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Combi System Field Study

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit working to mobilize the Northwest to become increasingly energy-efficient for a sustainable future. One of NEEA's market transformation strategies is supporting emerging technologies through field testing to demonstrate performance in cold northwest climates and identify potential barriers to market adoption. NEEA has identified natural gas combined space heating and water heating (combi) systems as a candidate for testing in the field. The combi technologies tested in this field trial use condensing tankless water heaters to provide space heating (SH) via a hydronic coil and domestic hot water (DHW) on demand. This trial builds on previous research intended to help design effective interventions for the uptake of emerging water heating and combi technologies in general, and in particular, for gas heat pump combi systems expected to enter the North American market in the next two to four years.

This report summarizes key learnings and performance results from the installation, operation and testing of six combi systems across Western Oregon, Central Oregon, and Eastern Washington, including field data from November 2019 through October 2020.

Combi System Overview

Two different natural gas fired combi systems were tested across six sites for this field trial. The iFLOW system tested included a hydronic air handling unit (AHU) and a separate condensing tankless water heater (TWH). The NTI system tested is a packaged unit including both the AHU and TWH packaged as a single unit. See Figure 1 and Figure 2 for renderings of the two systems.

FIGURE 1 – IFLOW IFLH COMBI SYSTEM

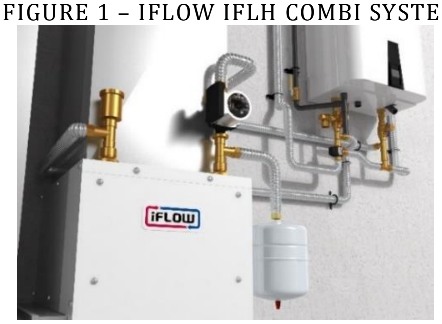

FIGURE 2 – NTI GF200 COMBI SYSTEM

Table 1 summarizes key product specifications and performance ratings for both combi systems tested as a part of this field trial.

TABLE 1 – COMBI SYSTEM MANUFACTURER SPECIFICATIONS & RATINGS

	iFLOW	NTI
Air Handler Model	iFLH-16000	GF200
Water Heater	Navien NPE-240A (External)	Navien NPE-240A (Internal)
Space Heating Input Capacity (Btu/hr)	19,900 to 80,200	19,900 to 80,000

Space Heating Efficiency	0.96 (TPF) Combined System[1]	97.1% (AFUE) SH Only
Maximum Airflow @ 0.6" w.c. (cfm)	1,222	1,200
DHW Heating Capacity (Btu/hr)	19,900 – 199,000	19,000 – 199,000
DHW Flow Rate (80°F ΔT) (gallons/min)	5.0	5.0
DHW Nominal Efficiency (Uniform Energy Factor)	0.96 UEF	0.96 UEF
Dimensions (W x H x D) – (inches)	16 x 27.1 x 20.8 (AHU) 17 x 27.4 x 13.2 (TWH)	17.8 x 38 x 38
Weight (pounds)	71 (AHU) 82 (TWH)	248

Research Goals

This NTI and iFLOW field trial was designed to understand the energy savings, installation, operation and customer experience with high-efficiency condensing natural gas fired residential space and water heating combination (combi) units compared to conventional forced air furnaces (FAF) and storage tank water heaters. This field trial included both qualitative and quantitative data collection activities to fully capture the impact on both the installer and owner, including installation barriers, end-user comfort and satisfaction, energy savings and non-energy benefits. Additionally, the field trial included a payback analysis to inform recommendations on utility incentives.

The results of this field trial will provide input into decisions about whether to promote and accelerate adoption of this technology, in addition to informing manufacturers of improvements needed in the design of equipment for increased performance and adoption in the future. This research is also intended to augment NEEA's ongoing work to understand the most effective ways to support the uptake of emerging water heater technology. Table 2 summarizes the research topics and goals of this field trial. The full list of research questions can be found in *Section 1.2 Research Objectives*.

TABLE 2 – RESEARCH QUESTIONS

Research Topics	Research Questions
Performance	How much energy do combi systems with condensing tankless water heaters save compared to conventional natural gas furnace and water heater systems?
Installer Experience	What is the installation experience for the installing contractor?
Homeowner Experience	What is the installation process for the system owner and how does the combi system meet their domestic hot water and space heating needs over one year?

Field Trial Approach

To accomplish the research goals the evaluation team identified and conducted a set of data collection and evaluation activities as summarized in Table 3. Ultimately, six units (three NTI, three iFLOW) were tested over a period of one year.

[1] The iFLOW air handlers do not come with a heat source and do not have a nominal AFUE. However, the combined iFLOW iFLH-1600 and Navien NPE-240A TWH have been tested through CSA P.9-11 and received a thermal performance factor (TPF) of 0.96 for combined system performance (report #14-06-M0279 Rv3).

TABLE 3 – RESEARCH AND EVALUATION ACTIVITIES

Activity	Description
Recruitment	Recruited and selected six suitable residences to test combi systems
Contractor Selection	Selected three sets of HVAC contractors to install combi systems in Bend, Portland, and Spokane
Installation Supervision	Supervised six combi system installations and provided technical support and limited guidance to installing contractors
Data Monitoring and Analysis	Monitored combi system performance and analyzed results to calculate annual gas savings relative to a conventional DHW & space heating system; collected detailed installation costs to calculate project economics
Installation Observations	Observed and recorded detailed notes on the installation process of six combi system installations
Homeowner Interviews	Interviewed homeowners upon completion of the unit installation to understand their perceptions and experience of the installation
Follow-up Interviews	Conducted bi-monthly interviews with homeowners beginning two months after installation to understand their experience and satisfaction with DHW and space heating needs

Site Selection Characterization

The primary goal of the site selection process was to find suitable residential houses with reasonable installation logistics in a range of building sizes, number of occupants, and climates. All sites were selected based on the following minimum requirements:

- Own their single-family home and not have plans to move within the year,
- Have a natural gas water heater as primary source of hot water,
- Have a central forced-air gas furnace as primary source of heat, and
- Have the water heater and furnace located within ten feet of one another.

Table 4 lists a few key characteristics of the six sites selected.

TABLE 4 – SITE CHARACTERISTICS

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Location	Bend, OR	Bend, OR	Portland, OR	Portland, OR	Spokane, WA	Spokane, WA
Annual Heating Degree Days (Base 65°F)	6,918	6,918	4,544	4,544	6,956	6,956
Year House was Built	1995	2004	1904	1911	1998	1976
Size of House (ft^2)	1,615	2,475	2,086	2,232	2,300	1,500
Number of Occupants	2	3	2	5	4	6

Summary of Performance Results

Table 5 summarizes key system performance results from the testing of the six combi systems. All annual performance results are based on metered data collected in the field and normalized to a typical weather year. The metered data for this report was collected from November 21st, 2019 through October 31st, 2020. The comparison system modeled to calculate the combi system annual gas savings is a 40-gallon tank water heater (WH) with a 0.62 UEF and a non-condensing forced-air furnace (FAF). The conventional space heating efficiency is calculated in an hourly model based on part-load efficiency curves. See *Section 5.4 Analysis* for more details.

The metered data collection period overlapped with the COVID-19 stay at home guidance provided across both Oregon and Washington. Participants reported via interviews that they were relatively unaffected by COVID-19-related changes, because they were either already retired, working from home part- or full-time, or still working as essential workers. Metered data confirms that there was little significant change in DHW or space heating loads at any of the sites between the pre- and post-COVID-19 period. For more information see *Section 6.1.1COVID-19 Impact* and *Appendix E. Pre- and Post-COVID DHW & SH Load Comparison.*

TABLE 5 - SUMMARY OF RESULTS

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Conventional System Modeled	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH
Conventional DHW UEF	0.62	0.62	0.62	0.62	0.62	0.62
Conventional Furnace AFUE	80%	80%	80%	80%	80%	80%
Conventional System Modeled Annual Efficiency	66.4%	68.0%	65.5%	66.1%	65.4%	63.7%
Conventional Annual Fuel (therms)	1,089	1,229	906	788	817	747
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Combi System Nominal Efficiency AFUE/UEF	NA/ 0.96	NA/ 0.96	NA/ 0.96	97.1%/ 0.96	97.1%/ 0.96	97.1%/ 0.96
Combi System Modeled Annual Efficiency	81.8%	94.7%	86.2%	91.0%	86.8%	83.8%
Combi System Annual Fuel (therms)	885	883	688	573	616	568
Annual Natural Gas Savings (therms)	204	346	218	216	201	179
Annual Natural Gas Savings	19%	28%	24%	27%	25%	24%
Annual Avoided Cost of Gas	$152	$257	$201	$199	$137	$122
Conventional System First Cost	$6,250	$6,250	$6,250	$6,250	$6,250	$6,250
Combi System First Cost	$10,488	$9,929	$12,343	$10,580	$9,500	$9,500
Simple Payback (years)	27.9	14.3	30.2	21.7	23.7	26.6

Findings and Recommendations

The following section summarizes the trial's overall findings and recommendations.

Combi System Performance

Combi systems save energy relative to conventional systems. On average the combi systems saved over 227 therms annually (24%) relative to a conventional forced-air furnace (FAF) with an 80% AFUE and a tank water heater with a 0.62 UEF. However, the combi systems only saved on average 71 therms annually (10%) relative to condensing FAF with 95% AFUE and 0.62 UEF WH. For a full summary of energy savings and comparisons, see *Section 6 Results*.

Better turndown capability of TWH (ability to operate continuously at lower part-load capacity without cycling) would help improve system performance in houses with smaller space heating loads. System performance was hurt by short cycling in many of the sites, especially in the smaller houses. The TWH tested in both system configurations has a 10:1 turndown (can operate at 10% capacity) with a minimum capacity of 19,000 Btu/hr. A TWH with 20:1 turndown would be beneficial for combi applications.

> **Recommendation:** Encourage manufacturers to develop TWHs with high turndown capabilities for combi applications. Ensure that contractors select a TWH (or other heat source) that is properly sized to meet the space heating and DHW load (not oversized) and TWH has high turndown and good part-load efficiency.

Thermostat scheduling increases energy savings. The sites using automatic schedules with night and unoccupied setback temperatures saw longer cycle times and better efficiency (more savings). The sites with the best performance (Sites 2 and 4) both used programmable smart thermostats and allowed the temperature at night to fall by more than 4°F causing the air handlers to run continuously for multiple hours in the morning. The remaining sites also controlled the combi air handlers with programmable thermostats but most used fixed heating setpoints without night setbacks. The two sites with night setbacks average 92.8% seasonal efficiency while the other four sites averaged 84.6%.

> **Recommendation:** Consider program designs that promote night setbacks and optimal thermostat setpoints either through customer education or contractor training.

Installation Process

Contractors need education on the potential use cases benefits of high-efficiency combi systems to overcome the barriers of high first cost and unfamiliarity with these appliances. Contractors new to high-efficiency combi systems felt they would be comfortable installing them after a typical sales demonstration, indicating that the increased complexity of the installation is not likely to be a significant barrier. However, high-efficiency combi system equipment alone costs 2-3 times that of conventional furnace and water heater equipment, and the installation costs are also greater. In order for contractors to carry and promote higher cost combi equipment, they need to understand the benefits these appliances provide customers, the value proposition, the market opportunity and have the knowledge and materials to trust that these appliances are reliable and won't create call backs for them.

> **Recommendation:** Engage manufacturers and distributors to provide training and education opportunities for business owners and contractors so that they, in turn, can educate and sell combi systems to homeowners.

The packaged NTI combi system requires less installation time and effort than the de-coupled iFLOW system (separate TWH and air handler) but is still more time and labor intensive than a conventional water heater and furnace replacement. Most of the installations included in this field trial took about two days to complete, however a contractor with more experience installing combi systems can often complete the installation in one day, especially the packaged NTI unit. For example, both Spokane NTI installations were completed in one day by a contractor with experience installing over 30 combi systems. NTI units overall seem easier to install given they are a single unit and do not require the separate installation and interconnection of two units as in the case of the iFlow and tankless water heater system. However, for installers with moderate experience, most NTI installations can be expected to take one workday and most iFLOW installations would take closer to one and a half work days. Conventional water heater and furnaces are rarely installed at the same time, but for as a reference point, a tanked WH installed can often be completed in a couple hours by a single installer and a conventional furnace replacement can be completed in a 6-8 hour day by a crew of one or two. Moreover, any iFLOW or NTI install will typically require the contractor's "A-team" while a conventional WH and furnace replacement can be undertaken by any residential installation team (often separate teams). See *Section 7 Technology Comparison* for more detailed information on the two combi systems.

Homeowners need a compelling value proposition and confidence in combi systems. Although some homeowners will conduct research to understand water and space heating options, most rely on recommendations from contractors and word of mouth from friends or family. Without a solid understanding of combi system benefits, performance and the ability to estimate their personal energy savings potential, homeowners will need to be convinced by their contractor that the systems are reliable and the $3,000-$5,000 in incremental cost is worthwhile.

> **Recommendation:** Provide independent comparisons of combi systems to other options to assist homeowners in understanding their options.

Increasing availability of combi equipment and peripheral components is necessary for broader uptake of the technology. Being a relatively unknown technology in the Northwest, the availability of the combi system equipment and necessary peripheral components needs to increase for the technology to be a viable option for contractors and homeowners. Even with early notice, it was challenging for contractors to secure all necessary equipment and peripheral components from the local distributors. Long lead times will be a challenge for contractors until combi system sales volumes increase.

> **Recommendation:** Engage manufacturers and distributers to increase availability of combi equipment and components.

Participant Experience

Respondents reported high rates satisfaction with their combi units over the course of the year-long field trial. Five out of six participants rated their satisfaction a 5 out of 5 throughout the trial (completely satisfied). One participant rated their satisfaction a 4 in the first two follow up interviews, due to initial hot water delivery issues (anti-scald valve left at default temperature of 100°F which has since been remedied) and another noted a lack of utility bill savings (though the participant also noted a change in their natural gas rate and increased DHW usage around the time of installation due to an increase in number of residents living in the house). The benefits participants reported included greater comfort levels owing to less fluctuation in temperature, more consistent hot water, and a noticeable decrease in heating system sound levels.

Longer installation process did not appear to be a barrier for participants. Participants were told in advance that the installation process would take longer than a typical water heater replacement, given this knowledge, none reported an issue with the amount of time it took.

Participant Interest, Awareness, and Motivation

Participants were primarily motivated by the opportunity to replace their existing water heater and furnace with a new system. Existing WH and furnace equipment was between 5-20 years old and participants were glad to receive equipment at no cost before their aging equipment needed repair or replacement. Other motivations included a general interest in new technology, a desire to become more energy efficient, and the hope of bill savings. Multiple participants also expressed excitement about being involved in research to test emerging technologies.

Awareness of combi technology was low among participants. None of the participants in the field trial recalled being aware of combi units prior to recruitment, and 2 of the 3 of the installation teams had never installed or serviced a combi system.

1. Overview

1.1 Field Trial

This combi system field trial is intended to provide an understanding of the system design and installation challenges and to quantify the energy savings of natural gas combi units (utilizing high-efficiency, condensing, tankless hot water heaters (TWH) combined with hydronic air handlers compared to traditional forced air furnaces (FAF) and storage tank water heaters. This field trial evaluated products from two manufacturers, the NTI GF200, and the iFLOW iFLH air handler combined with a high-efficiency, condensing TWH.

The NTI unit is a packaged combi unit (furnace and water heater in a single package) while the iFLOW unit is a hydronic air handler that comes standard with the controls necessary to operate as a combi system with any number of hot water heaters. For this field trial the iFLOW units were combined with condensing TWHs. Six units (3 NTI, 3 iFLOW) were tested over a period of one year and results in addition to informing manufacturers of improvements needed in the design of equipment for increased performance and adoption in the future.

This field trial included both qualitative and quantitative data collection activities designed to fully capture the impact from the installer to the system owner, including installation barriers and end-user comfort and satisfaction, and document any non-energy benefits. Additionally, the field test will include payback analysis to inform NEEA recommendations for utility incentives.

This filed trial builds on previous research intended to help design effective interventions for the uptake of emerging water heating and combi technologies in general, and in particular, for gas heat pump combi systems expected to enter the North American market in the next two to four years.

1.2 Research Objectives

1.2.1 <u>Combi System Performance</u>

1. Do gas combi systems, using high-efficiency, condensing, tankless water heaters provide energy savings over conventional gas furnaces and water heaters?
2. How much energy do combi systems save over conventional gas systems?

1.2.2 <u>Installation Process</u>

1. What is the installation experience from the installer perspective? What elements of installation are familiar or intuitive and what lies outside their experience?
2. What are installers' potential barriers? How might these be overcome?

1.2.3 <u>Participant Experience</u>

1. How do participants evaluate the installation process? What are the customers' experiences of the installation process?
2. Are participants satisfied with the combi unit? How does this compare to the equipment it replaced? Does it provide enough hot water? Does it adequately heat their home?
3. Do they have any concerns or issues with the unit?

Participant Interest, Awareness, and Motivation

1. What motivated participants to participate in the field trial?
2. What do they see as the benefits of their new combi unit? What are the barriers?
3. What was their previous awareness of combi systems and equipment?

1.3 Research Activities

This section describes the set of data collection and evaluation activities conducted to address the research objectives and questions listed above.

1.3.1 Recruitment

The research team (NEEA, Energy 350, and ILLUME) developed a list of characteristics for suitable test sites. The primary goal was to find a range of building sizes, number of occupants, and climates to understand the capability and energy savings potential of combi systems in the field. After collecting over 100 potential participants, follow-up emails, phone calls, and eventually site visits were completed to vet the most promising sites. Six sites were selected across three locations: Bend, OR (Cascade Natural Gas), Portland, OR (NW Natural), and Spokane, WA (Avista). For additional information, see *Section 2 Implementation*.

1.3.2 Guide Development

The research team developed an observational guide as a tool intended to organize and systematize installation observations, which can vary greatly depending on the experience and preparation of the installation teams as well as the installation site itself. Guides for post installation homeowner interviews and bimonthly follow up interviews were also developed with an aim of understanding the homeowner experience of both the installation and living with the combi units over the course of the field trial period. All guides were revised and refined according to NEEA's feedback and can be found in full in the Appendices.

1.3.3 Contractor Selection

After selecting the six field sites, three separate HVAC contractors, one in each city, were selected to install the combi systems. Only the Spokane contractor had previous experience installing combi systems, but the other two had significant experience installing the condensing tankless water heaters tested as a part of the system. In general, the three contractors are highly regarded and specifically market themselves as providers of high-efficiency space and water heating systems.

1.3.4 Installation Supervision

The six installations were attended by a technical supervisor from the evaluation team. The goal was to mostly observe and provide resources (installation manuals, manufacturer FAQs, troubleshooting) when necessary. Contractors were encouraged to install the equipment according to the manufacturer's recommendation, and guidance was only provided in a few cases where challenges arose, or guidance was requested. The technical supervisor also guided areas of the installation where data monitoring equipment (water and gas flow meters) was required to be installed in line with the combi system piping.

1.3.5 Installation Observations

The research team observed and took detailed notes on all six installations as a means of assessing what worked and what barriers existed for installers, and whether this differed based on the type of combi unit installed or the existing HVAC system and water heater. Where possible, team members asked installers questions to ascertain the steps involved in the process, what they learned from one installation to the next, how they overcame obstacles, and how the process might be simplified for other installers who may not have experience installing combi units.

1.3.6 Data Monitoring and Analysis

To measure the performance of the combi systems in the field, a variety of temperature sensors, water, gas, and airflow flow meters were installed. See *Section 5 Data Collection Methodology and Analysis* for more details.

1.3.7 Homeowner Interviews

The research team member present at installation observations interviewed homeowners immediately following the installation in all but one instance, where this interview was conducted by phone at the homeowner's convenience two days after. ILLUME compiled the feedback from these interviews and analyzed them with an eye to understanding the homeowner's immediate experience of the installation and whether this varied from their expectations; expectations about the equipment; and motivations for participating in the field trial.

1.3.8 Follow-up Interviews

Research team members conducted bi-monthly interviews with homeowners starting two months after installation and initial homeowner interview (i.e. mid-November 2019 through October 2020). The feedback from these interviews was analyzed with a goal of understanding the homeowners' experience living with the combi unit, whether they had experienced any issues, and to gauge their satisfaction with the equipment overall and compared with what it replaced.

2. Implementation

2.1 Recruitment and Site Assessment

NEEA collaborated with ILLUME and Energy 350 to recruit employees from its funding gas utilities (Cascade Natural Gas, Avista, NW Natural, and Puget Sound Energy, as well an Energy Trust of Oregon) to participate in the field trial via email, sending invitation emails in September 2019. Recruitment emails highlighted the offer of retaining ownership of the combi unit for participating in the field trial. The emails also included a link to a short qualifying survey screener. To be eligible for this trial, participants had to:

- Own their single-family home and not have plans to move within the year,
- Have a natural gas water heater as primary source of water,
- Have a central forced-air gas furnace as primary source of heat, and
- Have the water heater and furnace located in proximity to one another.

Once sites were narrowed down to a short list, the research team contacted eligible participants discussing to discuss site eligibility in greater detail. Combi unit installations began in mid-November 2019 and concluded in early December 2019.

2.1.1 Sample Design

The research team worked together with NEEA to identify the set of parameters across which the performance of and satisfaction with a combi unit might vary. This list included home vintage (new construction, existing), climate zones (4C and 5B), occupancy (low, medium, high) and control topology (single zone, multi-zone). To balance a sample size of 6 across these and the four screeners identified above, the research team ultimately selected the following sample of homes:

TABLE 6 – SITE CHARACTERISTICS

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Location	Bend, OR	Bend, OR	Portland, OR	Portland, OR	Spokane, WA	Spokane, WA
Annual HDD_65 (TMY)	6,918	6,918	4,544	4,544	6,956	6,956
Year House was Built	1995	2004	1904	1911	1998	1976
Size of House (ft^2)	1,615	2,475	2,086	2,232	2,300	1,500
Conditioned Floors	1	2	2 + basement	2 + basement	2 + cond. Basement	1
Number of Occupants	2	3	2	5	4	6+

2.2 Installation

2.1.2 Procurement of Equipment

iFLOW

- iFLOW iFLH AHUs and circulator pumps were purchased directly from the manufacturer and shipped from Ontario, Canada as they do not currently have a NW distributor.
- Navien condensing THWs were procured by the contractors and are stocked at many local distributors in both Portland and Bend.
- Piping kits, flow switches, and outdoor air temperature sensors were unavailable from iFLOW and were purchased online from a plumbing parts distributor after discussions with iFLOW technical support.

NTI

- NTI GF200 combi furnaces were procured through a Portland distributor and shipped from Salt Lake City, UT to Portland and Spokane. However, the Spokane contractor could easily have procured the combi furnaces through their local distributor if needed. The Spokane contractor saw an opportunity to carry a combi unit and developed a relationship with a regional NTI salesperson, who found a local distributor to supply the equipment.
- The piping kits for the two Spokane installs were provided through the local distributor, but the kit was backordered for the Portland install and delayed installation by two weeks.

Contractor Selection and Scheduling

After selecting the six field sites, three separate HVAC contractors, one in each city, were selected to install the combi systems. Only the Spokane contractor had previous experience installing combi systems, but the other two had significant experience installing the condensing tankless water heaters tested as a part of the system. In general, the three contractors are highly regarded and specifically market themselves as providers of high-efficiency space and water heating systems.

3. Site Characterization

Table 7 lists the existing equipment from the six sites.

TABLE 7 - EXISTING EQUIPMENT SCHEDULE

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Water Heater	40-gallon Bradford White	75-gallon Ruud	180 MBH Tankless Rinnai	29-gallon Rheem	40-gallon Bradford White	40-gallon Bradford White
WH Date of Install	1995	2004	2006	2014	2010	2010
WH Efficiency (UEF)	0.58	0.53	0.82	0.71	0.58	0.63
Furnace (Input Capacity)	Goodman (80 MBH)	Lennox (88 MBH)	Goodman (69 MBH)	Carrier (80 MBH)	Armstrong (80 MBH)	Trane (60 MBH)
Furnace Date of Install	2005	2004	2006	2005	2008	2015
Furnace Efficiency (AFUE)	80%	80%	95%	96.2%	80%	95%
Air Conditioning?	Yes	No	No	No	Yes	No
Supplemental Heating?	Gas fireplace	No	No	No	Gas fireplace	Electric wall heat

Figure 3 through Figure 13 show the existing furnace and water heater at each of the six sites.

3.1 Site 1 Bend iFLOW #1

FIGURE 3 – SITE 1 FURNACE

FIGURE 4 – SITE 1 WATER HEATER

3.2 Site 2 Bend iFLOW #2

FIGURE 5 – SITE 2 FURNACE AND WATER HEATER

3.3 Site 3 Portland iFLOW

FIGURE 6 – SITE 3 FURNACE

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FIGURE 7 – SITE 3 WATER HEATER

3.4 Site 4 Portland NTI

FIGURE 8 – SITE 4 FURNACE

FIGURE 9 – SITE 4 WATER HEATER

3.5 Site 5 Spokane NTI #1

FIGURE 10 – SITE 5 FURNACE

FIGURE 11 – SITE 5 WATER HEATER

3.6 Site 6 Spokane NTI #2

FIGURE 12 – SITE 6 FURNACE

FIGURE 13 – SITE 6 WATER HEATER

4. Installation Process and Experience

This section describes the combi unit installation, including challenges, what worked well, and the installation contractors' and homeowners' experience of it. We note that a more detailed comparison of the benefits and disadvantages of both models is included in *Section 7 Technology Comparison*.

4.1 Installer Experience

4.1.1 Installation Process

This section provides an overview of the installation process, detailed descriptions can be found in Section *4.1.2 Detailed Descriptions of Installations*.

Research team members observed and took detailed notes using the Installation Observation Guide at all six installations to understand the installation experience from the installer perspective, potential barriers for installers, and how these might be mitigated.

TABLE 8 – SITE INSTALLATION TIMES

Location	Bend		Portland		Spokane	
Site	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Time to install	2 ½ days	2 days	2 days	2 days	1 day	1 day

Installation overview: Present at installations were two or more installers, an electrician and a plumber (usually just for the part of the process specific to their role), an Energy 350 team member to install data-collection equipment and assist as needed, and an ILLUME team member observing the process. After installation, the Energy 350 team member explained the system to the homeowner and answered any questions they had.

Contractor experience and installation timing: Installations varied in the amount of time they took primarily depending on the experience of the contractors Teams 1 and 2 (who collectively installed all 3 iFLOW combi systems) did not have experience with combi units, while Team 3 had fairly extensive experience. The first iFLOW unit installation took two and a half days, while the others took two. The two NTI units installed by contractors with experience with combi units were both completed in one day, while the NTI installation completed by the team without combi experience took two days. which they described as typical of their experience.

We note that replacing both a water heater and furnace at the same time is rare, and generally not completed by the same installation team. A typical tank water heater install takes 1-2 hours, while a like-for-like furnace replacement can range from 4-8 hours, as there are variables such as air conditioner and duct modifications.

