Final Memo to:
Massachusetts PAs
Massachusetts EEAC EM&V Consultants
Copied to:
Chad Telarico, DNV GL

From: Christopher Dyson, DNV GL
Date: April 25, 2019
Prep. By: Edilson Abreu, Christopher Dyson, DNV GL

IMPACT EVALUATION OF COMMERCIAL WATER HEATERS: FINDINGS FROM PROJECT 77 PILOT STUDY

1 EXECUTIVE SUMMARY

1.1 Background

One of the primary research tasks of the Commercial and Industrial (C&I) Upstream Gas Water Heater Impact Evaluation (Project 77) is a subsample pilot study designed to test various field measurement methods and technologies for measuring the operating characteristics of commercial water heaters (WH). The Project 77 work plan contains the following research objectives for this pilot study:

- This pilot evaluation will test and compare the results of a variety of field measurements for a small sample of 10 sites, comparing a variety of lower-cost measurements and water/gas bills to the higher-cost measurements to determine the most accurate way to estimate savings without unreasonable expense.
- The goal of the field data collection will be to gather information in support of two parameters:
    - The amount of natural gas used by the water heater.
    - The deviation of water heater operating efficiency from nameplate efficiency.

Because of the intrusive nature of some of the pilot measurements, which involved cutting into gas and water lines, it was challenging to recruit customers into this pilot study. The evaluation team ultimately was able to recruit six sites. The sites contained a total of twelve WHs, six WHs were monitored at four sites, Sites 571 and 48 both had two WHs monitored at different buildings hence ‘a’ and ‘b’. Table 1-1 provides a summary description of the sites which have received monitoring devices.

Table 1-1. Monitoring summary

WH Type	Site #	Strata	Sector	WH Size (Btu/hr)	Controls Monitor*	Make - Model
Volume[1]	184	1a	Multifamily	285,000		Lochinvar: AWN286PM
	202	2a	Multifamily	600,000	X	Lochinvar: AWN601PM
Tankless[2]	571a	2b	School	199,000		Rinnai: REU-KBD3237FFUDC-US
	571b	2b	Restaurant	199,000		Rinnai: REU-KBD3237FFUDC-US
Tank Style[3]	48a	1c	Multifamily	199,000		Lochinvar: SNA201-100
	48b	1c	Multifamily	199,000		Lochinvar: SNA201-100

*WH with pre-installed monitoring systems (Modbus, etc.) that can be accessed digitally. The strata in the sample design included: Multifamily - Volume water heater- 1a, Comm-Multifamily - Instantaneous water heater -1b, Comm-Multifamily - Storage water heater - 1c, Commercial - Volume water heater - 2a, Commercial - Instantaneous water heater - 2b, Commercial - Storage water heater - 2c, Multifamily - Instantaneous water heater - 3b, Multifamily - Storage water heater - 3c. Due to the intrusive nature of the pilot evaluation (cutting into gas and water lines) it was difficult to recruit customers for these pilot sites and we were not able recruit sites for all the strata. However, we were able to recruit sites for these other strata for the less intrusive "full sample" of WH sites.

In a July 2018 memorandum, the Project 77 team presented some preliminary findings from this pilot study. However, it took longer to gather the complete set of pilot data due to the following factors:

- One site where the evaluation team had installed measurement equipment was in Lawrence, Massachusetts. In mid-September a series of natural gas explosions in Lawrence and nearby communities meant that the evaluators could not retrieve the logger equipment from that site until November 2018.
- One site where the evaluation team had installed measurement equipment was in a school. Because the equipment had been installed when school was out of session, the Project 77 team had to wait to gather a few months of data that were representative of WH use when school was in session before retrieving the data loggers.

On January 17, 2019 the Project 77 team presented some preliminary findings from the complete set of pilot data to the Massachusetts Energy Efficiency Advisory Council (EEAC) consultants and Program Administrator (PA) representatives at the weekly CIEC meeting. The EEAC/PA representatives provided some feedback on these preliminary results. On February 21, 2019 the evaluation team submitted a draft version of this memorandum with EEAC/PA comments due in March. On April 5, 2019 the evaluation team submitted a draft final memorandum which addressed the March EEAC/PA comments. The evaluation team received additional PA comments on this draft final memorandum on April 18, 2019 and April 23, 2019. This final memorandum addresses those final comments.

