CALIFORNIA
ENERGY COMMISSION

Energy Research and Development Division

FINAL PROJECT REPORT

Commercial Hot Water Systems Field Retrofit Characterization Study

Lab Testing Report

Gavin Newsom, Governor

April 2021 | CEC-500-2021-024

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ACKNOWLEDGEMENTS

The authors recognize the manufacturers that donated water heaters to the laboratory to support this project. More specifically, the authors thank A.O. Smith and Intellihot for their product contributions.

PREFACE

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

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ABSTRACT

Frontier Energy, operator of the Pacific Gas & Electric Company's Food Service Technology Center, working in conjunction with Pacific Gas and Electric Company, and the Southern California Gas Company, performed a technical study of commercial hot water systems for the California Energy Commission's Building Natural Gas Technology Program.

This project monitored gas and electric energy use and water consumption at all points on an existing hot water system at a full-service restaurant (FSR). The project similarly monitored the hot water system at an elementary school with emphasis placed on point-of-use monitoring in the dishroom. The existing hot water system at each site was then replaced with a more efficient, optimized system.

The scope of the field monitoring project included solicitation of test sites; monitoring of baseline gas, electricity, and water consumption and water pressure; replacement of site equipment; monitoring of the optimized system gas, electricity, and water consumption and water pressure; analysis of collected data and writing a report. The average daily results showed significant water and energy savings and an overall increase in the hot water delivery performance at both sites as well as an increase in the overall delivery efficiency at the FSR.

Keywords: Food service, commercial hot water, energy efficiency

Please use the following citation for this report:

Huestis, Edwin, Amin Delagah, Angelo Karas, and Michael Slater. 2021. *Commercial Hot Water Systems Field Retrofit Characterization Study.* California Energy Commission. Publication Number: CEC-XXX-2021-024.

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EXECUTIVE SUMMARY

Introduction

Water heaters are one of the most energy-intensive appliances in commercial kitchens. Moreover, the design of hot water systems in commercial kitchens has not changed significantly for decades. While there have been advancements in water heater efficiency, system improvements have concentrated on water-reducing measures at the tap, which has degraded hot water delivery performance, since lower flow rates translate directly into longer wait times at the tap. Improving the distribution system efficiency and hot water delivery performance has been largely neglected, resulting in little or no energy savings for hot water systems, especially in commercial kitchens, and this energy use accounts for a large portion of the total building energy use. While emerging technologies and system design strategies for advanced distribution systems exist to improve system efficiency and hot water delivery performance, they have exhibited low market use, with negligible adoption by designers and builders**.** Similarly, proper identification and adoption of high-performance heaters and dish machines (dish washers) that can simplify the hot water system design has also been lacking.

Project Purpose and Approach

This project compares the water and energy use, system efficiencies, and hot water delivery performance of different hot water systems by combining lab and field work. It aims to show significant water and energy savings and improved system performance through the demonstration of higher efficiency equipment, superior system design, distribution system controls, and operating best practices. The project has four major components: two field demonstration studies in commercial kitchens, laboratory testing for validation of measures, and developing a design tool and cost calculator. The field study component consisted of water and energy submetering of two existing hot water systems: one in a medium-sized full-service restaurant and one in an elementary school. Researchers then modified the systems with more efficient equipment and documented savings and performance improvements.

The lab portion of the study ran simulations on dozens of different hot water system configurations to determine the optimal combination of design elements for a site with a similar hot water demand to the full-service restaurant. The information learned through the laboratory and field tests was refined and incorporated into a design tool and cost calculator for commercial kitchen and plumbing designers and engineers to use as a comparative tool for their projects. The project also provided the public an assortment of educational documents on the project website, including an updated commercial kitchen hot water system design guide and design examples, field case studies, and presentations to key stakeholders including operators, health departments, building codes and standards personnel, designers, engineers, and efficiency experts. This report focused on the laboratory testing conducted for validation of generation and distribution system measures.

Project Results

This report contains the water and energy use data and analysis from the baseline system and optimized replacement system simulations as tested in the laboratory. In total, 65 hot water system configurations where tested, included 36 baseline distribution system test scenarios and 29 replacement distribution system scenarios. The four types of natural gas fired water heaters tested includes standard efficiency and condensing storage and tankless waters heaters. Of these four types, the most popular type tested in the laboratory and highest performing was the condensing storage water heater, which was involved in 24 tests. The second highest performing heater was the condensing tankless heater, although testing the unit proved to be difficult with many of the non-continuous recirculation test scenarios. The non-condensing tankless heaters was third regarding performance, followed by the non-condensing storage heater, which is the most common installed unit in foodservice applications but offers the lowest operating and system efficiencies in the group.

Out-of-Wall System Efficiency is defined as the thermal energy of water leaving the system minus thermal energy of water entering the system, divided by the total energy input to the system. The water heater operating efficiency, overall out-of-wall system efficiency, and average hot water delivery temperature at each simulated end-use fixture were calculated for each test scenario. Comparisons were made with the baseline and replacement systems and key outcomes were identified, including:

- Adding pipe insulation to baseline hot water system was effective, increasing out-of-wall system efficiencies by 20 percent to 30 percent and increasing the average delivery temperature by 4°Farenheit (F) to 5°F.
- Changing the water recirculation return location on the condensing storage water heater from the lower port to the upper port under the "on", "aquastat" and "timeclock" recirculation scenarios resulted in an average in an out-of-wall system efficiency increase of 3.5 percent
- Lowering the recirculation pump flow rate from a 3.5 gallons per minute (gpm) to 1 gpm with the continuous recirculation test resulted in a 9.7 percent improvement for the condensing tankless water heater.
- Replacing a non-condensing water heater with a condensing one, in both tankless and storage types, improved water heater operating efficiency by an average of 19 percent and out-of-wall system efficiency by an average of 21 percent.
  Unfortunately, not all the test results were conclusive due to mechanical problems in the test apparatus. A leaking check valve used on the hot water supply line caused back flow to occur at times during testing, resulting in lower delivery temperatures than expected, and artificially high operating and system efficiency improvements. While the higher efficiencies in some cases were realistic and encouraging to see, future tests should be conducted to measure efficiency improvement at similar delivery temperatures or energy delivered to the end-use fixture for a fair comparison with the other recirculation control strategies.

Lessons Learned

This laboratory research project was challenging since much of the research had not been previously conducted, especially the numerous system variables and test scenarios. Successes in the laboratory design included setup modularity with a flexible water conditioning system, water heater test cells, the distribution system rack and automated draw locations, and automating the 24-hour tests.

Overall, the laboratory tests were successfull and highlighted the increase in efficiencies of condensing water heaters especially when coupled with comprehensive pipe insulation and a recirculation control strategy. Unfortunately, the full potential of quantitative data from the laboratory was not achieved because of problems with distribution system pipe bonding materials, and with the check valve selected to prevent back flow. There were also incompatibilities with the condensing tankless heater chosen for the lab tests and operational errors with certain tests that limited the quantifiable results. In hindsight, it would have been more beneficial to change the method used for normalizing each laboratory test for comparison. Equalizing the water and energy outputs at the end-use fixtures instead of normalizing to the water and energy use at the heater would ensure that the delivered energy and temperature at the end-use fixtures for every test was similar. Multiple tests of each test configuration are necessary to make the required adjustments to the heater outlet temperature to ensure the tests are equal.

The laboratory tests showed clear qualitative results that validated many of the project goals, however they fell short of quantifying the savings from each test accurately enough to develop future utility incentive programs. The tests delivered some new findings not initially intended, specifically showing the impact of recirculation flow rates on operating and system efficiency. Ultimately, the laboratory testing made some giant leaps in establishing a path to comprehensively test hot water systems and laid the groundwork for future testing to deliver improved results. Training seminars highlighted the advantages of this research to the intended users.

Benefits to California

The savings results exceeded the researcher's projections in the proposal for the average food service field site. The results showed a 20 percent increase in water heater operating efficiency, 10 percent decrease in water use and 40 percent decrease in energy use. When implemented, these improvements translate to over a hundred million dollars of savings for California food service operators.

Technology transfer efforts for this project have been significant. The efforts have been in the form of utility-sponsored training, so utilities can advise their customers, and presentations at various industry conferences. In 2020, the team converted the historical in-person classes from the Food Service Technology Center to webinars and posted the recordings online at California Energy Wise (caenergywise.com). One of the most impactful industry forums where information was shared was the biennial Multi-Unit Foodservice Equipment Symposium (MUFES), which is focused on designers and specifiers for commercial and institutional multi-unit foodservice operators. The research team was informed by Disneyland Resort that they had immediately put many recommendations from this presentation into action (particularly with respect to point of use heaters). Other high-impact venues include The ACEEE Hot Water Forum and Foodservice Consultants Society (FCSI) conference. Foodservice consultants are the designers of commercial kitchens and dish room operations.

Some of the technical content previously hosted on fishnick.com has been migrated to the California Energy Wise utility website. The design guides were among the first round of content to be moved and have been in constant demand. The water heating design guide was downloaded 188 times in 2020 and 17 times to date in 2021. The hot water energy savings calculator will be hosted on fishnick.com starting mid-2021.

Continuing the research is necessary to demonstrate new best-in-class equipment and design techniques and to refine existing results for potential inclusion in future Title 20 and Title 24 energy regulations. Updated test results can be used to improve the design tool and cost calculator and inform hot water system stakeholders across residential, commercial and industrial sectors. The findings from this research will be especially important to commercial kitchen designers, plumbing professionals and regulatory bodies. Coupled with more specific research, they can help pivot the industry away from the inefficient hot water system designs found in nearly all existing facilities and move California closer to reaching Zero Net Energy hot water systems.

CHAPTER 1: Introduction, Background and Objective

Introduction

Frontier Energy, operator of the Food Service Technology Center (FSTC) conducted this demonstration study to measure the energy and water reduction and operating cost benefits of optimized hot water systems in commercial and institutional food service facilities. The project is primarily funded by the California Energy Commission Building Natural Gas Technology (BNGT) grant program, with co-funding from Pacific Gas and Electric Company (PG&E) and Southern California Gas Company (SoCalGas). The laboratory testing portion of this study was completed by PG&E's Applied Technology Services (ATS) in their hot water system laboratory.

Before beginning the lab testing, real-world water use data was generated through a study of two food service establishments in California. The first was The Counter, a full-service restaurant (FSR) in PG&E service territory in San Mateo (San Mateo County). The second was Franklin Elementary School, in Santa Barbara (Santa Barbara County) in SoCalGas territory. Field monitoring began with the existing baseline hot water systems and proceeded to the modified systems, which incorporated more efficient equipment and advanced distribution system controls such as point-of-use water heaters, demand recirculation pumping and exhaust-air heat recovery dishmachines.

The average daily hot water use profiles of the original (baseline) system and the replacement (optimized) system at The Counter were provided to the ATS laboratory to guide them in building a laboratory that could mimic the operation of the restaurant site to measure water heater operating efficiency (WHOE), out-of-wall system efficiency (OWSE) and hot water delivery performance. In the laboratory, the water heater test cell was capable of switching between four water heaters depending on the test scenario. The distribution system test cell was able to switch from the original and replacement distribution systems, with or without pipe insulation and switch the recirculation pump on and off using multiple control strategies. The end-use fixture test cell included eight outlet points with control valves used to mimic water use at each sink or dishwasher based on the baseline and replacement operating profiles.

The project meets two of the four BNGT Demonstrations in Building Technology Innovation target areas: (1) advanced domestic hot water systems, with a focus on showcasing innovative hot water distribution systems and their interaction with high-efficiency ultra-low NO_x water heaters and water-using devices that incorporate waste heat recovery systems, and (2) commercial foodservice sector, with high-energy intensity in their daily cooking, refrigeration, hot water system, lighting, and kitchen ventilation/HVAC operations.

Background

History

Storage and tankless water heaters and hot water systems developed into an industry around the start of the 20th century. With regards to the evolution of commercial hot water systems, the rest of the 20th century involved standardizing and increasing the rated efficiency of heaters, reducing tank idle losses and figuring out how to distribute hot water so it is available in a timely manner at the point-of-use (POU). POU is a catch all to describe an end-use sink, fixture or equipment such as a dishmachine. Hot water system design has not changed significantly since Roy B. Hunter published Methods of Estimating Loads in Plumbing Systems (Hunter 1940).

In the 21st century, new technologies such as hybrid water heaters and heat pump water heaters were successfully introduced to provide flexibility and improve the efficiency of heaters. In addition, POU water use was greatly reduced through the introduction of water efficiency products such as ENERGY STAR dishmachines, WaterSense pre-rinse spray valves and aerators. Unfortunately, improvements to the distribution system during this time lagged considerably and many of the high-efficiency water heaters were not able to perform to their specifications in a conventional distribution system and hot water delivery performance continued to decline as water use declined.

As energy-efficient building systems matured with space heating/cooling systems, lighting, cooking appliances and kitchen ventilation systems, hot water system designs did not keep up, thus the energy use of hot water systems especially in commercial kitchens did not reduce significantly and started to account for a larger proportion of the total building energy use. Hot water research started to pick up steam and receive significant funding in the last decade to characterize real world hot water use, WHOE and understand the limitations of water heaters and distribution system designs.

Comprehensive water heater testing began at PG&E's ATS Water Heater Laboratory in 2007 (Figure 1). The laboratory was focused on executing identical draw profiles at consistent inlet water and air temperatures on six residential water heaters to support the federal water heater test method development process.

Figure 1: Pacific Gas and Electric Company Residential Water Heater Laboratory

Source: PG&E

In 2010, the laboratory expanded from a residential water heater focus to a commercial hot water system testing facility (Figure 2). The laboratory testing completed in 2013 supported an earlier California Energy Commission research project that used daily water use profiles from a quick-service restaurant and mimicked the operation of the system in the laboratory. The first-generation commercial hot water laboratory tested standard efficiency and condensing tankless and storage water heaters and measured each heater's thermal efficiency and standby heat loss. It also varied the inlet water temperature to measure the efficiency of each heater to gauge the impact of preheating the inlet water from drainwater and refrigerant heat recovery technologies or solar water heating. It went further to measure the system delivery efficiency, now called the OWSE for a number of retro-commissioning measures including with and without pipe insulation, aquastat and timeclock recirculation controls, no recirculation, with continuous recirculation, and with and without flue damper on the standard efficiency storage heater. This important project expanded the best practice guidelines for designing and operating commercial kitchen hot water systems.

Figure 2: Pacific Gas and Electric Company Commercial Hot Water System Laboratory

Source: PG&E

The vision for ATS's Generation II Hot Water System Laboratory was to include the capabilities of the past residential and commercial test setups and expand the laboratory to employ a modular design so it can easily adapt to changing test setups and distribution systems. The goal of the laboratory was to automate testing and expand the control of test variables while maintaining instrumentation accuracy. Ultimately, the laboratory was seeking to expand versatility and focus more on performance testing and validation.

Improvement Opportunities

Innovative and emerging technologies exist that can significantly improve the efficiency of hot water systems. Despite the availability, these energy-efficient technologies are not widely used in the market. For instance, high-efficiency water heaters and preheating technologies such as solar water heating, while available and mature, have low penetration rates. Advanced distribution system designs are not mature, though the components are available. This is likely one example in an overarching problem where most designers or owners prefer to keep using 'tried-and-true' equipment and distribution system designs and operating temperature parameters. They lack familiarity with and have concerns over newer equipment and distribution system designs that have not been tested for performance, functionality, resource savings, or reliability.

Objectives

The two field demonstration projects and laboratory testing were to document the water and energy use of specific components in each conventional and replacement gas-fired primary hot water system, calculate WHOE and system delivery efficiency, and showcase the hot water delivery performance to characterize each system's overall design. Calculating the savings and improvements in delivery performance from the baseline to replacement case should validate the advanced optimization techniques. Combining validation with technology transfer through the dissemination of newly developed educational materials should hopefully encourage the design, engineering, building and foodservice community to adopt these measures. The results may be used to develop more precise savings potential estimates for similar FSRs and cafeterias in the laboratory to support the development of incentive programs by utilities for existing and new facilities. The validation of the replacement technologies and design practices can be used to overcome the "business as usual" design and build practices in industry, financial, regulatory, operational and other barriers to adoption. The last objective of this report is to showcase strong innovation with hot water system design and integration of technologies to provide a clear differentiation with all existing hot water systems to gain strong support by the Energy Commission, the California Public Utilities Commission (CPUC), and utilities to speed up and expand advanced commercial hot water system research, demonstration and implementation initiatives.

Laboratory Objectives

The lab study was designed to measure the water and energy use and efficiency for different hot water system designs in a repeatable laboratory environment. The objective was to compare 76 separate combinations of technologies, including four water heaters, two distribution systems, multiple recirculation schemes, and with and without pipe insulation. This experiment evaluated the interactions between these combinations of technologies and the effect they would have on the WHOE, OWSE and hot water delivery performance. Because evaluating these technologies in the field is time consuming and expensive, this lab study was a convenient way to generate a large amount of data about currently available products and design strategies. This data was used for multiple projects such as the design guide and the design tool and cost calculator. The lab will hopefully support the development of packaged incentives (multiple complementing measures) for utilities which would be a major step from the existing widget-based deemed incentive approach. The key goals for the laboratory testing were:

- To show that the simulated demand circulation is superior to continuous recirculation.
- To save 20 percent on distribution system pipe heat losses from switching from continuous recirculation to simulated demand circulation.
- Simulated demand circulation should increase the operating efficiency of the water heater by 5 percent.
- Simulated demand circulation should decrease pump electrical use by 80 percent while maintaining hot water delivery performance at hand sinks.

CHAPTER 2: Laboratory Configuration

Test Apparatus Overview

Two hot water distribution systems were constructed in the laboratory to simulate the FSR field site, one representing the original baseline system and the other representing the centralized main loop portion of the optimized replacement system. The decentralized portion comprising the electric point-of-use heaters and cold-water-feed dishmachine were not considered in the lab simulation. A set of four heaters—condensing and non-condensing models of storage tank and tankless heaters—were plumbed in parallel into a supply and return header that would allow for the eight possible combinations of heaters and distribution systems. Solenoid and ball isolation valves were used to tie in the heater under test while isolating the others from the test system. The remaining parameter variables included system insulation, recirculation pump control measures (timer switch, aquastat, demand controls, constant operation, or off), recirculation flow rate, recirculation return location for the condensing storage water heater, simulated aeration of end uses and reduction of branch piping diameter. The test apparatus accounted for all energy entering, leaving and being stored in the system. Analysis methods will be discussed in detail later in the report.

Water Conditioning System

A 7-ton chiller and water heater (Figure 3) was used to continuously temper incoming city water to approximately 58°F in a storage tank.

Figure 3: Water Conditioning System With 7-Ton Chiller

Source: Frontier Energy, Inc.

Water Heater Test Cell

The water heater test cell was configured in a square configuration with 4 test bays housing the four types of water heaters tested in this project (Figure 4).

Figure 4: Commercial Water Heater Test Cell

Source: Frontier Energy, Inc.

Distribution System Test Rack

The copper uninsulated baseline distribution system and insulated optimized system each consisting of a recirculation supply and return piping placed on a vertical racking structure is shown in Figure 5.

Figure 5: Distribution System Test Rack (Left) and Eight Draw Locations (Right)

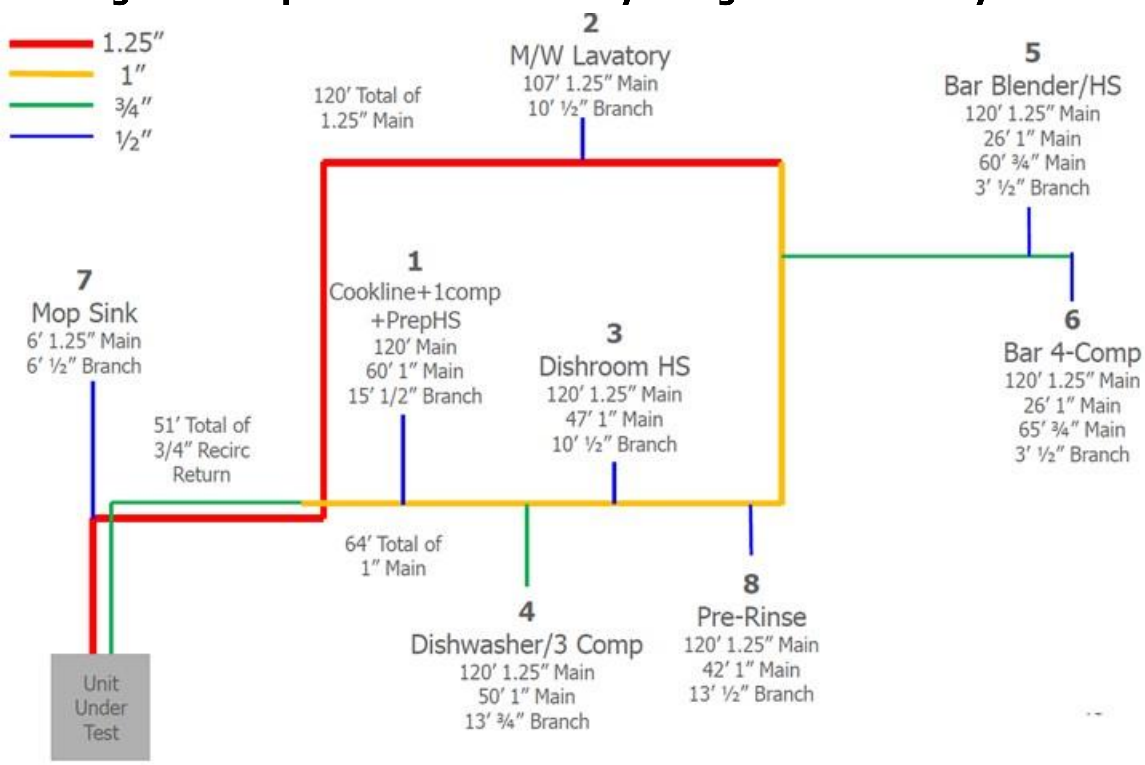
Source: Frontier Energy, Inc.

Isolation valves were installed on city water inlet, recirculation return and water heater supply piping. The water heater under test with system recirculation would have all isolation valves open. The water heaters that weren’t under test remained isolated from the rest of the system by maintaining all respective city water, supply water and recirculation return valves in a closed position. A check valve was installed on the recirculation return line to mitigate backflow to end uses.

Baseline Distribution System and Eight Draw Locations

The laboratory had eight individually automated draw stations available for testing. Since the baseline system at the restaurant had a total of 13 points of use, some of the fixtures were combined for testing in the laboratory in a manner that would mimic the field site distribution system layout as much as possible. Figure 6 shows the implemented laboratory design of the baseline system from The Counter Restaurant.

Figure 6: Implemented Laboratory Design of Baseline System

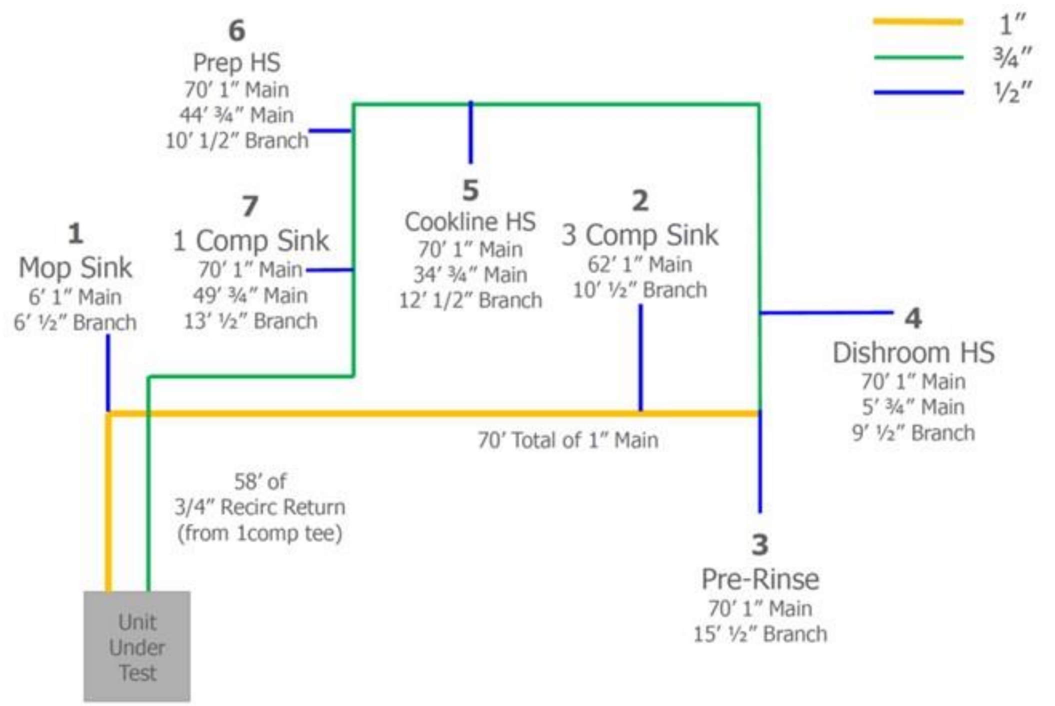


Source: Fisher-Nickel

Optimized Distribution System and Seven Draw Locations

Unlike the baseline system, the optimized system did not require combined fixture draw points, since six of the end-use fixtures including the dishwasher, lavatory sinks and bar sinks where no longer connected to the centralized hot water distribution system. Figure 7 shows the implemented laboratory design of the optimized system. In addition, the length and diameter of piping was significantly reduced to account for the compactness of the optimized distribution system and lower maximum flow rate required by the limited number of fixtures.