Sources consulted: The installers who did not have previous experience tended to favor the hand-drawn schematics provided by Energy 350 and used the manuals where they had more specific questions. They found the manufacturer manuals adequate overall, with remaining questions mainly relating to the interconnection of the TWH and AHU. The installers who did have previous experience with combi units did not consult any sources outside of the team other than to overcome a minor issue in commissioning (outdoor temperature sensor was not connected).

Process summary: The following is a generic summary of the installation process for each type of combi unit. We note that this represents the general order of steps contractors took.

iFLOW

TABLE 9 – IFLOW INSTALLATION PROCESS

Step	Description
Initial installer site visit	The installer or another employee of the company visited the home to assess the space containing the water heater and furnace to inform decisions on equipment configuration, pipes and fittings for the space, and set up.
Decommission and removal of existing equipment	Removal of existing water heater and furnace.
Install TWH	Install new hot and cold-water lines, mount TWH unit and connect gas lines per manufacturer instructions.

Install vent for TWH	Install a vent for the TWH as dictated by home structure and unit set up.
Install iFLOW air handler unit	Mount AHU per manufacturer instructions regarding clearance, and depending on space, whether it will incorporate an air-conditioning unit, and in proximity to the TWH.
Wire AHU and connect to circuit	Wire the AHU to power source and connect circulating pump and thermostat to AHU.
Plumb TWH and AHU together	Plumb a line to bring hot water from the TWH to the AHU, incorporating a circulating pump, and a return line to the TWH incorporating an expansion tank.
Install iFLOW temperature sensors	Install sensors at indicated points in system: (1) supply water sensor to the supply end of the water heating coil; (2) return water sensor to the return end of the water heating coil; and (3) supply air sensor to the water heating coil exchanger, return air sensor in the discharge air path, and the Ambient Temperature sensor.
Commission system	Purge air from heating loop, flush hot water coil, then bring the system online and check that it responds to calls for heat and hot water; resolve any issues. At this time, the team also checked the connection between the AHU and the iFLOW app for sensor readings and remote control.

NTI

TABLE 10 – NTI INSTALLATION PROCESS

Step	Description
Initial installer site visit	The installer or another employee of the company visited the home to assess the space containing the water heater and furnace to inform decisions on equipment configuration, pipes, and fittings for the space, and set up.
Decommission and removal of existing equipment	Removal of existing water heater and furnace.
Install NTI unit	Installers set up unit for specific needs of the space, including capping plumbing on unused side. Installers slide unit into place, incorporating existing air-conditioning unit if applicable, replacing any piping prone to corrosion with PVC. They also

	connect the gas line and set up condensate lines, filter, air intake, and exhaust.
Wire NTI unit and connect to circuit	Wire unit to power source and replacing existing circuit to be code-compliant if necessary.
Install iFLOW air handler unit	Mount AHU per manufacturer instructions regarding clearance, and depending on space, whether it will incorporate an air-conditioning unit, and in proximity to the TWH.
Wire NTI unit and connect to circuit	Wire unit to power source and replacing existing circuit to be code-compliant if necessary.
Plumb NTI unit	Flush boiler and connect plumbing to unit, incorporating expansion tank.
Commission system	Bring the system online and check that it responds to calls for heat and hot water; resolve any issues.

4.1.2 Detailed Descriptions of Installations

The following sections describe, in more detail, issues that arose during individual installations, including where they diverged from the process summarized above.

Bend Installations (iFLOW)

Team: This was the first combi installation for this team, which comprised two HVAC installers with approximately eight years of experience each. At necessary junctures, they were joined by two electricians (one licensed, one apprentice), and a plumber to perform electrical and plumbing work.

Issues:

- The teams' lack of familiarity with the equipment and the absence of one of the installers on the first day due to illness played a part in an installation that took longer than expected (2 ½ day installation).
- Extra fittings and components were hard for the installers to track down.
- Energy 350 requested an iFlow piping connection kit, but none were available, so installers had to piece this together on their own. While the connections they ended up using are commonly available, it amounted to more work and time.
- In addition, the flow switch required for combi systems to connect the TWH to the AHU was also not available for the iFLOW. Their representative suggested that contractors would have these readily available, but this was not the case, as combi units are uncommon in the Pacific Northwest. The Energy 350 team member was ultimately able to find and purchase one online.
- Lack of comprehensive, consistent instructions for connecting TWH and AHU made this process confusing for the team.

- The circulating pump recommended by Navien had a wiring schematic that was unfamiliar to the contractors and took additional time for them to understand and execute (this added about 15-minutes only on the first install).
- Confusion regarding whether the outside air temperature sensor was needed. The manual seemed to indicate it was optional, but in troubleshooting the lack of response to calls for heating, the team discovered it was required. It turns out the sensor is only optional when the unit is connected to the online weather station via the home's wi-fi connection.
- The iFLOW app (which is necessary for operation) was unintuitive and connectivity to it was inconsistent owing to in-app bugs.

Sources consulted: The installers consistently consulted the hand-drawn diagram provided by Energy 350, as well as the manual for the iFLOW which included generic installation schematics. The hand-drawn diagram seemed to be favored because it provided slightly more detail on the specific elements of the installation, and it was the team's first combi installation. The team felt the main difficulty not covered in manuals was connecting the TWH and the AHU. The Energy 350 team member also placed a call to the technical support team for assistance with equipment start up before the outdoor air temperature sensor was connected. The electricians consulted the manual for the electrical wiring of the circulator pump and air handler as well.

FIGURE 14 – SYSTEM INSTALLATION SCHEMATIC FROM IFLOW MANUAL

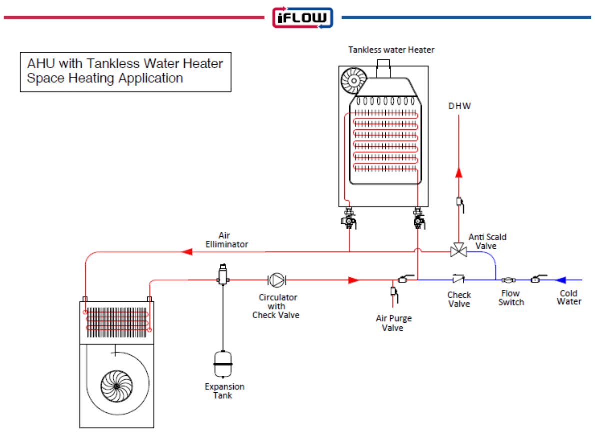
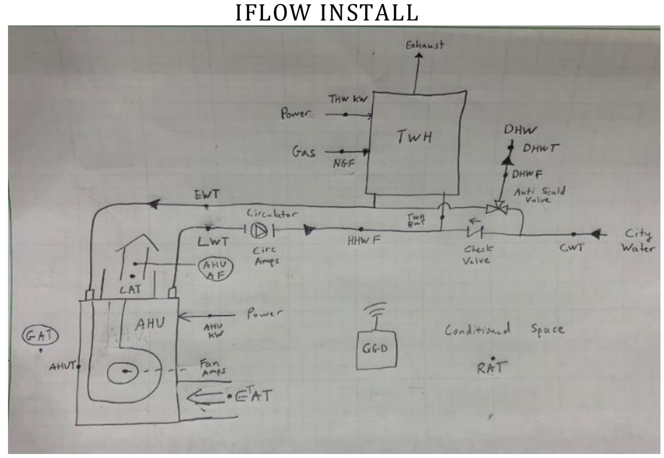


FIGURE 15 – HAND DRAWN SCHEMATIC FOR FIRST IFLOW INSTALL



"The manuals were fine, they had generic wiring diagrams and plumbing diagrams and that's what we went off of. The thing that was missing was a manual that was like Navien to the iFLOW, and better instructions around those connections. The wiring constructions were confusing, and we had to call to figure out how to hook those up. This could be taken care of by a rep teaching the supervisor how it works too." – HVAC installer

Summary Takeaways: The first installation took slightly over two days because of the issues described above. The installer felt that the second installation, which took less than two days, was considerably easier owing to the experience of having completed one. Additionally, for the second job, the installer was able to come and measure the space first and have the sheet metal fittings made ahead of time which likewise sped the process.

Spokane Installations (NTI)

Team: This team had experience installing combi units (from 2 – 10 jobs) and comprised two HVAC installers with around 10 years of HVAC experience each and a plumber with 30 years of experience. They were joined by two electricians for part of the process.

Issues:

- This team did not experience any significant issues with either installation, and noted that in general, the main challenge is size and weight of the units (around 250 pounds) and site-specific issues such as suboptimal configurations of existing equipment, ducting, or space to work in. They noted that, owing to its size, NTIs can be difficult to work with because they can cover or obscure things like sump pumps or floor drains (the unit is wider, deeper, and heavier than a conventional furnace). (For unit dimensions see *Appendix D. Combi Equipment Submittals.*)
- The team had some difficulty removing the furnace in the first installation because of bad initial placement.
- There was one minor issue in the first installation at commissioning, where initially the unit did not respond to calls to heat. After consulting the manual (the only time they did so), they discovered a wiring issue with the door switch indicating the door was open when it was not, and therefore would not engage. They noticed there was no error message for this.

Sources consulted: The team did not consult any manuals on the first installation until the very end to try to figure out the issue with calls for heat. They discussed steps with each other, as all had experience installing combi units. On the second installation, they referenced the NTI manual while considering code requirements for PVC material (and length) and outside exhaust filter.

Summary Takeaways: Both installations took one day, which the installers said was typical for their combi unit jobs and had no significant obstacles.

Portland Installations (iFLOW 1st and NTI 2nd)

Team: This team did not have experience with combi units and, unlike the Bend team, did not have the benefit of installing the same type of equipment back to back. The team comprised two HVAC installers, with 20 and 15 years of experience respectively, and a plumber with 30 years of experience. They were joined by two electricians for part of the process.

Issues:

- Lack of experience slowed the team on both installs, and they did not have the benefit of a learning curve from job to job.
- There were no significant combi-related issues. The primary obstacles for both installations seemed to be that the installers did not have the opportunity to see the site beforehand and did not receive sufficient information or preparation about the site or technology from their manager. They also lacked most of the necessary equipment and parts and had to make multiple trips to the hardware store both installations.
- The NTI installation had two minor issues:

- An O-ring on one of the water connection caps was ‘a penny’s width’ too wide and could not be secured, and the team had to find a way to reattach the O-ring.
- The old filter box was slightly too large for the return air opening and had to be modified; however, the custom-made, smaller filter box, which is a common field modification in installations, did not depress the door switch, and a temporary work around was put in place to complete the unit startup. Later that day, the door switch was permanently depressed.

Sources consulted: They mainly used the hand-drawn schematic provided by the Energy 350 team and consulted the team directly.

Summary Takeaways: Although no significant issues arose, both jobs were hampered by insufficient preparation of the installation team (no site visit by installers and insufficient communication from the HVAC manager to the installers). When asked which combi unit they preferred, they chose the iFLOW unit because it was smaller and comprised two pieces and was therefore easier to install in any space.

4.1.3 Barriers and Potential Solutions

This section comprises a summary of the barriers we observed contractors encountering during installation, along with the potential means of addressing them.

Lack of experience with the equipment: This was initially an issue for the Bend and Portland installers (installers in Spokane had experience with combi units). The Bend installers, who had the opportunity to install a second iFLOW unit, noted that the experience of one install made the second considerably simpler and easier.

For installations of iFlow combi units, the main issue was in connecting the AHU and TWH, as they had experience installing each piece of equipment on its own. Installers used manuals successfully, but mainly when specific problems arose rather than guiding the process overall, suggesting the importance of a direct, guided experience.

Solution: Installers noted that typically, when a new piece of equipment is introduced to the team, they receive a demonstration and/or on-the-job support from a tech or sales representative. The installers we spoke to felt that even one supported installation was sufficient to avoid most issues and delays caused by lack of familiarity, and that support by phone would resolve remaining job-specific issues if necessary.

“The main thing is having someone to call. We can call techs [at other companies] pretty easily. I don’t know if iFLOW is just a little company or if there’s someone we can touch base with, but I would want to call someone who know what’s going on. If there’s a circuit board issue that’s when I call reps. Generally, I’m not calling after an initial install.” - HVAC installer

One installer also observed that combi units may require more than HVAC training provides.

“This plumbing is more advanced because it’s boiler plumbing. You need to have a wide skill range, a standard HVAC installer might not have that, years ago I would have had no idea what I was doing.” - HVAC installer

Difficulty sourcing and securing some parts: This was an issue noted by installers of both types of combi units installed for this field trial. For the NTIs, installers commented on a shortage of kits supplied by the manufacturer that include mixing valves and other components that the contractor ordered but did not receive. For the iFLOW combi units, it appeared to be a lack of clarity in the installation manual regarding the components required to connect the AHU with the TWH and whether an outdoor air sensor was required for the system to function.

Solution: Engage distributors and manufacturers to make parts more readily available.

"We could have used a list of things you need [for the iFLOW combi set up], you need a pump, you need two aerators, expansion tank, but not a kit exactly. It would be nice to know which pump should be used though, that seems to matter." – HVAC installer

Size of the units: In the retrofit applications included in this trial, the size of the combi units created extra work. This manifested in different ways. Because of their smaller size, iFLOW units required field modifications and sheet metal transitions to connect with existing ducting, which increased installation time.

Solution: Ensuring there is a pre-install site visit with sufficient pictures and measurements so that the installation team can either pre-fabricate sheet metal transitions or budget for additional time in the field.

4.2 Participant Perspective

4.2.1 Participant Experience, Interest, and Motivation

The research team conducted post-installation interviews to assess customer experience during combi unit installation, and their expectations and motivations for participating in the field trial. The team conducted five in-home participant interviews and one by phone using the Post-installation Interview Guide (Appendix 2).

The following subsections address research questions related to installation experience. For findings about the long-term participant experience see *Section 6.4 Participant Satisfaction*

.

Reasons for Participating

NEEA, with assistance from the research team, recruited participants from its funding natural gas utilities to take advantage of the opportunity to replace their existing water heater and furnace with new equipment. Several mentioned that they viewed the field trial as a win-win situation where they could help with research to see if combi units are a suitable water and home heating option for their area and benefit by upgrading their water heater and furnace. A few noted that they were preparing to replace one or both of these appliances in the near future and felt the timing was ideal. While none of the participants said they were aware of combi technology previously, several said they became interested in the new technology and motivated by curiosity and a desire to conserve energy. None reported any concerns about participating in the trial or about the combi system itself.

Installation Experience

All six participants were present for all or most of the installation process and were very satisfied with it. They reported that the installers were professional and courteous during their visits and they appreciated the time the Energy 350 team spent acquainting them with the system. As part of recruitment, participants were informed that the process would be longer than a typical water heater installation and none reported any issue with the time it took. Several were curious about the process and equipment and checked in periodically to ask questions.

Initial Expectation

Most participants thought there would be noticeable benefits to the new equipment. Several hoped to save money on energy given higher efficiency levels and not having to maintain the temperature of a tanked water heater. Several also expected to have more consistent heating in their homes and a steadier supply of hot water.

5. Data Collection Methodology and Analysis

This section describes the methodology used to calculate the annual energy savings and simple payback of the gas absorption heat pumps relative to the existing boiler and hot water heater system.

5.1 Instrumentation and Data Acquisition

All data is metered continuously in 1-minute intervals, which is uploaded every four hours to a secure, cloud-based data storage center for easy access.

Table 11 lists the metering equipment used in the trial and all sensor and meter accuracies. All sensors and meters were for research purposes only and are not required for a typical install. Figure 16 and Figure 17 show all metering data points and their relative location to the combi equipment.

TABLE 11 – INSTALLED METERING EQUIPMENT

ID	Parameter	Unit	Sensor/Meter	Range	Accuracy
T01	City Water Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T02	Domestic Hot Water Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T03	Water Heater Entering Water Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T04	AHU Loop Entering Water Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T05	AHU Loop Leaving Water Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T06	AHU Return Air Temp	°F	J-Type Thermocouple Omega FF-FI-24S-SLE	32 to 392°F	0.75%
T07	AHU Supply Air Temp	°F	Smart Temp Sensor Onset S-TMB-M005	-40 to 212°F	±0.36°F
T08	AHU Skin Temp	°F	Smart Temp Sensor Onset S-TMB-M006	-40 to 212°F	±0.36°F

T09	Garage/Basement Air Temp	°F	Smart Temp Sensor Onset S-TMB-M007	-40 to 212°F	±0.36°F
T10	Indoor Zone Air Temp	°F	Wireless NTC Thermistor Monnit MNS2-9-W2-TS-ST	-40 to 185°F	±0.45°F
T11	Outdoor Air Temp	°F	Wireless NTC Thermistor Monnit MNS2-9-IN-TS-ST-L03	-40 to 185°F	±0.45°F
F01	Water Heater Gas Flow	ft^3	Temperature Compensated Diaphragm Gas Flow Meter Elster American Meter AC-250	-30 to 140°F 0 to 250 SCFH (0.25 PSIG)	±0.5%
F02	Domestic Hot Water Flow	gpm	Hi-Def Hot Water Flow Meter EKM EKM-HOT-SPWM-075-HD	0 to 22 gpm 32 to 194°F	1.5% >0.89 gpm
F03	AHU Loop Water Flow	gpm	Hi-Def Hot Water Flow Meter EKM EKM-HOT-SPWM-075-HD	0 to 22 gpm 32 to 194°F	1.5% >0.89 gpm
F04	AHU Air Flow	fpm	Velocity & Temp Sensor Onset T-DCI-F350-W5B3	100 to 2,000 fpm	±4% + 20 fpm
J01	Water Heater Power	kWh	Pulse Power Meter Wattnode WNB-3Y-208-P3	48 to 62Hz	±0.5%
J02	Circulator Pump Power	amps	Split-Core Current Transformer CCS ACTL-0750-020	0 to 24 amps -22 to 131°F	±0.75% 1 to 120% rated
J03	AHU Blower Power	kWh	Pulse Power Meter Wattnode WNB-3Y-208-P3	48 to 62Hz	±0.5%
J04	AHU Total Power	kWh	Pulse Power Meter Wattnode WNB-3Y-208-P3	48 to 62Hz	±0.5%
CGD	Cellular Gateway Device	N/A	Cellular Remote Monitoring Station Onset RX3000	-40 to 140°F	±8 seconds per month

FIGURE 16 – IFLOW COMBI SYSTEM & METERING SCHEMATIC

Combi Equipment Schedule				
Tag	**Manufacturer**	**Model**	**Capacity**	**Flow**
AHU	iFLOW	iFLH-16000W	80,200 Btu/hr	1,222 CFM
TWH	Navien	NPE-240A	199,000 Btu/hr	10.1 GPM
CP	Grundfos	UPS15-58RU	19.4 ft	17.2 gpm

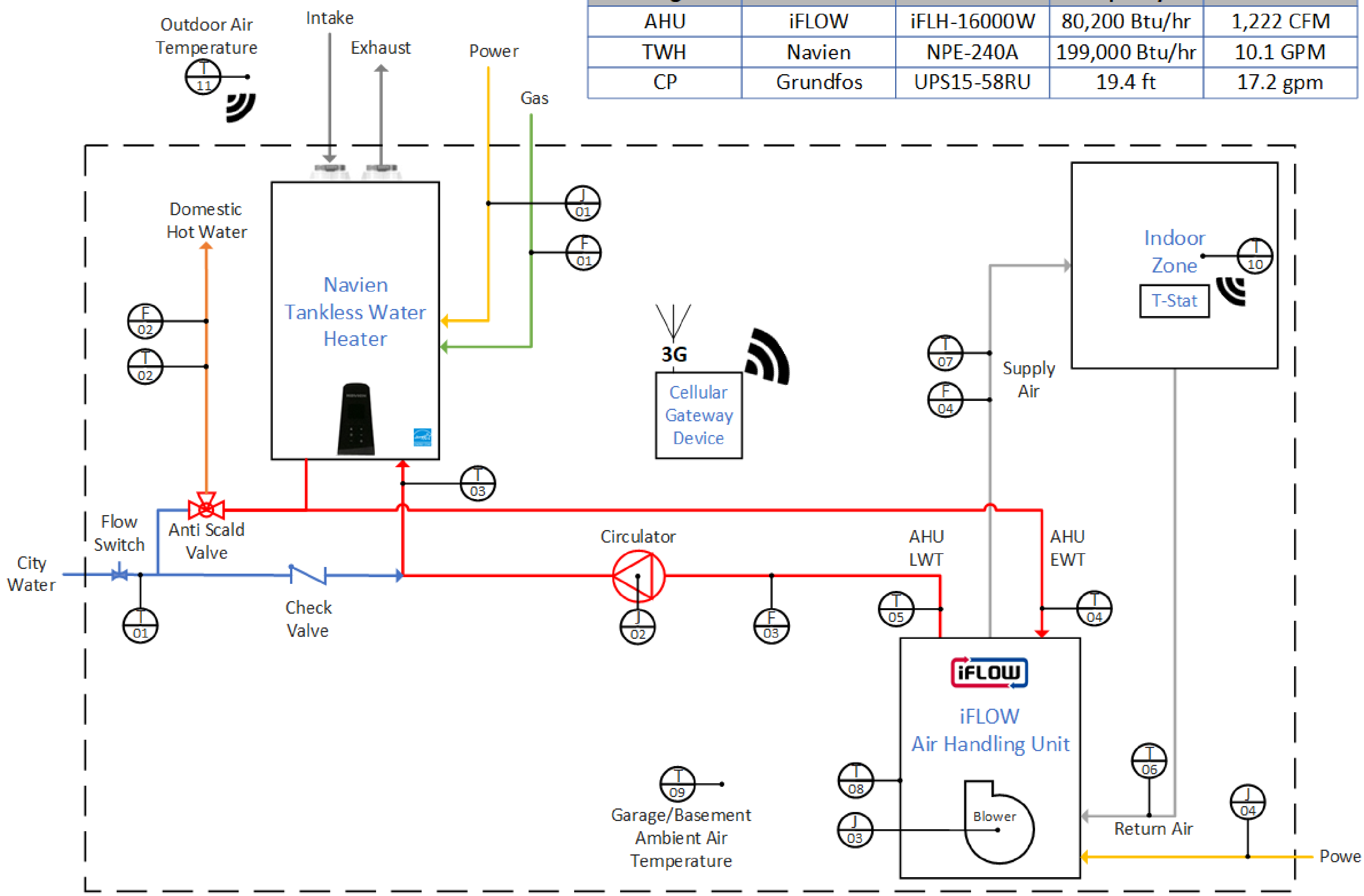


FIGURE 17 - NTI COMBI SYSTEM & METERING SCHEMATIC

Combi Equipment Schedule				
Tag	**Manufacturer**	**Model**	**Space Heating Capacity**	**DHW Heating Capacity**
AHU	NTI	GF200	19,900 – 80,000 Btu/hr	19,900 – 199,000 Btu/hr

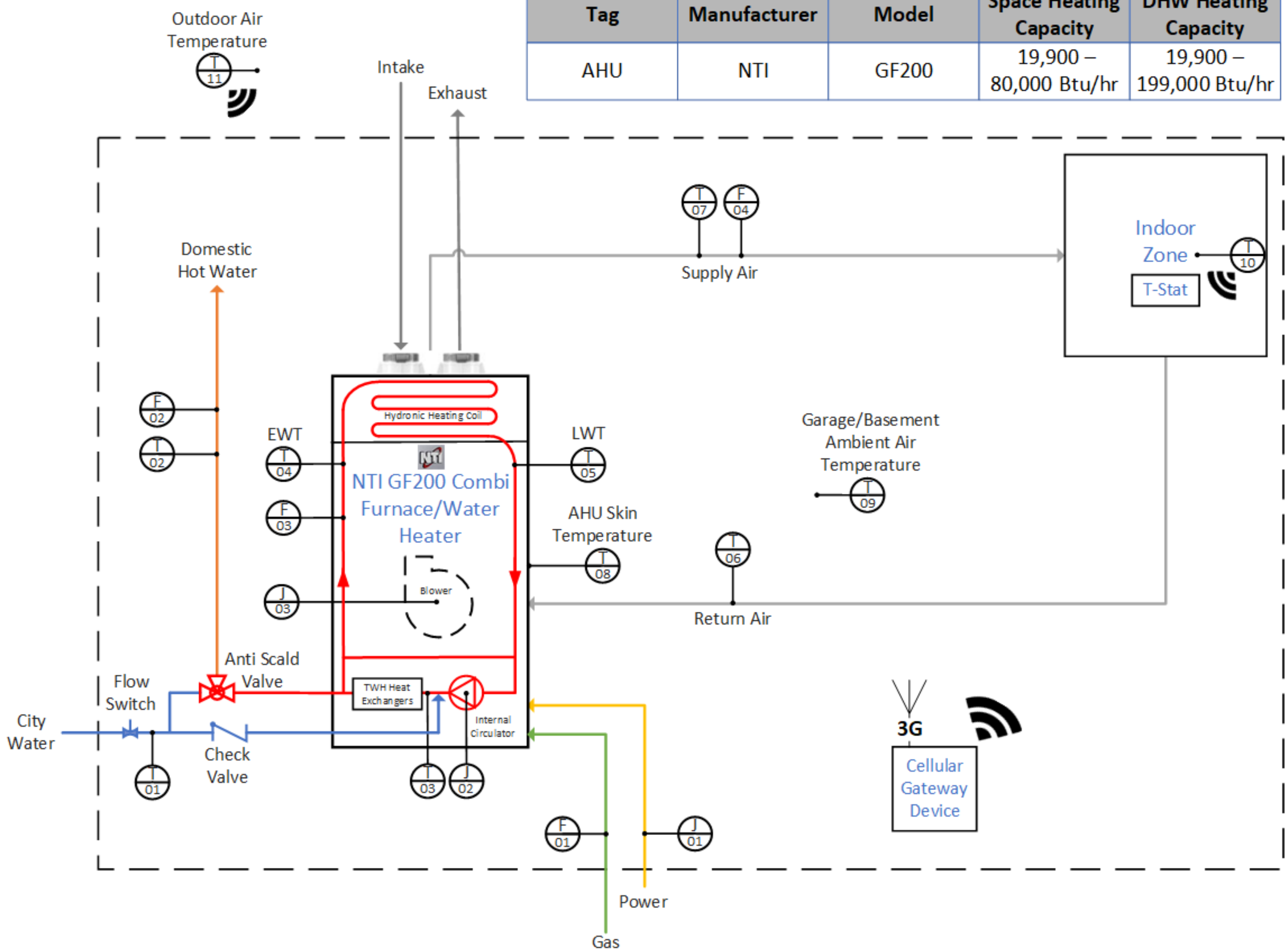


Figure 18 through Figure 23 show example data metering setups.