[1] Volume water heaters can be either tankless units with an input rating greater than 4,000 Btuh/gal of water stored or; tank-style (storage) water heaters with a heating input capacity of 500 Mbtuh or greater

[2] Tankless water heaters, also known as demand-type or instantaneous water heaters, generate hot water only as needed. When a hot water tap is turned on, cold water is pulled into the unit and a flow sensor activates a gas burner. Volume water heaters are similar to tankless water heaters in that they use a heat exchanger to heat water.

[3] A tank-style WH, also known as a storage WH, provides hot water by maintaining a reservoir of hot water in a storage tank. When a hot water tap is turned on, hot water is released from the top of the tank and is replaced by cold water entering the bottom of the tank.

1.2 Key Findings

As noted, the Project 77 subsample pilot study had research objectives which included: 1) measuring key operating characteristics of various types of commercial WHs rebated by the Initiative; and 2) assessing the effectiveness of various methods and technologies used to conduct these measurements.

Table 1-2 provides the estimated and measured operating characteristics for the three rebated commercial WH technologies. The ability to assess the quality of the DNV GL metered data was limited due to the general unavailability of historic gas and water consumption data. If available, these data could have been be used to assess the general quality of the DNV GL interval meter data values by looking at the ratio of metered gas and water usage to the monthly billed consumption during summer months.

Table 1-2 Key Operating Characteristics of Rebated Equipment, as Measured

Operating Characteristics	Water Heater Technology			
	Tank-Style	Tankless	Volume Heater	
	Sites 48a and 48b Totals	Sites 571a and 571b Totals	Site 184	Site 202
Sector	Multi-family	School / Restaurant	Multifamily	Multifamily
Gas Consumption	8 MMBtu/month (8 MCF/month)	428 MBtu/month (415 CF/month)	23 MMBtu/month (22 MCF/month)	109 MMbtu/month (106 MCF/month)
Water Consumption	6,346 gals/month (212 gals/day)	2,085 gals/month (70 gals/day)	128 gals/month (4 gals/day)	311,138 gals/month (10,371 gals/day)
Operating Hours	1,332 hrs/yr (4 hrs/day)	84 hrs/yr (<1 hr/day)	2,560 hrs/yr (7 hrs/day)	5,287 hrs/yr (15 hrs/day)
Energy Efficiency	Inconclusive	Inconclusive	Inconclusive	Inconclusive

A few specific observations on the nature of the data for the various sites and WHs include:

- Historic gas and water consumption data were provided for the tank-style WHs and the DNV GL metered data seemed low when compared to summer gas load and annual water consumption.
- No historic gas and water consumption data were provided for the tankless WH and one of the sites 571b produced no gas or water data due to a meter malfunction.
- Water consumption for the tankless WH site 571a could not be measured accurately because it was a constant flow system.
- Historic gas and water consumption data were provided for volume heater WH site 202, but not for site 184.
- The DNV GL metered gas consumption for site 184 WH corresponds to 53% of the summer gas load, however the metered water consumption was less than 1% of billed.
- The DNV GL gas meter data was used to calculate the operating hours for all three WH technologies.
- The meter data quality was insufficient to calculate energy efficiency for any of the sites, see Section 1.3 for more explanation.

Table 1-3 shows the different methods and technologies that the pilot study used to measure the key operating characteristics of the Initiative-rebated WHs. For each method/technology, we assess the quality of the data and provide comments and explanations on what factors might be contributing to incomplete, anomalous, or difficult-to-interpret data.

