°F) while some equipment may have small "booster" heaters to raise the temperature at a fixture or piece of equipment (e.g., raising to 180°F at dishmachine). Also, restaurants commonly employ hot water recirculation loops, which usually operate "always on" but are increasingly demand-based. In terms of HVAC equipment, heat pumps, commercial furnaces, rooftop units (RTUs), evaporative cooling equipment, and exhaust fans (with and without heat recovery) are common. HVAC equipment must be sized properly to handle these high ventilation loads and large internal and year-round heat gain that can result in restaurant HVAC consuming 5-7 times the energy than other commercial building types (e.g., office buildings).

The Integrated THP system, as deployed at demonstration sites, is a "hybrid" system, in the sense that the THP will (a) provide hot water in series with conventional gas-fired water heater(s) and (b) A/C supplemental to the building's existing A/C equipment. The THP system consists of three major components: a low-cost THP providing high-efficiency heating and supplemental cooling to separate hydronic/chilled water loops, an indirect storage tank to provide hot water in series with the conventional gas-fired water heater, and an indoor cooling coil installed either as a standalone cooling coil within the kitchen or within the existing ductwork. The THP is designed as a water-to-water heat pump with a "four-pipe" design, shifting heat from a chilled water loop (A/C) to a hot water loop (SHW), providing hot water and A/C simultaneously. The THP is also designed to operate in a SHW-only mode, wherein the chilled water loop absorbs heat from an integrated outdoor coil, completely within the THP cabinet, so it can operate as an air-to-water THP as well. The overall system shown in the figure below**,** illustrating how the THP component integrates with the balance of the system, with the THP upgrading heat drawn from the restaurant via the chilled water loop (supplemental cooling) or as an air-to-water THP drawing heat from the outdoor air.

Thermal Heat Pump Component

This low-cost THP is a direct-fired, single-effect, absorption heat pump using the ammonia/water working pair, with an operating heating COP of 1.4-1.9, and an estimated Annual Fuel Utilization Efficiency of >140% and a projected unit cost of ~40% an equivalent THP [GTI, 2019]. It yields 40% or greater therm savings when deployed to provide hot water, as demonstrated in prior lab and field testing of earlier generations, and is anticipated to have an equipment cost approximately ½ that of comparable THP equipment [Glanville, 2019]. To offset A/C energy consumption, this THP can be modified to deliver hot water and supplemental A/C, sized to provide 80,000 Btu/hr (23 kW) of hot water *and* 2.5 tons of cooling (8.8 kW) with 4:1 modulation, simultaneously, as designed by a startup company specializing in absorption heat pumps, with technical support from the authors and other industry partners.

Within the THP the compression of the liquid refrigerant/absorbent solution is performed by the solution pump, which requires only about 2% of the total energy input to the heat pump. The thermal energy from the modulating, 55,000 Btu/hr (16 kW) gas burner is required to drive the refrigerant vapor from its absorbed state in the desorber (or "generator"). This desorption process occurs at an elevated temperature—250-300°F—thus exiting flue gases still have useful heat, which is recovered in a separate condensing heat exchanger (CHX), integrated within the hot water loop. As the ammonia/water pair has a significant heat of absorption, this is recovered at the absorber as well by the same hydronic loop as the condenser. Thus, the THP heats the hydronic loop via three inputs: condenser heat from the heat pump effect, recovered heat of absorption in the absorber, and heat recovery of the flue gases via the CHX. Because only a portion of the heat to the hot water loop is from the condenser, the A/C capacity is roughly 40% of the hot water capacity, which is well-suited for hot water-intensive operations like restaurants.

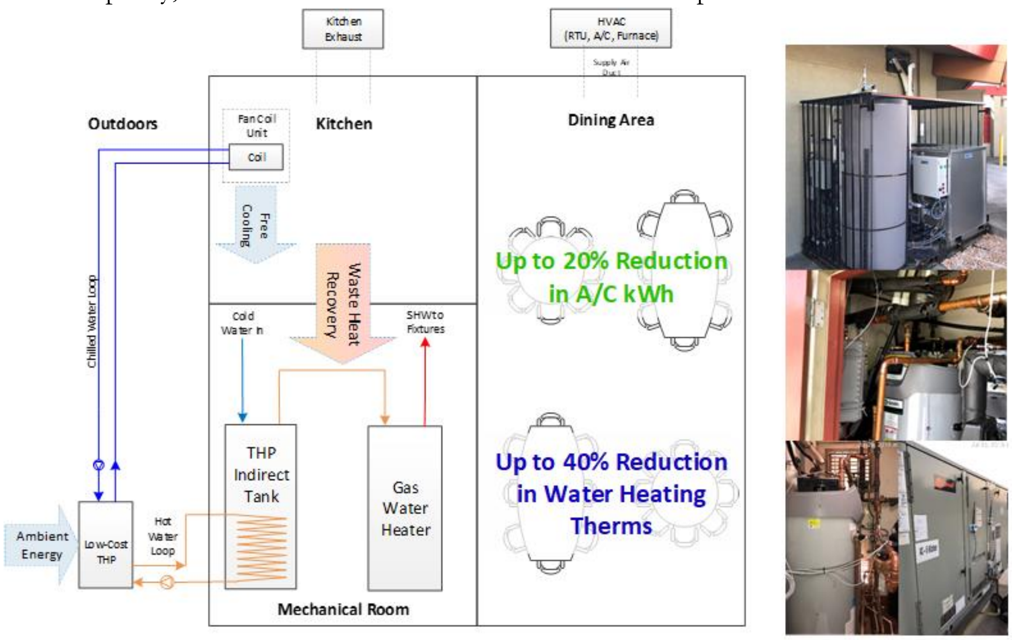

Figure 2 Simplified Diagram of Integrated THP System for Hot Water and A/C with Installation Photos

Integrated System Considerations

Concerning system controls, the integrated THP system was sized and controlled to be *hot water-led*, the THP will cycle on to meet a call for hot water (i.e., a thermostat call). If, when the THP cycles on there is also a call for space cooling at the indoor cooling coil, the THP will direct chilled water to this coil for supplemental A/C. If there is no call for space cooling, the THP will instead use the outdoor-coupled HX within its cabinet. The indirect storage tank is used as a) a buffer between the SHW demand and the operation of the GHP to prevent unwanted GHP short-cycling and b) meeting the required "double-wall" HX requirement between a refrigerant (NH_3) and potable water.

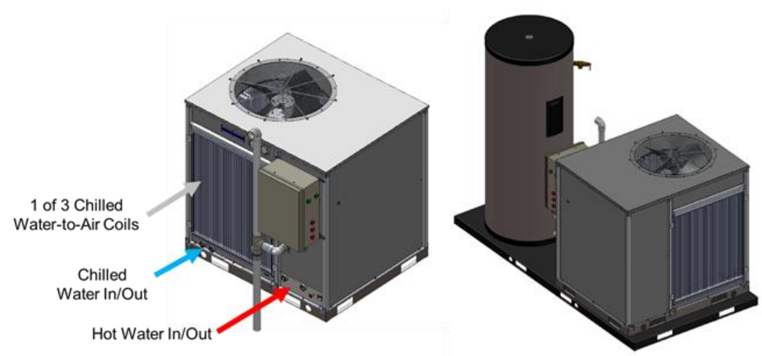

Figure 3 Rendering of THP and Temporary Skid Layout

On component sizing, deployed as an integrated system for hot water and supplemental A/C, the THP is sized only to carry a portion of the peak SHW load. SHW loads can vary by factors of two or greater from day-to-day and large portions of a restaurant's 2,000+ gal/day consumed for SHW can occur in a few hours each day (e.g., kitchen clean-up) [Delagah, 2013], so it was expected to be most cost-effective for the THP to carry most of the SHW load, most of the time, with a "peaking" and "baseload" relationship between the conventional water heater(s) and the THP, borrowing the electricity generation analogy. The balance is important, as "too much" or "too little" GHP is undesirable as a) with under-sizing, if not enough of the load is carried by the THP this can offer only a minimal improvement over the baseline case and b) if the THP is over-sized relative to the load and conventional water heaters, the value of the THP(s) will not be realized operating at part-load much of the time.

Concerning the additional cooling output, generally it was assumed that the added 0.5-2.2 tons of cooling will be useful in all instances, with the range depending on THP modulation. In mild Los Angeles, with only 1,200 heating degree days per year on average[1], the internal loads within the kitchen are expected to demand year-round cooling. Prior studies of thermal comfort in commercial kitchens revealed that restaurant cooking staff were equally uncomfortable during winter and summer months [Stoops, 2013], so it is anticipated that cooling from the GHP will be useful, particularly during peak business hours.

Finally, as a concern for the physical layout of the THP system at each restaurant site, it is convenient to install the THP component, the indirect storage tank, and the associated outdoor piping, instrumentation, and controls on a skid. While primarily motivated by the temporary nature of this installation and the difficulty in locating additional space within mechanical rooms for the indirect storage tanks, the additional benefit is a compact and reliable factory installation of plumbing connections and components, decreasing the effort and potential for errors during installation. A rendering is shown in Figure 3, with omitted enclosures and connections for clarity.

