BUILDING TECHNOLOGIES PROGRAM

Laboratory Evaluation of Gas-Fired Tankless and Storage Water Heater Approaches to Combination Water and Space Heating

T. Kingston and S. Scott
Building America Partnership for Improved Residential Construction

March 2013

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Laboratory Evaluation of Gas-Fired Tankless and Storage Water Heater Approaches to Combination Water and Space Heating

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Definitions

AFUE	Annual fuel utilization efficiency
AH	Air handler
BA	Building America
BEopt	Building Energy Optimization
Btu	British thermal unit
CEE	Center for Energy and Environment
cf	Cubic foot
cfm	Cubic feet per minute
DHW	Domestic hot water
EE	Energy efficiency
EF	Energy factor
EIA	Energy Information Administration
gpm	Gallons per minute
GTI	Gas Technology Institute
h	Hour
HHV	Higher heating value
kBtu	Thousand Btu
LBNL	Lawrence Berkley National Laboratory
LHV	Lower heating value
MMBtu	Million Btu
RTD	Resistance temperature detector
s	Second
WH	Water heater
yr	Year

Executive Summary

Home builders are exploring more cost-effective packaging of space and water heating in a new generation of combined space and water heating systems (combos). Major water heater (WH) manufacturers are now developing or marketing pre-engineered forced air combos. These emerging combo technologies offer the opportunity to conduct meaningful tests, under controlled laboratory operations, that differentiate the performance of the various packaged equipment configurations being offered. Such laboratory controlled system comparisons have been lacking and are needed to help guide best practices and validate simulation models within the Building America Program and elsewhere.

Standardized testing for combo systems requires the air handler unit (AHU) to be tested against space heating loads and the WH to be tested separately against water heating loads. The laboratory tests conducted for this project subjected the combined AHU and WH to realistic and coincidental space and domestic hot water (DHW) loads. The results highlight the attributes of combo technologies that use traditional storage WHs and tankless WHs as their thermal engines.

Because they store hot water, storage WHs perform well by quickly delivering water at set point for short demands. They deliver varying water temperatures during long draws, however, because of temperature stratification in the tank. Tankless technology performs well with long draws at steady flow rates. The following general findings and recommendations were derived from the laboratory evaluations of tankless and storage combo systems:

- The tankless combo system that was tested maintained more stable DHW and space heating temperatures than the storage combo system that was tested. Most notably, temperature stratification in the storage tank caused supply air temperature instability. In some cases the inconsistent temperatures were enough to create uncomfortable conditions, such as draftiness from the AHU.
- The storage combo system that was tested delivered DHW at the tempered setting (120°F) faster than the tankless combo system. The tankless system, however, reached 115°F nearly as fast (i.e., within 10 s) as the storage system.
- The tankless combo system that was tested consistently achieved better daily efficiencies (i.e., 84%–93%) than the storage combo system (i.e., 81%–91%) when the AHU was sized adequately and the water flows and WH temperature set points were adjusted properly to achieve significant condensing operation. To achieve more consistent condensing operation, it was necessary to minimize the return water temperatures from the AHU by lowering the WH set point and reducing the water flow. These adjustments were governed by comfort in terms of air temperature and air flow delivered. When condensing operation was not achieved, the tankless and storage systems performed with lower efficiencies than when condensing was achieved. In those noncondensing cases, the tankless and storage systems performed with about the same daily efficiencies (i.e., 75%–88%).
- AHUs currently packaged with combo systems are not designed to optimize condensing operation for condensing WHs. More research is needed to develop AHUs specifically designed for condensing WHs.

* System efficiencies greater than 90% were achieved only on days where continuous and steady space heating loads were required and significant condensing operation was achieved. For days where heating was required only at night or the space heating loads were “peaky,” the system efficiencies fell below 90%.