Figure 7: Implemented Laboratory Design of Optimized System



Source: Fisher-Nickel

Temperature Measurement and Calibration

Internal tank temperatures were taken with evenly-spaced type-T thermocouples mounted on a rod replacing the water heater anode rod. All other temperatures were taken with four wire resistance temperature detectors (RTD). Fast response RTDs were used to take temperature measurements at the city water inlet, water heater outlet and fixture water outlet locations. RTDs were calibrated against a laboratory standard temperature sensor in an ice bath (32°F), and an isothermal block (116°F and 200°F). The range of calibration temperatures was selected to bind all temperatures seen by each probe during testing.

Pressure Measurement and Calibration

Pressure transmitters were used to measure laboratory barometric pressure and gas header pressure for compensation of natural gas volume flow (Figure 8). The Barometric pressure transmitter was calibrated using a pressure tester while the gas header pressure transmitter was calibrated with a dead weight tester.

Figure 8: Gas Pressure Transmitter (Left) and Barometric Pressure Transmitter (Right)

Source: Fisher-Nickel

Flow Measurement and Calibration

Nutating disc positive displacement flow meters were used to measure water flow at each simulated fixture and recirculation flow rate in the recirculation return line. A ½" Coriolis flow standard was used to calibrate each of these water flow meters. Gas flow measurements were taken with a diaphragm meter equipped with a pulse output (Figure 9). A calibration was performed on the diaphragm meter.

Figure 9: Natural Gas Volumetric Flow Meters with Pulsing Output Totalizers

Data Acquisition and Controls

The instrumentation was connected to multiple rack-mounted Compact Rio modules from National Instruments, depending on the signal type. The signal conditioning modules included different units for RTDs, thermocouples, voltage and pulse count (water and gas meters) inputs, plus both analog and digital output modules for the solenoid valves. Each rack included an Ethernet communications module that enabled the system to be accessed from anywhere on the local network.

A local computer connected to the Ethernet network ran a program written in National Instrument's LabVIEW graphical programming language. This program was developed to read all the measurement devices, display the readings and additional calculated values on screen, and save the data to disk for later analysis, as well as control the water draws. The system was programmed such that the water draws could be automated over a 24-hour period. The scan rate for sampling from the Compact Rio modules and updating the screen was set at 2 Hz, although the internal scan rate of the modules was 10 Hz.

Operation

As part of the data acquisition and control program built in LabVIEW, a user interface was designed for the test operator to visually monitor the test apparatus. The interface integrates both manual and automatic controls where a draw profile script is programmed to automatically run on the system.

Isolating each individual draw point was accomplished with a solenoid valve. Modulation of flow was accomplished with either a globe valve or pressure compensating valve to achieve the desired static flowrate. A thermocouple probe was used for temperature measurement of water exiting the main recirculation header to each branch line. RTDs with low thermal mass tips installed immediately downstream of each solenoid valve were used to capture the simulated out-of-wall delivery temperature for each respective fixture.

CHAPTER 3:
Laboratory Test Method

Conventional System 24-Hour Draw Profile

Table 1 includes a summary of the hot water usage patterns from the field study. In total there were more than 1,700 individual draws recorded on 14 fixtures.

Table 1: Field Monitoring Results – Hot Water Use by Fixture

14 Monitored Hot Water Fixtures	Volume (gallons)	Average Calculated Flow Rate (gpm)	Number of Uses per Day	Mass Weighted Temperature (˚F)
1-Compartment Sink	36.82	2.99	24	126.2
Prep Hand Sink	4.25	1.42	23	96.6
Cookline Hand Sink	6.53	.188	29	100.6
Women’s Lavatory	9.97	0.61	83	113.0
Men’s Lavatory	8.17	0.42	101	105.0
Dishroom Hand Sink	3.66	0.72	22	n/a
Dishwasher	303.28	4.58	214	128.1
3-Compartment Sink	154.95	2.59	48	129.6
Bar Hand Sink	2.95	1.61	12	95.5
Pitcher Hand Sink	29.88	0.35	698	92.5
4-Compartment Left Sink	16.00	3.20	3	128.1
4-Compartment Right Sink	43.18	3.30	12	117.6
Mop Sink	40.36	5.27	4	125.0
Pre-Rinse Sink	61.31	0.50	434	114.9
TOTAL	721.32			

Source: Frontier Energy, Inc.

Baseline System 24-Hour Draw Profile

Flow data from the fourteen fixtures in the field site were reduced and combined to represent 8 individual fixtures that would be automated during the laboratory test in Table 2. The field data were reduced by rounding off the draw durations to the nearest five-second interval then used as a binary indication for opening and closing the simulated fixture in the laboratory. The average desired flowrate was then calculated by dividing the total flow from the field study by the total duration of open valve time in the laboratory script.

Table 2: Baseline System Laboratory Testing Draw Volumes and Fixture Combinations

Combined 8 Fixtures	Volume (gallons)	Average Calculated Flow rate (gpm)	Number of Uses per Day
1: 1 Comp Sink, Prep, Cookline	47.61	3.16	76
2: Men's and Women's Bathroom	18.14	0.52	184
3: Dish Hand Sink, Dishwasher	306.94	4.31	22
4: 3-Compartment Sink	154.95	2.59	262
5: Bar Hand Sink, Pitcher HS	32.83	0.37	710
6: 4-Compartment Sink Left and Right	59.18	3.29	15
7: Mop Sink	40.36	5.21	4
8: Pre-Rinse	61.31	0.50	434
TOTAL	721.32		1,707

Source: Fisher-Nickel

Optimized System 24-Hour Draw Profile

In the optimized case, the seven individual fixtures on the centralized hot water system are refined in Table 3 for the laboratory test.

Table 3: Optimized System Laboratory Testing Draw Volumes and Fixture Combinations

Combined 7 Fixtures	Volume (gallons)	Average Calculated Flow rate (gpm)	Number of Uses per Day
1: Mop Sink	40.36	5.27	4
2: 3-Compartment Sink	154.95	2.59	48
3: Pre-Rinse	61.31	0.50	434
4: Dishroom Hand Sink	3.66	0.72	22
5: Cookline	6.53	1.88	29
6: Prep Hand Sink	4.25	1.42	23
7: 1-Compartment Sink	36.82	2.99	24
TOTAL	307.89		584

Source: Fisher-Nickel

Data Collection and Processing

All data were captured at five second intervals using National Instruments LabVIEW data acquisition systems and software. Data files were then loaded into an analysis template that applies the methods discussed in the laboratory analysis chapter of this report. Upon completion of testing the data were analyzed to ensure that all automated solenoid valves were firing properly and instrumentation was properly reading.

General Test Conditions and Equipment Under Test

The impacts of the following variables on OWSE were studied:

- Water Heater
- Distribution System Design
- Distribution System Insulation
- Recirculation Pump Control
    - Off 100 percent of the time
    - On 100 percent of the time
    - Timer Switch (time control)
    - Simulated D'MAND Controls
    - Aquastat (temperature and time control)
- Recirculation Flowrate
- Recirculation Return Location on Condensing Tank Heater
- End Use Aeration and Vertical Pipe Drop Diameter Reduction

Water Heater Types

A breadth of understanding on the performance impacts of water heater selection on commercial hot water systems was desired. Thus, four typical water heaters used in commercial applications were selected for laboratory testing. The water heaters selected are shown are listed and shown in Figures 10 and 11:

- Condensing Storage: A. O. Smith Cyclone MXi, Model Number BTH-199, 100-gallon, 199,900 Btu/h input, 97 percent Rated TE.
- Non-Condensing Storage: A.O. Smith Master-Fit, Model Number BTR-197, 100-gallon, 199,000 Btu/h input, 80 percent Rated TE.
- Condensing Tankless: Intellihot, Model Number i200P, 199,950 Btu/h input, 94 percent Rated TE.
- Non-Condensing Tankless: Rinnai, Model #: R94LSi, 199,000 Btu/h input, 84 percent Rated TE.

Figure 10: Non-Condensing Storage Water Heater (Left) and Modulating Condensing Storage Water Heater with Middle and Lower Recirculation Return Port (Right)

Source: Frontier Energy, Inc.

Figure 11: Paralleled Non-Condensing Tankless Water Heater (Left) and Condensing Tankless Water Heater (Right)

Source: Frontier Energy, Inc.

Distribution System Types

Two unique distribution system designs were built in the laboratory and used for testing. The baseline system design was built to replicate the baseline system clockwise flow design at the FSR field site. The optimized system design included a reduction in diameter and overall length of piping to replicate the FSR replacement counterclockwise system loop.

Distribution System Controls

None—No Recirculation

A set of tests was performed with no recirculation from the distribution system back to the water heater under test. These tests were used to identify the impact of system insulation and distribution system length/volume on delivery temperatures on non-recirculating systems. Furthermore, the associated adverse effect on efficiency that recirculation can have on storage water heaters were analyzed.

None—Continuous Recirculation

Continuous recirculation enables a hot water system to maintain elevated temperature in the distribution system but increases the thermal losses in the distribution system as the temperature difference between the loop temperature and ambient increases. This test will quantify the impact that continuous recirculation has on OWSE as compared to the Timer Switch, D'MAND Controls and Aquastat recirculation strategies. Testing while using continuous recirculation can also serve as a "best case" for delivery temperature and a benchmark for comparison to the other three strategies. The flow rate of the pump was changed from the nominal 3.5 gpm found in the field site to understand the impact by lowering and increasing the flow rate to 1 gpm and 6 gpm, respectively.

Timer Switch

The recirculation pump was turned off between 11:30 pm and 5:30 am in an effort to reduce heat losses of the distribution system during periods of time when the system was not using any hot water. This control, performed with LabVIEW, was applied to mimic the use of a timer switch to control a recirculation pump.

Simulated Demand Control

Simulated demand control circulation was simulated using LabVIEW through turning the recirculation pump on and off based on temperature readings from the tee farthest from water heater supply. The pump turned on when the temperature at the tee dropped below 100F, and off once it had reached 115F. This test assessed the performance improvement associated with reducing the temperature of the return water to the water heater using temperature feedback from within the distribution system. The timer switch was also enabled, preventing the pump from operating between 11:30 pm and 5:30 am. The purpose of this simulation was to get close to the real-world operation of a D'MAND system with inline temperature sensor at the last tee and occupancy sensor placed in common area in the kitchen.

Aquastat

A simple controller was programmed to start the recirculation pump once the surface temperature of the pipe immediately downstream of the pump reached 5 degrees below 115°F. The recirculation pump was located about. 15 feet from each water heater return. The timer switch was also enabled, preventing the pump from operating between 11:30 pm and 5:30 am. This configuration simulated a readily available recirculation pump option that includes an integrated timer and a pipe-surface-mounted clip-on aquastat.

Pipe Insulation

Baseline system laboratory testing was performed with and without distribution system foam pipe insulation. Foam insulation applied to the distribution systems was 1" thick. The optimized system was insulated for every laboratory test since the purpose of the test was to showcase optimization strategies.

Vertical Pipe Branch Drop Diameter

The drop for the hand sink fixture in the proposed distribution system was reduced from ½" to 3/8". This modification was performed to increase the velocity in the drop and reduce the volume in an effort to increase delivery temperature.

Testing Matrix

Baseline Testing Matrix

All testing performed using the baseline distribution system is included in Table 4.

Table 4: Laboratory Test Matrix using Baseline Distribution System

Test #	Water Heater	Recirculation Pump Control	Nominal Recirculation Rate (gpm)	System Insulation
35	Condensing Storage	Off	0	Off
36	Condensing Storage	On, Middle Port Return	~3.5	Off
37	Condensing Storage	On, Bottom Port Return	~3.5	Off
38	Condensing Storage	Demand Controls	~3.5	Off
39	Condensing Storage	Timeclock	~3.5	Off
40	Condensing Storage	Aquastat	~3.5	Off
41	Condensing Tankless	Off	0	Off
42	Condensing Tankless	On	~3.5	Off
44	Condensing Tankless	Timeclock	~3.5	Off
45	Condensing Tankless	Aquastat	~3.5	Off
46	Non-Condensing Storage	Off	0	Off
47	Non-Condensing Storage	On	~3.5	Off
48	Non-Condensing Storage	Demand Controls	~3.5	Off
49	Non-Condensing Storage	Timeclock	~3.5	Off
50	Non-Condensing Storage	Aquastat	~3.5	Off
51	Non-Condensing Tankless	Off	0	Off
52	Non-Condensing Tankless	On	~3.5	Off
53	Non-Condensing Tankless	Demand Controls	~3.5	Off
54	Non-Condensing Tankless	Timeclock	~3.5	Off
55	Non-Condensing Tankless	Aquastat	~3.5	Off
56	Condensing Storage	Off	0	On
57	Condensing Storage	On	~3.5	On
58	Condensing Storage	Demand Controls	~3.5	On
59	Condensing Storage	Timeclock	~3.5	On
60	Condensing Storage	Aquastat	~3.5	On
62	Condensing Storage	On	~3.5	On
66	Non-Condensing Storage	Off	0	On
67	Non-Condensing Storage	On	~3.5	On
68	Non-Condensing Storage	Demand Controls	~3.5	On
69	Non-Condensing Storage	Timeclock	~3.5	On
70	Non-Condensing Storage	Aquastat	~3.5	On
71	Non-Condensing Tankless	Off	0	On
72	Non-Condensing Tankless	On	~3.5	On
73	Non-Condensing Tankless	Demand Controls	~3.5	On
74	Non-Condensing Tankless	Timeclock	~3.5	On
75	Non-Condensing Tankless	Aquastat	~3.5	On

Source: Frontier Energy, Inc.

Optimized Testing Matrix

All testing performed using the optimized distribution system is included in Table 5.

Table 5: Laboratory Test Matrix using the Optimized Distribution System

Test #	Water Heater	Recirculation Pump Control	Nominal Recirculation Rate (gpm)	System Insulation
1	Condensing Storage	Off	0	On
2	Condensing Storage	On, Lower Port Return	~3.5	On
3	Condensing Storage	On, Middle Port Ret.	~3.5	On
4	Condensing Storage	On, Middle Port Ret.	~6	On
5	Condensing Storage	On, Middle Port Ret.	~1	On
6	Condensing Storage	Demand Control, Lower Port Ret.	~3.5	On
7	Condensing Storage	Demand Control, Middle Port Ret.	~3.5	On
8	Condensing Storage	Timeclock, Lower Port Ret.	~3.5	On
9	Condensing Storage	Timeclock, Middle Port Ret.	~3.5	On
10	Condensing Storage	Aquastat, Lower Port Ret.	~3.5	On
11	Condensing Storage	Timeclock, Middle Port Ret.	~3.5	On
12	Condensing Tankless	Off	0	On
13	Condensing Tankless	On	~3.5	On
14	Condensing Tankless	On	~1	On
16	Condensing Tankless	Timeclock	~3.5	On
17	Condensing Tankless	Aquastat	~3.5	On
18	Non-Condensing Storage	Off	0	On
19	Non-Condensing Storage	On	~3.5	On
20	Non-Condensing Storage	Demand Controls	~3.5	On
21	Non-Condensing Storage	Timeclock	~3.5	On
22	Non-Condensing Storage	Aquastat	~3.5	On
23	Non-Condensing Tankless	Off	0	On
24	Non-Condensing Tankless	On	~3.5	On
25	Non-Condensing Tankless	On	~1	On
26	Non-Condensing Tankless	Demand Controls	~3.5	On
27	Non-Condensing Tankless	Timeclock	~3.5	On
28	Non-Condensing Tankless	Aquastat	~3.5	On
29	Condensing Storage	Off	0	On
30	Condensing Storage	Off	0	On

Source: Frontier Energy, Inc.

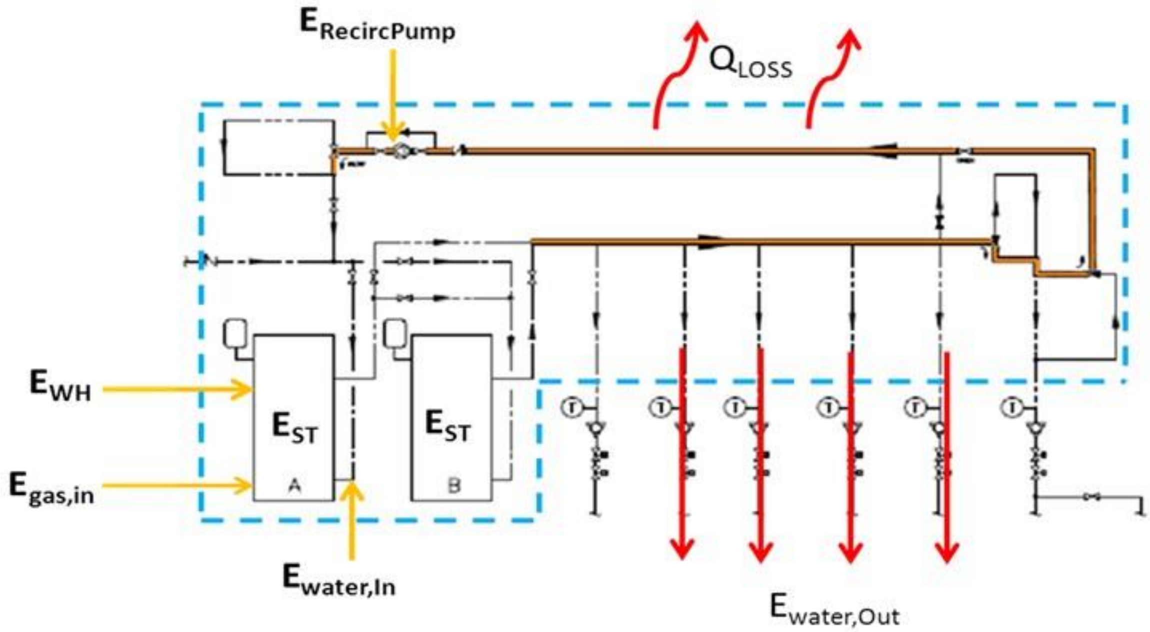
CHAPTER 4: Laboratory Analysis

Efficiency Calculations

Out-of-Wall System Efficiency

Out-of-Wall System (OWSE) was defined as the net gain of thermal energy between hot water supplied and water entering the system, divided by the total energy input to the system. In Figure 12, the boundaries of the control volume are identified, along with the energy entering the control volume, leaving the control volume and stored in the control volume. Point-of-use heating was not included in laboratory testing and thus is not included in the calculation of OWSE.

Figure 12. System Control Volume Boundary Definition Used for Establishing Out-of-Wall System Efficiency



Energy storage only taken into account when testing storage heaters.

More specifically, OWSE was defined as the amount of energy required to heat a volume of water to a measured temperature rise (the temperature difference between the simulated fixture and the cold supply inlet) divided by the summation of natural gas energy input and electrical energy input during each 24-hour test. System energy storage was also taken into account by calculating the change in energy content of the storage tank from start to finish of the laboratory test.

Two different OWSEs were calculated for each test and are described further in this section.

1. **Test OWSE** – The uncorrected OWSE of a 24-hr. test.

2. **Normalized OWSE** – OWSE normalized to a specified total delivery volume. This step is taken to improve consistency of the energy performance comparison between tests. All reported results labeled as OWSE represent normalized values otherwise stated.

The units used in all analyses are listed:

- Volume: (ft^3)
- Mass: (album)
- Temperature: (°F)
- Pressure: Gas (inches H_2O), Barometric (psia)
- Specific Heat (Btu/lbm °F)
- Energy: Gas, Equivalent Electric (Btu), Electric (kWh)
- Demand: Electric (W)
- Higher Heating Value (Btu/ft^3)

Calculation of Test Out-Of-Wall System Efficiency

The test OWSE was calculated using the following formula for baseline and optimized 24-hour draw profiles:

$$\eta._{DELIVERY-TEST} = \frac{O.E._{TEST} + \Delta E_{Storage}}{I.E._{TEST}}$$

Equation 1: Calculation of System Efficiency for a Tank-Type Water Heater

Where:

$O.E._{TEST}$ = Total system energy output during each test

$\Delta E_{Storage}$ = System energy storage difference between the beginning and end of each test

$I.E._{TEST}$ = Total system energy input during each test

Output Energy Calculations

Output energy was calculated as the difference in energy content of the water leaving and entering the system.

Equation 2: Total 24-Hour System Energy Output

$$O.E._{TEST} = E_{out,Fixture} - E_{in,CityWater}$$

Where:

$E_{out,Fixture} = \sum_1^n E_{out,Fixture,i}$ = Total energy content of water delivered at each simulated end use fixture

$E_{in,CityWater} = \sum_1^n E_{in,CityWater,i}$ = Total energy content of city water entering the system, specific to the water heater under test

Energy Content of Water Leaving the System

Equation 3: Energy Content of City Water Leaving the System throughout 24-Hour Draw Profile

$$E_{out,Fixture,i} = V_{water,Drain,i} * \rho_{water} * c_{p,water} * T_{outlet,Fixture,i}$$

Where:

$V_{water,Drain,i}$= Total volume of fixture water from simulated fixture draw i

ρ_{water} = Water density, assumed to be 8.33 lb/gal

$c_{p,Water}$ = Water specific heat, 0.998 Btu/lbm °F

$T_{outlet,Fixture,i}$ = Average of temperature at fixture i, with measurements taken only during draws

Energy Content of Water Entering the System

$$E_{in,CityWater,i} = V_{water,Drain,i} * \rho_{water} * c_{p,water} * T_{inlet,CityWater,i}$$

Equation 4: Energy Content of City Water Entering the System throughout 24-Hour Draw Profile

Where:

$V_{water,Drain,i}$= Total volume of fixture water from simulated fixture draw i

ρ_{water} = Water density, assumed to be 8.33 lb/gal

$c_{p,Water}$ = Water specific heat, 0.998 Btu/lbm °F

$T_{inlet,CityWater}$ = Average of temperature measurements taken only during draws

Storage Energy Calculations

Energy content of the water within the storage tank, inside the defined system control volume, will change between the beginning and end of each test and was accounted for.

$$\Delta E_{Storage} = V_{tank} * cp_{water} * \rho_{water} * (\theta_E - \theta_S)$$

Equation 5: Calculation of Stored Energy Content Difference in System from Beginning to End of Each 24-Hour Draw Profile

Where:

V_{tank} = Storage Tank Volume (gallons)

$c_{p,Water}$= Water specific heat, 0.998 Btu/lbm °F

ρ_{water} = Water density, assumed to be 8.33 lb/gal

θ_S = Mean tank temperature at the beginning of the test

θ_E = Mean tank temperature at the end of the test

$\Delta E_{Storage}$ = Change in energy content of the water heater storage tank between the beginning and end of each test

Input Energy Calculations

Total system energy input during a 24-hour draw profile test included chemical energy in entering natural gas and electrical energy supplied to the recirculation pump. Water heater electrical energy input was considered negligible and excluded from energy performance calculations.

$$I.E._{TEST} = \left(V_{gas,STD} * HHV_{gas}\right) + E_{aux}$$

Equation 6: Total System Energy Input During Each 24-Hour Draw Profile Test

Where:

$$V_{gas,STD} = V_{gas,ACT} * \left(\frac{460+60}{460+T_{gas}}\right) * \left(\frac{\left(p_{gas} * .036\right) + p_{atm}}{14.73}\right)$$ = Standard cubic feet of natural gas

Equation 7: Calculation of natural gas volume at standard conditions

$V_{gas,ACT}$ = Actual cubic feet of gas delivered to the water heater

T_{gas} = Natural gas compensation temperature, taken at each natural gas volume meter

p_{gas} = Natural gas compensation pressure, taken at the natural gas supply header

p_{bar} = Barometric pressure

E_{aux} = Electric energy entering the system from recirculation pumping (Btu)

HHV_{gas} = Natural gas energy content (Higher Heating Value)

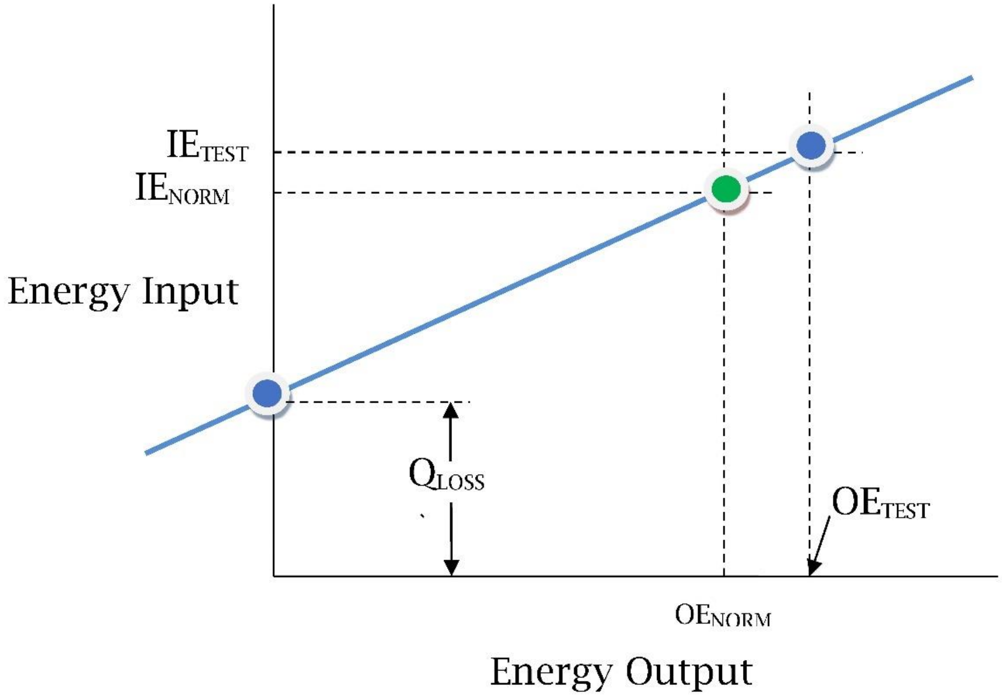
Calculation of Normalized Out-of-Wall System Efficiency

Due to experimental variances in flow control parameters, variations in the total water volume delivered occurred between tests when the same total delivery volume was desired. Because system efficiency trends with input it is important to have equivalent input conditions when comparing system efficiency optimized across different tests, the energy output and the efficiency were normalized to the same volume of inlet water so that a fair comparison could be made. Normalization volume was 350 gallons for the baseline system and 850 gallons for the optimized system.

