Field Study of an Intelligent, Networked, Retrofittable Water Heater Controller

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DISCLAIMER

Abstract

The Gas Technology Institute (GTI) in collaboration with Center for Energy and Environment (CEE) conducted a CARD-funded field study to validate the performance, cost-effectiveness, and direct energy savings of the Aquanta, a smart water heater controller introduced to the market in 2016.

Thirty-three (33) Aquanta smart water heater controllers were retrofitted onto 11 residential electric storage water heaters and 22 on residential gas storage water heaters. Ten sites were fully monitored with measurement and verification (M&V) instrumentation to validate the technology's ability to save energy and to accurately monitor daily water and energy usage.

The field evaluation validated the ease of installing the controller with most installations taking between 60 and 90 minutes to complete. The controller was found to save energy two ways. First, the controller reduces the energy lost from storing hot water by lowering the tank temperature set point and eliminating unnecessary reheats. Second, the controller reduces the amount of energy delivered to the fixture by eliminating or reducing over heating (i.e. less mixing). There also was a noticeable shift in Energy Use Profile.

Savings from the controller averaged 2.3% by one analysis method and 9.3% by another, but individual results ranged considerably. The wide variability in savings in both analyzes suggest the need for a larger population of sites and an increased length to the monitoring period in order to obtain more robust results.

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Definition of Terms and Acronyms

AI Mode	Aquanta Intelligence Mode - Period of controller activity where data collection is active and the controller actively suppresses water heater on-time based on learned water heater operational habits.
Base Mode	Baseline Mode - Period of controller activity where, data collection is active but no active control takes place.
CARD	Minnesota Department of Commerce, Conservation Applied Research and Development
CEE	Center for Energy and Environment
CIP	Conservation Improvement Program that are utility-based.
CTWH	Condensing Tankless Water Heater
DER	Minnesota Department of Commerce, Division of Energy Resources
GTI	Gas Technology Institute
kWh	Kilowatt Hours - Unit of energy equal to 3412.14 Btus.
M&V	Measurement and Verification
NTWH	Non-condensing Tankless Water Heater
RECS	Residential Energy Conservation Survey
StWH	Storage Water Heater
Therms	Therms - Unit of energy equal to 100,000 Btus.
TRM	Technical Reference Manual
U.S. EIA	U.S. Energy Information Administration
U.S. DOE	U.S. Department of Energy
Wi-Fi	A technology for wireless local area networking with devices based on the IEEE 802.11 standards.

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Executive Summary

Introduction

The Gas Technology Institute (GTI) in collaboration with Center for Energy and Environment (CEE) conducted a CARD-funded field study to validate the performance, cost-effectiveness, and direct energy savings of the Aquanta, a smart water heater controller introduced to the market in 2016.

The Aquanta, an intelligent, networked, retrofittable water heater controller is compatible with electric storage water heaters and gas storage water heater models with electronic gas-control valves. The technology offers the ability to track, report, and control energy consumption.

In Minnesota, water heating is the second largest consumer of residential energy in the state, amounting to over half a billion dollars in consumer spending annually. A one percent reduction in energy usage equates to 2.7 Million therms and 22 Million kWh saved and $4.7 Million in avoided cost to Minnesota's consumers.

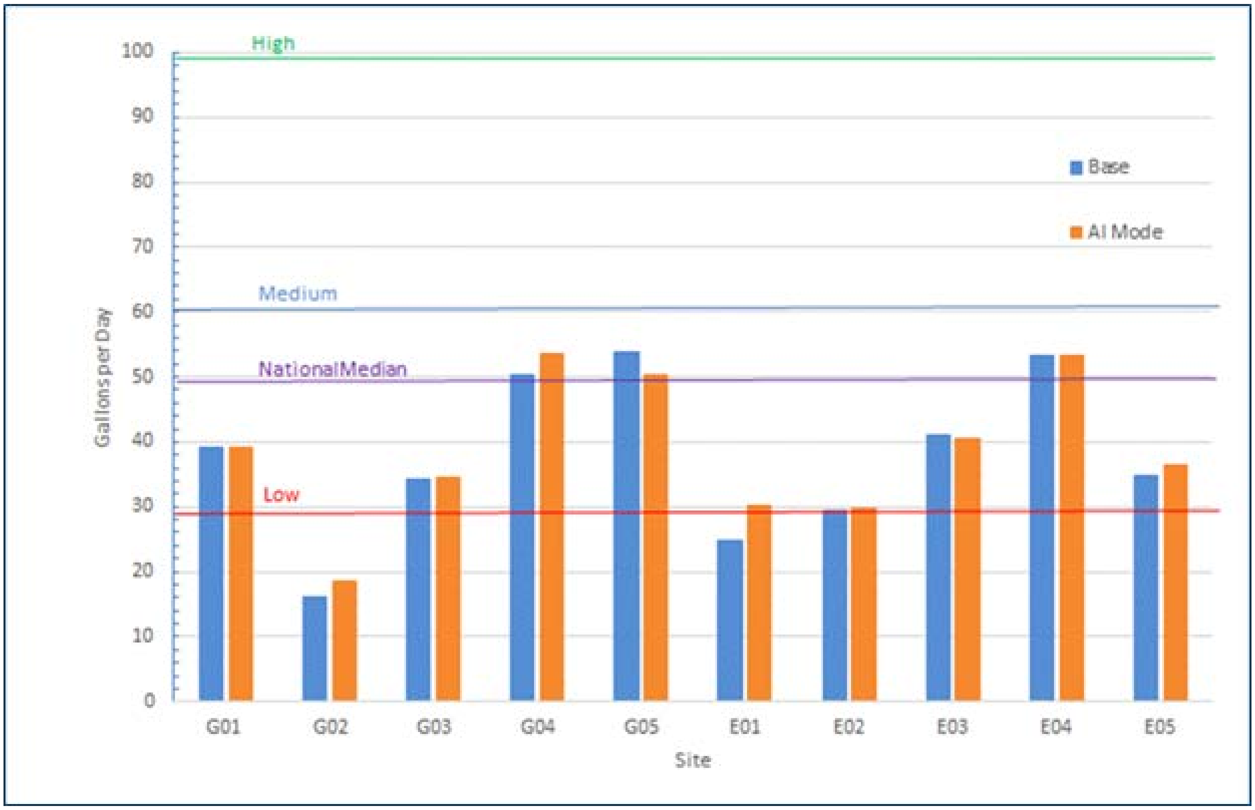
Method

Thirty-three (33) Aquanta water heater controllers were retrofitted into existing residential water heaters, with a 33/67 split between electric and gas. Ten sites were fully monitored with measurement and verification (M&V) instrumentation to validate the technology's ability to save energy and to accurately monitor daily water and energy usage. During the field evaluation, homeowners and occupants were restricted from interacting with the controller. The controllers operated alternately between Base Mode and Aquanta Intelligence (AI) Mode. In Base Mode, data collection is active but no active control takes place. In AI Mode, data collection is active and the controller actively suppresses water heater on-time based on learned water heater operational habits.

Results

The detailed analysis on 10 M&V sites show the median usage for all M&V sites was 34.5 gallons per day (GPD), and the average is 38.2 GPD. In 2014, Lawrence Berkeley National Laboratory, analyzed data of 159 field study homes where hot water was measured in sites located throughout the U.S and found the National Median at 49.6 GPD with high, medium, and low GPD clusters that averaged at 98.5 GPD, 60.5 GPD, and 29.4 GPD respectfully. The M&V sites fall below the National Median and into the Classification of "Low Usage" (Figure 1). The national averages may be atypical to Minnesota water usage generally, or the M&V sites that were selected may be low use outliers for some specific reason (e.g. they are practicing water conservation, such as using low flow showerheads). Other analysis by the CEE and the Florida Solar Energy Center report median hot water usage at 40 GPD, closer to what was found in this study.

Figure 1. Comparison of M&V Site Hot Water Use by Mode to National Averages

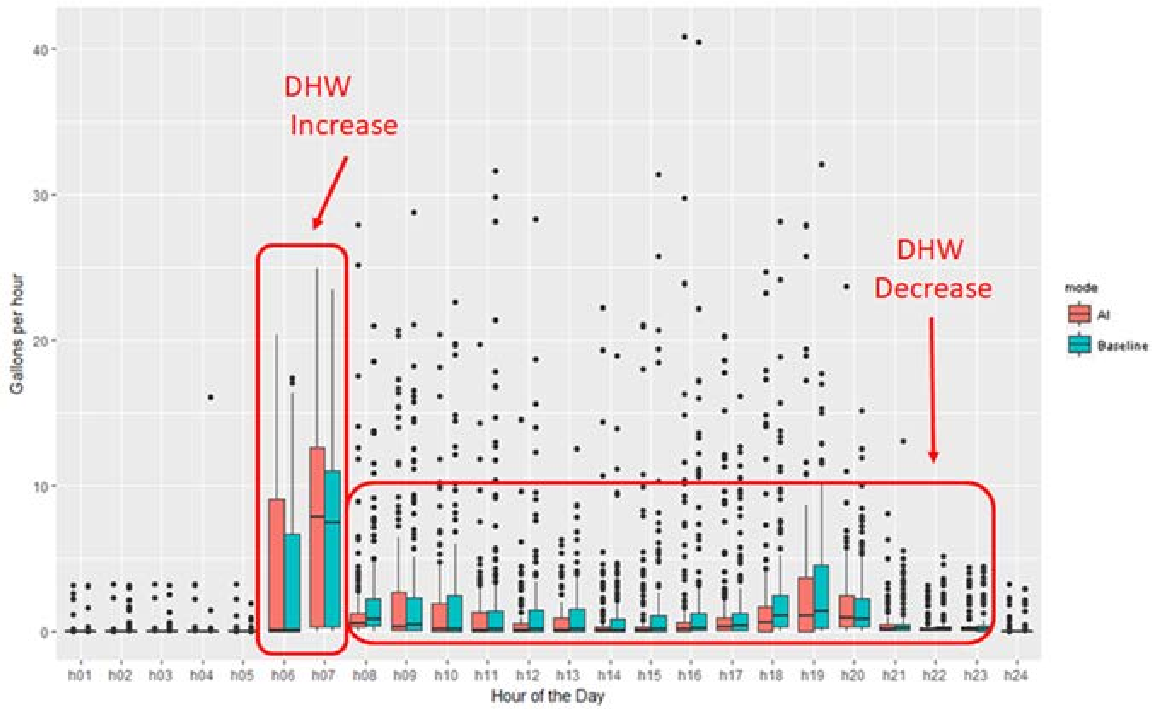


In AI Mode, all M&V sites show a reduction in delivered hot water temperature over Base Mode. Electric M&V sites had an average 1.7°F reduction in delivered hot water temperature compared to an average of 6.2°F for Gas M&V Sites. It is worth noting that the temperature set point of Electric M&V sites centered around 120°F. The temperature set point Gas M&V sites centered around 125, with one outlier at 135°F.

The gallons per day increased with AI mode active for all M&V sites except for Site G05. The average increase was 1.6 GPD. Site G05, with a natural gas water heater and two occupants using 49.7 GPD showed a decrease of 9%, or 5.2 GPD. Sites with low gallons per day usage show the highest percent increase in gallons per day.

In AI Mode, the controller shifts hot water use and burner reheat patterns in a home. Two sites, one electric (E05) and the other gas (G01) experienced some shift in hot water use where gallons per hour increased during periods of high hot water demand and decreased during periods of low hot water demand. Each site exhibited its own unique traditional periods of high and low use that varied slightly by hour of day or day of week. In Figure 2, these hours of high demand were gallons per hour increased were hours 6 and 7 for Site G01. Gallons per hour decreased from hours 8 through 23, a period of low demand.

Figure 2. Site G01 - Median Usage and Interquartile Range of Water Use by Hour of Day by Mode

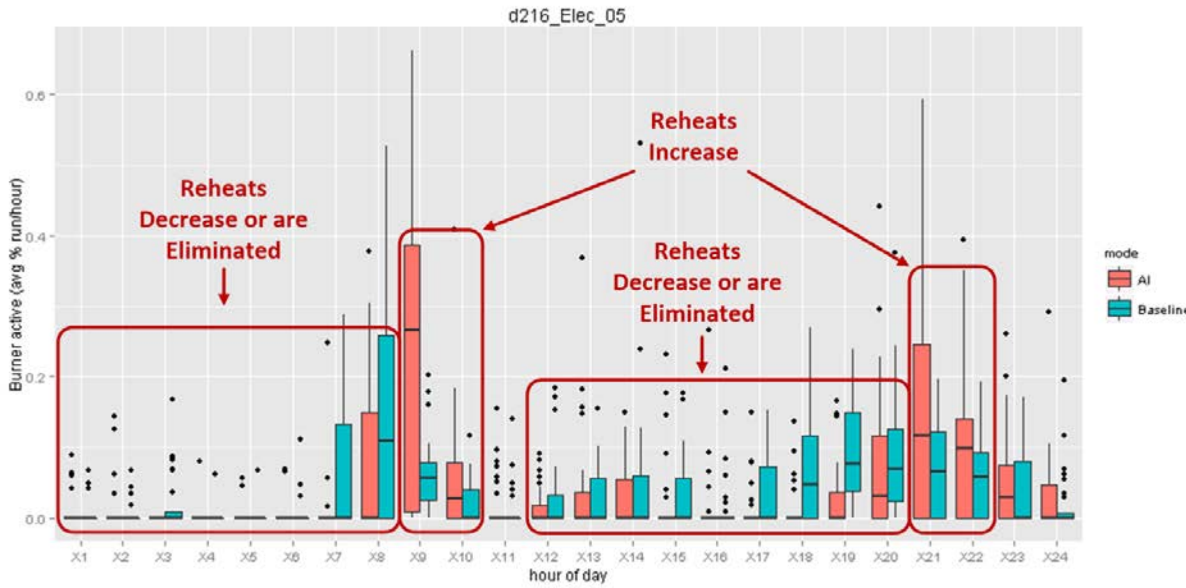


Data from all ten sites shows that during periods of high hot water demand, gallons per hour use increases and during periods of the low hot water demand gallons per hour use diminish in comparison to baseline operation. Two sites, one electric (E05) and the other gas (G01) experienced some shift in the period where thermal energy available in the tank is adequate to meet hot water demand. Each site exhibited its own unique traditional periods of little or no hot water demand that varied slightly by hour of day or day of week. In our sample sties, these hours were 1-7 and 15-18 for Site E05, and hours 1-6 and 11-17 for Site G01 (Figure 3).

Data from all ten sites shows that during or immediately following period of high hot water demand, the number of reheats increased in comparison to baseline operation.

In AI Mode, the weekly median efficiency for all M&V site water heaters is higher than in the Base Mode except for Site G05, with two occupants and high gallons per day usage (49.7 GPD).

Figure 3. Site G01 – Gas Water Heater Burner On-time by Hour of Day by Mode



Two methods of analysis used in calculating savings found uneven results: one method based on a Combined Seasonal Dataset, and the other based on Separate Base and AI Seasonality Datasets.

Using a Combined Seasonal Dataset, where results were statistically significant, Gas M&V Sites produced an average savings of 0.1 percent in AI Mode over Base Mode, and electric M&V Sites produced an average savings of 1.0 percent. This shows that the controller can increases water heater efficiency. However, there is wide variability in savings: For Gas M&V Sites, Site G01 showed the largest percent savings per year, 2.5 percent, while the lowest is Site G02 at -4.0 percent (Table 1). The largest percent savings per year for Electric M&V Sites is Site E04 at 2.8 percent, while the lowest is Site E02 at -1.1 percent (Table 1).

Table 1. Gas M&V Sites - Combined Seasonal Dataset Results

Mode	Metric	G01	G02	G03	G04	G05
Base Mode	Qin (Btu/day)	33208	21570	32746	33401	46248
	Qout (Btu/day)	19251	9462	19618	27023	29040
	Efficiency	58.0%	43.9%	59.9%	80.9%	62.8%
AI Mode	Qin (Btu/day)	32378	22442	32764	33488	45543
	Qout (Btu/day)	19251	9462	19618	27023	29040
	Efficiency	59.5%	42.2%	59.9%	80.7%	63.8%
Savings	(Btu/day)	830	-871	-18	-87	705
	Percent	2.5%	-4.0%	-0.1%	-0.3%	1.5%

Table 2. Electric M&V Sites - Combined Seasonal Dataset Results

Mode	Metric	E01	E02	E03	E04	E05
Base Mode	Qin (Btu/day)	14160	17698	25138	31477	19176
	Qout (Btu/day)	10985	13808	19452	27807	15170
	Efficiency	77.6%	78.0%	77.4%	88.3%	79.1%
AI Mode	Qin (Btu/day)	14047	17897	24868	30594	18698
	Qout (Btu/day)	10985	13808	19452	27807	15170
	Efficiency	78.2%	77.2%	78.2%	90.9%	81.1%
Savings	(Btu/day)	113	-198	270	883	478
	Percent	0.8%	-1.1%	1.1%	2.8%	2.5%

Using Separate Base and AI Seasonality Datasets, where results were not statistically significant, Gas M&V Sites produced an average savings of 9.3 percent in AI Mode over Base Mode. Electric M&V Sites show negative savings, is -2.3 percent in AI Mode than in Base Mode.

Table 3. Gas M&V Sites - Separate Seasonal Dataset Results

Mode	Metric	G01	G02	G03	G04	G05
Base Mode	Qin (Btu/day)	36169	21929	33051	33263	54925
	Qout (Btu/day)	21362	9089	19888	26813	36340
	Efficiency	59.1%	41.4%	60.2%	80.6%	66.2%
AI Mode	Qin (Btu/day)	29482	23577	32557	33734	35339
	Qout (Btu/day)	17050	10287	19424	27253	21102
	Efficiency	57.8%	43.6%	59.7%	80.8%	59.7%
Savings	(Btu/day)	6686	-1648	495	-471	19586
	Percent	18.5%	-7.5%	1.5%	-1.4%	35.7%

Table 4. Electric M&V Sites - Separate Seasonal Dataset Results

Mode	Metric	E01	E02	E03	E04	E05
Base Mode	Qin (Btu/day)	13231	17964	25387	30957	18778
	Qout (Btu/day)	10128	13883	19983	28159	15249
	Efficiency	76.5%	77.3%	78.7%	91.0%	81.2%
AI Mode	Qin (Btu/day)	15246	18159	23651	31389	18887
	Qout (Btu/day)	12245	14100	18210	28578	15356
	Efficiency	80.3%	77.6%	77.0%	91.0%	81.3%
Savings	(Btu/day)	-2015	-195	1736	-432	-109
	Percent	-15.2%	-1.1%	6.8%	-1.4%	-0.6%

Again, while the controller can increase water heater efficiency, there is wide variability in savings: For Gas M&V Sites, Site G05 showed the largest percent savings per year, 35.7 percent, while the lowest M&V gas site is Site G02 at -7.5 percent (Table 3). The largest percent savings per year for Electric M&V

Sites is Site E03 at 6.8 percent, while the lowest is Site E01 at -15.2 percent (Table 4).The wide variability in savings in both analyses suggest the need for a larger population of sites and an increased length to the monitoring period.

Less definitive was the actual impact on energy used to heat hot water. The data shows increased hot water usage at lower supply water temperatures. This trade off makes the impact of energy output (volume * constant *(supply T - inlet T) harder to determine clear trends. At all M&V sites, as cold water inlet temperature decreases, more energy per gallon of hot water is required to reach a temperature set point. In AI Mode, at lower cold water inlet temperature, the controller consistently uses less energy per gallon of hot water than Base Mode. In AI Mode, as cold water inlet temperature rises, 50 percent of the M&V Sites show a slower rate of change in energy use per gallon of hot water than Base Mode, and 50 percent of the sites showed a higher rate of change in energy use per gallon in AI Mode than Base Mode. This implies that at some point a crossover occurs where Base Mode uses less energy use per gallon than AI Mode. This occurred at three sites.

In evaluating fidelity of its data output, the field study determined that the controller has the ability to track water heater performance. Slight variances in controller cold water inlet temperature to M&V data suggest the algorithm can be improved for better accuracy. The field study compared available controller algorithms, from conservative to aggressive, used in AI Mode smart control to M&V data and found no measurable difference in produced savings.

The field study successfully validated the “ease of installation” of the controller. According to field installers, the average installation took approximately 60 to 90 minutes depending on the time it took to drain the water and install the in-tank enthalpy sensor. The cost of the controller is $150, and assumes the unit is self-installed by the homeowner. If installed by a plumber, additional costs for labor are expected to range from $45 to $225. In a utility-based efficiency program, the controller is probably best installed by either a licensed plumber or the homeowner. For electric water heaters in particular the research team did not believe a third party technician could perform the installation.

A field evaluation survey was sent to all thirty-three participants of which thirty-one provided feedback. While participants rated their “Hot Water” experience as either “satisfied” or “very satisfied” upon probing, five respondents noted variability in the delivered hot water temperature. Lower water temperatures and longer wait periods were noticed during “off-peak” times of use and involved handwashing, small water draws, and baths. When asked to choose an average wait time range for hot water to reach a fixture or shower, fifty-five percent reported wait times from 0 to 10 seconds. Twenty-nine percent identified a wait times between 10 and 20 seconds. Sixteen percent identified wait times over 20 seconds. Field issues were reported at five sites during the field evaluation, but only one (a failed enthalpy sensor) was related to the Aquanta controller units installed.

Recommendations

The inconsistent results seen in this field test point to the need for further research on controllers such as the one investigated in this study, including:

1. The variability of usage and small incremental savings require a much larger population and a longer period of data collection.
2. There is a need to investigate the characteristic difference in the sites that showed high savings and those that showed little or negative savings.
3. Lab test data on tank heat-up over a series of cold water inlet temperatures would help improve the controller algorithm to reduce the observed variance in controller cold water inlet temperature to M&V data.

Introduction

Background

Water heating in Minnesota is the second largest consumer of residential energy in the state, amounting to over half a billion dollars in consumer spending annually. The estimated 1.2 million homes with gas storage-style water heating consume approximately 270 million therms of water heating energy annually, while the estimated 750,000 electric water heaters consume 2.7 terawatt-hours of energy annually[1][2][3][4][5].

Add-on intelligent water heater controllers have been proposed as a cost-effective way to reduce the energy consumption for a significant number water heaters already installed in Minnesota. Approximately 1.5 million water would qualify for an add-on intelligent controller[6]. Energy savings is achieved from a combination of a "virtual" reduction of hot water tank set points, automatic "vacation" settings and heating control algorithms based on individual site usage patterns. In Minnesota, with its cold water inlet temperatures and higher tank standby loss from cooler ambient environment, the water heater savings has the potential to be quite significant.

Assuming a 10% annual energy savings on existing qualified gas water heaters, the potential benefit to the Minnesota consumer is $15 million on 17.8 million therms of natural gas saved[7]. Similarly a 10% annual energy savings among existing electric water heaters, the benefit to Minnesota consumers is $32 million on 272 million kWh saved[8]. The technology offers the potential of an immediate energy savings to an existing stock of water heaters where the average service life is 13 years[9].

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[1] U.S. EIA, 2009 Residential Energy Survey, Table CE3.3 Household Site End-Use Consumption in the Midwest Region, Totals and Averages, 2009

[2] U.S. EIA, 2009 Residential Energy Survey, Table CE3.8 Household End-Use Expenditures in the Midwest Region, Totals and Averages, 2009

[3] U.S. EIA, 2009 Residential Energy Survey, Table HC8.9 Water Heating in U.S. Homes in Midwest Region, Divisions, and States, 2009

[4] U.S Census Bureau Minnesota Housing Statistics, 2013 (https://www.census.gov/quickfacts/fact/table/MN/PST045217)

[5] U.S. DOE, ENERGY STAR® Market Profile, pp 28-29, September 2010

[6] Add-on intelligent water heater controllers can be installed on all electric storage water heaters, 750,000 units, and on gas storage waters heaters that have powered gas valves, 792,000 units (2013 estimate).

[7] Based on 22.5 therms per year saved, 10%, at 84.5¢ per therm (2013$) for 792,000 gas water heaters.

[8] Based on 362.8 kWh per year saved, 10%, at 11.8¢ per kWh (2013$) for 750,000 gas water heaters.

[9] Energy Efficiency Standards for Pool Heaters, Direct Heating Equipment and Water Heaters (EE-2006-STD-0129), 2009-11-23 Technical Support Documents: Chapter 8 Life-Cycle Cost and Payback Period Analysis, 8.7.1 Product Lifetimes Water Heaters, page 8-48 - 8-49, Table 8.7.1 Water Heaters: Product Lifetime Estimates and Sources (https://www.regulations.gov/document?D=EERE-2006-STD-0129-0170)

Objectives

The Gas Technology Institute (GTI) and the Center for Energy and Environment (CEE), or the project team, conducted a study to validate the field performance and energy savings of the one of these add-on intelligent water heater controllers and to evaluate their potential for inclusion within Minnesota's Technical Reference Manual (TRM) and as a program measure within utility Conservation Improvement Program (CIP) portfolios.

Specifically the field study was to:

1. validate the time and ease of the installation procedure;
2. evaluate the reliability of the technology and fidelity of its data output;
3. establish baseline water heating energy and water usage in a residential and potentially small commercial context;
4. measure the energy savings resulting from the technology's advanced controls;
5. measure any impact on end-users' subjective experience;
6. evaluate the cost effectiveness of the technology in the context of a broad deployment; and
7. quantify potential utility demand side management.

Intelligent Water Heater Controller

In 2016, the Aquanta was introduced to the market by the manufacturer, Aquanta Inc., formerly Sunnovatons (Figure 4). At that time of the proposal, the Aquanta was the only add-on smart water heater controller available for both electric and natural gas residential and small commercial storage water heaters and therefore chosen for the field study.

According to the manufacturer, the system is designed to be self-installed by anyone with enough experience and confidence to install a new water faucet. Aquanta is compatible with electric water heaters, and with gas models that have electronic gas-control valves. It can be installed on older gas water heaters with mechanical controls and used to report energy consumption and other information; however, in those models it will not be able to provide intelligent control to the burner.

Figure 4. Aquanta Unit Installed on an Electric Storage Water Heater

Aquanta features include:

- The ability to learn and report a home's hot-water usage patterns.
- The ability to suggest and implement a water-heating schedule to prevent standby firings of the water heater during periods of non-use.
- Remote water heater on and off capabilities using a smartphone app.
- Messaging alerts on water heater activity including water heater leak detection and monitoring (optional networked valve to shut off water supply to the water heater).
- Water heater maintenance scheduling and messaging alerts.
- Demand side management capabilities.

The manufacturer suggest the Aquanta can provide up to 40% energy savings in situations where water heaters have high standby losses occurring due to a combination of high temperature set point and low hot water demand limited to short predicable periods of time. For example, Bradford-White Corporation, in its introduction of a programmable setback control for its ICON™ water heater, published test results with fuel savings of 36.8 percent for a low demand test site where the tank set point temperature was lowered to 85°F from 130°F during long standby periods[10].

The Aquanta achieves energy savings by reducing standby losses through intelligent control and/or by enabling utility demand side management measures, including demand response, peak shaving, time-of-use pricing and behavioral efficiency.

[10] Plumbing Engineer Magazine, Product Application - Water heater study reveals significant fuel savings from new Programmable Setback Control, pp 50-51, November 2010.

The Aquanta intelligent networked water heater controller has some features unique compared to existing programmable setback controls:

- Easy of install: the technology is designed for installation in 30-45 minutes on an existing electric storage water heater or a gas storage water heater with either a powered or a milli-volt powered water heater gas valve control. The installation does not require specialized equipment or training to retrofit on an existing storage water heater.
- Retrofittable to both electric and gas storage water heaters: the technology can be retrofitted to approximately 60 percent of Minnesota's installed water heater base[11].
- Enhanced analytic capabilities: the technology relies on patent-pending sensing that allows for the discerning of both individual and "fleet" water heating energy and usage patterns. This enables local autonomous "learning" heating control algorithms to match individual usage patterns and fleet analytics for use in utility demand side management applications for more effective grid operations.
- Networked and smart home enabled: the technology was built to be WI-FI internet-connected, taking advantage of 21st century technologies in low cost, reliability high speed communications. This allows for real-time quantification of both local and fleet energy usage, but also - in combination with its analytic capabilities - provides predictive data for use in utility operations. The technology can be combined with other smart home technologies, creating a unified home energy management system.

Appendix A contains a presentation by the manufacturer that presents an overview of the Aquanta water heater controller and its features.

[11] According to U.S. Energy Information Agency, Residential Energy Consumption Survey 2015, water heaters are 55.4 percent gas and 38.5 percent electric in the region that includes Minnesota. Discussion with water heater manufacturers suggest approximately 40 percent of gas water heaters have gas powered or millivolt powered valves that allow partial or full use of intelligent control features, (38.5 + (55.4 x .40) = 60.7.

Methodology

The project team planned to install fifty (50) water heater controllers in existing residential and potentially some small commercial sites, with a 50/50 split between electric and gas water heating. Ten sites (five electric and five natural gas) would be fully monitored to validate the technology's ability to accurately monitor daily water and energy usage. Site requirements include broadband connectivity and the ability for the unit to communicate through the site's Wi-Fi router. Field operations include site recruitment, site characterization, and installation. The proposed period of performance was for 12 months; system operation would alternate between baseline measurement and intelligent control on a quarterly basis, with half starting in the former mode and half beginning in the latter.

Site Selection, Validation, Installation, and Commissioning

Prior to site selection, the project team developed and finalize a work plan, and timeline that allowed for the deployment of the intelligent, networked water heater controllers in Minnesota utility territories. The workplan included coordination with the manufacturer and the field team to ensure appropriate protocols, procedures, and criteria were in place, including those for: site recruitment; site selection; coordination of installations; data collection, analysis and reporting; training of field staff; and implementation of surveys.

Given the time constraints for getting units into the field, GTI planned to identify and eliminate potential problem sites where 1) the installation were not up to current code and require additional funds outside the scope of this program to get them into code compliance; 2) the water heater unit did not qualify for replacement due to age or location; or 3) the homeowner did not qualify (moving within a year) or is unwilling to participate.

GTI expedited the selection of field evaluation sites through prescreening qualification surveys. Specifically, GTI:

- Developed a list of potential evaluation sites generated though utility, Sunnovations, and community outreach activities
- Contacted and conducted a pre-qualification survey with potential site owners
- Sent out Field agreement to site owner for review and signature
- Provide CEE field staff with a list of pre-qualified evaluation sites for field inspection, installation and commissioning

As part of the site screening process GTI also eliminated sites that did not have broadband connectivity and the ability for the unit to communicate through an existing Wi-Fi router. In addition, GTI targeted sites to achieve the following ideal breakdown of water heater types and numbers:

- 30-gallon storage: 5 electric and 5 natural gas = 10 units total

- 40-gallon storage: 10 electric and 10 natural gas = 20 units total
- 50-gallon storage: 10 electric and 10 natural gas = 20 units total

It was anticipated that approximately 100 sites would be identified in the first stage of this screening process, and that through the phone surveys this group would be reduced to approximately 60 pre-qualified sites.

Once potential sites were pre-qualified, the field team performed site visits to confirm the site qualified for controller installation. Once confirmed as a valid test site, the Aquanta was installed and commissioned. From among the test sites, a subset were selected for detailed monitoring to provide independent Energy Management and Verification (EMV) At these EMV sites additional data acquisition equipment was installed to allow third party measurement and verification to ensure that the data collection and analysis through the Aquanta was accurate. A qualified local plumbing contractor was used at these sites to install sensors and meters, and CEE field staff followed-up to install the data acquisition equipment.