1 Problem Statement

1.1 Introduction

Many field tests of combo systems have recently been completed, are ongoing, or planned, including several within the Building America (BA) Program. In early field testing, though, combination space and water heating systems (combos) have often experienced integration issues. These issues stemmed from component compatibility and operational controls that resulted from built-up configurations that mixed and matched components from multiple equipment manufacturers. Now, however, newer, pre-engineered combo products with matched components are entering the marketplace. These promise more consistent and improved operation. The newer combo systems emerging in the form of these matched packages also offer the opportunity to conduct meaningful tests under controlled laboratory operations that differentiate the performance of the alternative packaged equipment configurations being offered. Such laboratory controlled combo system comparisons have been lacking and are needed to help guide best practices and validate simulation models within the BA program and elsewhere.

1.2 Background

Home builders and HVAC/domestic hot water (DHW) equipment manufacturers are exploring more cost-effective packaging of space and water heating in a new generation of combos. The utility industry, recognizing this growing market potential, provided funding to the Gas Technology Institute (GTI), through its Utilization Technology Development (UTD) gas and combined utility research consortium. In November 2011, GTI completed a project that identified, through modeling efforts, technical capabilities and market opportunities for efficient combined space and water heating systems. Based on GTI's research, two combo system configurations were found to warrant laboratory evaluation for technology differentiation. These included combo systems incorporating tankless water heaters (WHs) and those with storage-based WHs. Modeling results from the research indicated that the tankless and storage-based combo systems were suitable in modestly sized homes, even in cold climates. Conducting high-resolution minute-by-minute load profiling as part of the research, however, revealed extreme peak conditions for short periods of time, particularly in cold climates where the city water supply can be very cold. During these periods, GTI found that combo system capacities could sporadically and briefly fall short of demands throughout the year.

Figure 1 shows an example of minute-by-minute simulated space heating (blue) and DHW (green) loads graphed chronologically for a 2,250-ft^2 home in Chicago built to BA2010 standards. For this example, maximum output capacities for various tankless WH combo systems are shown overlaid to identify where output capacity shortfalls might occur for that model. Surprisingly, the data showed that the well-insulated home would theoretically require the largest hydronic furnace available for combo systems, but that system could be run at 120°F as opposed to 140°F. Furthermore, the coincidental DHW loads could potentially surpass the largest tankless WH burner capacity. Those results led to the following questions:

1. Would storage-based combo systems, although smaller than tankless WHs in output capacity, be better suited to "ride out" brief capacity shortfalls during extreme conditions?

2. How well do the two systems respond and prioritize varying combined loads?
3. How do the systems compare in terms of energy efficiency (EE)?