FIGURE 18 – DATA MONITORING HUB

FIGURE 19 – NATURAL GAS FLOW METER

FIGURE 20 – AHU HW FLOW METER INTERNAL TO NTI

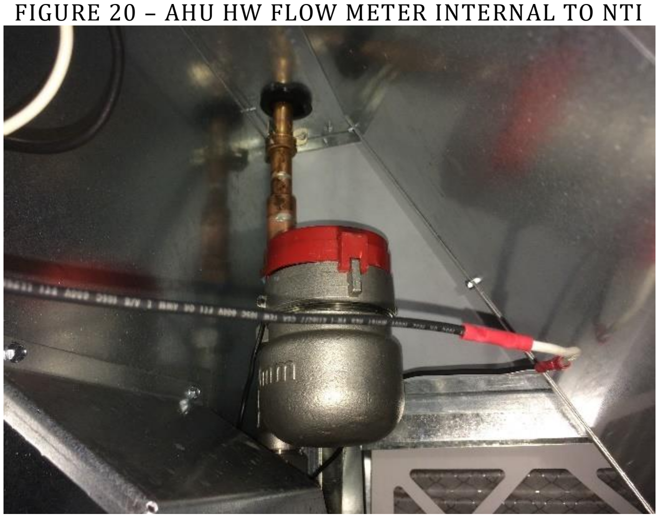


FIGURE 21 - REAL POWER METER & CT

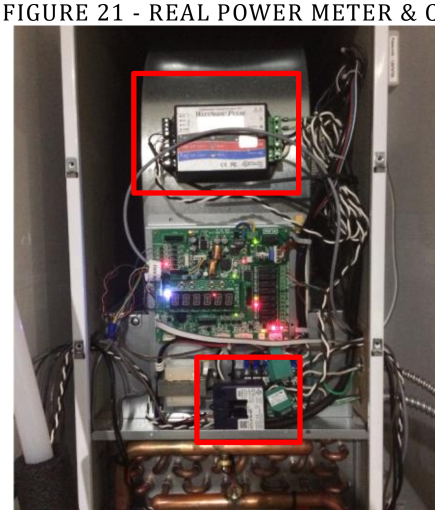


FIGURE 22 – INSULATED DHW FLOW METER

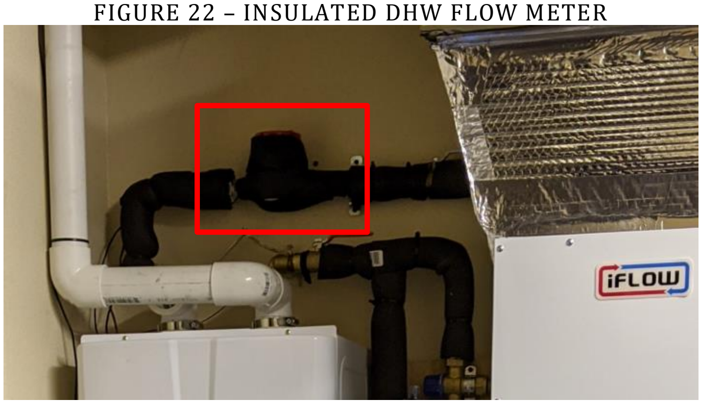
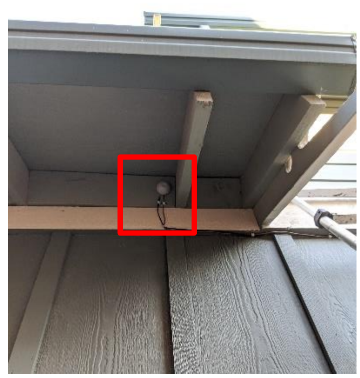


FIGURE 23 – OUTDOOR AIR TEMP SENSOR



5.2 Data Collection

All data was measured continuously in 1-minute intervals and collected using a cellular data acquisition device which was uploaded to a secure cloud-based server on 4-hour intervals. The following data was measured:

- Water temperatures: DHW Supply, Cold City Water, AHU EWT, AHU LWT, TWH EWT (°F)
- Water flow: DHW supply & hydronic space heating loop (gallons)
- Air temperatures
  - Space Heating Air: Supply/return air temperature
  - Outdoor, indoor and ambient garage
- AHU supply air velocity
- Input gas volume (ft^3)
- System power
  - AHU and total system real power/energy (kWh)
  - Circulator pump and AHU blower current (amps)

5.3 Protocols

The following section describes the calculations, equations, and adjustments used to post-process the raw data collected from the data acquisition system.

5.3.1 <u>Domestic Hot Water Heat Output</u>

The DHW heat output is calculated at one-minute intervals from the raw metered data using Equation 5.1.

$$[Eq\ 5.1]\quad Q_{DWH}\ [Btu] = V_{DHW} \times \bar{\rho} \times \bar{C}_p \times (T_{supply} - T_{city})$$

Where:
V_{DHW} = Metered volume of DHW delivered to the house [gallons]
$\bar{\rho}$ = Density of water at 120°F [lbs/gallon]
$\bar{C}_{p,DHW}$ = Specific heat of water at 90°F (midpoint of 60°F incoming and 120°F supply) [Btu/lb]
T_{Supply} = Supply temperature of the DHW measured at outlet of TWH [°F]
T_{City} = Inlet temperature of the cold city water measured at inlet of TWH [°F]

Adjustments

- T_{city} is adjusted to minimum temperature of draw (15-minute window)
- T_{supply} adjusted by dropping first two reading and averaging remaining draw temperatures

5.3.2 <u>Space Heating Heat Output</u>

Due to the challenges in accurately measuring airflow in the field, space heating heat output is calculated based on the water temperature drop across the hydronic coil. Skin losses from the AHU to the ambient are calculated based on the temperature difference between AHU exterior and the ambient air temperature as show later in Equation 5.4.

$$[Eq\ 5.2]\quad Q_{SH}\ [Btu] = V_{SH} \times \bar{\rho} \times \bar{C}_{p*} \times (T_{EWT} - T_{LWT})$$

Where:
V_{SH} = Volume of hot water measured through the AHU heating coil [gallons],
$\bar{\rho}$ = Density of water at 120°F (midpoint of 100°F LWT and 140°F EWT) [lbs/gallon],
$\bar{C}_{p*}$ = Specific heat of water at 120°F (midpoint of 100°F and 140°F) [Btu/lb],
T_{EWT} = Temperature of water entering the AHU heating coil [°F]
T_{LWT} = Temperature of water leaving the AHU heating coil [°F]

Adjustments

- T_{EWT} and T_{LWT} for the first two minutes of a space heating cycle are dropped and replaced with the average entering and leaving water temperatures for the following 15-minutes are used
- For the iFLOW units which use a 2 minute heat flush feature, an air side heat calculation is used while there is no water flow through the coil but hot air continues to be delivered [1.08 x CFM x (T_{supply} – T_{return})]

5.3.3 Combi System Energy Input

The combi system energy input is measured by a volumetric gas flow meter and adjusted by the site specific daily or monthly heat content factors (HHV) provided by the utilities as shown in Equation 5.3.

$$[Eq\ 5.3]\quad Q_{NG}\ [Btu] = V_{NG} \times HHV$$

Where
V_{NG} = Volume of natural gas measured into the combi system [ft^3]
HHV = Higher Heating Value (HHV) of natural gas [Btu/ft^3]

5.4 Analysis

5.4.1 Combi System

The energy inputs and outputs from Equations 5.1-3 are summed over hourly, daily, and annual intervals using Equation 5.4.

$$[Eq\ 5.4]\quad Field\ Efficiency\ Factor = \frac{Net\ Combi\ Heat\ Output}{Natural\ Gas\ Input} = \frac{Q_{SH} + Q_{DHW} - Q_{shell}}{Q_{NG}}$$

Where:
Q_{DHW} = Heat output from water heater over a given interval [Btu]
Q_{SH} = Heat output from AHU over a given interval [Btu]
Q_{shell} = Heat loss from the AHU to the ambient (garage or basement) [Btu]
Q_{NG} = Energy input from natural gas [Btu]

The annual Field Efficiency Factor (FEF) is calculated using the following methodology:

1. Calculate daily SH and DHW usage from Equations 5.1 and 5.2. (Figure 24 and Figure 25)
2. Calculate daily heating degree days (HDD_65) from local weather station and correlate with SH load. (Figure 26)
3. Calculate daily total system efficiency (DHW & SH) and correlate to daily space heating utilization (percent of full load) (Figure 27)
4. Apply space heating equations to HDD from typical weather year data to get daily space heating load for annual model (TMY3).
5. Apply actual DHW usage from field trial to annual model.
6. Split year into “space heating” and “non-space heating” days based on HDD cutoff (i.e. <3 HDD/day is a non-heating day for Site 2).
7. For space heating days calculate total system efficiency based on daily space heating percent of full load.
8. Calculate gas input by dividing total DHW and SH load by daily efficiency.
9. For non-space heating days calculate DHW only efficiency relative to daily water usage and apply to daily water usage.
10. Sum annual DHW and SH output heat and divide by annual gas input as shown in Equation 5.4 to calculate annual FEF.

Figure 24 through Figure 27 show example trends and correlations referenced in the FPF methodology.

FIGURE 24 – DAILY DHW USAGE

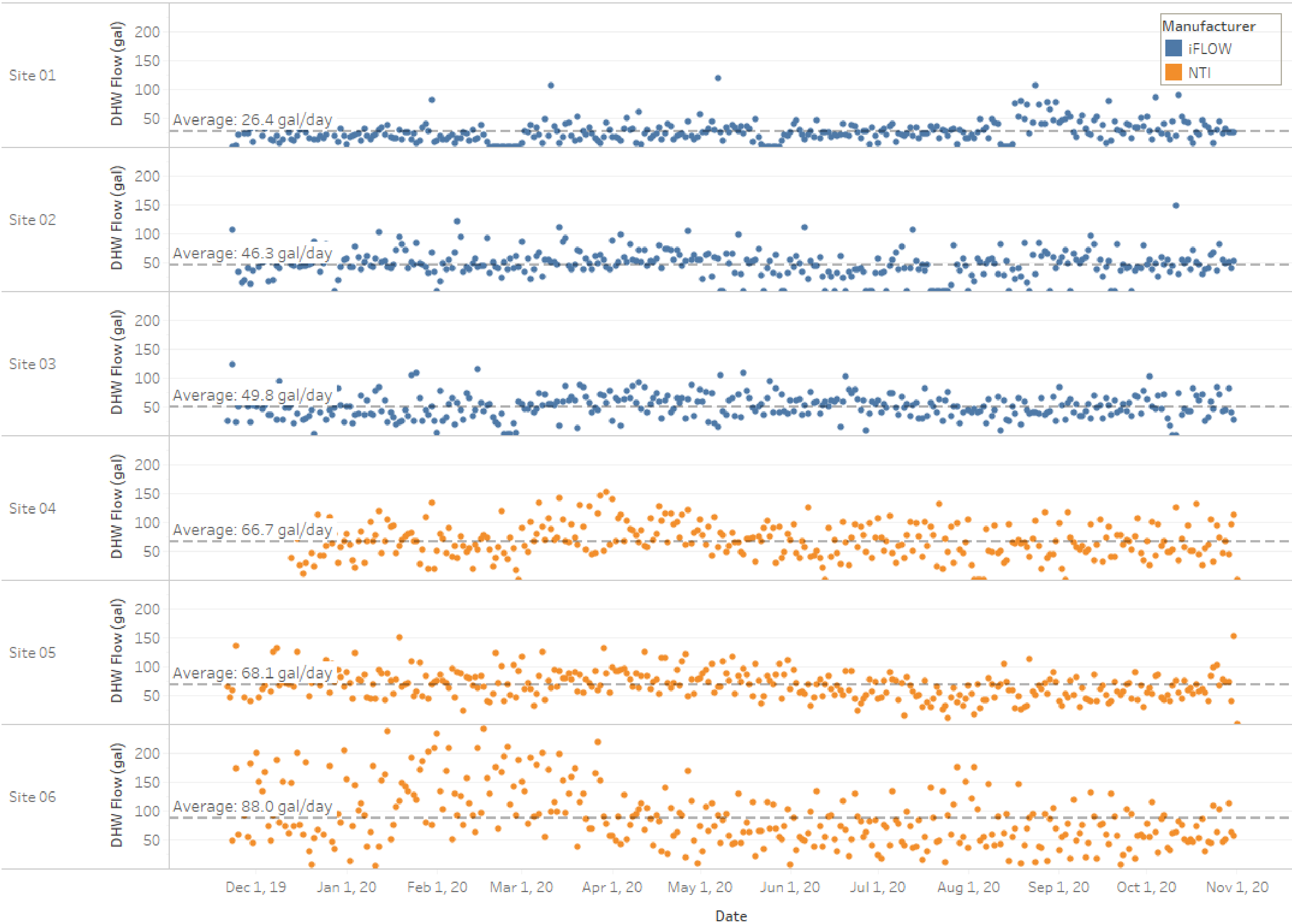


FIGURE 25 – DAILY SPACE HEATING LOADS

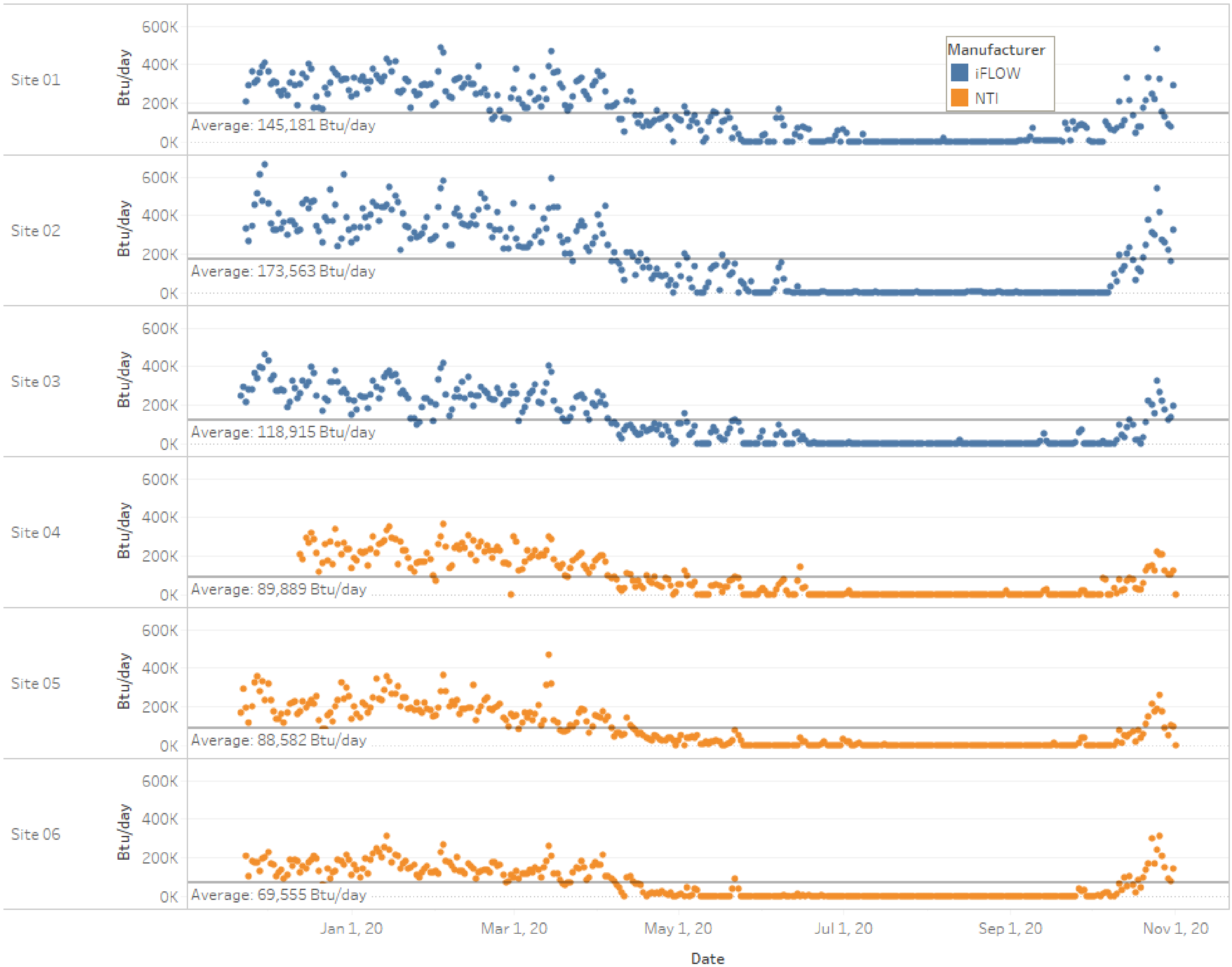


FIGURE 26 – DAILY SPACE HEATING LOAD (OUTPUT HEAT) VERSUS HDD

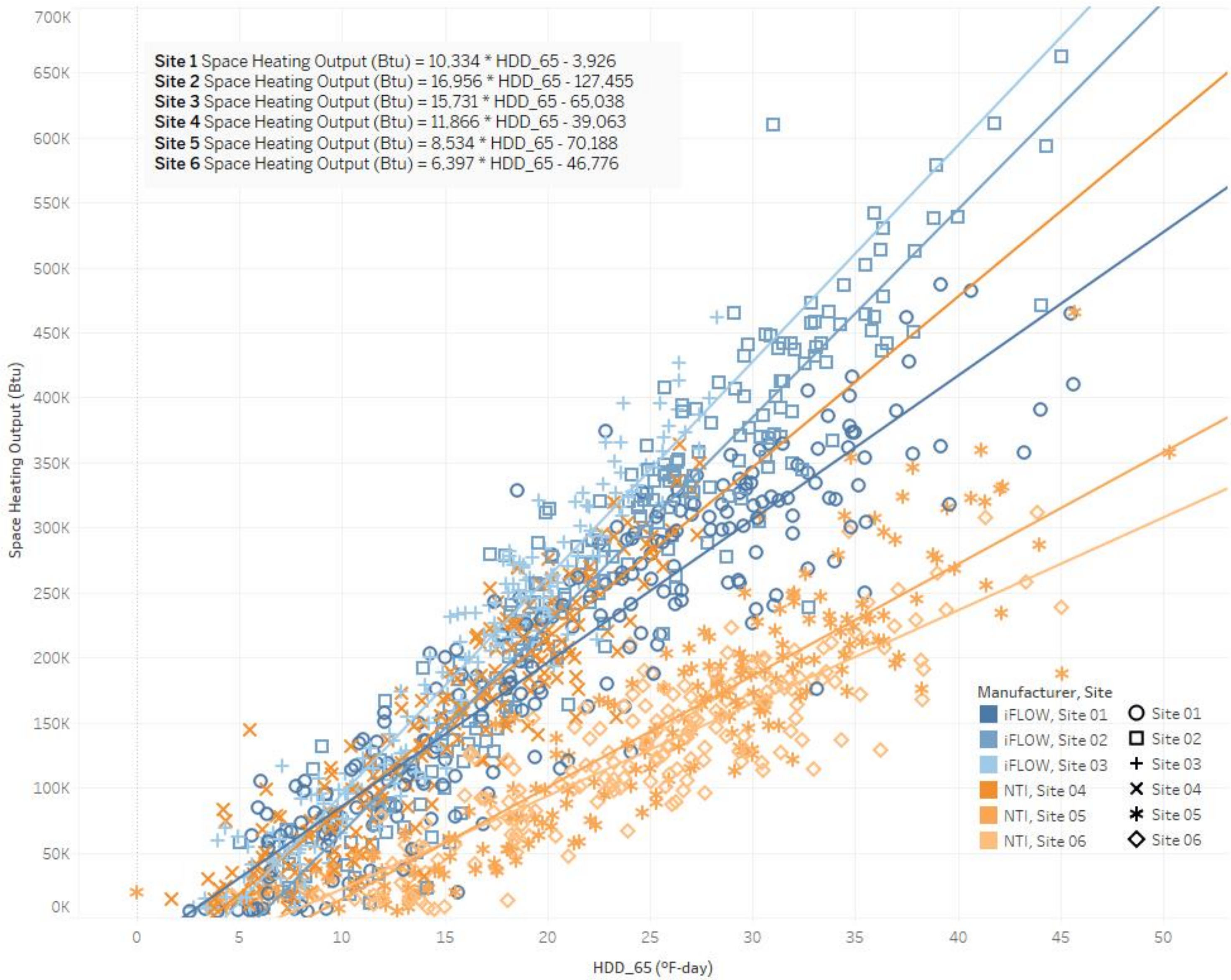
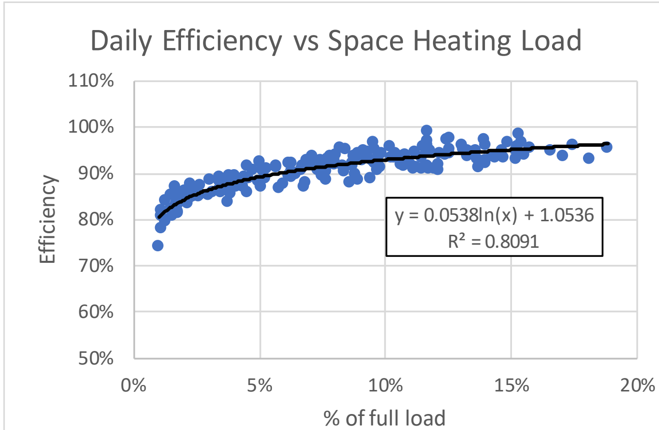


FIGURE 27 – SITE 4 EFFICIENCY VERSUS DAILY PERCENT OF FULL LOAD



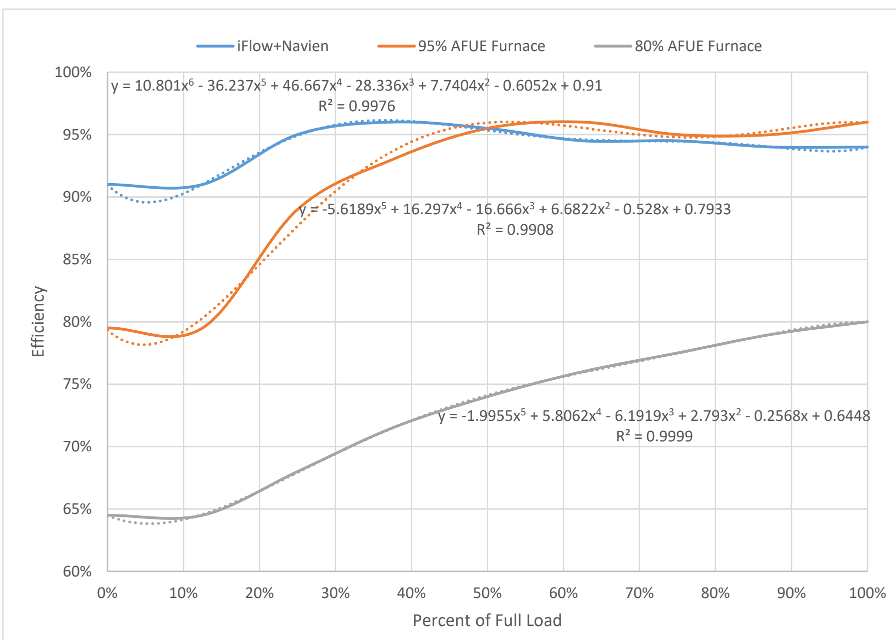
5.4.2 Conventional DHW and SH System

The conventional systems modeled include the following:

1. Gas forced air furnace (FAF) with 80% AFUE + 40-gallon tank water heater with 0.62 UEF
2. Condensing gas FAF with 95% AFUE + 40-gallon tank water heater with 0.62 UEF

Water heater efficiency was assumed to align with UEF but conventional furnace space heating efficiencies were calculated based on part load efficiency curves generated in lab testing as shown in Figure 28 (NEEA, 2019).

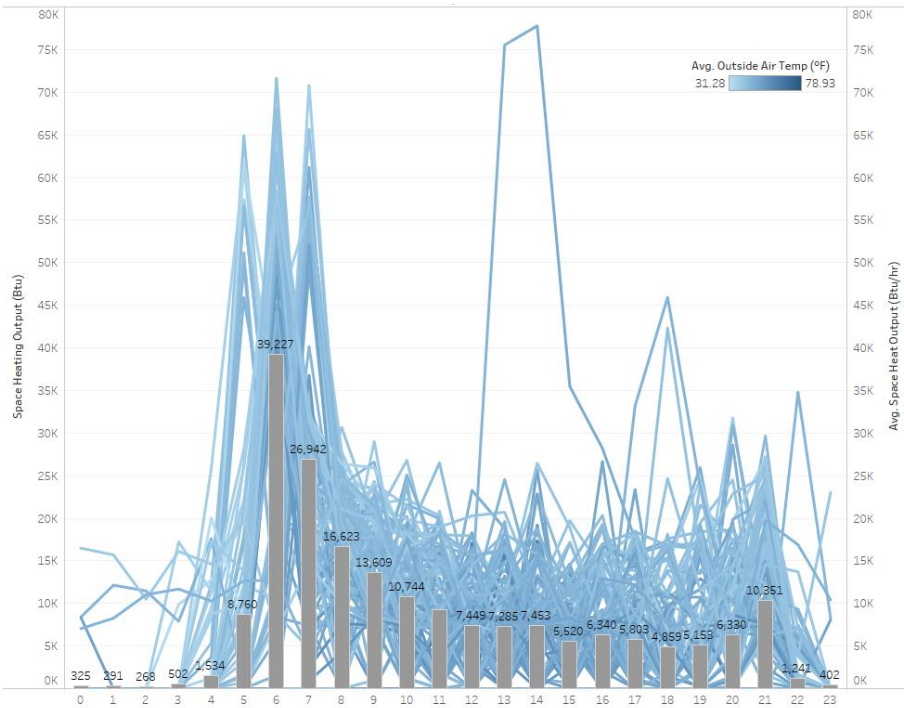
FIGURE 28 – PART LOAD EFFICIENCY CURVES



The daily space heating load calculation for a typical weather year as described in *Section 5.4.1 Combi System* was also used for the conventional space heating load. However, the daily loads were then disaggregated into an hourly load based on the typical space heating load profile for each site. Figure

29 shows the space heating load profile for site 4. The bars show an average for the given hour of the day during the heating season. The proportion of space heating load for each hour was applied to the daily space heating load.

FIGURE 29 – SITE 4 DAILY SPACE HEATING LOAD



5.4.3 Gas Energy Input

Diaphragm gas meters were installed to monitor the volumetric gas flow (cubic foot pulses) into the heat pumps. All meters are temperature-compensated and equipped with electronic pulse output. The daily or monthly gas energy content values, in higher heating values (HHV), were provided by the sites' natural gas utility. Table 12 lists the average monthly gas energy factors as provided by the utility.