Graphical Representation of Out-Of-Wall System Efficiency Normalization

The performance of the system is illustrated in Figure 13. The relationship between energy input and output of the system is assumed linear for the purposes of this normalization. This relationship between system energy input and output can be established using the point-slope formula for a line, with the line referred to as the system performance line in this analysis. The intersection of the y-axis can be considered the energy required to maintain system temperature at zero output, also referred to as total system standby loss, with energy input increasing from there as a function of increasing output.

Figure 13: Normalization of 24-hour Profile Tests for Comparison



Source: Fisher-Nickel

Equation 8: System Performance Line Equation

$$IE_{NORM} = m * OE_{NORM} + \text{S.L.}$$

Where:

m = $\frac{IE_{TEST} - S.L.}{OE_{TEST}}$ = Slope of system performance line

$I.E._{TEST}$ = Total system energy input during each test

$O.E._{TEST}$ = Total system energy output during each test

S.L. = Total energy required to maintain system temperature at zero energy output for 24 hours, also referred to as standby loss

IE_{NORM}= Normalized total energy input into the system during each 24-hr test

Equation 9: Calculation of Normalized Total System Output Energy during each 24-hour test

$$OE_{NORM} = O.E._{TEST} * \frac{V_{NORM}}{V_{TEST}}$$

Where:

V_{NORM} = Total delivery volume for normalization of system output

V_{TEST} = Actual total delivery volume measured during test

Once the characterization of the performance line is complete, the Normalized OWSE can be calculated.

Equation 10: Normalized Out-of-Wall System Efficiency

$$\eta_{OWSE} = \frac{OE_{NORM}}{IE_{NORM}}$$

Calculation of Water Heater Operating Efficiency

The WHOE (for Test and Normalized water volumes) was calculated in the same manner as OWSE, with the only exception being that the water heater outlet temperature was used instead of the average fixture outlet temperature in the energy output equation.

All average temperatures for all calculations using water heater outlet temperature and fixture temperature are mass weighted.

CHAPTER 5: Laboratory Results and Discussion

Tables 6 and 7 show the OWSE data used for this section's graphs. They include the average fixture delivery temperature for reference.

Table 6: Baseline System Efficiency Summary Data

Test Number	Water Heater*	Recirc Pump Control**	Nominal Recirc Rate	System Insulation	Normalized Out-of-Wall Efficiency	Average Delivery Temp (°F)
36	CS	On, MPR	3.5 gpm	Off	65.0%	115.7
57	CS	On	3.5 gpm	On	82.1%	121.1
42	CT	On	3.5 gpm	Off	60.0%	106.6
62	CT	On	3.5 gpm	On	79.2%	107.2
47	NCS	On	3.5 gpm	Off	48.1%	115.4
67	NCS	On	3.5 gpm	On	62.1%	121.1
52	NCT	On	3.5 gpm	Off	52.8%	111.0
72	NCT	On	3.5 gpm	On	66.1%	114.7
46	MNS	Off	0 gpm	Off	63.0%	108.2
35	CS	Off	0 gpm	Off	85.6%	107.7
51	NCT	Off	0 gpm	Off	68.0%	98.2
41	CT	Off	0 gpm	Off	60.0%	112.4
56	CS	Off	0 gpm	On	90.9%	116.3
66	NCS	Off	0 gpm	On	69.1%	118.5
71	NCT	Off	0 gpm	On	70.1%	105.7
37	CS	On, LPR	3.5 gpm	Off	56.7%	113.5
38	CS	DC	3.5 gpm	Off	74.8%	111.6
39	CS	Timeclock	3.5 gpm	Off	70.3%	115.6
40	CS	Aquastat	3.5 gpm	Off	68.2%	113.7
44	CT	Timeclock	3.5 gpm	Off	59.9%	106.0

Test Number	Water Heater*	Recirc Pump Control**	Nominal Recirc Rate	System Insulation	Normalized Out-of-Wall Efficiency	Average Delivery Temp (°F)
45	CT	Aquastat	3.5 gpm	Off	59.5%	112.4
48	NCS	DC	3.5 gpm	Off	61.3%	112.7
49	NCS	Timeclock	3.5 gpm	Off	53.4%	114.6
50	NCS	Aquastat	3.5 gpm	Off	54.2%	114.4
53	NCT	DC	3.5 gpm	Off	62.2%	105.7
54	NCT	Timeclock	3.5 gpm	Off	58.4%	111.0
55	NCT	Aquastat	3.5 gpm	Off	57.7%	108.0
58	CS	DC	3.5 gpm	On	90.1%	116.0
59	CS	Timeclock	3.5 gpm	On	84.2%	120.9
60	CS	Aquastat	3.5 gpm	On	84.3%	119.6
68	NCS	DC	3.5 gpm	On	70.1%	118.7
69	NCS	Timeclock	3.5 gpm	On	65.5%	121.0
70	NCS	Aquastat	3.5 gpm	On	65.8%	121.2
73	NCT	DC	3.5 gpm	On	73.5%	110.1
74	NCT	Timeclock	3.5 gpm	On	71.5%	116.7
75	NCT	Aquastat	3.5 gpm	On	71.4%	118.1

*** CS (Condensing Storage); CT (Condensing Tankless); NCS (Non-Condensing Storage); NCT (Non-Condensing Tankless)**

**** MPR (Middle Return Port); LPR (Lower Return Port); DC (Demand Control)**

Source: Fisher-Nickel

Table 7: Optimized System Efficiency Summary Data

Test Number	Water Heater*	Recirculation Pump Control**	Nominal Recirculation Rate	Normalized Out-of-Wall Efficiency	Average Delivery Temp (°F)
1	CS	Off	0 gpm	82.5%	106.1
5	CS	On, MPR	1 gpm	68.6%	116.6
3	CS	On, MPR	3.5 gpm	65.9%	116.1
4	CS	On, MPR	6 gpm	64.6%	115.1
2	CS	On, LPR	3.5 gpm	62.9%	113.4
6	CS	Demand Control, LPR	3.5 gpm	81.2%	108.1
7	CS	Demand Control, MPR	3.5 gpm	80.5%	108.5
11	CS	Aquastat, MPR	3.5 gpm	68.7%	113.9
9	CS	Timeclock, MPR	3.5 gpm	68.5%	116.7
10	CS	Aquastat, LPR	3.5 gpm	67.0%	111.6
8	CS	Timeclock, LPR	3.5 gpm	66.1%	113.3
12	CT	Off	0 gpm	75.4%	103.0
14	CT	On	1 gpm	76.4%	112.9
17	CT	Aquastat	3.5 gpm	67.8%	103.2
16	CT	Timeclock	3.5 gpm	67.9%	112.0
13	CT	On	3.5 gpm	63.4%	111.7
18	NCS	Off	0 gpm	59.9%	94.8
20	NCS	Demand Control	3.5 gpm	50.4%	96.3
22	NCS	Aquastat	3.5 gpm	53.3%	112.0
21	NCS	Timeclock	3.5 gpm	50.8%	115.4
19	NCS	On	3.5 gpm	48.0%	115.8
23	NCT	Off	0 gpm	69.3%	95.3
26	NCT	Demand Control	3.5 gpm	66.5%	100.7
25	NCT	On	1 gpm	59.1%	106.7

Test Number	Water Heater*	Recirculation Pump Control**	Nominal Recirculation Rate	Normalized Out-of-Wall Efficiency	Average Delivery Temp (°F)
28	NCT	Aquastat	3.5 gpm	57.9%	110.3
27	NCT	Timeclock	3.5 gpm	57.5%	112.8
24	NCT	On	3.5 gpm	53.4%	113.1

*** CS (Condensing Storage); CT (Condensing Tankless); NCS (Non-Condensing Storage); NCT (Non-Condensing Tankless)**

**** MPR (Mi Fisher-Nickel**

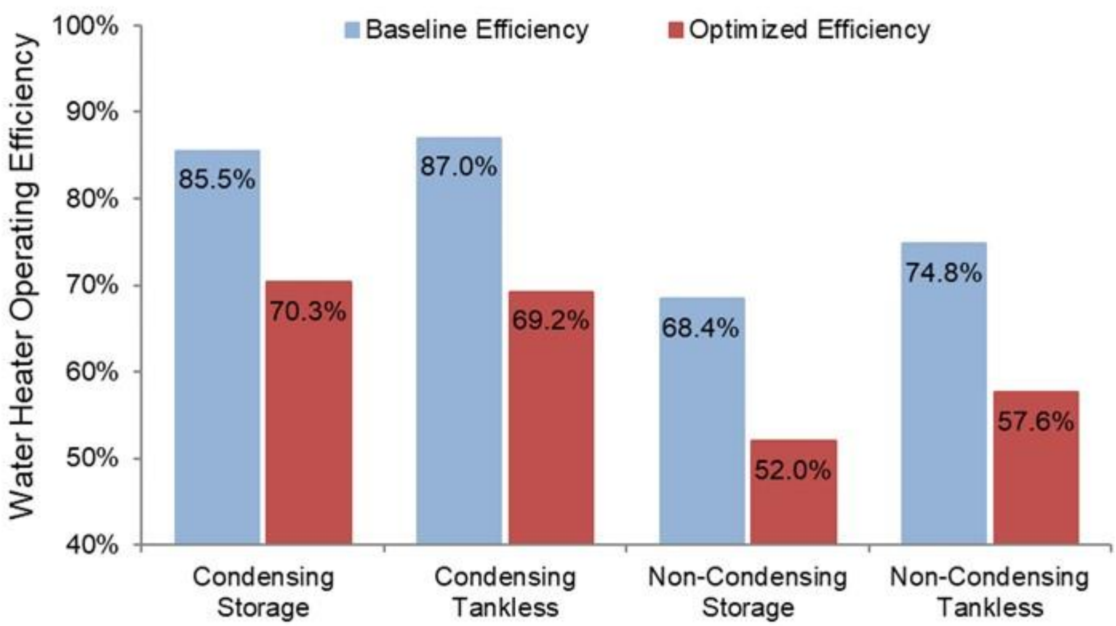
Source: Fisher-Nickel

Water Heater Performance — Continuous Recirculation

Water Heater Operating Efficiency

Figure 14 shows the WHOEs for the baseline and optimized distribution system configurations for each water heater under test. All cases include a constant recirculation rate of 3.5 gpm with pipe insulation. WHOE improved by 20 percent and 26 percent between the condensing storage and non-condensing storage tests for the baseline and optimized efficiency test, respectively. Similarly, with the tankless heaters, WHOE improved by 14 percent and 17 percent, respectively. The average WHOE improvement from selecting a condensing heater was 19 percent.

Figure 14: Water Heater Operating Efficiency of Heaters with Recirculation On



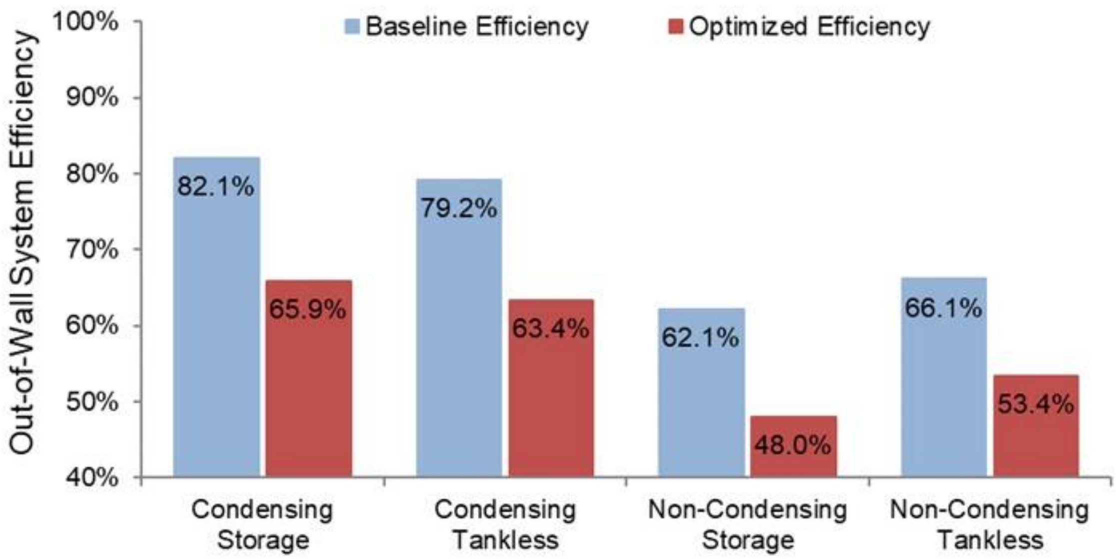
Source: Frontier Energy, Inc.

The only efficiency outlier in this test was the condensing tankless heater at 87 percent WHOE in the baseline efficiency test, which was abnormally higher than the condensing storage water heater at 85.5 percent. One consideration for the elevated WHOE is that the average outlet water heater temperature at 115°F for the baseline tankless condensing heater was 13°F lower than the average of the seven other heaters tested at 128°F. Otherwise the results are in accordance with results previously documented in the prior CEC report that mimicked the quick-service restaurant water profile.

Out-of-Wall System Efficiency

Figure 15 shows the OWSEs for the baseline and optimized distribution system configurations for each water heater under test. All cases include a constant recirculation rate of 3.5 gpm with pipe insulation. OWSE improved by 24 percent and 27 percent between the condensing storage and non-condensing storage tests for the baseline and optimized efficiency test, respectively. Similarly, with the tankless heaters, OWSE improved by 17 percent and 16 percent, respectively. The average OWSE improvement from selecting a condensing heater was 21 percent.

Figure 15: Out-of-Wall System Efficiency of Heaters with Recirculation On



Source: Frontier Energy, Inc.

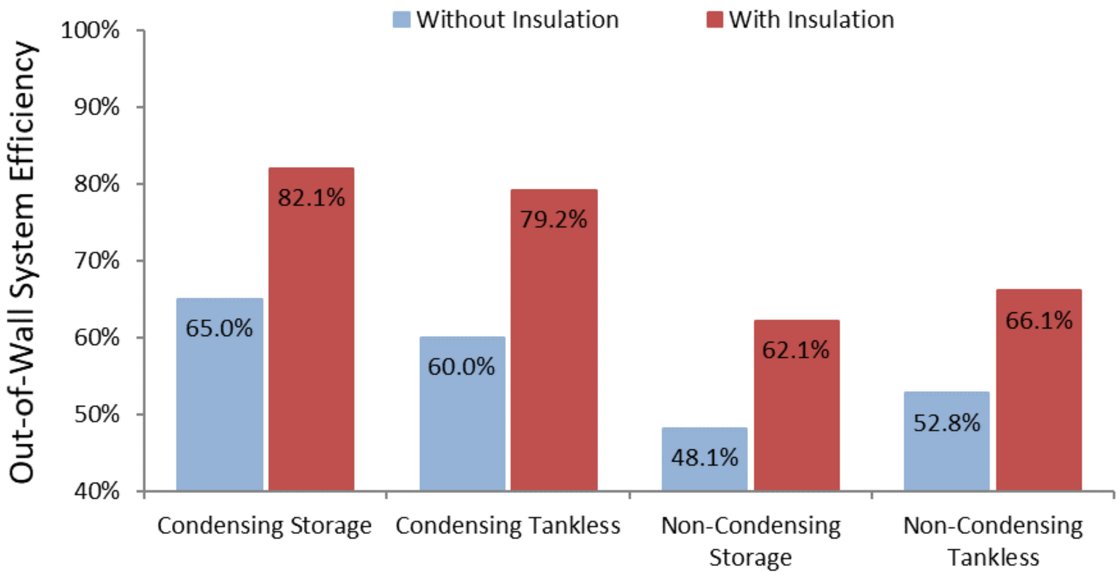
With the WHOE and OWSE, a clear hierarchy pattern of water heater performance emerged, with the condensing water heater performing the best and followed in succession by the condensing tankless, then the standard efficiency tankless and lastly the non-condensing storage heater, which is most prominently installed in commercial kitchens in California. Comparing the efficiency decrease from the WHOE to OWSE, the results show an average drop of 4.5 percent for the storage heaters and 6.6 percent for the tankless heaters. Thus, there is 5.6 percent drop when averaging all four heaters from an average WHOE of 70.6 percent to a 65.0 percent OWSE. Put simply, the average water heater and recirculating loop combination account for a 29 percent of the losses and the branch drops account for 6 percent of the heat losses in the system.

Pipe Insulation—Baseline Distribution System

Out-of-Wall System Efficiency

Figure 16 shows the OWSEs for the baseline distribution system configurations with and without insulation for each water heater under test. All cases include a constant recirculation rate of 3.5 gpm. OWSE improved between 20 to 30 percentage points with insulation. The increase in performance is a result of the reduction in thermal losses to ambient, thus increasing the outlet temperature at each fixture and therefore the amount of system energy output. The improvement does not appear to be impacted by the specific water heater supplying the system.

Figure 16: Out-of-Wall System Efficiency vs System Insulation on Baseline System with Recirculation On

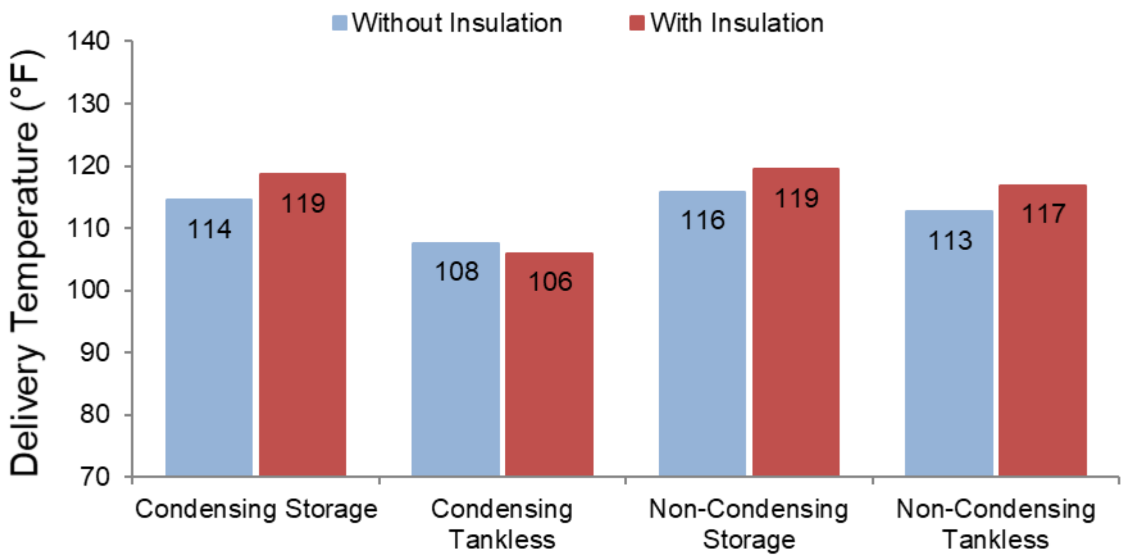


Source: Frontier Energy, Inc.

Out-of-Wall Delivery Temperature

The output temperature at Fixture 1 (combination of three sinks including the preparation and cookline handsinks and 1-compartment sink) increased between 4°F and 5°F by adding system insulation. Figure 17 shows the delivery temperature at Fixture 1 for all types of water heaters tested. Note the discrepancy in delivery temperature for the condensing tankless water heater. Issues identified with the condensing tankless unit will be discussed further in the key takeaways section.

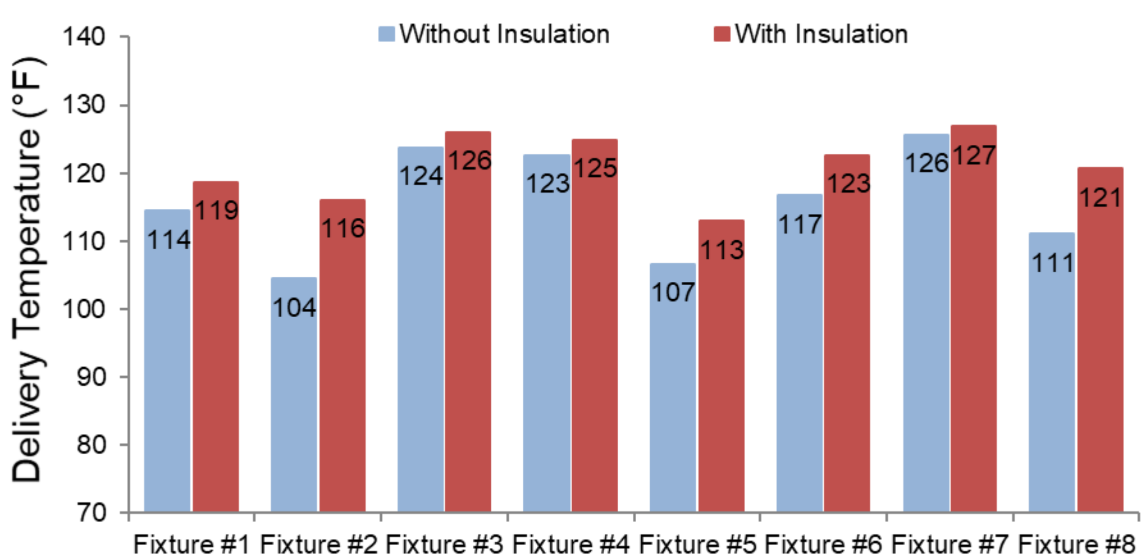
Figure 17: Delivery Temperature vs. System Insulation on Baseline System with Recirculation On



Source: Frontier Energy, Inc.

Fixture delivery temperature increased for every end use fixture when insulation was added to a distribution system operating under continuous recirculation and ranged between 3°F to 12°F, depending on the fixture. Figure 18 below depicts the average delivery temperature at all fixtures for the condensing storage water heater. Results are presented for the condensing storage water heater due to the +/- 2°F deadband setpoint, and thus a consistent water heater supply temperature.

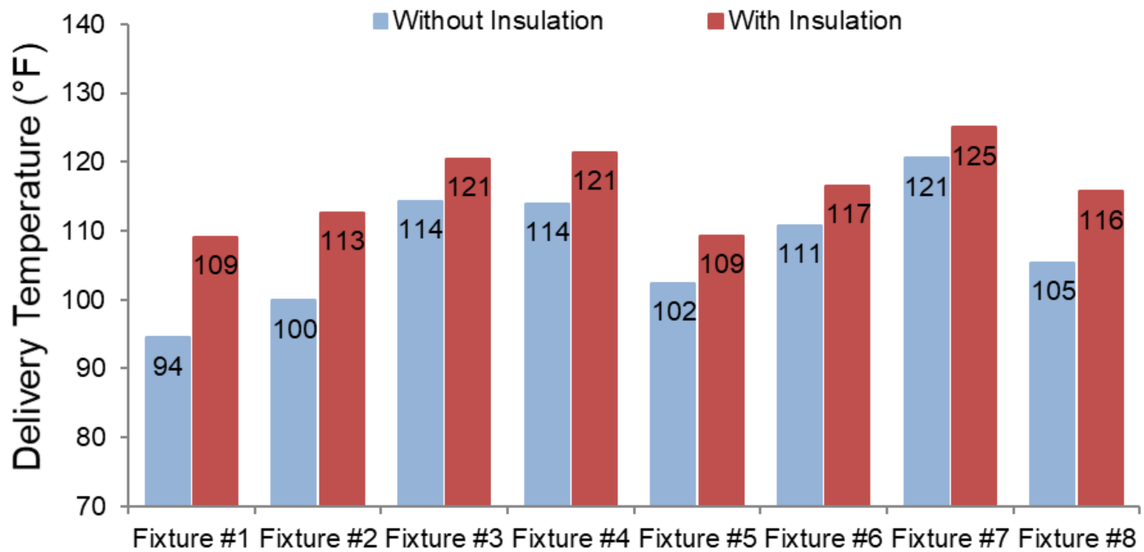
Figure 18: Delivery Temperature at all Fixtures with and without System Insulation on Baseline System with Recirculation On



Source: Frontier Energy, Inc.