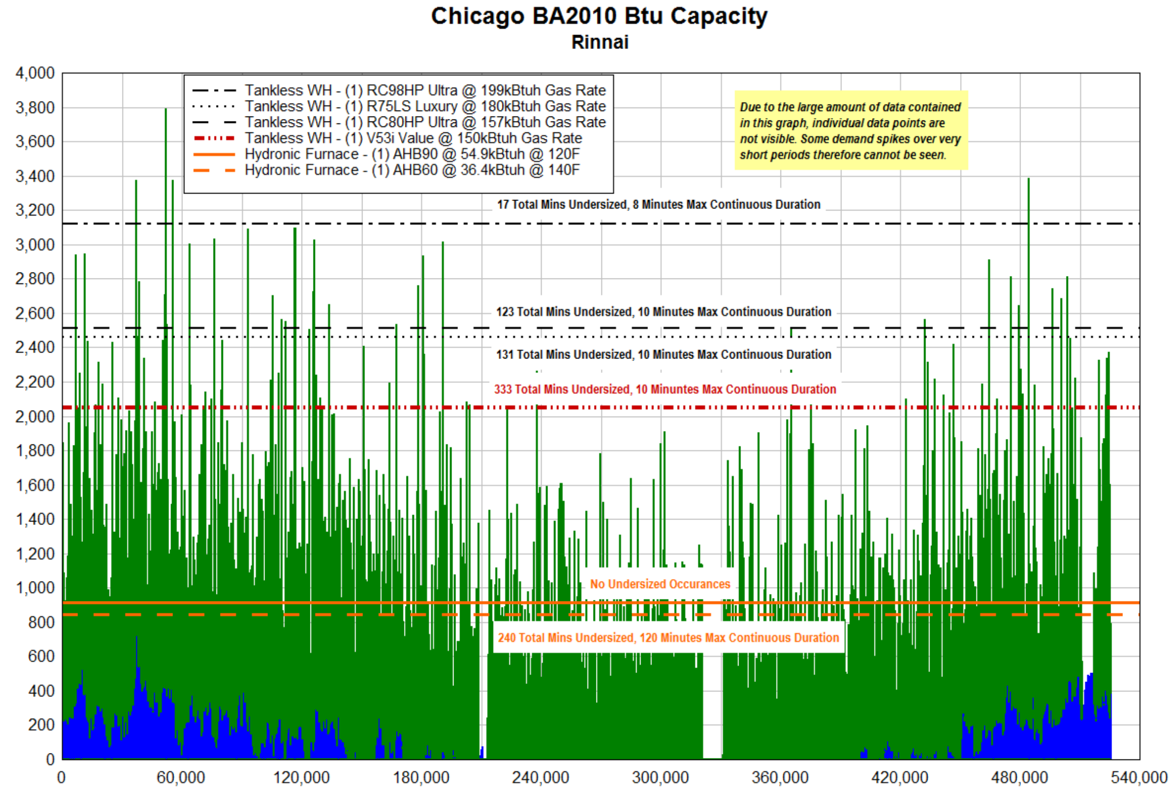


Figure 1. Chronological load data for Chicago home built to BA2010 standards

1.3 Relevance to Building America's Goals

Using the Energy Plus 6.0 computational engine, space heating and DHW load profiles were generated for Chicago, Atlanta, and Houston, which represent BA's cold, mixed-humid, and hot-humid climate categories, respectively. The load profiles were developed for a two-story, 2,250-ft^2, single-family house (see Figure 2) with three bedrooms and two bathrooms. The Energy Plus models were designed to BA2010 standards[1] or better, and standards based on Lawrence Berkeley National Laboratory (LBNL) work[2] that defined prototypical homes by vintage and location. The combo systems were evaluated in the laboratory against a battery of selected 24-h test days in each climate.

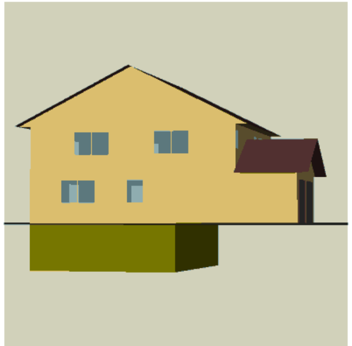


Figure 2. Model home

[1] http://www1.eere.energy.gov/buildings/building_america/analysis_spreadsheets.html.
[2] Huang, J.; Hanford, J.; Yang, F. (November 1999). *Residential Heating and Cooling Loads Component Analysis.* LBNL-44636. Berkeley, CA: LBNL. Accessed January 7, 2013: http://gundog.lbl.gov/dirpubs/44636.pdf.

As an order of magnitude, 2.9 million two-story single-family homes that were 2,250 ft^2 or less were built after 1940 in major metropolitan areas of Illinois, Georgia, and Texas. This information comes from Energy Information Administration (EIA) Residential Energy Consumption Survey Data Tables.[3]

The models were used to compare baseline equipment with combo systems and to estimate whole-house energy savings. The baseline model assumed a heating furnace with an annual fuel utilization efficiency (AFUE) of 95% and a DHW heater with an energy factor (EF) of 0.65. The combo system energy model assumed a tankless WH with an EF of 0.96. Whole-house energy savings with combos compared to the baseline equipment were estimated at 5%–12%, with the higher levels of savings estimated to occur in cold climates. These savings with combo systems indicated great potential toward the BA program goal of reducing home energy use by 30%–50%.