FIELD DEMONSTRATION

Following site selection, the authors monitored baseline energy consumption and operating conditions of the existing water heating and A/C equipment for seven months, followed by the installation and commissioning of the integrated THP systems, monitoring for twelve months, and with decommissioning the THP, a 'second baseline' period commenced for an additional three months to monitor high-efficiency replacement water heaters. The two restaurant demonstration sites were located in Los Angeles county, Site #1 is a 24-hour diner from a local chain of 18 restaurants and Site #2 is a full service restaurant (FSR) from a national chain with 23 locations in Los Angeles and Orange counties, both sites are located in California Climate Zone 9. On the 'second baseline', this began with the THP decommissioning in March 2020 and ran through June 2020. During this time, the COVID-19 outbreak spiked in California, and both restaurants ceased dine-in operations and shifted to serving takeout and delivery orders only. As a result, it is difficult to draw conclusions from this period in comparison to the "business as usual" measurements in the initial baseline and THP system monitoring periods, so only the original baseline is used.

Baseline Measurements

The existing equipment at the two restaurant sites are summarized in the below, including indoor water heating equipment, water heating system components, and the mechanical A/C equipment. Both sites had water heaters operating with delivered temperature settings of 140°F (60°F) and with 24/7 recirculation. Extensive monitoring was performed to quantify air and water temperatures and energy (gas/electricity) inputs to water heating and HVAC equipment, sampling at a frequency of 15 seconds to 1 minute (depending on site activity) by on-site dataloggers.

Table 1. Equipment Summary at Demonstration Sites

Site	Water Heating System	Water Heaters	A/C Equipment
#1 – 24-Hr Diner	4 Restroom Sinks; 4 Hand Sinks; 2 Utility Sinks; 1 Pre-rinse Valve; 1 Mop Sink; One Conveyer-Type Dishmachine (Internal Booster); 2 Ice Cream Dipper Wells; Recirculation Pump (24/7)	Two identical Storage-Type Water Heaters, 100 Gal. (378 L), 270 kBtu/h (79.1 kW) input, 82% TE	5 Heat Pumps, all 5-ton capacity; 1 RTU, 12.5 ton capacity
#2 - FSR	5 Restroom Sinks; 5 Hand Sinks; 6 Utility Sinks; 1 Pre-rinse Valve; 1 Mop Sink; 1 Three Compartment Sink; 2 Underbar Sinks; One Conveyer-Type Dishmachine (Internal Booster) ; Recirculation Pump (24/7)	Two Storage-Type Water Heaters, both 100 Gal. (378 L), 199 and 250 kBtu/h (52.6 / 73.2 kW), with 97% / 96% TE	5 RTUs, 7.5 (2), 10, and 15 (2) ton capacity

[1] Average of 2017, 2018, 2019 seasons, LAX weather station.

Throughout the seven months monitoring period, the two restaurant sites had substantial hot water consumption consistently well suited for the integrated THP system. Site #1 had an average 2,722 gallons (10,290 L) of SHW consumed per day, with a peak of 3,736 gal. (14,120 L), with a peak demand of 11.9 GPM (45.0 LPM), annualized input of 8,300 therms (875.5 GJ) and 716 kWh, and an average delivered efficiency of 70.0%. Site #2 had an average 4,821 gallons (18,223 L) of SHW consumed per day, with a peak of 6,995 gal. (26,441 L), with a peak demand of 19.7 GPM (74.5 LPM), annualized input of 13,100 therms (1,381.8 GJ) and 966 kWh, and an average delivered efficiency of 79.1%. In the figure below, the Site #1 and Site #2 hot water demand patterns are compared, hourly hot water consumption for every day over the seven month period. What is clear is the 24-hour diner (Site #1) truly has around the clock demand, with steady hot water consumption throughout the day with a small lull in consumption around midnight. By contrast, the FSR (Site #2) consumes about twice as much in aggregate versus Site #1 but with a significantly different distribution. The Site #2 has a well-established consumption pattern, with a steady ramp up from 6a-8a up through the end of the dinner rush about 9p-10p, which is followed by a spike in consumption in off-hours cleaning and preparation to just after midnight. Concerning rooftop HVAC measurements, the weather normalized power demand is shown in Figure 4 which, when extrapolated to the measured weather in 2019 yields a 79 MWh demand for Site #1 and a 71 MWh demand for Site #2. While Site #1 is a larger restaurant, it has more efficient equipment and is closer to the coast while Site #1 is further inland.

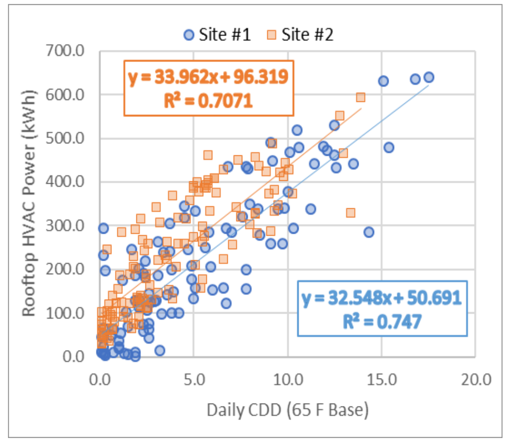

Figure 4 Rooftop HVAC Power Draw For A/C – Baseline Period

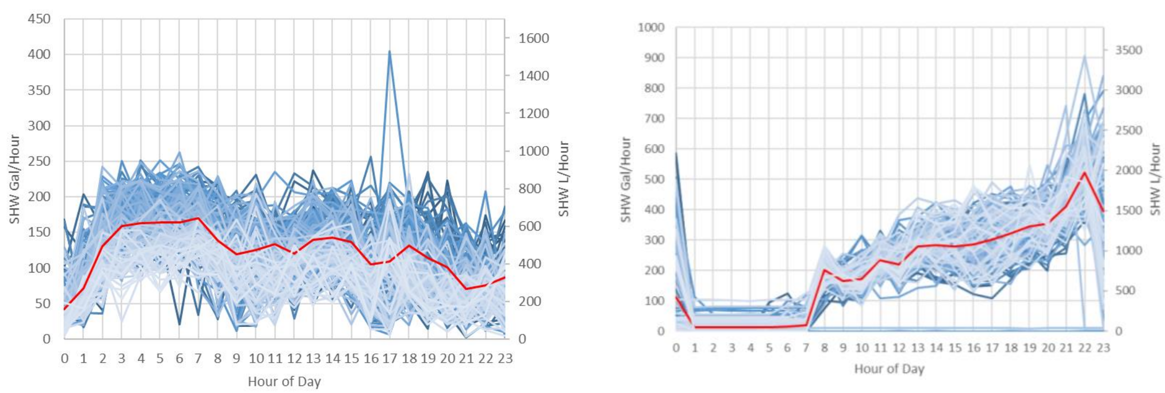

Figure 5 Baseline Hot Water Demand Patterns for Site #1 (Left) and Site #2 (Right)

Integrated THP System Measurements

THP systems were installed and commissioned in early 2019, operated for 12 months. Collectively, the THP system operation was marked by near constant operation, commonly for several days at a time for Site #1 (24-hr diner). Similarly, calls for cooling were observed throughout the monitoring period, in the heating and cooling season. Site #1 had 4,790 operating hours and 1,150 cycles while Site #2 had 4,220 operating hours and 597 cycles. Concerning operational COPs (gas basis, HHV), Site #1 showed a range of 1.10-1.30 (heating) and 1.30-1.70 (heating/cooling) and Site #2 showed a range of 1.25-1.45 (heating) and 1.40-1.90 (heating/cooling), with return water temperature at the THP predominantly between 100°F-125°F (38°C-49°C). Ambient temperatures at both sites varied, ranging from 35°F-111°F.

Concerning the SHW load fraction, defined as the portion of hot water output each day generated by the THP versus the overall Integrated THP System (THP + gas water heaters), Figure 6 highlights the split between sites, with the THP at Site #1 covering the majority of the SHW load most days, due to the lower overall demand and its even spread throughout the day. Contrasted with Site #2, with a larger overall demand (nearly twice) and 'peakier' draw pattern, the THP at Site #2 is simultaneously much more commonly cycling on/off and operating at full capacity when on. The THP at Site #1 is nearly always on, modulating the THP to load follow, which satisfies demand *but does not often reach a steady state efficiency*, which is reflected in the THP efficiency noted earlier. When comparing the baseline versus integrated THP system periods using the linearized "Input/Output" method, a reliable method of comparing daily delivered efficiency of heating equipment [Bohac, 2010], the delivered efficiency curves for the THP itself and the overall Integrated System (THP + gas water heaters) are shown in Figure 7 for heating and heating/cooling output modes. When sorted by daily SHW load, Site #2 with an average of 4,400 gallons/day (16,630 L) could expect a heating/cooling delivered efficiency of approximately 1.65 for the THP (assuming it is perfectly sized) or 1.10 for the Integrated System for THP as sized in this study, over the baseline performance of 0.75. On the rooftop HVAC monitoring during this period, the normalized comparison to prior curves (Figure 4) showed a reduction of 14% at both sites, saving a projected 10,820 kWh/year (Site #1) or 9,660 kWh/year (Site #2).