Table 1-3: Assessments of Methods/Technologies for Measuring Commercial WH Characteristics

Method/Technology	Quality/Reliability of Data	Comments, Explanatory Factors
Water Flow Meters	Inconsistent quality, unreliable	See section 2.1.3 for details
Gas Flow Meters	Consistent quality, very reliable	Three different meters all produced consistent reads. One meter had a pulsar fail during deployment and had to be replaced. Data quality was negatively impacted by the difficulties encountered with the loggers and modems.
Condensate Pump meters	Inconsistent quality, semi-reliable	See section 2.1.4 for details
Temperature and Humidity for Flue Gas Exhaust	Poor quality, unreliable	See section 2.1.6 for details
Combustion Fan and Electric Load Meters	Poor quality, unreliable	See section 2.1.5 for details
Central loggers	Low quality, semi-reliable	See section 2.1.1 for details
Cellular Modems for Remote Monitoring	Inconsistent quality, semi-reliable	See section 2.1.2 for details
Thermometers and Graduated Containers for Spot Measurements	Consistent quality, semi-reliable	See section 2.1.7 for details

1.3 Conclusions

Key lessons learned from the pilot study include:

- Commercial systems require more site-specific data gathering, and intricate metering configurations. While the study's more intrusive measurement methods (e.g., installing gas and water meters) had a good design foundation, they were still not robust enough to address the intricacies encountered in the field.
- Gas usage was successfully monitored at the sites that did not experience significant problems with the modems and loggers. If gas consumption is all that is desired, then sub-metering gas usage pre and post WH retrofits is one method to get savings, though such a calculation would rely on consistent water usage. Furthermore, sub-metering is also intrusive, costly, and potentially dangerous.
- Determining operating thermal efficiencies using low-cost, unobtrusive field monitoring methods is not feasible. The pilot monitoring produced data with many quality issues because of faulty meters, and

modem or logger connectivity problems. In conclusion the distribution systems and operations at commercial and industrial facilities are too complex (various mixing valves, constant circulation, different end uses, etc.) for low-cost, unobtrusive, metering to accurately capture water flowrates and temperatures to produce reasonable and intelligible data. Robust, and therefore complex, monitoring systems are required to capture all the necessary flows and parameters of large commercial and non-residential sites like the ones in this pilot sample. Combustion efficiency could likely be monitored over time in a less invasive and more accurate way, but it was not a monitoring option chosen for this pilot study because water consumption data was a higher priority for the PA's for this study.

These kinds of measurements would produce more reliable estimates, for gas and condensate data, with the following improvements (which are discussed in more detail in the main body of the memorandum):

- Greater use of existing integrated controls or monitoring capabilities if certain barriers (e. g, the ability to understand/translate proprietary controls language) can be overcome;
- Improved measurement methods and equipment (e.g., higher quality meters and sensors), for example if the water pipes (hot and cold pipes immediately surrounding the DHWs) onsite are bare or have removable insulation then measuring their surface temperatures could potentially improve the accuracy of water temperature readings;
- Refined M&V plans reviewed by 3rd party (manufacturers, subject matter experts, etc.) to ensure that deployment will be successful;
- More time spent onsite understanding the facility (e.g., areas with best signal strength for modems), the WH system operation and sequencing, and the distribution system components and end uses;
- More complete collection of historical gas and water consumption data.

2 DETAILED FINDINGS

This section contains more detailed discussion of the findings summarized above.

2.1 Assessing the Performance of the Measurement Equipment

The following are the evaluation team's observations on the performance of the methods and equipment used in the pilot study along with recommendations for improving them in any future studies.

2.1.1 Central Loggers

Two Campbell Scientific model types (CR300 and CR800) were used. Both models had inconsistent or missing data. The logger programming language is specific to the manufacturer's equipment so there was a steep learning curve in programming the loggers to verify proper sampling and data storage. Campbell Scientific technical support was very helpful in reviewing the programs prior to installation and assisting with onsite troubleshooting. They frequently accessed the data loggers remotely to assist with troubleshooting. The programs could be edited and uploaded remotely.

The measured equipment was typically far from the datalogger so long wires were run to the terminal blocks in the data logger. Anyone working in the area could accidently or purposefully move the wires which could break the connection in the terminal block. There is no easy fix for this because the water heater must be accessed for repairs and maintenance.