TABLE 12 – AVERAGE MONTHLY GAS ENERGY CONTENT FACTORS (BTU/FT^3)

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Location	Bend, OR	Bend, OR	Portland, OR	Portland, OR	Spokane, WA	Spokane, WA
Utility	Cascade	Cascade	NWN	NWN	Avista	Avista
November-2019	933	933	1,090	1,068	986	986
December-2019	933	933	1,099	1,073	988	988
January-2020	933	933	1,102	1,080	987	987
February-2020	934	934	1,097	1,075	985	985
March-2020	937	937	1,085	1,062	988	988
April-2020	933	933	1,077	1,054	982	982
May-2020	930	930	1,089	1,065	980	980

June-2020	928	928	1105	1079	979	978
July-2020	929	929	1110	1084	978	978
August-2020	937	937	1121	1095	987	987
September-2020	932	932	1103	1076	983	983
October-2020	947	946	1097	1075	999	999
Average	**934**	**934**	**1,092**	**1,069**	**985**	**985**

6. Results

6.1 Field Test Performance Results

Table 13 shows key performance results from the field trial data from November 2019 through October 2020. Each system was monitored for over 320 days (341 days on average). These results are not annualized or normalized for a typical weather year. For annualized results see *Section 6.2 Annualized Energy Savings Results*. On average the combi systems performed with a total field efficiency of 86.6% ranging from 80.5% to 94.1% over the field test monitoring period.

TABLE 13 – FIELD RESULTS TO DATE

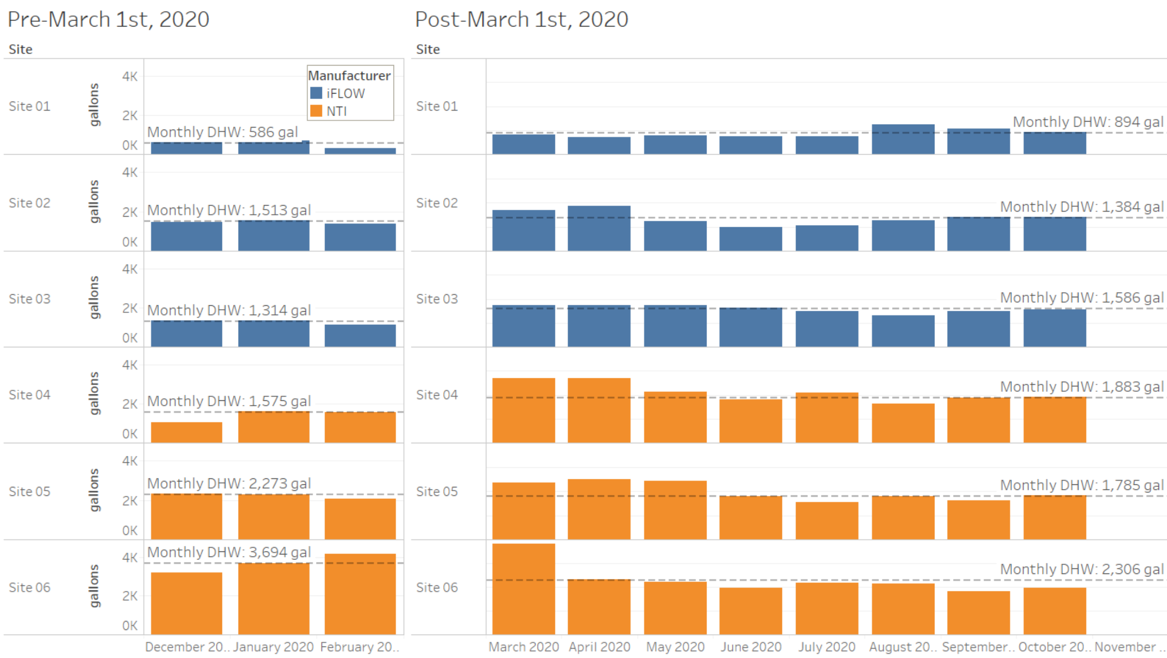
Site ID	Tech	Location	Thermostat	Data (days)	Avg. OAT (°F)	HDD (°F-day)	System Efficiency (gas only)	System Electric Consumption (kWh)	DHW (gal/day)	Avg. Heat Cycle (min)	TWH EWT (°F)	SAT (°F)	Airside ΔT (°F)
1	iFLOW	Bend, OR	Standard	344	52.4	5,417	80.5%	726.2	26.4	10.2	111.3	108.6	35.6
2	iFLOW	Bend, OR	Ecobee	344	50.6	5,833	94.1%	604.9	46.3	60.9	97.4	102.4	33.7
3	iFLOW	Portland, OR	Standard	346	56.2	3,628	84.6%	512.0	49.6	14.5	105.3	98.4	31.9
4	NTI	Portland, OR	Nest	324	56.5	3,420	90.2%	412.7	66.9	29.8	88.7	102.2	30.7
5	NTI	Spokane, WA	Programmable	346	50.3	5,856	86.6%	651.9	68.3	17.2	100.5	102.6	36.4
6	NTI	Spokane, WA	Programmable	344	50.4	5,787	83.8%	396.4	88.0	12.6	102.0	102.4	30.1
Average:				341	52.8	4,990	86.6%	550.7	57.6	24.2	100.8	102.8	33.1

6.1.1 COVID-19 Impact

The metered data collection period overlapped with the COVID-19 stay at home guidelines provided across both Oregon and Washington. However, participants reported via interviews that they were relatively unaffected by COVID-19-related changes, because they were either already retired, working from home part- or full-time, or still working as essential workers. Metered data confirms that there was no significant change in DHW or space heating loads at any of the sites between the pre- and post-COVID-19 period.

As seen in Figure 30, three of the six sites had lower DHW usage post-March 1st, 2020. Four of the sites (2, 4, 5 and 6) did appear to have a short-term bump in usage in March but returned to more typical usage in April or May. Regardless, the field test DHW usage of the six sites (26-88 gallons per day) is well within typical usage for Northwest residences with 2-6 occupants. We believe both the total space heating and DHW loads and system performance were not significantly altered by the extremely atypical year 2020 has been. For more information see *Appendix E. Pre- and Post-COVID DHW & SH Load Comparison*.

FIGURE 30 – MONTHLY DHW USAGE PRE- AND POST-MARCH 1ST, 2020



6.1.2 DHW Usage

Daily site DHW usage varied greatly and ranged from 26 to 88 gallons per day (gpd) with an average across the six sites of 57.6 gpd. This translates to an average of 13.6 MMBtu of DHW load or about 23% of total combi system output. However, the proportion of DHW load ranged greatly as well with DHW accounting for 8.8% of the system load at Site 1 and 40.2% at Site 6. These differences are primarily due to the relationship between the number of occupants and the size and construction of the residence. Figure 31 shows the proportion of DHW load over the duration of the field trial for each site, and Figure 32 and Figure 33 show the daily and monthly DHW consumption of the six sites.

FIGURE 31 – ANNUAL DHW PROPORTION OF TOTAL COMBI LOAD

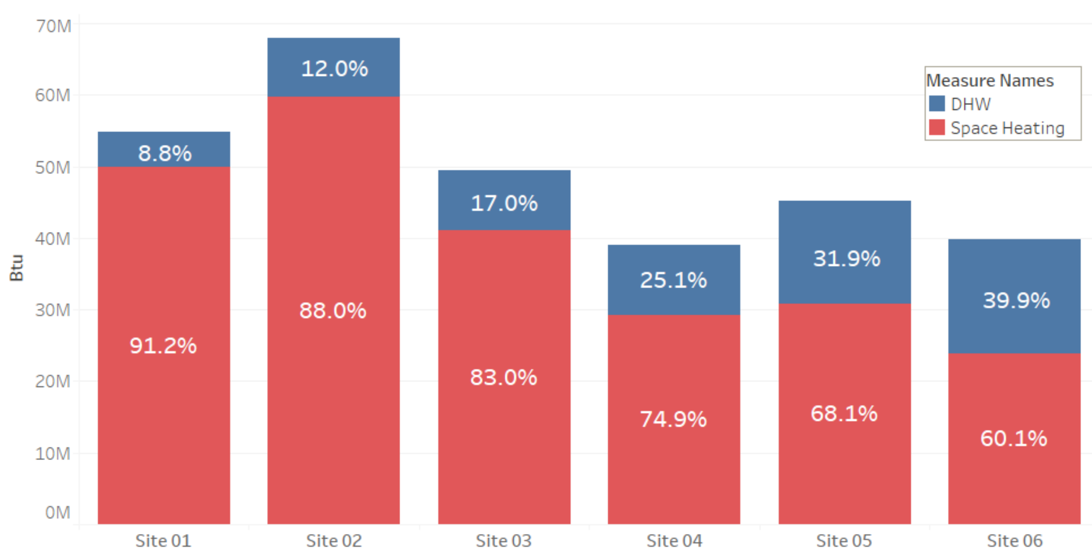


FIGURE 32 – DAILY DHW USAGE

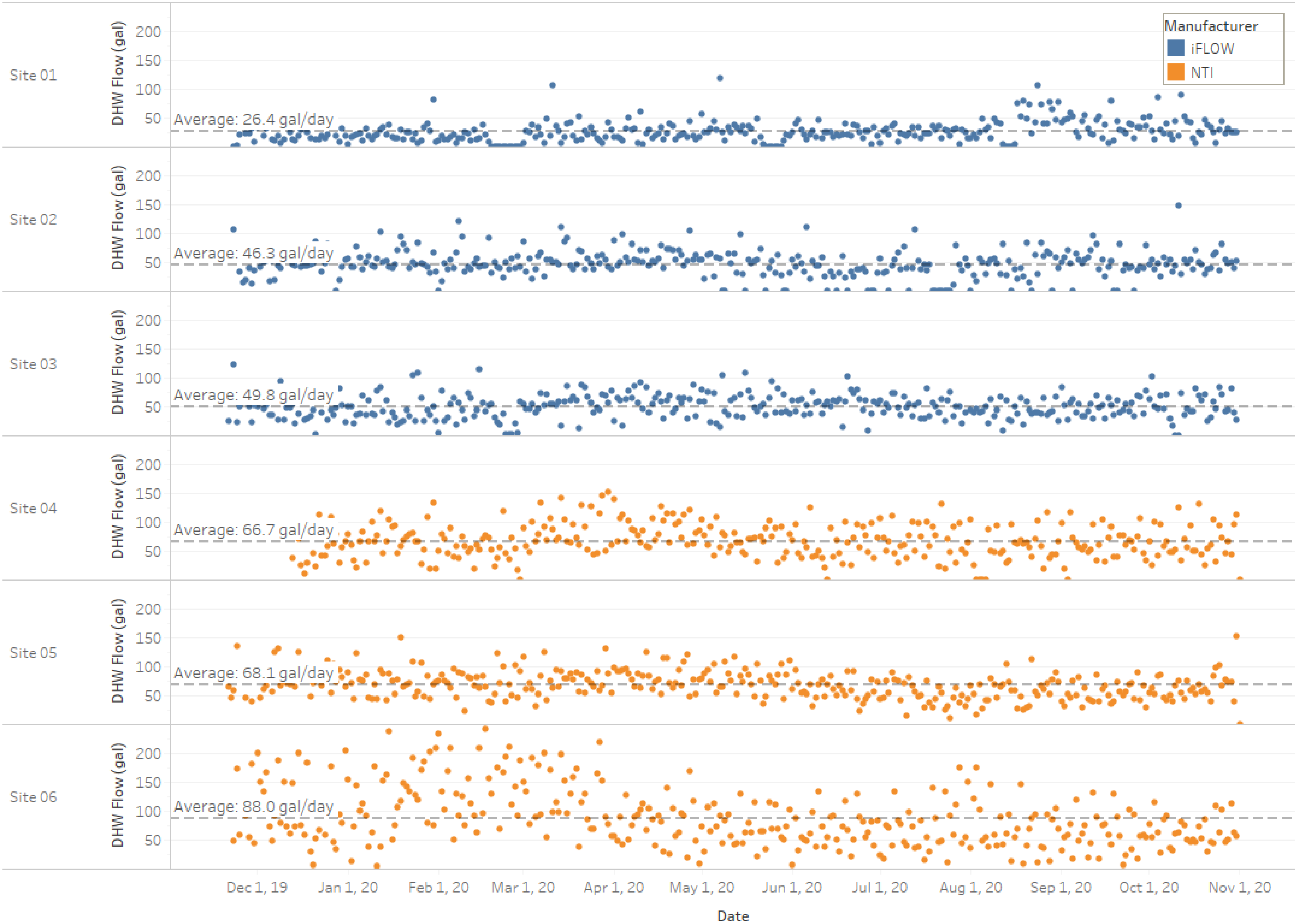


FIGURE 33 – MONTHLY DHW USAGE

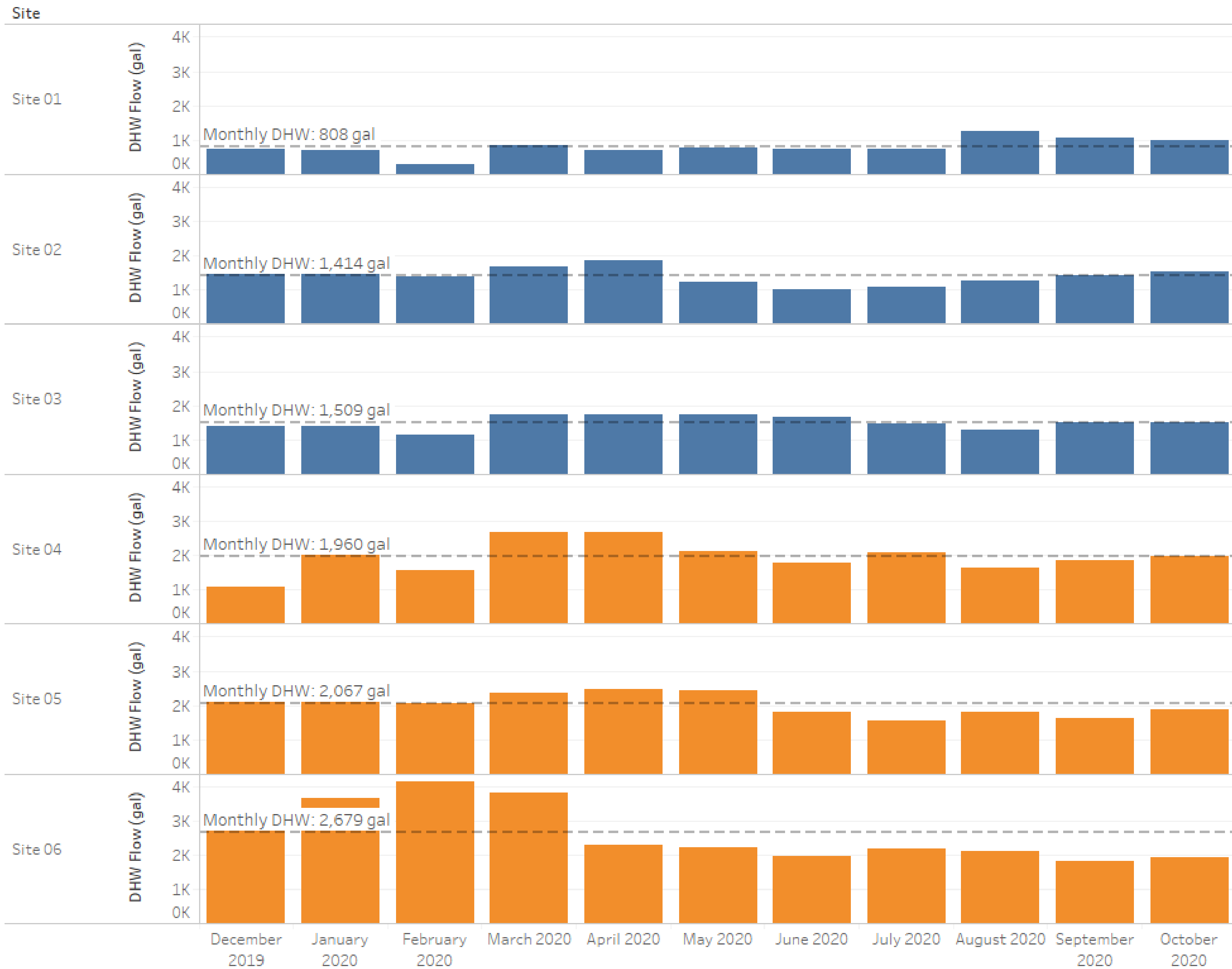
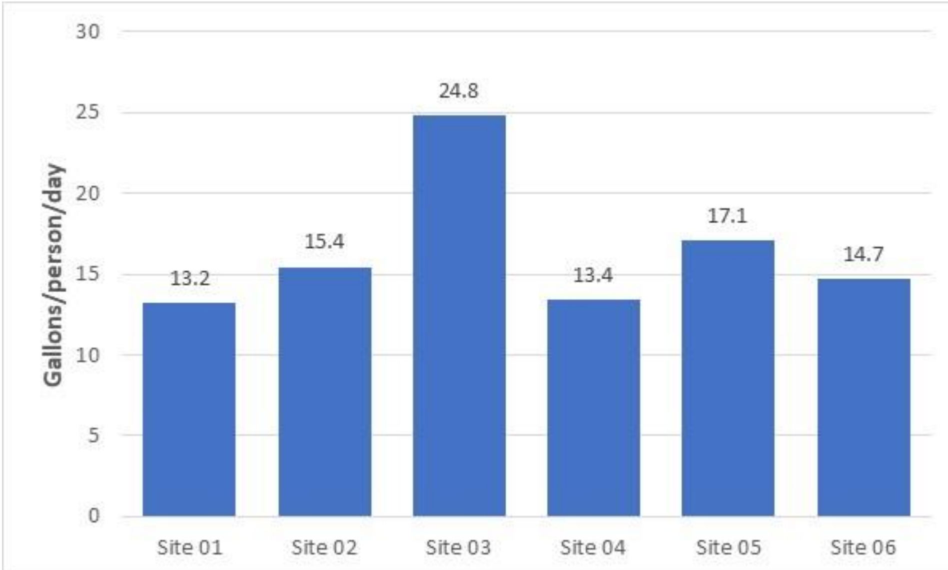


Figure 34 shows the average daily DHW draw of the six sites normalized by number of occupants. On average the sites drew 16.4 gallons per person per day.

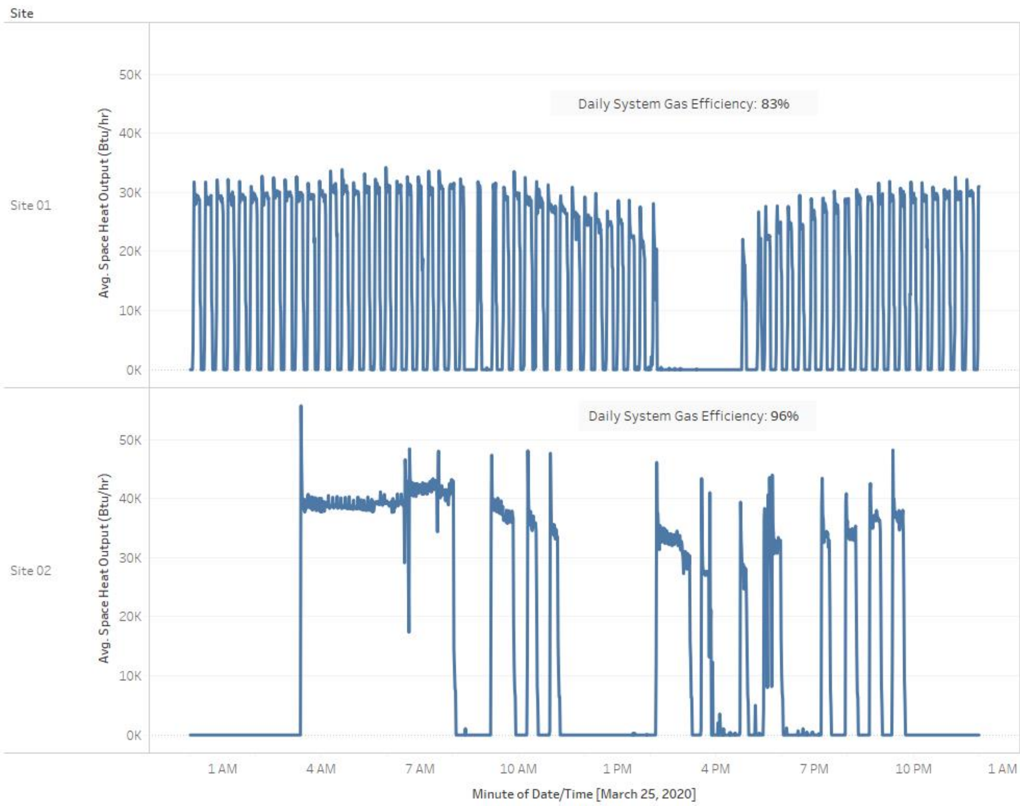
FIGURE 34 – DAILY DHW DRAW NORMALIZED BY NUMBER OF OCCUPANTS



6.1.3 Short Cycling

The sites with the longest space heating cycles tended to perform with the highest efficiency, and conversely the sites with the shortest cycles performed with the poorest efficiency. Figure 35 shows a 24-hour period of space heating output on March 25, 2020 from Site 1 and Site 2 which are both located in Bend, OR and have the iFLOW + Navien combi system. The Site 1 AHU cycles every 20 minutes (15 minutes on, 5 minutes off) resulting in over 50 cycles that day and a daily gas efficiency of 83%. On the same day, Site 2 which uses a smart thermostat with temperature setbacks at night and midday and a larger hysteresis (the difference between the temperature at which the thermostat switches on and off) comes on for one long cycle in the morning (4 ½ hours) and then with cycles ranging from 30 to 90 minutes the rest of the day. The daily efficiency for Site 2 on this day was 96%. In general, thermostats with scheduled temperature setbacks and larger hysteresis not only reduce the space heating load by decreasing the temperature difference between indoors and outdoors, but then tend to allow longer heating cycles which can also increase the efficiency of the system. Both scheduled setbacks and hysteresis are adjustable in most smart and programmable thermostats.

FIGURE 35 – SITE 1 SHORT CYCLING



While the temperature setbacks help alleviate short cycling, the minimum capacity of the water heater can be an issue for the performance at all sites. Figure 36 shows the average hourly space heating load of the six sites during the heating season and the minimum heat capacity of the water heater for reference. The sites without any temperature setbacks (Site 1, 3 and 6) have flatter load profiles and there is not a single hour during the day with an average space heating load above the minimum capacity. This results in relatively short cycle times on all but the coldest days. Even the sites with temperature setbacks enabled have 2-4 hours during the day with average space heating loads above the minimum heat output of the TWH. For this reason, it is critical that a heat source is properly selected to meet the space heating and DHW load (not oversized) and the TWH has high turndown and good part-load efficiency.

FIGURE 36 – DAILY SPACE HEATING LOAD PROFILES

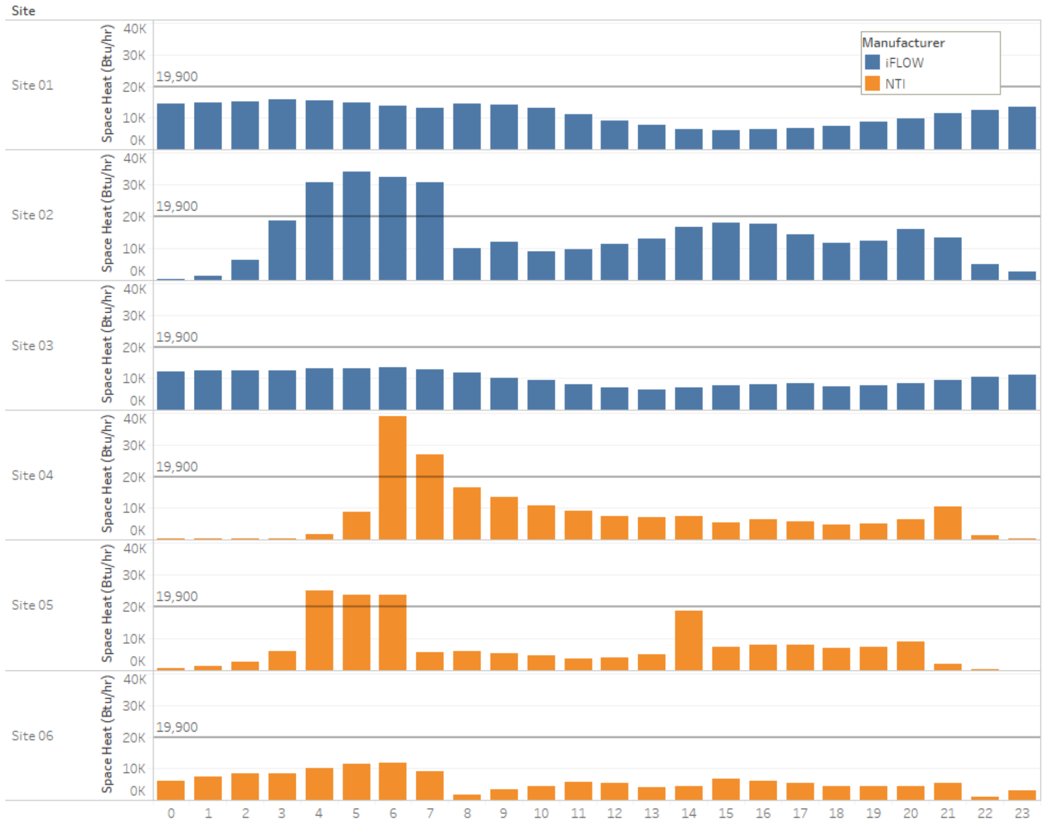
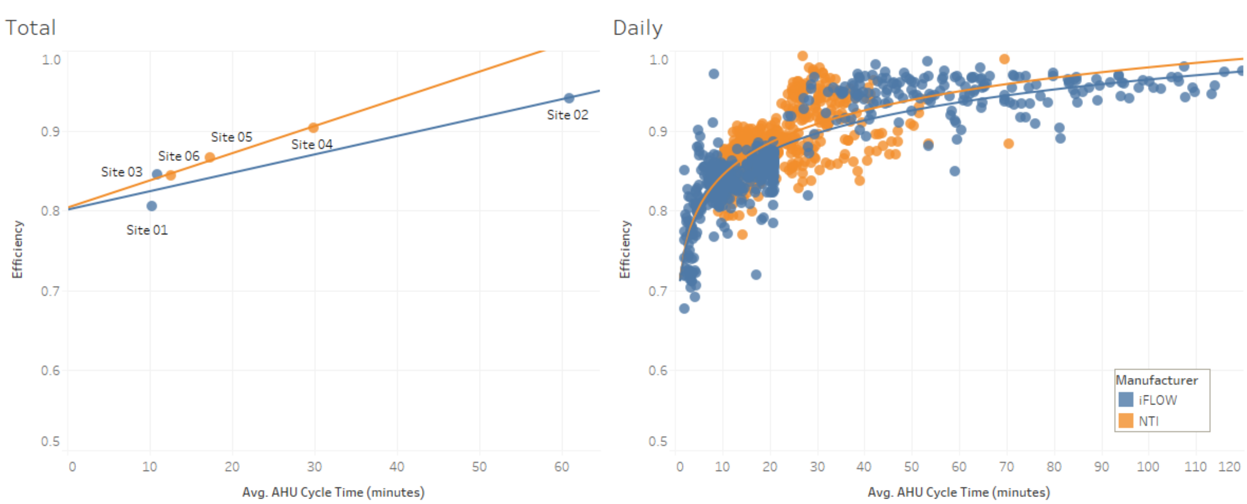


Figure 37 shows the strong relationship between cycle time and system efficiency on both a daily and total basis. The systems with the longest and fewest number of cycles have the highest efficiencies.