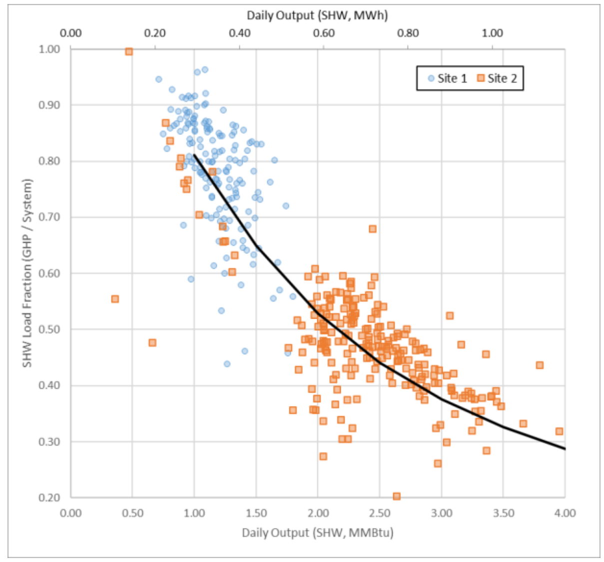

Figure 6 SHW Load Fraction for both Sites

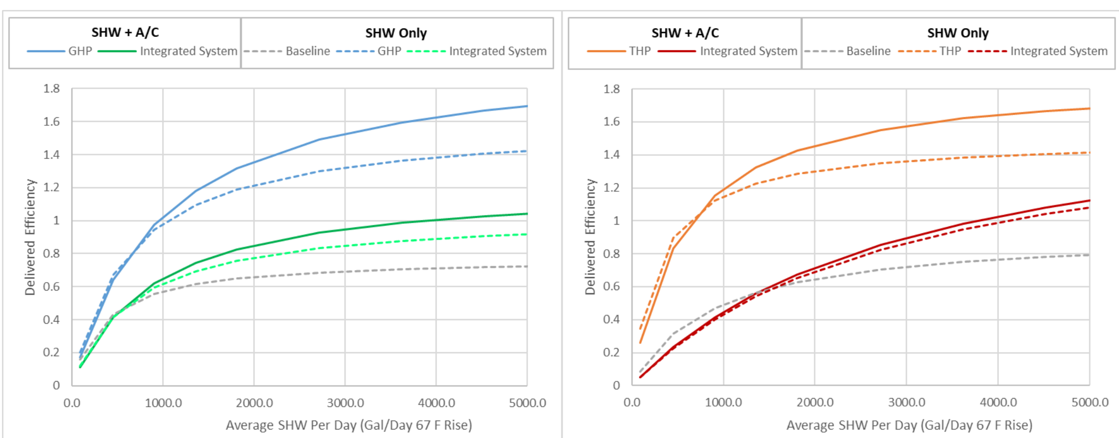

Figure 7 Projections of Delivered Efficiency (Gas Basis) for Site #1 (Left) and Site #2 (Right) – Field Data

When extrapolating results and including the net power savings, the difference of avoided A/C power consumption versus incremental power consumption from the THP, pumps, and fans, Site #1 and Site #2 both show attractive economics. Using typical California utility rates, $0.91/therm and $0.15/kWh (ignoring time-of-use or demand charges), the sites would see the following savings:

- **Energy Consumption:** Natural gas savings at both sites were 16%-26% for the Integrated System and 52%-53% for the THP itself. The daily net electricity increase for both sites (as-is) is 8 kWh (Site #1) and 4.9 kWh (Site #2).
- **Operating Cost:** Site #1 and Site #2 would save $967 and $2,775/year with reduced gas consumption. Net

savings of $536 and $2,514/year for gas & electricity combined, for the two sites respectively.

- **Simple Payback:** Using mature quantity production estimates of THP and standard water heating equipment costs, simple paybacks for the Integrated THP System range from 1.1 to 6.4 years on a gas basis.
- **Climate Impact:** Net greenhouse gas reductions are 42,560 lbs/year (44.5%) for Site #1 and 75,480 lbs/year (43.8%) for Site #2, using 144.2 lb CO2e/MMBtu gas and 613.8 lb CO2e/MWh baseload power in CA (2018).

CONCLUSION

In this paper, the authors have outlined an innovative integrated approach to reducing energy consumption in commercial water heating, specifically for restaurants. With the opportunity for advancing commercial water heating technology in this sector defined, the authors outlined the potential for up to 40% reduction in natural gas consumed for hot water intensive business, while simultaneously reducing the building A/C load by up to 20%. The authors described a novel Integrated THP System, designed and installed at two demonstration restaurant sites in Los Angeles. Following a review of baseline monitoring results, the THP system results were reviewed, showing strong potential for energy and cost savings, for but nuances between the sites highlighted the impact of component sizing and controls based on the magnitude and distribution of hot water loads. The authors recommend continued investigation and investment into this commercial water heating approach, due to its potential for cost-competitive GHG emission reductions suitable for new construction or building retrofit.

ACKNOWLEDGMENTS

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COMMERCIAL GAS HEAT PUMPS FOR HOT WATER AND A/C

DEMONSTRATION IN RESTAURANT APPLICATIONS

Technical Summary of CEC PIR-16-001

PROJECT OVERVIEW

- **Technology Demonstration:** Monitor performance of prototype fuel-fired heat pump water heaters (HPWHs) at two restaurants in the Los Angeles basin.
- **Market Transformation:** Develop stakeholder-facing literature, code analysis, and simulation tools. Quantify product barriers through market research and outreach.
- **Project Team:** GTI (Lead), SMTI, A.O. Smith, ADM Associates, Frontier Energy, ARW Inc., JC Mechanical Inc., BR Laboratories.

KEY FINDINGS

- **Energy Efficiency:** HPWHs achieved 52%-53% therm savings and with "free cooling" an added 14% kWh savings for building A/C measured.
- **Operating Cost:** Projected savings of >$2,500/year, < 2.0 year simple payback estimated. On sizing GHP, 30%-60% of peak demand is optimal range.
- **Emissions:** Up to 48% GHG reduction projected, with pre-commercial HPWHs certified as Ultra Low NO_x and using natural refrigerant with no ozone or climate impact (ODP = GWP = 0).
- **Reliability:** Over 12 mo. period, 9,000+ GHP operating hours for both sites, with HPWHs frequently operating 24/7, meeting 3,000+ gal/day demand.
- **Barriers:** Complex retrofits at both sites requires innovation in installation approaches, but no major barriers per code analysis or market research.

THE TECHNOLOGY

In this project, the team demonstrated the potential of an innovative technology at two restaurant sites in the Los Angeles basin, a low-cost gas-fired heat pump (GHP) for integrated commercial water heating and air-conditioning (A/C). The GHP is a direct-fired, single-effect, absorption heat pump using an ammonia/water working pair, with an operating heating Coefficient of Performance (COP) of 1.40-1.90 (fuel HHV basis). In prior laboratory testing and field applications for space heating, it has an estimated Annual Fuel Utilization Efficiency of >140% and is anticipated to have an equipment cost approximately half that of comparable GHP equipment[1]. To offset A/C energy consumption, this GHP was modified to deliver hot water and supplemental A/C, sized to provide 80 kBtu/h of hot water and 2.5 tons of cooling simultaneously, with 4:1 modulation. This GHP is designed by a startup company specializing in gas-fired heat pumps, Stone Mountain Technologies, Inc. (SMTI), with technical support from GTI and A.O. Smith.

At each site, the GHP was installed as an *Integrated GHP System*, with the GHP component providing hot water in series with indoor conventional storage-type water heaters, while supplementing building A/C in parallel to existing rooftop HVAC equipment. While standard installations place only the GHP outdoors (rooftop or concrete pad), for this project the GHP was coupled with its buffer tank and the associated controls and instrumentation on a removable skid with added anti-vandalism caging. This "skidding" approach was convenient due to the temporary nature of this project but is not common practice.

Figure 1: Commercial Gas Heat Pump Skid Package Installed at Host Site

MARKET OPPORTUNITY

There's a lot of recent innovation in the residential water heating industry, with tankless, heat pump, and grid-connected technologies flourishing. Receiving less attention, innovations in commercial-sized equipment are emerging too, where commercial buildings a) consume 10-100x the hot water as a typical home and b) are commonly served by multiple heaters as a system. For gas-fired commercial water heaters, which represent the majority of the non-"residential-duty" commercial water heating market, approximately 77% of shipments are storage type, 14% are boilers coupled with indirect storage tanks (IST), and 9% are tankless type[2].