Monitoring, Analysis, and Reporting

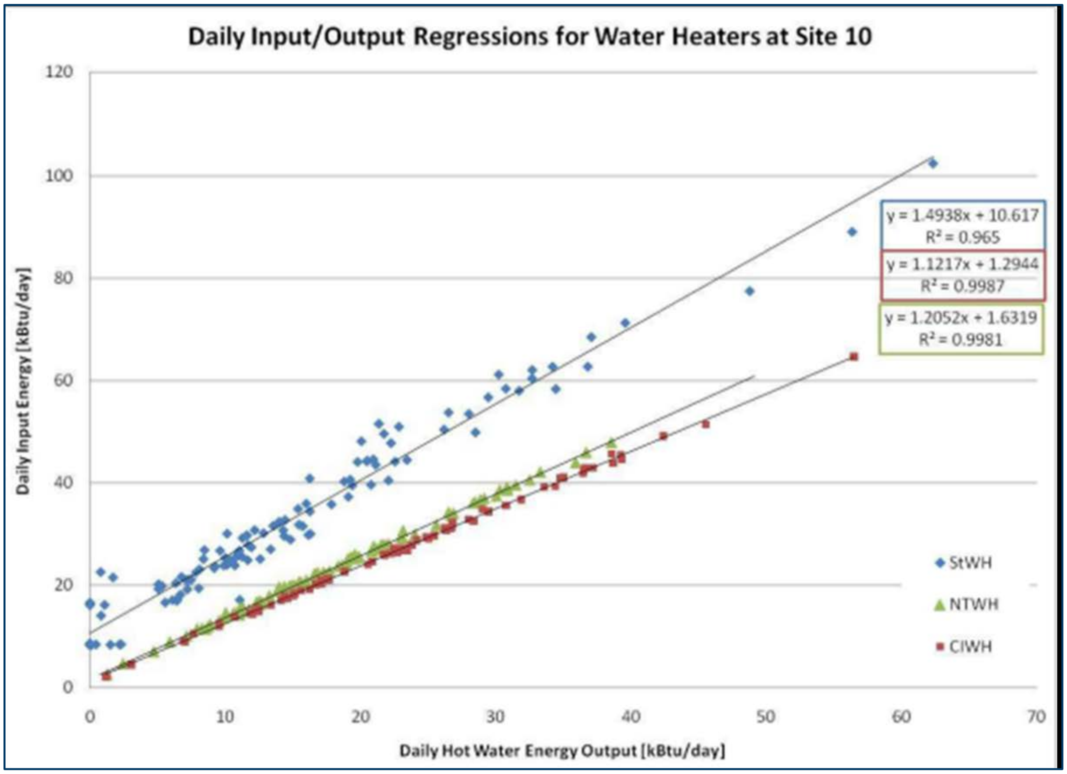
The data collection and analysis of energy savings for this project was calculated using data collected by the controller. These savings were verified using third party measurement and verification in a subset of the sites to ensure that the data collection and analysis was accurate.

A sample of ten homes (~20%) was selected for independent verification. The independently verified test sites were representative of the full project site pool and split between homes with electric and gas water heaters. These homes had the Aquanta controller installed, commissioned, and operated as all other sites, but had additional data collection equipment installed, including:

- Electric or natural gas energy consumption
- Water heater runtime
- Water flow rate
- Inlet and outlet water temperature

This additional data collection was used to perform a more detailed data analysis than is possible in the full set of test homes. An energy input output method was used to determine the annual energy consumption of the water heater with and without the controller active. This analysis approach has been used previously by CEE for a CARD-funded field characterization of tankless water heaters. Figure 5 shows the energy consumed to provide the daily hot water demand for three different water heaters, a natural draft storage water heater (StWH), a non-condensing tankless (NTWH), and a Condensing tankless (CTWH). A similar plot was developed for the existing water heater at each M&V site with and without the intelligent controller. The input output relationship was analyzed with the average hot water load (also measured) to determine the annual energy usage and controller savings.

Figure 5. Sample Graph - Daily energy input versus hot water energy output for three water heaters



Hot water usage can vary greatly for a single-family residence over time, masking the potential to determine savings over a short monitoring period. To address this issue, the proposed period of performance was 12 months. During the monitoring period system operation alternated between baseline measurement and intelligent control on a quarterly basis, with half of the sites starting in the former mode and the other half beginning with the later.

Results of the analysis include energy savings, carbon savings, simple payback, and an assessment of the water heater and controller's abilities to meet the desired hot water load.

Data Acquisition

Controller

The Aquanta collects, analyzes, and uploads data to a cloud-based server where it is accessible to the homeowner. For this study the manufacturer agreed to provide controller data from all test sites at 5 second intervals for analysis. Table 5 summarizes the data points provided by the manufacturer for our analysis.

Table 5. Controller Data Points Provided

Variable	Unit	Description
Date-Time Stamp	Date and Time	Real time summarized in 5-second intervals
Energy Stored	kW	Energy available
Water Temp In	°C	Water temperature into tank
Water Temp Out	°C	Water temperature out of tank
Energy In	kW	Electric and/or natural gas used to replenish and reheat
Energy Out	kW	Energy utilized (hot water)
Standby Loss	kW	Energy Loss (Jacket and flue losses)

Measurement & Verification

In addition, ten sites from among the test sample were fully monitored to verify the integrity of the data collected by the Aquanta controller. This data was also used to estimate energy savings from the controller. Figure 6 identifies the physical location of M&V measurement data points. Table 6 summarizes the measurements made by the data acquisition system.

Figure 6. Measurement Data Points

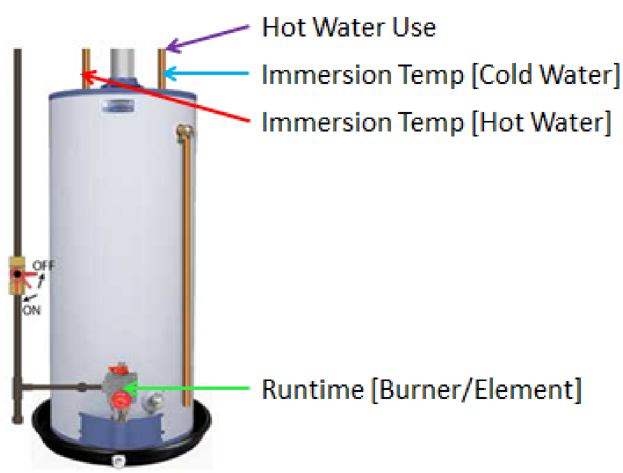


Table 6. Measurement Data Point Descriptions

Sites	Measurement	Methodology		
Gas	Water heater runtime	1. Current switch on gas valve or	2. Gas valve pressure switch or	3. Thermocouple on the WH vent or burner
Electric	Water heater runtime	CT installed on the WH elements		

Sites	Measurement	Methodology
All	Hot water use	Positive displacement flow meter on inlet to water heater
	Inlet water temperature	Immersion RTD temperature probe installed between 0.5 and 1 foot from the water heater inlet
	Outlet water temperature	Immersion RTD temperature probe installed between 0.5 and 1 foot from the water heater outlet
	Ambient temperature	Thermocouple placed near water heater

Data was collected at each site at one-second intervals and under two modes of operation, baseline or Base Mode, where the controller was actively monitoring and not controlling the water heater, and AI mode, where the controller was actively monitoring and controlling the water heater runtime.

Information on measurement equipment and data handling can be found in Appendix B.

Occupant Feedback

Field evaluation participants were surveyed at the midpoint and end of the field evaluation. During the field evaluation, homeowners and occupants were restricted from interacting with the controller. For that reason, the survey focused on the “Hot Water” experience and not the control device. The objective was to obtain occupant feedback on changes in their “Hot Water” experience as a result of water heater controller. The survey was sent to all field test participants via email or through an on-line format.

The survey was short, no more than 10 questions, and probed three aspects of the field evaluation: 1) a validation by participants that key site information had not changed, 2) a rating of the participants experience in the field evaluation process, and 3) a rating of the participants “Hot Water” experience.

Results

Site Selection, Validation, Installation and Commissioning

Site Selection

Our initial objective was to identify 100 sites via local plumbers and utilities throughout Minnesota, conduct pre-qualifying phone calls to reduce this list down to 60 sites qualifying for inspection, to find and commit the 50 sites. In reality, local plumbers and most utilities were non-responsive. This extended the period of site selection from 4 months to 12, and expanded the methods of recruitment. Specifically:

- GTI contacted 12 Minnesota plumbers in Sartell, Saulk Center, Mankato, Elgin, Lake Shore, Cambridge, Brainerd, Duluth, Rochester, and Minneapolis to seek their paid assistance in soliciting participation by staff and customers. The Minneapolis plumber was successful providing some field sites.
- GTI approached Minnesota utilities (Xcel, Centerpoint, Dakota Electric Association, Rochester Public Utility, Otter Tail Power, and Duluth Dept. of Public Works and Utilities) for assistance in soliciting participation by staff, customers, and trade allies are participating utilities. Both Xcel and Centerpoint sent internal solicitations to employees resulting in some field sites.
- GTI contacted not-for-profit energy efficiency consortia and groups (North Star Community Development Association in Duluth, Three Rivers Capital, Rochester Area Builders, and Rochester Habitat for Humanity, Ecolibrium3, and SolarbyUS.com) soliciting participation by staff and customers. Ecolibrium3 sent out an email request for participation to 1500 individuals that resulted in 22 potential leads resulting in a number of sites within the Duluth area.
- Aquanta solicited participation through their company website and issued a press release. These actions resulted in a number of potential leads resulting in some field sites.
- CEE solicited participation from internal staff and external contacts resulting in some field sites.
- GTI contracted, Inspire, a professional survey research company to sign up field test sites. These actions resulted in a number of potential leads resulting in some field sites.

GTI established a website and survey to prescreen potential sites. To qualify for participation a site had to meet the following criteria:

- The site had to have a single water heater that could be retrofitted with an Aquanta controller.
- The site had to have Wi-Fi access that would allow the controller to be networked.
- The site had to have broadband internet access.
- The homeowner had to be willing to participate and not plan to move for that location throughout the duration of the field evaluation.
- Sites that were up to current code requirements.

From this effort approximately 120 leads were identified and pursued. From this list less than 40 sites proceeded to site validation.

Site Validation

The purpose of site validation is to confirm online survey information through an on-site visit by a qualified technician, specifically that the water heater qualifies to participate and that the current installation is up to code. In practice, however, the validation of each site was effectively achieved through email communication where the site owner provided photos of the water heater installation including the current piping and venting arrangement, access to electric power, water heater nameplate information, and a photo of the gas valve if relevant. In addition the site owner validated Wi-Fi and internet access at the water heater using a cell phone or laptop computer for confirmation.

Once validated, the site owner entered into a participation agreement that allowed site access, participation in surveys, and assured occupancy throughout the period of the study in exchange for keeping the controller at the end of the study. An installation date was set once the agreement was in place. Thirty-three of the 40 sites made it through the validation process. Due to the extended period of site selection and resources invested, a decision was made to close out the recruitment phase and proceed with installation once these 33 sites were validated.

Site Installation

Though the manufacturer claims that the Aquanta unit can be installed by a knowledgeable homeowner, it is customary and prudent in a new product field evaluation to have all installations handled by a trained qualified professional contractor. This ensures that all product installed are as per manufacturer specifications and in a consistent manner. It also allows a secondary check to confirm existing equipment is up-to-code, and is functioning properly and safely.

One professional plumber was contracted to install all controllers and monitoring equipment. One site, however, had previously self-installed the controller. Each installation process included:

- Installing the Aquanta unit.
- Installing additional M&V equipment where applicable.
- Testing to validate Wi-Fi and internet communication.

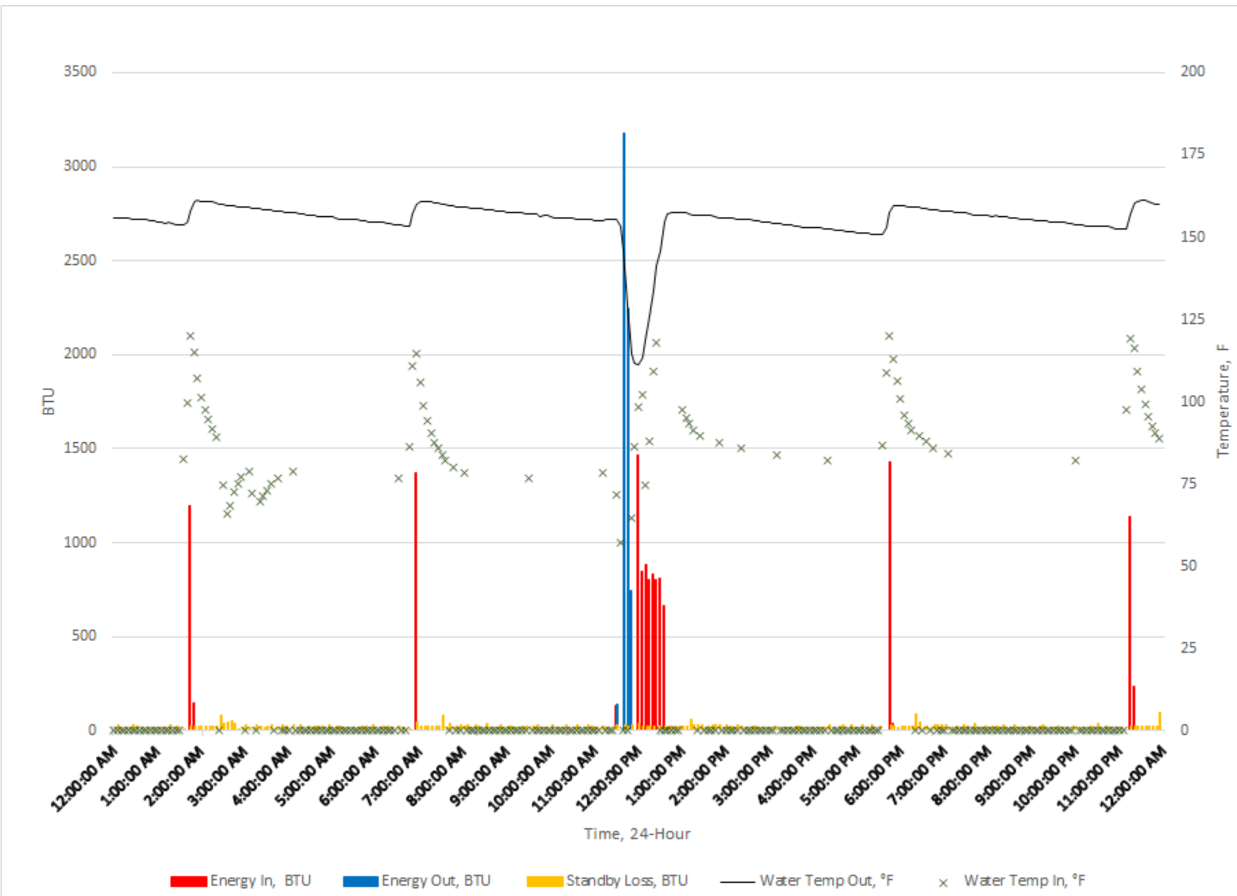
The average Aquanta installation took approximately 60 - 90 minutes depending on the time it took to drain the water to install the in-tank sensor. All installations went smoothly with no unforeseen issues related to the initial installation. There were a couple of issues with sensors and connectivity that took additional troubleshooting by field staff and Aquanta to resolve. All installations were completed by a professional plumber but the installation steps in the manual were straightforward, easy to understand, and adhered to standard safety practices. As a result, a knowledgeable homeowner might be able to complete the installation. However, some homeowners may not be comfortable removing and re-installing the TMP valve or installing the controller in-line with the electrical supply.

Commissioning

There are two aspects to site commissioning: first, validating on-site at the time of installation that the water and all field test equipment was operating properly and safely; and secondly, proving successful off-site communication and data transfer with the controller and monitoring equipment when applicable. All 33 sites were installed and commissioned from August 2, 2016 through February 6, 2017.

Figure 7 is a graphical representation of a single day of data communicated and downloaded from the controller at site G07. The site data validates that the controller is actively monitoring the water heater energy input, usage, standby loss, and hot water inlet and outlet temperatures.

Figure 7. Site G07 - January 17, 2017 Daily Profile



During the field tests, there were issues at five sites which required equipment repairs or change-outs. One site had a leak in the M&V equipment which required several site visits to correct; two sites had leaks in the water heaters themselves which required installation of new water heaters; one site had a failure in the gas valve which required a replacement valve; and one site had the enthalpy sensor on the Aquanta fail which needed to be replaced. The final issue was the only known one related to the controller unit itself. All five sites were recommissioned after these issues were resolved. Details are in Appendix C.

Field Sites Details

The initial proposal called for 50 field sites, 10 of which to be M&V sites that included monitoring equipment for measurement and verification. As previously mentioned, due to the extended recruitment period only 33 sites were contracted for the field study, 10 of which were M&V sites.

Table 7 shows a breakdown of the field sites by water heater fuel type and size, and the number that were also M&V sites. The original goal was to have an even split between water heaters that operated on natural gas and those that operated on electricity. In actuality, 22 field sites, or 67 percent, were natural gas. Eleven field sites, or 33 percent, were electric. The percent breakdown in sites is a close representation of the in-situ make-up of water heaters in Minnesota based on U.S. EIA RECS 2009 regional data that reports 56 percent gas and 36 percent electric make-up in the region that includes Minnesota[12].

Table 7. Breakdown of Field Sites by Water Heater Type and Size

Fuel	Water Heater Size	Total	M&V
Gas	40 - Gallon	12	2
Gas	50 - Gallon	10	3
Electric	40 - Gallon	1	0
Electric	50 - Gallon	9	5
Electric	80 - Gallon	1	0
		33	10

Location

Sites were to be widely dispersed throughout the State of Minnesota. Recruiting efforts fell short of this objective. Figure 8 shows the approximate locations of the field sites within Minnesota. Electric water heater locations are identified with red markers and natural gas water heaters with blue markers. Figure 9 shows that 75 percent of the field study sites were located in the Greater Minneapolis / St. Paul Area [16 sites: 14 Natural Gas; 2 Electric] and the Greater Duluth Area [9 sites: 4 Natural Gas; 5 Electric]. The other eight sites were in other parts of the state.

[12] U.S. Energy Information Administration, 2009 Residential Energy Survey, Table HC8.9 Water Heating in U.S. Homes in Midwest Region, Divisions, and States, 2009

Figure 8. Field Site Location Map

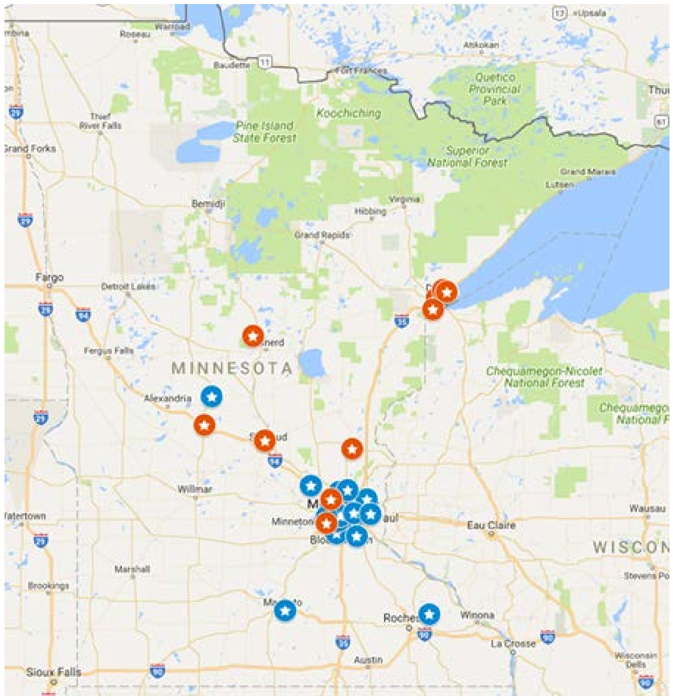
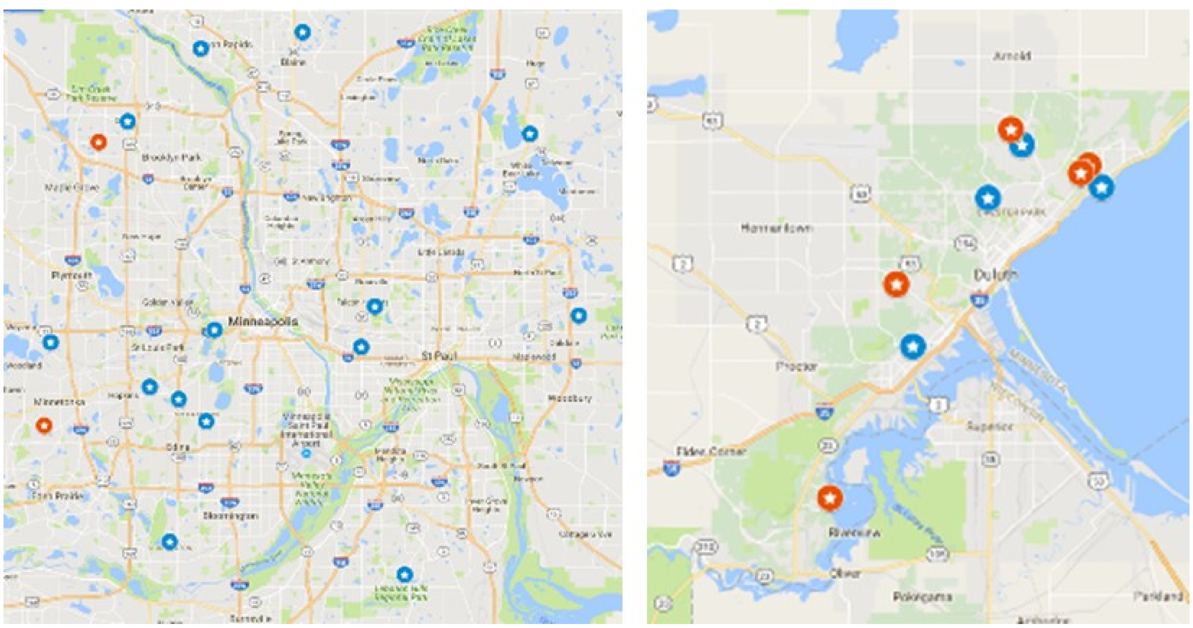


Figure 9. Field Sites within the Greater Minneapolis and Duluth Areas



Occupancy, and Lifestyle

Table 8 summarizes sites characteristics of the 33 field sites. The median occupancy was 3.0 occupants per site with a range of 1 to 8 occupants. On average weekly showers compared to baths occurred 7 times more often than baths, with a median of 14 showers per week. All but one site used a dishwasher with a median of 3.0 cycles per week. All sites reported having a clothes washer with a median of 5.0 wash cycles per week. Details on each site can be found in Appendix D.

Table 8. Summary Site Characteristics - 33 Field Sites

Site	Occupants	Bathrooms	Faucets	Showers	Showers / Wk	Baths / Wk	Dishwash Cycles / Wk	Clothes Wash Cycles / Wk
Min	1	1	2	1	6	0	0	1
Max	8	5	10	4	25	10	28	21
Median	3.0	2.0	5.0	2.0	14.0	0.0	3.0	5.0

Table 9 highlights sites characteristics of each M&V site. The median occupancy was 3 per site with a range of 1 to 8 occupants. On average weekly showers compared to baths occurred 6 times more often than baths, with a median of 12.5 showers per week. All M&V used a dishwasher with a median of 2.5 cycles per week. All M&V sites reported having a clothes washer with a median of 4.5 wash cycles per week.

Table 9. M&V Site Characteristics

Site	Occupants	Bathrooms	Faucets	Showers	Showers / Wk	Baths / Wk	Dishwash Cycles / Wk	Clothes Wash Cycles / Wk
G01	4	2	6	2	14	4	4	5
G02	2	2	3	1	11	0	3	4
G03	2	2	6	2	14	0	1	5
G04	4	4	8	3	18	0	3	20
G05	2	2	4	2	14	0	0	4
E01	2	1.5	4	1	14	0	4	4
E02	1	3	5	3	7	0	1	2
E03	5	3	5	2	10	3	7	21
E04	8	2	3	2	6	8	1	5
E05	4	1	2	1	9	4	2	4
Min	1	1	2	1	6	0	0	2
Max	8	4	8	3	18	8	7	21
Median	3.0	2.0	4.5	2.0	12.5	0.0	2.5	4.5

Table 10 highlights some characteristics of the water heaters at the M&V sites. There were 5 electric sites (all 50 gal) and 5 natural gas sites (2 - 40 gal, 3 - 50 gal). All 3 major storage water heater manufacturer's product were represented (Rheem, A.O. Smith, and Bradford White Corporation) in the sample. As mentioned above, the median number of occupants per M&V sites was 3. Regarding water heater efficiency, the median Energy Factor rating for gas was 0.67 and the median Energy Factor rating for electric as was 0.91.

Table 10. M&V Sites - Water Heater Characteristics

Site	Number of Occupants	Fuel Type	Water Heater Size	Water Heater Unit	Hot Water Use GPD	Energy Factor
G01	4	Gas	50	American Standard PCG6250T403NOV	36.2	0.70
G02	2	Gas	40	Rheem XG40S09HE38U0	18.1	0.62
G03	2	Gas	50	AO Smith FPSH 50 250	34.0	0.62
G04	4	Gas	50	AO Smith GPVL 50 200	52.5	0.70
G05	2	Gas	40	Rheem 43V P40 SE2	35.0	0.67
E01	2	Electric	50	Rheem PROE 50 T2 RH95	24.6	0.95
E02	1	Electric	50	Marathon MR 502 45 B	31.3	0.95
E03	5	Electric	50	Reliance 606 650 DOCT	36.0	0.90
E04	8	Electric	50	AO Smith ECT 52 200	45.6	0.91
E05	4	Electric	50	Bradford White M250T6DS-1NCWW	31.6	0.90

Figure 10 graphs the gallons per day of each M&V site by Mode. In Base Mode, the median was 34.5 gallons per day (GPD), and the average is 38.2 GPD. In 2014, Lawrence Berkeley National Laboratory, LBNL, analyzed the data of 159 field study homes where hot water was measured in sites located throughout the U.S.[13] The analysis identified three (3) clusters of daily hot water usage, the averages of which are identified on the graph with horizontal lines. Cluster 1 is defined as Low Usage where hot water usage us less than 44 GPD. The average for the Low Usage Cluster, 29.4 GPD, is the Red Line in the graph. Cluster 2 is defined as Medium Usage, ranges from 44 to 80 GPD. The average for Medium Usage Cluster, 60.5 GPD, is the Blue Line in the graph. Cluster 3, defined as High Usage is greater than 80 GPD. The average for High Usage Cluster, 98.5 GPD, is the Green Line in the graph. The National Median for the LBNL data is 49.6 GPD, identified by the Purple Line. The M&V sites fall below the National Median and into the Classification of "Low Usage".

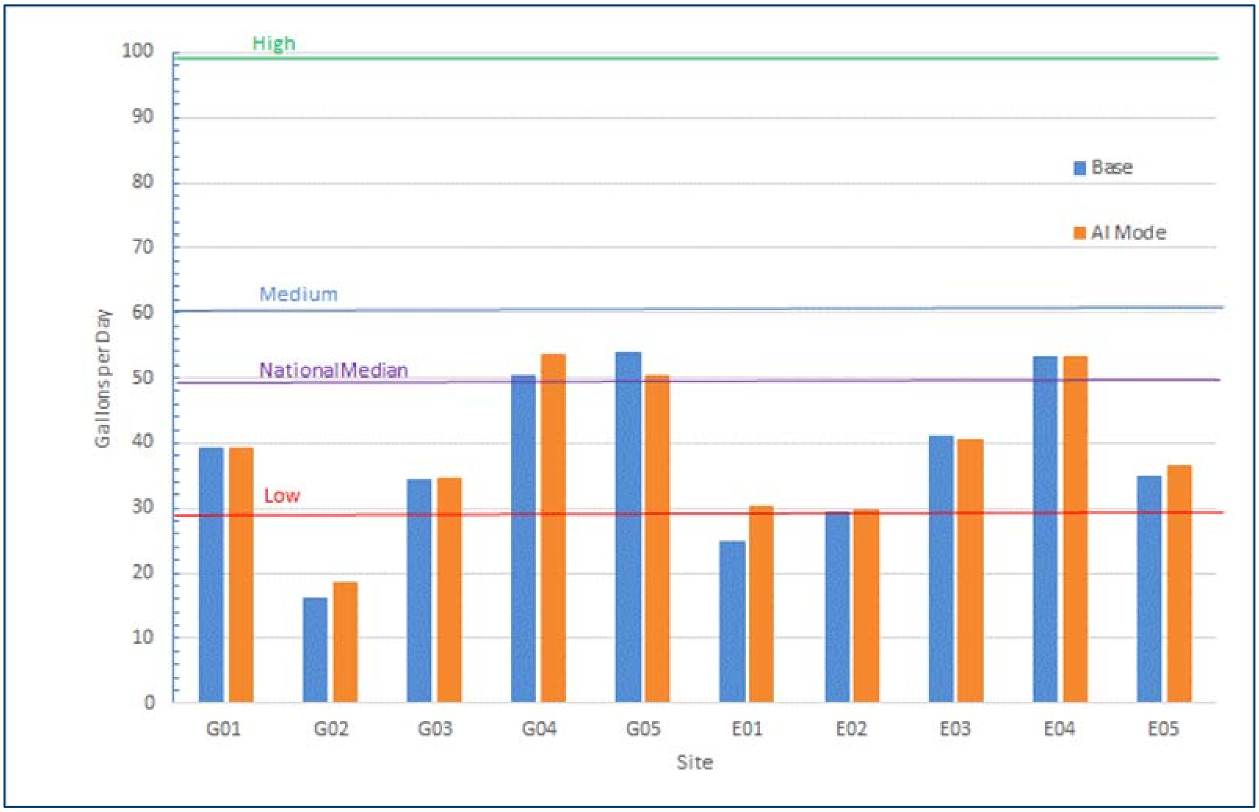
It is noteworthy that in a previous study of 40 Minnesota homes, the CEE found the median hot water usage at 40 GPD for houses with an average occupancy of 2.7[14]. This result is consistent with a Florida

[13] J. Lutz, M. Melody, Typical Hot Water Draw Patterns Based on Field Data, LBNL, November, 2010.

[14] D. Bohac, B. Schoenbauer, M. Hewett, M. Lobenstein, T. Butcher. Actual Savings and Performance of Natural Gas Tankless Water Heaters. Minneapolis: Center for Energy and Environment, 2010.

Solar Energy Center Meta Study where the hot water usage for a 2.5 person home is estimated at 40 GPD[15].

Figure 10. Comparison of M&V Site Hot Water Use by Mode to National Averages



Data Analysis of Intensively Monitored Sites

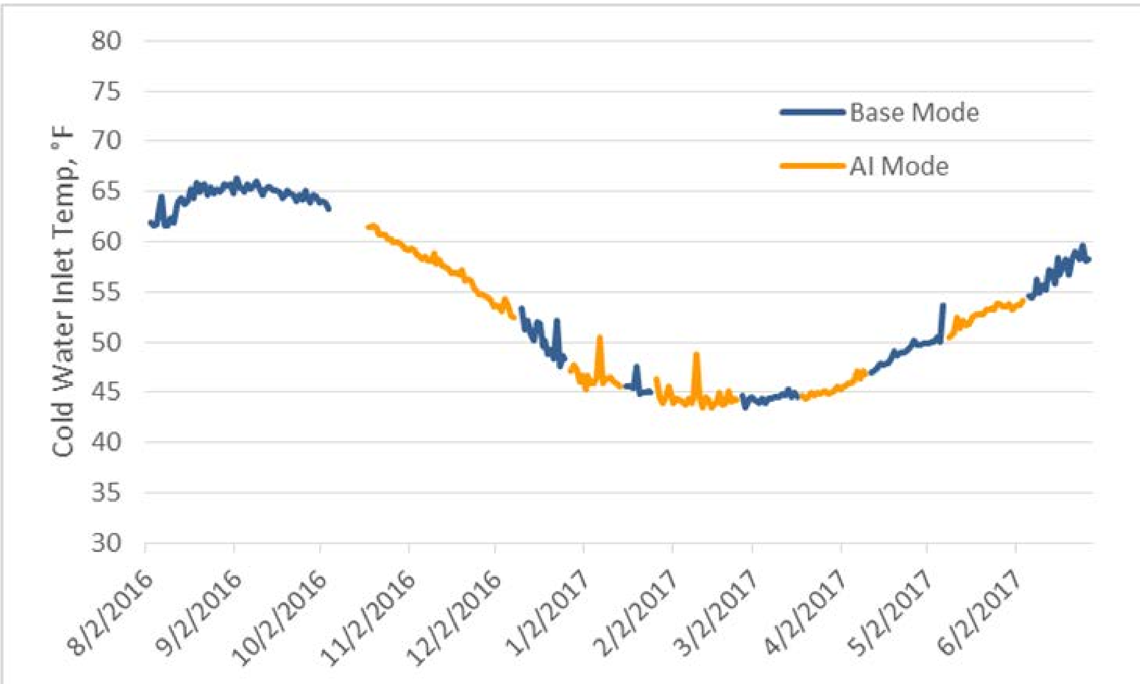
Ten sites were fully monitored with measurement and verification (M&V) instrumentation to validate the technology's ability to accurately monitor daily water and energy usage. During the field evaluation, homeowners and occupants were restricted from interacting with the controller. The controllers operated alternately between Base Mode and Aquanta Intelligence (AI) Mode. In Base Mode, data collection is active but no active control takes place. In AI Mode, both data collection is active and the controller actively controls water heater on-time based on learned hot water heater use habits of the occupants. At the time of our study, the utility demand side management features were not yet enabled in the smart controller chosen for the field study and therefore not investigated.