The increase in delivery temperature upon insulating the distribution system was more pronounced when system recirculation was turned off. Delivery temperature improvement ranged between 4°F to 15°F depending on the fixture. Delivery temperatures dropped about 5°F or more on average at each fixture upon turning off the recirculation pump with an insulated system. Figure 19 illustrates the delivery temperature at all fixtures.

Figure 19: Delivery Temperature at all Fixtures with and without System Insulation on Baseline System with Recirculation Off



Source: Frontier Energy, Inc.

Recirculation Return Location—Optimized Distribution System using Condensing Storage Water Heater

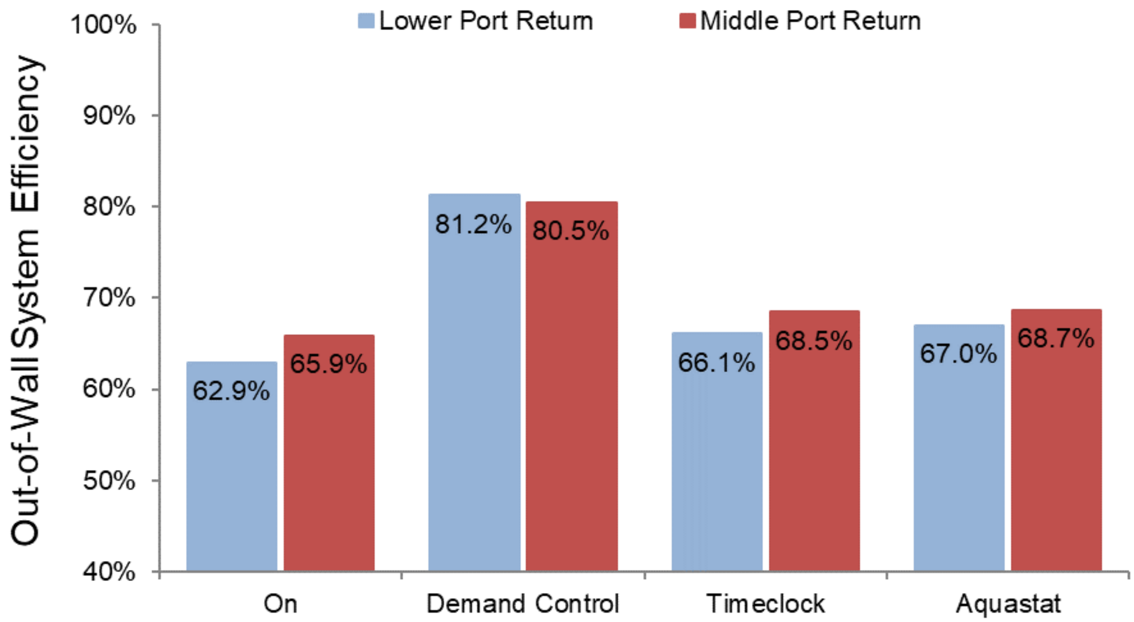
Condensing storage water heaters may include a dedicated recirculation return port at closer location to the center of the tank (as opposed to tapping into the supply inlet piping at the bottom of the tank). This upper return port (Figure 20) is placed strategically to enable temperature stratification within the storage tank, and under certain conditions enable energy recovery from condensation of the exhaust gases. The impact of recirculation return location was studied in the laboratory by testing with the recirculation directed to either the bottom or center of the tank using a three-way diverting valve.

Figure 20: Location of Dedicated Upper Return Port Vs. Lower Supply Port

Source: Frontier Energy, Inc.

The results in Figure 21 demonstrate that OWSE improved by an average of 3.5 percent or a couple percentage points when applying continuous recirculation and with the option to control the pump with a timer switch or aquastat.

Figure 21: Out-of-Wall System Efficiency at either Condensing Storage Tank Return Port with Various Pump Control Strategies



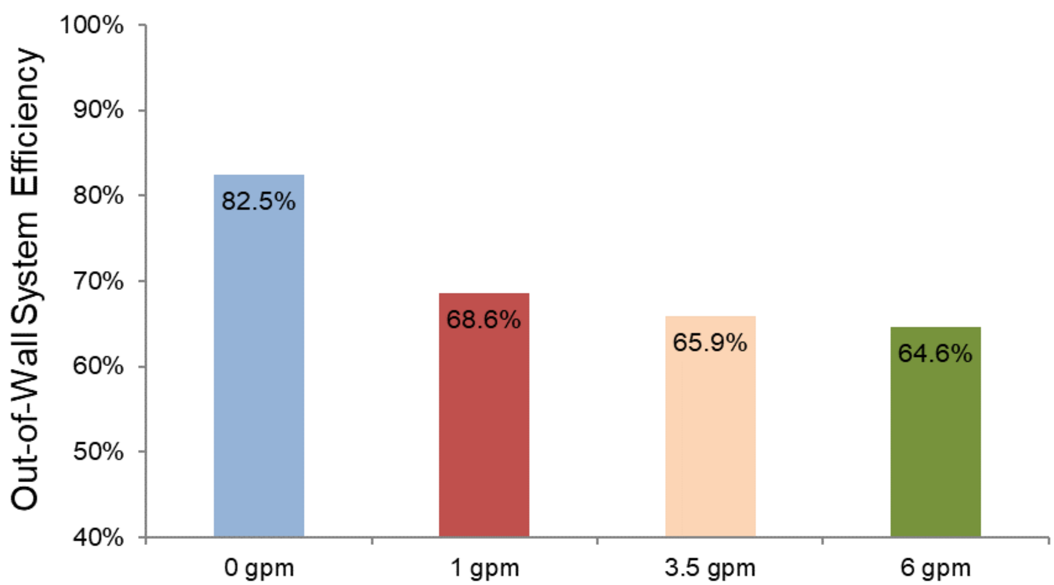
Source: Frontier Energy, Inc.

This is a key finding as a storage water heater with continuous recirculation is a common hot water system design, and operating savings are guaranteed with the addition of an upper return port. The results for the simulated demand control circulation indicate little change in performance, possibly due to the fact that performance was already significantly improved versus other control strategies. The lack of improvement seen when using the simulated demand control circulation could be because the return water temperature was significantly lower and closer to room air temperature and only experienced during the limited periods when the pump was operating. Field testing in the restaurant with D'MAND control circulation showed a return water temperature of 82°F, which suggests that it may be best to utilize the lower port for the recirculation return water since the temperature at that location of the tank is closer to the cold water supply temperature.

Recirculation Water Flow Rate — Optimized Distribution System using Condensing Storage Water Heater

Recirculation pump control strategies discussed in the previous section involved running the pump at a constant flowrate when operating at approximately 3.5 gpm. An optimal flowrate can also be established in addition to a modification of the runtime. Figure 22 demonstrates that the OWSE improves considerably as the recirculation rate is reduced to a condensing storage water heater. An improvement of 5.8 percent OWSE was found through reducing the flowrate in the distribution system from about 6 gpm to about 1 gpm. In a more typical field installation where the pump is operating at a 3.5 gpm flow rate, reducing it to 1 gpm would result in a 4.0 percent increase in efficiency. The improvement in performance likely results from the reduction in heat transfer coefficient inside the pipe with reduce flowrate, along with a reduction in return temperature to the condensing storage heater. Additionally, the lower flow rate would support temperature stratification in the storage heater for improved condensing operation.

Figure 22: Out-of-Wall System Efficiency at Upper Return Port for a Condensing Storage Heater at Various Flow Rates



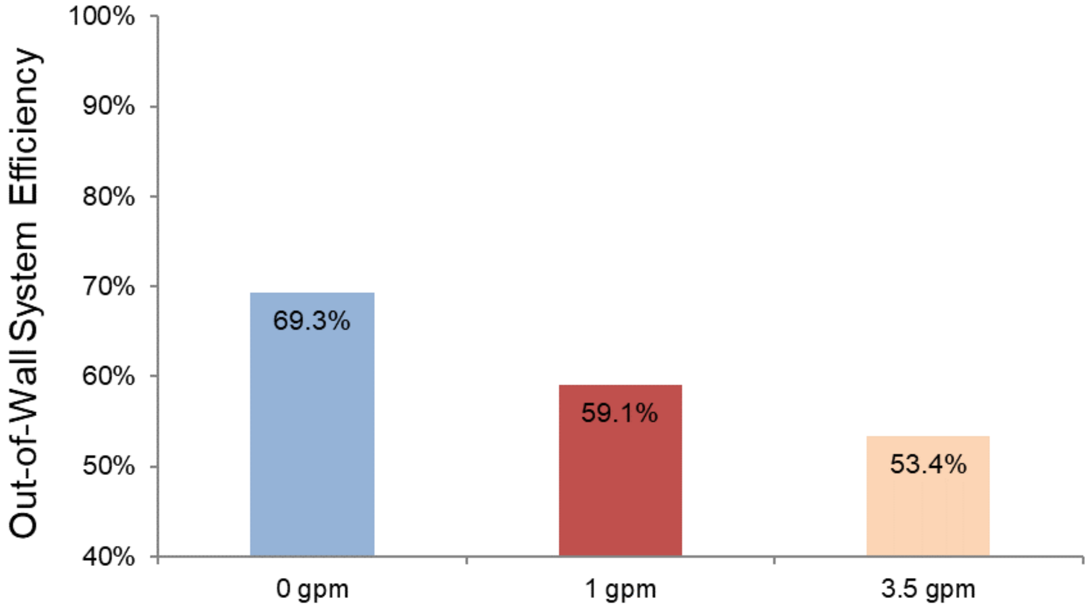
Source: Frontier Energy, Inc.

Recirculation Rate — Optimized Distribution System using Non-Condensing Tankless Water Heater

Efficiency

OWSE also demonstrated an improvement when reducing the recirculation flow rate for a non-condensing tankless water heater tied to the optimized distribution system (**Figure 23**). An OWSE improvement of 9.7 percent resulted from a reduction of recirculation flowrate from 3.5 gpm to 1 gpm. It should be noted that the outlet temperature provided by the non-condensing tankless water heater also decreased 4°F when reducing the flowrate from 3.5 gpm to 1 gpm. For reference, the condensing storage water heater output temperature only decreased 1°F when reducing recirculation flowrate from 3.5 gpm to 1 gpm.

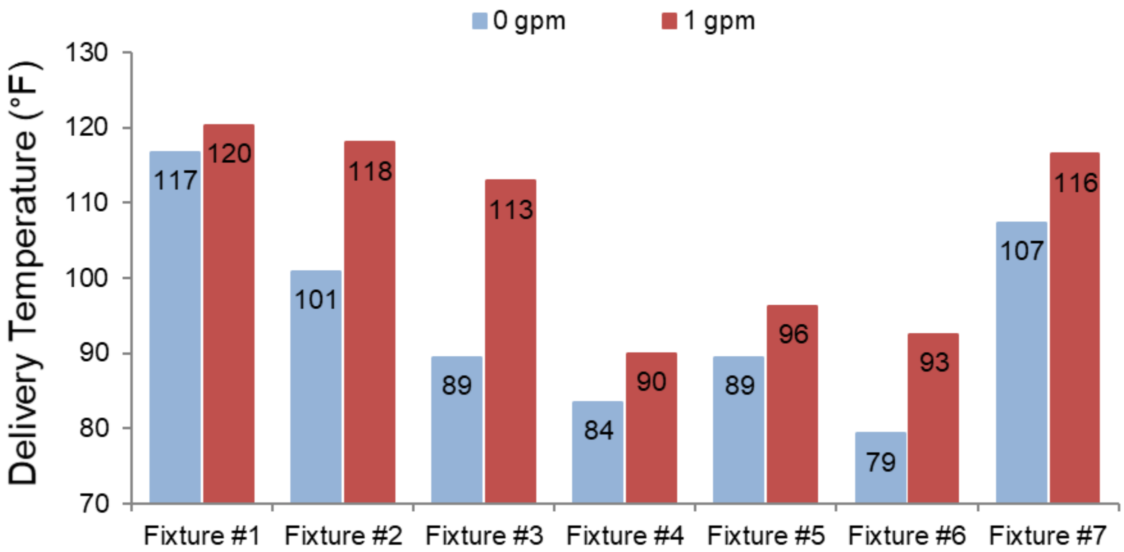
Figure 23: Out-of-Wall System Efficiency for a Non-Condensing Tankless Heater at Various Flow Rates



Delivery Temperature

The average delivery temperature reduced significantly with the removal of system recirculation. Some fixtures saw a reduction as high as 20°F in average delivery temperature when reducing the recirculation rate from approximately 1gpm to 0 gpm. Note in Figure 24 that the reduction in temperature is the least for fixture 1, the mop sink, which has an average draw rate of over 5 gpm. It is possible that some of the smaller draws are not activating the burner. For example, the average flow rate of fixture 3 was the lowest of the fixtures at 0.5 gpm, and this fixture saw the largest reduction in delivery temperature.

Figure 24: Delivery Temperature for a Non-Condensing Tankless Water Heater with Very Low (1 gpm) and No System Recirculation



Source: Frontier Energy, Inc.

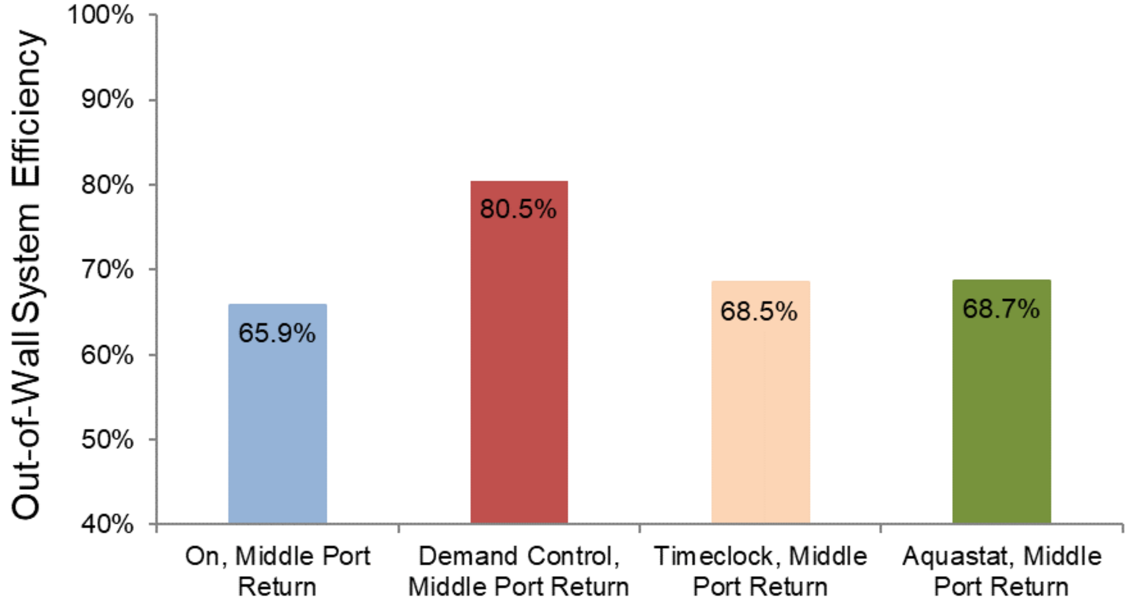
Recirculation Pump Control Strategies for the Optimized Distribution System

Condensing Storage Water Heater with System Insulation and Middle Port Return

Control of the system recirculation pump using the timer switch and aquastat resulted in approximately 4 percent increase in OWSE over the constant recirculation rate. These results suggest that there is minimal benefit of the aquastat over the timer switch. The aquastat temperature settings (115°F pump off, 110°F pump on) in the laboratory is atypical to how it is commonly used in the field (120°F pump off, 100°F pump on). With this setting, the pump operated for 4.4 hours at 3.5 gpm per day. The field setting would increase the OWSE, but the savings are partially offset in the laboratory test since the timer was used in conjunction with the aquastat sensor placed near the pump during testing thus turning off the pump for 25 percent of the day when the aquastat would have been operating in a typical field installation. This test would benefit from a redo, as a higher water heater outlet and aquastat setpoint temperatures are needed to represent real-world operation and to also minimize legionella in system's outside foodservice that are higher risk segments and that consume considerably less water.

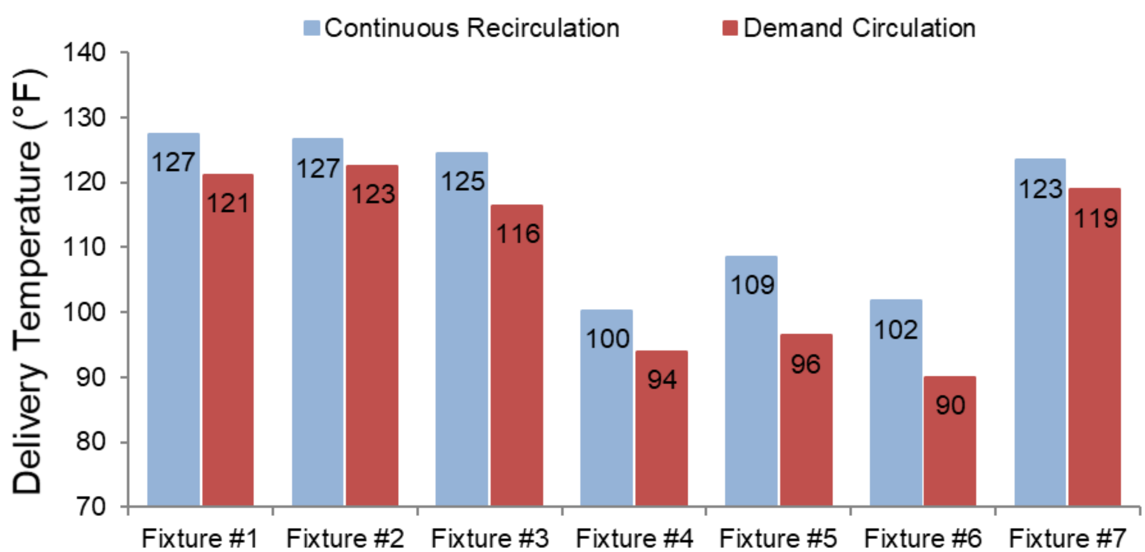
Simulated demand control circulation provided a significant improvement in OWSE over all the other control strategies but did result in a 5°F reduction in delivery temperatures (average of lower or middle port return tests) from 113°F to 108°F from the continuous recirculation case to the simulated demand control case (Figures 25 and 26).

Figure 25: Out-of-Wall System Efficiency and various Recirculation Control Strategies With a Condensing Tank Water Heater Tied to the Optimized System



Source: Frontier Energy, Inc.

Figure 26: Delivery Temperature and various Recirculation Control Strategies with a Condensing Tank Water Heater Tied to the Optimized System



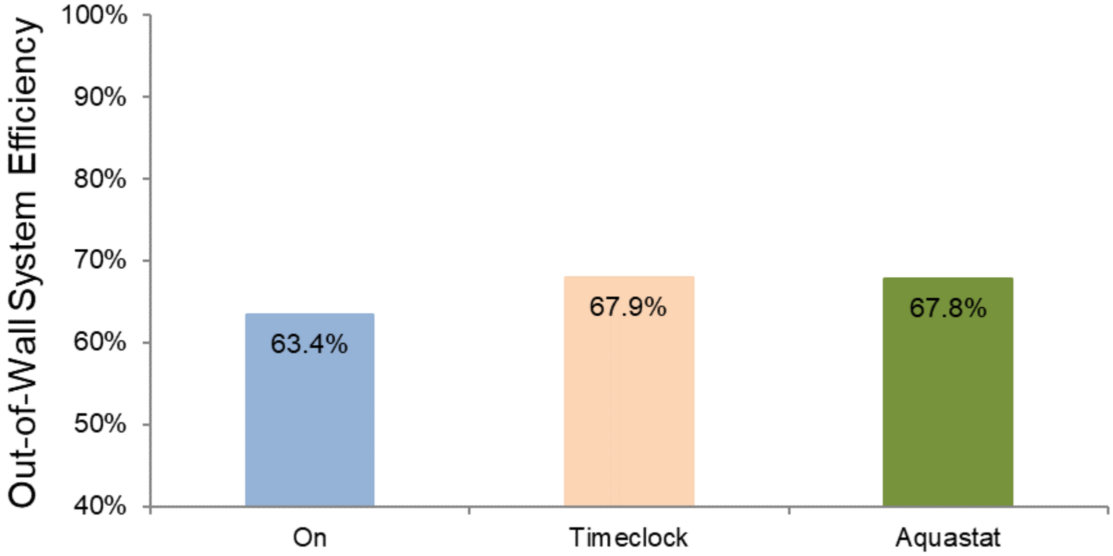
Source: Frontier Energy, Inc.

The laboratory testing was completed prior to the field testing of D'MAND Kontrol® System, thus the researchers could not rely on the field data of occupancy or default temperature setpoints of the D'MAND controller in setting up the laboratory simulation. The lab researcher simulated demand circulation by utilizing a timer during non-operating hours to turn off the pump while during the operating hours, it used a larger on/off setpoint temperatures of 100°F/115°F, with the placement of the inline (internal) temperature sensor at the last T in the distribution line. The laboratory tests are not a representation of the D'MAND system, but it provides a good understanding of how it will operate. The pump in the simulated demand system operated for 20 minutes at 3.5 gpm over a 24-hour test period, whereas the pump in the field demonstration operated for 35 minutes at 1 gpm.

Condensing Tankless Water Heater with System Insulation

An integrated pump within the condensing tankless water heater in series with the distribution circulation pump could not be turned off during testing, and thus the results below demonstrate little change in system performance (Figure 27). The integrated pump did not operate continuously. The slight increase in performance could be due to a reduced amount of system losses during the hours that the distribution system recirculation pump was not in operation.

Figure 27: Out-of-Wall System Efficiency and various Recirculation Control Strategies with a Condensing Tankless Water Heater Tied to the Optimized System

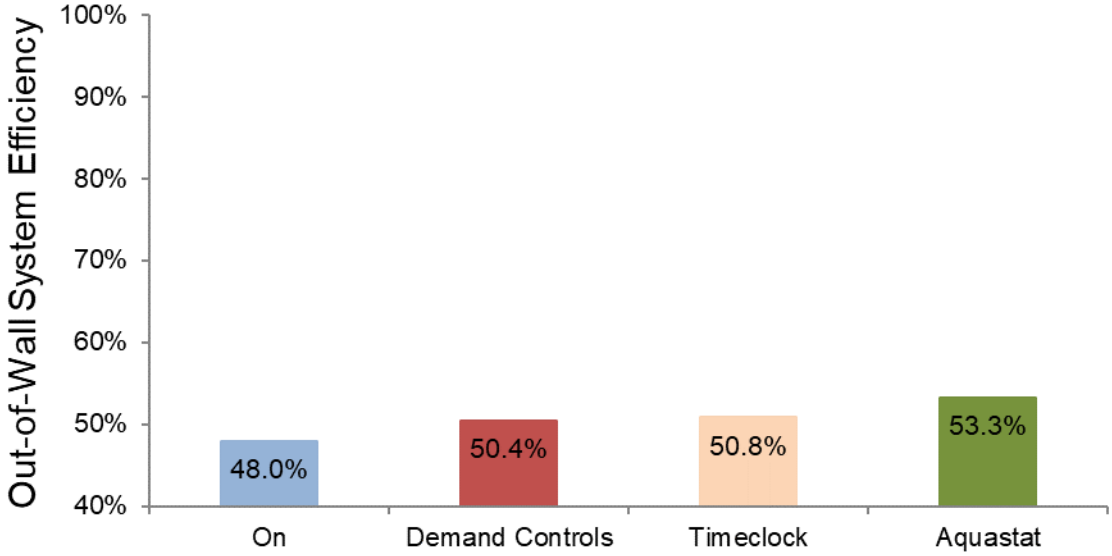


Source: Frontier Energy, Inc.

Non-Condensing Storage Water Heater with System Insulation

OWSEs for the Non-Condensing Storage Water Heater were consistently low, below 55 percent, for all recirculation control strategies in Figure 28. The simulated demand circulation pump control strategy was lower than the timeclock and aquastat control strategies, which didn't make sense.