FIGURE 37 – TOTAL SYSTEM EFFICIENCY VERSUS AHU CYCLE TIMES (ALL SITES)



6.1.4 DHW Draws Coincident with Space Heating

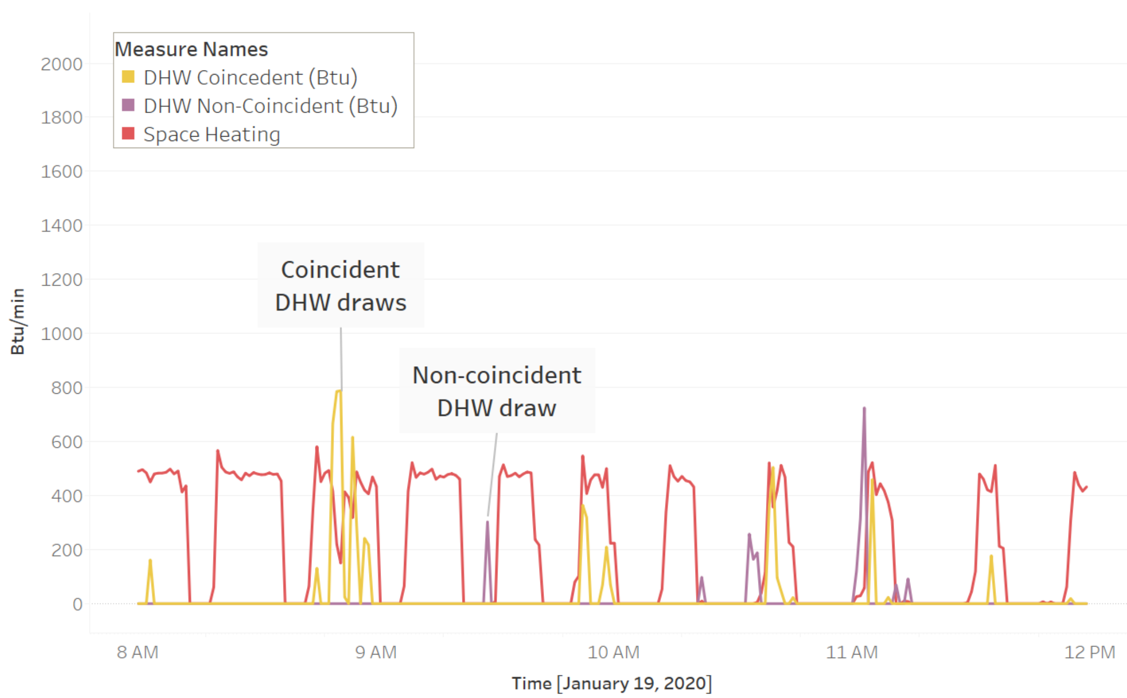
Table 14 summarizes the percent of DHW load that was coincident with space heating loads and the DHW load as a percent of the total combi system load (DHW and space heating). On average across the six sites, 18.4% of DHW load was coincident with space heating annually. Another way to say this is that approximately 81.6% of DHW draws took place when there was no call for heating.

TABLE 14 – DHW LOAD COINCIDENT WITH SPACE HEATING SUMMARY

Site ID	Tech	Coincident DHW Load (Btu)	Non-Coincident DHW Load (Btu)	Percent Coincident DHW	Percent DHW Load of Total (%)	Total System Gas Efficiency (%)
1	iFLOW	1,214,925	3,589,208	25.3%	8.8%	80.5%
2	iFLOW	2,514,591	5,642,628	30.8%	12.0%	94.1%
3	iFLOW	1,404,311	6,971,325	16.8%	17.0%	84.6%
4	NTI	946,431	8,839,152	9.7%	25.1%	90.2%
5	NTI	2,404,865	12,006,808	16.7%	31.9%	86.6%
6	NTI	1,719,709	14,158,845	10.8%	39.9%	83.8%
Average:		1,700,805	8,534,661	18.4%	22.5%	86.6%

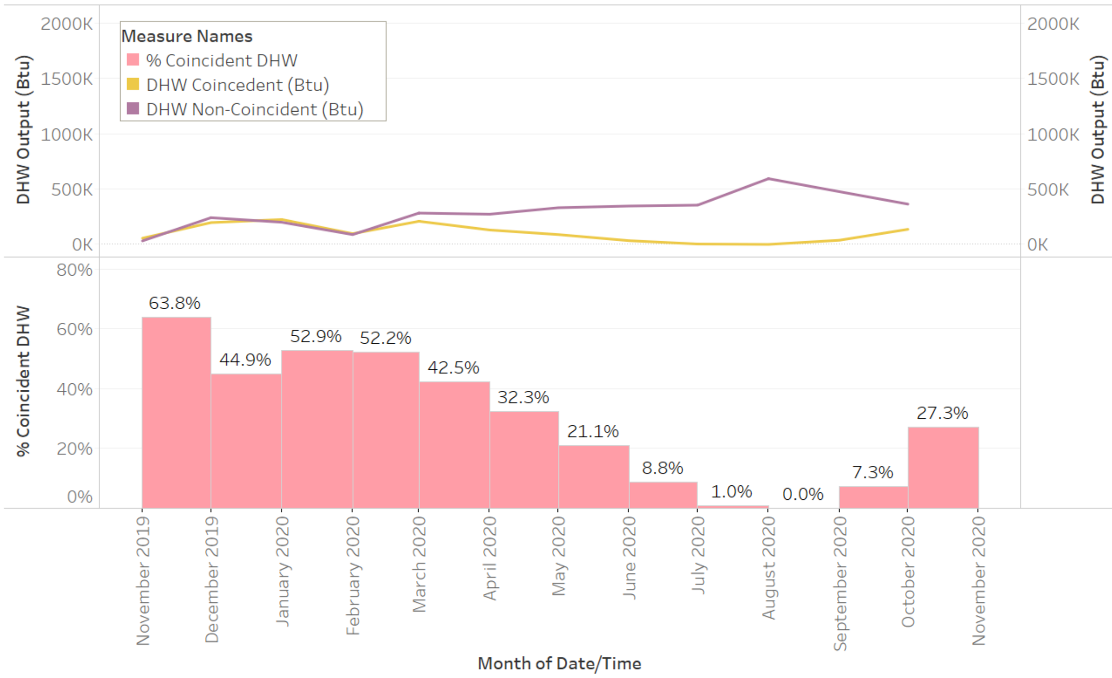
Figure 38 shows a time series of space and DHW draws and space heating cycles. Since Site 1 has a very high cycle rate with very little time between calls for heat, the DHW draws are likely to be coincident with space heating.

FIGURE 38 - COINCIDENT DHW DRAWS (SITE 1)



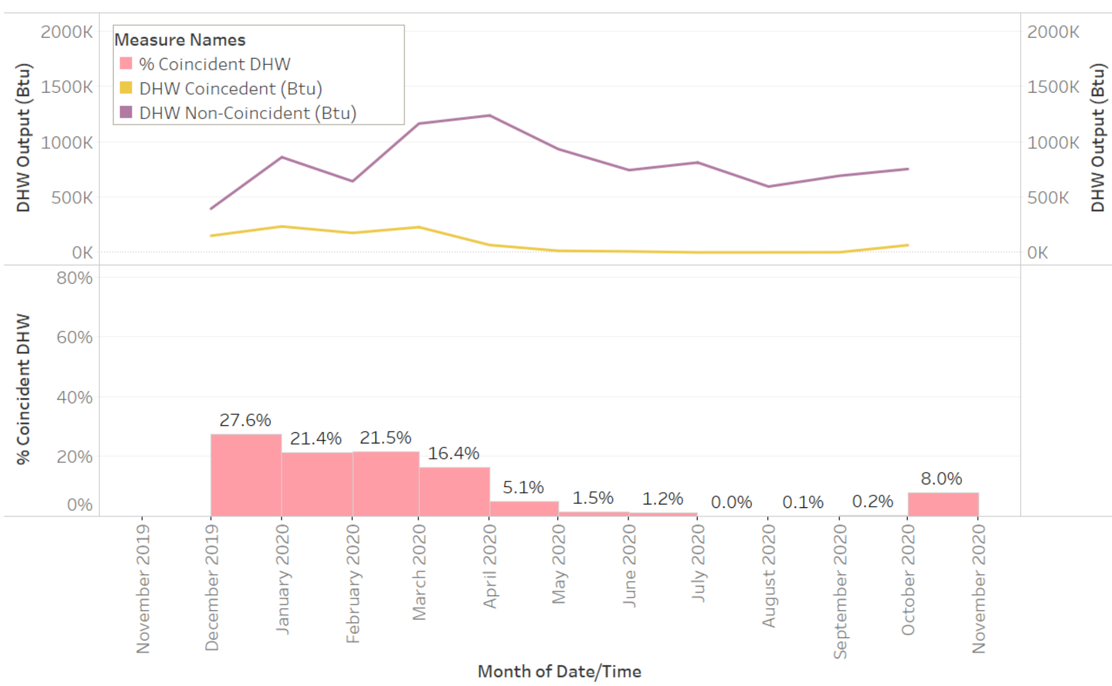
In fact, during many winter months over half of all DHW load was coincident with space heating. However, the coincidence is very low during the warmer summer months as there is almost no heating load (see Figure 39).

FIGURE 39 – MONTHLY COINCIDENT DHW DRAWS (SITE 1)



Site 4 had relatively low coincident DHW loads even in the winter heating months as shown in Figure 40.

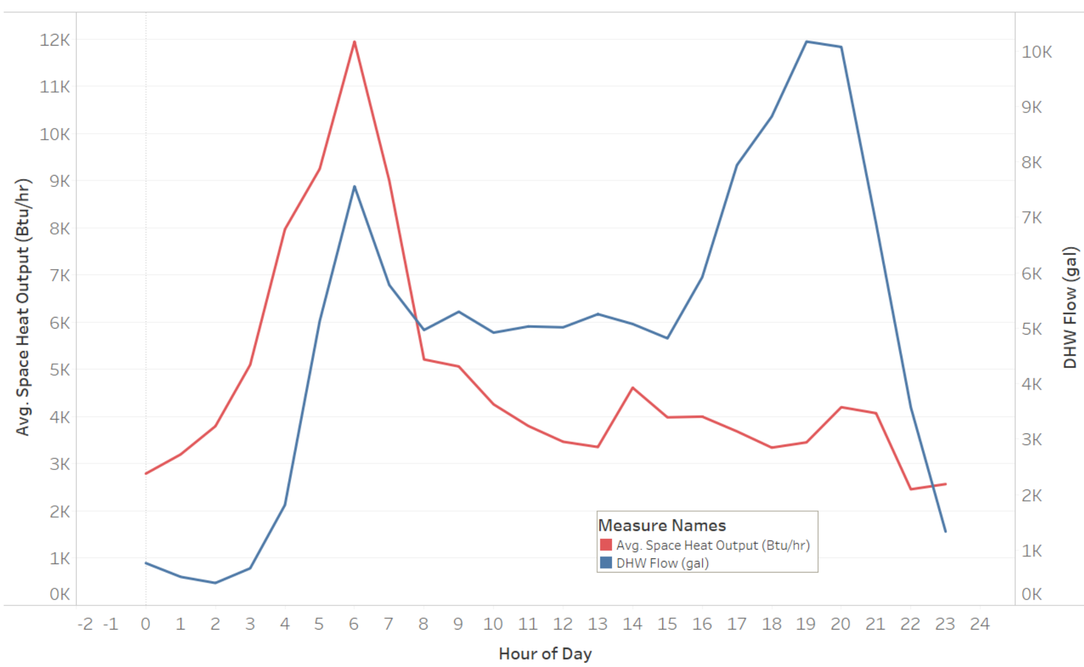
FIGURE 40 – MONTHLY COINCIDENT DHW LOAD (SITE 4)



The low coincidence of the DHW and space heating at site 4 can be seen in Figure 41 and Figure 42 which show that a majority of the DHW draws took place between 3 and 11 pm while the peak heating load took place between 5 and 8 am. This may be partially due to the site's night setback schedule. Despite site 4's low coincidence, the site had the second highest annual efficiency at 91% due to long cycle times and a high amount of condensing operation which is discussed in *Section 6.1.5 TWH Condensing Operation* below.

FIGURE 41 – COINCIDENT DHW DRAWS (SITE 4)

FIGURE 42 – DHW & SPACE HEATING LOAD PROFILES (SITE 4)



6.1.5 TWH Condensing Operation

With multiple sites have total system efficiencies below 85% it is clear that the tankless water heater was not always condensing during space heating. While we did not actively measure weather the TWH was condensing or not, we did meter the water temperature entering the TWH (TWH EWT). Especially when there is no coincident DHW load, if the TWH leaving water temperature (LWT) setpoint is too high or the temperature drop across the AHU coil is too low, the water returning to the TWH will fall be above 100°F and the unit is unlikely to be condensing. To get a sense of how often the TWH was condensing we assume than if the TWH EWT is above 100°F it will not be condensing, and anytime TWH EWT is below 100°F it will be condensing.

Figure 43 shows each site's total efficiency compared to the percent of total heating load in which the THW EWT was below 100°F as well as the average TWH EWT during heating. Site 1 which has the lowest efficiency of the six had an average TWH EWT of 111.3°F and was condensing less than 10% of total DHW and space heating loads. This may have had an even larger effect on system performance than the short cycling issues noted in the previous section. Conversely, site 2 was in condensing operation over 77% of the heating load and the average TWH EWT 95°F.

FIGURE 43 – SITE EFFICIENCY RELATIVE TO CONDENSING OPERATION & TWH EWT

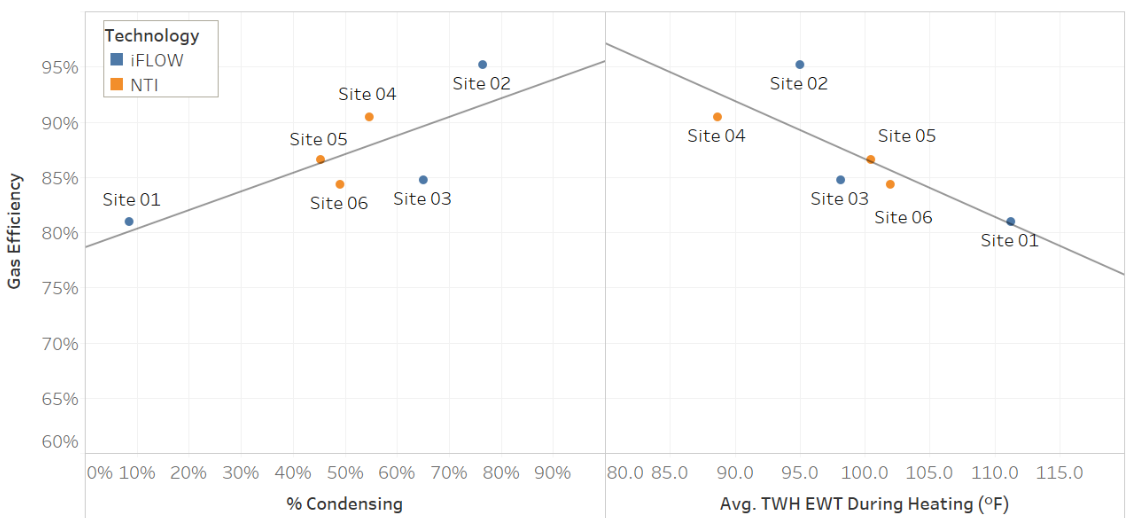


Table 15 summarizes the total and percent of load in which the TWH is assumed to be condensing or not condensing.

TABLE 15 – CONDENSING OPERATION

Site ID	Tech	Total Load TWH Condensing (Btu)	Total Load TWH Not-Condensing (Btu)	% Condensing	Average TWH EWT During Heating (°F)	System Gas Efficiency (%)
1	iFLOW	5,520,811	49,225,594	10.1%	111.3	80.5%
2	iFLOW	52,332,456	15,530,394	77.1%	95.0	94.1%
3	iFLOW	33,224,130	16,177,530	67.3%	98.1	84.6%
4	NTI	21,298,928	17,700,331	54.6%	88.7	90.2%
5	NTI	20,484,876	24,664,829	45.4%	100.5	86.6%
6	NTI	19,527,050	20,272,399	49.1%	102.0	83.8%
Average:		**25,398,042**	**23,928,513**	**50.6%**	**99.3**	**86.6%**

6.2 Annualized Energy Savings Results

Table 16 shows the annualized performance results calculated based on a typical weather year. The six combi systems are expected to save on average 227 therms (24%) relative to a conventional 80% AFUE furnace and a gas tanked water heater with 0.62 UEF. With a $4,140 average incremental cost the combi systems' expected payback is 24.1 years on average.

TABLE 16 – ANNUALIZED PERFORMANCE DATA

Site ID	Tech	Location	Avg. OAT (°F)	Annual HDD (°F-day)	Daily DHW Usage (gal/day)	Total System Gas Efficiency (%)	80% Furnace & 0.62 UEF WH Calc. Eff. (%)	Combi System Annual Savings (Therms)	Combi System Annual Savings (%)	Utility Marginal Gas Rate ($/Therm)	Annual Savings ($/year)	Simple Payback (years)
1	iFLOW	Bend, OR	47.8	6,918	24	81.8%	66.4%	204	19%	$0.7429	$152	27.9
2	iFLOW	Bend, OR	47.8	6,918	47	94.7%	68.0%	346	28%	$0.7429	$257	14.3
3	iFLOW	Portland, OR	54.0	4,544	50	86.2%	65.5%	218	24%	$0.9246	$201	30.2
4	NTI	Portland, OR	54.0	4,544	67	91.0%	66.1%	216	27%	$0.9246	$199	21.7
5	NTI	Spokane, WA	47.7	6,956	69	86.8%	65.4%	201	25%	$0.6826	$137	23.7
6	NTI	Spokane, WA	47.7	6,956	89	83.8%	63.7%	179	24%	$0.6826	$122	26.6
Average:			49.8	6,139	57	87.4%	65.9%	227	24%	$0.7834	$178	24.1

6.3 Economics

6.3.1 Paybacks

Table 17 shows the simple payback of the six combi systems compared to a conventional furnace and tank water heater system.

TABLE 17 – SIMPLE PAYBACKS COMPARED TO CONVENTIONAL SYSTEM

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Conventional System Modeled	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH
Conventional DHW UEF	0.62	0.62	0.62	0.62	0.62	0.62
Conventional Furnace AFUE	80%	80%	80%	80%	80%	80%
Conventional System Modeled Annual Efficiency	66.4%	68.0%	65.5%	66.1%	65.4%	63.7%
Conventional Annual Fuel (therms)	1,089	1,229	906	788	817	747
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Thermostat	Prog. Honeywell	Ecobee3	Ecobee4	Nest	Prog. Honeywell	Program. Honeywell
Combi System Modeled Annual Efficiency	81.8%	94.7%	86.2%	91.0%	86.8%	83.8%
Combi System Annual Fuel (therms)	885	883	688	573	616	568
Annual Natural Gas Savings (therms)	204	346	218	216	201	179
Annual Natural Gas Savings	19%	28%	24%	27%	25%	24%
Annual Avoided Cost of Gas	$152	$257	$201	$199	$137	$122
Simple Payback (years)	27.9	14.3	30.2	21.7	23.7	26.6

Table 18 shows the simple payback of the six combi systems compared to a conventional high-efficiency condensing furnace and tank water heater system.

TABLE 18 – SIMPLE PAYBACKS COMPARED TO CONVENTIONAL SYSTEM WITH CONDENSING FAF

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Conventional System Modeled	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH	FAF + WH
Conventional DHW UEF	0.62	0.62	0.62	0.62	0.62	0.62
Conventional Condensing Furnace AFUE	95%	95%	95%	95%	95%	95%
Conventional Total System Modeled Annual Efficiency	82.7%	83.9%	79.4%	78.4%	76.4%	72.5%
Conventional Annual Fuel (therms)	875	997	747	664	699	657
Combi System Tested	iFLOW	iFLOW	iFLOW	NTI	NTI	NTI
Combi System Efficiency	81.8%	94.7%	86..2%	91.0%	86.8%	83.8%
Combi System Annual Fuel (therms)	885	883	688	573	616	568
Annual Natural Gas Savings (therms)	-10	114	59	91	83	89
Annual Natural Gas Savings	-1%	11%	8%	14%	12%	14%
Annual Avoided Cost of Gas	-$7	$85	$55	$84	$57	$61
Simple Payback (years)	N/A	31.6	92.9	39.4	39.5	37.1

6.4 Participant Satisfaction

At each follow-up interview, the interviewer asked participants to assess their satisfaction with the combi system on a scale from 1 (not at all satisfied) to 5 (completely satisfied). Five participants rated their satisfaction a 5 and one a 4 at the first follow up in February. The participant who rated it a 4 had initial issues for several weeks with hot water not being hot enough, but this had since been rectified. This issue was not related to the equipment itself but rather due to an anti-scald valve (which was installed down-stream from the TWH) having been set at too low of a temperature by the contractor.

The following interview in April had the same results, with one participant rating their satisfaction a 4 (not the same participant as in February) noting that their energy bill had gone up. However, this participant also reported a recent notice from their utility saying they had been moved to a different rate and that this may have been the source of the increase (we note that the participant was unsure, and unable to confirm this). The data also shows that Site 6 consumed DHW at an abnormally high rate in February and March, which was well above their monthly average with many days exceeding 200 gallons (see Figure 32 and Figure 33). No participant reported any equipment problems or any issues requiring maintenance. From this point on, all participants rated their satisfaction a 5 out of 5 in the final three interviews (June, August, October).

Overall, participants were highly pleased with their combi units. Comparing their comfort levels between their previous and new appliances, all participants felt their homes maintained a more consistent temperature, while one said the house was considerably more comfortable because previously their home fluctuated greatly in temperature. Most also said they appreciated the endless hot water. An unexpected benefit for several participants was the quietness of the system, with several participants reporting that they “hardly noticed it running.” This was likely due to the highly efficient, variable speed blower fans on the AHU.

7. Technology Comparison

7.1 iFLOW Advantages

- **Installation flexibility (size of equipment):** two separate pieces of equipment (TWH and hydronic air handler) allow for more installation options than the large packaged NTI. The iFLOW air handler is much smaller and lighter enabling a single installer to transport the unit and install in tight spaces. The air handler will almost always be smaller than the furnace it is replacing and can be installed in any orientation (upflow, downflow, horizontal). The NTI is wider and deeper than many furnaces and can only be installed in an up-flow orientation. The separate condensing TWH can be installed anywhere within an acceptable distance from the iFLOW (max piping depends on TWH and circulation pump used) allowing for more flexibility in locating the appliance for convenient access or out of sight installation.
- **Design flexibility:** while this field trial only tested the iFLOW air handler combined with a condensing tankless water heater made by Navien, the unit can be paired with any number of water heaters in a range of capacities. The iFLOW air handlers come in three sizes with maximum airflows ranging from 941-1423 cfm and maximum heating capacity from 65,000-95,000 Btu/hr. The NTI unit comes in one size with the Navien condensing TWH packaged within the furnace delivering a maximum of 1,450 cfm and 80,000 Btu/hr of space heating capacity. An additional advantage of having separate equipment is that if the water heater or air handler needs replacement only the failed component needs to be replaced. If a packaged unit fails and cannot be repaired the whole unit must be replaced.
- **More configurability and energy efficiency features:** the iFLOW system uses a heat flush cycle to extract residual heat from the heat exchanger after a call for heating and has more options for other energy efficiency features like an adjustable HW temperature reset. However, our field data has shown the performance of the two systems to be similar so far.

7.2 NTI Advantages

- **Cost:** in this field trial, the NTI combi systems cost on average $9,860 fully installed while the iFLOW systems averaged $10,920. Part of the difference is that the NTI unit costs between $300-$500 less than the iFLOW equipment depending on configuration and in part due to less labor and peripheral components (circ pump, communication cable, etc.)
- **Ease of installation:** the NTI installation is more straightforward and requires less labor than the iFLOW system. There is a single appliance to install instead of two, although the existing furnace will need to be removed and the existing water heater disconnected or removed entirely. Additionally, since the NTI unit is a packaged, there is much less plumbing required than in the iFLOW installation. Typically, the NTI only requires a short pipe run of the DHW supply and city water intake from the location of the existing water heater to the location of the furnace. The iFLOW requires an entire hydronic loop to be installed in the field to provide the space heating hot water from the TWH to the air handler. This work cannot be completed

by many water heater installers[2] as it requires some pipe fitting skills and knowledge of hydronic loops.

- **Availability in the Northwest:** currently the NTI unit is easier to procure in the Northwest than the iFLOW air handler. The NTI GF200 is in stock in Salt Lake City, Utah and carried by multiple HVAC distributors in Portland and one distributor in Spokane. The units were shipped and delivered within a few days of ordering. The iFLOW units are currently manufactured and ship from Toronto, Canada and require 2-3 weeks for transit. No distributors in the Northwest carry the iFLOW product line.

8. Installation Recommendations

Installing Contractor Recommendations to Maximize Performance

- Select a hot water heater with highest efficiency and highest turndown (lowest minimum capacity) that sufficiently meets the space heating and DHW requirements of the residence
- Select programmable thermostat and work with homeowner to set a schedule that fits their schedule and train them to make adjustments on their own.
- Set hysteresis (difference in temperature between when heat comes on and when heat switches off) on thermostat to a minimum of 1.5°F. This option is usually found within the advanced settings of a thermostat and allows the temperature to float to avoid excessive short-cycling.
- Minimize hot water piping runs and insulate all piping, fittings, and ductwork to prevent heat loss.

9. Conclusion

Combi systems save energy relative to conventional furnace and water heater systems. On average, the combi systems in this yearlong field test which use high-efficiency condensing tankless water heaters saved over 227 therms annually (24%) compared to a conventional non-condensing furnace with an 80% AFUE and a tanked water heater with a 0.62 UEF. The total system performance of the combi systems averaged 87.4% compared to a modeled system performance of 65.9% for the conventional system. Additionally, the combi systems performed extremely reliably over the year as there were no equipment failures, service calls, or comfort issues with any of the systems.

Real world performance and energy savings could be higher with better equipment selection and controls. Four of the six sites tested with real world efficiencies of well below manufacturer reported values and lab testing (<90%). One of the primary reasons for the difference was inefficiencies from short cycling. The system performance could be improved by increasing the length of cycle times. Three ways this could be accomplished are (1) increasing temperature setbacks, (2) increasing thermostat hysteresis (temperature differential between when thermostat switches on and switches off) and (3) selecting a heat source with high turndown (low minimum capacity).

[2] The majority of those who install residential tank and tankless water heaters are not plumbers by have a specialty water heater installer license. Many are not practiced in installing detailed hydronic loops. This type of work is more often completed by commercial pipe fitters or plumbers.