[15] D. Parker, P. Fairy, J. Lutz, Estimating Daily Domestic Hot Water Use in North American Homes, Florida Solar Energy Center, June 2015

Period of Performance

For each M&V site, the full dataset used in this analysis was collected from 8/3/2016 to 6/28/2017, Figure 11 illustrates this period of performance for site G01 by tracking the cold water inlet temperature over 320 days, differentiating 156 days in Base Mode operation (Blue) and 140 days in AI Mode (Gold).

Figure 11. M&V Site G01 Cold Water Inlet Temperature over Monitoring Period by Controller Mode



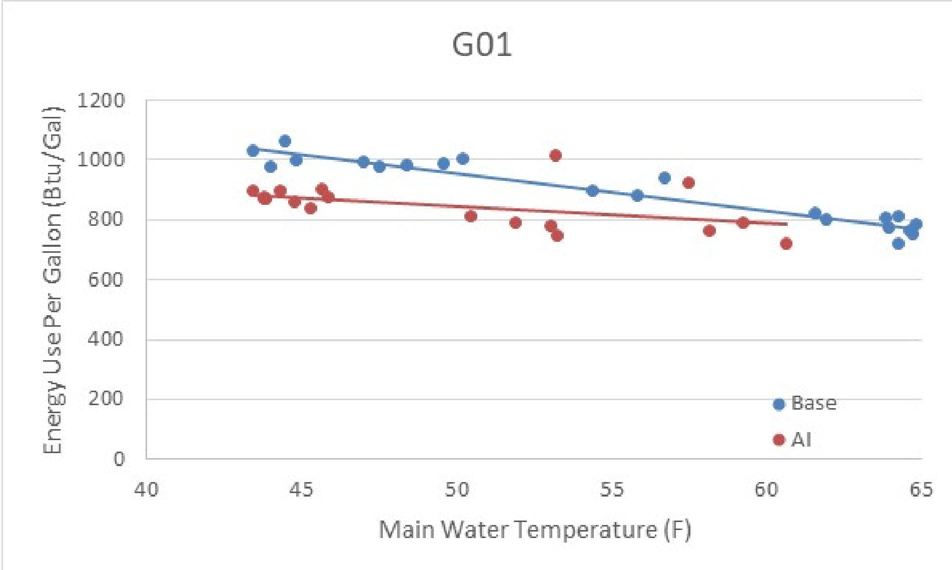
Energy Consumption per Gallon

The following series of graphs plot the energy necessary to produce each gallon of hot water by Mode. On the Y-axis is average weekly energy use per gallon (Btu/gal) and on the X-axis is the cold water Inlet temperature (°F). Base Mode operation is defined by the Blue Line and AI Mode is defined by the Red Line. Sites with natural gas water heaters have the designation of G as part of their site identifier and those with electric have the designation of E.

Figure 12 plots the energy necessary to produce each gallon of hot water by Mode for site G01, which has four occupants. There are two observations:

1. as the cold water inlet temperature decreases, more energy is required to heat up the hot water to its setpoint, and
2. in AI Mode, the water heater consistently used less energy than the Base Mode per gallon of hot water used in the home.

Figure 12. Site G01: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode



These trends were consistent with all sites. The controller achieves this energy reduction per gallon by eliminating over heating (or lowering the set point temperature) and eliminating unnecessary reheating.

Most consistent with the results seen at site G01, were those observed at sites G02 (two occupants), G04 (four occupants), E01 (two occupants), E02 (one occupants), E03 (five occupants), and E05 (four occupants), as seen respectively in Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, and Figure 18.

Figure 13. Site G02: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

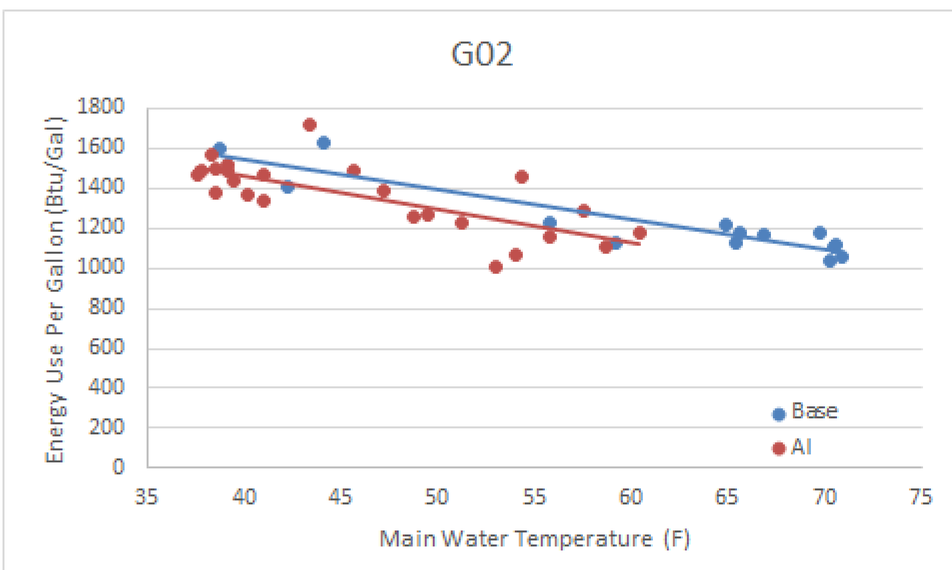


Figure 14. Site G04: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

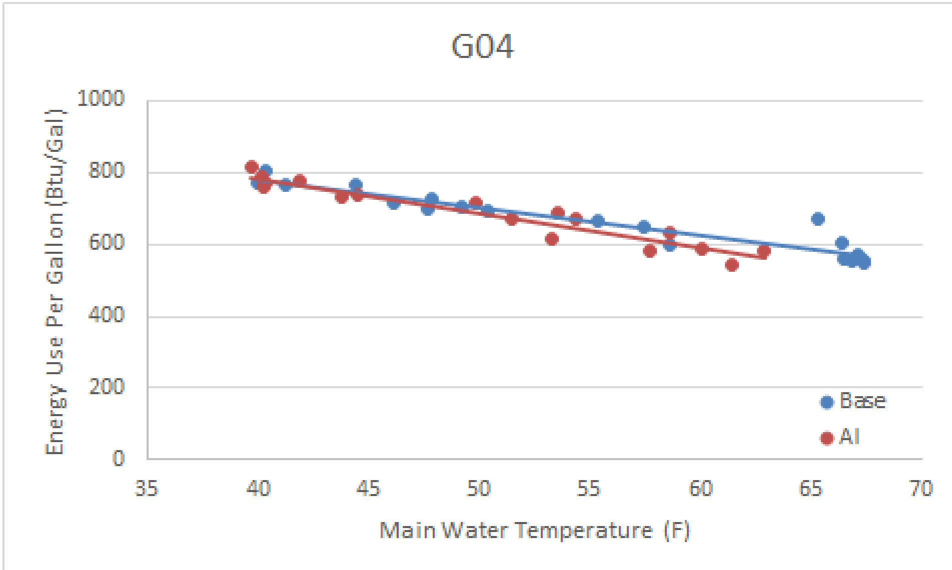


Figure 15. Site E01: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

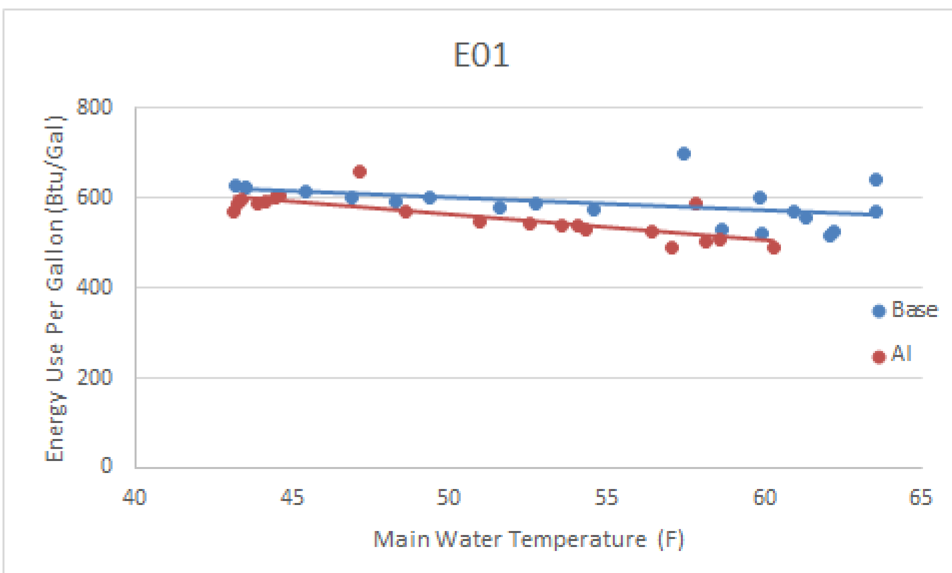


Figure 16. Site E02: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

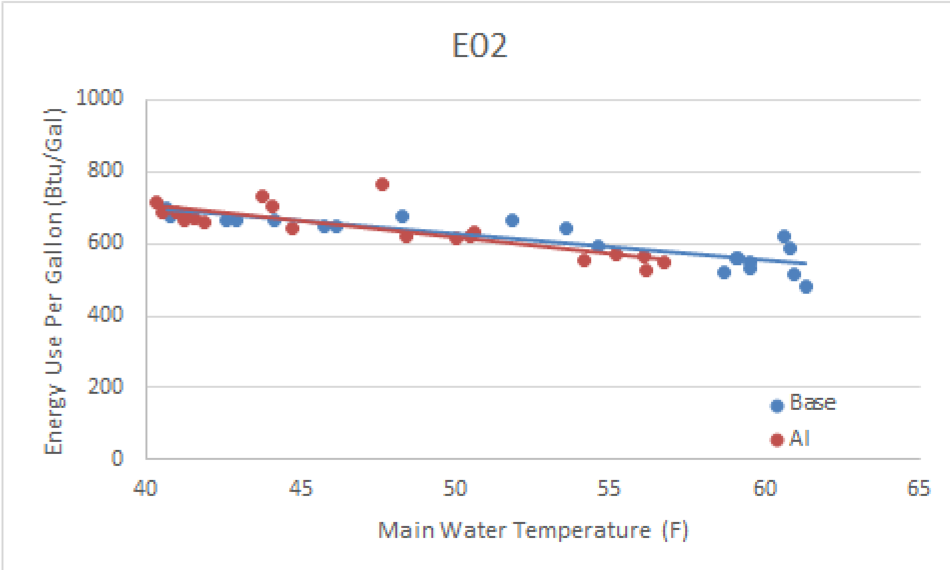


Figure 17. Site E03: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

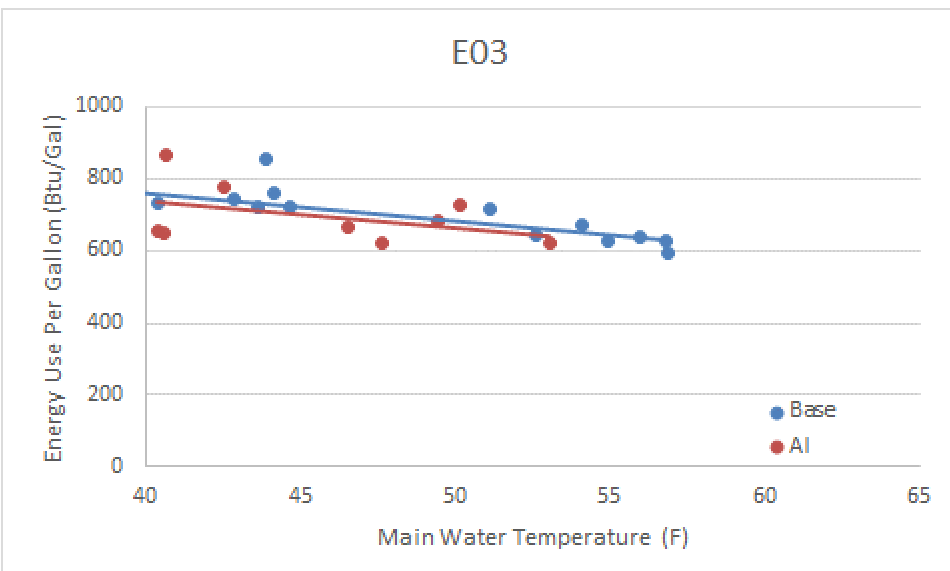
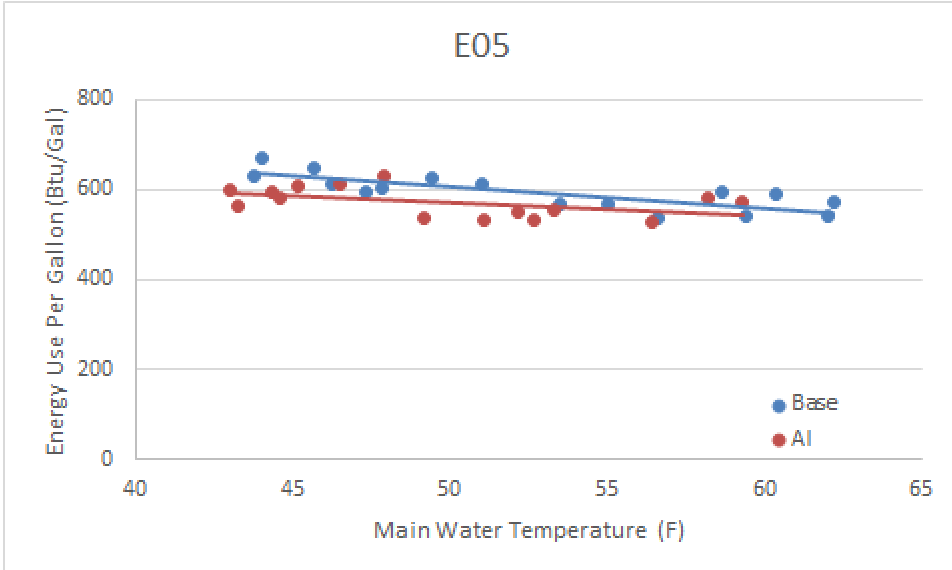


Figure 18. Site E05: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode



Plots for sites G03 (two occupants), G05 (two occupants), and E04 (eight occupants) show a slight variation from the previous results (Figure 19, Figure 20, and Figure 21). While the water heaters at these sites used less energy overall per hot water in the AI Mode, the energy use per gallon of hot water declined at a slower rate than Base Mode as cold water inlet temperatures increased. Eventually for each of these sites, a crossover occurred where the water heater used more energy per gallon of hot water in the AI Mode than in the Base Mode. This crossover was at main water temperatures of about 50.8°F for Site G03, 58.0°F for Site G05, and 49.6°F for Site E04.

Figure 19. Site G03: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

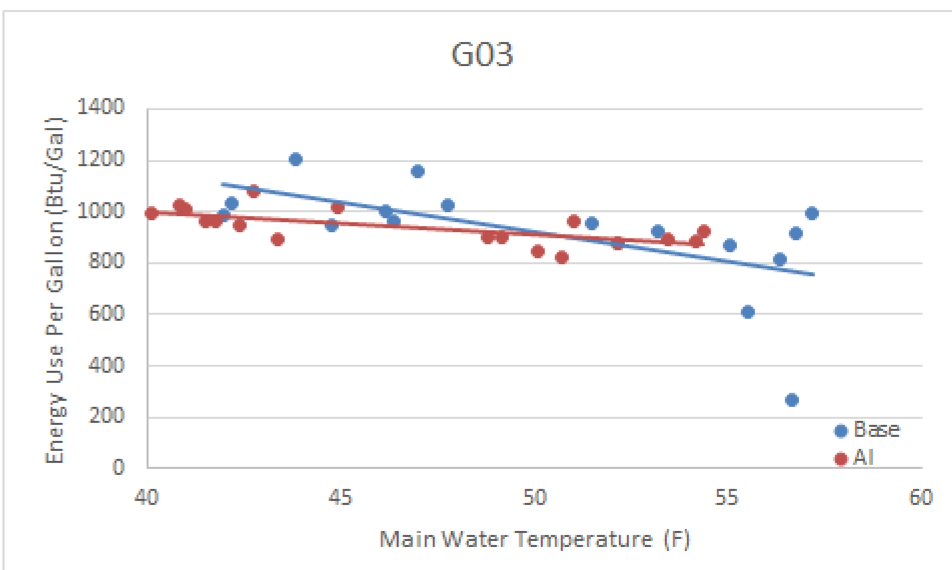


Figure 20. Site G05: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode

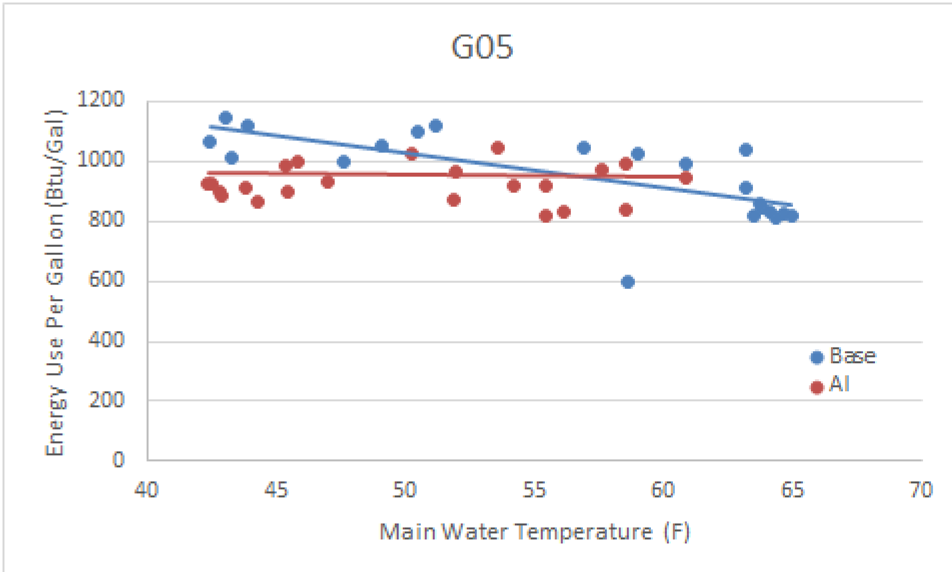
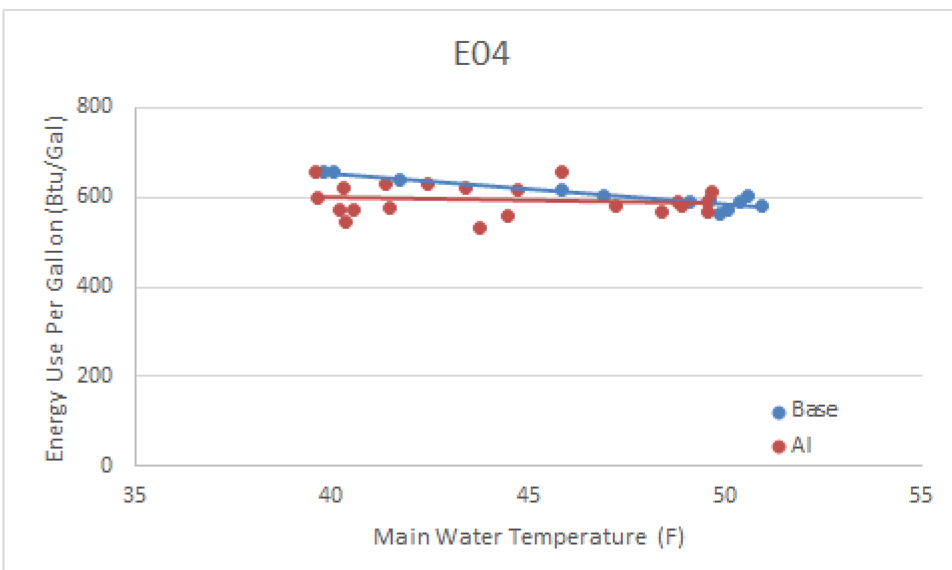


Figure 21. Site E04: Energy Use per Gallon versus Cold Water Inlet Temperature by Mode



The plot for site G05 shows additional differences compared to the other sites (Figure 20). In contrast to other sites, the trend that as the cold water inlet temperature decreases, more energy is required to heat up the hot water is only observed in Base Mode. In addition, in AI Mode energy use remains flat so that as the cold water Inlet temperature increases, the energy use per gallon remains the same.

To summarize the observations from this analysis:

1. As the cold water inlet temperature decreases, more energy is required to heat up the hot water to its set point.
2. At low cold water inlet temperatures, the controller in AI Mode, consistently used less energy per gallon of hot water used in the home than Base Mode.
3. In AI Mode, five M&V Sites (G01, G03, G05, E04 and E05) showed a slower rate of change in energy use per gallon of hot water than Base Mode (as cold water inlet temperatures warmed). At three of these of these five sites (G03, G05, and E04) a cross-over occurred at higher cold water inlet temperatures where the Base Mode showed a lower energy use per gallon than AI Mode.

Delivered Water Temperature

Figure 22 is a boxplot of average delivered hot water temperature by mode for every draw 2 to 4 minutes in duration for site G01, which has a natural gas water heater and four occupants. The figure shows that for site G01 in AI Mode, the delivered hot water temperature is 119°F at the 50th percentile compared to 123°F at the 50th percentile in the Base Mode. This indicates a potential energy savings. For example: that 5°F reduction in delivered hot water temperature at site G01, if maintained permanently throughout the year, would result in a 6% energy savings.

Figure 22. Average Hot Water Temperature Draw by Mode

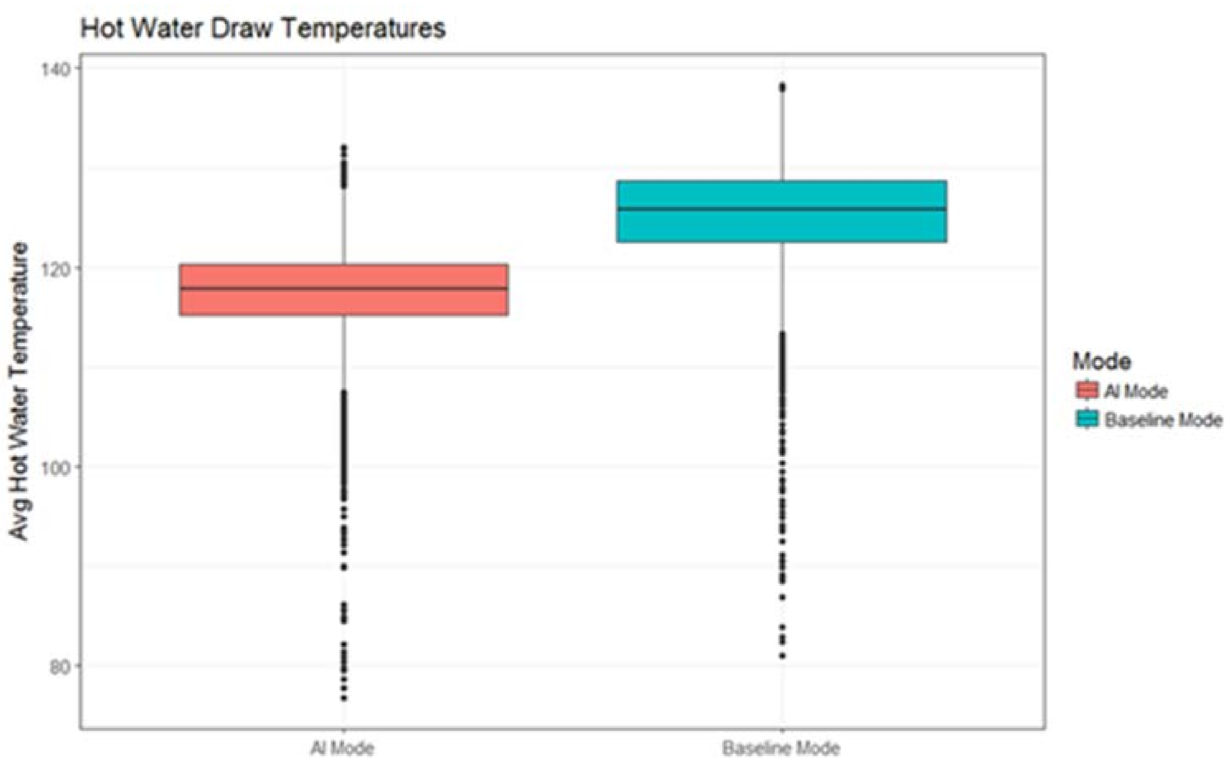


Figure 23 is a graph of average delivered hot water temperature by mode for all Gas M&V Sites using box plots that show the median usage and interquartile range. The figure shows that in AI Mode, the median delivered hot water temperature is 123°F at the 50th percentile compared to 128.1°F at the 50th percentile in the Base Mode; a reducing in temperature of 6.2°F.

Figure 23. Gas M&V Sites - Average Weekly Hot Water Draw Temperatures by Mode

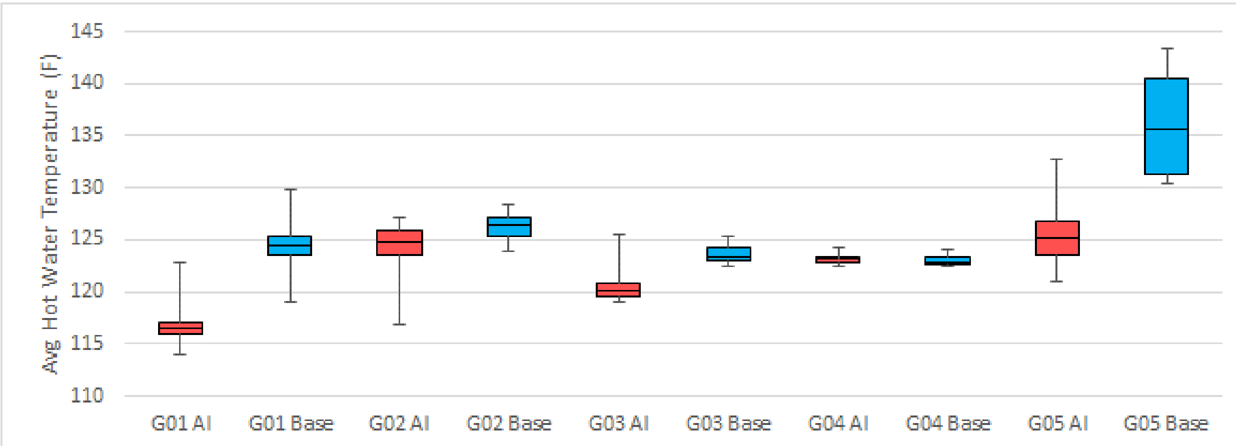
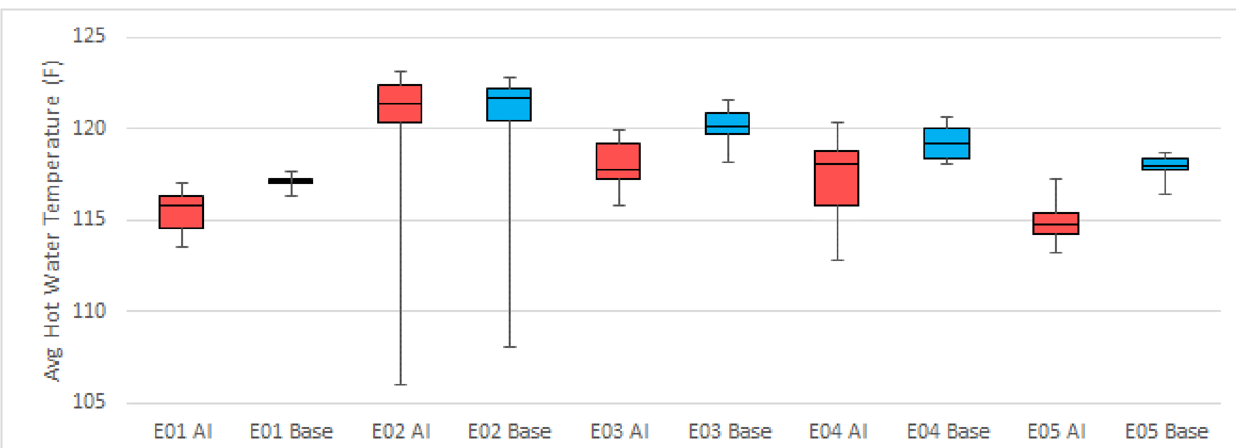


Figure 24 is a graph of average delivered hot water temperature by mode for all Electric M&V Sites using box plots that show the median usage and interquartile range. The figure shows that in AI Mode, the median delivered hot water temperature is 123°F at the 50th percentile compared to 117.6°F at the 50th percentile in the Base Mode; a reducing in temperature of 1.7°F.

Figure 24. Electric M&V Sites - Average Hot Water Weekly Temperature Draw by Mode



M&V Sites, in AI Mode, consistently show a reduction in delivered hot water temperature. In general, Electric M&V sites had lower baseline temperature set points compared to Gas M&V Site. While Electric

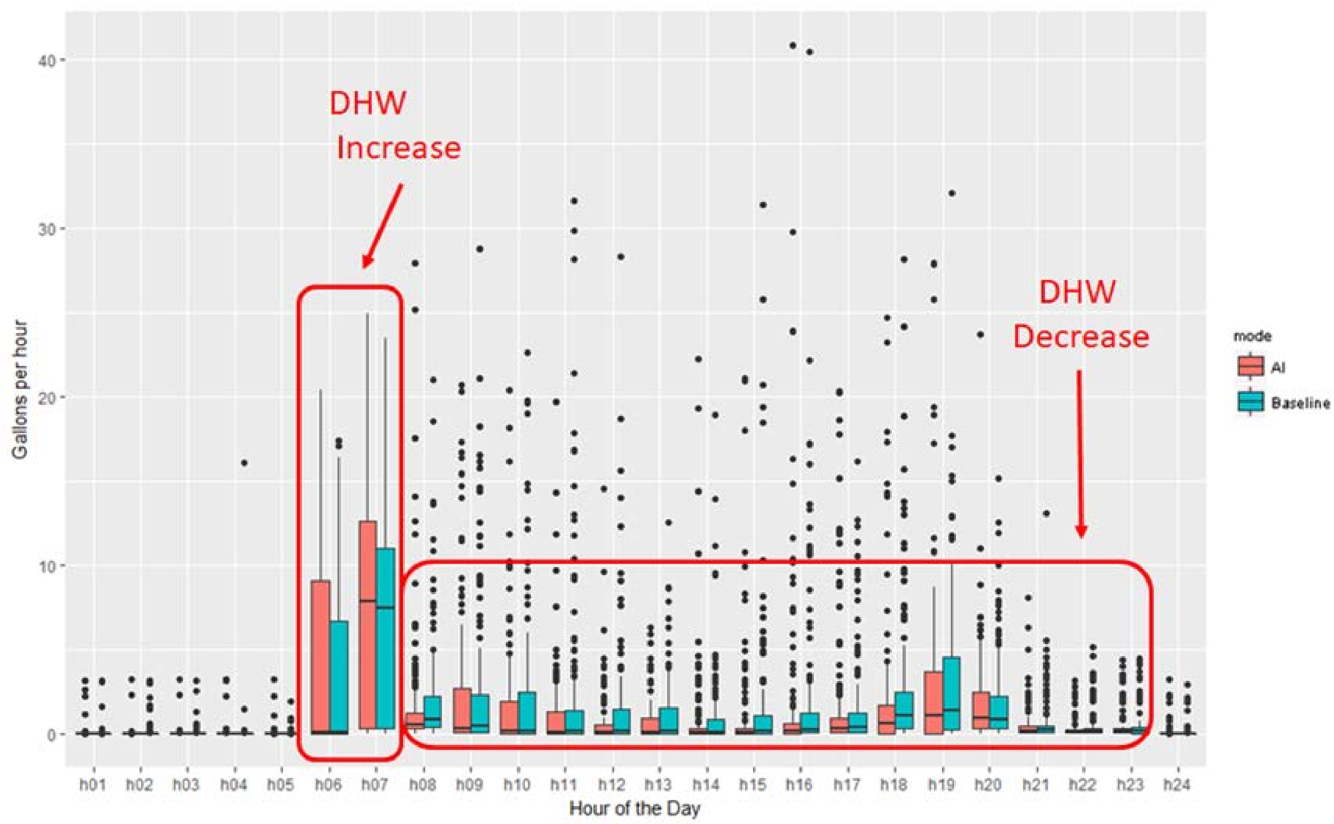
M&V Sites maintained the 120°F factory setting[16], Gas M&V were at a higher settings, centered around 125°F, with one outlier at 135°F[17].