1.4 Cost Effectiveness

Energy modeling was done with Building Energy Optimization (BEopt) interface software (Energy Plus) and the Typical Meteorological Year 3 weather database for regional climates. Three distinct categories of the standard BA home model were developed to represent homes of varying quality and vintages. For detailed modeling parameters of the house and construction categories, see Appendix A. The categories are as follows:

- Vintage: represents a BA prototype home built before 2000
- BA2010: represents a BA prototype home built to BA2010 standards
- Max EE: represents a BA prototype home built better than BA2010 standards.

Table 1 shows the calculated energy and cost savings between the baseline and combo system models by region, along with the regional natural gas prices per the EIA.[4] The modeling results indicate \$50–\$200+ annual gas cost savings for the model home, depending on location and vintage.

Table 1. Estimated Energy and Cost Savings

	Gas Price	Vintage		BA2010		Max EE	
	$/MMBtu	MMBtu	$/yr	MMBtu	$/yr	MMBtu	$/yr
Chicago	9.10	25.7	233	13.7	125	11.6	105
Atlanta	15.09	12.8	193	9.3	141	7.5	114
Houston	10.44	6.8	71	5.6	58	5.0	53

[3] http://205.254.135.24/consumption/residential/data/2009/#tabs-1.

[4] EIA (June 29, 2012). "Natural Gas Explained: Natural Gas Prices." Accessed January 7, 2013: http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_prices.

Installed cost data for baseline and combo systems equipment are being collected by the Center for Energy and Environment (CEE)[5] as part of its federally funded program to install more than 400 combo systems in Minnesota homes. Table 2 summarizes preliminary data for installed costs. The installed cost data are based on only eight installations of the 400 that are planned.

Table 2. Estimated Installed Costs for Baseline and Combo Systems

Comparable Equipment	Installed Cost ($)
Baseline furnace: 95% AFUE, 2-stage, electronically commutated motor furnace	3,500
Baseline hot water heater: 50-gal storage, power vented, EF = 0.65	1,500
Combo system: tankless WH and air handler (AHU), EF = 0.96	6,500

1.5 Tradeoffs and Other Benefits

As Table 2 indicates, estimated installed costs for the baseline total $5,000. The installed costs for the combo system are currently estimated at $6,500. It should be recognized that newer technology comes with higher costs. Contractors installing the combo systems for the CEE project, the basis for combo system installed costs, had very little experience with combo systems. The research team expects contractors to become more familiar with the installations, which will drive installed costs down. Furthermore, volume in the market is expected to bring these new technology installations into common practice, which will drive down equipment and installation costs and improve cost effectiveness.

Although cost effectiveness is marginal at this point, estimated whole-house energy savings are encouraging as shown in Table 3.

Table 3. BEopt Estimated Whole-House Energy Savings

	Vintage (%)	BA2010 (%)	Maximum EE (%)
Chicago	9	9	12
Atlanta	9	10	11
Houston	7	8	9
Phoenix	5	6	7

[5] Schoenbauer, B. (July 31, 2011). "Installing Combination Systems: Optimized Designs and Potential Performance Problems." Minneapolis, MN: CEE. Accessed January 7, 2013: http://www.buildingscienceconsulting.com/services/documents/file/2011-07-31%20Combi%20Systems%20Expert%20Meeting/CEE_Schoenbauer_Combi%20Lab%20v3%20-%20BA%20experts%20mtg.pdf.

2 Experiment

2.1 Research Questions

Combo systems are a promising path toward more cost-effective space and water heating efficiency improvements in new high performance homes or in existing home retrofits. To pursue this path, though, many questions about the emerging matched packaged equipment configurations and their respective operational characteristics when meeting combined space and water heating loads must be answered. The latest generation of combo system configurations is designed around emerging high-efficiency residential WHs or boilers coupled with hydronic-coil-equipped AHUs or radiant heating loops. The high-efficiency "single thermal engine" used in the combo system configurations could be a condensing storage WH or a condensing tankless WH or boiler.