Combi system installations are more labor intensive than conventional systems and require more planning, skill, and experience from the installing contractor. In particular, the decoupled iFLOW system with separate air handler and TWH may require as much as 1 ½ to 2 days of installation for a two-person crew and requires significant piping to connect the air handler to the TWH. The NTI system requires much less labor since the piping between the TWH and air handler are integral to the system. However, installing contractors should still plan for full 1 to ½ day installations due to the coordination of the mechanical work (air handler, ductwork modifications, controls) and plumbing work (DHW piping, flue/exhaust piping, valving, condensate disposal). While most of this work is required with a conventional system replacement, the two system (DHW & FAF) are separate and very little if any work is required. In fact, the two replacements typically would not take place at the same time or by the same contractor. None of these challenges are insurmountable, but they do add cost to the installation and make it more challenging and less likely for installation contractors to successfully sell combi systems to homeowners.

The participants were extremely satisfied with the combi system. Participants reported an increased level of comfort due to less temperature fluctuation, more consistent hot water, and a noticeable decrease in the noise level of the furnace/air handler. Participants also expressed the sentiment that both combi systems are composed of reliable and well-made equipment and provide an excellent user experience.

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Appendix A – Recruitment Screener

Appendix B – Observation Field Guide

Appendix C – Combi Equipment Issues Log

Appendix D – Combi Equipment Submittals and Technical Documentation

Appendix E – Pre- and Post- COVID DHW & SH Load Comparison

Appendix A. Recruitment materials

Landing page

[THIS IS THE LANGUAGE THE SURVEY RESPONDENT WILL SEE AFTER CLICKING THE LINK TO THE SURVEY. THIS PAGE WILL ALSO CONTAIN THE NEEA LOGO AS MOCKED UP BELOW.]

Thank you for taking the next few minutes to answer questions about whether your home qualifies for a free high-efficiency residential combined space and water heater (combi) system. This should only take a few minutes. We will gather responses and begin recruitment on a rolling basis with qualified applicants by calling to confirm eligibility for participation.

Open drop-down menus by clicking on this icon within the survey.

Click on the "Next" and "Back" buttons at the bottom of each page to navigate through the survey.

Screener Survey

A1. Do you own your home? [single RESPONSE]

1. *Yes*
2. *No* [Terminate]

98. Not sure [Terminate]

[IF 0 = 1]

A2. Next we have a few questions about your water and home heating systems. It's fine if you're not sure and does not mean you can't participate!

Is your primary heating and water heater natural gas*? [single RESPONSE]*

1. *Yes*
2. *No* [Terminate]

98. Not sure

[IF A2 = 1 or 98]

A3. Is your primary heat central forced-air gas furnace?

1. *Yes*
2. *No* [Terminate]

98. [Not Sure]

[IF A3 = 1 or 98]

A4. Are your hot water heater and furnace near each other?

1. ***Yes***
2. ***No*** [Terminate]

98. [Not Sure]

[IF A4 = 1 or 98]

A5. Do you have any of the following additional heating in your home, excluding portable space heaters?

1. Electric wall heaters
2. Wood or pellet burning stove
3. Other
4. None

A6. Does your home have a zoned heating and cooling system (e.g. different areas of your home are controlled by separate thermostats)?

1. ***Yes, I have multiple zones***
2. ***No, my home is a single zone***

98. [Not Sure]

A7. What is the typical *number of people in your home? [DROP DOWN MENU, SINGLE RESPONSE]*

1. 1
2. 2
3. 3
4. 4
5. 5
6. 6
7. More than 6 people
8. Occupancy varies

A8. What is your zip code? [Open Response]

A9. Who is your gas utility?

1. ***Avista***
2. ***Cascade Energy***
3. ***NW Natural Gas***
4. ***Puget Sound Energy***

98. [Not Sure]

CLOSING LANGUAGE:

Thank you for taking the time to respond to our field trial recruitment questions. We will contact you in the near future with more information about this field demonstration.

If you have any questions, please contact Eric Olson, Sr. Product Manager, Northwest Energy Efficiency Alliance at eolson@neea.org.

TERMINATE LANGUAGE:

We appreciate your time and responses, at this time your home is not suitable for this field demonstration.

If you have any questions, please contact Eric Olson, Sr. Product Manager, Northwest Energy Efficiency Alliance at eolson@neea.org.

Recruitment completion Email

Subject Line: Recruitment Completed for Residential Combined Space and Water Unit Field Study

Sender: NEEA

Dear ***[XX],***

Thank you for taking the time to respond to our field study recruitment questions. We have completed recruiting based on the needs of this study. We very much appreciate your help in this effort!

Sincerely,

Eric Olson
Sr. Product Manager
Northwest Energy Efficiency Alliance
eolson@neea.org

Appendix B. Homeowner interview guides

This appendix includes the post-installation and bi-monthly follow-up homeowner interview guides.

Overview

In tandem with the observation of the combi unit installation, the goal of this portion of the research is to understand the homeowners' experience of the installation, including:

- What were their motivations for taking part in the field study?
- What are their expectations of the install, and how the actual process compared?
- What concerns did they have beforehand, and how these were addressed?
- What are their expectations of the equipment?
- What was their previous awareness of combi systems and equipment?

To identify issues and better understand the installation experience, we plan to observe the installation of six combi units (3 each of the NTI GF200 and the iFLOW iFLH air handler combined with a high-efficiency, condensing, tankless hot water heater).

We plan to conduct these interviews with the homeowner after the completion of the installation (while at the home), but if this is not possible or if there are any installations we are unable to attend, a member of the research team will contact the homeowner as soon as possible after the installation is complete to gather their responses by telephone.

This guide is not intended to be read verbatim but rather used as a reference for the research team in exploring topics with homeowners – we may ask questions differently or probe on certain topics based on the homeowners' responses and the installation itself.

Post-Installation Interview Guide

The ILLUME researchers present at the installation will introduce themselves at a convenient time and ask the homeowner if they have 20-25 minutes after the installation to discuss their experience, motivations to participate and perceptions. The following questions can be asked or made at any point during the install, as appropriate.

INTRODUCTION:

*ILLUME observers will have introduced themselves at the beginning of the installation, **the following will be read before the post-installation interview**.*

Part of our role in this study is to gather information on homeowners' experience with the installation. This discussion should take no more than 20 minutes. There are no right or wrong answers, and your responses will not affect your participation in the field study or ability to keep the equipment. Furthermore, no personally identifying information will be connected to your responses and will not be reported publicly without your consent. Would it be alright if we record our conversation now for note-taking purposes?

QUESTIONS FOR THE HOMEOWNER

1. Can you describe how you **decided to have a combi unit installed** in your home? *Open-ended, probe for the following if needed:*
    a. What **space** and **water heating** equipment did this replace? How old was each appliance? Had there been any issues with it? How well did you feel these were functioning before?
    b. Had you **heard of** or **considered** a combi unit before this opportunity to have one installed came up?

2. Can you describe the process of scheduling and the following **site visit**?
    a. **Who** was present for the visit?
    b. What **questions** did you have, if any? Were they answered?
    c. How was the scheduling **process** for you? How about for scheduling the installation itself? *Probe for ease, difficulties etc.*

3. Let's discuss the **installation** next. If a friend asked what it was like, what would you tell them? *Open ended, then probe the following:*
    a. What were your **expectations** of the install?
        i. What informed these expectations?
        ii. How close was the experience to this?
    b. Did any new **questions** arise at the time of the install? Were they answered?
    c. What **concerns** about the installation, if any, did you have beforehand? How, if at all, were these addressed? Was this at the site visit, installation, or both?
    d. Were there any **unplanned considerations** that you were consulted on? What were these?
        i. What information, if any, did the installers provide?
        ii. Did you feel you had enough information to make an informed decision?

4. How, if at all, do you think having this equipment will **impact your daily life**?
    a. In terms of **water** heating?
    b. **Space** heating?

5. Did someone on the install team **explain the equipment,** how to use it and/or what maintenance is required? Who?
    a. Do you have any remaining **questions** about the use or maintenance of the equipment?
    b. [If so] Have these been addressed? How?

Follow up feedback

As you may recall, part of the purpose of this study is to understand the experience of living with this equipment. In order to understand this, we will be following up with you monthly with a few questions about how you're finding this experience, whether you have questions or concerns, via a 5-10 minute call. We will email you monthly in order to schedule a time using our Zoom video-conference platform that's convenient for you.

Monthly follow up Guide

The ILLUME researchers will follow up with homeowners bi-monthly after the install (and for the duration of the project?) in order to understand and assess the homeowners' experience of living with the combi system. We will conduct this 5-10 minute monthly follow up using our Zoom platform so that we can record and view anything the homeowner wishes to show us with its video capability (unless the participant prefers to use speak by voice call only).

QUESTIONS FOR HOMEOWNER:

Introduction:
Hello, [PARTICIPANT NAME], this is [ILLUME RESEARCHER NAME], thank you for getting on the phone with us today. As we discussed at the installation, I'd like to ask you a few questions about the combi system, which shouldn't take more than 10 minutes. Is it okay if I record our conversation for notetaking purposes?

1. Have you had **any issues** with your combi system since the installation/last time we spoke? *Open-ended, probe for the following if needed:*
    a. Can you describe this experience?
    b. Did you take any action yourself?
    c. Did you speak to the installer or anyone else to address these issues?
        i. [If yes] Did anyone visit your home to service it? If so, what did they do?
        ii. How did they address the issue?
    d. Has the issue been resolved to your satisfaction?

2. How does this **compare** to your comfort level with the space heating equipment that was replaced? Water heating?[Probe for specifics on water heating comfort differences.]
    a. [Probe for specifics on HVAC heating comfort differences.]
    b. [If customer is less comfortable] What, if any, actions have you taken to increase your comfort level? How have they improved the situation?
        i. [If not addressed] Have you or any other household member made any changes to daily routines as a result of any changes resulting from the new equipment?

3. How would you **rate your satisfaction** with the combi unit on a scale from 1, not at all satisfied, to 5, completely satisfied?
    a. Can you tell me about your reasons for choosing this rating?
    b. [Ask on 2nd follow up if different from the past rating] I see that your rating has changed from the last time we spoke from [RATING], can you describe what has changed with the system to change your rating?

4. Is there anything else you'd like to share with me about your experience with the combi unit in your home?

Appendix C. Combi Issues Log

Last Updated:	11/17/2020	(0 days ago)

Issue ID	Issue Date	Site (Anonymized)	Combi System Equipment	Issue/Challenge	Installation/ Operation	Issue Description	Resolution/Next Steps	Status	Unit Down Time (If after install)	Technology or Installation Related
01-1	11/13/2019	Site 01 (Bend iFLOW A)	iFLOW IFLH-14000 Navien NPE-210A	Parameter P28	Installation	- Initially the iFLOW unit would not start up when given a call for heat - After troubleshooting w/ iFLOW tech support, they recommended changing parameter P28 in the Navien WH controls to "ON"	Changed Parameter P28 in Navien "Special Parameter" mode (R&D information menu)	Resolved	N/A	Installation
01-2	11/13/2019	Site 01 (Bend iFLOW A)	iFLOW IFLH-14000 Navien NPE-210A	Outside Air Temp Sensor	Installation	- After contractor attempted to start-up the iFLOW, it only ran for 2-minutes - iFLOW tech support recommended installing an ambient air temperature sensor (which did not ship with equipment)	Installed outside air temperature sensor	Resolved	N/A	Installation
01-3	11/14/2019	Site 01 (Bend iFLOW A)	iFLOW IFLH-14000 Navien NPE-210A	Short Cycling	Operation	- The iFLOW unit has been short cycling (typically 11 minutes on, 7 minutes off) or around 4 cycles per hour - The system efficiency appears to be lower than expected and lower than that of systems with longer cycle times	TBD	Ongoing	None	Technology (Selection/design)
02-1	11/22/2019	Site 02 (Bend iFLOW B)	iFLOW IFLH-16000 Navien NPE-210A	PVC Vent Pipe Low Spot	Installation	- The night after the installation, the participant noticed a small puddle where the condensate liquid had leaked onto the garage floor - It was discovered that there was a low spot in the PVC vent pipe at a 90 degree elbow near the outdoor wall penetration	The contractor shortened the vertical member to eliminate the low spot	Resolved	N/A	Installation
03-1	11/19/2019	Site 03 (Portland iFLOW)	iFLOW iFLH 16000 Navien NPE-240A	Short Cycling	Operation	- The iFLOW unit has been short cycling (typically 7 minutes on, 7 minutes off) or around 4 cycles per hour - The system efficiency appears to be lower than expected and lower than that of systems with longer cycle times	We sent iFLOW engineers the raw data, which they analyzed and believe the typical heat loss is less than the minimum TWH input (19,900 Btu/hr); we have since changed the minimum heat cycle from 5-minutes to 20-minutes in the thermostat advanced settings.	Resolved	None	Technology (Selection/design)
04-1	12/11/2019	Site 04 (Portland NTI)	NTI GF200	Return Air Door Switch	Installation	- The installing contractor failed to depress the side return door switch when securing the filter box directly to the side opening of the unit keeping the unit from operating	The contractor left the site; Energy 350 diagnosed and resolved the isssue by depressing the switch	Resolved	N/A	Installation
05-X		Site 05 (Spokane NTI A)	NTI GF200	No issues during installation or since at Site 05						
06-X		Site 06 (Spokane NTI B)	NTI GF200	No issues during installation or since at Site 06						

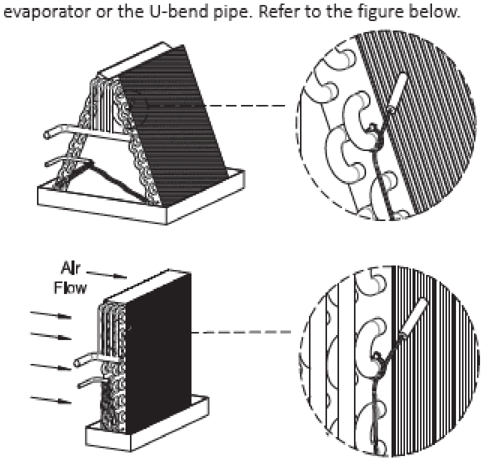
Issue 01-1

The iFLOW manual refers to the ambient temperature sensor as an "option", yet we found that the air handler did not function well before this was installed.
According to iFLOW, the same outdoor temperature reset can work if using the wi-fi version and connecting the unit to the home internet.
We find this problematic because wi-fi router SSIDs and passwords often change, which could disable proper operation of the air handler.
Also, the iFLOW unit did not ship with an ambient temperature sensor and we were required to purchase one from a local equipment distributor.
We recommend including an ambient temperature sensor with the unit and listing the installation as recommended in the manual.
We also recommend iFLOW ships an ambient temperature sensor & flow switch with the air handler.

8) Temperature sensors:

The iFLOW air handlers come equipped with 5 wire sensors that plug into connectors on the control board for easy servicing.

1. Supply water sensor: mounted on the supply end of the water heating coil.
2. Return water sensor: mounted on the return end of the water heating coil.
3. Supply air sensor: mounted above the water heating coil exchanger to detect supply air temperature and freezing temperatures
4. Ambient temperature sensor (option): modulates air handler operation based on ambient temperature. Provides outdoor reset function.
5. **Return air sensor**: installed in return air path. If you install the slab coil on the return air side, you must install the return air sensor before the slab coil.
6. **A/C Evap sensor**: mount on the A coil, or on the slab coil. It should be installed on the surface of the cold air outlet on the evaporator or the U-bend pipe. Refer to the figure below.



9) Installing the iFLOW air handler with a Navien tankless water heater:

Use with communication cable between iFLOW AHU to Navien tankless water heater. Connect the thermostat to the iFLOW AHU at the the thermostat connector. Connect the communication cable for iFLOW AHU to the cascade communication port on the Navien Water Heater Panel. **The parameter P28 of the NAVIEN TL WH should be set to ON** (Refer to Navien Tankless Water Heater Installation Manual)

10.5.2 Entering the R&D Information Menu

This section describes how to enter the R&D information mode to configure various parameters and control system functions.

Entering the R&D Information Menu

Follow the instructions below to enter the R&D information menu.

1. On the Front panel, press the Power button to turn off the water heater.
2. Enter the R&D information menu by pressing the Up (+) button three times, the Down (-) button three times, and then the Up (+) button four more times.
3. In the R&D information menu, use the Up (+) or Down (-) buttons to move to 2.PAR (Parameter information mode), and then press the Info button.

Issue 01-2

While the Bend installing contractor was very familiar with the Navien NPE water heaters, they had never installed an iFLOW combi system. The contractor read through the manual before and during the installation, but they (nor Energy 350) caught the P28 parameter note.
It may be challenging for most contractors to read through both manuals (50 and 103 pages respectively) to find this sequence.
We recommend including the sequence to enter the R&D menu within the iFLOW manual for convenience.

iFLOW Manual excerpt (P.13):

9) Installing the iFLOW air handler with a Navien tankless water heater:

Use with communication cable between iFLOW AHU to Navien tankless water heater. Connect the thermostat to the iFLOW AHU at the the thermostat connector. Connect the communication cable for iFLOW AHU to the cascade communication port on the Navien Water Heater Panel. **The parameter P28 of the NAVIEN TL WH should be set to ON** (Refer to Navien Tankless Water Heater Installation Manual)

Navien NPE Series Installation & Operation Manual excerpt (P.65; P.70):

6.5 Setting the Parameters

Follow the instructions below to enter the Special Parameter mode and change parameter settings.

> **CAUTION**
>
> Parameters must be set by a qualified professional with an extensive understanding of the water heating system. Setting parameters improperly may lead to property damage or injury.

1. On the front panel, press the Power button to turn off the water heater.
2. Enter the R&D information menu by pressing the Up [+] button three times, the Down [-] button three times, and then the Up [+] button four more times.
3. In the R&D information menu, use the Up [+] or Down [-] button to move to 2.PAR (Parameter Information mode), and then press the Information button.

AHU Communication (P.28)

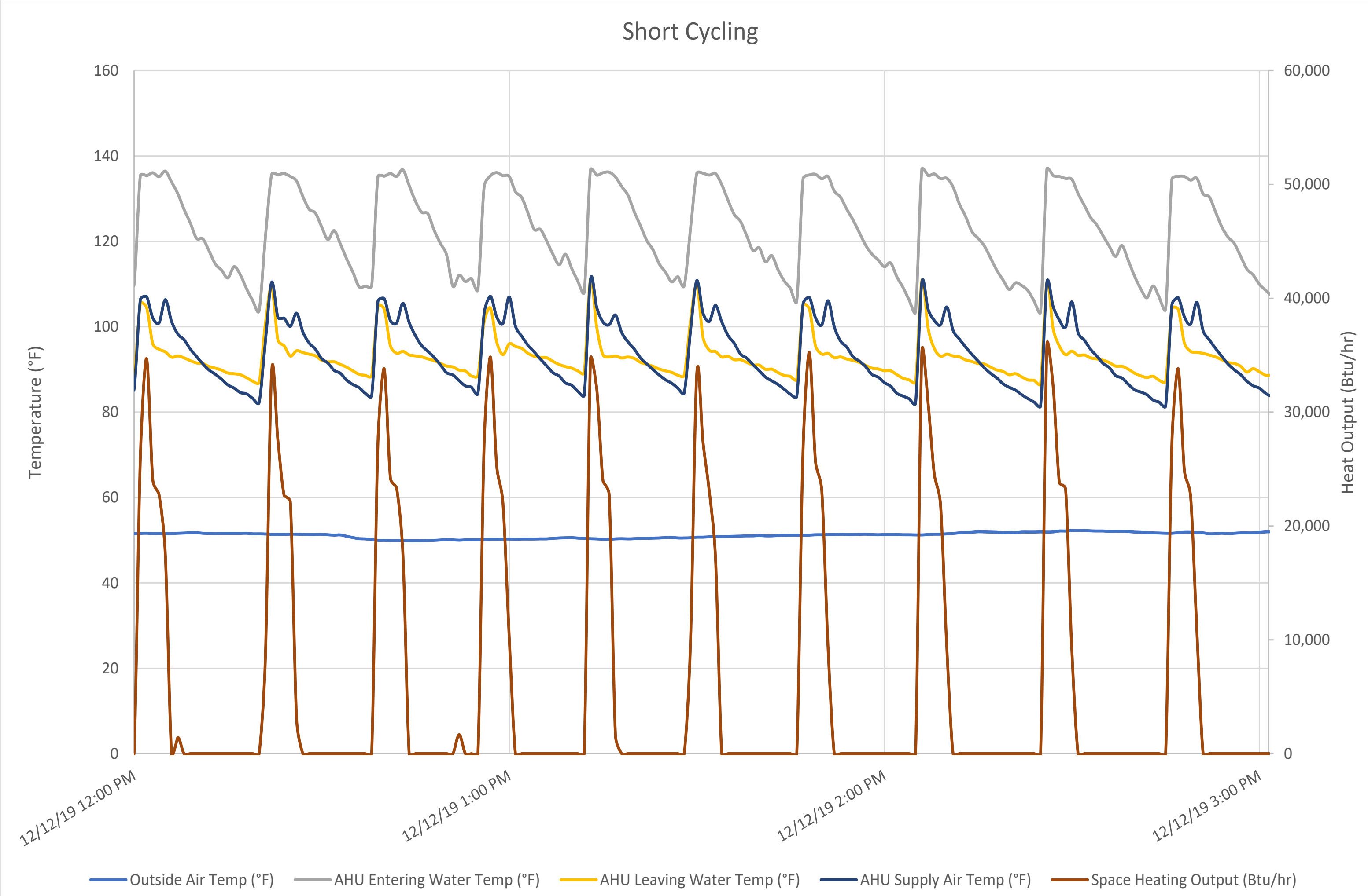
Item	Description	Display
1. OFF	Disable AHU Communication. (Default: Off)	1.oFF
2. ON	Enable AHU communication.	2. oN
Settings error	AHU Option Board Connection or Cascade Settings or Cascade Protocol settings (P.01) NR/NP/NCW Settings.	-- -- -- --

Issue 01-3 and 03-1

(2) of the (3) iFLOW systems have been short cycling (7-11 minute cycles on average)

The efficiency of these sites is lower than the third iFLOW site and lower than expected

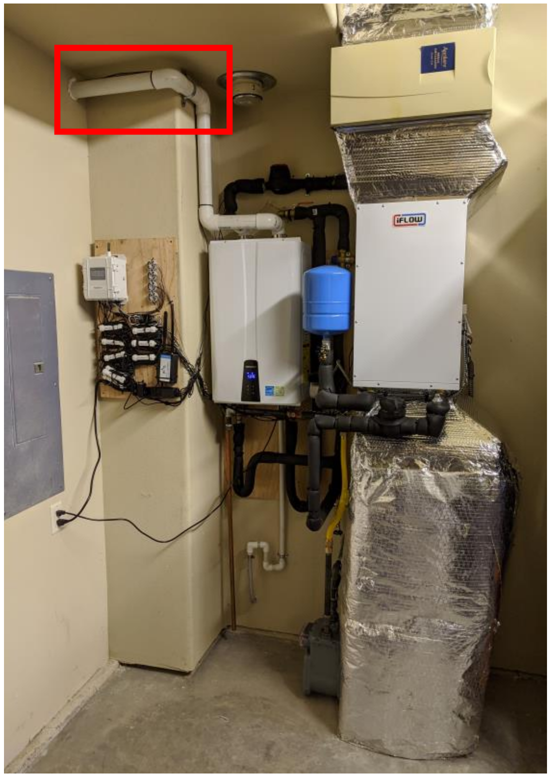
We sent the raw data set (shown in the figure below) to iFLOW engineers and the believe the heat loss is lower than the minimum of the Tankless Water Heater (19,900 Btu/hr)



Issue 02-1

There was a slight low spot in the PVC vent elbow near the outdoor wall penetration.

During the first night after installation, the homeowner spotted a small leak of the condensate fluid on the garage floor.



Issue 04-1

The installing contractor failed to depress the door switch when fastening the filter rack to the side return of the NTI combi unit.

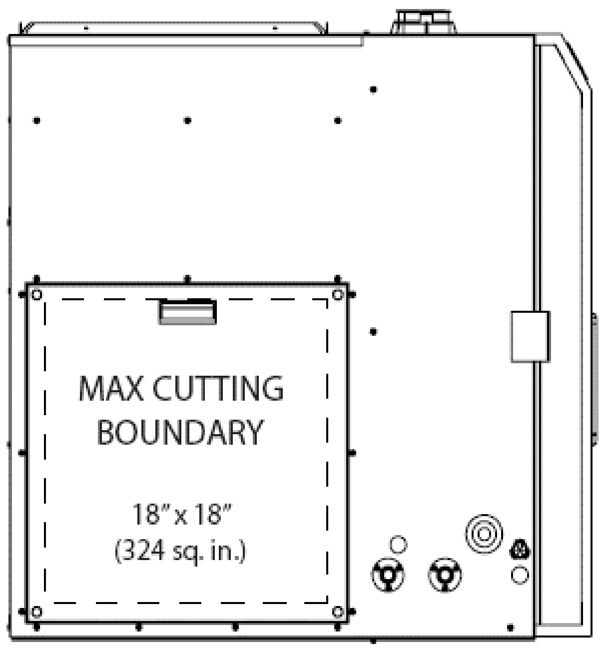
Exerpt from GF 200 Installation Manual (P. 13)

a) Side return:

When routing return air into the side of the unit, an opening may be cut into the central area of the side door, taking care not to excise the screw holes.

If installing a cabinet-mounted filter rack, it may be fastened (with self-tapping screws no longer than ¾" (0.75 in.)) to both the remaining door material *and* the cabinet, such that it overlaps the door frame. However, DO NOT drill holes or cut away any material from the cabinet itself.

Alternatively, one may remove the side door entirely and install a filter rack directly to the opening, taking care to ensure that the door switch is fully depressed (or bypassed) by the new ductwork.



iFLOW INTELLIGENT AIR HANDLER
ADVANCED TECHNOLOGIES

HIGH EFFICIENCY
- Highest performance at 98% efficiency. (TPF 0.98/CSA P.9-11)
- Ultra efficient heat exchanger design.
- Full modulation capabilities to suit space load requirements extending system run time and eliminating short cycles improving efficiency.
- Variable speed ECM blower provides control of air flow that can be adjusted to suit space load requirements and duct system.
- Intelligent pump modulation provides control of water flow that can be adjusted

COMFORT & FLEXIBILITY
- Space zoning with integral control provides temperature control on each each level or specific rooms.
- Single, double, and quad smart zoning with integral control providing thermal storage technology.
- Hybrid heating system using dual fuels and match air handler with any hot water heat source.