Figure 28: Out-of-Wall System Efficiency and Various Recirculation Control Strategies with Non-Condensing Storage Water Heater Tied to Optimized System



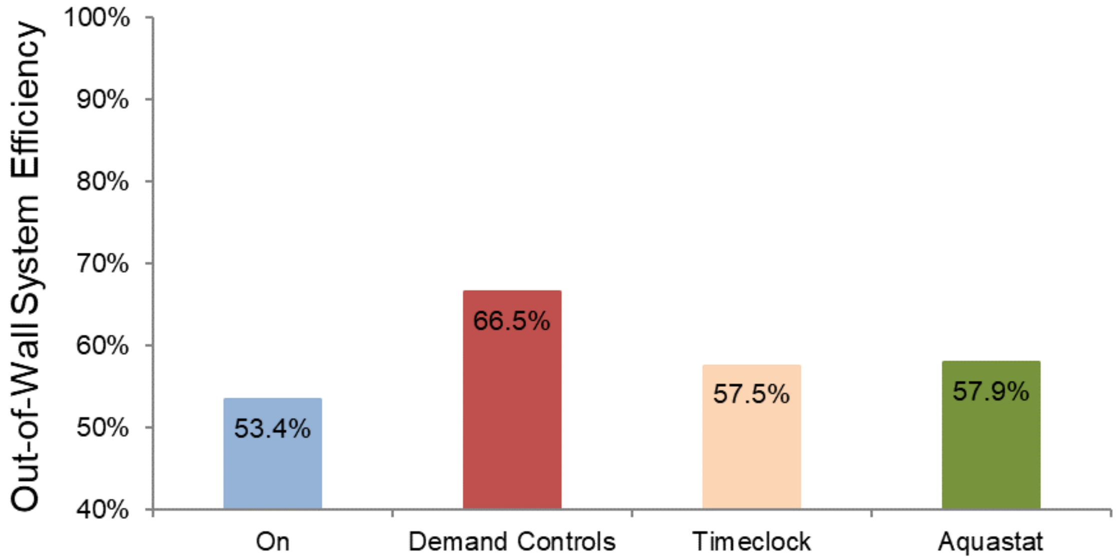
Source: Frontier Energy, Inc.

Looking deeper into it, the water temperatures for the simulated demand circulation including average water heater supply temperature of 138°F was elevated and average delivery temperature at 3-compartment sink of 96°F was down sharply for a difference of 42°F. This indicates that this was an outlier test as compared to the same test for the condensing storage heater where the difference was 8°F. The 3-compartment sink received water at 96°F which is roughly 30°F lower than the other recirculation test cases for the non-condensing storage heater. The system was not working properly, and thus this test result for demand controls for the non-condensing storage heater is invalid. It is likely that the check valve downstream of the recirculation pump malfunctioned, and water was flowing backwards through the recirculation return to the end use fixtures. This hypothesis is supported by the fact that the WHOE for the simulated demand circulation strategy was over 100 percent, indicating that the water heater was not heating up all of the water sent to the end use fixtures.

Non-Condensing Tankless Water Heater with System Insulation

Control of the system recirculation pump using the timer switch and aquastat resulted in approximately 8 percent increase in OWSE over the constant recirculation rate. These results continue to suggest that there is minimal benefit of the aquastat over the timer switch. Demand control circulation provided a significant improvement in OWSE at 66.5 percent in Figure 29, though did result in a 6°F reduction in average delivery temperatures to 101°F from the pump on strategy.

Figure 29: Out-of-Wall System Efficiency and Various Recirculation Control Strategies with Non-Condensing Tankless Water Heater Tied to Optimized System

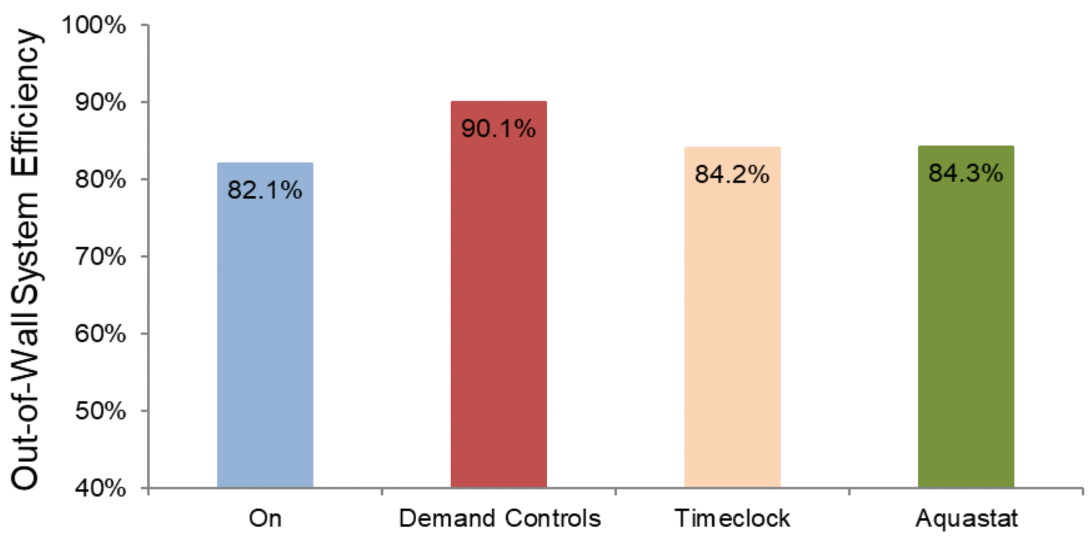


Source: Frontier Energy, Inc.

Recirculation Pump Control Strategies with the Baseline Distribution System

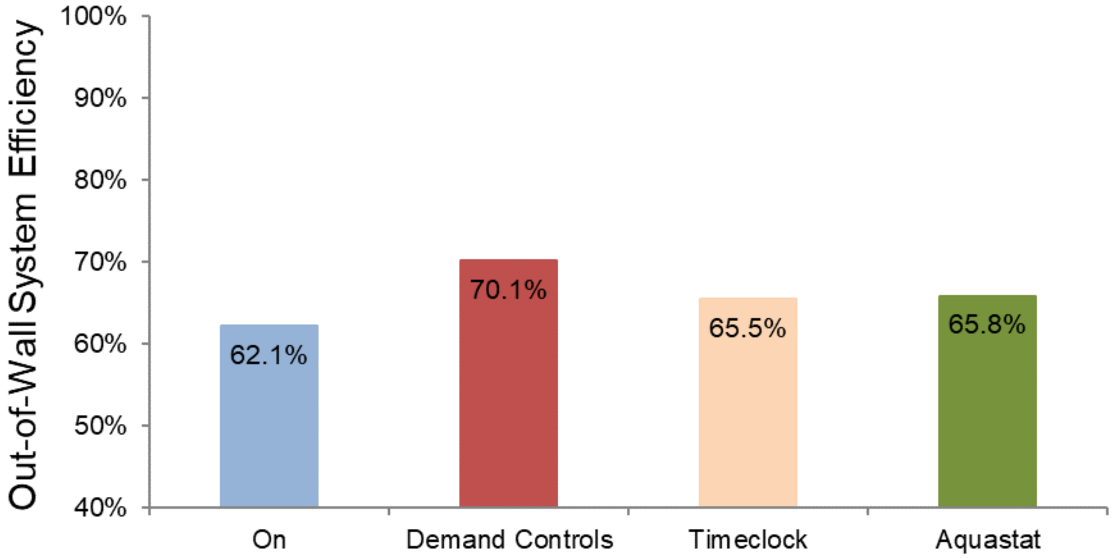
Control of the system recirculation pump using the timer switch and aquastat resulted in increases in OWSE over the constant recirculation rate for all water heater types when tied to the baseline distribution system. These results continue to suggest that there is minimal benefit of the aquastat over the timer switch, consistent with the results from the optimized system. Demand control circulation provided a significant improvement in OWSE for all water heater types though did result in a reduction in delivery temperatures (Figures 30, 31 and 32).

Figure 30: Out-of-Wall System Efficiency and Various Recirculation Control Strategies with Condensing Storage Water Heater Tied to Baseline System



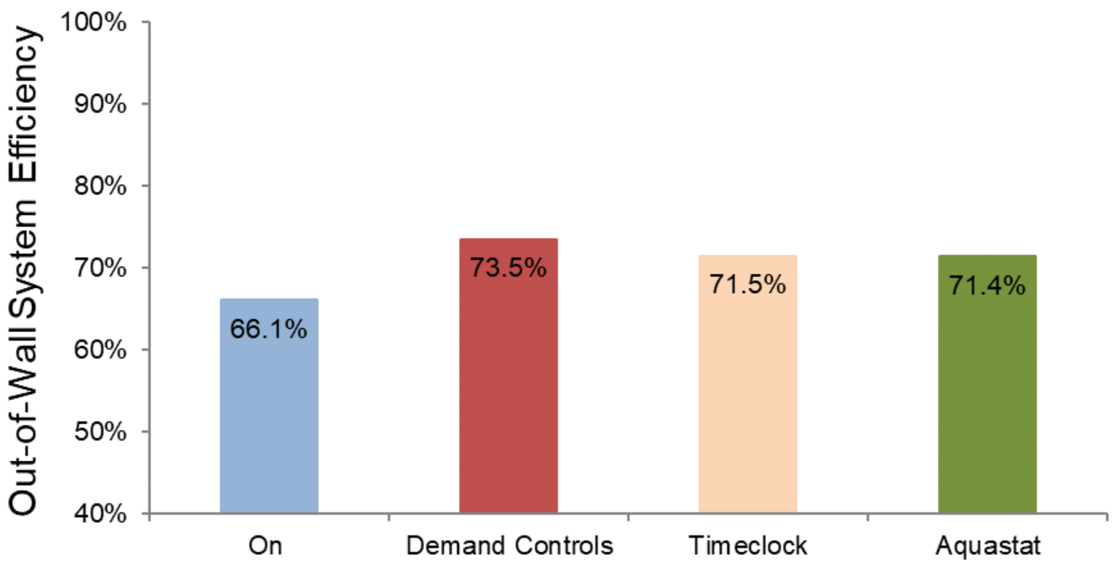
Source: Frontier Energy, Inc.

Figure 31: Out-of-Wall System Efficiency vs. Recirculation Control Strategies with a Non-Condensing Storage Water Heater Tied to the Baseline System



Source: Frontier Energy, Inc.

Figure 32: Out-of-Wall System Efficiency versus Recirculation Control Strategies with Non-Condensing Tankless Water Heater Tied to Baseline System



Source: Frontier Energy, Inc.

Operating Time of Recirculation Pump Control Strategies

Conversion of 24-Hour Pump Electricity Use to Pump Operating Time

The pump electricity use is stated in the lab results for each test in Appendix A. The pump electricity use under the continuous recirculation test over the 24-hour period consistently adds up to 12.3 kW. The electricity use for the demand control, timeclock and aquastat tests are converted to hours of operation based on the ratio of the pump electricity use to the maximum stated for the 24-hour period. For example, the timeclock test involves turning off the pump for a 6-hour period, which results in 2.7 kW of electricity use at the pump. Taking 2.7 kW and dividing by 3.6 kW and multiplying by 24 hours equals 18 hours of runtime. This calculation from pump electricity use to pump daily hours of operation was completed for all tests listed in Table 8. Highlighted sections indicate tests where the water pump data is questionable, which may indicate a faulty run with regard to pump operating time or inaccurate data.

Table 8: Water Pump Daily Operating Time

	Condensing Storage (h)	Non-Condensing Storage (h)	Non-Condensing Tankless (h)
Baseline System without Insulation			
Demand Control	24.0	1.4	2.6
Timeclock	24.0	18.0	18.0
Aquastat	24.0	6.3	10.6
Baseline System with Insulation			
Demand Control	0.7	0.4	0.9
Timeclock	18.0	18.0	18.0
Aquastat	10.1	8.5	12.0
Optimized System with Insulation			
Demand Control	0.3	1.3	0.6
Timeclock	18.0	18.0	18.0
Aquastat	4.4	4.2	5.6

Source: Frontier Energy, Inc.

Parsing out the questionable data, the results confirm that the timeclock tests worked well in turning off the pump for a 6-hour period during the late-night hours. The aquastat run time for the baseline system without insulation was roughly halve that at nine hours when averaging the non-condensing storage and tankless heaters. With the optimized system with insulation, the aquastat controlled pump operated for about a quarter of the time ranging from four hours for the storage heaters to five and half hours for the tankless heater. Looking at the demand control and aquastat data and comparing the non-condensing storage and tankless units, a pattern emerges that the runtime of the pump for the tankless heater is extended by 25 percent to 55 percent. Intuitively, this may be due to the fact that tankless heaters typically deliver water at 5°F below their setpoint and add a cold water slug each time they activate into the distribution line cooling the line further, whereas storage heaters typically deliver at 5°F above their setpoint thus operating the pump for a shorter time period as the controller setpoint temperature is met in a shorter time period.

The simulated demand controller operates the pump for the least amount of time ranging from approximately 20 minutes for the for the condensing storage heater to close to 40 minutes for the non-condensing tankless heater in the optimized case with insulation. The simulated demand circulation showed a reduction of at least 97 percent in operating time and pump electricity use from the continuous recirculation test. This met one of the goals of the research project, which was to demonstrate 80 percent electric savings. In comparison in the restaurant study, the D'MAND controller operated the pump for 35 minutes on average which corresponds reasonably with the lab test. The operating time is extended to roughly 30 minutes to one hour for the heaters in the baseline tests with insulation and further to 1.5 hours for the non-condensing storage heater without pipe insulation.

Simulated Demand Circulation Versus Continuous Recirculation

The results from the simulated demand circulation test for the non-condensing and condensing storage heater tests for the optimized system were not accurate due to the issue with the malfunctioning check valve that was causing elevated WHOEs at above the theoretical maximum values for each heater. The test results for the non-condensing tankless heaters did not such issues, thus key results from each of the recirculation control strategy tests are shown in Table 9 starting with the least efficient but with the best out-of-wall delivered energy. The findings show that a timeclock to turn off the recirculation pump during off hours improved WHOE and OWSE without impacting the energy delivered or the delivery temperature. The aquastat was almost as effective with the delivered energy and temperature with a slight improvement in OWSE. Between the last three pump control tests, there was a consistent increase in efficiency and decrease in delivery temperature going from the 1 gpm continuous recirculation test to demand circulation and lastly with the no flow test.

Table 9: The Effect of Recirculation Pump Control Strategies of the Non-Condensing Tankless Heater on Efficiency, Output Energy and Delivery Temperature

Recirculation Pump Control	Water Heater Operating Efficiency	Out-of-Wall System Efficiency	Heater Energy Input (Btu)	Out-of-Wall Energy Output (Btu)	Total System Losses (Btu)	Average Delivery Temp. (°F)
On ~3.5 gpm	57.6%	53.4%	342,517	181,959	160,558	113.1
Timeclock	62.2%	57.5%	317,824	182,474	135,350	112.8
Aquastat	56.7%	57.9%	300,573	173,573	127,000	110.3
On ~1.0 gpm	66.3%	59.1%	284,811	169,152	115,659	106.7
Demand	71.4%	66.5%	186,325	117,505	68,820	100.7
Off	79.5%	69.3%	172,896	119,852	53,044	95.3

Source: Frontier Energy, Inc.

The simulated demand circulation test was able to achieve a 25 percent increase in WHOE and OWSE versus the 3.5 gpm continuous recirculation test. Demand circulation reduced gas use at the heater by 46 percent, electricity use of the pump by 97 percent (as stated earlier) and reduce system losses by 57 percent, while only seeing a decline of 35 percent in out-of-wall energy output. To clearly quantify the savings potential of demand circulation and other control strategies, future tests would need to adjust heater setpoints of subsequent tests to deliver an equal amount of energy out-of-wall to compare against the baseline 3.5 gpm continuous recirculation test.

Key Takeaways

Key takeaways from the laboratory research results are summarized.

Retrocommissioning Opportunities

- The addition of a Timer Switch and Aquastat consistently improved OWSE and WHOE.
- There was not a significant improvement in performance of the aquastat above the timer switch alone. Note that the aquastat was “layered” with the timer switch, and thus under aquastat and timer switch control, the recirculation pump did not operate between 11:30 pm and 5:30 am. Thus, it could be deduced that there would be no performance benefit above that of constant recirculation with an aquastat with only a 5oF deadband tested in the laboratory—versus the typical 20oF deadband found in field installations.
- The performance improvement of simulated demand control circulation was consistent across all water heaters and distribution systems (except as discussed in the results section for test cases where there was clearly water bypassing the water heater and flowing directly to end uses through the return line). Improvements in system performance were likely due to the increased tolerance in the deadband for the demand circulation scenario. Since the feedback for the controller was inside the distribution pipe at the tee of the last fixture, there was more comfort with relaxing pump cut in the temperature setpoint to 100oF, with cut out at 115oF. The aquastat used a temperature probe further down the distribution system at the discharge of the recirculation pump that was placed on the surface of the pipe. The setpoint for the aquastat was also 115oF cut-out but with a 5oF deadband. It is possible that the aquastat could have yielded better performance results with different installation and programming approaches. Having temperature feedback inside the pipe will mitigate the damping effect of a surface temperature measurement and provide a more reliable means of distribution system temperature control.

Reducing Recirculating Pump Flow Rate

- The lower the recirculation rate the better the OWSE and WHOE. Reducing recirculation flow rates reduces heat transfer to ambient and improves stratification within the tank of storage water heaters in two ways. Low recirculation flow rates cause lower return water temperatures and less mixing in the tank due to recirculation, thus allowing for improved performance of condensing storage water heaters.

Proper Use of Upper Port Recirculation Return Line

- Upper recirculation return ports improve performance of condensing storage water heaters by keeping the warmer water in the top portions of the tank, allowing the cooler water in the bottom portion of the tank to absorb the energy released when water vapor in the exhaust gases are condensed.

Moving from Continuous Recirculation to Demand Circulation

- The simulated demand circulation provides more control over desired delivery temperature without sacrificing as much system losses as continuous recirculation in all scenarios. Both OWSE and WHOE will increase with lower recirculation return temperature to the water heater allowing for increased periods of condensing operation with applicable heaters.
- Simulated demand circulation increased the WHOE by 25 percent, which exceeded the project goal of 5 percent, albeit at a 35 percent lower out-of-wall energy output.
- The results showed that simulated demand circulation is superior by increasing OWSE and WHOE versus the three recirculation strategies. There would still be significant savings if the heater outlet temperature and/or flow rate of the pump was increased to deliver hot water to an equal out-of-wall energy output or average temperature with the continuous recirculation test.
- The simulated demand controller decreased pump electrical use by 97 percent, which was greater than the stated goal of 80 percent while maintaining reasonable hot water delivery performance at hand sinks.

Balancing High System Efficiencies and Delivery Temperatures

- Starting with the supply side, the best energy conversion efficiency is made possible when you can achieve as much condensing operation as possible.
- Delivery temperatures are improved with recirculation, but with warmer water returning to the water heater, the energy conversion efficiency of the water heater is reduced.
- Recirculation rate should be reduced as much as possible while still maintaining adequate delivery temperature.
- Water heaters that allow for condensing operation with system recirculation, such as a condensing storage water heater with upper recirculation return port, provide a balance between energy conversion efficiency and adequate delivery temperatures.

Inflexibility of Hybrid Condensing Tankless Heater (Integrated Pumping)

- The hybrid condensing tankless water heater the lab received was designed to operate without an external recirculation pump, and thus was not a good fit for this laboratory study. Care must be taken when selecting equipment for use in the field that is flexible for use with other equipment, such as an external system recirculation pump with its own controller.
- Eight out of ten tests except for the pump on test were omitted due to the limitations of the hybrid condensing tankless water heater.

CHAPTER 6: Conclusions and Recommendations

Conclusions

Laboratory testing provided comprehensive parametric experimental results of commercial hot water systems. Based on these results it is recommended to select a condensing water heater, reduce the length and diameter of distribution piping as much as possible (per code), insulate the distribution system and control the recirculation pump based on an in pipe temperature measurement at the most critical location (minimum temperature allowed). If the pump must operate continuously or frequently, it is best to reduce the flowrate as much as possible while still maintaining the required minimum out-of-wall delivery temperature.

This laboratory research project proved to be extremely challenging as much of the research had not been previously completed and the number of system variables and test scenarios being tested was daunting. Successes include the design of the modular laboratory with flexible water conditioning system, water heater test cells, distribution system rack and automated draw locations, and automating the 24-hour tests.

Specific conclusive findings include the following efficiency improvement measures:

- Lowering the pump water flow rate from a typical 3.5 gpm to 1 gpm under the continuous recirculation test resulted in a 4.0 percent improvement in out-of-wall system efficiency for the condensing tankless heater to the middle port and a 9.7 percent improvement for the condensing tankless water heater
- Changing the water recirculation return location from the lower port to the upper port under the recirculation scenarios (on, aquastat, timeclock) resulted in an average increase in out-of-wall system efficiency of 3.5 percent on the condensing storage water heater
- In the baseline configuration with a constant 3.5 gpm recirculation flow rate, the addition of pipe insulation improved the out-of-wall system efficiency for the four types of water heaters by 20 percent to 30 percent and improved delivery temperatures by 4°F to 5°F
- Adding a condensing storage heater to replace a non-condensing storage heater or condensing tankless to replace a non-condensing tankless unit to the baseline and optimized system with continuous recirculation improved water heater operating efficiency by an average of 19 percent and out-of-wall system efficiency by an average of 21 percent in the four test cases

Based on the water heater operating efficiency and out-of-wall system efficiency tests, the water heaters ranked from highest efficiency to lowest are: condensing storage, condensing tankless, non-condensing tankless, and non-condensing storage.

Lessons Learned

The instrumentation as initially installed was adequate, but the excessive use of pipe dope in the copper pipe connections during installation, which is sparingly used for potable hot water systems if at all caused major damage to some of the original instrumentation at the automated draw locations. This impacted the baseline system tests as well as all the simulated demand control tests for both the baseline and optimized distribution systems which occurred at the end of the testing period. This impacted the flow rate setting at several draw locations which were designed to mimic low flow rate sinks and caused variability in the total system draw volume for the tests mentioned. More importantly, a design flaw with the selection of a check valve that was intended to minimize the total head (differential pressure) on the pump caused periods of back flow (when water from the heater exits from the recirculation return location in the reverse direction towards the draw location) when a pump was not in operation. This affected mainly the delivery temperature and efficiency results for when the recirculation pump control was in the off or simulated demand control position.

As discussed, the condensing tankless heater used in this study was an atypical unit with an integrated pump that was not suitable for the test setup. Lastly, the simulation of the demand control strategy can be improved to better match the actual D'MAND system in future tests and the aquastat should be tested with a larger deadband without the addition of a timeclock to match real-world applications.

Taking everything into account, the laboratory tests showed some clear qualitative results that validated many of the project goals, but fell short of accurately quantifying the savings from each test to document savings estimates from the baseline to develop future utility incentive programs. Although the testing came up short in some areas, it delivered some new findings not initially intended, namely with showing the impact of recirculation flow rates on operating and system efficiency. Ultimately, the laboratory testing made some giant leaps in establishing a path to comprehensively test hot water systems and future testing will address the shortcomings to deliver improved results.

Recommendations

Laboratory Improvement Opportunities

It is recommended that the laboratory undergo improvements with regard to instrumentation to be able to simulate low flow fixtures and plumbing equipment to eliminate back flow under the non-continuous recirculation scenarios. Moving forward, it would be best to focus testing on a single water heater at a time with an insulated system rather than scripting dozens of tests with a variety of water heaters and pump flow rates. The focus should be on ensuring that the energy out-of-wall is consistent between tests and that adjustments upstream with the heater thermostat or pump controls are taken to ensure the results are readily comparable from a water and energy use, efficiency and delivery temperature standpoint. The focus of the testing should be more on distribution system design and recirculation pump control strategies.

The pump operating control scheme for the simulated demand control circulation test should closely match flow rates and occupancy data for the 24-hour field water use profile while relying on the laboratory inline return temperature sensor. Thus, the daily pump run time, operating profile and flow rate from the lab test should closely match the recorded field test to ensure an accurate comparison. Also, the 24-hour draw profile which is scripted should be dependent on total volume instead of duration to improve consistency between draw profiles.

The laboratory tests should be scripted by energy output instead of scripted draw volume or duration. Thus, the water heater and recirculation system performance should be compared at equivalent out-of-wall energy outputs.

Future Testing

Receiving funding to improve the laboratory testing facility is a high priority, followed by retesting the inconclusive baseline and optimized distribution system tests for the full-service restaurant. Then, the laboratory should be utilized to develop energy performance standards for recirculation flow rate and control. Future laboratory testing would benefit from regular oversight by a technical advisory committee that would include a master plumber and other senior hot water system researchers.

Additionally, a standard condensing tankless water heater, a hybrid heater (wall hung with integrated small storage tank) with the capability to operate without recirculation, and larger hybrid heaters that mate multiple tankless units to one storage tank should be tested. On the electric heater side, it would be ideal to setup a point-of-use tankless and mini-tank heater test cell assembly to use the five point-of-use heater water use profiles available from the restaurant field site tests. This would allow an apples-to-apples water and energy use comparison in the laboratory of the total baseline and optimized system as installed in the field.

The centralized water heater test cell would benefit from including light and medium duty commercial heat pump water heaters such as the CO_2 split system that can store water at elevated temperatures and two 120-gallon standalone R-134a heat pump water heaters that should meet the water heating load of at least the optimized system. The benefit of this expansion in testing is that it would allow for a comparison of advanced electric water heaters as California moves towards its decarbonization goals. The second benefit is that the lab results can be used to develop a heat pump water heater sizing guideline for California Environmental Health Association based on hot water demand, storage volume and generation capacity. Currently, there is no viable sizing guideline for heat pump water heaters that wouldn’t result in grossly oversizing the unit for the application. This barrier to market use is problematic as the hot water load in commercial kitchens is one of the largest segments in the commercial, industrial and institutional segments.

APPENDIX A: Lab Testing Results

Tables A-1 and A-2 summarize test system results.