Hot Water Use

A way the Aquanta controller saves energy is by eliminating unnecessary reheats of the water in the tank when there is no demand. One effect of suppressing water heater tank reheats is a lower tank overall temperature. This may result in increased hot water use during high demand periods.

Figure 25 is a graph of hot water use from site G01, over all days on an hour by hour bases using box plots that show the median usage and interquartile range. The data shows an increase in hot water usage in AI Mode during a periods of high hot water demand, hours 6 and 7. Conversely, during periods of low to medium use, hours 8 through 23, hot water use is diminished.

Figure 25. Site G01 - Median Usage and Interquartile Range of Water Use by Hour of Day by Mode



[16] Technical Bulletin 31 by A.O. Smith states the temperature range on a residential electric water heater that typically stores between 20 and 80 gallons of hot water is from 90° F to 150°F, with the usual factory setting of 120°F (https://www.hotwater.com/lit/bulletin/bulletin31.pdf)

[17] Technical Bulletin 35 by A.O. Smith states the temperature range on a residential gas water heater is from 80° F ±10° to 160°F ±10°, with a recommended range between 120°F and 140°F and a factory setting of 120°F (https://www.hotwater.com/lit/bulletin/bulletin35.pdf)

Figure 26 is a graph of hot water use from site E05, over all days on an hour by hour bases using box plots that show the median usage and interquartile range. The data shows an increase in hot water usage in AI Mode during a periods of high hot water demand, hours 8, and 19-21. Once again during periods of low to medium use, hours 1, 4-7, and 9-18, hot water use is diminished.

Figure 26. Site E05 - Median Usage and Interquartile Range of Water Use by Hour of Day by Mode

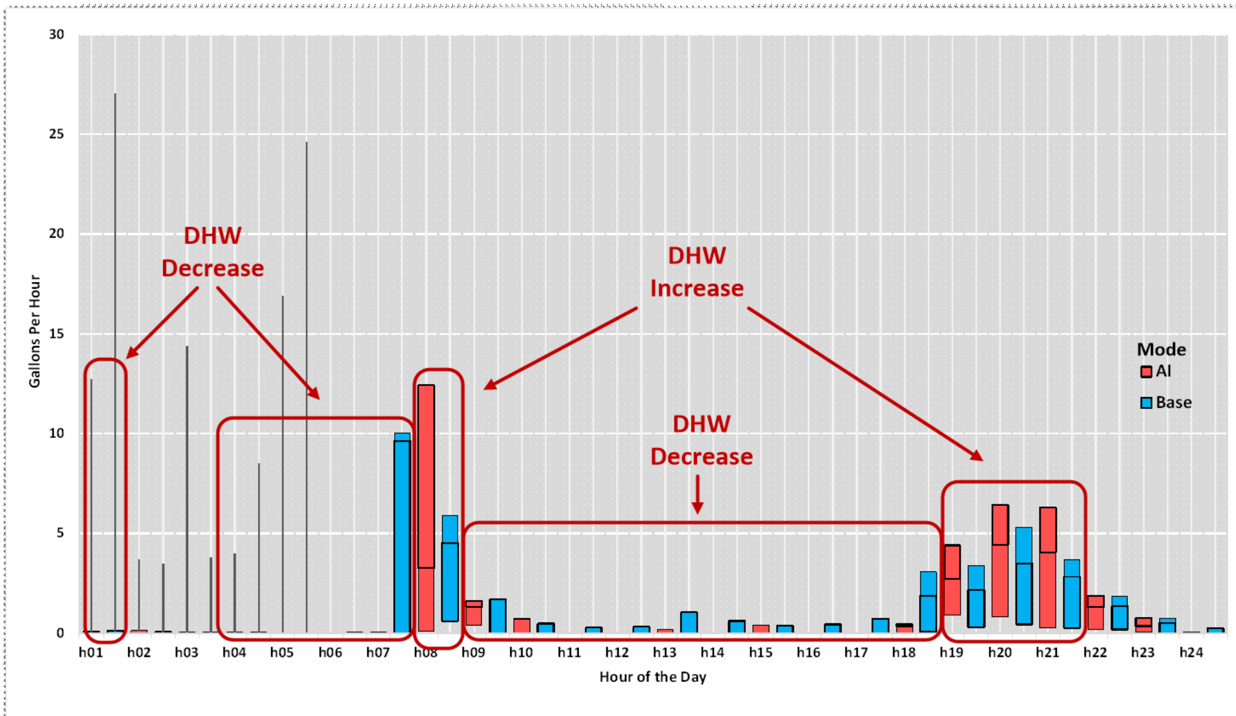


Figure 27. Gas M&V Sites - Median Usage and Interquartile Range of Gallons per Day Water Use by Mode

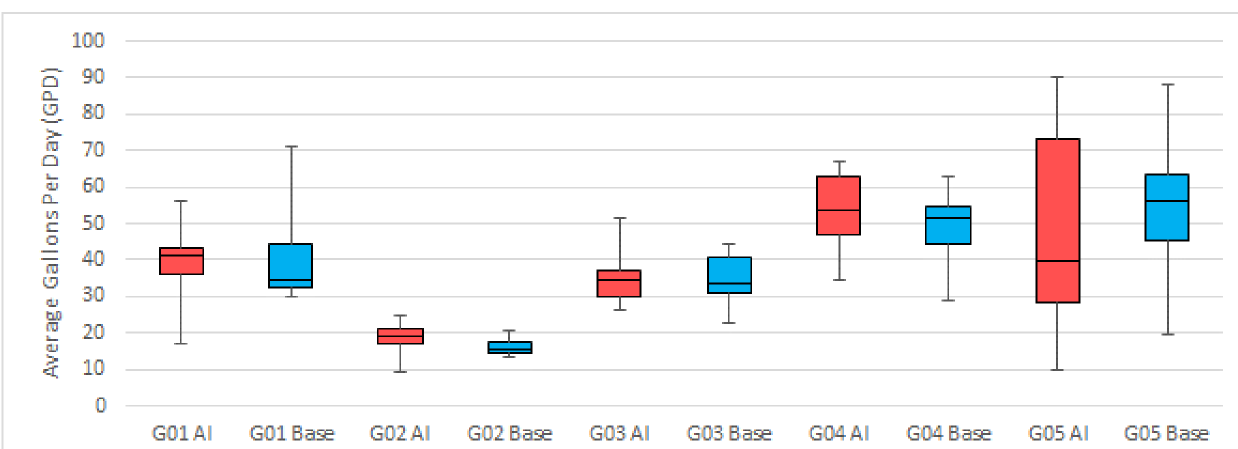


Figure 27 is a graph of weekly averaged gallons per day (GPD) water use for Gas M&V Sites using box plots that show the median usage and interquartile range. The figure shows that in AI Mode, the weekly median gallons per day for all gas sites is higher at the 50th percentile compared to the 50th percentile in the Base Mode except for site G05 with two occupants.

Table 11 compares the averaged gallons per day (GPD) water use for Gas M&V Sites. All Gas M&V sites show an increase in gallons per day usage when in AI mode. In AI Mode, Site G02 with two occupants and the low gallons per day usage (18.5 GPD), showed the greatest increase with 14% (2.3 GPD). Site G05, with two occupants and high gallons per day usage (49.7 GPD), showed a decrease of 9% (5.2 GPD).

Table 11. Gas M&V Sites - Averaged Weekly Gallons per Day Water Use by Mode

	G01	G02	G03	G04	G05
Base Mode (GPD)	39.1	16.1	34.4	49.8	54.9
AI Mode (GPD)	39.3	18.5	34.7	53.4	49.7
GPD Delta	0.2	2.3	0.3	3.7	-5.2
Percent Change	1%	14%	1%	7%	-9%

Figure 28 is a graph of weekly averaged gallons per day (GPD) water use for Electric M&V Sites using box plots that show the median usage and interquartile range. The figure shows that in AI Mode, the weekly median gallons per day for all electric sites is higher at the 50th percentile compared to the 50th percentile in the Base Mode.

Figure 28. Electric M&V Sites - Median Usage and Interquartile Range of Gallons Per Day Water Use by Mode

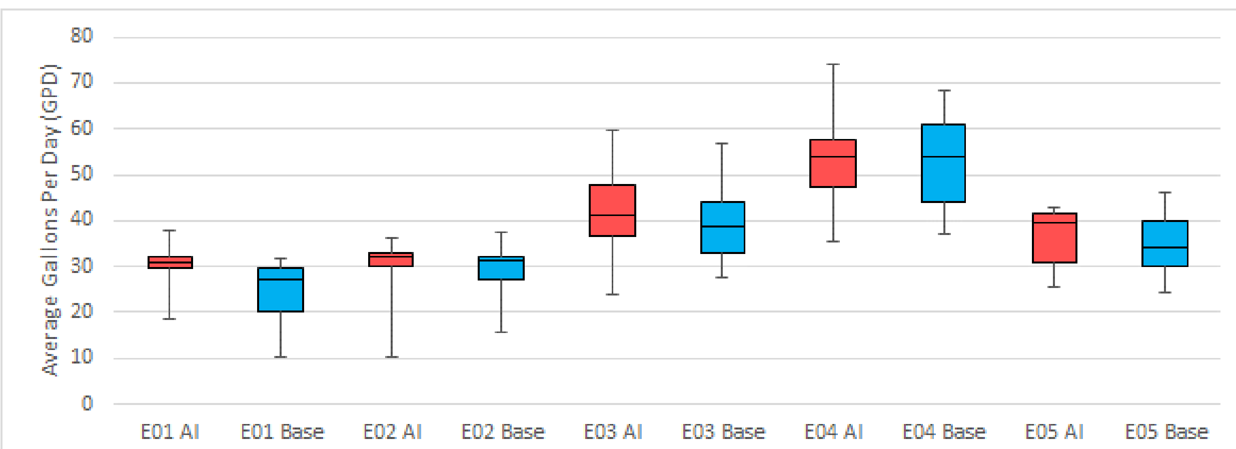


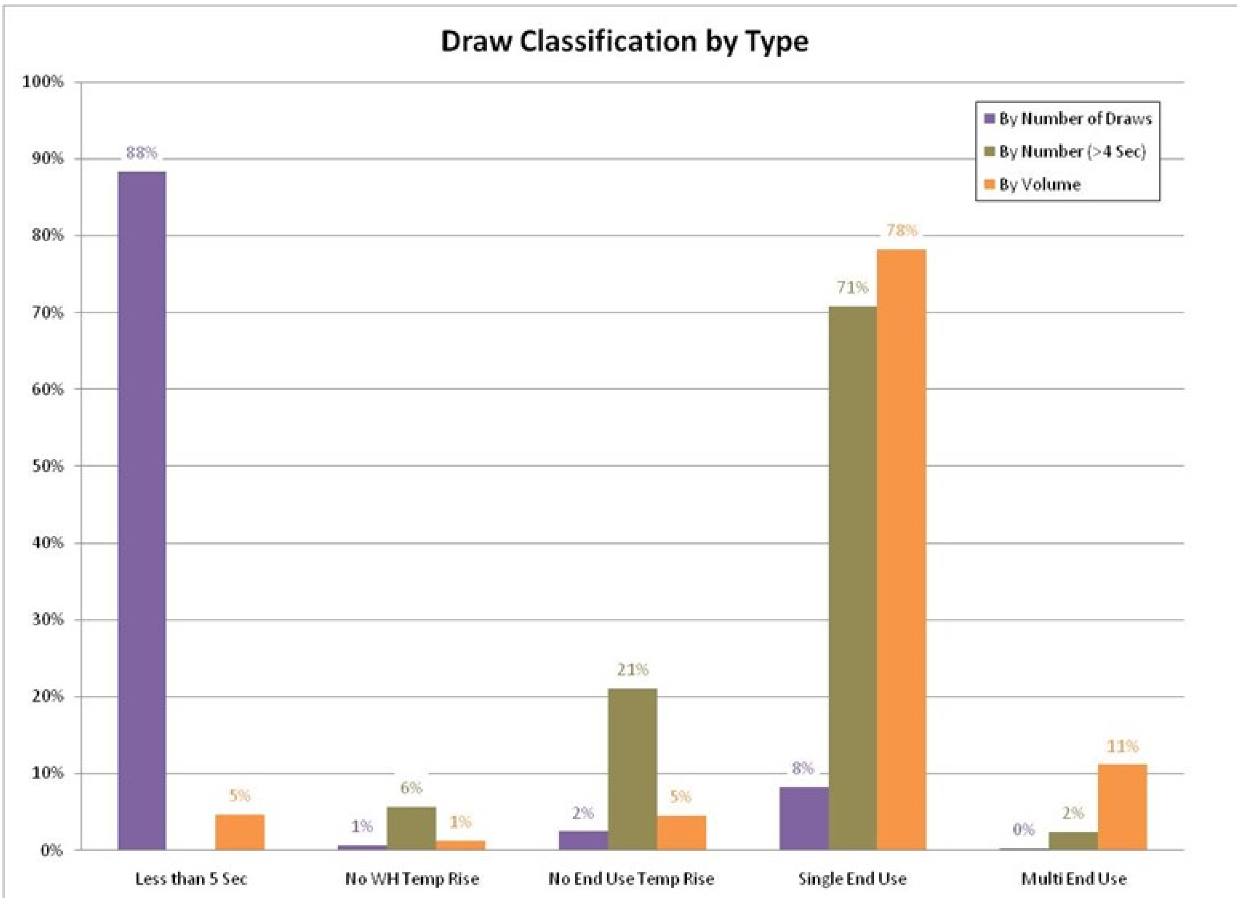
Table 12. Electric M&V Sites - Averaged Weekly Gallons per Day Water Use by Mode

	E01	E02	E03	E04	E05
Base Mode (GPD)	24.7	29.5	40.0	53.2	34.9
AI Mode (GPD)	30.2	29.8	40.6	53.3	36.5
GPD Delta	5.5	0.3	0.6	0.1	1.6
Percent Change	22%	1%	2%	0%	5%

Table 12 compares the averaged gallons per day (GPD) water use for Electric M&V Sites. All Electric M&V sites show an increase in gallons per day usage in AI mode. In AI Mode, Site E01 with two occupants and the low gallons per day usage (30.2 GPD), showed the greatest increase with 22% (5.5 GPD). Site E04, with eight occupants and high gallons per day usage (53.3 GPD), showed the least increase of electric M&V Sites with 0% (0.1 GPD).

An increase in gallons per day (GPD) water use observed at all M&V Sites except for site G05, with two occupants and a high gallons per day usage (49.7 GPD) in Base Mode, which showed a decrease of 9% (5.2 GPD). Sites with low gallons per day usage show the highest percent increase.

Figure 29. CEE Study - Classification of Hot Water Draw by Type



Another consideration is that of short draws, less than 5 seconds, where hot water may never get to its intended point of use. Figure 29 is an analysis of draws from a CEE study of hot water use in Minnesota homes. The first column group shows that 88 percent of hot water draws were less than 5 seconds and represented only 5% of the daily volume[18]. In addition, the third column group shows that another 2 percent of draws, 5 seconds or greater, also never reach their end use.

In Base Mode, these short draws, where hot water never reaches its intended point of use, may trigger a reheat. In AI Mode, it is observed that the tank temperature is lower, less hot water is used, and as result, unnecessary reheats may be avoided.

Reheat Profiles

Figure 30 is a second by second analysis of all days of operation showing the percent of burner runtime by hour of day by controller mode for site E05 which has an electric water heater and four occupants. As expected, AI Mode shifts the burner on-time, since it is responding to actual demand and not a fixed set point. The thermal energy available in the tank is adequate to meet hot water demand in hours 1-8 and 12-20, traditional periods of little or no hot water demand. During or immediately following period of high hot water demand, the number of reheats increases in comparison to baseline operation.

Figure 30. Site E05 - Electric Water Heater Burner On-time by Hour of Day by Mode

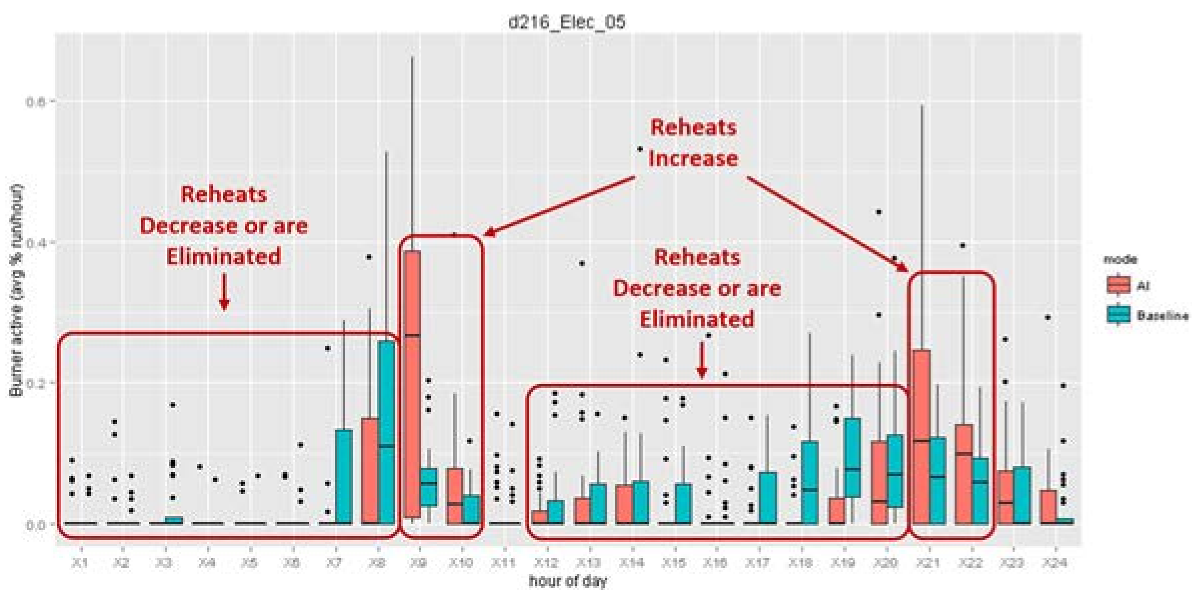
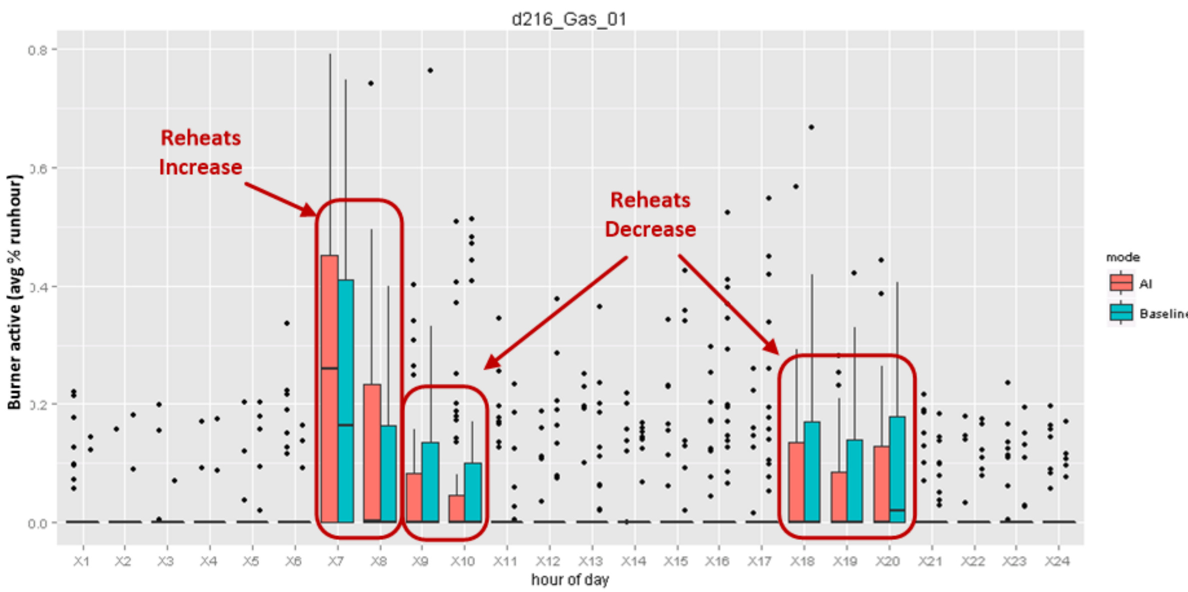


Figure 31 is a second by second analysis of all days of operation showing the percent of burner runtime by hour of day by controller mode for site G01 which has a gas water heater and two occupants. As expected, AI Mode shifts the burner on-time, since it is responding to actual demand and not a fixed set point. The thermal energy available in the tank is adequate to meet hot water demand in hours 9, 10,

[18] B. Schoenbauer, D. Bohac, M. Hewett, 2012, Measured Residential Hot Water End Use, ASHRAE Transactions, 2012 ASHRAE Chicago, CH-12-014, Volume 118, pages 872 – 889 (https://www.ashrae.org/technical-resources/ashrae-transactions).

and 18-20. During the period of highest hot water demand, hours 7 and 8, the number of reheats increase in comparison to baseline operation.

Figure 31. Site G01 – Gas Water Heater Burner On-time by Hour of Day by Mode



Sites E05 and G01 are examples of electric and gas sites showing that in AI Mode, a shift occurs in burner on-time. Comparing the two sites we find that the shifts are responding to actual demand and not a fixed set point. Each site shows a different period where the thermal energy available in the tank is adequate to meet hot water demand, hours 1-7 and 15-18 for Site E05 and hours 9, 10, and 18-20 for Site G01. All sites exhibited their own unique traditional periods of little or no hot water demand that may have varied slightly by hour or day. And all sites show that during or immediately following period of high hot water demand, the number of reheats increased in comparison to baseline operation.

Determining Daily and Annual Energy Use

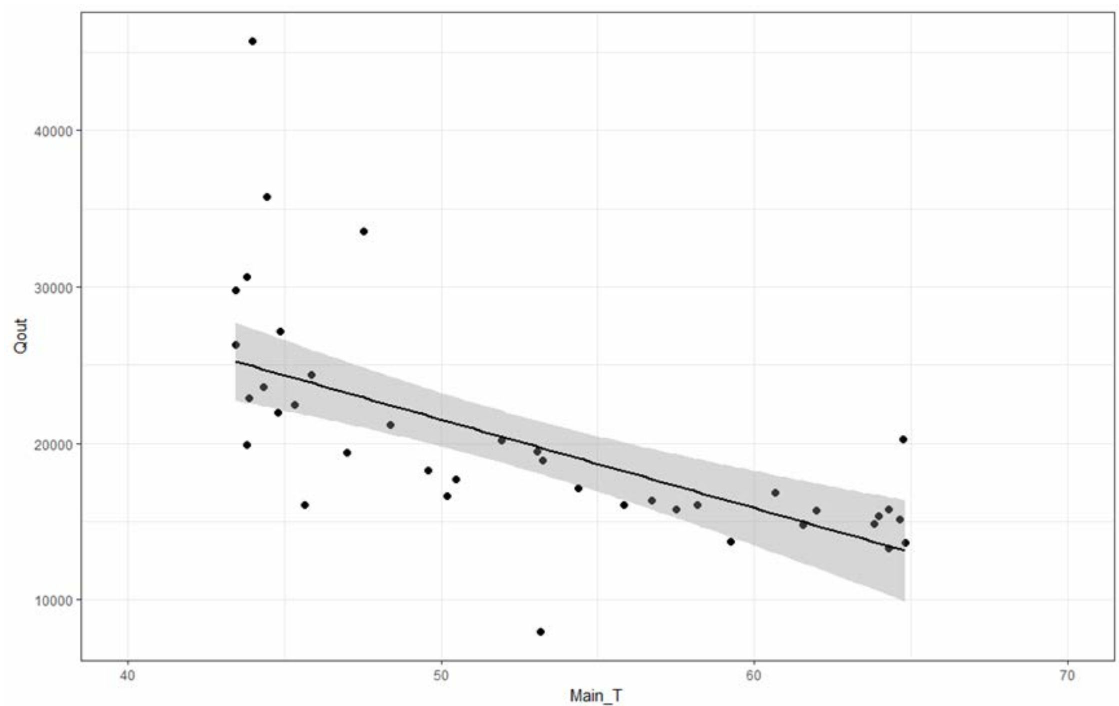
Seasonality

There are significant seasonal effects for water heating in Minnesota because there is a wide range of water temperatures that come into a home. The effect of seasonality on hot water usage is as follows:

1. It takes more energy to heat 45°F water than 65°F water.
2. For water use that require a specific delivered temperature, the hot water volume may increase as more hot water is required in mixing to achieve a specific delivered temperature when the cold water inlet temperature is lower.
3. Behavioral impacts due to a lower cold water inlet temperature may result in higher hot water use.

Seasonality effects the same variables that the Aquanta is impacting; delivered water temperature and the associated energy used to heat the water. To isolate the impact of the Aquanta, the impact of seasonality was determined at each site. Figure 32 shows this seasonality relationship at Site G01. Throughout the period of performance, the cold water inlet temperature ranged from about 43°F to about 65°F. Plotting the hot water use (Qout) against the cold water inlet temperature it is observed that the lower the cold water inlet temperature the higher the energy out, or hot water use. While Site G01 exhibited large seasonal impacts, almost doubling output, not all field sites experienced such an extreme.

Figure 32. Site G01 - Hot Water Use (Qout) versus Cold Water Inlet Temperature



To account for seasonality, an annual cold water inlet profile for each site was developed based on a statistical model that relates cold water inlet temperature to weather data. This is illustrated in Figure 33 where measured cold water inlet temperatures (Yellow dots) from Site G01 are fitted to a statistical model of annual average local weather data and adjusted for ground water temperature. It is through this model that an annual average cold water inlet temperature is established for each site. The average annual cold water inlet temperature for Site G01 is 54.2 ^{o}F.

Figure 33. Site G01: Cold Water Inlet Profile

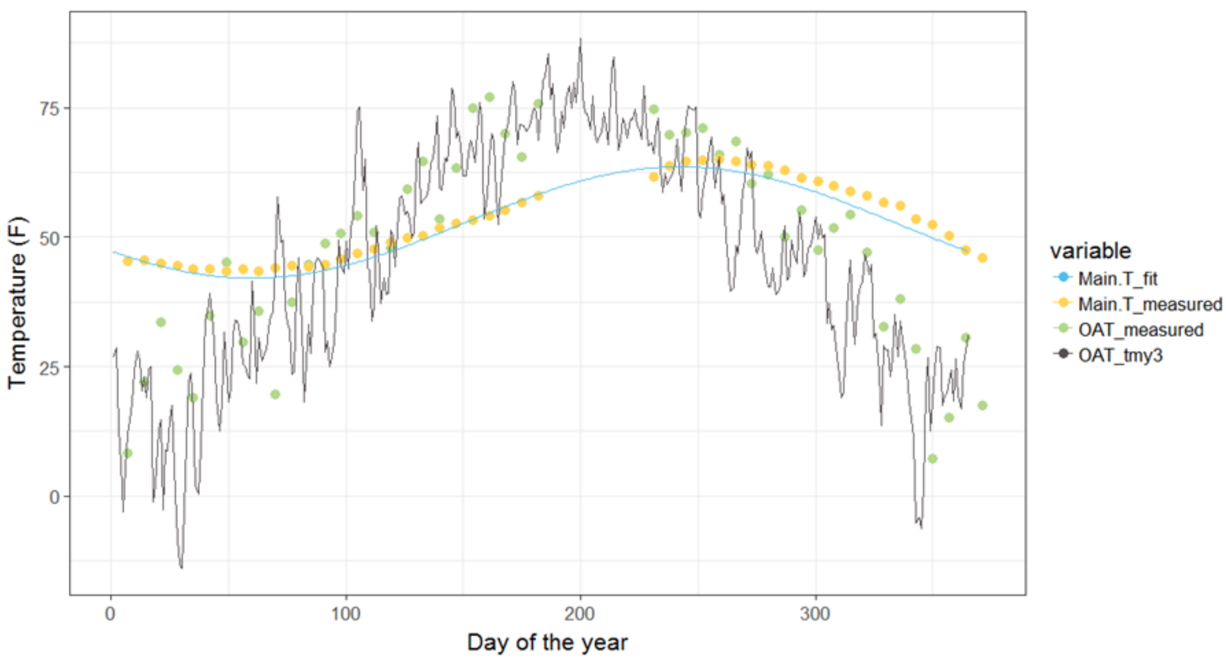
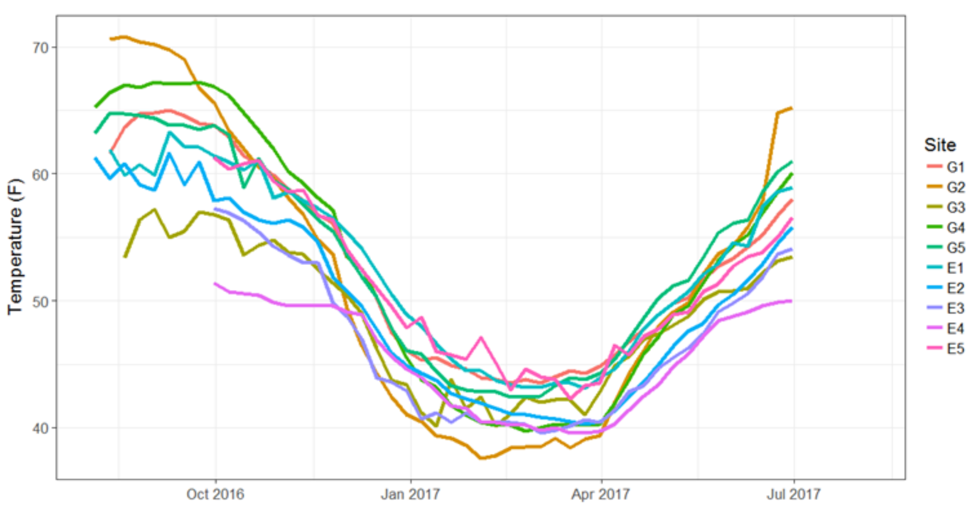


Figure 34. Cold Water Inlet Profile for all M&V Sites



G01	G02	G03	G04	G05	E01	E02	E03	E04	E05
54.2	54.9	53.2	55.2	55.3	56.4	52.8	52.2	47.5	55.2

Figure 34 profiles the cold water inlet temperature of all 10 M&V sites. Temperature range from 70.5 ^{o}F to 38 ^{o}F, with a median temperature of 54.6 ^{o}F. In the field evaluation, all M&V gas sites were located in the Greater Minneapolis-St. Paul Area with water sourced from the Mississippi River. The cold water inlet temperature of the M&V gas sites had a mean of 54.6^{o}F with a variance of 0.6. In contrast, M&V electric sites were scattered locations where water is sourced from wells of varying depths. This wider variation in where water is sourced for the electric sites may be reflected in the wider variance seen in their data which had a mean cold water inlet temperature of 52.8°F and a variance of 9.4.

Water Heater Performance

M&V data was collected on one second intervals at the ten sites where intensive monitoring took place. This data was compiled into daily energy consumption, Qin, and daily energy delivered in hot water, Qout. Figure 35 plots the relationship between energy consumed (in this case natural gas) and energy delivered (hot water) in both Base and AI Modes for site G01, which has four occupants. Qout divided by Qin equals the daily efficiency. The plot shows that the water heater operating in AI-Mode consumes less energy (Y-axis) than in Base Mode for this particular site, and is therefore more efficient.

Statistical analysis, p-value test, showed that the difference in the mode of operation is significant, e.g. AI Mode operation is impacting the water heater efficiency at this site.