Laboratory tests were conducted on these two condensing storage and condensing tankless combo system configurations, with select space heating delivery components, primarily to explore the following issues:

1. Space and water heating load profile matching with equipment capacity
2. Control response providing equipment capacity modulation and space and water heating load demand prioritization
3. Supplied water temperature and equipment efficiency.

The tests were intended to characterize key operational attributes and to differentiate the performance of the two combo approaches. The results can help guide best practices and validate simulation models within the BA program and elsewhere.

2.2 Technical Approach

The performance evaluations for each of the two combo systems entailed a group of 24-h space and water heating load profile tests. The profiles represented daily DHW draw profiles overlaid on daily space heating load profiles spanning operating conditions from hot to mixed to cold climates. The load profiles were generated in 1-min increments, and the tests were conducted at that resolution. DHW draws were based on BA's Domestic Hot Water Event Schedules for a three-bedroom house (see footnote 1). The draws are in 6-s time-step profiles and were reduced to minute-by-minute data. Each chronological draw across every time step was summed for 1 min and reported in gallons per minute. The Energy Plus computational engine was used to generate space heating loads in 1-h increments. Each hour from those calculations was divided by 60 to obtain minute-by-minute loads. The aggregate minute-by-minute data represented the load profiles for each of the 24-h profile tests.

The load profiles were also used to create load duration graphs for each of the models. Load duration graphs show the loads across the year sorted in order of highest to lowest loads. These graphs show non-chronological durations of time during which systems can be undersized or oversized.

Figure 3 shows space heating loads for the three home categories in each of the climate zones. The primary graph shows the loads in descending order across 6,000 h, and the imbedded graph shows the peak loads in descending order across the highest 40 h. The Chicago Vintage home category is typical of an old unweatherized home into which a combo system could be retrofit. The graphs indicate that even the largest hydronic AHU would fall short of meeting the peak heating demands of such a modeled home. On the other hand, the graphs indicate that several of the modeled homes that are tighter (BA2010, Max EE) or in warmer climates need only the smallest hydronic AHU. The analysis does not rule out these combo system packages for cold-climate retrofits because it was done for only one size of home. Instead, the analysis suggests that cold-climate retrofits in unweatherized homes should be cautiously examined.

Figure 4 shows DHW loads in each of the climate zones. DHW loads are affected by the climate zones because of the water supply temperatures. Although the DHW loads are short in duration (e.g., 500 h/yr), their peak demands are high compared to space heating.