Optimized (Proposed) System

Table A-1: Optimized System Test Results

Test 1 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	82.50%
Distribution System:	Proposed	Test Out of Wall Efficiency:	82.50%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	214,871
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	171,759
System Insulation:	On	Total System Losses (Btu):	43,113
Other Notes:	N/A	Normalized WH Op. Efficiency:	95.31%
		Test Out WH Op. Efficiency:	95.31%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	208.9	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	82.8
Usage (std. ft^3)	206.4	Tank 1	119.0		
Btu/Std. ft3	1041	Tank 2	109.2	Average Tank Ending Temp, θE	89.5
Gas Input (Btu)	214871	Tank 3	100.2		
Energy Input - Electric		Tank 4	85.5	Energy Storage (Btu/test)	5507.6
Usage (avg W)	0.0	Tank 5	68.0		
Elec Input (kWh)	0.0	Tank 6	60.4		
Elec Input (Btu)	0.0	Avg Temp.	90.4		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	128.3

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	44.6	166.0	95.4	3.6	5.4	5.7	29.8
Temp (°F)	122.5	120.4	113.8	91.8	99.1	82.9	112.0
Energy Out (Btu)	23,931	86,126	44,272	1,017	1,848	1,171	13,393

Test 2 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	**62.92%**
Distribution System:	Proposed	Test Out of Wall Efficiency:	**62.77%**
Recirculation Pump Control:	On, Lower Port Return	Total System Energy Input (Btu):	**290,164**
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	**182,069**
System Insulation:	On	Total System Losses (Btu):	**108,095**
Other Notes:	N/A	Normalized WH Op. Efficiency:	**66.59%**
		Test Out WH Op. Efficiency:	**66.43%**

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	269.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	117.7
Usage (std. ft^3)	266.9	Tank 1	122.8		
Btu/Std. ft3	1041	Tank 2	121.8	Average Tank Ending Temp, θE	117.8
Gas Input (Btu)	277881	Tank 3	121.6		
Energy Input - Electric		Tank 4	120.4	Energy Storage (Btu/test)	58.7
Usage (avg W)	150.0	Tank 5	119.5		
Elec Input (kWh)	3.6	Tank 6	119.0		
Elec Input (Btu)	12,283.0	Avg Temp.	120.8		

Average System Water Inlet Temp (°F)	58.1
Average Water Heater Supply Temp (°F)	124.8

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	44.7	163.3	94.9	4.3	5.9	5.5	29.2
Temp (°F)	123.4	122.8	120.1	99.8	107.9	98.4	121.4
Energy Out (Btu)	24,268	87,792	48,895	1,495	2,452	1,832	15,335

Test 3 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	65.89%
Distribution System:	Proposed	Test Out of Wall Efficiency:	65.72%
Recirculation Pump Control:	On, Middle Port Return	Total System Energy Input (Btu):	291,890
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	193,333
System Insulation:	On	Total System Losses (Btu):	98,557
Other Notes:	N/A	Normalized WH Op. Efficiency:	70.33%
		Test Out WH Op. Efficiency:	70.14%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	271.1	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	109.1
Usage (std. ft^3)	268.6	Tank 1	126.5		
Btu/Std. ft3	1041	Tank 2	125.6	Average Tank Ending Temp, θE	107.3
Gas Input (Btu)	279607	Tank 3	125.5		
Energy Input - Electric		Tank 4	124.4	Energy Storage (Btu/test)	-1515.4
Usage (avg W)	150.0	Tank 5	124.0		
Elec Input (kWh)	3.6	Tank 6	89.6		
Elec Input (Btu)	12,283.0	Avg Temp.	119.3		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	128.9

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	43.9	165.6	94.2	4.2	5.0	5.2	29.3
Temp (°F)	127.5	126.6	124.5	100.3	108.5	101.8	123.4
Energy Out (Btu)	25,339	94,454	52,108	1,487	2,096	1,909	15,940

Test 4 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	64.64%
Distribution System:	Proposed	Test Out of Wall Efficiency:	64.60%
Recirculation Pump Control:	On, Middle Port Return	Total System Energy Input (Btu):	293,215
Nominal Recirculation Rate (gpm):	~6 gpm	Out of Wall Energy Delivery (Btu):	189,609
System Insulation:	On	Total System Losses (Btu):	103,606
Other Notes:	N/A	Normalized WH Op. Efficiency:	68.48%
		Test Out WH Op. Efficiency:	68.43%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	277.0	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	123.0
Usage (std. ft^3)	269.9	Tank 1	124.5		
Btu/Std. ft3	1041	Tank 2	124.1	Average Tank Ending Temp, θE	122.8
Gas Input (Btu)	280932	Tank 3	123.6		
Energy Input - Electric		Tank 4	123.6	Energy Storage (Btu/test)	-195.1
Usage (avg W)	150.0	Tank 5	123.4		
Elec Input (kWh)	3.6	Tank 6	116.1		
Elec Input (Btu)	12,283.0	Avg Temp.	122.6		

Average System Water Inlet Temp (°F)	57.9
Average Water Heater Supply Temp (°F)	127.0

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	46.0	163.9	94.8	4.6	5.8	5.1	29.2
Temp (°F)	124.6	125.2	122.4	99.3	111.2	100.2	122.4
Energy Out (Btu)	25,533	91,662	50,816	1,570	2,570	1,786	15,673

Test 5 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	68.65%
Distribution System:	Proposed	Test Out of Wall Efficiency:	68.84%
Recirculation Pump Control:	On, Middle Port Return	Total System Energy Input (Btu):	283,386
Nominal Recirculation Rate (gpm):	~1 gpm	Out of Wall Energy Delivery (Btu):	196,556
System Insulation:	On	Total System Losses (Btu):	86,830
Other Notes:	N/A	Normalized WH Op. Efficiency:	73.48%
		Test Out WH Op. Efficiency:	73.69%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	266.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	116.2
Usage (std. ft^3)	260.4	Tank 1	126.3		
Btu/Std. ft3	1041	Tank 2	124.0	Average Tank Ending Temp, θE	114.5
Gas Input (Btu)	271103	Tank 3	121.8		
Energy Input - Electric		Tank 4	120.2	Energy Storage (Btu/test)	-1473.6
Usage (avg W)	150.0	Tank 5	117.2		
Elec Input (kWh)	3.6	Tank 6	69.1		
Elec Input (Btu)	12,283.0	Avg Temp.	113.1		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	129.3

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.1	168.0	95.0	4.3	5.7	5.3	29.3
Temp (°F)	127.6	126.8	124.3	100.0	112.1	100.8	124.4
Energy Out (Btu)	26,095	96,095	52,291	1,488	2,559	1,871	16,157

Test 6 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	81.25%
Distribution System:	Proposed	Test Out of Wall Efficiency:	79.23%
Recirculation Pump Control:	Demand Control, Lower Port Return	Total System Energy Input (Btu):	205,244
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	163,445
System Insulation:	On	Total System Losses (Btu):	41,799
Other Notes:	N/A	Normalized WH Op. Efficiency:	97.81%
		Test Out WH Op. Efficiency:	95.39%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	200.3	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	92.5
Usage (std. ft^3)	197.0	Tank 1	119.9		
Btu/Std. ft3	1041	Tank 2	110.4	Average Tank Ending Temp, θE	91.5
Gas Input (Btu)	205073	Tank 3	101.9		
Energy Input - Electric		Tank 4	88.6	Energy Storage (Btu/test)	-828.5
Usage (avg W)	2.1	Tank 5	73.6		
Elec Input (kWh)	0.1	Tank 6	61.3		
Elec Input (Btu)	170.6	Avg Temp.	92.6		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	129.8

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	40.6	138.5	104.9	5.0	7.5	5.3	26.3
Temp (°F)	121.2	121.4	115.8	93.1	96.5	89.1	119.4
Energy Out (Btu)	21,338	73,079	50,392	1,459	2,390	1,367	13,420

Test 7 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	80.50%
Distribution System:	Proposed	Test Out of Wall Efficiency:	77.72%
Recirculation Pump Control:	Demand Control, Middle Port Return	Total System Energy Input (Btu):	204,018
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	159,870
System Insulation:	On	Total System Losses (Btu):	44,148
Other Notes:	N/A	Normalized WH Op. Efficiency:	95.99%
		Test Out WH Op. Efficiency:	95.99%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	200.1	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	86.0
Usage (std. ft^3)	195.8	Tank 1	119.1		
Btu/Std. ft3	1041	Tank 2	109.3	Average Tank Ending Temp, θE	84.4
Gas Input (Btu)	203849	Tank 3	100.6		
Energy Input - Electric		Tank 4	87.6	Energy Storage (Btu/test)	-1307.8
Usage (avg W)	2.1	Tank 5	72.9		
Elec Input (kWh)	0.0	Tank 6	63.9		
Elec Input (Btu)	168.5	Avg Temp.	92.2		

Average System Water Inlet Temp (°F)	58.5
Average Water Heater Supply Temp (°F)	132.2

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	41.1	138.5	97.7	4.6	6.5	5.3	25.9
Temp (°F)	121.1	122.5	116.4	94.0	96.4	90.1	118.9
Energy Out (Btu)	21,371	73,678	46,999	1,342	2,053	1,395	13,030

Test 8 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	66.07%
Distribution System:	Proposed	Test Out of Wall Efficiency:	66.24%
Recirculation Pump Control:	Timeclock, Lower Port Return	Total System Energy Input (Btu):	278,652
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	184,807
System Insulation:	On	Total System Losses (Btu):	93,845
Other Notes:	N/A	Normalized WH Op. Efficiency:	70.41%
		Test Out WH Op. Efficiency:	70.41%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	264.6	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	115.6
Usage (std. ft^3)	258.8	Tank 1	124.0		
Btu/Std. ft3	1041	Tank 2	122.7	Average Tank Ending Temp, θE	115.3
Gas Input (Btu)	269439	Tank 3	121.5		
Energy Input - Electric		Tank 4	120.3	Energy Storage (Btu/test)	-217.1
Usage (avg W)	112.5	Tank 5	115.7		
Elec Input (kWh)	2.7	Tank 6	107.5		
Elec Input (Btu)	9,213.3	Avg Temp.	118.6		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	124.9

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.8	164.4	97.3	4.6	5.2	6.2	29.7
Temp (°F)	123.6	122.6	120.3	99.7	108.6	98.0	120.6
Energy Out (Btu)	24,966	88,176	50,358	1,593	2,197	2,072	15,445

Test 9 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	**68.51%**
Distribution System:	Proposed	Test Out of Wall Efficiency:	**68.40%**
Recirculation Pump Control:	Timeclock, Middle Port Return	Total System Energy Input (Btu):	**282,489**
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	**194,528**
System Insulation:	On	Total System Losses (Btu):	**87,962**
Other Notes:	N/A	Normalized WH Op. Efficiency:	**73.14%**
		Test Out WH Op. Efficiency:	**73.14%**

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	271.3	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	118.1
Usage (std. ft^3)	262.6	Tank 1	127.6		
Btu/Std. ft3	1041	Tank 2	126.4	Average Tank Ending Temp, θE	116.5
Gas Input (Btu)	273390	Tank 3	125.1		
Energy Input - Electric		Tank 4	122.4	Energy Storage (Btu/test)	-1301.8
Usage (avg W)	111.1	Tank 5	113.9		
Elec Input (kWh)	2.7	Tank 6	75.5		
Elec Input (Btu)	9,099.8	Avg Temp.	115.1		

Average System Water Inlet Temp (°F)	57.8
Average Water Heater Supply Temp (°F)	129.2

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.8	164.5	95.0	4.4	5.4	5.4	27.6
Temp (°F)	127.7	126.6	124.4	102.8	110.6	100.0	124.5
Energy Out (Btu)	26,623	94,087	52,619	1,648	2,372	1,895	15,284

Test 10 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	**66.98%**
Distribution System:	Proposed	Test Out of Wall Efficiency:	**67.19%**
Recirculation Pump Control:	Aquastat, Lower Port Return	Total System Energy Input (Btu):	**277,008**
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	**183,026**
System Insulation:	On	Total System Losses (Btu):	**93,982**
Other Notes:	N/A	Normalized WH Op. Efficiency:	**74.21%**
		Test Out WH Op. Efficiency:	**74.21%**

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	272.1	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	116.3
Usage (std. ft^3)	263.9	Tank 1	122.4		
Btu/Std. ft3	1041	Tank 2	118.6	Average Tank Ending Temp, θE	120.0
Gas Input (Btu)	274749	Tank 3	115.2		
Energy Input - Electric		Tank 4	110.8	Energy Storage (Btu/test)	3094.0
Usage (avg W)	27.6	Tank 5	103.6		
Elec Input (kWh)	0.7	Tank 6	94.1		
Elec Input (Btu)	2,259.1	Avg Temp.	110.8		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	127.9

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	46.2	162.8	97.1	5.0	7.1	5.8	29.7
Temp (°F)	124.9	121.7	119.3	95.9	103.6	94.8	121.2
Energy Out (Btu)	25,685	86,212	49,501	1,565	2,706	1,788	15,568

Test 11 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	68.71%
Distribution System:	Proposed	Test Out of Wall Efficiency:	68.38%
Recirculation Pump Control:	Aquastat, Middle Port Return	Total System Energy Input (Btu):	267,526
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	184,700
System Insulation:	On	Total System Losses (Btu):	82,826
Other Notes:	N/A	Normalized WH Op. Efficiency:	77.42%
		Test Out WH Op. Efficiency:	77.42%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	260.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	112.2
Usage (std. ft^3)	255.4	Tank 1	124.1		
Btu/Std. ft3	1041	Tank 2	119.4	Average Tank Ending Temp, θE	110.0
Gas Input (Btu)	265918	Tank 3	115.2		
Energy Input - Electric		Tank 4	108.2	Energy Storage (Btu/test)	-1755.0
Usage (avg W)	19.6	Tank 5	97.2		
Elec Input (kWh)	0.5	Tank 6	65.4		
Elec Input (Btu)	1,607.3	Avg Temp.	104.9		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	130.3

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	46.9	156.5	94.5	4.7	7.5	5.4	29.1
Temp (°F)	126.9	124.1	121.3	98.7	105.0	98.4	123.4
Energy Out (Btu)	26,852	85,969	49,719	1,605	2,931	1,801	15,822

Test 12 Results Summary							
Water Heater:		Condensing Tankless		Normalized Out of Wall Efficiency:		75.38%	
Distribution System:		Proposed		Test Out of Wall Efficiency:		75.38%	
Recirculation Pump Control:		Off		Total System Energy Input (Btu):		218,196	
Nominal Recirculation Rate (gpm):		0 gpm		Out of Wall Energy Delivery (Btu):		164,484	
System Insulation:		On		Total System Losses (Btu):		53,711	
Other Notes:		N/A		Normalized WH Op. Efficiency:		92.90%	
				Test Out WH Op. Efficiency:		92.90%	
Energy Input - Gas		Energy Input - Electric		Average System Water Inlet Temp (°F)			57.6
Usage (act. ft^3)	209.8	Usage (avg W)	0.0	Average Water Heater Supply Temp (°F)			126.9
Usage (std. ft^3)	209.6	Elec Input (kWh)	0.0				
Btu/Std. ft3	1041	Elec Input (Btu)	0.7				
Gas Input (Btu)	218195						
Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	37.6	165.9	102.1	4.3	7.6	5.5	29.0
Temp (°F)	120.7	117.5	111.0	88.7	95.6	79.1	108.5
Energy Out (Btu)	19,721	82,618	45,380	1,099	2,398	987	12,283

Test 13 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	63.36%
Distribution System:	Proposed	Test Out of Wall Efficiency:	62.90%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	280,324
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	176,320
System Insulation:	On	Total System Losses (Btu):	104,004
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.21%
		Test Out WH Op. Efficiency:	68.71%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	261.0	Usage (avg W)	149.9	Average System Water Inlet Temp (°F)	58.8
Usage (std. ft^3)	257.5	Elec Input (kWh)	3.6	Average Water Heater Supply Temp (°F)	126.6
Btu/Std. ft3	1041	Elec Input (Btu)	12,277.3		
Gas Input (Btu)	268047				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	35.6	156.5	101.1	4.5	7.9	6.7	29.1
Temp (°F)	124.3	123.1	120.6	98.1	101.6	93.1	121.1
Energy Out (Btu)	19,396	83,682	51,991	1,464	2,795	1,900	15,092

Test 14 Results Summary			
Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	76.38%
Distribution System:	Proposed	Test Out of Wall Efficiency:	62.87%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	279,703
Nominal Recirculation Rate (gpm):	~1 gpm	Out of Wall Energy Delivery (Btu):	175,850
System Insulation:	On	Total System Losses (Btu):	103,853
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.07%
		Test Out WH Op. Efficiency:	68.47%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	261.3	Usage (avg W)	149.3	Average System Water Inlet Temp (°F)	59.0
Usage (std. ft^3)	256.9	Elec Input (kWh)	3.6	Average Water Heater Supply Temp (°F)	126.8
Btu/Std. ft3	1041	Elec Input (Btu)	12,229.7		
Gas Input (Btu)	267473				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	37.1	161.5	96.2	4.0	6.2	5.6	29.1
Temp (°F)	123.8	123.3	120.3	97.2	108.0	97.5	120.4
Energy Out (Btu)	19,992	86,366	49,047	1,258	2,528	1,794	14,867

Test 16 Results Summary			
Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	67.90%
Distribution System:	Proposed	Test Out of Wall Efficiency:	66.89%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	257,762
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	172,406
System Insulation:	On	Total System Losses (Btu):	85,356
Other Notes:	N/A	Normalized WH Op. Efficiency:	74.50%
		Test Out WH Op. Efficiency:	73.39%

Energy Input - Gas		Energy Input - Electric		Average System Water Inlet Temp (°F)	58.6
Usage (act. ft^3)	239.4	Usage (avg W)	113.5	Average Water Heater Supply Temp (°F)	126.8
Usage (std. ft^3)	238.7	Elec Input (kWh)	2.7		
Btu/Std. ft3	1041	Elec Input (Btu)	9,289.6		
Gas Input (Btu)	248472				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	35.8	151.6	98.4	4.8	7.7	6.4	29.0
Temp (°F)	124.0	122.8	120.7	97.7	101.8	95.9	120.8
Energy Out (Btu)	19,470	80,899	50,763	1,542	2,757	1,986	14,990

Test 17 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	67.75%
Distribution System:	Proposed	Test Out of Wall Efficiency:	67.29%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	208,340
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	140,184
System Insulation:	On	Total System Losses (Btu):	68,156
Other Notes:	N/A	Normalized WH Op. Efficiency:	71.11%
		Test Out WH Op. Efficiency:	70.62%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	195.2	Usage (avg W)	77.0	Average System Water Inlet Temp (°F)	58.4
Usage (std. ft^3)	194.1	Elec Input (kWh)	1.8	Average Water Heater Supply Temp (°F)	109.9
Btu/Std. ft3	1041	Elec Input (Btu)	6,307.5		
Gas Input (Btu)	202032				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	38.2	157.0	101.0	5.0	7.9	5.3	29.5
Temp (°F)	121.8	108.5	99.5	88.0	88.9	95.1	120.8
Energy Out (Btu)	20,122	65,359	34,510	1,222	2,007	1,632	15,332

Test 18 Results Summary			
Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	**59.92%**
Distribution System:	Proposed	Test Out of Wall Efficiency:	**59.92%**
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	**211,980**
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	**126,927**
System Insulation:	On	Total System Losses (Btu):	**85,053**
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~105.44%~~
		Test Out WH Op. Efficiency:	~~105.44%~~

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	206.0	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	130.2
Usage (std. ft^3)	203.6	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.6	Average Tank Ending Temp, θE	130.3
Gas Input (Btu)	211980	Tank 3	121.0		
Energy Input - Electric		Tank 4	114.5	Energy Storage (Btu/test)	93.6
Usage (avg W)	0.0	Tank 5	121.1		
Elec Input (kWh)	0.0	Tank 6	N/A		
Elec Input (Btu)	0.0	Avg Temp.	121.3		

Average System Water Inlet Temp (°F)	58.6
Average Water Heater Supply Temp (°F)	131.9

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.6	164.1	109.8	4.1	7.5	5.9	29.6
Temp (°F)	119.1	101.1	93.1	83.5	87.8	76.4	102.8
Energy Out (Btu)	22,954	58,015	31,540	855	1,822	877	10,864

Test 19 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	**47.98%**
Distribution System:	Proposed	Test Out of Wall Efficiency:	**48.05%**
Recirculation Pump Control:	On	Total System Energy Input (Btu):	**378,220**
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	**183,456**
System Insulation:	On	Total System Losses (Btu):	**194,764**
Other Notes:	N/A	Normalized WH Op. Efficiency:	**51.96%**
		Test Out WH Op. Efficiency:	**52.04%**

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	355.5	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	129.2
Usage (std. ft^3)	351.5	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.9	Average Tank Ending Temp, θE	127.1
Gas Input (Btu)	365937	Tank 3	128.2		
Energy Input - Electric		Tank 4	127.8	Energy Storage (Btu/test)	-1721.1
Usage (avg W)	150.0	Tank 5	128.1		
Elec Input (kWh)	3.6	Tank 6	N/A		
Elec Input (Btu)	12,283.0	Avg Temp.	128.3		

Average System Water Inlet Temp (°F)	62.0
Average Water Heater Supply Temp (°F)	129.4

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.0	165.6	94.6	4.5	7.4	5.2	29.1
Temp (°F)	127.2	126.5	124.4	99.7	108.2	99.3	125.5
Energy Out (Btu)	24,363	88,801	49,036	1,417	2,844	1,616	15,380

Test 20 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	50.41%
Distribution System:	Proposed	Test Out of Wall Efficiency:	47.22%
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	203,303
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	101,362
System Insulation:	On	Total System Losses (Btu):	101,941
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~103.32%~~
		Test Out WH Op. Efficiency:	~~96.78%~~

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	197.7	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	132.5
Usage (std. ft^3)	194.7	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	133.1	Average Tank Ending Temp, θE	126.1
Gas Input (Btu)	202633	Tank 3	127.8		
Energy Input - Electric		Tank 4	121.8	Energy Storage (Btu/test)	-5360.0
Usage (avg W)	8.2	Tank 5	127.8		
Elec Input (kWh)	0.2	Tank 6	N/A		
Elec Input (Btu)	669.7	Avg Temp.	127.6		

Average System Water Inlet Temp (°F)	59.3
Average Water Heater Supply Temp (°F)	137.5

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	38.0	128.5	95.9	4.4	6.3	6.0	23.7
Temp (°F)	114.9	95.5	99.0	83.7	86.4	85.2	109.5
Energy Out (Btu)	17,551	38,711	31,637	892	1,411	1,289	9,870

Test 21 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	50.85%
Distribution System:	Proposed	Test Out of Wall Efficiency:	50.66%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	352,773
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	178,468
System Insulation:	On	Total System Losses (Btu):	174,306
Other Notes:	N/A	Normalized WH Op. Efficiency:	54.93%
		Test Out WH Op. Efficiency:	54.72%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	332.4	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	128.3
Usage (std. ft^3)	330.0	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	129.6	Average Tank Ending Temp, θE	128.6
Gas Input (Btu)	343561	Tank 3	128.8		
Energy Input - Electric		Tank 4	127.8	Energy Storage (Btu/test)	230.9
Usage (avg W)	112.5	Tank 5	128.7		
Elec Input (kWh)	2.7	Tank 6	N/A		
Elec Input (Btu)	9,212.8	Avg Temp.	128.7		

Average System Water Inlet Temp (°F)	62.2
Average Water Heater Supply Temp (°F)	129.5

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	44.9	157.2	96.3	4.2	7.3	6.0	29.1
Temp (°F)	126.8	126.0	124.2	99.0	107.8	98.7	125.5
Energy Out (Btu)	24,149	83,400	49,694	1,294	2,754	1,833	15,343

Test 22 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	53.30%
Distribution System:	Proposed	Test Out of Wall Efficiency:	53.32%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	338,513
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	175,199
System Insulation:	On	Total System Losses (Btu):	163,314
Other Notes:	N/A	Normalized WH Op. Efficiency:	60.21%
		Test Out WH Op. Efficiency:	60.24%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	325.6	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	121.0
Usage (std. ft^3)	323.1	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	129.0	Average Tank Ending Temp, θE	127.4
Gas Input (Btu)	336347	Tank 3	126.1		
Energy Input - Electric		Tank 4	122.7	Energy Storage (Btu/test)	5301.9
Usage (avg W)	26.4	Tank 5	126.0		
Elec Input (kWh)	0.6	Tank 6	N/A		
Elec Input (Btu)	2,166.0	Avg Temp.	126.0		

Average System Water Inlet Temp (°F)	60.2
Average Water Heater Supply Temp (°F)	130.2

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	45.7	158.6	98.8	4.1	7.4	6.4	29.5
Temp (°F)	123.6	121.1	121.0	96.6	103.8	96.0	122.1
Energy Out (Btu)	24,038	80,250	49,894	1,243	2,670	1,918	15,186