Figure 35. Site G01: Energy In (Qin) versus Energy Out (Qout)

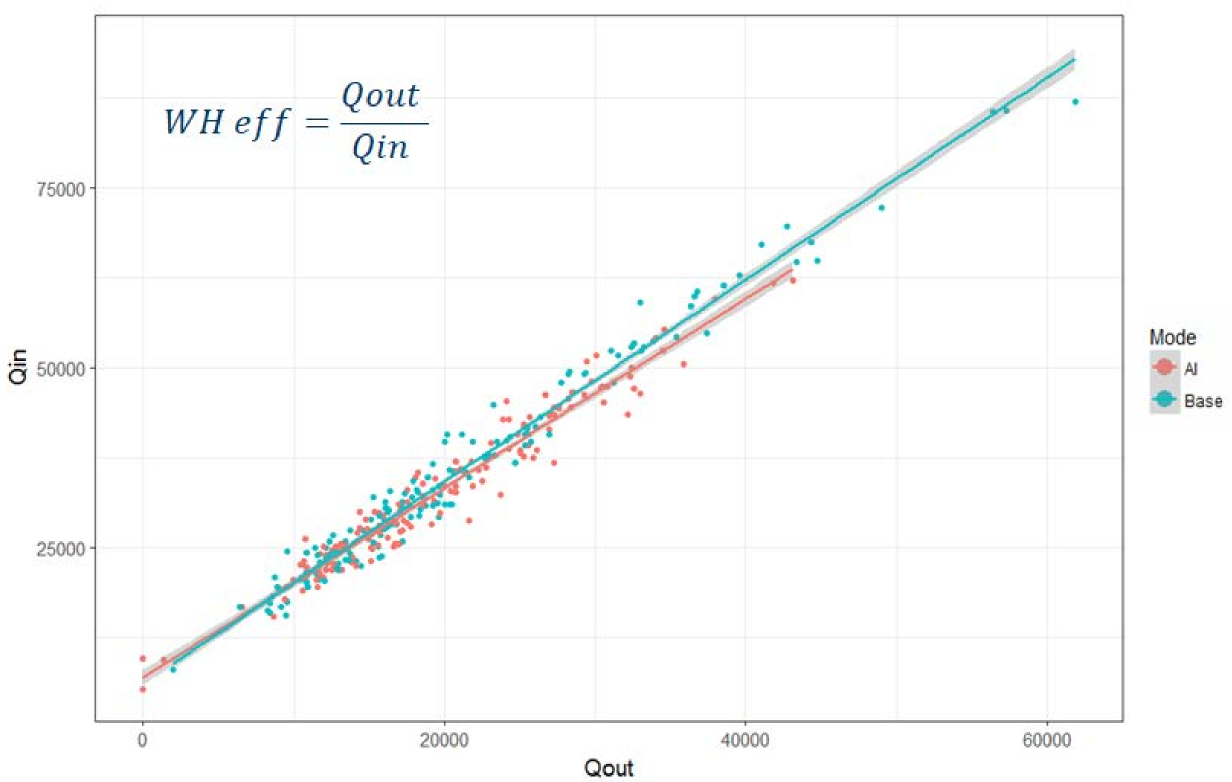
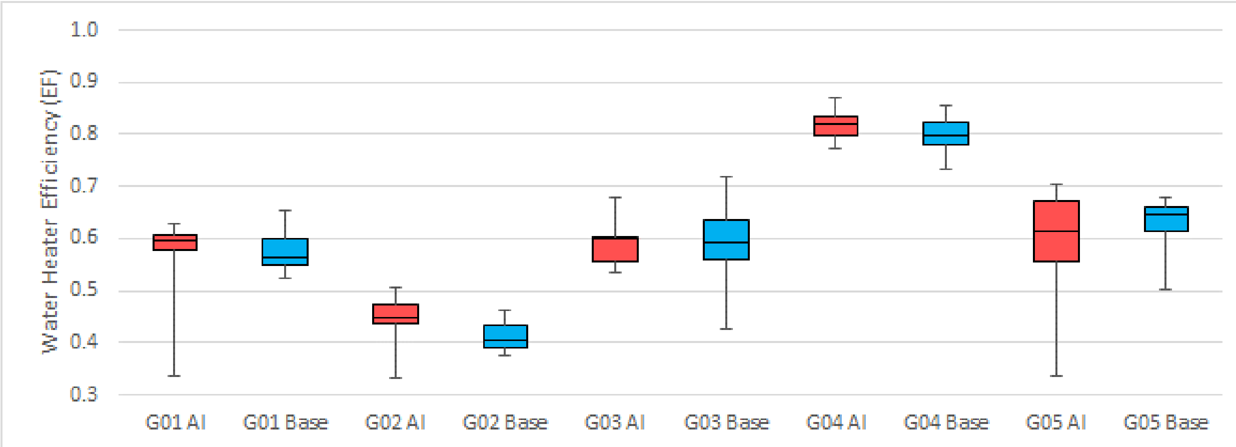


Figure 36 is a graph of weekly averaged efficiencies for Gas M&V Site water heaters using box plots that show the median efficiency and interquartile range. The figure shows that in AI Mode, the weekly median efficiency for all gas M&V site water heaters is higher at the 50th percentile compared to the 50th percentile in the Base Mode except for Site G05, which had two occupants and high gallons per day usage (49.7 GPD).

Figure 36. Gas M&V Sites - Median and Interquartile Range of Water Heater Efficiency by Mode



At site G05, there was statistically there is no difference between the modes at median usage Qout (26,600 btu/day). In this range, the error bands overlap and the small differences in mode were difficult to measure at these levels. However, Figure 37 shows that as we got to a higher load at G05, the reduction in supply water temperature, does improves the overall performance of the AI mode.

Figure 37. Site G05: Energy In (Qin) versus Energy Out (Qout)

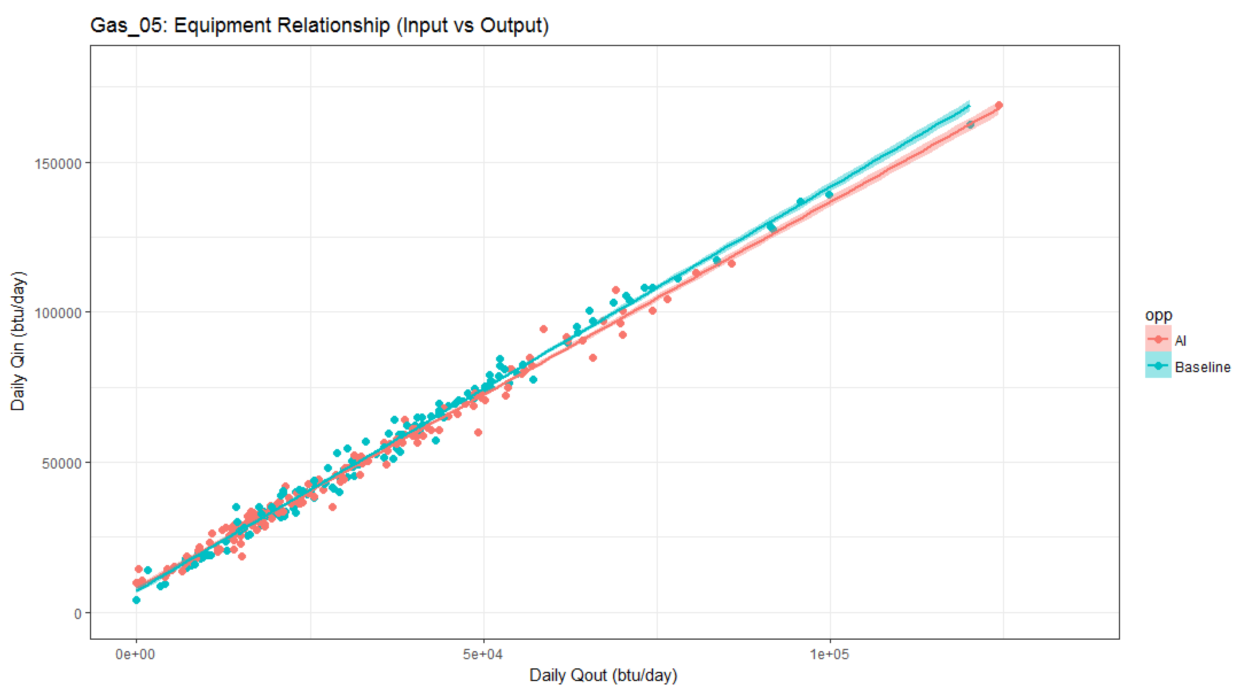
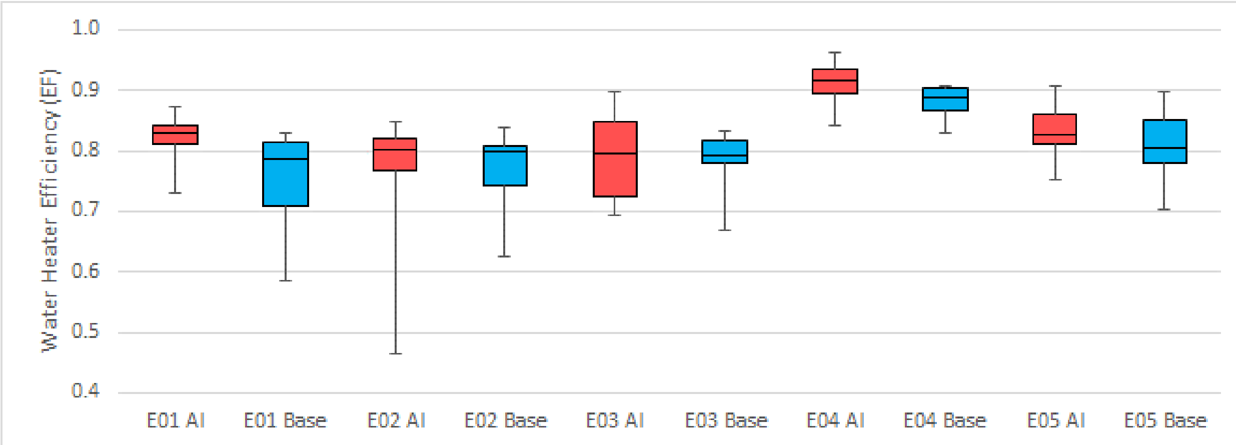


Figure 38 is a graph of weekly averaged efficiencies for Electric M&V Site water heaters using box plots that show the median efficiency and interquartile range. The figure shows that in AI Mode, the weekly median efficiency for all electric M&V sites water heaters is higher at the 50th percentile compared to the 50th percentile in the Base Mode.

Figure 38. Electric M&V Sites - Median and Interquartile Range of Water Heater Efficiency by Mode



Daily Energy Use

As already discussed, in order to determine the impact of the Aquanta on daily energy use, seasonality of inlet water had to be taken into account.

Seasonality of water use, defined as fluctuations in the cold water inlet temperature throughout the year, can impact water heating in much the same way that the Aquanta impacts water heating. A lower cold water inlet temperature may result in higher hot water use; it takes more energy to heat 45°F water than 65°F; and more hot water is needed to mix hot and cold water to a specific delivered temperature when the cold water is lower. To determine the impact of the Aquanta on daily energy use, seasonality had to be taken into account.

Two analysis methods were used in account for seasonality to estimate energy use. Both methods first required developing an annual cold water inlet profile based on measured data fitted to a well-established statistical model of annual average local weather data and adjusted for ground water temperature.

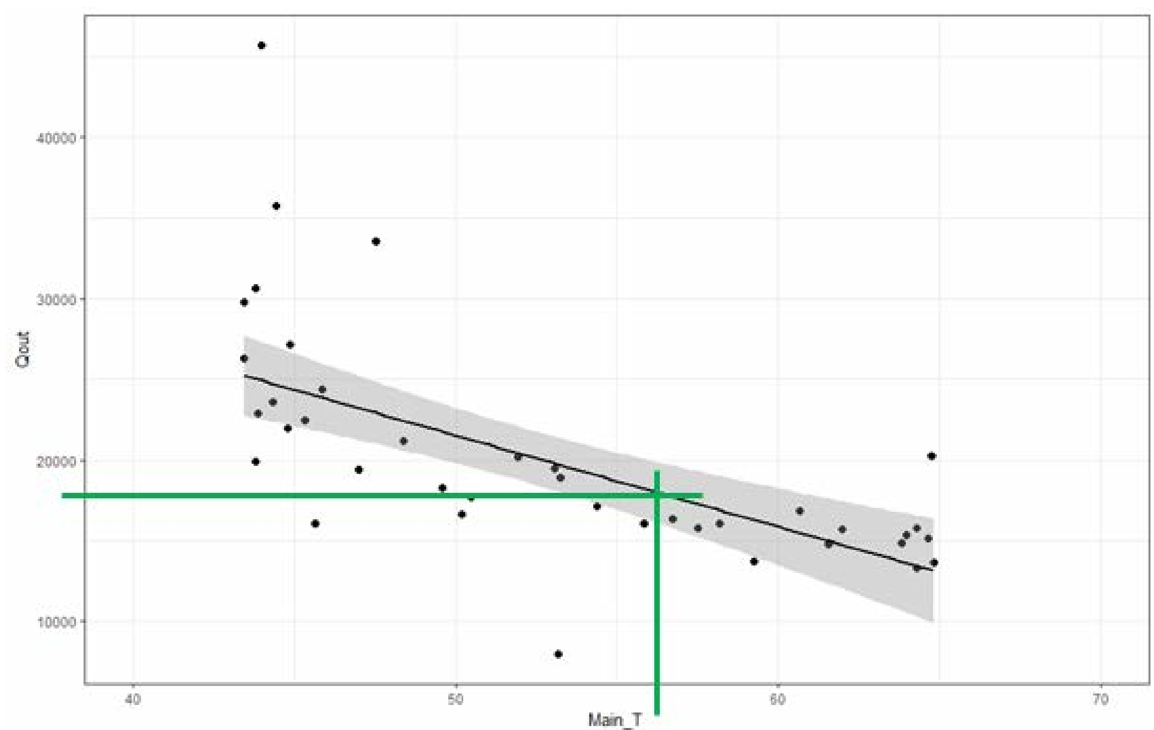
One analysis method uses the Combined Seasonality Dataset of both Base and AI Modes to develop a plot of the average delivered hot water energy (Qout) against the weekly inlet water temperature. By locating the annual average cold water inlet temperature, one could determine the daily energy out (Btu/day). Applying the water heater performance efficiencies calculated from Base and AI Modes, the daily energy in (daily energy use) and delta savings can be calculated.

The alternative analysis method uses separate Base and AI Seasonality dataset to calculate daily energy out (Btu/day) of for each Mode separately. The water heater performance efficiencies from Base and AI Modes are then used to calculate the daily energy in (daily energy use) and delta savings.

Daily Use Based on a Combined Mode Dataset

A combined daily energy use can be calculated using data from both AI and Base Modes. Figure 39 plots the average delivered hot water energy (Qout) for each week against the inlet water temperature for that week for Site G01. Using the annual average main water temperature, 54.2 ^{O}F, the daily average hot water use (Qout) is determined, 19,156 Btu/day, or approximately 23 Gallons/day for this site.

Figure 39. Site G01: Determining Daily Energy Use Using a Combined Mode Dataset



Using the relationship Qout / Qin equals the daily efficiency, the operational efficiencies of each mode previously determined and Energy out (Qout) are used to calculate Energy In (Qin). Table 13 shows the results of these calculations for Site G01. The delta savings between Modes is 830 Btu/day, or an annual percent savings of 2.5% for site G01.

Table 13. Site G01: Combined Seasonal Dataset Results

Mode	Efficiency	Daily Qout (Btu/day)	Daily Qin (Btu/day)	Savings (Btu/day)	Percent Savings
Base	0.58	19,251	33,208		
AI	0.59	19,251	32,378	830	2.5%

Table 14 uses the Combined Seasonal Dataset to calculate efficiency and savings by Mode for all Gas M&V Sites. On average, in AI Mode, water heater efficiency showed a gain of 0.1 percent. Site G01, with 870 Btu/day and an annual savings of 2.5 percent shows the highest savings for Gas M&V Sites.

Site G02, with two occupants and the low gallons per day usage (18.5 GPD), shows the least savings with -871 Btu/day, or an annual savings of -4.0 percent.

Table 14. Gas M&V Sites - Combined Seasonal Dataset Results

Mode	Metric	G01	G02	G03	G04	G05
Base Mode	Qin (Btu/day)	33208	21570	32746	33401	46248
	Qout (Btu/day)	19251	9462	19618	27023	29040
	Efficiency	58.0%	43.9%	59.9%	80.9%	62.8%
AI Mode	Qin (Btu/day)	32378	22442	32764	33488	45543
	Qout (Btu/day)	19251	9462	19618	27023	29040
	Efficiency	59.5%	42.2%	59.9%	80.7%	63.8%
Savings	(Btu/day)	830	-871	-18	-87	705
	Percent	2.5%	-4.0%	-0.1%	-0.3%	1.5%

Table 15 uses the Combined Seasonal Dataset to calculate efficiency and savings by Mode for all Electric M&V Sites. On average, in AI Mode, water heater efficiency showed a gain of 1.0 percent. Site E04, with eight occupants and high gallons per day usage (53.3 GPD) produced a savings of 883 Btu/day, a 2.8 percent annual savings. Site E02, with one occupant and low gallons per day usage (29.2 GPD), shows the least savings for Electric M&V Sites with -192 Btu/day, or an annual savings of -1.1 percent.

Table 15. Electric M&V Sites - Combined Seasonal Dataset Results

Mode	Metric	E01	E02	E03	E04	E05
Base Mode	Qin (Btu/day)	14160	17698	25138	31477	19176
	Qout (Btu/day)	10985	13808	19452	27807	15170
	Efficiency	77.6%	78.0%	77.4%	88.3%	79.1%
AI Mode	Qin (Btu/day)	14047	17897	24868	30594	18698
	Qout (Btu/day)	10985	13808	19452	27807	15170
	Efficiency	78.2%	77.2%	78.2%	90.9%	81.1%
Savings	(Btu/day)	113	-198	270	883	478
	Percent	0.8%	-1.1%	1.1%	2.8%	2.5%

Overall water heater efficiency gained in AI Mode; 0.1 percent for Gas M&V sites and 1.0 percent for Electric M&V sites. Least gains in water heater efficiency occurred at sites with low gallons per day usage.

Daily Use Based on Separate Mode Datasets

In the previous section, since there was no statistical difference between the Modes, data from both AI and Base Modes were treated as one dataset to determine daily energy use. The high levels of variance make statistical differentiation between operating modes difficult to determine. However, since the

Aquanta was found to reduce set point temperatures and reduce energy use per gallon of hot water delivered, there is good indication that the Aquanta impacts the energy delivered.

As an alternative analysis to determine the daily average energy use (Qout) data from Base and AI Modes were developed and analyzed separately. Figure 40, Site G01 Energy Out data of each mode is plotted separately against cold water inlet temperature. Using the annual cold water inlet temperature, 54.2°F, we can then determine the daily annual energy out for each mode. AI Seasonal Qout = 17,090 Btu/day and Base Seasonal Qout = 21,586 Btu/day for this site.

Figure 40. Site G01: Determining Daily Energy Use Using Separate Mode Datasets

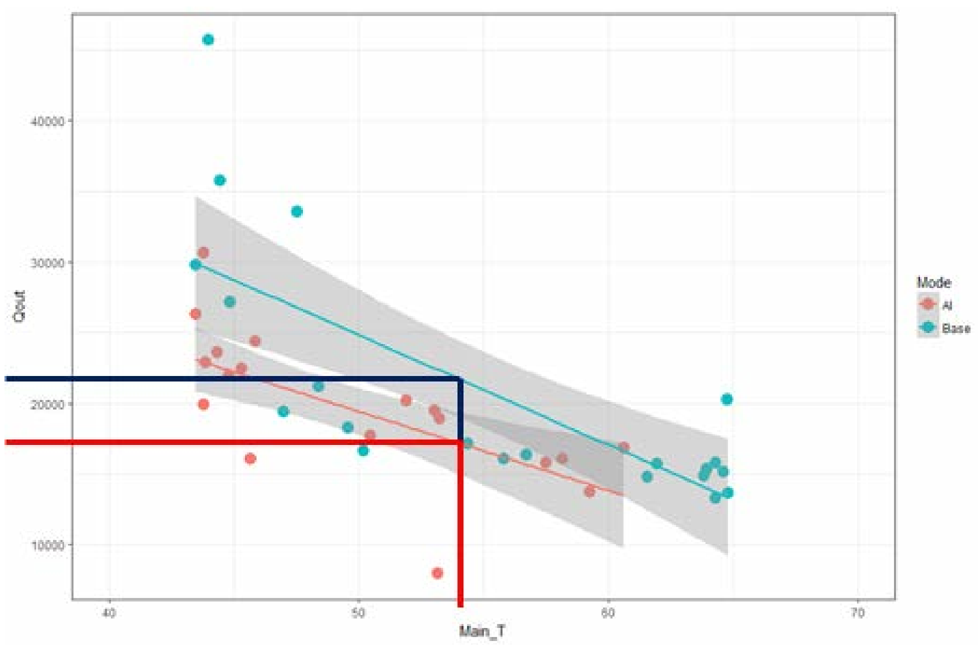


Table 16 shows the results for Site G01 when the daily Energy Out (Qout) and Mode efficiencies are used to calculate the daily Energy In (Qin). The delta savings between Modes of 6686 Btu/day, a percent savings of 18.5% for site G01.

Table 16. Site G01 - Separate Seasonal Mode Dataset Results

Mode	Efficiency	Daily Qout (Btu/day)	Daily Qin (Btu/day)	Savings (Btu/day)	Percent Savings
Base	0.59	21,362	36,169		
AI	0.58	17,050	29,482	6,686	18.5%

Table 17 uses Separate Seasonal Mode Datasets to calculate efficiency and savings by Mode for all Gas M&V Sites. On average, in AI Mode, water heater efficiency showed a gain of 0.1 percent. Site G05, with 19586 Btu/day and an annual savings of 35.7 percent shows the highest savings for Gas M&V Sites. Site G02, with two occupants and the low gallons per day usage (18.5 GPD), shows the least savings with -1648 Btu/day, or an annual savings of -7.5 percent.

Table 17. Gas M&V Sites - Separate Seasonal Mode Dataset Results

Mode	Metric	G01	G02	G03	G04	G05
Base Mode	Qin (Btu/day)	36169	21929	33051	33263	54925
	Qout (Btu/day)	21362	9089	19888	26813	36340
	Efficiency	59.1%	41.4%	60.2%	80.6%	66.2%
AI Mode	Qin (Btu/day)	29482	23577	32557	33734	35339
	Qout (Btu/day)	17050	10287	19424	27253	21102
	Efficiency	57.8%	43.6%	59.7%	80.8%	59.7%
Savings	(Btu/day)	6686	-1648	495	-471	19586
	Percent	18.5%	-7.5%	1.5%	-1.4%	35.7%

Table 18 uses Separate Seasonal Mode Datasets to calculate efficiency and savings by Mode for all Electric M&V Sites. On average, in AI Mode, water heater efficiency showed a loss of 2.3 percent. Site E03, with five occupants and moderate gallons per day usage (40.6 GPD) produced a savings of 1736 Btu/day, a 6.8 percent annual savings. Site E01, with two occupants and low gallons per day usage (30.2 GPD), shows the least savings for Electric M&V Sites with -2015 Btu/day, or an annual savings of -15.2 percent.

Table 18. Electric M&V Sites - Separate Seasonal Dataset Results

Mode	Metric	E01	E02	E03	E04	E05
Base Mode	Qin (Btu/day)	13231	17964	25387	30957	18778
	Qout (Btu/day)	10128	13883	19983	28159	15249
	Efficiency	76.5%	77.3%	78.7%	91.0%	81.2%
AI Mode	Qin (Btu/day)	15246	18159	23651	31389	18887
	Qout (Btu/day)	12245	14100	18210	28578	15356
	Efficiency	80.3%	77.6%	77.0%	91.0%	81.3%
Savings	(Btu/day)	-2015	-195	1736	-432	-109
	Percent	-15.2%	-1.1%	6.8%	-1.4%	-0.6%

Summary of Daily Energy Use Results

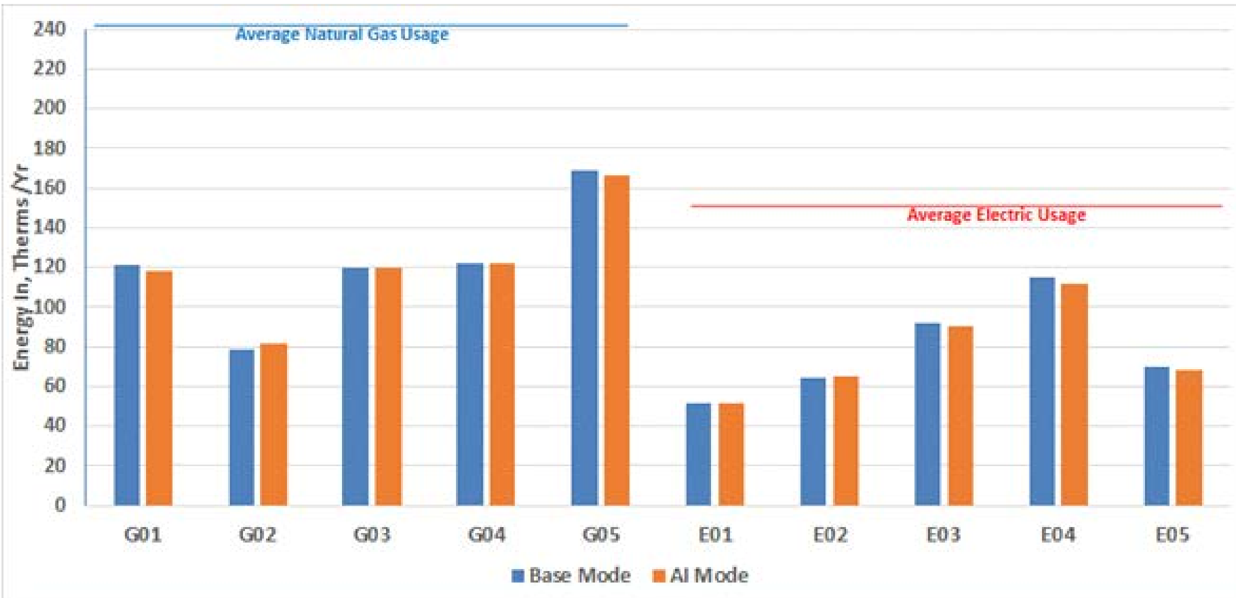
In summary of Gas M&V Sites, using the Combined Seasonality Dataset the largest percent savings per year is 2.5%, Site G01, while the lowest at -4.0% is Site G02. The average percent savings using this method is -0.1%. Using separate Base and AI Seasonality datasets, the largest percent savings per year is 35.7%, Site G05, while the lowest is -7.5% at Site G02. The average percent savings is 9.3%.

In summary of Electric M&V Sites, using the Combined Seasonality Dataset the largest percent savings per year is 2.8%, Site E04, while the lowest is -1.1% at Site E02. The average percent savings is 0.6%. Using separate Base and AI Seasonality datasets, the largest percent savings per year is 6.8%, Site E03, while the lowest is -15.2% at Site E01. The average percent savings is -2.3% using this method.

The wide variability in savings in both analyzes suggest the need for a larger population of sites and an increased length to the monitoring period in order to obtain more robust results.

Figure 41 plots the Annual Energy Use (Therm/yr) for both electric and gas M&V sites. The results are from the combined seasonality dataset for both modes and compares them with the national annual average as calculated by the U.S. DOE Energy Star® analysis for both gas (Blue Line) and electric (Red Line)[19]. Two observations are noticed: 1) on average, the annual usage for the M&V sites is 50% less than the national averages and 2) the AI Mode shows 1% less energy use than Base Mode.

Figure 41. Comparing M&V Sites Annual Energy Use (Therm/yr) to National Averages



The numbers for national average energy use are based on average hot water use of 60.5 GPD, whereas the ten M&V sites used an average 38.2 GPD. The national averages may be atypical to Minnesota water usage generally, or the sites that were selected may be low use outliers for some specific reason (e.g. they are practicing water conservation, such as using low flow showerheads).

Aquanta Controller Performance

Controller Algorithm Changes

A feature of the Aquanta is the ability to remotely update the software on the controller though the homeowner's Wi-Fi connection. This allows for continuous improvement and implementation of control algorithms and security updates without a hardware change. During the field study, the manufacturer

[19] U.S. DOE, ENERGY STAR® Residential Water Heaters: Final Criteria Analysis, April 2008.

updated the controller algorithm on five occasions. This was done to assess homeowner-directed options in implementing varying degrees of aggressiveness in energy conservation.

Figure 42 plots weekly energy in/out (Qin/Qout) for AI Modes and reveals that although there are slight changes in impact, these changes between algorithm updates are not statistically significant.

Figure 42. Impact of Algorithm Changes

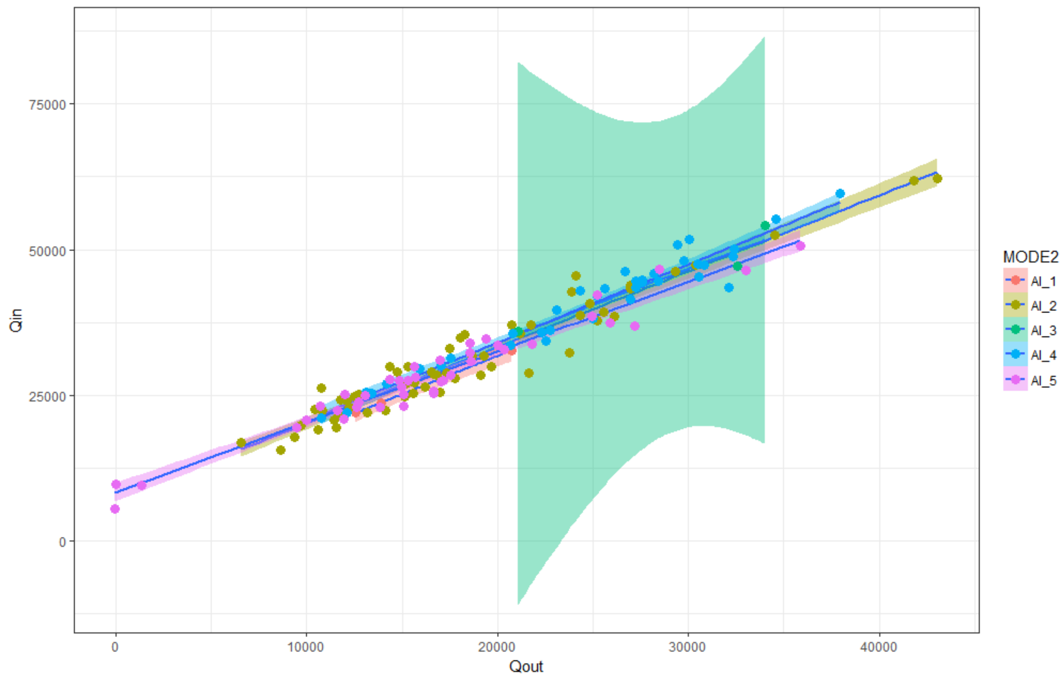
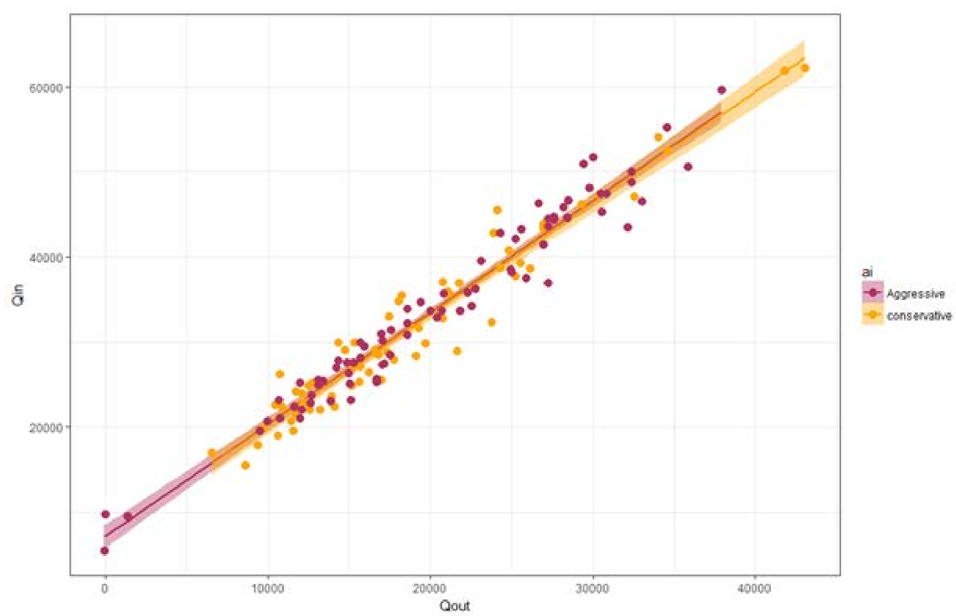


Figure 43. Aggressive Vs Conservative Algorithms



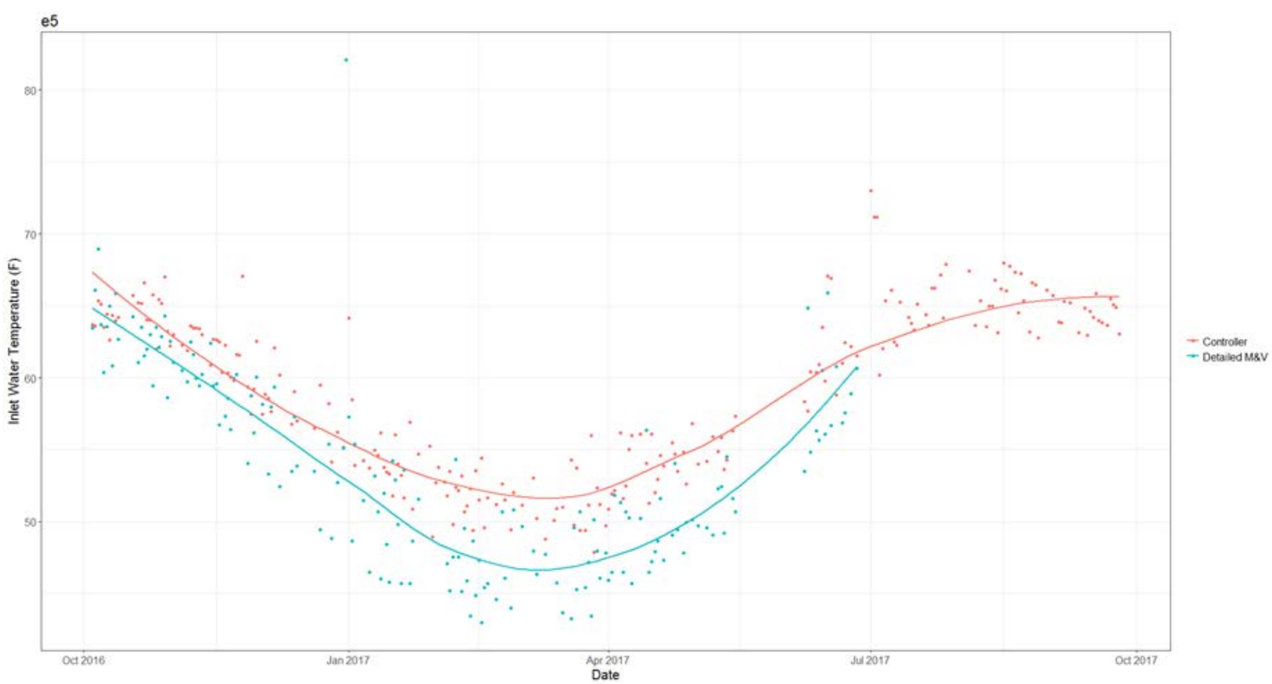
The Aquanta smart controller also offers different algorithm options that the homeowner can use to pursue energy conservation either conservatively or aggressively. Figure 43 compares the most conservative (pre-1/11/2017), and the most aggressive (post- 1/24/2017) AI modes as plotted by daily Energy in (Qin) versus Energy out (Qout). Once again there is no statistically significant difference noted in the daily model.