2.1.2 Cellular Modems

All modems used were the same Sierra Wireless Raven XT model. The cellular signal strength for each site varied significantly which resulted in inconsistent performance and data collection. These older model modems were directly connected to the data loggers and antenna were placed where the wireless signal was strongest within a 50-foot radius. Much of the programming related to connecting to the central loggers and the cloud server was done prior to deployment but some barriers could only be discovered during installation. Unfortunately, a trained, manufacturer approved, technician was not present to ensure proper deployment which resulted in frequent return visits to troubleshoot issues encountered during deployment.

Mechanical rooms are typically concrete and buried deep in the building making for poor cellular service. Schools, while in session, block cellular signals to and from the building. Unless the site WIFI is made available a different method of data transfer should be used.

2.1.3 Water Meters

Two different meter types were used. Meters were tested and calibrated prior to deployment. The Omega FP type meters were the most frequently used because they fit pipes ≥2 inches but they produced the most inconsistent data. The Minol 130 type meters fit pipes ≤1 inch and required less troubleshooting during deployment than the Omegas. Data quality was negatively impacted by faulty meter sensors, and the difficulties encountered with the loggers and modems. Some of the WH monitored were not lead units which could have been the reason for minimal operating data.

Distribution system operation should be carefully noted to ascertain whether there is constant or intermittent flow through the WH. Sequencing of the WH should also be noted to record whether a unit is in a primary, secondary or backup role and if the units regularly rotate roles to extend their useful life.

2.1.4 Condensate Pumps and Meters

All condensate pumps (Little Giant VCMA-15), and electrical load meters (Magnelab SCT-0750-020 20A current transformers) installed were the same model, but the data captured was inconsistent. Pumps and meters were tested and calibrated prior to deployment to determine the data needed to be collected from this equipment once it was installed. Data quality was impacted by onsite operating conditions (inlet water temperatures too high for condensing), previously discussed issues affecting the loggers and modems, and improper setup of some of the pre-existing condensate lines which resulted in leaks.

2.1.5 Combustion Fan

All electrical load meters (20A current transformers) used on combustion fan were the same but the data captured was incomprehensible and it was not possible to distinguish relevant data from signal noise. Meters were tested and calibrated prior to deployment. Data quality was also negatively impacted by the issues affecting the loggers and modems detailed in sections 2.1.1 and 2.1.2. The best electric load meter accuracy occurs when the load operates as close to the full rating of the meter as possible, but the data recorded was very low amplitude and very noisy indicating that the meters were likely oversized.

2.1.6 Exhaust Gas

The initial meter models chosen for measuring characteristics of the exhaust gas (temperature, humidity, etc.) were not suited for the conditions encountered in the field. The Oregon Scientific Multi-zone weather station – RAR502 meters were intended for spot measurements only. The humidity range on these units is 25% to 95%. After 95% RH they fail to read accurately.

Testo hygrometers model number 635-2 with Testo probe 0636 9735 were used for spot measurements as an alternative to the weather stations. The probe range for humidity is 0 to 100% but water would condense on the probe and cause bad or false readings.

Proper meter selection is important, backup meters should be readily available. Intake air characteristics should also be measured to improve accuracy.

2.1.7 Spot Measurements

Spot measurements were conducted to record temperatures of WH room air, tank surface, and inlet and outlet water temperature. WH tank dimensions and the amount of condensate removed by the condensate pump were also spot measured. These measurements showed reasonable precision and consistency. However, the various temperatures are more dynamic than expected and should be metered long-term instead of relying on spot measurements for better accuracy. Inlet and outlet temperatures were particularly difficult to spot measure near the WH and the nearby taps had inaccessible mixing valves which decreased the accuracy of the temperature measurements for the WH's outlet water.

2.1.8 Historic Usage Data

Historic data gas and water usage was only provided by site contacts for three of the six sites. As noted, these data could have been be used to assess the general quality of the DNV GL interval meter data values by looking at the ratio of metered gas and water usage to the monthly billed consumption during summer months. However, it is important to note that it is often difficult to find gas or water billing data in which water heating was the exclusive load at any point in the year.