Test 23 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	69.32%
Distribution System:	Proposed	Test Out of Wall Efficiency:	69.32%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	172,896
Nominal Recirculation Rate (gpm):	0 gpm	Out of Wall Energy Delivery (Btu):	119,852
System Insulation:	On	Total System Losses (Btu):	53,044
Other Notes:	N/A	Normalized WH Op. Efficiency:	79.45%
		Test Out WH Op. Efficiency:	79.45%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	167.3	Usage (avg W)	2.8
Usage (std. ft^3)	165.9	Elec Input (kWh)	0.1
Btu/Std. ft3	1041	Elec Input (Btu)	229.6
Gas Input (Btu)	172667		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	105.4

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	44.4	157.1	98.9	4.6	7.4	6.5	29.9
Temp (°F)	116.8	100.9	89.5	83.5	89.4	79.3	107.3
Energy Out (Btu)	21,692	55,967	25,865	984	1,923	1,157	12,262

Test 24 Results Summary							
Water Heater:		Non-Condensing Tankless		Normalized Out of Wall Efficiency:		53.36%	
Distribution System:		Proposed		Test Out of Wall Efficiency:		53.12%	
Recirculation Pump Control:		On		Total System Energy Input (Btu):		342,517	
Nominal Recirculation Rate (gpm):		~3.5 gpm		Out of Wall Energy Delivery (Btu):		181,959	
System Insulation:		On		Total System Losses (Btu):		160,558	
Other Notes:		N/A		Normalized WH Op. Efficiency:		57.62%	
				Test Out WH Op. Efficiency:		57.36%	
Energy Input - Gas		Energy Input - Electric		Average System Water Inlet Temp (°F)			58.2
Usage (act. ft³)	321.6	Usage (avg W)	150.0	Average Water Heater Supply Temp (°F)			126.6
Usage (std. ft³)	317.2	Elec Input (kWh)	3.6				
Btu/Std. ft3	1041	Elec Input (Btu)	12,282.3				
Gas Input (Btu)	330235						

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	41.7	155.1	100.6	4.9	7.8	5.1	29.8
Temp (°F)	123.4	123.2	121.6	99.1	104.6	97.1	122.9
Energy Out (Btu)	22,618	83,848	53,076	1,679	3,028	1,656	16,053

Test 25 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	59.12%
Distribution System:	Proposed	Test Out of Wall Efficiency:	59.39%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	284,811
Nominal Recirculation Rate (gpm):	~1 gpm	Out of Wall Energy Delivery (Btu):	169,152
System Insulation:	On	Total System Losses (Btu):	115,659
Other Notes:	N/A	Normalized WH Op. Efficiency:	66.32%
		Test Out WH Op. Efficiency:	66.63%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	263.8	Usage (avg W)	150.0	Average System Water Inlet Temp (°F)	58.1
Usage (std. ft^3)	261.8	Elec Input (kWh)	3.6	Average Water Heater Supply Temp (°F)	122.6
Btu/Std. ft3	1041	Elec Input (Btu)	12,283.0		
Gas Input (Btu)	272528				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	43.1	162.1	102.6	4.0	7.1	5.4	29.9
Temp (°F)	120.3	118.0	112.9	90.0	96.3	92.5	116.5
Energy Out (Btu)	22,315	80,725	46,764	1,062	2,246	1,533	14,507

Test 26 Results Summary			
Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	66.49%
Distribution System:	Proposed	Test Out of Wall Efficiency:	63.06%
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	186,325
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	117,505
System Insulation:	On	Total System Losses (Btu):	68,820
Other Notes:	N/A	Normalized WH Op. Efficiency:	71.36%
		Test Out WH Op. Efficiency:	67.68%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	182.7	Usage (avg W)	4.0	Average System Water Inlet Temp (°F)	58.3
Usage (std. ft^3)	178.7	Elec Input (kWh)	0.1	Average Water Heater Supply Temp (°F)	107.4
Btu/Std. ft3	1041	Elec Input (Btu)	327.0		
Gas Input (Btu)	185998				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	37.4	132.0	99.0	4.9	6.3	5.1	24.3
Temp (°F)	117.6	103.2	100.5	89.6	93.3	89.3	111.1
Energy Out (Btu)	18,439	49,279	34,678	1,284	1,829	1,328	10,669

Test 27 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	57.54%
Distribution System:	Proposed	Test Out of Wall Efficiency:	57.41%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	317,824
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	182,474
System Insulation:	On	Total System Losses (Btu):	135,350
Other Notes:	N/A	Normalized WH Op. Efficiency:	62.20%
		Test Out WH Op. Efficiency:	62.07%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	299.9	Usage (avg W)	112.5
Usage (std. ft^3)	296.5	Elec Input (kWh)	2.7
Btu/Std. ft3	1041	Elec Input (Btu)	9,212.8
Gas Input (Btu)	308611		

Average System Water Inlet Temp (°F)	58.1
Average Water Heater Supply Temp (°F)	126.5

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	42.0	156.1	100.7	5.0	7.8	5.7	29.8
Temp (°F)	122.4	123.0	121.8	98.3	104.7	96.2	122.9
Energy Out (Btu)	22,438	84,138	53,338	1,659	3,034	1,811	16,056

Test 28 Results Summary					
Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	57.93%		
Distribution System:	Proposed	Test Out of Wall Efficiency:	57.75%		
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	300,573		
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	173,573		
System Insulation:	On	Total System Losses (Btu):	127,000		
Other Notes:	N/A	Normalized WH Op. Efficiency:	56.71%		
		Test Out WH Op. Efficiency:	56.53%		

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	287.5	Usage (avg W)	35.3	Average System Water Inlet Temp (°F)	58.1
Usage (std. ft^3)	286.0	Elec Input (kWh)	0.8	Average Water Heater Supply Temp (°F)	117.2
Btu/Std. ft3	1041	Elec Input (Btu)	2,888.9		
Gas Input (Btu)	297684				

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	43.0	157.4	97.9	3.7	7.4	6.1	30.3
Temp (°F)	121.1	119.7	118.7	94.2	102.1	96.7	119.1
Energy Out (Btu)	22,540	80,583	49,300	1,120	2,720	1,957	15,353

Test 29 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	76.95%
Distribution System:	Proposed	Test Out of Wall Efficiency:	76.95%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	208,661
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	162,555
System Insulation:	On	Total System Losses (Btu):	46,106
Other Notes:	Simulated Aerator	Normalized WH Op. Efficiency:	96.80%
		Test Out WH Op. Efficiency:	96.80%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	203.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	87.9
Usage (std. ft^3)	200.4	Tank 1	119.6		
Btu/Std. ft3	1041	Tank 2	110.0	Average Tank Ending Temp, θE	85.5
Gas Input (Btu)	208661	Tank 3	101.3		
Energy Input - Electric		Tank 4	88.5	Energy Storage (Btu/test)	-1996.7
Usage (avg W)	0.0	Tank 5	74.0		
Elec Input (kWh)	0.0	Tank 6	61.2		
Elec Input (Btu)	0.0	Avg Temp.	92.5		

Average System Water Inlet Temp (°F)	58.1
Average Water Heater Supply Temp (°F)	133.3

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	40.1	140.0	101.8	5.3	6.5	3.5	25.8
Temp (°F)	121.7	122.1	116.7	91.5	95.3	79.0	119.1
Energy Out (Btu)	21,201	74,528	49,638	1,477	2,018	606	13,086

Test 30 Results Summary			
Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	77.41%
Distribution System:	Proposed	Test Out of Wall Efficiency:	77.41%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	208,503
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	161,895
System Insulation:	On	Total System Losses (Btu):	46,608
Other Notes:	Modified Drop Diameter	Normalized WH Op. Efficiency:	94.76%
		Test Out WH Op. Efficiency:	94.76%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	203.0	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	86.3
Usage (std. ft^3)	200.3	Tank 1	119.3		
Btu/Std. ft3	1041	Tank 2	109.6	Average Tank Ending Temp, θE	85.7
Gas Input (Btu)	208503	Tank 3	102.1		
Energy Input - Electric		Tank 4	89.2	Energy Storage (Btu/test)	-497.0
Usage (avg W)	0.0	Tank 5	73.8		
Elec Input (kWh)	0.0	Tank 6	61.2		
Elec Input (Btu)	0.0	Avg Temp.	92.5		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	131.5

Fixture Name	Mop	3-Comp	Pre-Rinse	Dishroom	Cookline	Prep	1-Comp
Volume (Gal)	40.6	137.8	101.5	5.3	6.5	6.4	25.4
Temp (°F)	121.3	122.0	116.0	94.8	94.5	90.9	119.5
Energy Out (Btu)	21,365	73,291	48,917	1,606	1,982	1,763	12,970

Source: Frontier Energy, Inc.

Baseline System

Table A-2: Baseline Test Results

Test 35 Results Summary			
Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	85.55%
Distribution System:	Baseline	Test Out of Wall Efficiency:	85.55%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	467,234
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	397,701
System Insulation:	Off	Total System Losses (Btu):	69,533
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~115.04%~~
		Test Out WH Op. Efficiency:	~~115.04%~~

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	460.4	Location	Avg. Temp (^{o}F)	Average Tank Starting Temp, θ_s	85.9
Usage (std. ft^3)	448.8	Tank 1	117.1		
Btu/Std. ft3	1041	Tank 2	107.3	Average Tank Ending Temp, θ_E	85.9
Gas Input (Btu)	467234	Tank 3	98.5		
Energy Input - Electric		Tank 4	83.3	Energy Storage (Btu/test)	58.7
Usage (avg W)	0.0	Tank 5	67.1		
Elec Input (kWh)	0.0	Tank 6	60.5		
Elec Input (Btu)	0.0	Avg Temp.	89.0		

Average System Water Inlet Temp (^{o}F)	57.7
Average Water Heater Supply Temp (^{o}F)	127.8

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	54.7	59.2	330.3	152.2	129.0	44.6	42.2	110.8
Temp (^{o}F)	94.5	99.9	114.3	113.9	102.4	110.7	120.5	105.4
Energy Out (Btu)	16,723	20,771	155,390	71,168	47,989	19,660	22,042	43,958

Test 36 Results Summary

Water Heater:	Condensing Storage
Distribution System:	Baseline
Recirculation Pump Control:	On, Middle Port Return
Nominal Recirculation Rate:	~3.5 gpm
System Insulation:	Off
Other Notes:	N/A

Normalized Out of Wall Efficiency:	65.01%
Test Out of Wall Efficiency:	67.63%
Total System Energy Input (Btu):	690,757
Out of Wall Energy Delivery (Btu):	465,212
Total System Losses (Btu):	225,545
Normalized WH Op. Efficiency:	76.30%
Test Out WH Op. Efficiency:	79.37%

Energy Input - Gas		In-Tank Condition	
Usage (act. ft^3)	662.3	Location	Avg. Temp (°F)
Usage (std. ft^3)	651.8	Tank 1	124.6
Btu/Std. ft3	1041	Tank 2	122.9
Gas Input (Btu)	678473	Tank 3	121.3
Energy Input - Electric		Tank 4	119.9
Usage (avg W)	150.0	Tank 5	118.7
Elec Input (kWh)	3.6	Tank 6	85.2
Elec Input (Btu)	12,283.7	Avg Temp.	115.4

Energy Storage	
Average Tank Starting Temp, θs	107.8
Average Tank Ending Temp, θE	108.6
Energy Storage (Btu/test)	660.6

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	128.1

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	56.6	59.6	327.5	151.8	134.4	43.6	41.6	122.1
Temp (°F)	114.4	104.5	123.7	122.6	106.6	116.7	125.7	111.1
Energy Out (Btu)	26,693	23,169	179,799	81,898	54,633	21,376	23,476	54,167

Test 37 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	56.71%
Distribution System:	Baseline	Test Out of Wall Efficiency:	59.58%
Recirculation Pump Control:	On, Bottom Port Return	Total System Energy Input (Btu):	714,745
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	426,584
System Insulation:	Off	Total System Losses (Btu):	288,161
Other Notes:	N/A	Normalized WH Op. Efficiency:	66.74%
		Test Out WH Op. Efficiency:	70.12%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	685.1	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	121.2
Usage (std. ft^3)	674.8	Tank 1	120.9		
Btu/Std. ft3	1041	Tank 2	119.1	Average Tank Ending Temp, θE	120.9
Gas Input (Btu)	702461	Tank 3	117.2		
Energy Input - Electric		Tank 4	115.2	Energy Storage (Btu/test)	-248.7
Usage (avg W)	150.0	Tank 5	113.3		
Elec Input (kWh)	3.6	Tank 6	112.9		
Elec Input (Btu)	12,283.7	Avg Temp.	116.4		

Average System Water Inlet Temp (°F)	61.8
Average Water Heater Supply Temp (°F)	124.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.4	55.8	327.1	151.3	137.0	44.4	41.9	150.6
Temp (°F)	112.4	103.1	120.0	119.5	103.5	112.4	122.5	114.1
Energy Out (Btu)	23,353	19,199	158,427	72,657	47,575	18,707	21,154	65,512

Test 38 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	74.80%
Distribution System:	Baseline	Test Out of Wall Efficiency:	77.16%
Recirculation Pump Control:	Demand Control	Total System Energy Input (Btu):	548,808
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	423,012
System Insulation:	Off	Total System Losses (Btu):	125,796
Other Notes:	N/A	Normalized WH Op. Efficiency:	95.94%
		Test Out WH Op. Efficiency:	98.96%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	530.9	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	89.9
Usage (std. ft^3)	515.4	Tank 1	118.1		
Btu/Std. ft3	1041	Tank 2	109.9	Average Tank Ending Temp, θE	90.5
Gas Input (Btu)	536524	Tank 3	103.4		
Energy Input - Electric		Tank 4	92.7	Energy Storage (Btu/test)	543.9
Usage (avg W)	150.0	Tank 5	77.7		
Elec Input (kWh)	3.6	Tank 6	63.1		
Elec Input (Btu)	12,283.7	Avg Temp.	94.2		

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	128.5

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	57.2	60.9	329.0	152.7	129.0	44.7	41.5	107.4
Temp (°F)	107.2	100.6	117.6	117.4	104.2	112.4	125.6	107.5
Energy Out (Btu)	23,520	21,738	163,859	75,805	49,859	20,327	23,424	44,479

Test 39 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	70.28%
Distribution System:	Baseline	Test Out of Wall Efficiency:	72.48%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	625,151
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	462,171
System Insulation:	Off	Total System Losses (Btu):	162,981
Other Notes:	N/A	Normalized WH Op. Efficiency:	84.55%
		Test Out WH Op. Efficiency:	87.20%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	598.8	Location	Avg. Temp (^oF)		
Usage (std. ft^3)	588.7	Tank 1	125.8	Average Tank Starting Temp, θs	122.0
Btu/Std. ft3	1041	Tank 2	123.9		
Gas Input (Btu)	612868	Tank 3	122.2	Average Tank Ending Temp, θE	109.6
Energy Input - Electric		Tank 4	119.3		
Usage (avg W)	150.0	Tank 5	110.0	Energy Storage (Btu/test)	-10312.2
Elec Input (kWh)	3.6	Tank 6	73.1		
Elec Input (Btu)	12,283.7	Avg Temp.	112.4		

Average System Water Inlet Temp (^oF)	57.7
Average Water Heater Supply Temp (^oF)	128.1

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	56.6	58.9	325.6	151.9	133.0	43.8	41.7	120.3
Temp (^oF)	114.3	104.8	124.0	121.7	106.7	117.0	125.0	111.1
Energy Out (Btu)	26,586	23,032	179,308	80,783	54,138	21,585	23,327	53,411

Test 40 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	68.16%
Distribution System:	Baseline	Test Out of Wall Efficiency:	71.31%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	639,257
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	462,242
System Insulation:	Off	Total System Losses (Btu):	177,014
Other Notes:	N/A	Normalized WH Op. Efficiency:	85.41%
		Test Out WH Op. Efficiency:	89.35%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	613.2	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	120.9
Usage (std. ft^3)	602.3	Tank 1	123.0		
Btu/Std. ft3	1041	Tank 2	118.4	Average Tank Ending Temp, θE	114.6
Gas Input (Btu)	626973	Tank 3	114.6		
Energy Input - Electric		Tank 4	108.8	Energy Storage (Btu/test)	-5248.4
Usage (avg W)	150.0	Tank 5	95.0		
Elec Input (kWh)	3.6	Tank 6	67.0		
Elec Input (Btu)	12,283.7	Avg Temp.	104.5		

Average System Water Inlet Temp (°F)	57.8
Average Water Heater Supply Temp (°F)	128.4

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	57.3	58.4	328.3	153.2	140.3	44.6	41.8	149.7
Temp (°F)	110.4	104.5	119.8	118.3	104.4	112.7	125.7	114.0
Energy Out (Btu)	25,064	22,684	169,144	77,054	54,357	20,329	23,626	69,984

Test 41 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	59.98%
Distribution System:	Baseline	Test Out of Wall Efficiency:	62.82%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	695,705
Nominal Recirculation Rate (gpm):	0 gpm	Out of Wall Energy Delivery (Btu):	439,062
System Insulation:	Off	Total System Losses (Btu):	256,644
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.91%
		Test Out WH Op. Efficiency:	73.21%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	677.8	Usage (avg W)	0.0
Usage (std. ft^3)	668.3	Elec Input (kWh)	0.0
Btu/Std. ft3	1,041	Elec Input (Btu)	0.0
Gas Input (Btu)	695,705		

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	121.6

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.9	48.7	301.0	149.0	173.1	40.3	33.6	159.8
Temp (°F)	108.7	102.0	115.9	116.6	104.8	113.0	123.8	114.4
Energy Out (Btu)	22,434	17,964	145,601	72,983	67,824	18,502	18,482	75,271

Test 42 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	60.02%
Distribution System:	Baseline	Test Out of Wall Efficiency:	61.38%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	615,293
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	378,675
System Insulation:	Off	Total System Losses (Btu):	236,618
Other Notes:	N/A	Normalized WH Op. Efficiency:	68.68%
		Test Out WH Op. Efficiency:	70.24%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	583.8	Usage (avg W)	150.0
Usage (std. ft^3)	579.3	Elec Input (kWh)	3.6
Btu/Std. ft3	1,041	Elec Input (Btu)	12,283.7
Gas Input (Btu)	603,009		

Average System Water Inlet Temp (°F)	57.9
Average Water Heater Supply Temp (°F)	115.7

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	44.0	60.1	246.0	113.0	145.3	35.4	30.5	225.3
Temp (°F)	107.5	97.0	112.0	109.2	99.9	107.1	106.2	113.9
Energy Out (Btu)	18,144	19,504	110,590	48,209	50,774	14,450	12,232	104,771

Test 44 Results Summary			
Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	59.86%
Distribution System:	Baseline	Test Out of Wall Efficiency:	59.22%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	571,876
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	339,791
System Insulation:	Off	Total System Losses (Btu):	232,085
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.13%
		Test Out WH Op. Efficiency:	68.38%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	545.3	Usage (avg W)	112.5
Usage (std. ft^3)	540.5	Elec Input (kWh)	2.7
Btu/Std. ft3	1,041	Elec Input (Btu)	9,212.8
Gas Input (Btu)	562,663		

Average System Water Inlet Temp (°F)	57.9
Average Water Heater Supply Temp (°F)	114.7

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	43.3	59.6	250.7	111.3	146.6	33.9	30.9	151.8
Temp (°F)	107.2	97.0	111.2	110.1	98.6	104.2	107.8	111.5
Energy Out (Btu)	17,758	19,380	111,093	48,357	49,639	13,044	12,829	67,690

Test 45 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	59.53%
Distribution System:	Baseline	Test Out of Wall Efficiency:	62.12%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	703,603
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	439,062
System Insulation:	Off	Total System Losses (Btu):	264,541
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.37%
		Test Out WH Op. Efficiency:	72.39%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	677.9	Usage (avg W)	95.9
Usage (std. ft^3)	668.3	Elec Input (kWh)	2.3
Btu/Std. ft3	1,041	Elec Input (Btu)	7,851.5
Gas Input (Btu)	695,752		

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	121.6

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.9	48.7	301.0	149.0	173.1	40.3	33.6	159.8
Temp (°F)	108.7	102.0	115.9	116.6	104.8	113.0	123.8	114.4
Energy Out (Btu)	22,434	17,964	145,601	72,983	67,824	18,502	18,482	75,271

Test 46 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	62.97%
Distribution System:	Baseline	Test Out of Wall Efficiency:	62.97%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	633,115
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	399,016
System Insulation:	Off	Total System Losses (Btu):	234,099
Other Notes:	N/A	Normalized WH Op. Efficiency:	90.78%
		Test Out WH Op. Efficiency:	90.78%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	615.7	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	130.6
Usage (std. ft^3)	608.2	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	127.5	Average Tank Ending Temp, θE	128.9
Gas Input (Btu)	633115	Tank 3	122.2		
Energy Input - Electric		Tank 4	114.0	Energy Storage (Btu/test)	-1476.5
Usage (avg W)	0.0	Tank 5	122.2		
Elec Input (kWh)	0.0	Tank 6	N/A		
Elec Input (Btu)	0.0	Avg Temp.	121.5		

Average System Water Inlet Temp (°F)	58.2
Average Water Heater Supply Temp (°F)	132.9

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	50.6	57.5	308.9	142.8	134.3	41.9	39.2	149.5
Temp (°F)	90.1	99.1	115.1	115.4	100.0	106.2	129.6	110.5
Energy Out (Btu)	13,415	19,570	146,287	67,965	46,739	16,743	23,295	65,002

Test 47 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	48.14%
Distribution System:	Baseline	Test Out of Wall Efficiency:	47.63%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	825,420
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	403,872
System Insulation:	Off	Total System Losses (Btu):	421,548
Other Notes:	N/A	Normalized WH Op. Efficiency:	57.66%
		Test Out WH Op. Efficiency:	57.66%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	791.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	128.8
Usage (std. ft^3)	781.1	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	127.9	Average Tank Ending Temp, θE	116.8
Gas Input (Btu)	813136	Tank 3	126.2		
Energy Input - Electric		Tank 4	125.2	Energy Storage (Btu/test)	-9991.6
Usage (avg W)	150.0	Tank 5	126.0		
Elec Input (kWh)	3.6	Tank 6	N/A		
Elec Input (Btu)	12,283.7	Avg Temp.	126.3		

Average System Water Inlet Temp (°F)	60.1
Average Water Heater Supply Temp (°F)	129.5

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	51.7	39.7	310.0	154.9	66.2	42.2	39.4	121.1
Temp (°F)	115.8	111.5	124.5	124.1	91.7	110.8	127.8	116.8
Energy Out (Btu)	23,959	16,965	165,962	82,511	17,439	17,808	22,187	57,041

Test 48 Results Summary

Water Heater:	Non-Condensing Storage
Distribution System:	Baseline
Recirculation Pump Control:	Demand Controls
Nominal Recirculation Rate:	~3.5 gpm
System Insulation:	Off
Other Notes:	N/A

Normalized Out of Wall Efficiency:	61.32%
Test Out of Wall Efficiency:	60.66%
Total System Energy Input (Btu):	641,298
Out of Wall Energy Delivery (Btu):	385,092
Total System Losses (Btu):	256,206
Normalized WH Op. Efficiency:	78.85%
Test Out WH Op. Efficiency:	78.85%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	638.1	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	129.1
Usage (std. ft^3)	615.4	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	126.1	Average Tank Ending Temp, θE	131.6
Gas Input (Btu)	640605	Tank 3	120.7		
Energy Input - Electric		Tank 4	114.1	Energy Storage (Btu/test)	2070.4
Usage (avg W)	8.5	Tank 5	120.8		
Elec Input (kWh)	0.2	Tank 6	N/A		
Elec Input (Btu)	692.4	Avg Temp.	120.4		

Average System Water Inlet Temp (°F)	58.5
Average Water Heater Supply Temp (°F)	132.4

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.3	48.0	304.5	141.0	114.0	41.7	39.4	83.0
Temp (°F)	109.1	97.3	119.9	120.8	105.7	113.5	129.8	105.4
Energy Out (Btu)	21,979	15,444	155,236	73,023	44,706	19,019	23,370	32,314

Test 49 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	53.44%
Distribution System:	Baseline	Test Out of Wall Efficiency:	53.43%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	764,065
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	408,988
System Insulation:	Off	Total System Losses (Btu):	355,077
Other Notes:	N/A	Normalized WH Op. Efficiency:	64.11%
		Test Out WH Op. Efficiency:	64.09%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	736.4	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	127.7
Usage (std. ft^3)	725.1	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.6	Average Tank Ending Temp, θE	127.2
Gas Input (Btu)	754852	Tank 3	126.9		
Energy Input - Electric		Tank 4	125.3	Energy Storage (Btu/test)	-401.5
Usage (avg W)	112.5	Tank 5	126.8		
Elec Input (kWh)	2.7	Tank 6	N/A		
Elec Input (Btu)	9,213.3	Avg Temp.	126.9		

Average System Water Inlet Temp (°F)	60.0
Average Water Heater Supply Temp (°F)	129.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.5	41.4	305.7	153.0	78.8	41.0	38.8	138.2
Temp (°F)	115.0	111.1	124.4	123.1	91.7	111.8	123.9	115.8
Energy Out (Btu)	24,007	17,613	163,817	80,328	20,780	17,651	20,620	64,174