Comparing different AI Mode algorithms showed no statistically significant difference in operational efficiency. Expanding the sample size and extending the period of data collection and analysis may provide different results. Future controller laboratory and field studies should continue to explore the potential for improving operational efficiency through different algorithms. We encourage the manufacturer to continue to modify and develop more aggressive algorithms for conserving energy without compromising occupant comfort.

Controller as a Measurement Device

Controller data was compared to measured field data from the ten M&V sites. Figure 44 compares the minimum daily cold water inlet temperature from the controller and the M&V equipment at Site E05, which has an electric water heater and four occupants.

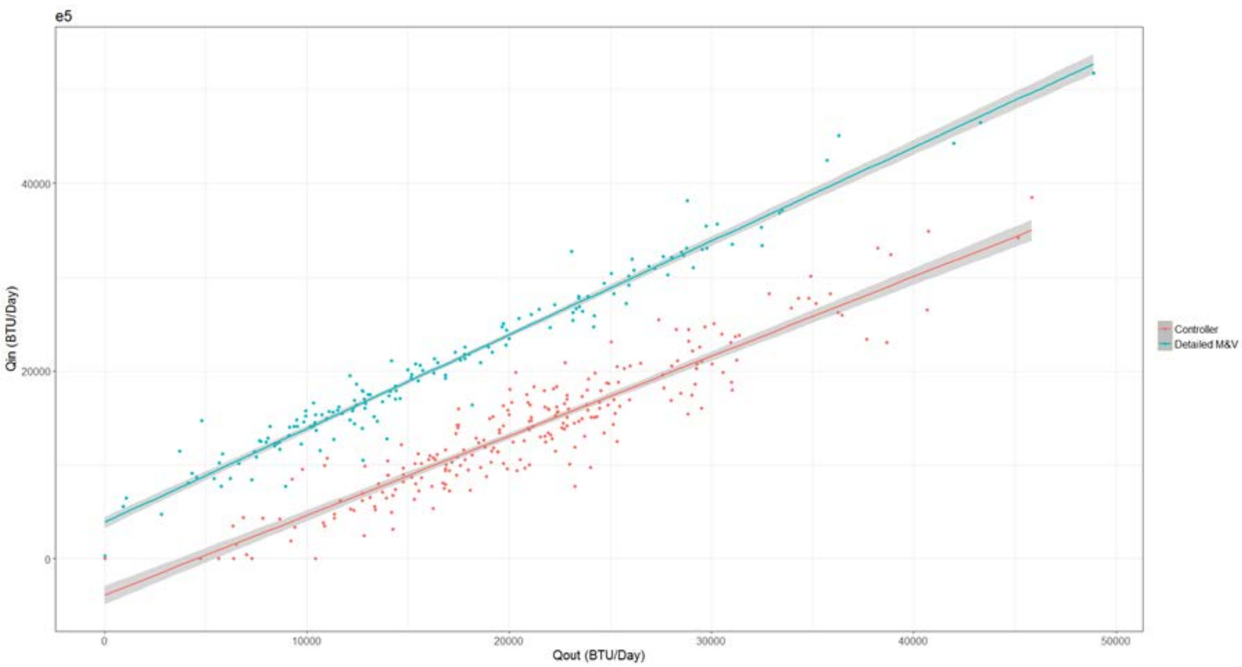
Figure 44. Site E05: Comparing Aquanta and M&V Data - Average Cold Water Inlet Temperature over Time



The graph shows that overall the controller tracks to the M&V data at Site E05, though the measured inlet water temperatures are higher with the controller. The controller measures its cold water inlet temperature at the lower interior of the tank, whereas the M&V sites measure cold water as it enters at the top of the tank. The slight variance may result from the fact that when the cold water inlet is at its lowest temperature, the burner or heating element operation and water mixing within the tank impact the measurements of the controller. Data on tank heat-up over a series of cold water inlet temperatures generated through additional laboratory testing could improve the algorithm. The results from Site E05 shown in Figure 44 are representative of all data analyzed from all ten of the field M&V sites.

Figure 45 compares the Aquanta and M&V daily Energy In (Qin) versus Energy Out (Qout) data for Site E05. Once again the graph shows the controller tracks to the M&V equipment at Site E05 which is representative of other sites for this analysis.

Figure 45. Site E05: Comparing Aquanta and M&V Data - Daily Energy In over Energy Out



These analyses shows that the controller has the ability to track water heater performance, though the cold water inlet temperature analysis suggests the Aquanta algorithm can be improved.

Occupant Feedback

Due to extended recruitment and installation period, field evaluation participants were surveyed only once, near the end of the field evaluation, instead of twice as originally planned. The survey, with ten questions, was distributed to all 33 field evaluation participants through email in both a printable format and a hyperlink to an online survey site. A copy of the survey can be found in Appendix E. Thirty-one participants provided feedback.

The first three questions were designed to ensure that the original site information had not changed and dealt with the type of water heater, the number of occupants, and the water heater temperature set point.

- All sites confirmed their type of water heater.
- One participant, Site G05, with a gas water heater and two occupants, experienced a temporary increase in occupancy, from two to seven, with the addition of two adults and three children.
- Three participants reported making adjustment the water heater temperature set point:
    - Site G14, has a natural gas water heater and three occupants, reported occasionally increasing and then decreasing the set point to fill a whirlpool bath citing the normal set of 120°F not adequate to fill whirlpool.
    - Site G22, has a natural gas water heater and three occupants, reported decreasing the set point slightly a few weeks after the controller installation.
    - Site G07, has a natural gas water heater and two occupants, reported testing the "Boost" and "Away" functionality, and other smart mode efficiency settings.

The fourth and fifth questions dealt with the field evaluation process to discern what changes can be implemented to improve the process in future field evaluations.

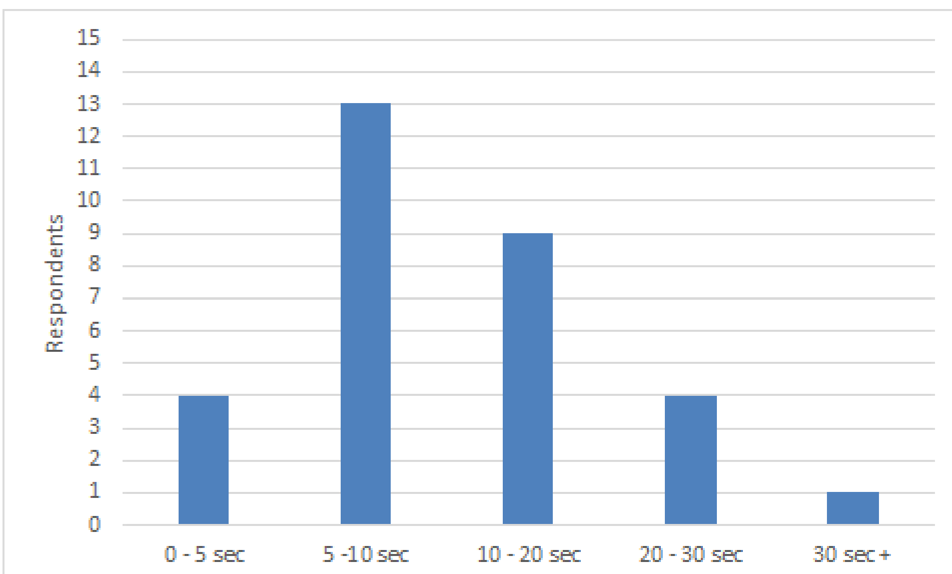
- Participants were asked to rate their level of satisfaction with all aspects of the field evaluation including: the qualification process, the Field Test Agreement, the installation scheduling, the installation, the length of time it took for the installation, the education process by the service technician, and the responsiveness of the Aquanta team to address any issues. Participant's response were overwhelmingly rated either "satisfied" or "very satisfied" with all aspects of the field evaluation.
- Participants were probed to clarify any issues or observation they had on field evaluation processes. Six participants gave a response.
    - Two sites noted the delay from initially qualifying for participation to the actual installation.
    - One site noted the fast response by the field representative in resolving a non-functional gas water heater (see Site G14 in Appendix C: Field Issues).
    - Two sites noted the need for clearer instruction on what is expected from participation.
    - One site found the installation of the M&V equipment "very intrusive" and wanted assurances that site would be restored to its original condition upon decommissioning. This concern was addressed during decommissioning

Questions six through eight probed details of their "Hot Water" experience.

- Participants were asked to rated their level of satisfaction with the amount of available hot water, the consistency of the delivered hot water temperature, the amount of hot water available per shower, and the amount of hot water available for non-shower activities. Participant's response were overwhelmingly rated either "satisfied" or "very satisfied" with all aspects of their "Hot Water" experience.

- When probed of any notice of change in the “Hot Water” experience, six participants gave a response. Five of these six respondents noted variability in the delivered hot water temperature since the installation of the Aquanta:
    - Site G02, has a natural gas water heater and two occupants, reported noticing lower hot water temperatures at non-normal time for brief periods like hand washing or washing a couple of dishes.
    - Site G03, has a natural gas water heater and two occupants, reported hot temperature variability depending on time of day and day of week, and noticed colder temperatures and longer wait times for hot water during “off peak” times.
    - Site G11, has a natural gas water heater and two occupants, reported that one occupant who takes baths at unpredictable times noticed that on occasion there was an inadequate amount of hot water.
    - Site E04, has an electric water heater and four occupants, reported noticing that the temperature seemed to vary at different times and attributed it to the use of the controller.
- Participants were asked to choose a time range of how long it normally takes to get hot water to a fixture or shower? Figure 46 plots the number of response (N=31) by selected ranges of wait times. Fifty-five percent of respondents had wait times from 0 to 10 seconds. Twenty-nine percent identified a wait times between 10 and 20 seconds. Sixteen percent identified wait times over 20 seconds.

Figure 46. Hot Water Wait Time to Point of Use



Question nine probed any final observations or thoughts. Six participants gave response. Three were satisfied with the product to date and did not notice any change in delivered hot water; one was interested in testing the user options, and the final two reiterated the long delay in delivered hot water to the point of use.

Question ten was optional and asked the participants to provide an email for future follow-up correspondence should it be necessary. Twelve respondents did provide emails. One respondent, G09, which has three occupants, required follow-up to clarify a statement "It seems like water is hotter, or hotter water is available faster" but the team did not find any data to support this claim.

Cost Benefit Analysis

Cost benefit analysis calculations are presented in terms of energy cost vs. targeted payback based on annual percent cost savings due to the controller. Due to the wide distribution in savings observed in the field study, four levels of savings were analyzed: 1%, 2.5%, 5% and 10%. The analysis incorporates changes in water heater efficiency as influence by hot water draw rates codified in the federal minimum efficiency standard for consumer water heaters implemented in 2015[20]. The analysis also uses a controller cost of $150, and assumes the unit is self-installed by the homeowner. If installed by a plumber instead, additional costs for labor are expected to range from $45 to $225[21].

In this field study, a single plumber contracted at a set fixed rate of $300 per site completed all controller installs and site safety inspections. Travel expenses were added to sites outside the greater Minneapolis-St Paul area.

In a utility-based efficiency program, the controller is probably best installed by either a licensed plumber or the homeowner. For electric water heaters in particular the research team did not believe a third party technician could perform the installation.

Table 19. 50 Gallon Electric Water Heater Annual Energy Economics by Draw Rates

	Draw Rates		
	Low	Medium	High
Uniform Energy Factor	0.91	0.92	0.93
Hot Water Consumption (Gal/day)	29.4	60.5	98.4
Annual Consumption (kWh/yr)	2191	4459	7180
Annual Cost of Operation ($/yr)[a]	$278	$565	$910

a. 2016 Minnesota Average Residential Electric Price (12.67¢/kWh)

[20] DOE Energy Conservation Standards for Consumer Water Heaters, Federal Register Number: 2016-29994 CFR:10 CFR Parts 429, 430, and 431 (https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8)

[21] Plumber hourly rates range from $45 to $150 per hour based on internet surveys at HomeAdvisor and CostHelper.

Table 19 is a comparison of energy consumption and cost for a 50 gallon electric storage water heater at different daily draw rates. The annual cost of operation (12.67 cents per kWh) is based on the average 2016 residential electric rate for Minnesota based on data from the U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO)[22].

Figure 47 shows the payback economics for a smart controller installed on a 50 gallon electric storage water heater producing an annual savings of 5%. At 12.67 cents/kWh, the controller yields a 10.8 year payback with low daily hot water use, a 5.3 year payback with medium daily hot water use, and a 3.3 year payback with high daily hot water use.

Figure 47. Payback Economics for a 50 Gallon Electric Water Heater with 5% Annual Savings

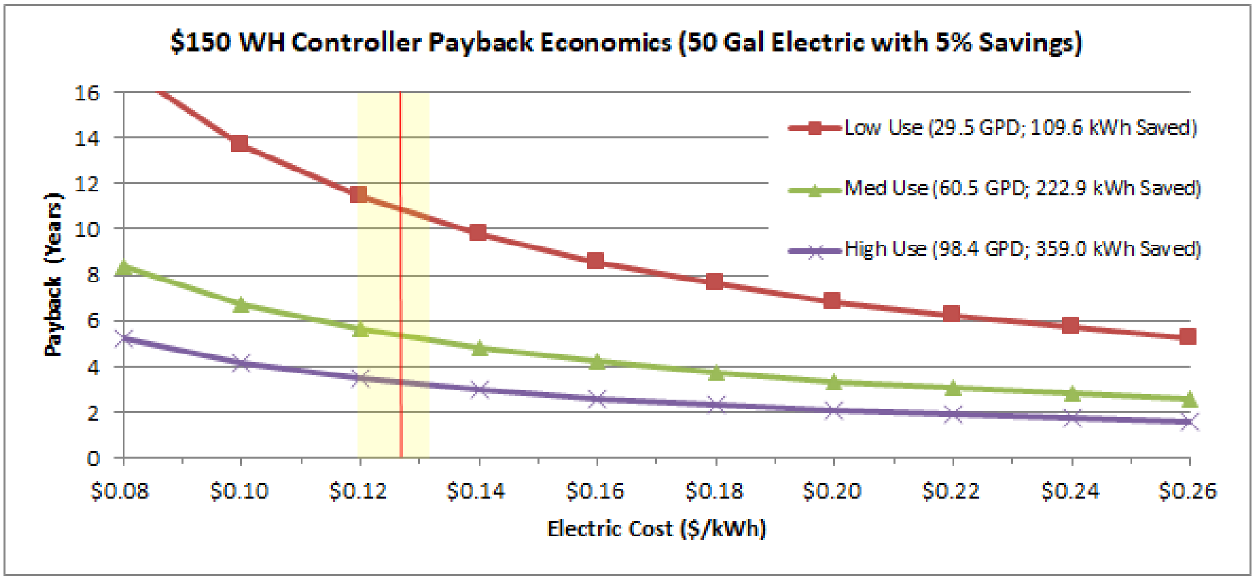


Table 20. 40 Gallon Gas Water Heater Annual Energy Economics by Draw Rates

	Draw Rates		
	Low	Medium	High
Uniform Energy Factor	0.52	0.58	0.64
Hot Water Consumption Gal/day	29.4	60.5	98.4
Annual Consumption (Therms/yr)	130	241	355
Annual Cost of Operation ($/yr)[a]	$104	$192	$283

a. 2016 Minnesota Average Residential Natural Gas Price (77.6¢/Therm)

[22] U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO) average 2016 Minnesota residential electric price, 12.67¢/kWh (https://www.eia.gov/electricity/data/state/).

Similarly, Table 20 compares energy consumption and cost for a 40 gallon gas storage water heater at different daily draw rates. The annual cost of operation (77.6 cents per therm) is based on the average 2016 residential electric rate for Minnesota based on data from the U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO)[23].

Figure 48 shows the payback economics for a smart controller installed on a 50 gallon gas storage water heater producing an annual savings of 5%. At 77.6¢/Therm, the controller yields a 29.7 year payback with low daily hot water use, a 16.0 year payback with medium daily hot water use, and a 10.9 year payback with high daily hot water use.

Figure 48. Payback Economics for a 40 Gallon Gas Water Heater with 5% Annual Savings

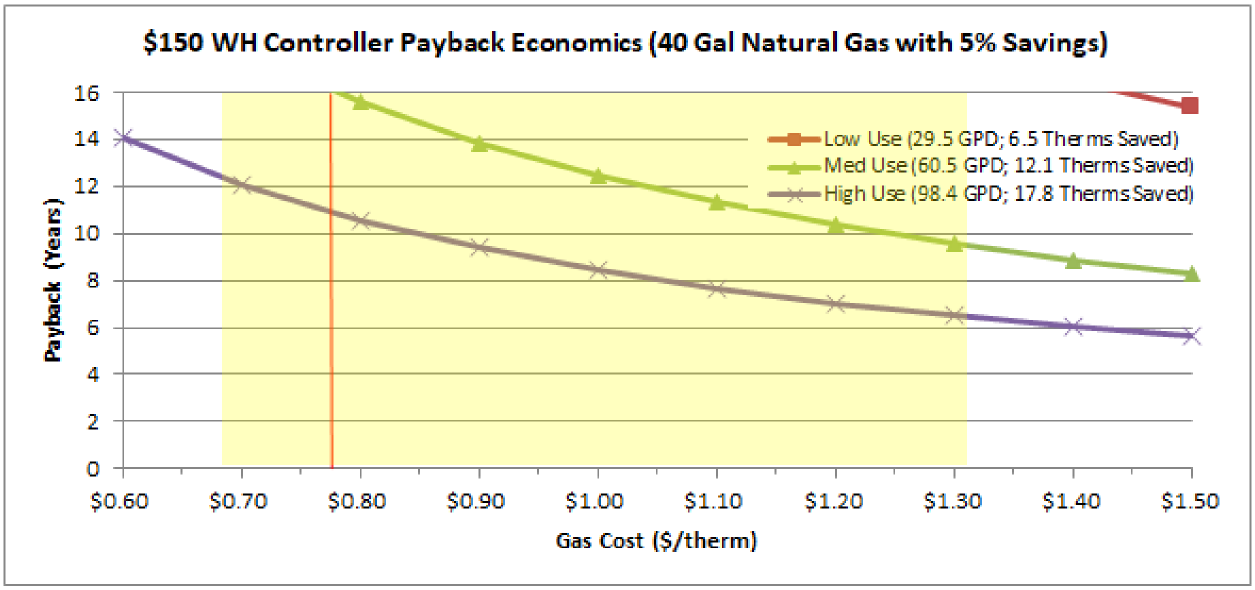


Table 21. Summary of Savings at Low, Medium, and High Draw Patterns

Water Heater Type				Annual Savings [a b]			
Fuel	**Size**	**UEF**	**Draw Pattern**	**1%**	**2.5%**	**5%**	**10%**
Electric	**50**	0.91	Low	$2.78	$6.94	$13.88	$27.76
		0.92	Medium	$5.65	$14.12	$28.25	$56.49
		0.93	High	$9.10	$22.74	$45.48	$90.97
Gas	**40**	0.52	Low	$1.01	$2.53	$5.05	$10.10
		0.58	Medium	$1.87	$4.68	$9.35	$18.71
		0.64	High	$2.76	$6.90	$13.79	$27.59

a. 2016 Minnesota Average Residential Natural Gas Price ($0.1267/kWh)
b. 2016 Minnesota Average Residential Natural Gas Price (77.6¢/Therm)

[23] U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO) average 2016 Minnesota residential gas price, 77.6¢/Therm (https://www.eia.gov/dnav/ng/hist/n3010mn3m.htm).

Table 21 summarizes the annual savings of the controller at low, medium and high draw patterns for typical size electric (50 gallon), and gas (40 gallon) water heaters. The analysis uses 2016 Minnesota average residential electric and gas prices and annual savings rates of 1%, 2.5%, 5% and 10%. In the analysis, the electric savings ranged from $2.78 to $90.97 per year and the gas savings ranged from $1.01 to 27.59.

If the controller total cost is $150 and an acceptable payback is no more than the average 13 year life expectancy[24] of the typical water heater, then the annual savings that must be achieved is $11.54 annually for either electric or gas. In the analysis both electric and gas water heaters have opportunity to achieve payback, with electric water having greater opportunity based on energy pricing.

Graphs on payback economics of all levels of savings analyzed (1%, 2.5%, 5% and 10%) can be found in Appendix F.

[24] U.S. DOE, ENERGY STAR® Market Profile, p 5, September 2010.

Conclusions and Recommendations

Conclusions

The detailed analysis on ten M&V sites showed:

1. The median usage for all M&V sites was 34.5 gallons per day (GPD), and the average is 38.2 GPD. In 2014, Lawrence Berkeley National Laboratory, analyzed data of 159 field study homes where hot water was measured in sites located throughout the U.S and found the National Median at 49.6 GPD with high medium, and low GPD clusters that averaged at 98.5 GPD, 60.5 GPD, and 29.4 GPD respectfully. The M&V sites fall below the National Median and into the Classification of "Low Usage". The national averages may be atypical to Minnesota water usage generally, or the M&V sites that were selected may be low use outliers for some specific reason (e.g. they are practicing water conservation, such as using low flow showerheads). Other analysis by the CEE and the Florida Solar Energy Center report median hot water usage at 40 GPD.
2. In AI Mode, all M&V sites show a reduction in delivered hot water temperature over Base Mode. Electric M&V sites had an average 1.7°F reduction in delivered hot water temperature compared to an average of 6.2°F for Gas M&V Sites. It is worth noting that the temperature set point of Electric M&V sites centered around 120°F. The temperature set point Gas M&V sites centered around 125, with one outlier at 135°F.
3. The gallons per day increased with AI mode active for all M&V sites except for Site G05. The average increase was 1.6 GPD. Site G05, with a natural gas water heater and two occupants using 49.7 GPD showed a decrease of 9%, or 5.2 GPD. Sites with low gallons per day usage show the highest percent increase in gallons per day.
4. In AI Mode, the controller shifts hot water use and burner reheat patterns in a home.
    a. Two sites, one electric (E05) and the other gas (G01) experienced some shift in hot water use where gallons per hour increased during periods of high hot water demand and decreased during periods of low hot water demand. Each site exhibited its own unique traditional periods of high and low use that varied slightly by hour of day or day of week. In our sample sites, these hours of high use were 8 for Site E05, and hours 6 and 7 for Site G01. Hours of low use were 1, 4-7, and 9-18 for Site E05, and hours 8-23 for Site G01.
    b. Data from all ten sites shows that during periods of high hot water demand, gallons per hour use increases and during periods of the low hot water demand gallons per hour use diminish in comparison to baseline operation.
    c. Two sites, one electric (E05) and the other gas (G01), experienced some shift in the period where thermal energy available in the tank is adequate to meet hot water demand. Each site exhibited its own unique traditional periods of little or no hot water demand that varied slightly by hour of day or day of week. In our sample sties, these hours were 1-7 and 15-18 for Site E05, and hours 1-6 and 11-17 for Site G01.

d. Data from all ten sites shows that during or immediately following period of high hot water demand, the number of reheats increased in comparison to baseline operation.

5. In AI Mode, the weekly median efficiency for all M&V site water heaters is higher than in the Base Mode except for Site G05, with two occupants and high gallons per day usage (49.7 GPD).
6. Two methods of analysis used in calculating savings found uneven results:
   a. Using a Combined Seasonal Dataset, where results were statistically significant, Gas M&V Sites produced an average savings of 0.1 percent in AI Mode over Base Mode, and Electric M&V Sites produced an average savings of 1.0 percent. This shows that the controller can increases water heater efficiency. There is wide variability in savings: For Gas M&V Sites, Site G01 showed the largest percent savings per year, 2.5 percent, while the lowest is Site G02 at -4.0 percent. The largest percent savings per year for Electric M&V Sites is Site E04 at 2.8 percent, while the lowest is Site E02 at -1.1 percent.
   b. Using Separate Base and AI Seasonality Datasets, where results were not statistically significant, Gas M&V Sites produced an average savings of 9.3 percent in AI Mode over Base Mode. Electric M&V Sites show negative savings, is -2.3 percent in AI Mode than in Base Mode. While the controller can increase water heater efficiency, there is wide variability in savings: For Gas M&V Sites, Site G05 showed the largest percent savings per year, 35.7 percent, while the lowest M&V gas site is Site G02 at -7.5 percent. The largest percent savings per year for Electric M&V Sites is Site E03 at 6.8 percent, while the lowest is Site E01 at -15.2 percent.
7. The wide variability in savings in both analyses suggest the need for a larger population of sites and an increased length to the monitoring period.
8. Less definitive was the actual impact on energy used to heat hot water. The data shows increased hot water usage at lower supply water temperatures. This trade off makes the impact of energy output (volume * constant *(supply T - inlet T) harder to determine clear trends.
   a. At all M&V sites, as cold water inlet temperature decreases, more energy per gallon of hot water is required to reach a temperature set point.
   b. In AI Mode, at lower cold water inlet temperature, the controller consistently uses less energy per gallon of hot water than Base Mode.
   c. In AI Mode, as cold water inlet temperature rises, 50 percent of the M&V Sites show a slower rate of change in energy use per gallon of hot water than Base Mode, and 50 percent of the sites showed a higher rate of change in energy use per gallon in AI Mode than Base Mode. This implies that at some point a crossover occurs where Base Mode uses less energy use per gallon than AI Mode. This occurred at three sites.
9. In evaluating fidelity of its data output, the field study determined that the controller has the ability to track water heater performance. Slight variances in controller cold water inlet temperature to M&V data suggest the algorithm can be improved for better accuracy. The field study compared available controller algorithms, from conservative to aggressive, used in the AI Mode smart control to M&V data and found no measurable difference in produced savings.

In addition:

10. The field study successfully validated the "ease of installation" of the controller. According to field installers, the average installation took approximately 60 to 90 minutes depending on the time it took to drain the water and install the in-tank enthalpy sensor. The cost of the controller is $150, and assumes the unit is self-installed by the homeowner.

    a. If installed by a plumber, additional costs for labor are expected to range from $45 to $225.
    b. In a utility-based efficiency programs, the controller is probably best installed by either a licensed plumber or the homeowner. For electric water heaters in particular the research team did not believe a third party technician could perform the installation.

11. A field evaluation survey was sent to all thirty-three participants of which thirty-one provided feedback.

    a. While participants rated their "Hot Water" experience as either "satisfied" or "very satisfied" upon probing, five respondents noted variability in the delivered hot water temperature. Lower water temperatures and longer wait periods were noticed during "off-peak" times of use and involved handwashing, small water draws, and baths.
    b. When asked to choose an average wait time range for hot water to reach a fixture or shower, fifty-five percent reported wait times from 0 to 10 seconds. Twenty-nine percent identified a wait times between 10 and 20 seconds. Sixteen percent identified wait times over 20 seconds.

12. The gallons per day increased with AI mode active for all M&V sites except for Site G05. The average increase was 1.6 GPD. Site G05, with a natural gas water heater and two occupants using 49.7 GPD showed a decrease of 9%, or 5.2 GPD. Sites with low gallons per day usage show the highest percent increase in gallons per day.

13. Field issues were reported at five sites during the field evaluation, but only one (a failed enthalpy sensor) was related to the Aquanta controller units installed.

Recommendations

The inconsistent results seen in this field test point to the need for further research on controllers such as the one investigated in this study, including:

1. The variability of usage and small incremental savings require a much larger population and a longer period of data collection.

2. There is a need to investigate the characteristic difference in the sites that showed high savings and those that showed little or negative savings

3. Lab test data on tank heat-up over a series of cold water inlet temperatures would help improve the controller algorithm to reduce the observed variance in controller cold water inlet temperature to M&V data.