- Compact size
- Fits in a closet
- Multi-Position

SPECIFICATIONS

Description		iFLH-14000	iFLH-16000	iFLH-18000
Heat Cap. Range	BTUH	27,834 - 62,786	34,211 - 76,982	42,376 - 94,633
Flow Rating	LPM / GPM	11.4 / 3	11 / 2.9	10.6 / 2.8
Return Air Temp.	°C / °F	22 / 72	22 / 72	22 / 72
E. S. P.	inWC	0.6 / 1.2	0.6 / 1.5	0.6
Airflow	SCFM	941 / 824	1222 / 1,009	1423
Cooling Capacity	Ton	1 - 2	1.5 - 3	2 - 4
Voltage	ACV/Hz/Ph	AC 120V 60Hz 1Ph	AC 120V 60Hz 1Ph	AC 120V 60Hz 1Ph
Motor	HP	1 / 2		3 / 4
	Type	ECM Eon		
	W	431 / 393	519 / 516	592
Piping Connection	Supply	Outside Diameter : 3 / 4" Male NPT / Inner Diameter : 1/2" Sweat		
	Return	Outside Diameter : 3 / 4" Male NPT / Inner Diameter : 1/2" Sweat		
Hydronic Heating Coil		Aluminum Ultra Efficiency Fins, Copper Tubing		

SMART Wi-Fi CONTROL

CONVENIENT & COST EFFECTIVE
- Combine domestic hot water and space heating in one efficient system.
- Simple installation and easily configured parameters using push button display.
- Eliminates the venting of the space heating unit and reduces the cost of two appliances.
- Suitable for new construction, retrofits, renovations and upgrades.

HIGH QUALITY
- Heavy gauge steel cabinet with powder coated finish.
- Insulated and sealed cabinet reduces air leakage and noise.
- Canadian made, engineered, designed, and fully supported.

FREE iFLOW APP AVAILABLE
- Easy management by Smartphone
- Complete platform for IoT

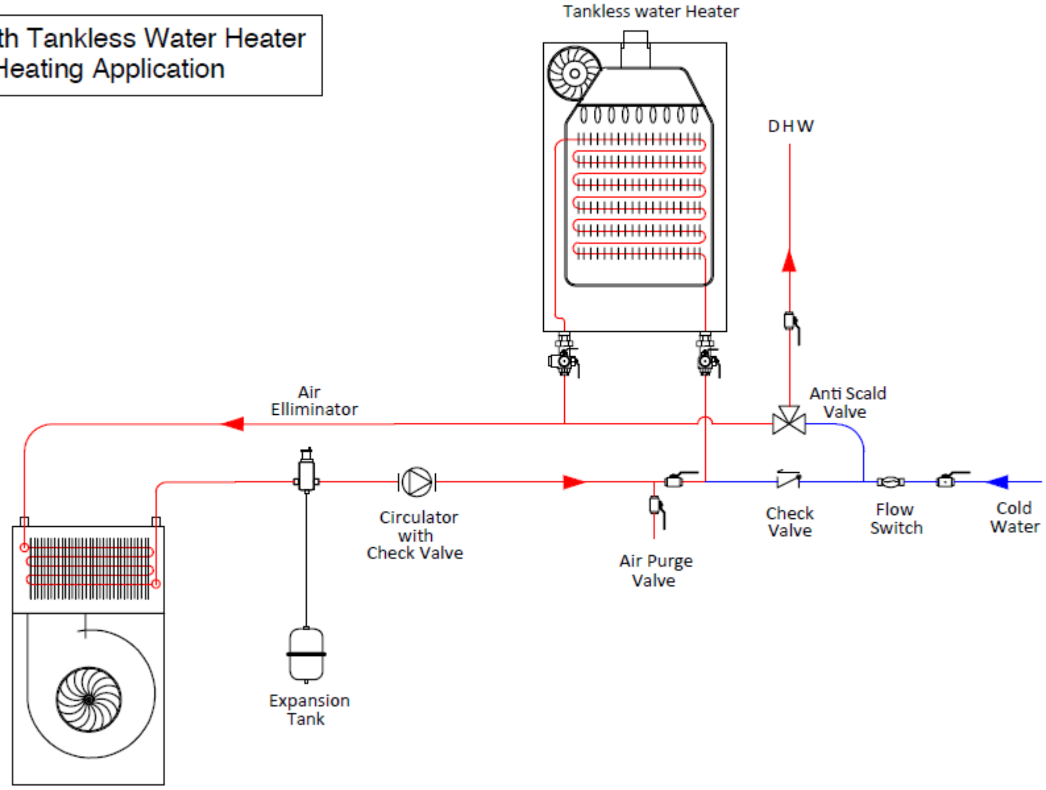
GET IT ON Google Play

Download on the App Store

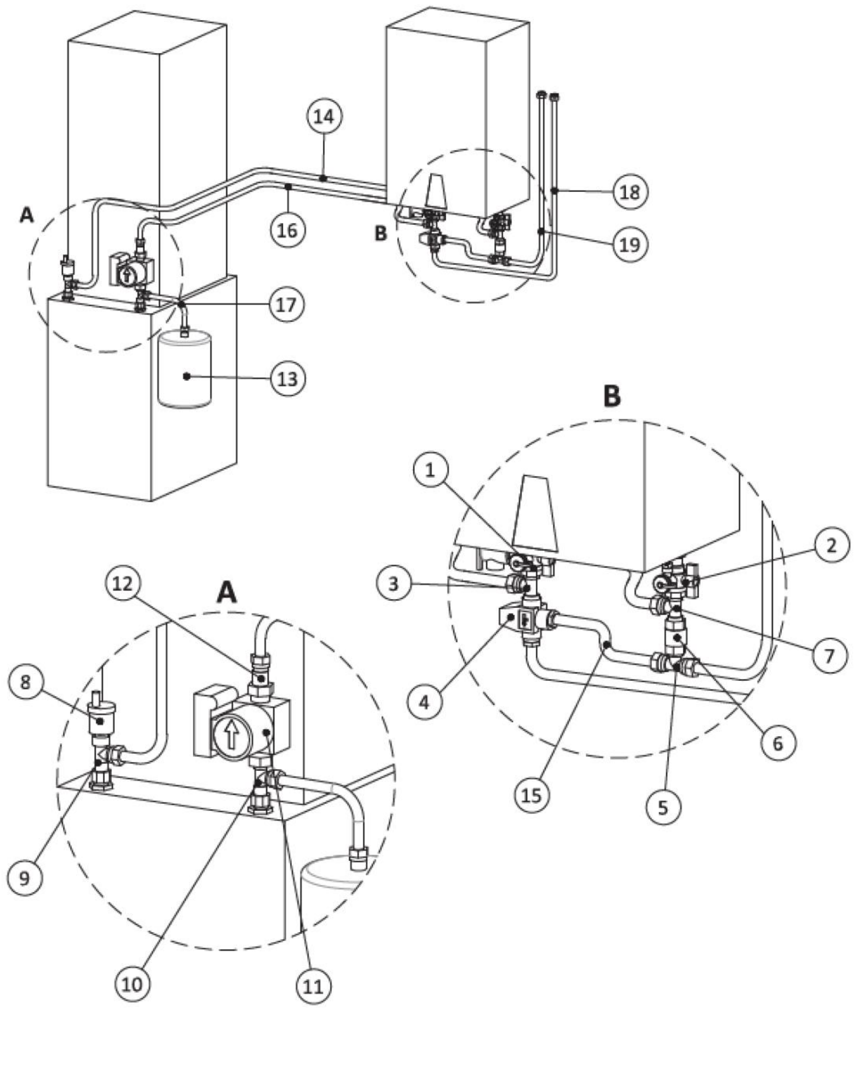
Specification

Description		iFLH-140000	iFLH-160000	iFLH-180000
Heating Capacity @ Entering Water Temperature	120°F	27,834 BTUH	34,211 BTUH	42,376 BTUH
	130°F	33,478 BTUH	41,357 BTUH	50,966 BTUH
	140°F	37,729 BTUH	48,379 BTUH	59,632 BTUH
	150°F	44,998 BTUH	55,485 BTUH	68,334 BTUH
	160°F	50,869 BTUH	62,632 BTUH	77,065 BTUH
	170°F	56,941 BTUH	69,769 BTUH	85,648 BTUH
	180°F	62,786 BTUH	76,982 BTUH	94,633 BTUH
Flow Rating	LPM / GPM	11.4 / 3	11 / 2.9	10.6 / 2.8
Return Air Temp.	°C / °F	22 / 72	22 / 72	22 / 72
E. S. P.	inWC	0.6 / 1.2	0.6 / 1.6	0.6 / 1.6
Airflow	SCFM	941 / 824	1222 / 1009	1423 / 1093
Cooling Capacity	Ton	1 - 2	1.5 - 3	2 - 4
Cabinet Size (W x D x H)	in	14 x 18 3/4 x 27 1/8	16 x 20 3/4 x 27 1/8	18 x 25 3/4 x 29 1/8
	mm	356 x 476 x 689	406 x 527 x 689	457 x 654 x 740
	Material	Cold Roll Steel Sheet Metal / Powder Coated		
Weight	kg	28.6	32	42
	lb	63	71	92.5
Supply Air Opening (W x D)	in	13 x 14	14 x 16	16 x 20
	mm	330 x 356	356 x 406	406 x 508
Return Air Opening (H x D)	in	12 x 16	13 x 18	14 x 23
	mm	406 x 304	457 x 330	584 x 355
Electrical	ACV/Hz/Ph	AC 120V 60Hz 1Ph	AC 120V 60Hz 1Ph	AC 120V 60Hz 1Ph
Motor	HP	1 / 2	1 / 2	3 / 4
	Type	ECM Eon	ECM Eon	ECM Eon
	W	431 / 393	519 / 516	592
Piping Connection	Supply	3/4" Male NPT Thread / 1/2" Soldering Connection		
	Return	3/4" Male NPT Thread / 1/2" Soldering Connection		
Hydronic Heating Coil		Aluminum Ultra Efficiency Fins, Copper Tubing		

AHU with Tankless Water Heater
Space Heating Application




iFLOW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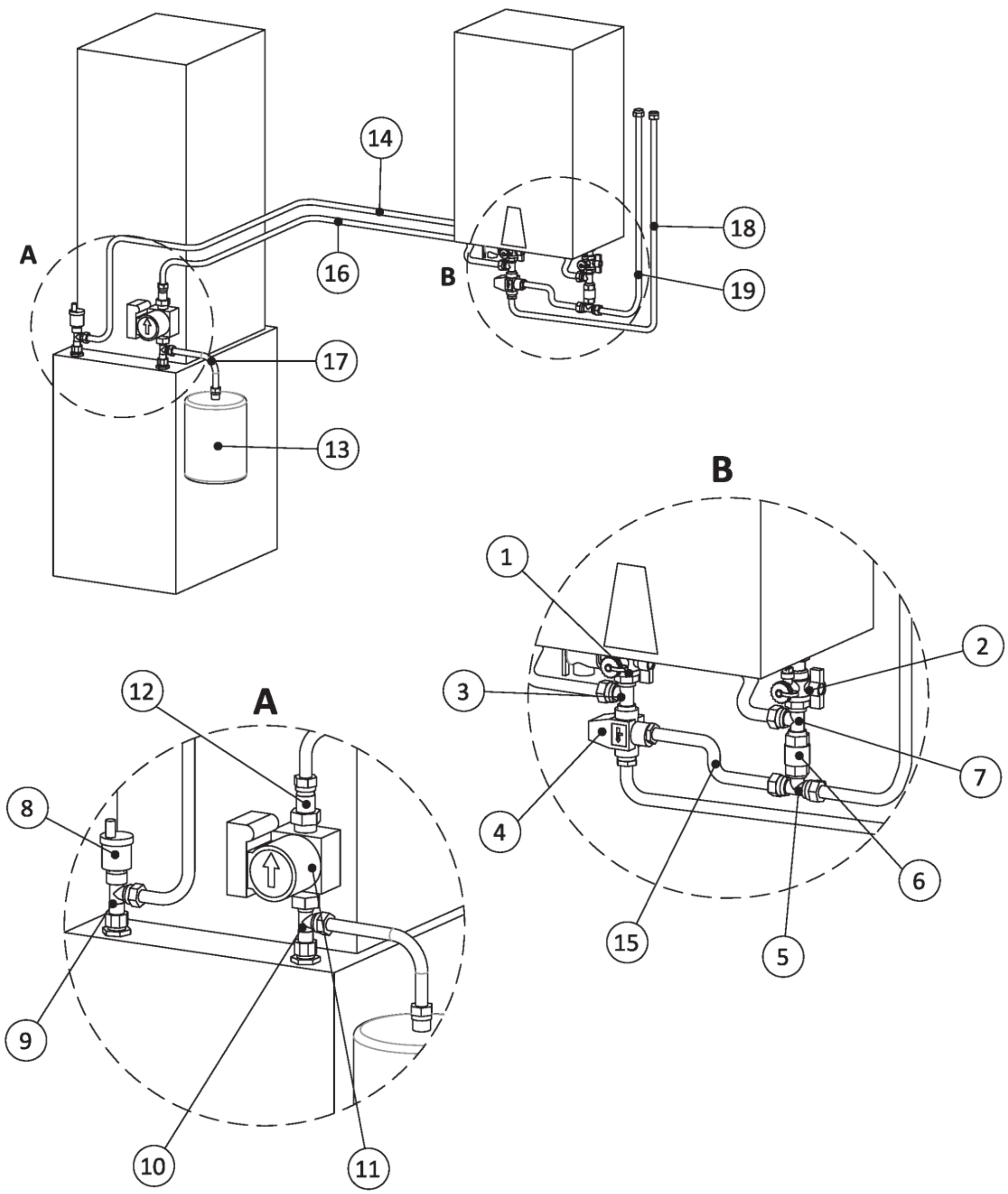
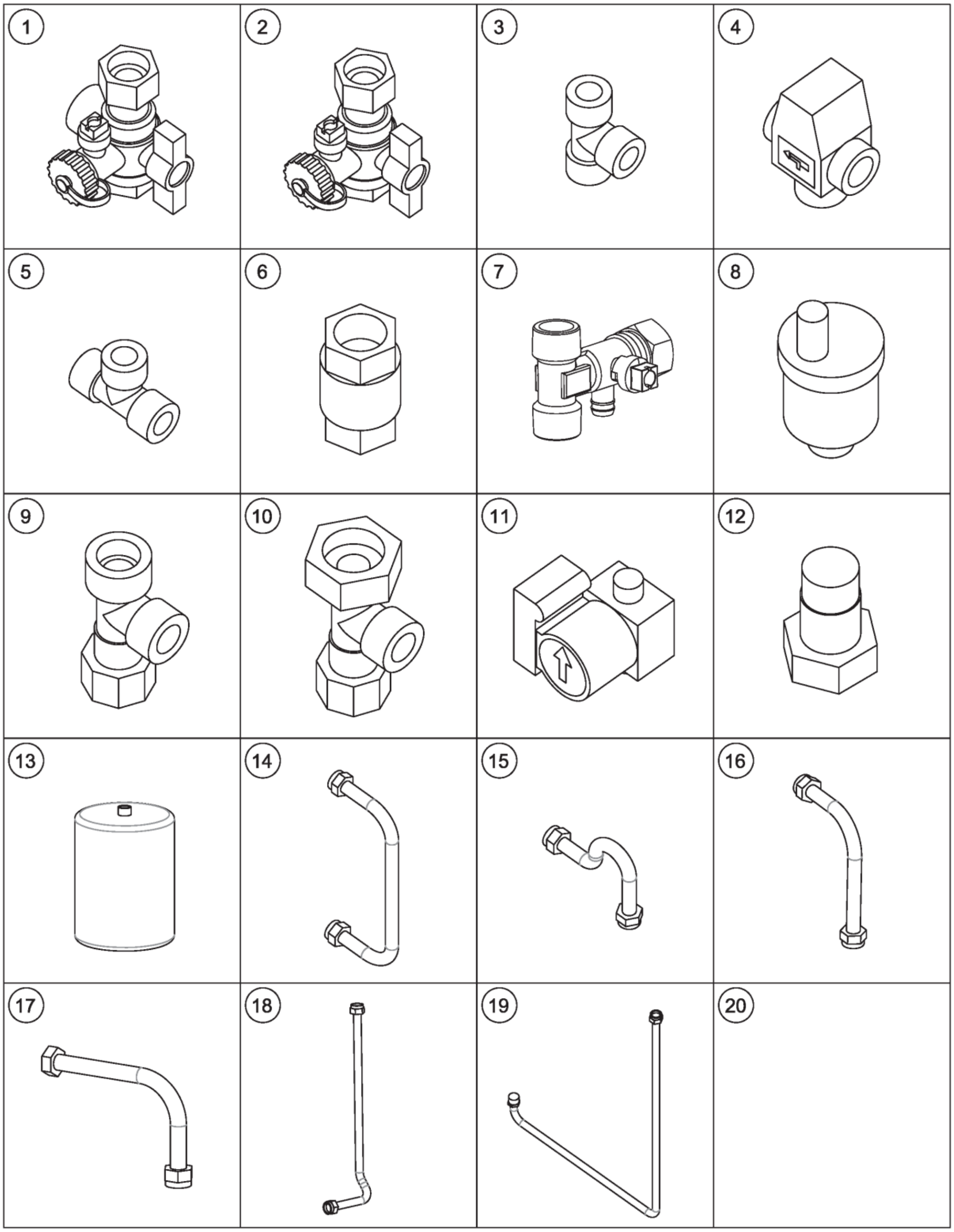
Installation on the wall

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EZEE PLUMBING KIT Parts List

No	Description	Part #	Q'ty	Remark
1	Tankless Water Heater Service Valve / Hot	EZEE VALVE HOT	1	
2	Tankless Water Heater Service Valve / Cold	EZEE VALVE COLD	1	
3	Tee Short Center / Supply	60EPFO1A	1	
4	Mixing Valve	60EPFO2A	1	
5	Tee Long Center / Cold	60EPFO3A	1	
6	Spring Check Valve 3/4"_15	60EPFO4A	1	
7	Tee with Valve / Return	60EPFO5A	1	
8	Air Vent 1/2"	60EPFO6A	1	
9	AHU Inlet Tee Union	60EPFO7A	1	
10	Circulator Tee Union w Check Valve	60EPFO8A	1	
11	Circulator / Grundfos UPS15-58RU	60EPFO9A	1	
12	Circulator Union	60EPF10A	1	
13	Expansion Tank	60EPF11A	1	
14	Pipe Female to Female / AHU Supply	60EPP12A	1	
15	Pipe Female to Male / Cold Mixing Water	60EPP13A	1	
16	Pipe Female to Female / AHU Return	60EPP14A	1	
17	Pipe Female to Female / Expansion Tank	60EPP15A	1	
18	Pipe Female to Female / Cold	60EPP16A	1	
19	Pipe Female to Female / Hot	60EPP17A	1	

2.2 Specifications

The following table lists the specifications for the appliance. Additional specifications about water, gas, electric, and air supplies (venting) appear in the Installation section.

Specifications		GF 200		
Heat Capacity (Input)	Natural Gas (NG) / Propane Gas (LP)	Space Heating: 19,900 – 80,000 BTU/H		DHW Heating: 19,900 – 199,000 BTU/H
Energy Efficiency	AFUE	97.1		
	UEF (NG & LP)			0.96
	EF (Canada) (NG & LP)			0.97
Flow Rate (DHW)	50°F (28°C) Temp Rise	7.8 GPM (30 L/m)		
	65°F (36°C) Temp Rise	6.1 GPM (23 L/m)		
	80°F (44°C) Temp Rise	5.0 GPM (19 L/m)		
Dimensions		17¾ in (W) x 38 in (H) x 38 in (D)		
Weight		248 lbs		
Installation Type		Indoor		
Venting Type		Forced Draft Direct Vent		
Ignition		Electronic Ignition		
Water Pressure		15 – 150 PSI		
Gas Supply Pressure (from source)	NG	3.5 – 10.5 in w.c.		See KD NAVIEN Water Heater Installation Manual (Supplied)
	LP	8 – 13 in w.c.		
Gas Manifold Pressure (min-max)	NG	-0.05 – -0.58 in w.c.		
	LP	-0.10 – -0.78 in w.c.		
Minimum Flow Rate*		0.5 GPM (1.9 L/m); < 0.01 GPM (0.04 L/m) with recirculation mode (factory default)*		
Connection Sizes	Cold Water Inlet	3/4 in sweat joint		
	Hot Water Outlet	3/4 in sweat joint		
	Gas Inlet	3/4 in NPT		
Power	Main Supply	120 V AC, 60 Hz		
Materials	Casing	Cold Rolled Carbon Steel		
	Heat Exchangers	Primary: Stainless Steel Secondary: Stainless Steel Tertiary: Copper (tubes); Aluminum (fins)		
	Interconnecting piping	Stainless steel, Copper, Brass (low-lead), Polymers (Viton™, EPDM, etc.)		
Venting**	Size	2 in	3 in	See KD NAVIEN Water Heater Installation Manual (Supplied)
	Length (max.)	60 ft	150 ft	
	No. of elbows (max).	6 (8 ft per 90°)	8 (5 ft per 90°)	
	Materials	CPVC, Polypropylene, PVC** Special Gas Vent Type BH (Class II, A/B/C)		
Safety Devices	Flame Rod, APS, Ignition Operation Detector, Water Temperature High Limit Switch, Exhaust Temperature High Limit Sensor, Power Surge Fuse, Door Interrupt Switches, Coil Freeze-protection Alogorithm, Anti-stagnation Sequence.			

*Energy consumption may increase when the system is configured for recirculation.
**High temperature venting material may be required. See 'Section 3.7 – Venting the Appliance' for details.

GF 200 With GREEN FURNACE Technology® NTI SUBMITTAL

Project Name: ____________________ Date:_____/_____/_____
Location:____________________
Engineer:____________________
Contractor:____________________ Rep:____________________

For: ☐ Reference ☐ Approval ☐ Review ☐ Construction

1 - GENERAL SPECIFICATIONS

Product Features:

- *Industry's Best Combi-Furnace*
- *With Full Modulation, 'One size fits all'*
- *4.8 GPM @ 80°F Temperature Rise*
- *Low NOx Emissions | NSF Low Lead Certified*
- *Stainless steel heat exchangers for extended life & durability*
- *Internal Recirculation & Buffer Tank*
  - *Eliminates cold water sandwich*
  - *No minimum flow rate required*
- *Simple Installation - Small Footprint*
  - *Venting 2" (60') | 3" (150')*
  - *Field Convertible to LP Gas*

Advanced Features:

- *Simultaneous DHW and Space Heating*
- *Automatic DHW priority above 170 MBH.*
- *DEC Star ECM Blower automatically adjusts to overcome static pressure to maintain CFM.*
- *Shaftless blower system reduces air flow restrictions and improves efficiency*
- *Negative pressure gas valve w/ pre-mix burner provides full modulation from 20-200 MBH*

Factory Supplied Items:

- *Flow switch*
- *Dual Inlet / Outlet Connections*
- *2" Vent Termination Caps*
- *2" Wall Flanges*

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GF 200 With GREEN FURNACE Technology® NTI SUBMITTAL

Project Name: ______________________________ Date: ____/____/____
Location: ______________________________
Engineer: ______________________________
Contractor: ______________________________ Rep: ______________

For: ☐ Reference ☐ Approval ☐ Review ☐ Construction

MODEL SPECIFICATIONS

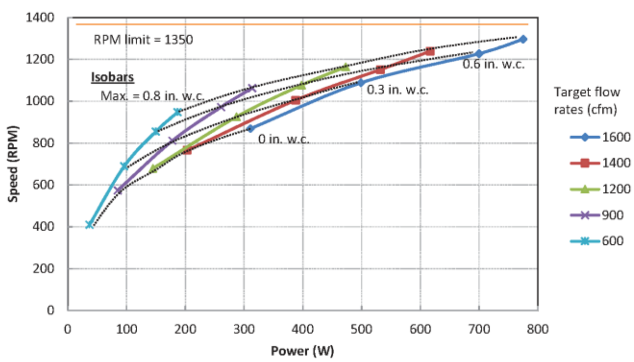
GF 200			
Heat Capacity (Input) (NG & LP)		Space Heating: 19,900 - 80,000 BTH/HR	DHW Heating: 19,900 - 199,000 BTU/HR
AFUE*	Furnace (for NG & LP)	97%	
Energy Factor	DHW (for NG & LP)	0.97	
Flow Rate	50 °F (28 °C) Temp Rise	7.8 GPM (29 L/m)	
	65 °F (36 °C) Temp Rise	6.0 GPM (23 L/m)	
	80 °F (44 °C) Temp Rise	4.8 GPM (18 L/m)	
Dimensions		17.75 in (W) x 38.0 in (H) x 38.0 in (D)	
Weight		248 lbs	
Venting Type		Forced Draft Direct Vent	
Venting Size		2" or 3"	
Water Pressure		15 – 150 PSI	
Conn. Sizes	Cold Water Inlet	3/4 in female sweat joint	
	Hot Water Outlet	3/4 in female sweat joint	
	Gas Inlet	3/4 in NPT	
Power Supply		120V AC, 60 Hz	
Heating Air Flow		500 - 1200 CFM	
Cooling Air Flow		490 - 1450 CFM	
Continuous Air Flow		350 - 725 CFM	
Supply Plenum		19-1/2" x 16-3/8"	
Return Options		Sides / Back / Bottom	

*Based on NTI lab testing. Results sent to AHRI; approval pending independent confirmation

Temperature Rise (°F)	Flow Rate GPM
50	7.8
55	7.1
60	6.5
65	6
70	5.5
75	5.2
80	4.8
85	4.6

Inlet	# of simultaneous 2.5 GPM showers
40 °F	
55 °F	
70 °F	

GF 200 — Blower performance



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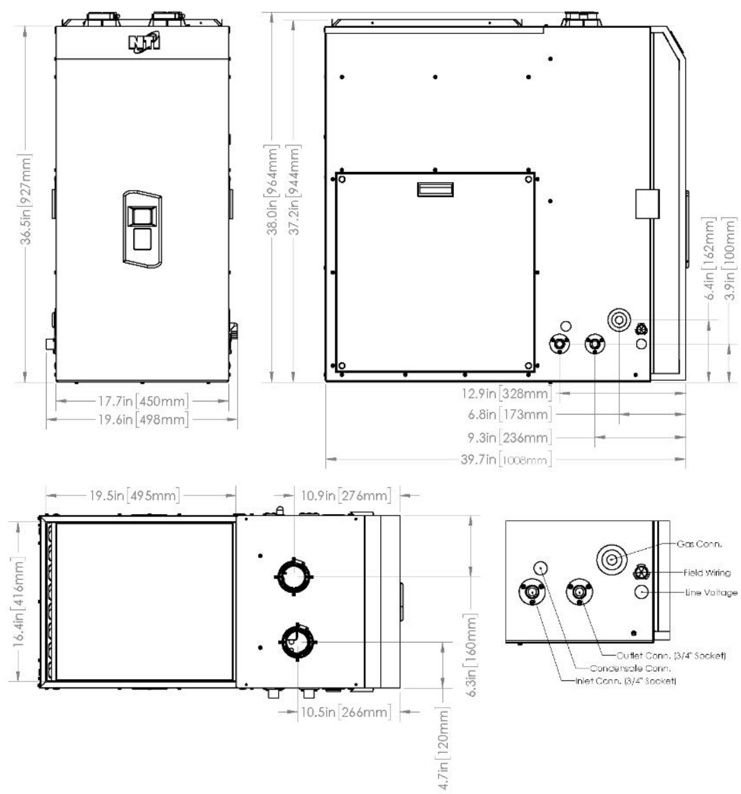
*Location:*______________________________
*Engineer:*______________________________
*Contractor:*______________________________ *Rep:*______________