Test 50 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	54.19%
Distribution System:	Baseline	Test Out of Wall Efficiency:	54.54%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	765,641
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	418,873
System Insulation:	Off	Total System Losses (Btu):	346,768
Other Notes:	N/A	Normalized WH Op. Efficiency:	67.15%
		Test Out WH Op. Efficiency:	67.57%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	744.0	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	129.6
Usage (std. ft^3)	732.4	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	127.6	Average Tank Ending Temp, θE	128.8
Gas Input (Btu)	762409	Tank 3	123.8		
Energy Input - Electric		Tank 4	121.0	Energy Storage (Btu/test)	-668.6
Usage (avg W)	39.5	Tank 5	123.8		
Elec Input (kWh)	0.9	Tank 6	N/A		
Elec Input (Btu)	3,232.0	Avg Temp.	124.1		

Average System Water Inlet Temp (°F)	59.0
Average Water Heater Supply Temp (°F)	130.7

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	56.4	37.6	316.6	158.8	80.9	41.2	39.8	137.1
Temp (°F)	113.9	110.4	122.4	122.2	91.2	110.8	128.1	115.6
Energy Out (Btu)	25,748	16,048	166,897	83,430	21,639	17,723	22,868	64,520

Test 51 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	68.05%
Distribution System:	Baseline	Test Out of Wall Efficiency:	68.05%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	451,859
Nominal Recirculation Rate (gpm):	0 gpm	Out of Wall Energy Delivery (Btu):	306,185
System Insulation:	Off	Total System Losses (Btu):	145,675
Other Notes:	N/A	Normalized WH Op. Efficiency:	92.99%
		Test Out WH Op. Efficiency:	92.99%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	438.4	Usage (avg W)	0.0
Usage (std. ft^3)	434.1	Elec Input (kWh)	0.0
Btu/Std. ft3	1041	Elec Input (Btu)	0.0
Gas Input (Btu)	451859		

Average System Water Inlet Temp (^{o}F)	57.9
Average Water Heater Supply Temp (^{o}F)	115.5

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.1	64.9	316.6	159.4	83.8	41.0	39.1	117.7
Temp (^{o}F)	89.5	88.2	103.8	105.9	84.6	94.5	120.0	98.8
Energy Out (Btu)	14,453	16,325	120,739	63,531	18,584	12,483	20,143	39,927

Test 52 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	52.79%
Distribution System:	Baseline	Test Out of Wall Efficiency:	51.84%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	733,460
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	380,017
System Insulation:	Off	Total System Losses (Btu):	353,443
Other Notes:	N/A	Normalized WH Op. Efficiency:	62.81%
		Test Out WH Op. Efficiency:	61.68%

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	698.7	Usage (avg W)	150.0	Average System Water Inlet Temp (°F)	58.0
Usage (std. ft^3)	692.8	Elec Input (kWh)	3.6	Average Water Heater Supply Temp (°F)	125.2
Btu/Std. ft3	1041	Elec Input (Btu)	12,283.7		
Gas Input (Btu)	721176				

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	54.3	39.1	304.2	143.9	84.6	38.2	36.5	109.4
Temp (°F)	112.7	98.9	121.1	120.9	90.4	109.3	123.8	110.8
Energy Out (Btu)	24,697	13,298	159,694	75,236	22,813	16,315	19,963	48,002

Test 53 Results Summary			
Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	**62.23%**
Distribution System:	Baseline	Test Out of Wall Efficiency:	**63.40%**
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	**569,782**
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	**362,727**
System Insulation:	Off	Total System Losses (Btu):	**207,055**
Other Notes:	N/A	Normalized WH Op. Efficiency:	**76.76%**
		Test Out WH Op. Efficiency:	**78.20%**

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	555.7	Usage (avg W)	19.8	Average System Water Inlet Temp (°F)	58.0
Usage (std. ft^3)	545.8	Elec Input (kWh)	0.5	Average Water Heater Supply Temp (°F)	118.0
Btu/Std. ft3	1041	Elec Input (Btu)	1,617.9		
Gas Input (Btu)	568164				

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.3	65.0	315.8	145.0	125.9	41.9	39.5	104.8
Temp (°F)	105.2	89.3	112.0	113.3	97.3	106.6	121.3	100.6
Energy Out (Btu)	21,685	16,880	141,637	66,638	41,131	16,935	20,781	37,041

Test 54 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	58.43%
Distribution System:	Baseline	Test Out of Wall Efficiency:	57.79%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	665,740
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	383,280
System Insulation:	Off	Total System Losses (Btu):	282,459
Other Notes:	N/A	Normalized WH Op. Efficiency:	69.64%
		Test Out WH Op. Efficiency:	68.88%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	639.1	Usage (avg W)	112.5
Usage (std. ft^3)	630.7	Elec Input (kWh)	2.7
Btu/Std. ft3	1041	Elec Input (Btu)	9,214.2
Gas Input (Btu)	656526		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	125.2

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	53.2	51.8	300.7	147.5	82.2	37.7	36.5	111.1
Temp (°F)	113.3	99.2	121.1	119.9	90.3	109.8	123.1	111.4
Energy Out (Btu)	24,463	17,770	157,720	75,965	22,085	16,242	19,753	49,283

Test 55 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	57.73%
Distribution System:	Baseline	Test Out of Wall Efficiency:	57.67%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	656,250
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	377,003
System Insulation:	Off	Total System Losses (Btu):	279,247
Other Notes:	N/A	Normalized WH Op. Efficiency:	67.61%
		Test Out WH Op. Efficiency:	67.54%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	633.0	Usage (avg W)	66.1
Usage (std. ft^3)	625.2	Elec Input (kWh)	1.6
Btu/Std. ft3	1041	Elec Input (Btu)	5,409.7
Gas Input (Btu)	650841		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	120.9

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	53.3	54.1	315.1	156.8	82.6	39.7	37.6	108.0
Temp (°F)	109.0	90.0	118.4	117.6	89.7	108.6	121.7	109.0
Energy Out (Btu)	22,576	14,367	158,170	77,688	21,777	16,702	19,942	45,782

Test 56 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	90.89%
Distribution System:	Baseline	Test Out of Wall Efficiency:	90.89%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	492,741
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	461,401
System Insulation:	On	Total System Losses (Btu):	31,340
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~109.55%~~
		Test Out WH Op. Efficiency:	~~109.55%~~

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	481.7	Location	Avg. Temp (°F)		
Usage (std. ft^3)	473.3	Tank 1	117.5	Average Tank Starting Temp, θs	124.4
Btu/Std. ft3	1041	Tank 2	109.8		
Gas Input (Btu)	492741	Tank 3	102.9	Average Tank Ending Temp, θE	108.7
Energy Input - Electric		Tank 4	91.2		
Usage (avg W)	0.0	Tank 5	79.1	Energy Storage (Btu/test)	-13125.9
Elec Input (kWh)	0.0	Tank 6	66.2		
Elec Input (Btu)	0.0	Avg Temp.	94.5		

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	127.9

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	59.7	43.5	341.1	159.1	96.1	45.3	43.5	136.4
Temp (°F)	109.1	112.7	120.5	121.3	109.2	116.5	125.0	115.7
Energy Out (Btu)	25,499	19,911	178,197	84,208	41,234	22,179	24,353	65,820

Test 57 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	82.06%
Distribution System:	Baseline	Test Out of Wall Efficiency:	82.89%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	598,686
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	476,031
System Insulation:	On	Total System Losses (Btu):	122,654
Other Notes:	N/A	Normalized WH Op. Efficiency:	85.52%
		Test Out WH Op. Efficiency:	86.38%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	576.3	Location	Avg. Temp (^oF)	Average Tank Starting Temp, θs	99.3
Usage (std. ft^3)	563.3	Tank 1	125.8		
Btu/Std. ft3	1041	Tank 2	124.2	Average Tank Ending Temp, θE	124.5
Gas Input (Btu)	586434	Tank 3	122.8		
Energy Input - Electric		Tank 4	121.5	Energy Storage (Btu/test)	20991.5
Usage (avg W)	149.6	Tank 5	120.4		
Elec Input (kWh)	3.6	Tank 6	81.2		
Elec Input (Btu)	12,251.7	Avg Temp.	116.0		

Average System Water Inlet Temp (^oF)	57.7
Average Water Heater Supply Temp (^oF)	128.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	59.1	39.9	330.7	157.3	86.0	44.0	43.0	121.4
Temp (^oF)	118.6	116.0	126.0	124.8	112.9	122.6	126.9	120.6
Energy Out (Btu)	29,898	19,337	187,664	87,776	39,429	23,720	24,735	63,473

Test 58 Results Summary			
Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	90.09%
Distribution System:	Baseline	Test Out of Wall Efficiency:	91.98%
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	490,353
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	458,376
System Insulation:	On	Total System Losses (Btu):	31,977
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~107.45%~~
		Test Out WH Op. Efficiency:	~~109.71%~~

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	478.2	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	93.2
Usage (std. ft^3)	470.7	Tank 1	116.5		
Btu/Std. ft3	1041	Tank 2	106.9	Average Tank Ending Temp, θE	88.3
Gas Input (Btu)	490016	Tank 3	98.8		
Energy Input - Electric		Tank 4	85.0	Energy Storage (Btu/test)	-4053.6
Usage (avg W)	4.1	Tank 5	69.7		
Elec Input (kWh)	0.1	Tank 6	61.3		
Elec Input (Btu)	336.2	Avg Temp.	89.7		

Average System Water Inlet Temp (°F)	57.6
Average Water Heater Supply Temp (°F)	127.9

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	61.3	41.3	344.3	156.1	94.6	46.4	43.8	133.9
Temp (°F)	111.0	113.6	120.2	120.6	109.8	115.8	121.9	115.4
Energy Out (Btu)	27,183	19,207	179,132	81,723	41,006	22,433	23,383	64,311

Test 59 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	84.16%
Distribution System:	Baseline	Test Out of Wall Efficiency:	84.84%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	560,492
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	475,487
System Insulation:	On	Total System Losses (Btu):	85,004
Other Notes:	N/A	Normalized WH Op. Efficiency:	91.61%
		Test Out WH Op. Efficiency:	92.36%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	541.9	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	118.8
Usage (std. ft^3)	529.6	Tank 1	126.7		
Btu/Std. ft3	1041	Tank 2	124.9	Average Tank Ending Temp, θE	119.8
Gas Input (Btu)	551278	Tank 3	123.3		
Energy Input - Electric		Tank 4	120.0	Energy Storage (Btu/test)	816.2
Usage (avg W)	112.5	Tank 5	109.5		
Elec Input (kWh)	2.7	Tank 6	68.5		
Elec Input (Btu)	9,213.5	Avg Temp.	112.2		

Average System Water Inlet Temp (°F)	57.7
Average Water Heater Supply Temp (°F)	128.4

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	59.1	40.0	330.7	157.5	86.2	44.0	42.9	121.1
Temp (°F)	118.6	116.0	126.0	124.6	112.8	122.6	126.3	120.7
Energy Out (Btu)	29,898	19,351	187,663	87,514	39,483	23,720	24,453	63,406

Test 60 Results Summary

Water Heater:	Condensing Storage	Normalized Out of Wall Efficiency:	84.27%
Distribution System:	Baseline	Test Out of Wall Efficiency:	85.72%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	570,626
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	482,693
System Insulation:	On	Total System Losses (Btu):	87,933
Other Notes:	N/A	Normalized WH Op. Efficiency:	93.16%
		Test Out WH Op. Efficiency:	94.76%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	551.6	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	108.7
Usage (std. ft^3)	543.2	Tank 1	125.4		
Btu/Std. ft3	1041	Tank 2	122.1	Average Tank Ending Temp, θE	117.6
Gas Input (Btu)	565480	Tank 3	119.7		
Energy Input - Electric		Tank 4	115.6	Energy Storage (Btu/test)	7422.3
Usage (avg W)	62.8	Tank 5	102.9		
Elec Input (kWh)	1.5	Tank 6	66.4		
Elec Input (Btu)	5,145.9	Avg Temp.	108.7		

Average System Water Inlet Temp (°F)	57.6
Average Water Heater Supply Temp (°F)	128.5

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	58.6	42.1	342.9	158.1	96.3	45.6	42.8	132.0
Temp (°F)	117.9	114.3	124.0	123.2	110.9	120.5	127.5	118.6
Energy Out (Btu)	29,363	19,816	189,168	86,132	42,669	23,822	24,848	66,875

Test 62 Results Summary

Water Heater:	Condensing Tankless	Normalized Out of Wall Efficiency:	79.20%
Distribution System:	Baseline	Test Out of Wall Efficiency:	75.88%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	412,475
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	313,247
System Insulation:	On	Total System Losses (Btu):	99,228
Other Notes:	N/A	Normalized WH Op. Efficiency:	87.01%
		Test Out WH Op. Efficiency:	83.37%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	390.9	Usage (avg W)	150.0
Usage (std. ft^3)	384.4	Elec Input (kWh)	3.6
Btu/Std. ft3	1,041	Elec Input (Btu)	12,283.7
Gas Input (Btu)	400,191		

Average System Water Inlet Temp (°F)	57.8
Average Water Heater Supply Temp (°F)	115.2

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	46.2	32.4	273.6	133.8	75.5	36.9	32.6	90.6
Temp (°F)	105.9	97.8	115.0	112.3	102.1	112.8	107.2	104.8
Energy Out (Btu)	18,457	10,771	130,012	60,577	27,782	16,870	13,391	35,386

Test 66 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	69.06%
Distribution System:	Baseline	Test Out of Wall Efficiency:	69.06%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	633,741
Nominal Recirculation Rate:	0 gpm	Out of Wall Energy Delivery (Btu):	439,072
System Insulation:	On	Total System Losses (Btu):	194,669
Other Notes:	N/A	Normalized WH Op. Efficiency:	83.70%
		Test Out WH Op. Efficiency:	83.70%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	621.5	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	101.5
Usage (std. ft^3)	608.8	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	126.5	Average Tank Ending Temp, θE	98.5
Gas Input (Btu)	633741	Tank 3	120.9		
Energy Input - Electric		Tank 4	114.7	Energy Storage (Btu/test)	-2481.8
Usage (avg W)	0.0	Tank 5	120.9		
Elec Input (kWh)	0.0	Tank 6	N/A		
Elec Input (Btu)	0.0	Avg Temp.	120.8		

Average System Water Inlet Temp (°F)	58.2
Average Water Heater Supply Temp (°F)	133.0

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	54.6	42.9	316.0	150.0	94.6	42.6	39.9	112.5
Temp (°F)	106.7	117.2	123.5	125.0	111.7	118.5	129.9	115.9
Energy Out (Btu)	21,992	21,046	171,509	83,313	42,037	21,351	23,805	54,019

Test 67 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	62.15%
Distribution System:	Baseline	Test Out of Wall Efficiency:	61.31%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	679,231
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	416,753
System Insulation:	On	Total System Losses (Btu):	262,478
Other Notes:	N/A	Normalized WH Op. Efficiency:	68.39%
		Test Out WH Op. Efficiency:	67.46%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	657.3	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	129.8
Usage (std. ft^3)	640.7	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.2	Average Tank Ending Temp, θE	129.1
Gas Input (Btu)	666948	Tank 3	127.0		
Energy Input - Electric		Tank 4	126.3	Energy Storage (Btu/test)	-600.6
Usage (avg W)	150.0	Tank 5	126.9		
Elec Input (kWh)	3.6	Tank 6	N/A		
Elec Input (Btu)	12,283.0	Avg Temp.	127.1		

Average System Water Inlet Temp (°F)	60.4
Average Water Heater Supply Temp (°F)	129.1

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.9	40.3	308.5	141.7	84.6	41.3	38.9	93.8
Temp (°F)	119.4	116.1	126.6	126.1	113.6	122.8	126.8	117.2
Energy Out (Btu)	25,981	18,646	169,894	77,498	37,464	21,417	21,510	44,343

Test 68 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	70.12%
Distribution System:	Baseline	Test Out of Wall Efficiency:	70.28%
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	632,479
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	442,801
System Insulation:	On	Total System Losses (Btu):	189,678
Other Notes:	N/A	Normalized WH Op. Efficiency:	84.18%
		Test Out WH Op. Efficiency:	84.37%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	618.2	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	105.5
Usage (std. ft^3)	607.4	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	125.6	Average Tank Ending Temp, θE	107.6
Gas Input (Btu)	632255	Tank 3	119.1		
Energy Input - Electric		Tank 4	110.6	Energy Storage (Btu/test)	1753.0
Usage (avg W)	2.7	Tank 5	119.1		
Elec Input (kWh)	0.1	Tank 6	N/A		
Elec Input (Btu)	223.9	Avg Temp.	118.6		

Average System Water Inlet Temp (°F)	58.2
Average Water Heater Supply Temp (°F)	132.8

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.1	43.9	316.1	149.3	94.6	41.7	39.9	119.6
Temp (°F)	113.2	115.1	123.5	123.9	111.9	117.2	128.8	116.3
Energy Out (Btu)	25,158	20,772	171,553	81,522	42,208	20,464	23,390	57,734

Test 69 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	65.46%
Distribution System:	Baseline	Test Out of Wall Efficiency:	64.76%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	643,797
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	416,568
System Insulation:	On	Total System Losses (Btu):	227,230
Other Notes:	N/A	Normalized WH Op. Efficiency:	72.03%
		Test Out WH Op. Efficiency:	71.26%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	625.5	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	129.9
Usage (std. ft^3)	609.6	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.9	Average Tank Ending Temp, θE	130.0
Gas Input (Btu)	634585	Tank 3	127.6		
Energy Input - Electric		Tank 4	126.1	Energy Storage (Btu/test)	56.6
Usage (avg W)	112.5	Tank 5	127.5		
Elec Input (kWh)	2.7	Tank 6	N/A		
Elec Input (Btu)	9,212.8	Avg Temp.	127.5		

Average System Water Inlet Temp (°F)	60.3
Average Water Heater Supply Temp (°F)	129.1

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.9	40.3	308.5	142.0	84.4	41.1	39.0	93.8
Temp (°F)	119.4	116.0	126.6	125.9	113.7	122.8	126.4	117.2
Energy Out (Btu)	25,994	18,657	169,967	77,353	37,434	21,381	21,409	44,373

Test 70 Results Summary

Water Heater:	Non-Condensing Storage	Normalized Out of Wall Efficiency:	65.82%
Distribution System:	Baseline	Test Out of Wall Efficiency:	65.74%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	680,986
Nominal Recirculation Rate:	~3.5 gpm	Out of Wall Energy Delivery (Btu):	445,102
System Insulation:	On	Total System Losses (Btu):	235,884
Other Notes:	N/A	Normalized WH Op. Efficiency:	73.06%
		Test Out WH Op. Efficiency:	72.97%

Energy Input - Gas		In-Tank Condition		Energy Storage	
Usage (act. ft^3)	661.8	Location	Avg. Temp (°F)	Average Tank Starting Temp, θs	115.6
Usage (std. ft^3)	650.0	Tank 1	N/A		
Btu/Std. ft3	1041	Tank 2	128.5	Average Tank Ending Temp, θE	119.4
Gas Input (Btu)	676645	Tank 3	126.1		
Energy Input - Electric		Tank 4	124.3	Energy Storage (Btu/test)	3139.8
Usage (avg W)	53.0	Tank 5	125.9		
Elec Input (kWh)	1.3	Tank 6	N/A		
Elec Input (Btu)	4,340.5	Avg Temp.	126.2		

Average System Water Inlet Temp (°F)	59.4
Average Water Heater Supply Temp (°F)	130.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.6	41.7	313.0	149.7	89.7	41.7	39.6	113.0
Temp (°F)	118.4	118.1	126.7	126.3	112.9	122.2	126.7	118.6
Energy Out (Btu)	27,272	20,334	174,935	83,223	39,879	21,752	22,145	55,562

Test 71 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	70.07%
Distribution System:	Baseline	Test Out of Wall Efficiency:	70.07%
Recirculation Pump Control:	Off	Total System Energy Input (Btu):	491,903
Nominal Recirculation Rate (gpm):	0 gpm	Out of Wall Energy Delivery (Btu):	345,689
System Insulation:	On	Total System Losses (Btu):	146,213
Other Notes:	N/A	Normalized WH Op. Efficiency:	~~104.85%~~
		Test Out WH Op. Efficiency:	~~104.85%~~

Energy Input - Gas		Energy Input - Electric			
Usage (act. ft^3)	478.9	Usage (avg W)	0.0	Average System Water Inlet Temp (°F)	58.0
Usage (std. ft^3)	472.5	Elec Input (kWh)	0.0	Average Water Heater Supply Temp (°F)	132.8
Btu/Std. ft3	1041	Elec Input (Btu)	0.0		
Gas Input (Btu)	491903				

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	56.2	49.1	318.4	143.8	114.5	41.8	36.9	69.0
Temp (°F)	104.3	104.3	113.2	114.4	105.8	109.4	120.7	73.6
Energy Out (Btu)	21,609	18,907	146,174	67,407	45,542	17,853	19,248	8,949

Test 72 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	66.09%
Distribution System:	Baseline	Test Out of Wall Efficiency:	64.52%
Recirculation Pump Control:	On	Total System Energy Input (Btu):	594,532
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	384,629
System Insulation:	On	Total System Losses (Btu):	209,903
Other Notes:	N/A	Normalized WH Op. Efficiency:	74.76%
		Test Out WH Op. Efficiency:	72.98%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	567.7	Usage (avg W)	146.9
Usage (std. ft^3)	559.6	Elec Input (kWh)	3.5
Btu/Std. ft3	1041	Elec Input (Btu)	12,028.5
Gas Input (Btu)	582503		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	125.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	50.0	53.4	292.8	132.0	105.3	38.6	35.2	68.6
Temp (°F)	116.8	108.7	124.4	124.1	114.1	120.1	124.2	84.8
Energy Out (Btu)	24,435	22,456	161,606	72,547	49,065	19,906	19,376	15,237

Test 73 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	73.51%
Distribution System:	Baseline	Test Out of Wall Efficiency:	73.60%
Recirculation Pump Control:	Demand Controls	Total System Energy Input (Btu):	491,507
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	361,971
System Insulation:	On	Total System Losses (Btu):	129,537
Other Notes:	N/A	Normalized WH Op. Efficiency:	81.79%
		Test Out WH Op. Efficiency:	81.89%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	483.2	Usage (avg W)	5.5
Usage (std. ft^3)	471.7	Elec Input (kWh)	0.1
Btu/Std. ft3	1041	Elec Input (Btu)	449.3
Gas Input (Btu)	491058		

Average System Water Inlet Temp (°F)	59.7
Average Water Heater Supply Temp (°F)	116.4

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	55.8	41.6	315.5	147.8	97.3	42.8	37.5	115.9
Temp (°F)	109.2	105.8	112.6	114.9	103.9	108.1	120.7	105.8
Energy Out (Btu)	22,968	15,935	138,827	67,809	35,749	17,224	19,012	44,447

Test 74 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	71.47%
Distribution System:	Baseline	Test Out of Wall Efficiency:	70.40%
Recirculation Pump Control:	Timeclock	Total System Energy Input (Btu):	570,581
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	399,776
System Insulation:	On	Total System Losses (Btu):	170,806
Other Notes:	N/A	Normalized WH Op. Efficiency:	78.61%
		Test Out WH Op. Efficiency:	77.43%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	547.2	Usage (avg W)	112.5
Usage (std. ft^3)	539.3	Elec Input (kWh)	2.7
Btu/Std. ft3	1041	Elec Input (Btu)	9,213.5
Gas Input (Btu)	561368		

Average System Water Inlet Temp (°F)	58.0
Average Water Heater Supply Temp (°F)	125.3

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	49.7	56.1	290.8	131.7	104.7	37.6	35.5	84.0
Temp (°F)	116.6	103.0	124.4	123.7	114.0	120.2	123.4	107.8
Energy Out (Btu)	24,224	20,946	160,500	71,889	48,731	19,438	19,313	34,734

Test 75 Results Summary

Water Heater:	Non-Condensing Tankless	Normalized Out of Wall Efficiency:	71.40%
Distribution System:	Baseline	Test Out of Wall Efficiency:	70.34%
Recirculation Pump Control:	Aquastat	Total System Energy Input (Btu):	578,537
Nominal Recirculation Rate (gpm):	~3.5 gpm	Out of Wall Energy Delivery (Btu):	406,036
System Insulation:	On	Total System Losses (Btu):	172,502
Other Notes:	N/A	Normalized WH Op. Efficiency:	73.80%
		Test Out WH Op. Efficiency:	72.71%

Energy Input - Gas		Energy Input - Electric	
Usage (act. ft^3)	565.0	Usage (avg W)	74.9
Usage (std. ft^3)	549.9	Elec Input (kWh)	1.8
Btu/Std. ft3	1041	Elec Input (Btu)	6,135.5
Gas Input (Btu)	572402		

Average System Water Inlet Temp (°F)	58.1
Average Water Heater Supply Temp (°F)	122.2

Fixture Name	1 Comp Sink, Prep, Cookline	Mens Bathrooms, Womens	Dish HS, Dishwasher	3-compartment Sink (3C)	Bar Hand Sink, Pitcher HS	4 Comp L, 4 comp R	Mop Sink	PreRinse (PR)
Volume (Gal)	52.5	36.2	301.7	143.5	84.8	40.8	36.6	93.8
Temp (°F)	116.6	114.4	123.9	122.6	110.0	119.1	123.2	115.2
Energy Out (Btu)	25,552	16,952	164,987	76,913	36,597	20,676	19,808	44,550