As a population, commercial water heaters are efficient. From 2009-19, high-efficiency commercial gas-fired water heaters (thermal efficiency ≥ 90%) have increased from 29% of shipments to 47%, a shift not seen for residential products[3]. As a result, stakeholders are looking to heat pumps for the next step beyond 'condensing efficiency'. For electric options in 2019, a manufacturer introduced a commercial integrated electric HPWH, with a rated COP of 4.2 (site basis) and a heat pump output capacity of 40 kBtu/h. For fuel-fired options, serving larger loads, several active demonstrations of heat pump systems have been performed, in schools, senior care facilities, hospitality, and other commercial buildings, in Oregon, Michigan, British Columbia, and Ontario[4]. These studies commonly involve one or multiple GHPs with an output capacity of 124 kBtu/h each and show therm savings vs. baseline equipment ranging from 18% to 50%, when serving commercial water heating loads[5,6].

This project focused on **the restaurant industry** which as a market sector consumes the most natural gas per square foot, with water heating representing the second highest thermal load after cooking. In California over 340 million therms are consumed for hot water in ~90,000 restaurants, representing more natural gas use than a million homes[7]. With an estimated efficiency of 140%, deployment of gas-fired HPWHs could yield therm savings of >40%[1] in restaurants, while displacing up to 20% of electricity demand for A/C, further enhancing energy and operating cost reductions. This potential was assessed in a year-long demonstration of pre-commercial GHP systems at two restaurants in the Los Angeles basin, summarizing system design and optimization, energy savings over a broad range of operating conditions, retrofit installation barriers, and interactive effects with building systems.

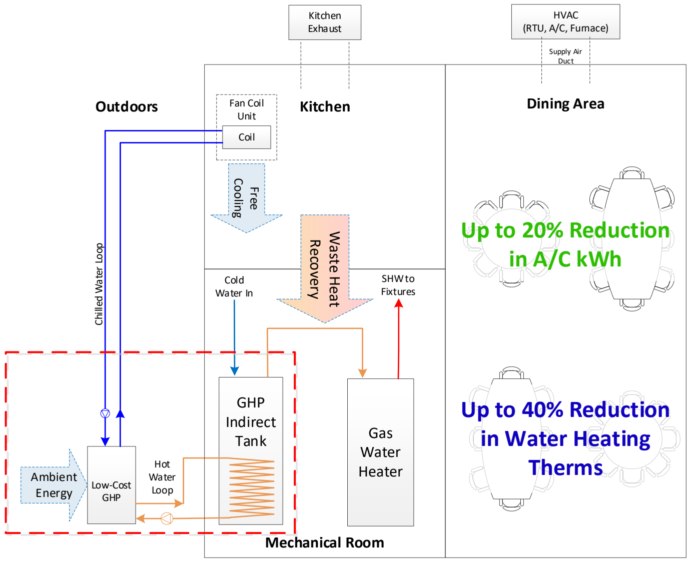

Figure 2: Simplified Diagram of Integrated GHP System

DEMONSTRATION RESULTS

With support from utility and manufacturing partners two restaurant sites were recruited, a national casual dining chain specializing in Italian-American cuisine and a regional Southern California 24/7 diner chain. After an extended monitoring period of existing water heating and HVAC equipment and certifying the GHP as *Ultra Low NOx* per the Air Quality Management District (AQMD) in late 2018, the team finalized the installation and commissioning plans. From late January to late February 2019, the project team completed the *Integrated GHP System* and data collection system commissioning, initiating the 12-month monitoring period.

Per the monitoring plan, 9,000+ hours of GHP operation with high hot water demand was measured at both sites, often exceeding 3,000 gallons/day. Measurements included the thermal output of the GHP unit, the indoor water heaters, rooftop HVAC, and other system components. Upon de-commissioning of the *Integrated GHP System* in March 2020 for both sites, high-efficiency "condensing" storage-type water heaters were installed for a "second baseline period". However, the impact of COVID-19 on normal restaurant operations limited the utility of this added dataset.

GHP system operation was marked by near constant operation, commonly for several days at a time for Site #1 (24-hr diner). Similarly, calls for cooling were observed throughout the monitoring period, both in winter and summer.

Table 1: GHP Operation Summary at Both Restaurant Sites

Location	GHP Operation	COP_{SHW} [$COP_{SHW+A/C}$]	Avg. SHW Load Fraction
Site #1: 24-Hr Diner	4,790 hrs. 1,150 cycles	1.10-1.30 [1.30-1.70]	74%
Site #2: Casual Dining	4,220 hrs. 600 cycles	1.25-1.45 [1.40-1.90]	43%

As shown in Table 1, the significant *Integrated GHP System* runtime provided an ample dataset, with operational COPs shown[A] for service hot water-only (SHW) and service hot water plus space cooling (SHW+A/C) modes, over the range of return water (100-125°F) and ambient temperatures measured (35-111°F). The *SHW load fraction* as shown is defined as the fraction of SHW generated by the GHP vs. the overall *Integrated GHP System*. This varies across sites, due to a) differences in daily demand – 2,225 gal/day (Site #1) vs. 4,400 gal/day (Site #2) and b) the demand profile, with Site #1 spreading SHW demand over a 24-hour period while Site #2 has a ramp to an evening peak followed by little demand overnight. As the GHP system at Site #1 is covering the majority of the SHW load most days (74% load fraction), the GHP is nearly always on and modulating in a "load following" mode. This satisfies demand, but the GHP does not often reach a steady state efficiency, reflected in slightly reduced COPs. By contrast Site #2 is more commonly cycling on/off and operating more efficiently at full capacity when on.

To compare measured baseline data to the *Integrated GHP System,* the linearized "Input/Output" method is used[9] and delivered efficiency curves are generated for the GHP itself and the overall *Integrated GHP System*, for SHW and SHW+A/C modes (see Figure 3). On the rooftop HVAC monitoring during this period, the weather-normalized analysis showed a reduction of 14% at both sites, saving a projected 10-11 MWh/year.

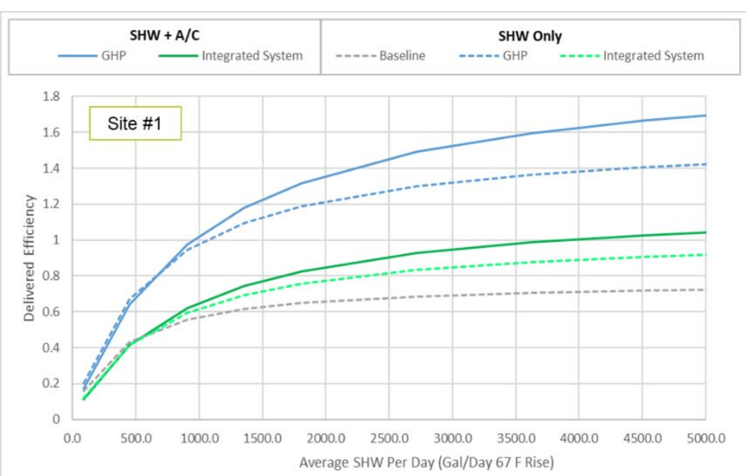

Figure 3: Delivered Efficiency Curves from Site #1 Dataset

INTEGRATED SYSTEM DESIGN

The ***Integrated GHP System*** has three primary components (see Figure 2): the outdoor **GHP** heats a hot water loop and cools a chilled water loop, the hot water loop delivers service hot water (SHW) from an **indirect storage tank (IST)**, and the chilled water loop delivers A/C from a **fan coil unit (FCU)**. In practice, the IST is used as a) a buffer between the SHW demand and GHP operation to prevent short-cycling and b) meeting the required "double-wall" HX requirement for potable water. The indoor FCU can be in-duct or separate, allowing installation flexibility. By using with pumped water loops for heating/cooling, the refrigerant is wholly contained within the GHP device outdoors.

On **system controls**, the *Integrated GHP System* was sized and controlled to be *hot water-led*, with the GHP only cycling on to meet a SHW demand. If when delivering SHW there is also a demand for A/C at the indoor cooling coil, the GHP will direct chilled water to this coil. Absent A/C demand, the GHP will use the outdoor-coupled HX within its cabinet, drawing ambient energy outdoors instead of to the indoor FCU.

On **GHP sizing**, the GHP is not sized to meet 100% of the peak demand, which a) can vary by factors of two or greater from day-to-day and b) large portions of a restaurant's 2,000+ gal/day can occur within a few hours (e.g., kitchen clean-up)[7]. So it is most cost-effective for the GHP to act as "baseload" SHW generation while conventional water heater(s) carry "peak" demand. Balance is key, as GHP under-sizing limits overall savings while GHP over-sizing causes inefficient part-load operation.

On **supplemental cooling,** the team assumed that the 0.5-2.2 tons of cooling are useful in all instances (range depends on modulation) due to internal kitchen heat gain. This is based on prior studies of thermal comfort in commercial kitchens, in which cooking staff were equally uncomfortable during winter and summer months[8]. Also, supplemental A/C is an optional system feature, hot water-only versions use air-source versions of the GHP.