For: ☐ *Reference* ☐ *Approval* ☐ *Review* ☐ *Construction*

2- PRODUCT DIMENSIONS



RECOMMENDED CLEARANCES

Clearance from:	Minimum clearance
Top	9 in
Back	Nil (if not return)
Front	4 in*
Side (No connections)	3 in
Blower access side	24 in
Side (Connections)	12 in

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Location:______________________
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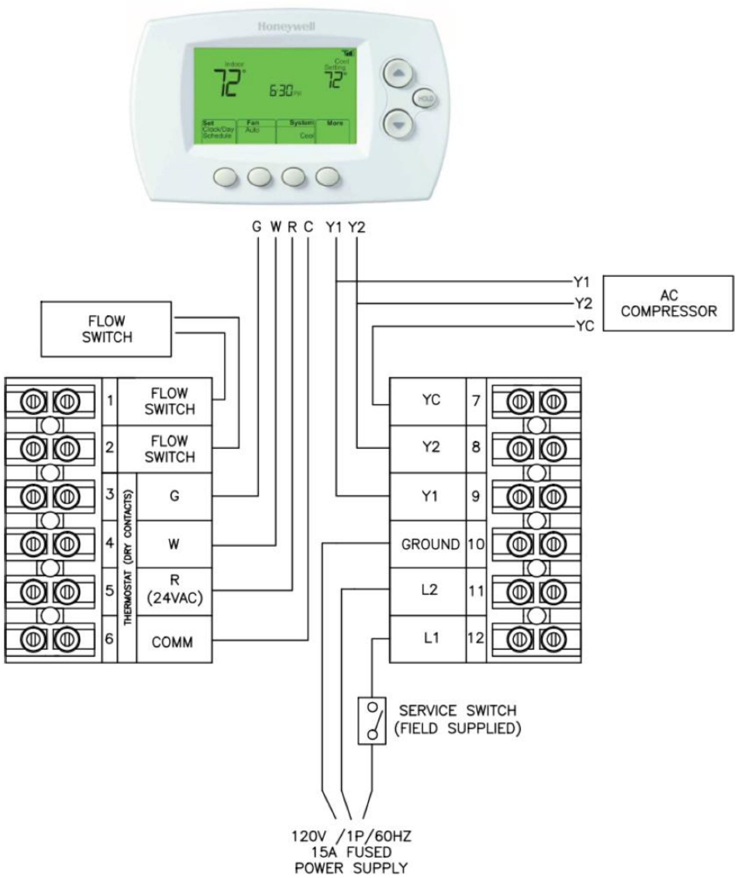
Contractor:______________________ Rep:____________

For: ☐ Reference ☐ Approval ☐ Review ☐ Construction

3- FIELD WIRING



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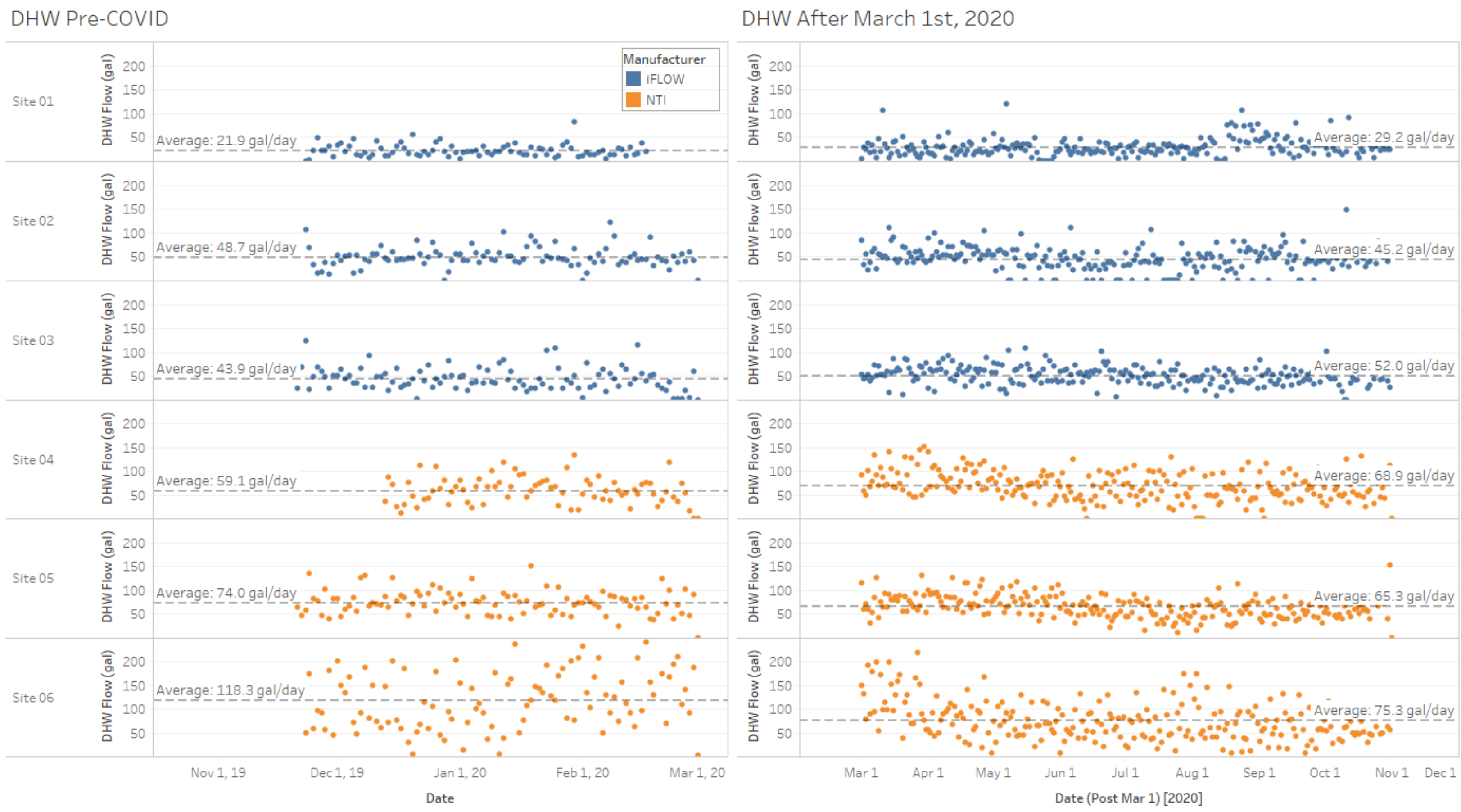
Appendix E. Pre- and Post-COVID DHW & SH Load Comparison

This field testing took place over most of 2020 and the occupants of all six sites certainly experienced significant disruptions to their daily routines from the COVID-19 outbreaks and stay at home orders. Three of the six sites did increase their daily DHW usage by an average of 8.4 gal/day (23%) after March 1st, 2020. However, the other three sites saw a decrease on average of 18.4 gal/day (-18%). The figure below shows the daily DHW usage in gal/day for the six field test locations pre- and post-March 1st.

FIGURE 44 - DHW USAGE PRE- AND POST-COVID



Similar to DHW loads, there is not a clear or significant change in either the space heating load or the performance of the systems after March 1st, 2020. The following figures compare the daily space heating load versus HDD and the daily system efficiency versus % of full load pre- and post-COVID stay at home orders.

FIGURE 45 – SITE 1 SPACE HEATING PRE- AND POST-COVID

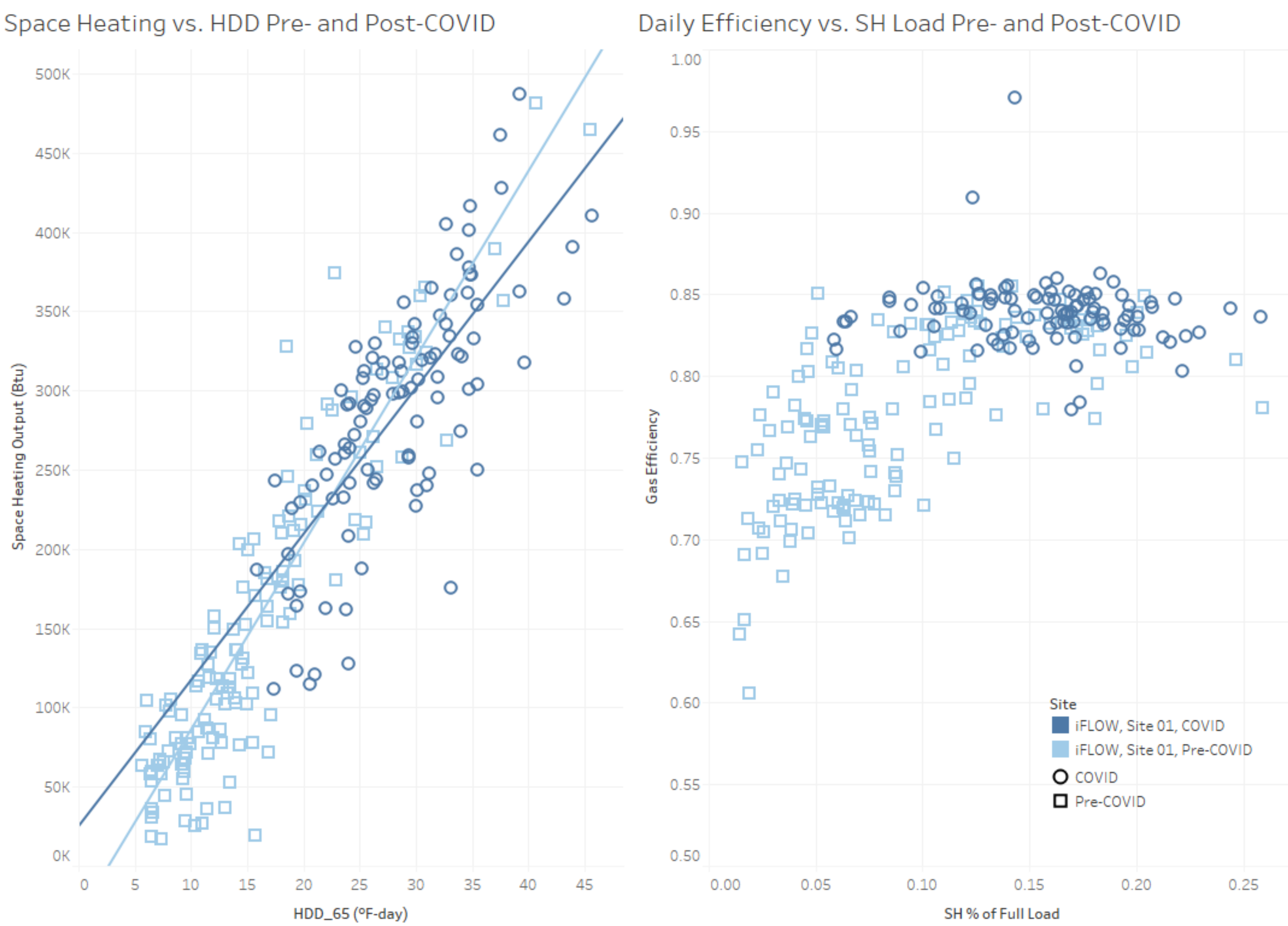


FIGURE 46 – SITE 2 SPACE HEATING PRE- AND POST-COVID

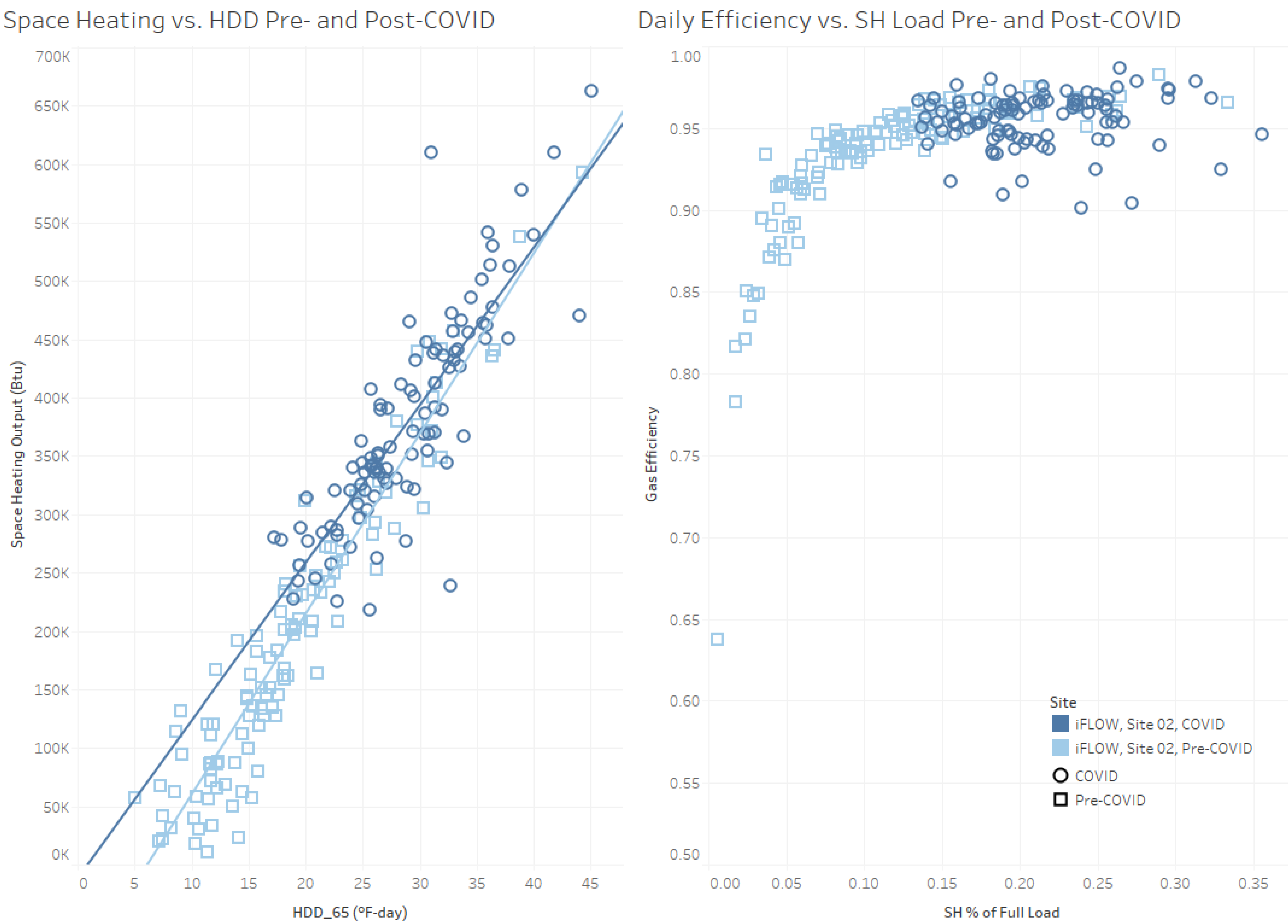


FIGURE 47 – SITE 3 SPACE HEATING PRE- AND POST-COVID

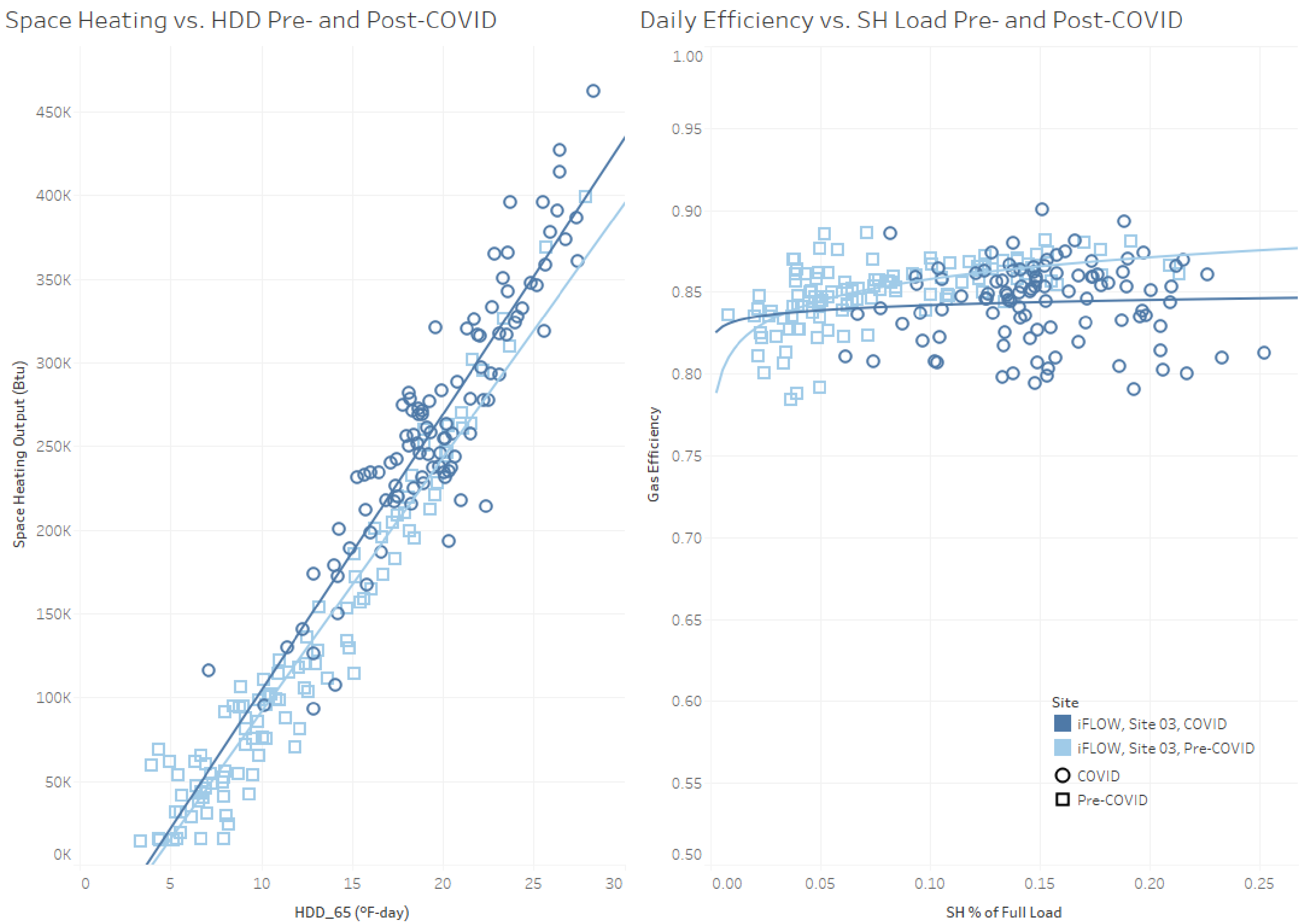


FIGURE 48 – SITE 4 SPACE HEATING PRE- AND POST-COVID

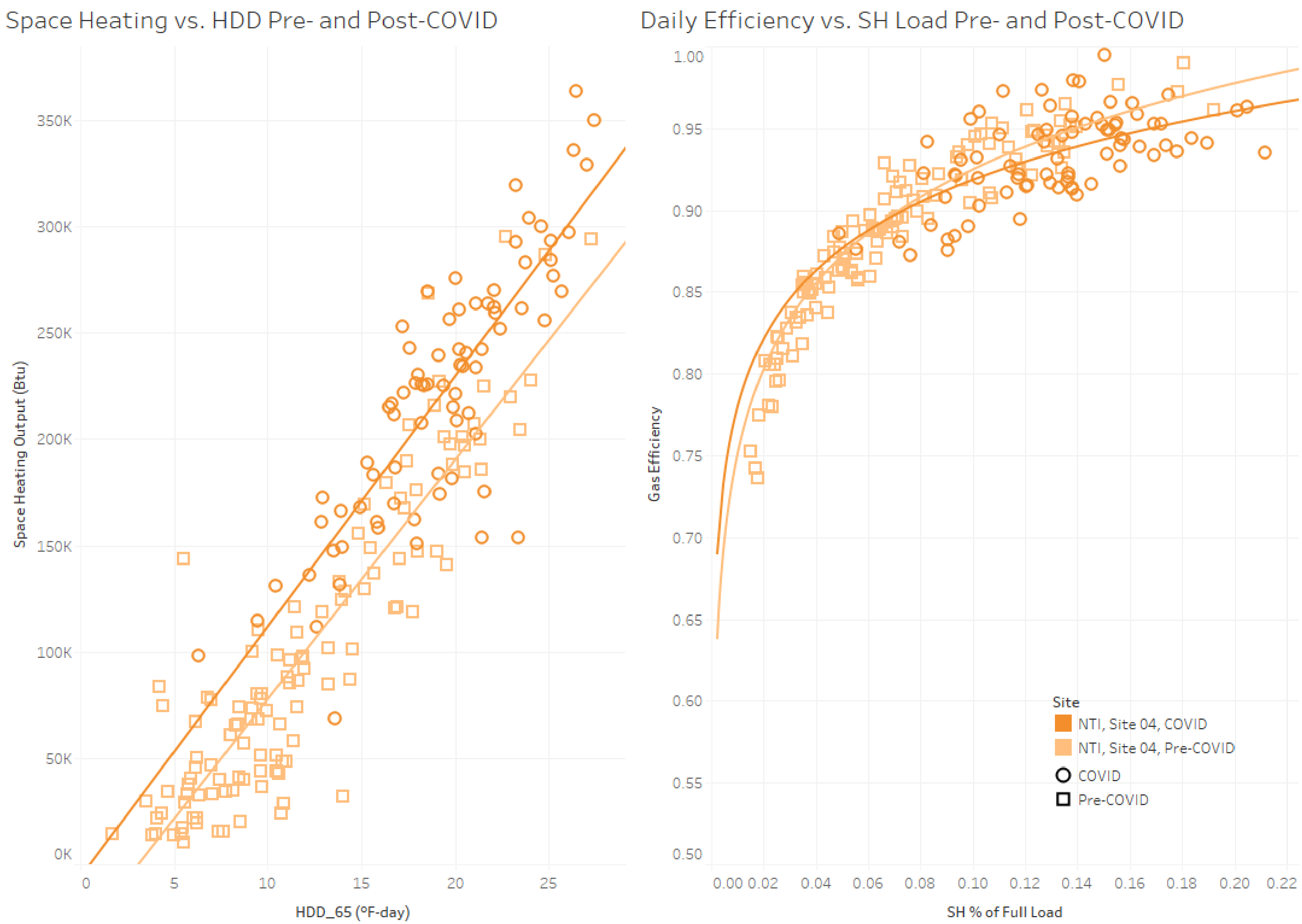


FIGURE 49 – SITE 5 SPACE HEATING PRE- AND POST-COVID

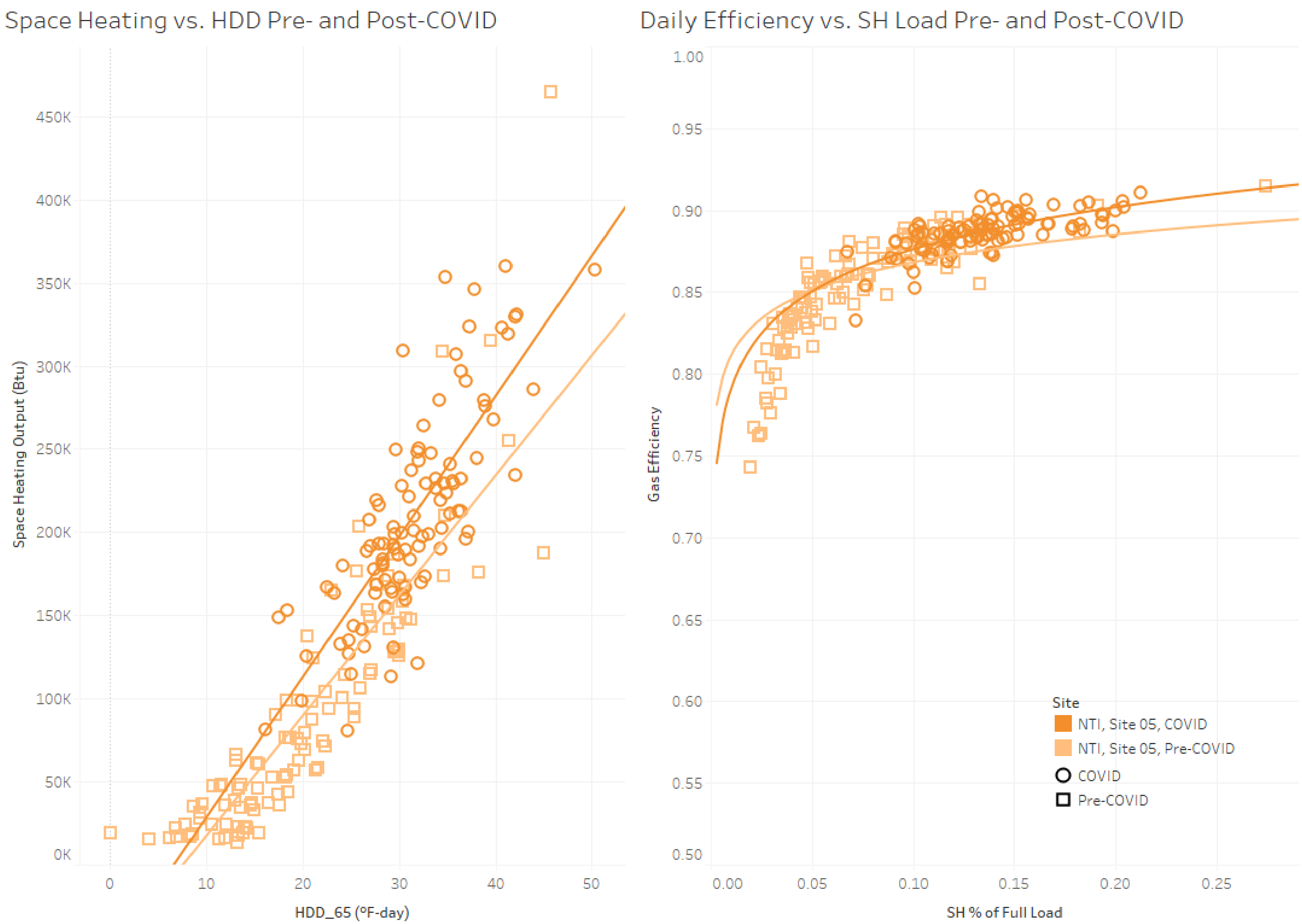


FIGURE 50 – SITE 6 SPACE HEATING PRE- AND POST-COVID