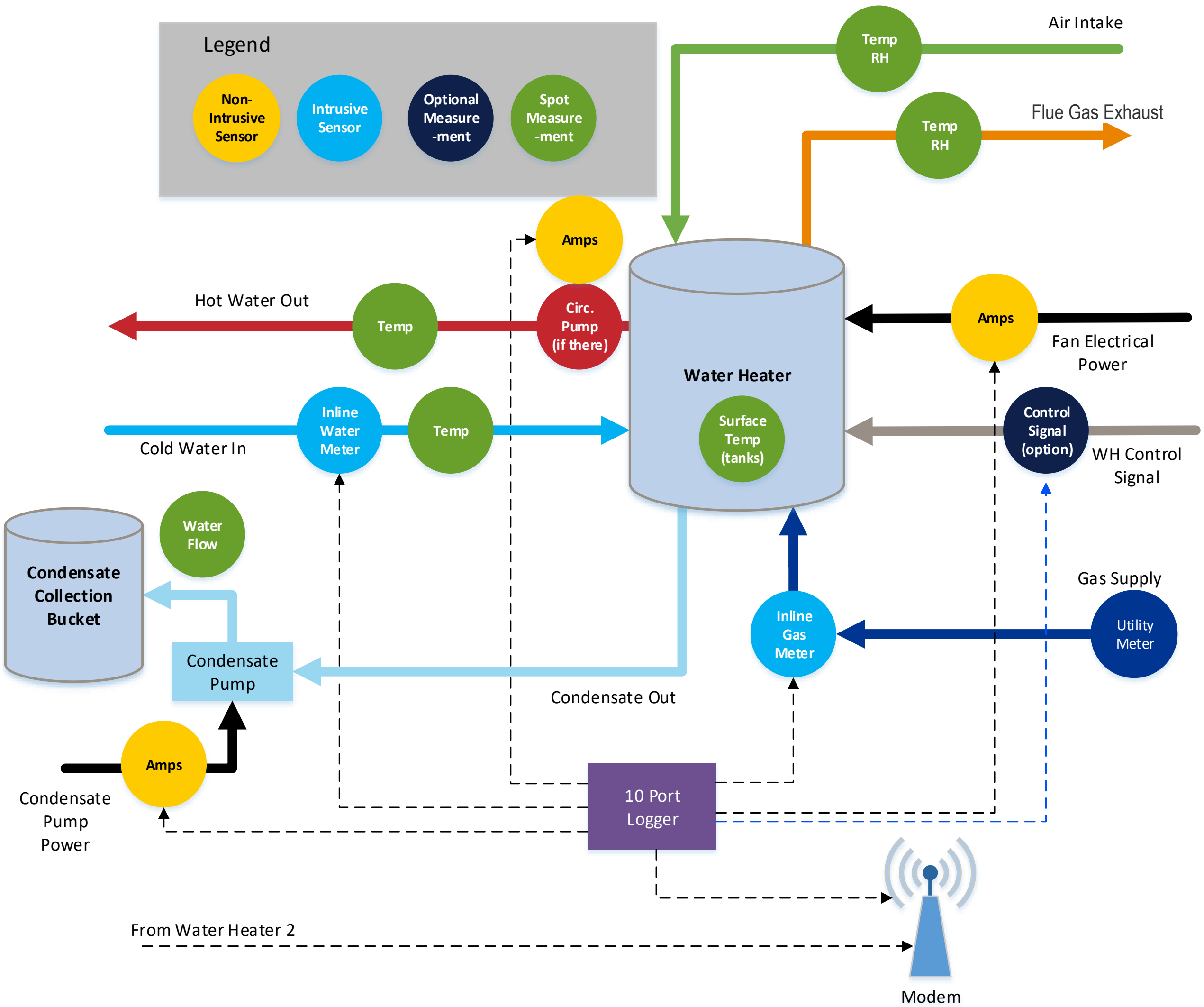
2.2 The Data Collection Methodology

This section describes how the pilot study collected the field data.