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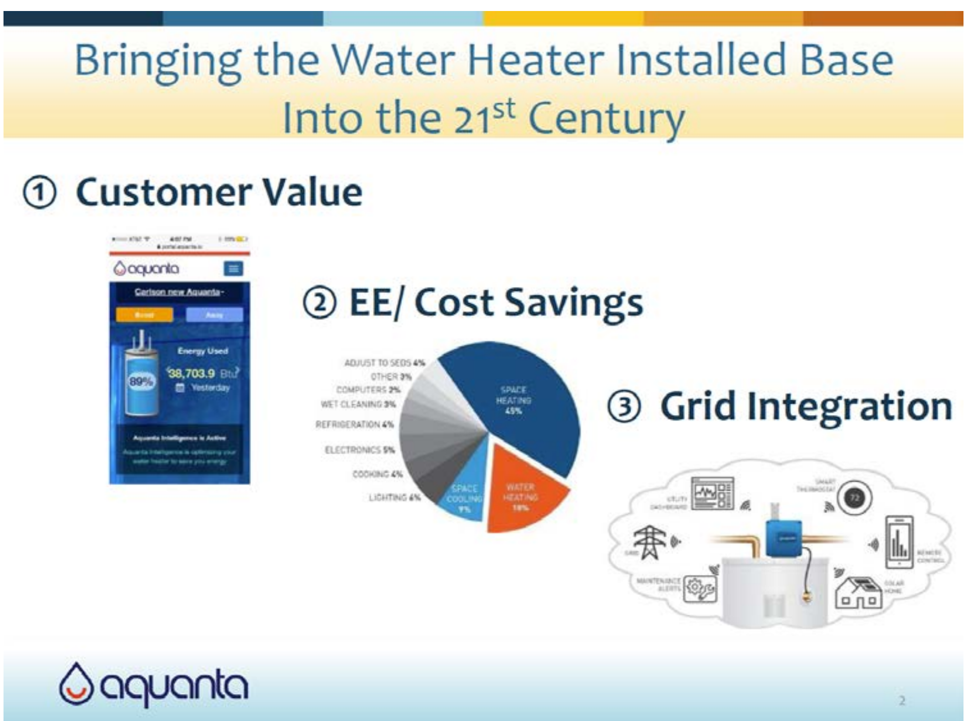
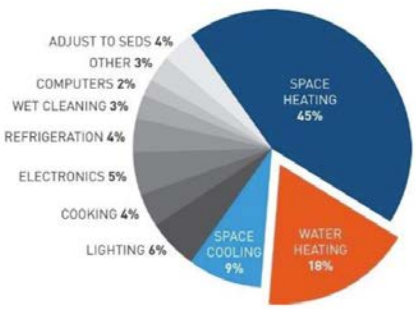
(https://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/WaterHeaterAnalysis_Final.pdf)

Appendix A: Aquanta Product Information



Water Heating Energy: An Untapped Opportunity

A BIGGER SLICE THAN MOST THINK



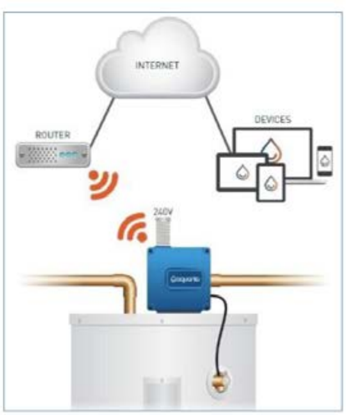
MACRO OPPORTUNITY

- 125mm+ Residential WH Installed Base in NA
- Annual Residential WH Impact
  - $32B energy spending
  - 2.9 Quads energy used
  - 150mm metric tons CO_2
- 20-50% of Energy Input Wasted
- $3.6B/Yr Utility Grid Integration Opportunity

aquanta

3

Aquanta Water Heater Controller



- **Networked,** Smart Home Enabled
  - Cloud-cloud integration w/ other platforms
- Enthalpy Sensor **Analytic Capabilities**
  - "Learning" algorithm
  - Enable and enhance Smart Grid
- Easy, (Near-)Universal **Retrofit**
  - < 60 min install; DIY-friendly
- **Electric and Gas** WH Versions
  - Compatible w/ 65-80% of US WH installed base

aquanta

4


Aquanta Water Heater Controller
aquanta
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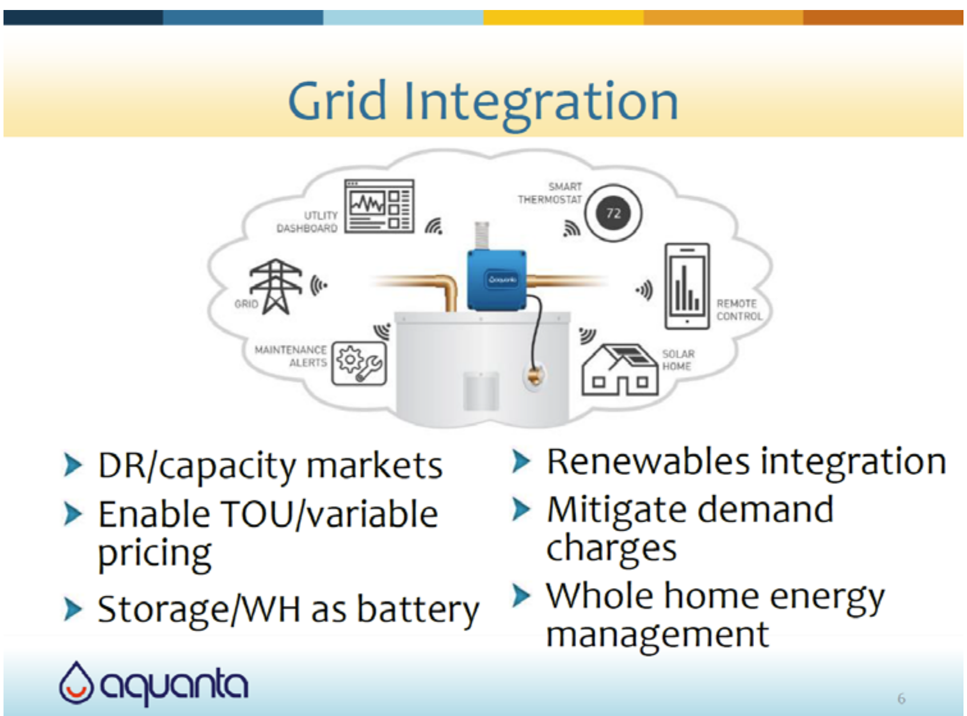
Grid Integration
UTILITY DASHBOARD
SMART THERMOSTAT
72
GRID
REMOTE CONTROL
MAINTENANCE ALERTS
SOLAR HOME
DR/capacity markets
Enable TOU/variable pricing
Storage/WH as battery
Renewables integration
Mitigate demand charges
Whole home energy management
aquanta
6

Enabling Diverse DSM Use Cases

1. **Aquanta Fleet Manager**
   - Load shifting, DR controls through fleet dashboard
   - Fleet O&M – device monitoring, alerts, Tier 1 support enablement
   - M&V – predictive analytics & post-event reporting
2. **Integration w/ Utility & 3rd Party DERMS/DRMS**
   - Full range of grid management use cases
   - Cloud-cloud integration via Aquanta API
   - OpenADR 2.0-enabled
3. **Automated TOU**
   - Aquanta TOU Scheduler feature optimizes water heating to pre-loaded TOU schedules & rates

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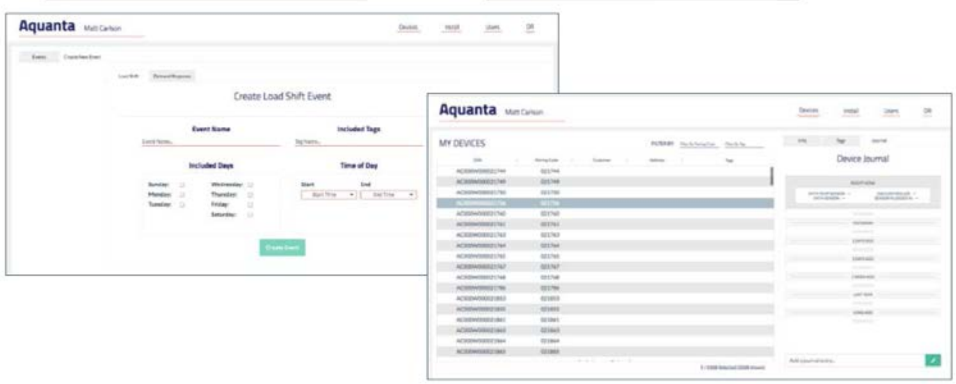
7

1. Aquanta Fleet Management Portal

FLEET DR CONTROLS | **MONITORING & OPERATIONAL SUPPORT**



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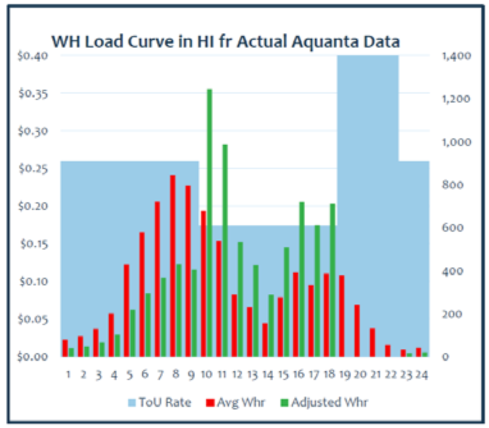
8

2. Utility System & 3rd Party Integration

- Unprecedented Visibility into Predicted and Real-time Load



aquanta

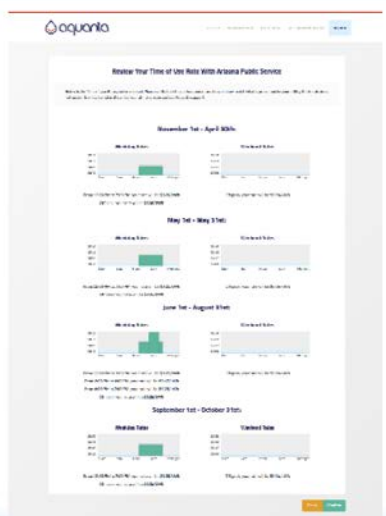
9

3. Automated TOU Scheduler

"The future is dynamic pricing enabled by smart technology that brings variable renewables and DER onto the grid at the right time and the right price."

- Brattle Group

- Aquanta optimizes to maximize off-peak heating & minimize peak heating
- End-user Savings Estimates:
  - APS - $66/yr
  - HECO - $128/yr
  - SCE - $151/yr



aquanta

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Appendix B: Monitoring Data

Data was collected at each fully-monitored site at a one second interval (Table 22). Several calculations were made using the one second interval data Table 22:

- The pulse output from the positive displacement flow meter was converted to a volume (198.4 pulses = 1 gallon) and a flow rate (pulses per one second interval to gallons per minute).
- The energy output (i.e. hot water leaving the water heater) was calculated. Q_{out} = Hot Water Volume *C *(Outlet_Temp – Inlet_Temp). The variable C combines the conversion constants and temperature dependent properties of water.
- The energy consumption (i.e. electric or gas used by the water heater) was calculated. First, the current value, gas pressure switch, or temperature measurement was converted to a burner or element status (i.e. is the burner ON/OFF). Then the one time burner firing rate, or resistance element power draw measurement was used to determine the energy consumed.

Table 22. M&V Monitoring - One Second Data Definitions

Variable Name	Type of Measurement	Unit
TIMESTAMP	Day/Month/Year/Hour:Minutes:Second	-
Inlet_Temp	Instantaneous water temperature	°F
Outlet_Temp	Instantaneous water temperature	°F
flow_pulse	pulse count	pulses
GPM	instantaneous flow rate	GPM
Ambient_Temp	Instantaneous air temperature	°F
Gas_Burner_Temp	Instantaneous air temperature	°F
Gas_Flue_Temp	Instantaneous surface mount temperature	°F
DHW_Amps	Instantaneous Gas Burner or Electric Resistance element	Amps
Burner_Runtime	on/off status	binary
Q_{in}	Energy delivered	btu/sec

M&V data was then processed to daily intervals.

- Several calculations were made to reach the daily level (see Table 23)
- The burner or element status is converted from an on/off to a daily runtime.
- The main temperature, the water temperature inlet to the home, is calculated by taking the minimum temperature measured at the Inlet_Temp immersion RTD. This methodology ensures that the main temperature will not include any warming effects from water stored in the homes plumbing at the conditioned space temperature.
- The water flow meter data is used to calculate the daily hot water runtime.

- NOAA data from the MSP airport weather station is looked up to provide the approximate daily average outdoor dry-bulb temperature at each site.

Table 23. M&V Monitoring - Daily One Second Data Definitions

Variable Name	Type of Measurement	Unit
Date	Day/Month/Year	-
Recs	Number of one-second measurements taken	#
Outlet_T_Avg	Average Outlet_Temp	°F
Inlet_T_Avg	Average Inlet_Temp	°F
Main_T	Minimum Inlet_temp	°F
Burner_RT	Runtime of the gas burner or electric elements	sec/day
DHW_RT	Runtime of hot water use in the home	sec/day
Q_{in}	Total energy consumed by the water heater	btu/day
Q_{out}	Total energy delivered as hot water by the water heater	btu/day
GPD_hot	Total volume of hot water	gallons
OAT	Average outdoor air temperature at MSP airport	°F
Eff	Daily efficiency (Qout/Qin)	-
$Q_{in.w}$	Total energy consumed by the water heater	Whr/day
$Q_{out.w}$	Total energy delivered as hot water by the water heater	Whr/day

The daily data was used for several different analysis, including:

- Comparison to Aquanta data
  - Gathering Aquanta data
    - The Analysis > Energy Explorer screen from the Aquanta fleet dashboard was used to collect the Aquanta data from each site.
    - The export function was used to collect and store data. Both the “Energy Use” and ‘Total Energy” were exported for each site.
    - Timestamps from the export function were assumed to be in the GMT timezone. These were converted to CDT for comparison to the M&V data.
    - Aquanta data was assumed to be the total Watt-hours consumed in a 5 minute interval. Any timestamp missing from the series was assumed to have zero use or delivery of energy.
      - Aquanta data was totaled for each day in the time series.
- Delta_E_Aux/Total Energy from the Aquanta device is compared to Qin from the M&V sites
- Delta_E_Use/Energy Use from the Aquanta device is compared to Qout from the M&V sites
- Water heater performance

- Linear models on Qout and Qin, and the daily Eff measurements define the performance of each water heater. These relationships can be compared to a database of similar data for many types of water heater studied by CEE.

- Annual energy use and controller savings
  - First, the Main_T and Qout data are used to determine the seasonally adjusted annual hot water load for each home.
  - Then, the Qout and Qin data are fit to a linear relationship.
  - Next, the seasonally adjusted annual hot water load and the Qin/Qout relationship are used to determine the annual energy use.
  - Finally, the annual energy use is compared at each home for time periods with and without the Aquanta controller active to determine the annual savings.

Aquanta Smart Controller Data

Data was analyzed from the water heater controller to assess how variables used in the control algorithms contribute to optimizing energy savings. Table 24 list the variables that can be measured or calculated based on the data collected by the water heater Aquanta smart controller.

Table 24. Aquanta Smart Controller Variables

Variable Name	Type of Measurement	Unit
Date-Time Stamp	Realtime 1 second data	Date and Time
Energy Stored	Energy available for use Kwh	kWh
Water Temp In	Water temperature into tank	°C
Water Temp Out	Water temperature out of tank	°C
Energy In	Electric and/or natural gas used to replenish and reheat	kWh
Standby Loss	Jacket and Flue loss	kWh
Energy Out	Energy utilized (hot water)	kWh
Hot Water Used	Calculated from Energy Out	Gallons
Hot Water Avail	Calculated from Energy Stored	Gallons
Energy Saved	Calculated from prevented reheats	kWh
Hot Water Flow	Water draw over time	Gallons/Minute
Standby Rate	Jacket and flue loss over time	kWh/Minute
Energy In Rate	Replenish and reheat over time	kWh/Minute

Modes

Data was collected under two modes of operation, baseline or Base Mode, where the controller was actively monitoring and not controlling the water heater, and artificial intelligence, or AI mode, where the controller was actively monitoring and controlling the water heater runtime.

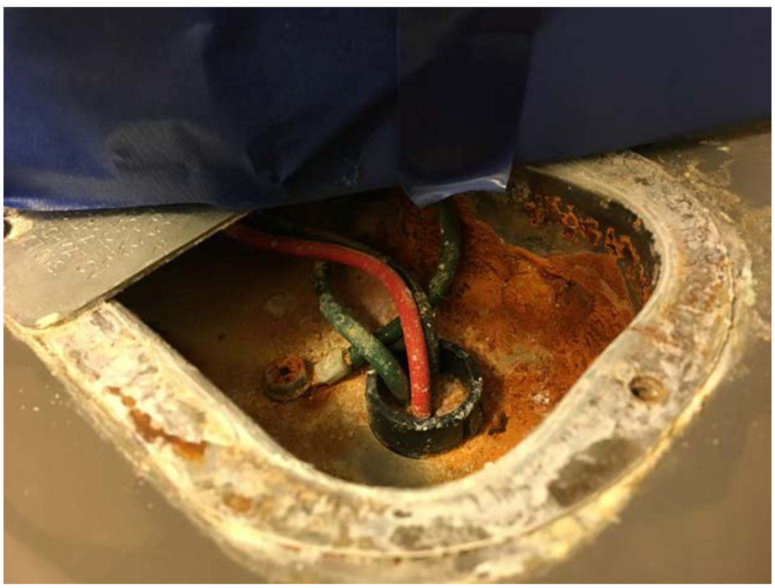
Appendix C: Field Issues

A field evaluation will always have some unexpected event that require a deviation form the plan. The following is a summary of issues that occurred in the field.

Site E01

Site E01, has an electric water heater and two occupants. In August, 2016, at the time of installation, M&V equipment, a flow meter and immersion RTD temp sensors, developed leaks that required the replacement of the metal electrical cover plate on the water heater (Figure 49), and multiple site visits to stop water leakage and clean up the rust.

Figure 49. Site E01 - M&V Sensor Leaks



Site G05

Site E05, has a natural gas water heater and two occupants. In November, 2016, CEE received email notice of a water heater leak from the bottom of the tank.

The plumber contracted for all field installs was called and determined that the leak in the 3 year old water heater was not due to the controller or M&V equipment installed as part of the field evaluation. The water heater was under warranty and covered by the manufacturer. The plumber replaced the water heater, reinstalled the controller and the site was recommissioned. To avoid loss of a field site and the time and expense of recruiting a new site, CEE covered the cost of labor associated with replacing the unit.

Site E05

Site E05, has an electric water heater and four occupants. In March 13, 2017, CEE received email notice of a water heater leak (Figure 50). The site owner was made aware of the leak through the add-on leak sensor that came with the controller. The alarm was only audible when near the water heater. The water heater was 8 years old.

On March 15, 2017, the plumber contracted for all field installs determined the leak to be unrelated to the controller or M&V equipment installed as part of the field evaluation. The plumber replaced the water heater, reinstalled the controller and the site was recommissioned. To avoid loss of a field site and the time and expense of recruiting a new site, CEE covered the cost of labor associated with replacing the unit.

In a normal installation, the homeowner would have received an alert through a smart phone app. In the field evaluation all participants were discouraged from installing this phone app feature in an effort to limit access to controlling the water heater.

Figure 50. Site E05 - Water Heater Leak

Site G14

Site G14, has a natural gas water heater and three occupants. In January 19, 2017, one day after the controller was installed, CEE received email notice of a water heater leak (Figure 51). The site owner was made aware of the leak through the add-on leak sensor that came with the controller. The alarm was only audible when near the water heater. The water heater was 8 years old.

On January 23, 2017, the plumber contracted for all field installs diagnosed a failed gas valve and determined that the failure was unrelated to the controller installed as part of the field evaluation. The plumber replaced the gas valve and the site was recommissioned. To avoid loss of a field site and the time and expense of recruiting a new site, CEE covered the cost associated with replacing the unit.

Figure 51. Site G14 - Failed Gas Valve

Site G02

Site G02, has a natural gas water heater and two occupants. A review of data on August 28, 2017, found an inactive enthalpy sensor with an error code issued August 17, 2017.

On September 3, 2017, the plumber replaced the enthalpy sensor. This is the only known component failure of the 33 controller units installed.

Appendix D: Screening, Commissioning and Site Characteristics

Table 25 lists the location and commissioning date of each field study site.

Table 25. Field Site Installations

Site	Location	Fuel Type	Tank Size (Gallons)	Commission Date	Fully Monitored
G01	St Louis Park	Gas	50	2-Aug-2016	Y
G02	St Paul	Gas	40	3-Aug-2016	Y
G03	White Bear Township	Gas	50	19-Aug-2016	Y
G04	Minneapolis	Gas	50	3-Aug-2016	Y
G05	Osseo	Gas	40	2-Aug-2016	Y
G06	Elgin	Gas	50	12-Dec-2016	N
G07	Albertville	Gas	40	23-Sep-2016	N
G08	Bloomington	Gas	50	19-Sep-2016	N
G09	Mankato	Gas	50	12-Dec-2016	N
G10	St Louis Park	Gas	40	19-Sep-2016	N
G11	Minneapolis	Gas	40	20-Dec-2016	N
G12	Wayzata	Gas	50	27-Dec-2016	N
G13	Long Prairie	Gas	40	31-Dec-2016	N
G14	Eagan	Gas	50	18-Jan-2017	N
G15	Oakdale	Gas	40	6-Feb-2017	N
G16	Duluth	Gas	40	27-Jan-2017	N
G17	Duluth	Gas	40	27-Jan-2017	N
G18	Duluth	Gas	40	27-Jan-2017	N
G19	Duluth	Gas	50	27-Jan-2017	N
G20	Blaine	Gas	50	16-Jan-2017	N
G21	St Paul	Gas	40	21-Dec-2016	N
G22	Coon Rapids	Gas	40	30-Dec-2016	N
E01	Maple Grove	Electric	50	9-Aug-2016	Y
E02	Minnetonka	Electric	50	3-Aug-2016	Y

Site	Location	Fuel Type	Tank Size (Gallons)	Commission Date	Fully Monitored
E03	Sauk Centre	Electric	50	28-Sep-2016	Y
E04	Cambridge	Electric	50	29-Sep-2016	Y
E05	Sartell	Electric	50	28-Sep-2016	Y
E06	Lake Shore	Electric	50	13-Jan-2017	N
E07	Duluth	Electric	40	27-Jan-2017	N
E08	Duluth	Electric	50	27-Jan-2017	N
E09	Duluth	Electric	50	27-Jan-2017	N
E10	Duluth	Electric	50	27-Jan-2017	N
E11	Duluth	Electric	80	27-Jan-2017	N

Table 26 provides detailed characteristics of individual field study site.

Table 26. Field Site Characteristics

Site	Tank Size (Gal)	Occupants	Bathrooms	Faucets	Showers	Dishwasher	Clothes washer	Showers Per Week	Baths Per Week	Dishwash Cycles Per Week	Clothes Wash Cycles Per Week
G01	50	4	2	6	2	Y	Y	14	4	4	5
G02	40	2	2	3	1	Y	Y	11	0	3	4
G03	50	2	2	6	2	Y	Y	14	0	1	5
G04	50	4	4	8	3	Y	Y	18	0	3	20
G05	40	2	2	4	2	Y	Y	14	0	0	4
G06	50	5	3.5	5	3	Y	Y	17	4	28	6
G07	40	2	2	7	2	Y	Y	14	0	5	5
G08	50	3	3	5	2	Y	Y	18	10	5	9
G09	50	3	3.5	7	4	Y	Y	15	1	4	2
G10	40	2	2	5	2	N	Y	6	0	0	2
G11	40	2	1.5	4	1	Y	Y	12	0	5	5
G12	50	2	3	5	3	Y	Y	10	0	1	4
G13	40	2	1.5	5	2	Y	Y	14	1	3	4
G14	50	3	4	10	3	Y	Y	10	0	5	5

Site	Tank Size (Gal)	Occupants	Bathrooms	Faucets	Showers	Dishwasher	Clothes washer	Showers Per Week	Baths Per Week	Dishwash Cycles Per Week	Clothes Wash Cycles Per Week
G15	40	4	3	5	3	Y	Y	25	0	7	15
G16	40	4	2	5	2	Y	Y	21	7	6	6
G17	40	4	1	3	1	Y	Y	20	2	10	10
G18	40	1	1.5	4	1	Y	Y	7	1	2	2
G19	50	4	2	4	2	Y	Y	10	5	5	5
G20	50	4	4	10	3	Y	Y	14	1	5	9
G21	40	2	3	3	2	Y	Y	19	2	3	5
G22	40	3	1.5	4	1	Y	Y	8	2	4	4
E01	50	2	1.5	4	1	Y	Y	14	0	4	4
E02	50	1	3	5	3	Y	Y	7	0	1	2
E03	50	5	3	5	2	Y	Y	10	3	7	21
E04	50	8	2	3	2	Y	Y	6	8	1	5
E05	50	4	1	2	1	Y	Y	9	4	2	4
E06	50	2	2	4	2	Y	Y	8	0	1	1
E07	40	2	1	4	1	N	Y	10	0	0	4
E08	50	2	2	6	2	Y	Y	14	0	2	6
E09	50	4	2.5			Y	Y	20	0	2	7
E10	50	1	2	4	2	N	Y	7	0	0	2
E11	80	5	5	8	4	Y	Y	18	5	7	5

Appendix E: Field Site Survey

MN CARD Aquanta Host Site Evaluation Survey

Aquanta Host Site Field Evaluation Survey #1

Thank you for your participation in this field evaluation of the Aquanta Smart Water heater Controller. Please fill out this survey to help GTI better understand this new technology.

1. Is your water heater Electric or Gas?

☐ Electric ☐ Gas

2. Has there been any change in the number of residents since the unit has been installed?

☐ Yes ☐ No

If Yes, please specify:

3. Did you ever adjust the thermostat of the your water heater or that of the Aquanta Smart Water Heater Controller since the unit was installed?

☐ Yes ☐ No

If Yes, please briefly explain changes:

1

4. How satisfied are you with various aspects of the Aquanta Field Evaluation to date?

	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
The qualification process?	◯	◯	◯	◯	◯
Executing the Field Test Agreement?	◯	◯	◯	◯	◯
Scheduling the installation?	◯	◯	◯	◯	◯
The installation?	◯	◯	◯	◯	◯
The length of the installation?	◯	◯	◯	◯	◯
The explanation of the Aquanta and/or the monitoring equipment?	◯	◯	◯	◯	◯
The responsiveness of the Aquanta team to any issues?	◯	◯	◯	◯	◯
Over satisfaction to date?	◯	◯	◯	◯	◯

5. Are there any particular field evaluation issues you would specifically like to tell us about?

☐ Yes ☐ No

If Yes, please briefly explain changes:

6. How satisfied are you with your "hot water" experience?

	Very satisfied	Satisfied	Neither satisfied nor dissatisfied	Dissatisfied	Very dissatisfied
The overall amount of hot water available?	◯	◯	◯	◯	◯
The consistency of hot water temperature?	◯	◯	◯	◯	◯
The amount of hot water available per shower?	◯	◯	◯	◯	◯
The amount of hot water available per non-shower activity?	◯	◯	◯	◯	◯

2

7. Since the installation of the Aquanta controller, have you noticed any change in your "hot water" experience?

☐ Yes ☐ No

If Yes, please explain:

8. How long does it take to get hot water to a fixture or shower?

- ◯ 0 - 5 sec
- ◯ 5 -10 sec
- ◯ 10 - 20 sec
- ◯ 20 - 30 sec
- ◯ 30 sec +

9. Do you have any other comments, questions, or concerns?

10. OPTIONAL: At what email address would you like to be contacted?

3

Appendix F: Benefit Cost Models

Cost benefit analysis calculations are presented in terms of payback to energy cost based on an annual percent energy savings due to the controller. Due to the wide distribution in savings observed in the field study, four levels of savings are analyzed: 1%, 2.5%, 5% and 10%. The analysis incorporates changes in water heater efficiency as influenced by hot water draw rates codified in the federal minimum efficiency standard for consumer water heaters implemented in 2015[25].

50 Gallon Electric Storage Water Heater Analysis

Table 27 compares the annual energy consumption and cost of operation for a 50 gallon electric storage water heater at different daily draw rates. For a low draw rate of 29.4 GPD, the Uniform Energy Factor is 0.91, the annual electric use is 2191 kWh/Yr, and the Cost of Operation is $278/Yr. For a Medium draw rate of 60.5 gallons per day, the Uniform Energy Factor is 0.92, the annual electric use is 4459 kWh/Yr, and the Cost of Operation is $565/Yr. For a High draw rate of 98.4 gallons per day, the Uniform Energy Factor is 0.93, the annual electric use is 7180 kWh/Yr, and the Cost of Operation is $910/Yr. The annual cost of operation is based on the average 2016 residential electric rate for Minnesota of 12.67 cents/kWh, from the U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO).

Table 27. 50 Gallon Electric Water Heater Annual Energy Economics by Draw Rate

Metric	Draw Rates		
	Low	Medium	High
Hot Water Consumption (Gal/day)	29.4	60.5	98.4
Uniform Energy Factor	0.91	0.92	0.93
Annual Consumption (kWh/yr)	2191	4459	7180
Annual Cost of Operation ($/yr)[a]	278	565	910

a. 2016 Minnesota Average Residential Electric Price (12.67¢/kWh)

Figure 52 graphs the payback of different hot water draw rates based on an annual savings of 1% for a $150 smart controller installed on a 50 gallon electric storage water heater. At 12.67 cents/kWh, the 2016 Minnesota Average Residential Electric Price marked by a vertical red line, the controller yields a 54.0 year payback with low daily hot water use, a 26.6 year payback with medium daily hot water use, and a 16.5 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of electricity are highlighted by the vertical yellow span.

[25] DOE Energy Conservation Standards for Consumer Water Heaters, Federal Register Number:2016-29994 CFR:10 CFR Parts 429, 430, and 431 (https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8)

Figure 52. Smart Controller Payback Based on a 1% Annual Savings; 50 Gallon Electric Water Heater

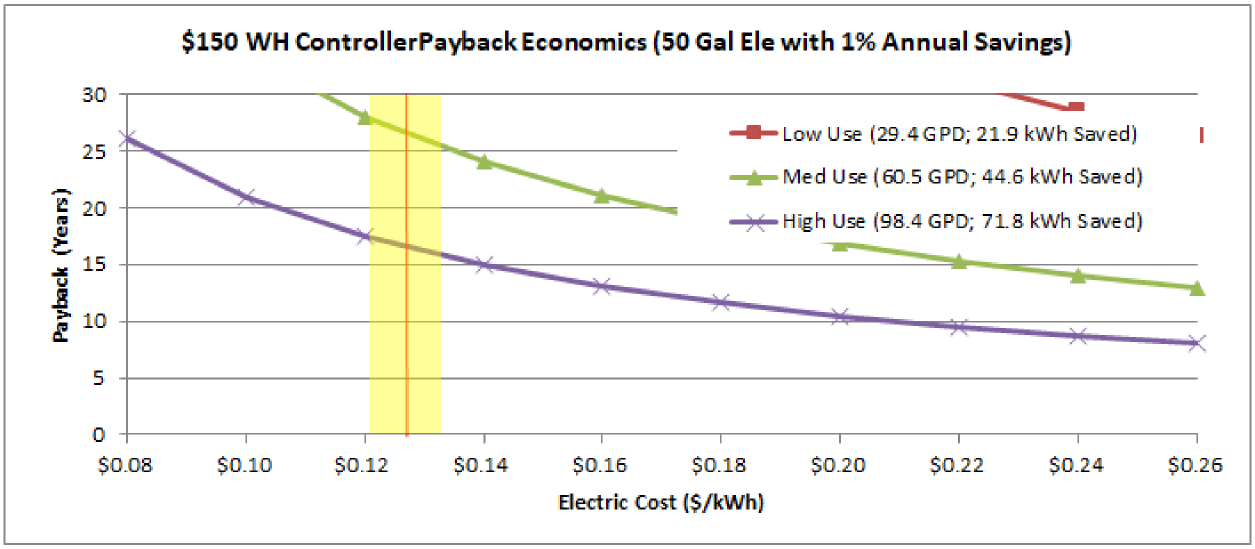


Figure 53 graphs the payback of different hot water draw rates based on an annual savings of 2.5% for a $150 smart controller installed on a 50 gallon electric storage water heater. At 12.67 cents/kWh, the 2016 Minnesota Average Residential Electric Price marked by a vertical red line, the controller yields a 21.6 year payback with low daily hot water use, a 10.6 year payback with medium daily hot water use, and a 6.6 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of electricity are highlighted by the vertical yellow span.

Figure 53. Smart Controller Payback Based on a 2.5% Annual Savings; 50 Gallon Electric Water Heater

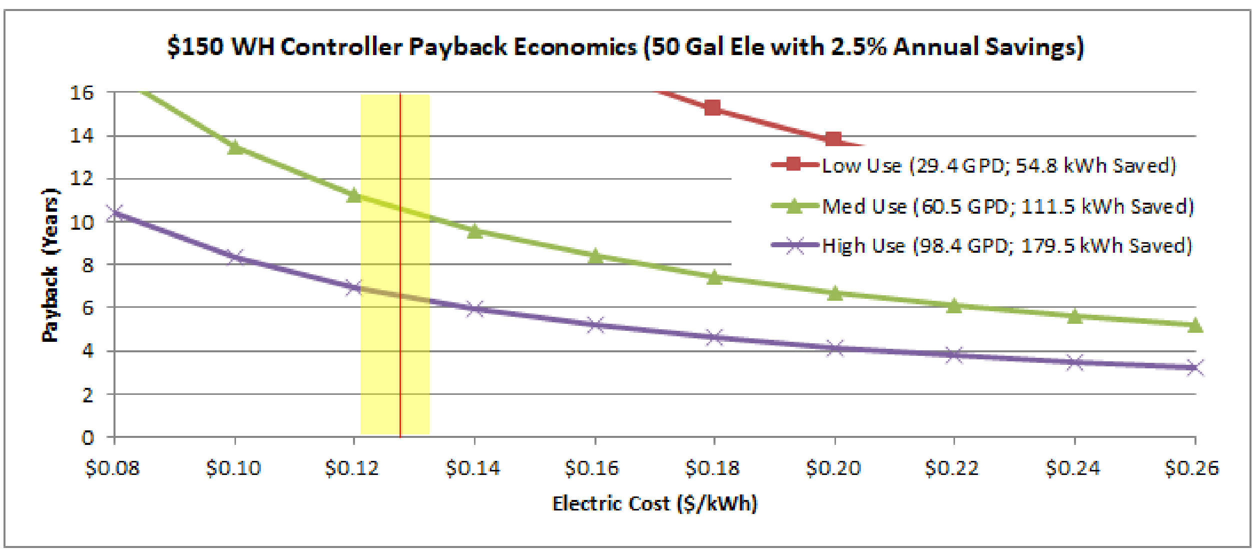


Figure 54 graphs the payback of different hot water draw rates based on an annual savings of 5% for a $150 smart controller installed on a 50 gallon electric storage water heater. At 12.67 cents/kWh, the 2016 Minnesota Average Residential Electric Price marked by a vertical red line, the controller yields a 10.8 year payback with low daily hot water use, a 5.3 year payback with medium daily hot water use, and a 3.3 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of electricity are highlighted by the vertical yellow span.