When extrapolating results and including the net power savings (the difference of avoided A/C power consumption versus incremental power consumption from the GHP, pumps, and fans), both sites show attractive economics. Using typical California utility rates, $0.91/therm and $0.15/kWh (ignoring time-of-use or demand charges), the team estimated the following:

- **Energy Consumption**: Therm savings at both sites were 16%-26% for the *Integrated GHP System* and 52%-53% for the heat pump itself. The daily net electricity increase for both sites (as-is) is 7-8 kWh.
- **Operating Cost**: Therm savings translate to $970-$2,780/year, or $620-$2,530 when including elec.
- **Simple Payback**: Using mature quantity production estimates of GHP and other standard equipment costs, simple paybacks for the *Integrated GHP System* range from 1.1 to 6.4 years (fuel savings basis).
- **Climate Impact**: Net greenhouse gas reductions are 46-48% using 2018 CA-statewide emission factors.

BARRIERS & OPPORTUNITIES

Through additional project tasks and stakeholder outreach, the team also outlined that:

- Through **market research**, contractors and owner/ operators in food-service, laundries, and multifamily (incl. senior living) cited higher energy efficiency and lower lifetime operating costs as compelling features.
- In documenting **installation and commissioning challenges**, the team outlined how best to address *Integrated GHP System* site-specific complexities in retrofit and new construction scenarios. Concerns with codes & standards were also reviewed in detail.
- Through **system modeling**, the team highlighted the challenges with system controls while identifying a 30%-60% "sweet spot" for GHP sizing relative to the estimated peak SHW load. The demo surprisingly covered a wide operational envelope, with the GHP covering 30%-95% of the daily load on average.

FOR MORE DETAIL

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Full project report and other deliverables to the California Energy Commission are expected to be posted online in early 2021 here: https://www.energy.ca.gov/energy-rd-reports-n-publications

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January 6, 2021

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[A] On a high heating value (HHV) basis.

gti

Commercial Integrated Gas Heat Pump Water Heating System

Market Research Report; October 2020
Prepared by Applied Research-West, Inc.

ARW

1

Background

- **Commercial market is ripe for a market transformation**
  - Water heaters are often not maintained and require emergency replacements
  - Life expectancy is 5-10 years
  - 37% are 10+ years old
  - Warranties typically last for only the first 3 years
- **The new thermally driven heat pump (TDHP), also referred to as the gas-fired heat pump water heater (GHPWH) here, was built with efficiency (cost and energy savings) in mind, and although there may be a higher cost of installation it will be mitigated by benefits derived to the commercial property owner** *(i.e. the end-users)*

2

Overall Key Objectives

IDENTIFY	General issues facing businesses that need replacement Water Heaters for commercial properties utilizing natural/propane gas
EXPLORE	Commercial businesses concerns and attitudes regarding their water heaters and the prospects for selling GHPWHs
ENGAGE	Business owners in detailed analysis of pricing for storage tank (standard and condensing) and GHPWHs
EXAMINE	The range of consumer transaction dynamics and attitudes regarding water heaters and their purchase
IDENTIFY	Difficulties that may surface in describing GHPWH technology to end-users
DISCOVER	Unexpected attitudes, strategies, and positioning concepts that may assist with market uptake (Evaluate Purchase vs. Rental)
PREPARE	Qualitative and Quantitative Research with the Commercial segment

3

Research Goals

- **Understand limitations** that new product might create for end-users in the commercial buildings space
- Discover **motivations for end-users to replace their current water heaters** *(e.g., efficiency, energy savings, etc.)*
- Ascertain **opportunities for the new product introduction**
- **Test and develop stimuli / exercises for the qualititative and quantitative research,** for each segment *(i.e. restaurants, laundromats, and apartments/senior living facilities)*

4

EXECUTIVE SUMMARY

ARW

5

S.W.O.T. ANALYSIS OF GHPWH

STRENGTHS
- Long term cost savings/Payback
- Energy savings/Fuel efficient
- Environmentally friendly
- Marketing message potential (makes business look good)
- Longer lasting product (durability/longevity)
- Supplemental space cooling option (and energy savings)
- Ability to retrofit (and potentially extend life of existing boiler)
- New "cutting-edge" technology
- Longer warranty could help market confidence
- Outside installation (space/ flexibility)
- Sleek design

WEAKNESSES
- Upper limit of product range (140K BTU/hr.) limits technology to medium-sized buildings
- Larger upfront cost
- Depends on sufficient interior and exterior space
- Project capacity requirements above 140 kBTU may require multiple units
- Difficult to retrofit
- No track record yet
- Outside installation (space concerns in dense areas and climate concerns)
- Possible worries about ammonia leak; could be mitigated through information and education

OPPORTUNITIES
- Leasing program (respondents are very enthusiastic about this option)
- Potential for rebate program
- The focal point should be on small and mid-sized building, where most commercial units are found
- Opportunity to be first to market
- Great for brand new developments & remodels
- Economical savings will deliver more LEED points

THREATS
- Status-quo attitude (contractors and/or building managers)
- Unwillingness to spend by end-users who don't expect to own their property for long (e.g. investors, start-ups, flippers, etc.)
- Some may have strong aversion to ammonia
- Some may wait until new technology matures
- Lack of interest in new products (by end-user)
- Fear of liability
- Big corporations with set project specs
- Fear new technology will be replaced with something better in a short time

6

DETAILED END-USER IN-DEPTH INTERVIEW (IDI) FINDINGS

7

Methodology – Contractor IDI's

IDI Details:

- 90 min., online-video In-Depth Interviews conducted between October and December 2019
- Focusing on 3 types of contractors: Mechanical Engineers, Plumbing Contractors, HVAC Contractors
- Prior to the interview, participants watched a brief video (slide) presentation describing the new technology

Screening Criteria:

- Decision Maker (owner or manager, no front-line technicians or sales people)
- Business is at least ½ commercial buildings, with a commercial focus on restaurants, nursing homes, laundromats, hotels and/or resorts
- Installed at least 15 commercial water heaters per year

Interviews covered contractors'…

- Business model, business outlook, current sales of tank and tankless water heaters
- Their reactions to the new technology
- Their opinions regarding the feasibility of selling it

Research was conducted Q3 of 2020 by ARW 8

8

Who We Talked to

8 *Mechanical Engineers*

5 *Plumbing Contractors*

5 *HVAC Contractors*

Majority see their businesses growing in the next 5 years…

& Most attribute their success to their exceptional service

Their clientele is mostly made up of repeat business

10-20% *Installs are tankless*

*Most like to learn about the latest technology however, many have concerns about being the *first* to market*

Research was conducted Q3 of 2020 by ARW 9

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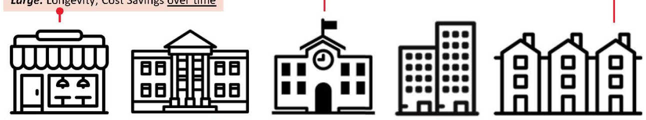
End-User Needs

Restaurants:
Dependability & Efficiency of hot water is mission critical
Small: Cost Savings at time of install
Large: Longevity; Cost Savings over time

Schools/Institutions:
Energy Savings is key; Cost Savings over time is second

Multifamily:
Speed of install is key; Generally like-for-like installs in replacement scenarios



Government Buildings:
Energy Savings & American-Made is key

Hospitality/Hotels:
Cost Savings at time of install is key

Research was conducted Q3 of 2020 by ARW 10

10

Project Decisions Often Left up to Client

- In a lot of cases, many **decisions are already made before the respondent (i.e. contractor) is involved** in a project
  - Particularly when the client is a larger corporation, the project is often fully spec'd out as they will have a set of plans they use at all their locations—down to the water heater brand, model, placement, etc.
  - However, even with smaller businesses, many times the project is an emergency situation or a simple leak, so the client just requests a like-for-like install
- Even when the project specifics are not already decided, respondents are **often working within a limited budget** (for install & maintenance), as well as **limited mechanical room space**
  - For contractors who operate in bigger cities (e.g. Pittsburg, New York, etc.), they are sometimes also operating under strict city regulations
- Plumbing & HVAC Contractors, particularly, tend to be cautious about making recommendations unless it's absolutely necessary due to **concerns over liability**; they are also more likely to just go with the status quo.
  - vs. Mechanical Engineers or Architects who generally will have more say in what goes in a job

"If the customer comes directly to me and it's up to me to offer them something, I in turn will go to either the supply house or the architect engineer. ***I'm not going to want to put something in that isn't going to work"***
Erin, full-service plumbing, Syracuse, New York

"They usually do one set of plans and then those plans are made to fit every location across America."
Chris, plumbing -HVAC contractor, Cleveland, Ohio

Research was conducted Q3 of 2020 by ARW 11

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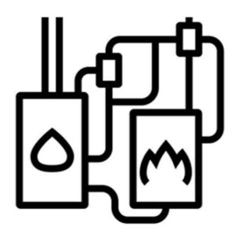


"If you can put me in front of a guy who writes the checks, I can usually sell them on some great stuff that's going to make him very happy in the long run."
Chris, plumbing & HVAC contractor, Cleveland, Ohio