2.2.1 Parameter Identification & Collection Method

Figure 2-1 shows the parameters and monitoring setup. The sites varied according to whether we monitored the controls signal, whether there was an external tank, or whether there was a circulation pump. We did not collect amperage data from circulation pumps that run all the time.

Figure 2-1. Logger setup



2.2.2 Preliminary controls monitoring update

As directed by the PAs and EEAC Consultants, DNV GL planned to add controls monitoring to three of the subsample pilot WHs, but was only successful at one site (202). Controls monitoring allowed us to tap into the internal sensors of the WH to capture the data they are measuring. It is far less intrusive than inline gas or water metering and could be performed without the help of an electrician as it is low voltage wiring. The key parameters that were captured at Site 202 are as follows, in order of importance:

1. Natural gas firing rate
2. Incoming/outgoing water temperature
3. Outgoing combustion air temperature

Most condensing water heaters use proprietary language for internal controls. Some use a traditional Modbus language or something that can be translated to Modbus. The learning curve to program the dataloggers to interpret Modbus was steep. Typically, the control card is offered as an add-on to the cost of the water heater. The cards are for extracting data for smart thermostats and EMS systems. None of the sites had purchased a card. Once the card is installed, it stays with the unit. Site 202 was willing to have the card installed. There is high potential for using communications monitoring for other high-rigor studies of important gas measures in the future if proper information is gathered ahead of time during site recruiting or scouting visits.

2.2.3 Site Selection

Sites were targeted for recruitment based on their WH models. WH models were prioritized based on their distribution in the commercial upstream WH program, detailed in Table 2-1.

Table 2-1 Targeted WH Types

Type	Manufacturer	Line	Savings	Count	Pct Meas.	Pct. Overall
Volume	Lochinvar	AWN	395,355	173	64%	25%
Volume	Aerco International	INN	44,113	7	7%	3%
Volume	Heat Transfer Products	MODCON	75,855	21	12%	5%
Volume	Heat Transfer Products	EP	39,860	37	6%	3%
Volume	Heat Transfer Products	EL	21,930	15	4%	1%
Storage	Heat Transfer Products	PH	177,752	771	40%	11%
Tankless	Navien	NPE	127,447	1432	33%	8%
Volume	AO Smith	XWH	87,671	2	3%	1%
Storage	AO Smith	BTH	46,018	199	10%	3%
Storage	State Industries*	GP6	133,238	578	30%	8%
Tankless	State Industries*	GTS	237,675	2673	61%	15%
Storage	Lochinvar	SN				

*AO Smith owns State Industries

Because of the intrusive nature of some of the pilot measurements, which involved cutting into gas and water lines, it was challenging to recruit customers into this pilot study. The evaluation team finally was able to recruit four sites, site 571 and 48 had two WH monitored at different buildings hence 'a' and 'b'. The sites contained a total of twelve WHs, six WHs were monitored. Table 2-2 provides a summary description of the sites which have received monitoring devices.

Table 2-2 Monitoring Summary

WH Type	Site #	Strata	Sector	WH Size (BTu/h)	Controls Monitor*	Make - Model
Volume	184	1a	Multifamily	285,000		Lochinvar: AWN286PM
	202	2a	Multifamily	600,000	X	Lochinvar: AWN601PM
Tankless	571a	2b	School	199,000		Rinnai: REU-KBD3237FFUDC-US
	571b	2b	Restaurant	199,000		Rinnai: REU-KBD3237FFUDC-US
Tank Style	48a	1c	Multifamily	199,000		Lochinvar: SNA201-100
	48b	1c	Multifamily	199,000		Lochinvar: SNA201-100

*WH with pre-installed monitoring systems (Modbus, etc.) that can be accessed digitally

2.2.4 Meter Selection

The evaluation team selected gas and water meters based on information about distribution line diameters, operating pressure, pipe material, and compatibility with loggers. It collected site-specific data during scouting visits and supplemented these with publicly-available data from the internet. Table 2-3 lists the gas meters and Table 2-4 lists the water meters that were used. The condensate pump model installed at all sites was a Little Giant VCMA-15. All electrical load meters were Magnelab SCT-0750-020 20A current transformers. Two Campbell Scientific model types (CR300 and CR800) were used. All modems used were the same Sierra Raven XT model.