Figure 54. Smart Controller Payback Based on a 5% Annual Savings; 50 Gallon Electric Water Heater

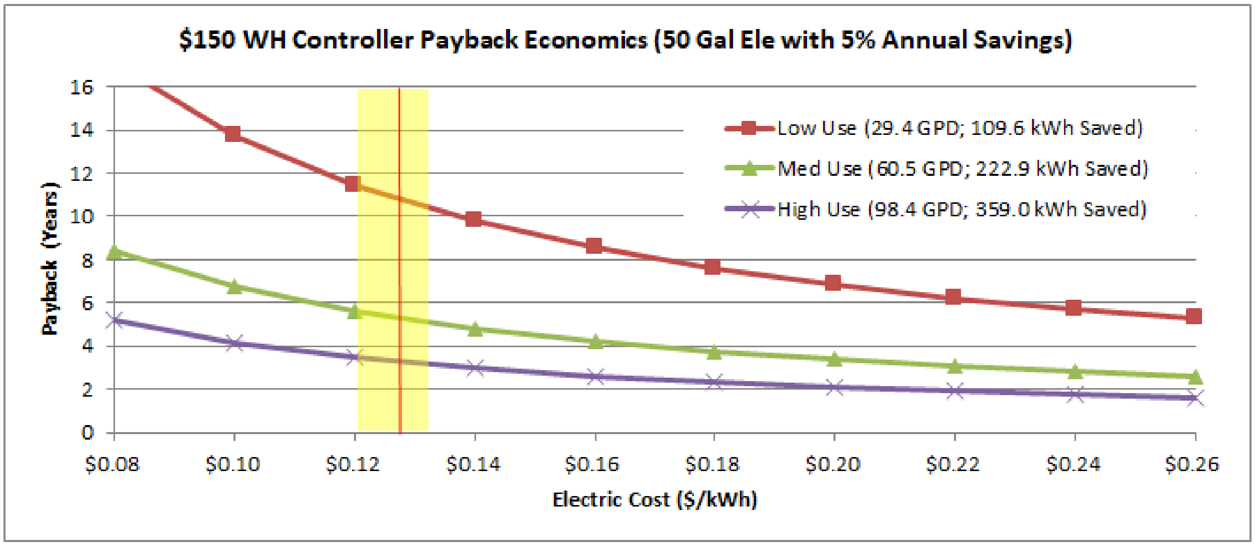
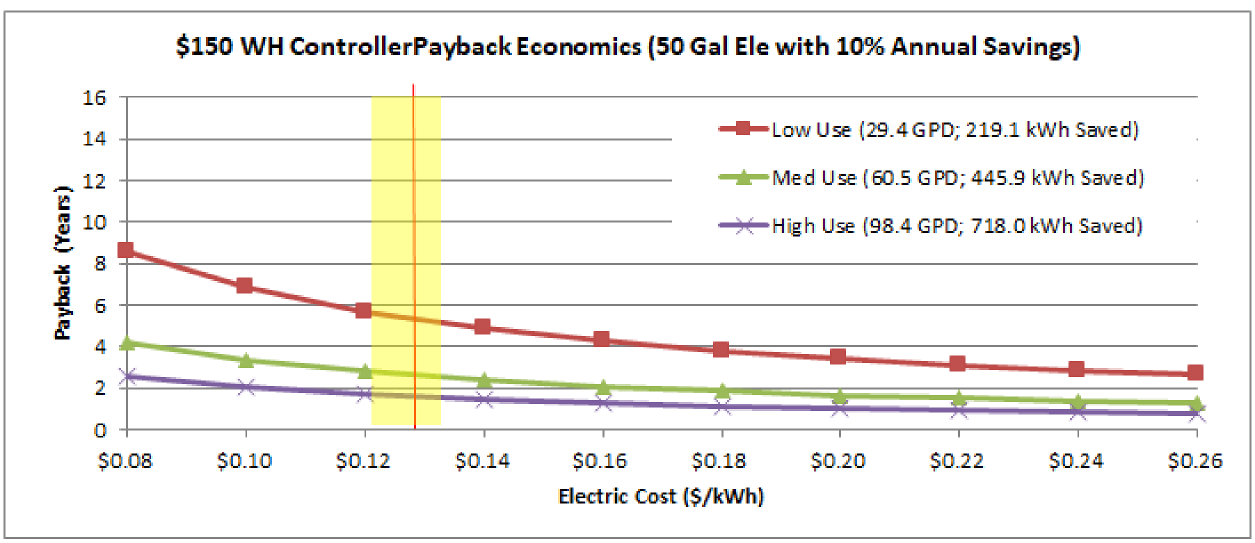


Figure 55 graphs the payback of different hot water draw rates based on an annual savings of 10% for a $150 smart controller installed on a 50 gallon electric storage water heater. At 12.67 cents/kWh, the 2016 Minnesota Average Residential Electric Price marked by a vertical red line, the controller yields a 5.4 year payback with low daily hot water use, a 2.7 year payback with medium daily hot water use, and a 1.6 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of electricity are highlighted by the vertical yellow span.

Figure 55. Smart Controller Payback Based on a 10% Annual Savings; 50 Gallon Electric Water Heater



40 Gallon Gas Water Heater Analysis

Similarly, Table 28 compares the annual energy consumption and cost of operation for a 40 gallon gas storage water heater at different daily draw rates. For a low draw rate of 29.4 GPD, the UEF is 0.52, the annual gas use is 130 Therms/Yr, and the cost of operation is $104/Yr. For a Medium draw rate of 60.5 gallons per day, the UEF is 0.58, the annual gas use is 241 Therms/Yr, and the cost of operation is $192/Yr. For a High draw rate of 98.4 gallons per day, the UEF is 0.64, the annual gas use is 355 Therms/Yr, and the cost of operation is $283/Yr. The annual cost of operation is based on the average 2016 Minnesota residential gas rate of 77.6 cents/Therm, from the U.S. Energy Information Administration's (EIA) 2016 Annual Energy Outlook (AEO).

Table 28. 40 Gallon Gas Water Heater Annual Energy Economics by Draw Rate

Metric	Draw Rates		
	Low	Medium	High
Hot Water Consumption Gal/day	29.4	60.5	98.4
Uniform Energy Factor	0.52	0.58	0.64
Annual Consumption (Therms/yr)	130	241	355
Annual Cost of Operation ($/yr)*	104	192	283

a. 2016 Minnesota Average Residential Natural Gas Price (77.6¢/Therm)

Figure 56 graphs the payback of different hot water draw rates based on an annual savings of 1% for a $150 smart controller installed on a 40 gallon gas storage water heater. At 77.6 cents/kWh, the 2016 Minnesota Average Residential Gas Price marked by a vertical red line, the controller yields a 148.5 year payback with low daily hot water use, an 80.2 year payback with medium daily hot water use, and a 54.4 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of gas are highlighted by the vertical yellow span.

Figure 56. Smart Controller Payback Based on a 1% Annual Savings; 40 Gallon Gas Water Heater

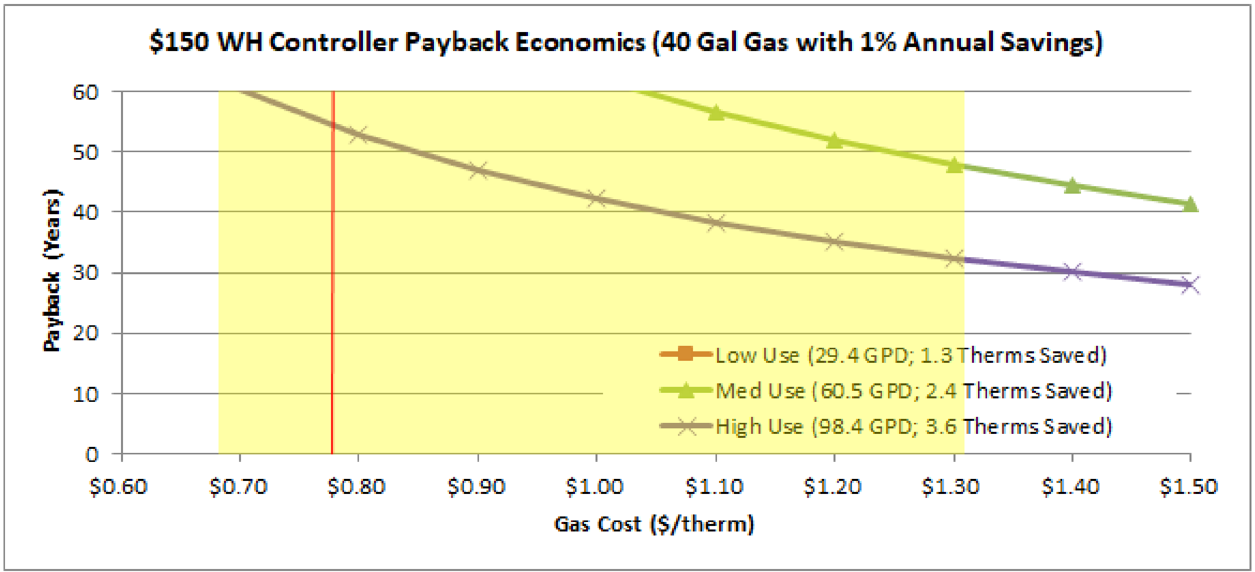


Figure 57 graphs the payback of different hot water draw rates based on an annual savings of 2.5% for a $150 smart controller installed on a 40 gallon gas storage water heater. At 77.6 cents/kWh, the 2016 Minnesota Average Residential Gas Price marked by a vertical red line, the controller yields a 59.4 year payback with low daily hot water use, a 32.1 year payback with medium daily hot water use, and a 21.8 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of gas are highlighted by the vertical yellow span.

Figure 57. Smart Controller Payback Based on a 2.5% Annual Savings; 40 Gallon Gas Water Heater

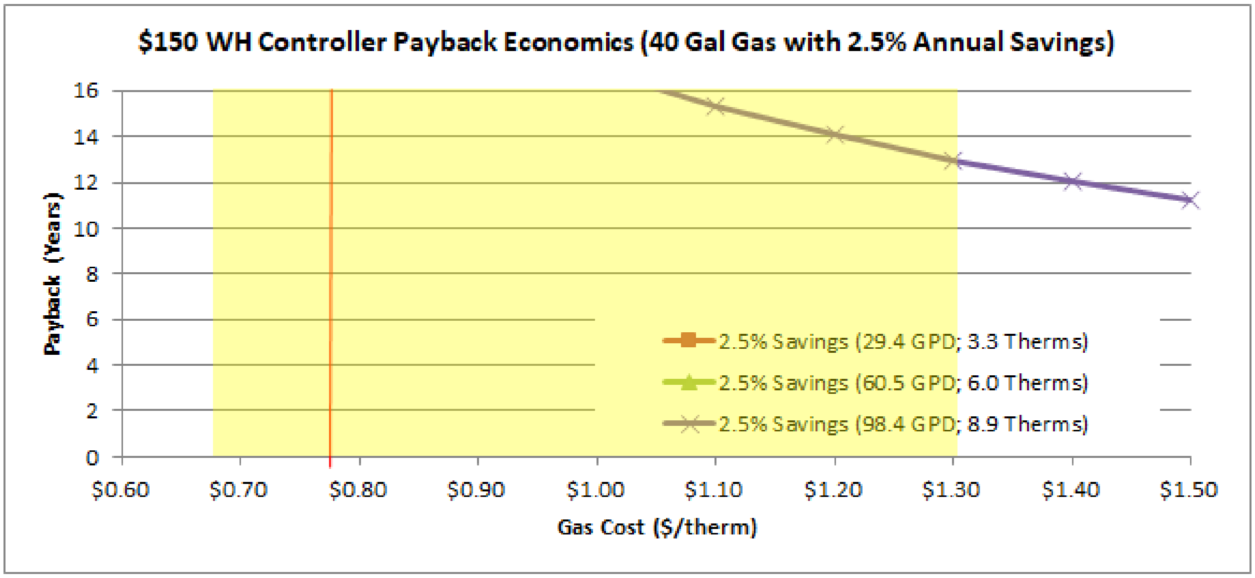


Figure 58 graphs the payback of different hot water draw rates based on an annual savings of 5% for a $150 smart controller installed on a 40 gallon gas storage water heater. At 77.6 cents/kWh, the 2016 Minnesota Average Residential Gas Price marked by a vertical red line, the controller yields a 29.7 year payback with low daily hot water use, a 16.0 year payback with medium daily hot water use, and a 10.9 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of gas are highlighted by the vertical yellow span.

Figure 58. Smart Controller Payback Based on a 5% Annual Savings; 40 Gallon Gas Water Heater

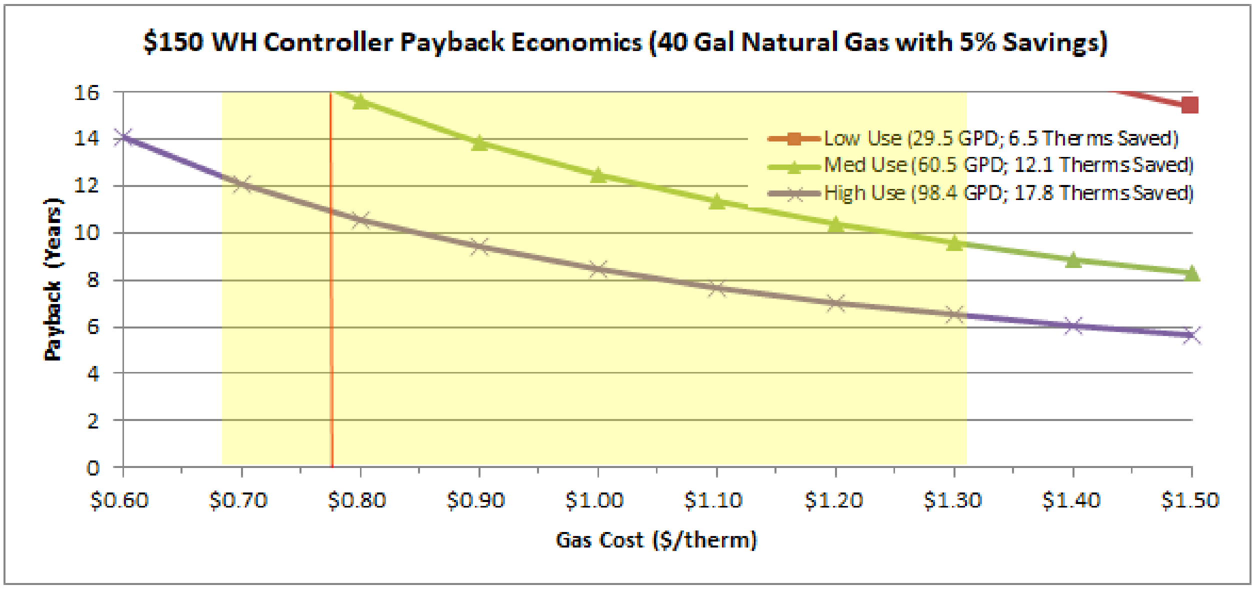
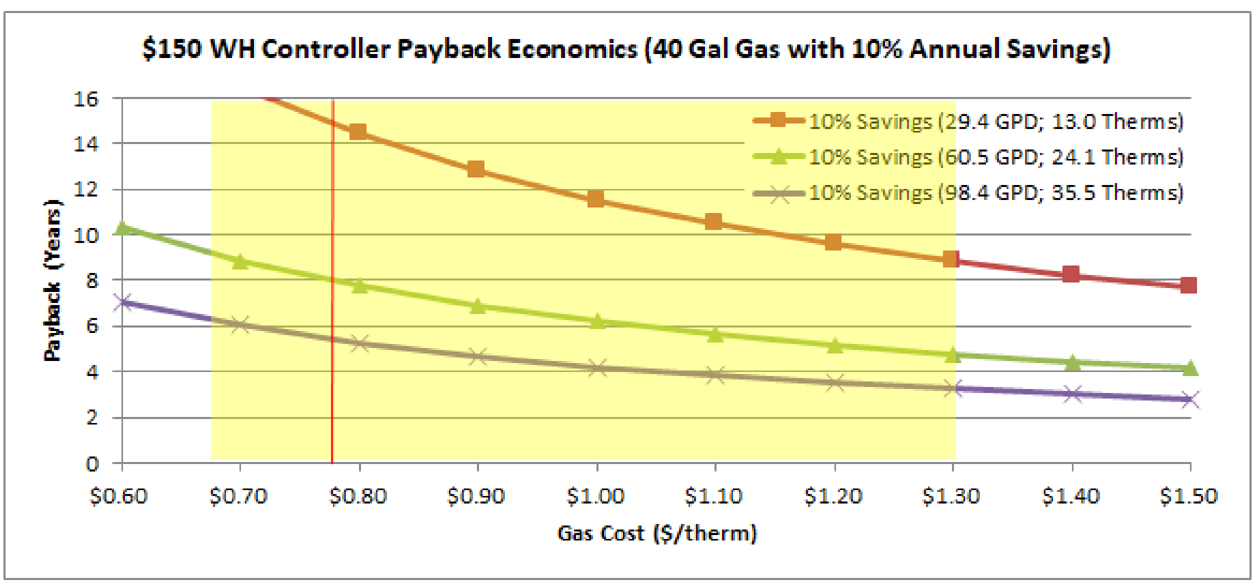


Figure 59 graphs the payback of different hot water draw rates based on an annual savings of 10% for a $150 smart controller installed on a 40 gallon gas storage water heater. At 77.6 cents/kWh, the 2016 Minnesota Average Residential Gas Price marked by a vertical red line, the controller yields a 14.8 year payback with low daily hot water use, an 8.0 year payback with medium daily hot water use, and a 5.4 year payback with high daily hot water use. Fluctuations in the 2016 monthly price of gas are highlighted by the vertical yellow span.

Figure 59. Smart Controller Payback Based on a 10% Annual Savings; 40 Gallon Gas Water Heater



Appendix G: TRM Drafts

Minnesota Technical Reference Manual Ver. X.X DRAFT

Residential Hot Water – Electric Water Heater Smart Controller

Version No.

X.X

Measure Overview

Description:

This measure involves installing a smart water heater controller with adaptive learning on residential storage-type electric water heaters to reduce reheats. The action can be performed by a utility representative on site during a home visit or by the homeowner.

The existing temperature set point is assumed to be 120°F unless specified.

Actions: Operations and Maintenance
Target Market Segments: Residential
Target End Uses: DHW

Applicable to: Residential customers in single-family homes and multi-family homes consisting of 2 units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size eletric water heaters

Algorithms

Unit kWh Use per Year = SpecificHeat x Density x Gal/day x 365.25 x (Tset - Tin)/ UEF/ ConversionFactor

Unit kWh Savings = Unit kWh Use per Year x Savings_Factor (Ref. 6)

Unit Therm Savings = 0

Unit Gallons Fuel Oil Savings per Year = 0

Unit Gallons Propane Savings per Year = 0

Measure Lifetime (years) = 13 See Table 3 (Ref. 3)

Unit Participant Incremental Cost = $0

Where:

SpecificHeat = 1.0 btu / (lb x °F)

Density = 8.34 lbs / gal

Gal/day = See US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Tset = 120°F Default factory setting (Table 2) unless measured (Ref. 4)

Tin = See average groundwater temperature by location per Standard Building America DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (all climates) (Ref. 2)

UEF = 0.9254 − (0.0003 x Vr) DOE Energy Conservation Standards for Consumer Water Heaters (Ref. 2)

ConversionFactor = 3,412 Btu/kWh (electric storage water heater)

SavingsFactor = 2% (Ref. 6)

Required from Customer/Contractor: Confirmation of storage water heater size in gal, project location (city/county), number of bedrooms,

Example:

From the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules select approximate Minnesota location, number of bedrooms, and water heater setpoint temperature [default is 120°F] to determine: hot water use in gallons per day and Tin.

Duluth; 4 bedrooms; 130°F set point: Tin = 45.2°F; 64.3 hot water gallons per day

Storage Water Heater size and fuel type: 50 gallon electric; UEF: 0.91

Unit kWh Use per Year = (1.0 Btu/lb°F) x (8.34 lb/gal) x (64.3 gal/day) x (365.25 day/yr) x (120°F - 45.2°F) x 4% / (0.91) / (3,412 Btu/kWh) = 5,349.5 kWh/Yr

Unit kWh savings = (5,632.4 kWh/Yr) * 0.02 savings = 107 kWh/Yr

Savings over water heater life = (107 kWh/Yr) * 13 Yr = 1,390.9 kWh

Deemed Input Tables:

Table 1: S Storage Water Heater Default Set Point Temperature (Ref. 4 & 5)

Fuel Type	Range	Set Point
Electric	90° F to 150°F	120°F
Natural Gas	80° F to 160°F	130°F

Table 2: Electric Storage Water Heater Efficiency (Ref. 1)

Fuel Type	Rated Storage Volume	Draw Pattern	Uniform Energy Factor
Electric	≥20 gal and ≤55 gal	Very Small	0.8808 − (0.0008 × Vr)
		Low	0.9254 − (0.0003 × Vr)
		Medium	0.9307 − (0.0002 × Vr)
		High	0.9349 − (0.0001 × Vr)
	>55 gal and ≤120 gal	Very Small	1.9236 − (0.0011 × Vr)
		Low	2.0440 − (0.0011 × Vr)
		Medium	2.1171 − (0.0011 × Vr)
		High	2.2418 − (0.0011 × Vr)

Table 3: Rated UEF of Most Typical Electric Storage Water Heater Sizes (Ref. 1)

Draw Pattern	Rated Storage Volume		
	30	40	50
Very Small	0.86	0.85	0.84
Low	0.92	0.91	0.91
Medium	0.92	0.92	0.92
High	0.93	0.93	0.93

Table 4: Storage Water Heater Life (Ref. 3)

Fuel Type	Range	Average
Electric	6 to 20	13
Natural Gas	6 to 20	13

Table 5: SavingsFactor Table (Ref. 6)

Setpoint	Savings
120°F	0%
125°F	1%
130°F	2%
140°F	4%
150°F	13%
160°F	20%

Methodology and Assumptions:

Water heater efficiencies are based on Uniform Energy Factor (UEF) of Consumer Water Heaters with low draw patterns of hot water use (Ref. 1).

Average water main temperatures, T_{in}, are calculated from 1 of 54 Minnesota locations found in the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Gallons per day use hot water use are calculated based on the number of bedrooms from 1 of 54 Minnesota locations found in the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Water heater temperature set point, T_{set}, are based on the default factory settings or as reported in field measurements by running hot water over a thermometer at the hot water outlet nearest the tank for 2 minutes (Ref. 4).

SavingsFactor is based on a DOE analysis partially validated with the MN CARD field data on water heater tank temperature set point, T_{set}, as listed in Table 5 (Ref. 6).

References:

1. DOE Energy Conservation Standards for Consumer Water Heaters, Federal Register Number:2016-29994 CFR:10 CFR Parts 429, 430, and 431 (https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8)
2. Standard Building America DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (all climates) (https://energy.gov/sites/prod/files/2014/05/f16/standard_dhw_events_0.zip)
3. Energy Efficiency Standards for Pool Heaters, Direct Heating Equipment and Water Heaters (EE-2006-STD-0129), 2009-11-23 Technical Support Documents: Chapter 8 Life-Cycle Cost and Payback Period Analysis, 8.7.1 Product Lifetimes Water Heaters, page 8-48 - 8-49, Table 8.7.1 Water Heaters: Product Lifetime Estimates and Sources (https://www.regulations.gov/document?D=EERE-2006-STD-0129-0170)
4. Technical Bulletin 31 by A.O. Smith states the temperature range on residential electric water heater that typically stores between 20 and 80 gallons of hot water is from 90° F to 150°F, with the usual factory setting of 120°F (https://www.hotwater.com/lit/bulletin/bulletin31.pdf)
5. Technical Bulletin 35 by A.O. Smith states the temperature range on residential gas water heater is from 80° F ±10° to 160°F ±10°, with recommended setting between 120°F and 140°F. Water heaters are shipped with a factory setting of 120°F (https://www.hotwater.com/lit/bulletin/bulletin35.pdf)
6. DOE Analysis predicts a 4%-22% based on a tank set point temperature of 120°F, reduced from 140°F through 160°F. The SavingsFactors (Table 3) are based on the DOE analysis partially validated with the MN CARD field data. The Minnesota CARD study “Intelligent, Networked, Retrofittable Water Heater Controller” determined a 1% savings based on a limited dataset of 10 homes. The study found the average tank set point temperature was reduced in smart mode by 5°F from 130°F to 125°F (https://energy.gov/energysaver/projects/savings-project-lower-water-heating-temperature)

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Residential Hot Water – Gas Water Heater Smart Controller

Version No.

X.X

Measure Overview

Description:

This measure involves installing a smart water heater controller with adaptive learning on residential storage-type gas water heaters to reduce reheats. The action can be performed by a utility representative on site during a home visit or by the homeowner.

The existing temperature set point is assumed to be 130°F unless specified.

Actions: Operations and Maintenance
Target Market Segments: Residential
Target End Uses: DHW

Applicable to: Residential customers in single-family homes and multi-family homes consisting of 2 units or more (this includes 2-, 3-, and 4-plexes and townhomes) with residential-size gas water heaters

Algorithms

Unit Therm Use per Year = SpecificHeat x Density x Gal/day x 365.25 x (Tset - Tin)/ UEF/ ConversionFactor

Unit Therm Savings = Unit Therm Use per Year x Savings Factor (Ref. 6)

Unit kWh Savings = 0

Unit Gallons Fuel Oil Savings per Year = 0

Unit Gallons Propane Savings per Year = 0

Measure Lifetime (years) = 13 See Table 3 (Ref. 3)

Unit Participant Incremental Cost = $0

Where:

SpecificHeat = 1.0 btu / (lb x °F)

Density = 8.34 lbs / gal

Gal/day = See US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Tset = 120°F Default factory setting (Table 2) unless measured (Ref. 4)

Tin = See average groundwater temperature by location per Standard Building America DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (all climates) (Ref. 2)

UEF = 0.9254 − (0.0003 x Vr) DOE Energy Conservation Standards for Consumer Water Heaters (Ref. 2)

ConversionFactor = 100,000 Btu/Therm

SavingsFactor = 2% (Ref. 6)

Required from Customer/Contractor: Confirmation of storage water heater size in gal, project location (city/county), and number of bedrooms.

Example:

From the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules select approximate Minnesota location, number of bedrooms, and water heater setpoint temperature [default is 130°F] to determine: hot water use in gallons per day and Tin.

Duluth; 5 bedrooms; 130°F set point: Tin = 45.2°F; 72.9 hot water gallons per day (High Use)

Storage Water Heater size and fuel type: 40 gallon gas; UEF: 0.64

Unit kWh Use per Year = (1.0 Btu/lb°F) x (8.34 lb/gal) x (72.9 gal/day) x (365.25 day/yr) x (130°F - 45.2°F) / (0.64) / (100,000 Btu/Therm) = 294.2 Therms/Yr

Unit Therm savings = (294.2 Therms/Yr) * 0.02 savings = 5.9 Therms/Yr

Savings over water heater life = (7.2 Therms/Yr) * 13 Yr = 64.7 Therms

Deemed Input Tables:

Table 1: Storage Water Heater Default Set Point Temperature (Ref. 4 & 5)

Fuel Type	Range	Set Point
Electric	90° F to 150°F	120°F
Natural Gas	80° F to 160°F	130°F

Table 2: Gas Storage Water Heater Efficiency (Ref. 1)

Fuel Type	Rated Storage Volume	Draw Pattern	Uniform Energy Factor
Electric	≥20 gal and ≤55 gal	Very Small	0.8808 − (0.0008 × Vr)
		Low	0.9254 − (0.0003 × Vr)
		Medium	0.9307 − (0.0002 × Vr)
		High	0.9349 − (0.0001 × Vr)
	>55 gal and ≤120 gal	Very Small	1.9236 − (0.0011 × Vr)
		Low	2.0440 − (0.0011 × Vr)
		Medium	2.1171 − (0.0011 × Vr)
		High	2.2418 − (0.0011 × Vr)

Table 3: Rated UEF of Most Typical Gas Storage Water Heater Sizes (Ref. 1)

Draw Pattern	Rated Storage Volume		
	30	40	50
Very Small	0.29	0.27	0.25
Low	0.54	0.52	0.50
Medium	0.60	0.58	0.56
High	0.65	0.64	0.63

Table 4: Storage Water Heater Life (Ref. 3)

Fuel Type	Range	Average
Electric	6 to 20	13
Natural Gas	6 to 20	13

Table 5: SavingsFactor Table (Ref. 6)

Setpoint	Savings
120°F	0%
125°F	1%
130°F	2%
140°F	4%
150°F	13%
160°F	20%

Methodology and Assumptions:

Water heater efficiencies are based on Uniform Energy Factor (UEF) of Consumer Water Heaters with low draw patterns of hot water use (Ref. 1).

Average water main temperatures, T_{in}, are calculated from 1 of 54 Minnesota locations found in the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Gallons per day use hot water use are calculated based on the number of bedrooms from 1 of 54 Minnesota locations found in the US DOE Building America Program. Building America Analysis Spreadsheet, Standard Benchmark DHW Schedules (Ref. 2)

Water heater temperature set point, T_{set}, are based on the default factory settings or as reported in field measurements by running hot water over a thermometer at the hot water outlet nearest the tank for 2 minutes (Ref. 4).

SavingsFactor is based on a DOE analysis partially validated with the MN CARD field data on water heater tank temperature set point, T_{set}, as listed in Table 5 (Ref. 6).

References:

1. DOE Energy Conservation Standards for Consumer Water Heaters, Federal Register Number:2016-29994 CFR:10 CFR Parts 429, 430, and 431 (https://www.ecfr.gov/cgi-bin/text-idx?SID=80dfa785ea350ebeee184bb0ae03e7f0&mc=true&node=se10.3.430_132&rgn=div8)
2. Standard Building America DHW Schedules for 1, 2, 3, 4 and 5 bedrooms (all climates) (https://energy.gov/sites/prod/files/2014/05/f16/standard_dhw_events_0.zip)
3. Energy Efficiency Standards for Pool Heaters, Direct Heating Equipment and Water Heaters (EE-2006-STD-0129), 2009-11-23 Technical Support Documents: Chapter 8 Life-Cycle Cost and Payback Period Analysis, 8.7.1 Product Lifetimes Water Heaters, page 8-48 - 8-49, Table 8.7.1 Water Heaters: Product Lifetime Estimates and Sources (https://www.regulations.gov/document?D=EERE-2006-STD-0129-0170)
4. Technical Bulletin 31 by A.O. Smith states the temperature range on residential electric water heater that typically stores between 20 and 80 gallons of hot water is from 90° F to 150°F, with the usual factory setting of 120°F (https://www.hotwater.com/lit/bulletin/bulletin31.pdf)
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6. DOE Analysis predicts a 4%-22% based on a tank set point temperature of 120°F, reduced from 140°F through 160°F. The SavingsFactors (Table 3) are based on the DOE analysis partially validated with the MN CARD field data. The Minnesota CARD study “Intelligent, Networked, Retrofittable Water Heater Controller” determined a 1% savings based on a limited dataset of 10 homes. The study found the average tank set point temperature was reduced in smart mode by 5°F from 130°F to 125°F (https://energy.gov/energysaver/projects/savings-project-lower-water-heating-temperature)