Upgrades & Payback Analysis

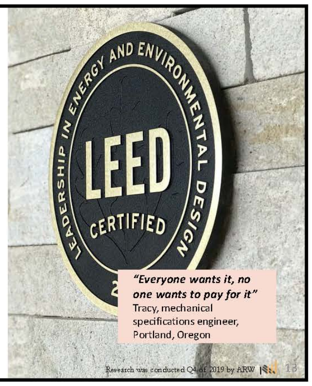
- Many times, respondents are talking with someone who doesn't necessarily have recommendation authority/influence and therefore, **have trouble upselling to a different technology**
  - In these cases, the person they do business with is given a budget by the owner and has no decision-making capability; this limits respondent's ability to make suggestions outside of what is already spec'd
- Therefore, **clients don't often ask for a payback analysis** for equipment / a product
- When respondents get the chance to suggest something new, and a payback analysis is requested, respondents will generally use simple percentages to communicate the payback *(e.g. you can save X%, or this product is X% more efficient)*
  - Many get this opportunity when they have direct contact with the owner, or when they're working on a remodel / new construction project. Thus collateral and training materials should be made available that demonstrate increased economics and payback

Research was conducted Q3 of 2020 by ARW 12

12

LEED & Energy Savings

- More and more **end-users are looking for energy savings**, which is driving a lot of decisions
- However, contractors and engineers are being **asked about acquiring an actual LEED certification** **<u>less and less</u> due to the cost**
  - In general, only institutions and other high profile buildings are most likely to still have interest in acquiring the LEED certification and plaque
  - Many end-users don't expect to own their property for long (e.g. investors, start-ups, flippers, etc.) and therefore don't see the value in the certification
- Though, LEED is still used as, and considered, the industry standard for a sustainable building; and therefore, respondents generally find that there is **value in the products they install to be worth extra LEED points regardless**



"Everyone wants it, no one wants to pay for it"
Tracy, mechanical specifications engineer, Portland, Oregon

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Generally Favorable GHPWH First Impressions, with some Hesitation

- After being introduced to the system, respondents are **initially impressed overall**, and many can see it applicable for most clients; features they are most impressed with initially:
  - Payback / Savings overtime
  - Flexibility of placement & fuel type (e.g. propane, etc.)
  - Energy savings
  - Space cooling
  - Unit completely sealed
  - Environmentally friendly
- Most respondents also showed **enthusiasm about the technology,** and had a lot of questions about how the GHPWH unit and technology worked in a real-world commercial application
- Though, some respondents who were initially hesitant brought up concerns with:
  - Unit complexity / Project Cost
  - Ammonia with regard to unit safety
  - Unit's heating capacity might not be sufficient to some needs
  - Confusion about how cooling function actually works or delivers savings
  - Roof or outdoor location for condenser may be unavailable in some urban corridors

GHPWH

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Though Excited, Contractors have a Range of Questions that must be Addressed…

- Contractors **concerned that product may not fit into every retrofitting situation,** but think the product is well suited for new construction, or expansions
- A few worry about a product that uses ammonia
  - In most cases, technical education was helpful in addressing concerns
  - Contractors will need clear information on how/why ammonia leaks are unlikely or may have only insignificant effects.
- Contractors like the flexibility of installing outside, or on the roof, but may **pose a space issue** in some situations
  - Particularly, higher rise buildings don't have much outside real-estate, and the roof space is limited or far from the mechanical room
  - Also, contractors are seeing the mechanical room itself getting squeezed as owners opt for more space for business
- Respondents **fear lack of support** at possible points of failure, that they will have **difficulty accessing the parts they need for a repair**, or need **guidance through maintenance**
- Due to higher upfront cost, they will **need to convince certain clients of the unit's value**
  - This is particularly difficult because a lot of businesses (e.g. Mom & Pop restaurants) don't see themselves necessarily lasting
- Some with larger clients feel the **MMBtu/h max output is too low** for a commercial application

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"I'd be a guinea pig…the technology's been around lots of years and now they've kind of mastered it."
Carl, full-service plumbing -HVAC contractor, Orange, California

"I don't want to be the first, truthfully, just solely because if it fails, then the whole thing comes back to us."
Ali, mechanical specifications engineer, San Antonio, Texas

Comfort Levels with Adoption Vary

- If questions and concerns are addressed, many are **interested in keeping an eye on, and learning more about the product**—some even offer to be a guinea pig
  - Particularly more aggressive or successful contractors feel excited about the prospect of being first / on the cutting edge of new technology
- **Though, <u>it comes back to liability</u>:** Some respondents mentioned that they would *at least* need to see the product installed and 'get to know it' for their comfort, while others would only feel confident if the product had a good track record
  - Because if the product doesn't work, they are ultimately liable
  - However, most would be more willing to install if the owner chose the product, if the supply chain backed up the product, or (for Plumbing/HVAC Contractors,) if it were recommended by an engineer or architect

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"We really feel that the education is what constantly gives us the edge here and we do it constantly, *I don't care if you're a 20-year guy or 30-[year] guy. Doesn't matter, you're in school here once a week"*
Rick, plumbing & mechanical contractor, Chicago, Illinois

Opportunities to Ease Adoption Concerns

- Due to enthusiasm about the new product and technology, contractors are **very receptive to the idea of viewing the installed unit in a seminar setting**
  - Most seem interested in learning about new technology and having new opportunities in general, even when a bit hesitant when talking about actually adopting the new technology right away
  - Many feel education is key to their success, and an important factor in their confidence installing or suggesting a product to their client
- Even more, **contractors are receptive to the idea of <u>viewing the unit installed</u> in a real world commercial application or field test**
  - With a field test, they want the opportunity to: compare the unit's energy consumption to other products, check if it's producing enough hot water to meet the demand of the building, and even talk with the owners and maintenance staff about the product
  - One respondent mentioned that seeing the unit in person was so important, that they would even send some of their employees to another state if necessary to view it in a field test setting

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GHPWH Selling Points

- As long as the unit can deliver on its promises, **respondents are excited about the prospect of the new technology <u>making them look good</u>** to their clients
- In general, respondents are most motivated to sell the GHPWH first based on **payback savings, energy savings, and efficiency**; followed by longevity
  - Though, longevity in most cases is <u>expected</u>, and is considered more of a 'cost of entry' feature
- Respondents also found the **potential for cooling & the possibility for longer-term warranty** as other unique & motivating selling points of the GHPWH
- However, many feel that the **client <u>has</u> to be the type particularly receptive to energy savings and efficiency** to have enough interest to begin with

*"I would be very interested in recommending because **as a consultant you always want to give your client…something new that can save them energy and can still do the job** energy efficiently wise. Even if they say "no" they still look at you as hey this guy's an expert"*
John, mechanical specifications engineer, Peoria, Illinois

"I've only been in maybe one or two restaurants that actually had enough cooling in the back kitchen…So that would be a great selling point"
Ben, full-service plumbing - HVAC contractor, Kingwood, Texas

"If it's efficient and it works and it's going to make us look good. *That's all it would take for me."*
Lance, full-service plumbing contractor, Boise, Idaho

"Well, it would just have to be based on the type of building and the owner. ***The owner is going to have to be somebody who really is looking, for new technology ways to save energy and is environmentally conscience.*** *If they're not …They're not going to want the system because it's going to cost more money than a traditional system"*
Tracy, mechanical specifications engineer, Portland, Oregon

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OEM Partners Favored for Initial Introduction

Key positives: Major brand; Backed up with warranty; Manufactures or Sources parts locally

Top of mind… AO Smith, Bradford White Water Heaters

Secondary… Lochinvar, Rheem

Other… PVI (A Watts Brand), Navien, Noritz, State Water Heaters

Key negatives: Sold by big box store *(e.g. Home Depot, Lowes, etc.)*; Brand with poor/no industry reputation

Top of mind… Rheem

Other… State Water Heaters

[These brands are] "just stuff that like Home Depot sells*…some of those lower ends we don't normally specify to begin with."*
Ali, mechanical specifications engineer, San Antonio, Texas

Research was conducted Q3 of 2020 by ARW 19

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Methodology – End-User Focus Groups

Focus Group Details:
- Three 90 min., online-video Focus Groups conducted June 2020
- Focusing on three distinct businesses (Restaurants, Laundromats, Apartment/Senior Living)
- During the focus group, participants are taken through a slide presentation describing the new technology

Screening Criteria:
- End-User and Decision Maker (owner, general manager, etc.) at restaurants, apartment/senior living, and laundromats
- Restaurants had to serve at least 50 meals daily before pandemic and use dishes and silverware
- Apartments/Senior living had to have at least 50% of units operating with central heating and water
- For laundromats, at least 40 washers need to be operated

Interviews covered contractors'…
- Business model, business outlook, current technology and water heater experiences
- Their reactions to the new technology
- Their opinions regarding the feasibility of using the new technology in their business

Research was conducted Q3 of 2020 by ARW

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Who We Talked to

4 *Restaurant End-Users*

3 *Apartment/Senior Living End-Users*

4 *Laundromat End-Users*

Most are the sole decision maker for their business, a few co-share the responsibility of making major decisions

Many have been negatively impacted by the current pandemic, but are hopeful for growth in the near future

Majority currently use both electricity and natural gas for hot water heating

*Most stay informed about innovations in their space, but many can be slower to adopt – particularly for investments they don't *need* to make*