Table 2-3 Gas Meters Deployed

Manufacturer	Model	Max Pressure (PSIG)
Elster	AC-630	25
MTW	G4	7.5
IMAC	BKG-4	5

Table 2-4 Water Meters Deployed

Manufacturer	Model	Max Pipe Diameter (inches)
FP	5300	2-12
MINOL	130	≤2

2.2.5 In Field Troubleshooting

When the evaluation team identified errors in remote data or malfunctions with metering equipment, it scheduled an emergency site visit with the site contact. In most cases, the evaluation engineer could resolve modem and datalogger problems with assistance from the metering equipment manufacturers. The manufacturer's technical representative could be contacted by phone and they frequently could directly connect to the modems and dataloggers to troubleshoot the issue. Manufacturers of the gas and water meters were also available by phone to assist in troubleshooting.

2.3 Analysis

This section describes how the pilot study analysed the data.

2.3.1 Data Cleaning

Data used in analysis included data stored in a cloud server and backups taken directly from the central loggers during retrieval visits. These two data sets were merged, and duplicate records were removed. The merged data set for each site was reviewed and time periods in which gas, water, and condensate records had significant overlap were selected. It became apparent that many sites had significant differences in the quantity of reads between parameters namely the water and condensate data had many less records than the gas resulting in consumption much lower than expected. The records for gas, water, and condensate were converted from digital readings to engineering units (cubic feet (CF) for gas, and gallons (gals) for water. To make the data volume more manageable and intelligible the values for each parameter was aggregated from sporadic sub-minute intervals to minute intervals.

Run-time variables were introduced into the analysis data at the minute level. Each minute with non-zero gas usage or water usage was flagged with a binary value. The run-time variables confirmed that nearly all sites had significantly less water usage reads than gas usage reads again indicating problems with the water meters. The run-time values were then aggregated from minute to hour intervals. The max firing rate variable was calculated as the highest minute interval gas consumption divided by max input capacity, and average firing rate was calculated as the total hourly gas consumption divided by max input capacity. Comparing firing rate and run-time variables with WH turndown ratios improved identification of short-cycle purge events as these events should not factor into efficiency calculations. All parameters were then aggregated from minute intervals up to hour intervals as necessary.

2.3.2 Operating Efficiency

Efficiency is typically calculated as a function of heat load (water usage, and inlet and outlet water temperatures) versus input energy i.e. gas usage. For systems with storage tanks, heat loss through the tank's surface should also be subtracted from heat load. However, the data which this pilot study collected, especially those related to water usage metering (as discussed above) were insufficient to allow the evaluation team to accurately determine whether the manufacturer's nameplate efficiency was accurate in installed operation.

2.3.3 Gas Usage and Condensate Correlation

An initial hypothesis was that condensate production would be correlated with gas usage. If proven true, this correlation would allow for a cost-effective non-intrusive monitoring method to determine gas usage for condensing WH. However, the data received from the pilot sites had significant data quality issues, especially those related to condensate monitoring, as explained previously. Yet some sites had enough data to evaluate the correlation between the two parameters (Table 2-5). The correlation coefficient 'R' measures the strength and direction of a linear relationship between two variables on a scatterplot. The value of 'R' is always between '+1' and '–1', an R with absolute value of 1 indicates perfect linear correlation. Three (184, 202, and 48B) of four sites show strong correlation between gas usage and condensate production as predicted. Sites 571a and 571b did not have enough condensate data to establish a correlation between gas usage and condensate production. Unfortunately, our monitoring methods inaccurately measured water usage and were insufficient to determine operating efficiency.

Table 2-5 Correlation Between Condensate Production and Gas Usage

Sites	184	202	48A	48B
Correlation Coefficient (R)	0.79	0.75	0.49	0.83