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Staying Abreast with Technology is Key

- Most respondents will make sure they are **staying abreast with the latest technology** through various sources including periodicals, industry trade shows, or a simple Google search. And most importantly competitive operators
  - Restaurant owners and GM's in particular have a large community to draw from, where they will also learn about innovation and exchange ideas through word of mouth
- Even if the respondent will not necessarily adopt the latest innovations right away, majority agree it's important to stay continually informed as technology and trends change

Periodicals mentioned ranged from general business magazines to industry specific, including…

Canadian Property Management — *Restaurant News* — *Business View* — *Enterprise* — *Planet Laundry*

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With Tight Margins, Adoption can be Slow – Laundromats being the most Flexible

- When exploring innovation, respondents are most frequently looking for technology with **better efficiency and a good ROI** *(i.e. by saving time & money)*
- However, many are operating businesses where they are running off of tight margins, and therefore, **need to be certain of a new technology or innovation before making the investment** by seeing it used in the market
  - Restaurant end-users also find that it is harder to navigate where to put their capital because of the ever-changing trends and landscape of the industry
- That said, **laundromat end-users were the most likely to consider themselves early adopters** and seemed the most open to spending on new technology that will improve their business and maximize their revenue per square foot
  - Particularly, if the innovation will help keep customers inside the laundromat for longer *(i.e. while their clothes are being washed)*, respondents will make more from snacks and other amenities offered

"Even if the right one comes along, you should still wait even longer to make sure that it's something that's going to work in the long run for the type of work you're doing."
Angel, Apartments; Fort Lauderdale, Florida

"Yeah, I mean, I'm looking at some of the equipment that's going to be higher efficiency, *and possibly letting people self steam clean and things like that, you know,* ***as a way to keep them inside the building, as much as possible."***
Eric, Laundromats; Fullerton, California

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> ***"It will always pay me to pay them for their professional advice."***
> Bryan, Apartments; Rochester, New York

> *"I have somebody that deals with the plumbing and is **a specialist and I've trusted ever since my business has been open years ago.** I had to replace my water heater actually when I first acquired my business… **I relied on the expertise of somebody else, you know, serving here as a consultant, and what their recommendation would be based on the size of my business"***
> Patrick, Laundromats; Brooklyn, New York

Respondents Rely on Contractors' Expertise

- Generally, respondents will **do their best to fix things in-house to save** on the cost associated with repairing a product or issue through a contractor
  - Many have a full maintenance staff for problems that may arise on a day-to-day basis, and have the ability to do most repairs in-house
- To further avoid a larger issue and to ensure the longevity of their products, most respondents agree that regular maintenance is key
  - Restaurant end-users are particularly concerned with the cost it takes to repair or replace a product through a contractor, and will invest in maintenance to save
- When there is a larger issue, and the need to hire outside of the business, respondents **usually have a list of pre-selected, trusted contractors** to choose from
- Since contractors are used only for issues that cannot be solved in-house, **respondents rely heavily on the contractors' expertise**, and trust their recommendations
  - Most feel they need the guidance as they do not know too much about the technology themselves

Industry Water Heater Needs are Unique, but All Share the Need for Efficiency

Restaurants

- Price, dependability, efficiency of hot water is most important due to demand for hot water and tight margins

> *"**Nobody wants to touch it until it's broken.** But when you understand that you can take a proactive stance, and you're getting the **benefit of technology and cost efficiency, then to me, it makes perfect sense**"*
> Emad, Restaurants; Secaucus, New Jersey

Apartments/Senior Living

- Energy efficiency, life expectancy, and warranty is the most important – followed by brand/reputation

> *"Of course, we're looking at life expectancy, but also energy efficiency. And **if it's going to pay for itself through energy efficiency, then we'll go ahead and make that investment** on the front end"*
> Randy, Senior Living; Fort Worth, Texas

Laundromats

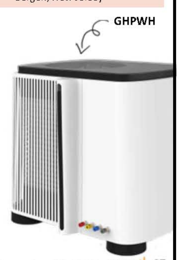
- Reliability, efficiency, and ability to support their business (multiple washers / dryers) is the most important – a bonus is anything that would help keep customers indoors

> *"Well, I know **first thing I'm looking for is reliability** you know, I'm trying to get the most useful life out of it. Because these are an investment. So you're trying to get your maximum return on investment."*
> Eric, Laundromats; Fullerton, California

Favorable GHPWH Impressions, with just a few Hesitant

- After being introduced to the system, respondents are generally **very impressed and interested;** features they are most impressed with:
  - Payback / Savings overtime
  - Energy savings / Fuel efficient
  - Environmentally friendly *(e.g. reduces air pollution, marketing potential, etc.)*
  - Space cooling / Supplemental cooling *(and potential savings from it)*
  - Exceeds life of existing boilers
  - Made by a major manufacturer
  - Ability to retrofit *(and potentially extend life of existing boiler)*
  - Sleek look
- **Many even said that the system was 'perfect'** and found no faults
- Though, a few respondents who were hesitant brought up concerns with:
  - Ammonia regarding unit safety *(limited to two apartment/senior living respondents)*
  - Unit size
  - Upfront cost *(particularly for businesses that may not last the duration of the unit's life)*
  - Max MMBtu/h output *(i.e. some felt the maximum was too low)*

> ***"I think it's beautiful… Everything you have down there. Everything's perfect on it."***
> Eli, Laundromats; North Bergen, New Jersey



Favorable GHPWH Impressions Amplified with Leasing Option

- **Nearly all respondents were open to, and excited about the leasing option** for the GHPWH
  - Many saying they would be willing to trade out their current system for the GHPWH through the leasing option – particularly if their current system was already nearing 10 years in age *(but some even otherwise)*
- Many found that the leasing option came with benefits that solved their Water Heater needs and if they had any initial concerns with the GHPWH regarding:
  - Maintenance being covered
  - No upfront cost
- Additionally, there were bonuses that came with the leasing option that respondents were enthusiastic about, including:
  - Ability to upgrade more frequently as newer technology comes out
  - Maintenance being broken down into a monthly payment, which improves their P&L
  - Potential to use it in conjunction with their current water heater to gain the efficiencies
- One respondent suggested that including a "buy back" or rebate option to the leasing program (like a car lease) would improve the leasing option even more – though they admitted they would swap out their current system even without it

Methodology – Commercial

Restaurants:

- 66 conjoint surveys among restaurant owners/key personnel responsible for equipment purchases
- Focused on full-service restaurants that served at least 100 meals daily (pre-pandemic) on washable dishes
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

Laundromats:

- 66 conjoint surveys among laundromat owners/key personnel responsible for equipment purchases
- Focused on laundromats or large laundries that operated at least 20 washers
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

Apartments/Senior Living

- 68 conjoint surveys among apartment/senior living owners or key personnel responsible for equipment purchases
- Focused on apartment buildings/senior living with at least 100 units with no one building with more than 50 units
- Once qualified, each respondent was exposed to the new technology then asked to choose between new versus existing.

Commercial Owners Business Considerations

- **Commercial owners overall were most willing to pay more for energy efficient** products because they know they save money
  - Those in the restaurant and laundromat businesses were slightly more motivated than those owning apartment/senior living
- When replacing major equipment in their operations, **all were most inclined to purchase the best equipment** available
  - Only restaurants had a modest interest in leasing products

Research was conducted Q3 of 2020 by ARW 31

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Conjoint-Purchase Intent

- Overall almost two-thirds of commercial owners (63%) were more likely to choose the Thermally Driven Gas Heat Pump (TDHP) over the standard or condensing gas water heater. And they were 3.5 times more likely choose ownership over leasing.
- Overall when choosing the TDHP over other water heaters (purchasing or leasing) they were more emphatic in their choice (Very Likely to Purchase) than those that choose either standard or condensing water heaters.
- Clearly the primary reason commercial owners choose the TDHP product over the other two options were Fuel Efficiency and Economic Payback. While among restaurant owners, the air conditioning option was somewhat of a consideration in their decision.
- Price played a very minimal role in the decision process although when priced at the very high-end, whether purchasing or leasing, there is some resistance for the TDHP product.
- When respondents were asked to use their own words behind their choice, fuel efficiency was the top of mind driver for all commercial owners. Interestingly, apartment/senior living owners also frequently mentioned TDHP's cutting-edge technology, while restaurant owners were likely to mention the cooling option.
- Commercial owners also in their own words had some reservations that might need to be addressed before acceptance of the TDHP product—Cost (upfront and maintenance); Actual specs/More information; Installation questions (space, ease. cost); Actual efficiency over time; Operational questions in different environments (cold versus heat); and Reliability.

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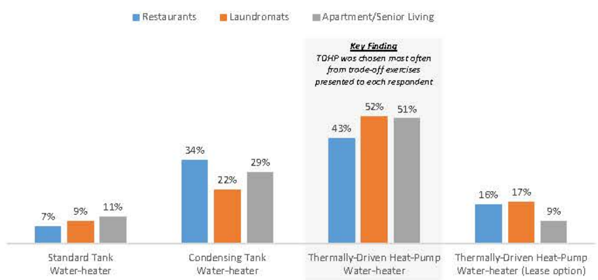
Preferred Choice From Trade-Off Exercise



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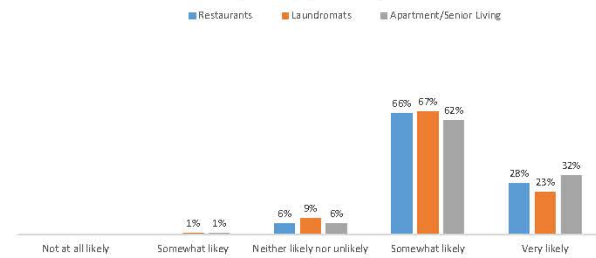
Overall Purchase Likelihood
(Of any product)



Q: You were asked to choose the best option out of just the four available options shown.
If this were a real situation, how likely is it that you would actually purchase your selected option?

Research was conducted Q3 of 2020 by ARW 34

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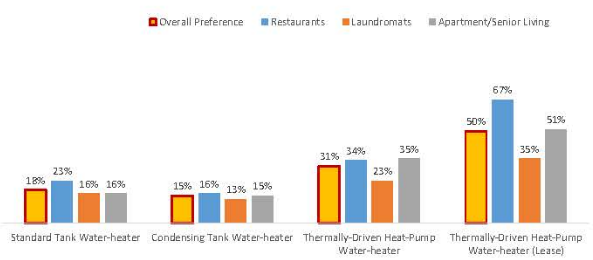
Purchase Likelihood by Product Preference
(Top Box: "Very Likely to Purchase")



Q: You were asked to choose the best option out of just the four available options shown.
If this were a real situation, how likely is it that you would actually purchase your selected option?

Research was conducted Q3 of 2020 by ARW 35

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Agreement with Attitudinal Statements

Strongly Agree	Restaurants	Laundromats	Apartments/ Senior Living
I'm willing to pay more for appliances that are highly energy efficient because I know in the long run it will save me money	68%	66%	43%
I'm very cost conscious and almost always buy the least expensive product available.	45%	52%	41%
I always look for the lowest priced appliance since they are usually all alike except for the bells and whistles	35%	38%	50%
I'm always looking for new products and ideas that help the business and am ready to be the first to try them, even before most of my competitors, if I think it will better my business	52%	38%	29%
I always try to buy "Green Products" when they are available	31%	33%	47%
I believe the environmental concerns are overblown, therefore I don't think we need to be so concerned	48%	27%	34%
I'm willing to pay much more for appliances that are highly energy efficient because they are saving the environment	35%	38%	35%

Q: Here are some general questions regarding your attitudes about life, please tell me for each how much you agree or disagree with the statement by answering Strongly Agree, Somewhat Agree, Neither Agree nor Disagree, Somewhat Disagree, or Strongly Disagree.

Research was conducted Q3 of 2020 by ARW 36

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Consideration of Factors Prior to Purchase
(Mean Score Rankings)

Ranking	Restaurants	Laundromats	Apartments/ Senior Living
We always purchase the best equipment we can find	2.15	2.41	2.06
When available we will buy refurbished equipment	2.73	2.36	2.29
We always look for the lowest price out there, no matter the brand	2.60	2.45	2.60
When possible, we try to lease our equipment	2.53	2.78	**3.04***

Q: In your operation when you replace major equipment, below are four scenarios that you might consider when replacing equipment, please order them as to how your company would make such a purchase, with the most likely purchase scenario being 1, 2nd 2, 3rd 3 and 4th and least a 4.

Scale of 1-4, with 1 being the most important and 4 most important, hence the lower the number the better the score.

: The leasing option is significantly less important to the apartment/senior living segment.

Research was conducted Q3 of 2020 by ARW 37

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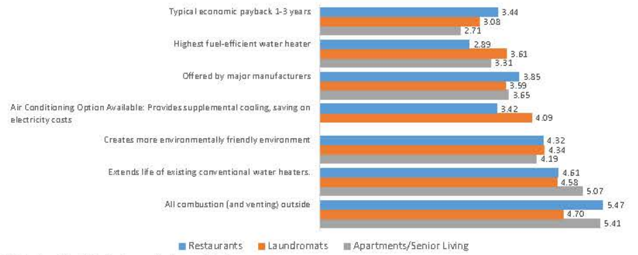
Importance of Attributes for the "New" Technology
(Mean Score Rankings)



Q: The following are the attributes for the new gas heat pump water heater.
Please rank them in order of importance to you in considering purchasing it for your laundromat:

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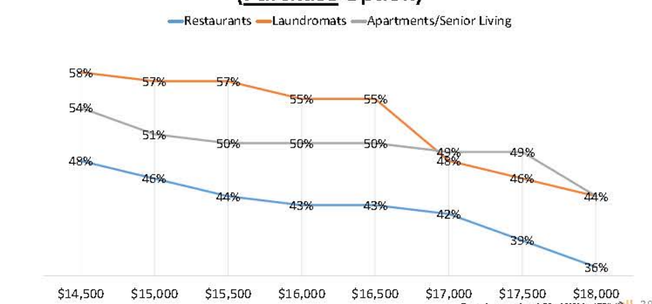
Price Elasticity Based on Total Cost of TDHP Installation
(Purchase Option)



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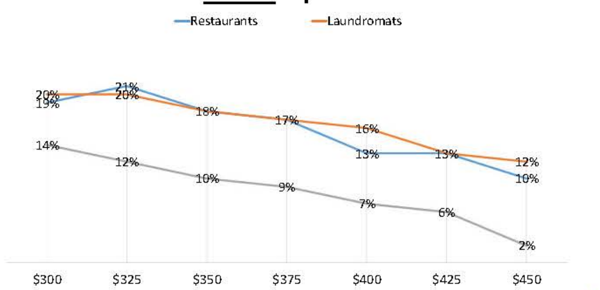
Price Elasticity Based on Total Monthly Cost of Lease Option



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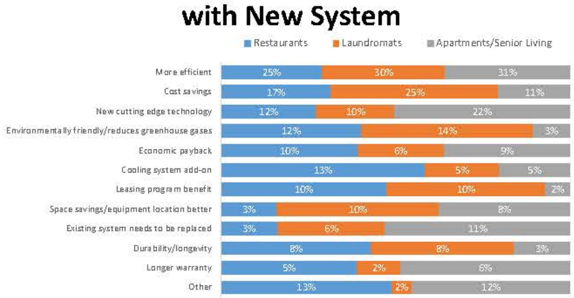
Reasons for Replacing Current Water Heater with New System



Q: What would make you replace this water heater with the new system?

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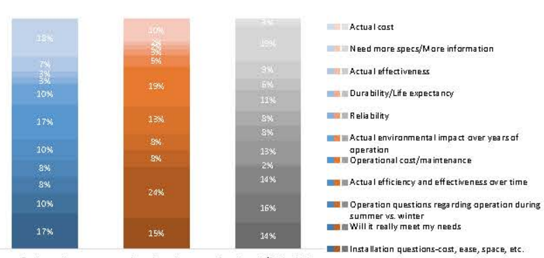
Reasons for Not Replacing System



Q: What would make you not want to replace your existing water heater system with this new system?

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New Product Perceptions

Restaurants

- 25% - No real advantage
- 18% - Unproven reliability or other problems untested
- 18% - Current system is fine/no need for change
- 8% - New technology may have new or other cost not known, like parts, installation, etc.
- 7% - Upfront cost too high
- 7% - Installation location/climate problems not really addressed
- 5% - Not that much more efficient than current system
- 3% - Not practical/always looking to new technology
- 3% - Environmentally being better is unproven
- 2% - Specs not clear/new technology may not be good for me
- 2% - Life expectancy of product/Durability/Warranty unproven
- 5% - Other
- 2% - Nothing

Laundromats

- 16% - No real advantage
- 14% - Upfront cost too high
- 14% - Current system is fine/no need for change
- 11% - New technology may have new or other cost not known, like parts, installation, etc.
- 10% - Not that much more efficient than current system
- 8% - Unproven reliability or other problems untested
- 8% - Environmentally being better is unproven
- 6% - Installation location/climate problems not really addressed
- 5% - Not practical/always looking to new technology
- 2% - Life expectancy of product/Durability/Warranty unproven
- 0% - Specs not clear/new technology may not be good for me
- 10% - Other
- 0% - Nothing

Apartments/Senior Living

- 19% - Upfront cost too high
- 15% - Current system is fine/no need for change
- 14% - No real advantage
- 8% - New technology may have new or other cost not known, like parts, installation, etc.
- 6% - Unproven reliability or other problems untested
- 6% - Specs not clear/new technology may not be good for me
- 6% - Life expectancy of product/Durability/Warranty unproven
- 6% - Environmentally being better is unproven
- 5% - Not practical/always looking to new technology
- 5% - Not that much more efficient than current system
- 3% - Installation location/climate problems not really addressed
- 12% - Other
- 5% - Nothing

Q: What do you think of this new product?

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