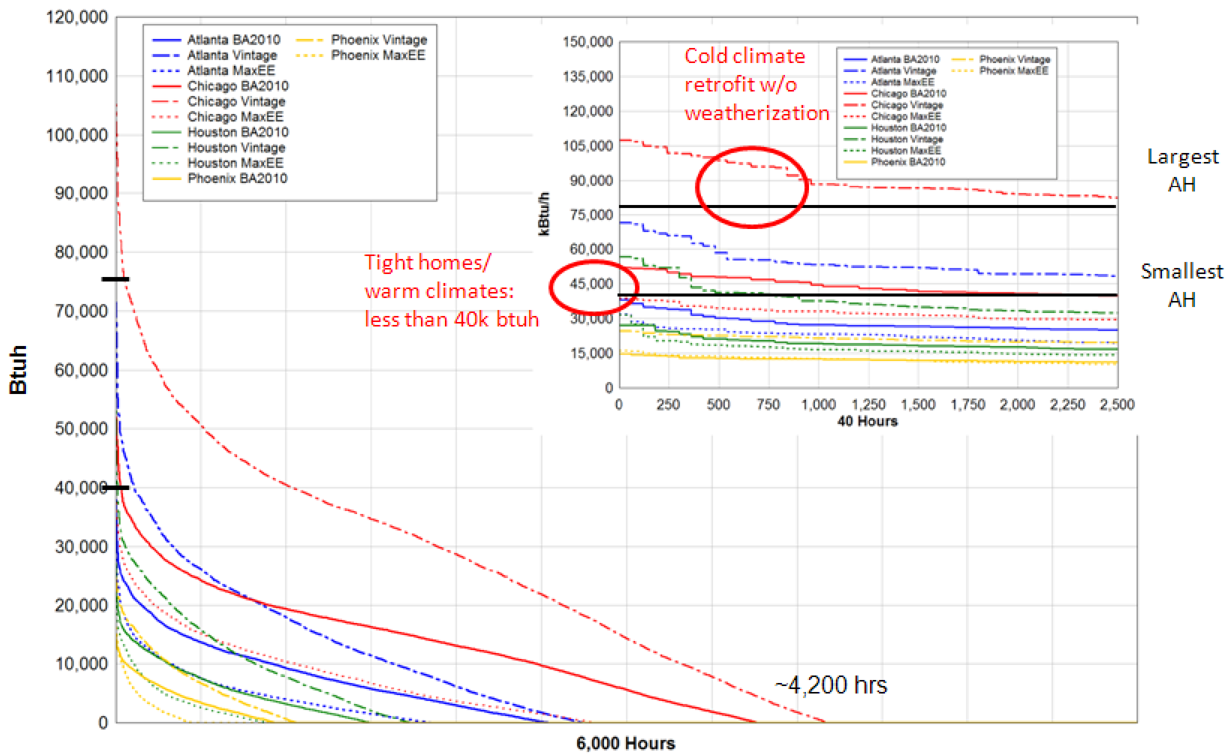


Figure 3. Noncoincidental space heating profiling

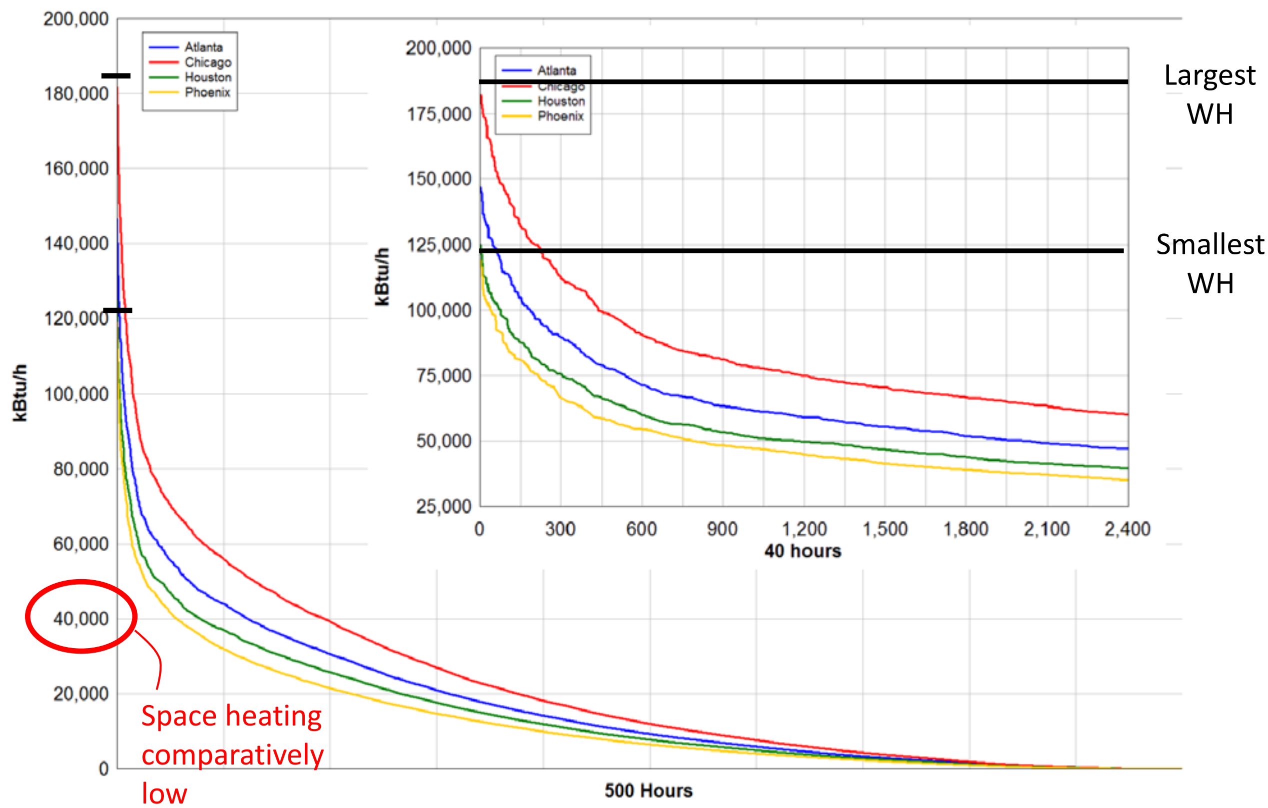


Figure 4. Noncoincidental DHW profiling

For each of the models, load duration curves were analyzed to estimate appropriate hot water heater and hydronic AHU sizes for the testing (see Appendix B for case-by-case analyses).

Although combo systems are being marketed as matched packaged systems, the hydronic AHUs are not specifically designed for condensing water heaters. If condensing water heaters are to actually condense and maximize operating efficiency, enough heat must be removed from the exhaust gas to cool it below the condensing temperature. If water is delivered to the AHU at too high of a temperature (e.g., >140°F), the hydronic AHUs cannot transfer enough heat to the air to sufficiently cool the return water. If the water returns to the WH at too high of a temperature, it might not cool the exhaust gas sufficiently to achieve condensing operation.

For the cold-climate models (Chicago), the load duration graphs indicate that space heating loads for the Vintage model are predicted to exceed the maximum capacity of the largest hydronic AHU for a significant time, even with the hydronic AHU operating at >140°. For the cold-climate tests, then, no Vintage models were selected. Eight representative 24-h BA2010 and Max EE datasets containing the load profiles were selected as shown in Table 4. The group of datasets includes at least 1 day in each month between November and March and comprises days with mean temperatures between about 5°F and 48°F. The following combo system configurations were tested against each of the datasets:

1. Models: BA2010 and Max EE
    A. Rinnai's RC80HP condensing tankless WHU with a capacity of 157 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 135°F
    B. AO Smith's Vertex condensing storage WHU with a capacity of 76 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 130°F.

Table 4. Representative Cold-Climate Days

Month/Day	Category	Mean Temperature (°F)	Supply Water (°F)
January 6	Max EE	5.0	44.6
January 26	Max EE	8.5	44.2
January 5	BA2010	15.6	46.7
December 3	BA2010	23.0	52.1
November 27	BA2010	30.1	53.3
December 11	BA2010	33.0	50.6
February 22	BA2010	43.1	44.2
March 29	BA2010	47.5	47.3

For the mixed-climate models (Atlanta), six representative 24-h Vintage and BA2010 datasets containing the load profiles were selected as shown in Table 5. The group of datasets includes at least 1 day in each month between December and April and comprises days with mean temperatures between about 26°F and 53°F. The following combo system configurations were tested against each of the datasets:

Table 5. Representative Mixed-Climate Days

Month/Day	Category	Mean Temperature (°F)	Supply Water (°F)
February 3	BA2010	25.6	56.2
January 26	BA2010	29.0	56.3
December 3	BA2010	34.6	62.0
February 6	BA2010	38.1	56.3
April 6	Vintage	46.1	62.6
March 23	Vintage	53.0	60.3

1. Models: Vintage

A. Rinnai's RC80HP condensing tankless WHU with a capacity of 157 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 135°F

B. AO Smith's Vertex condensing storage WHU with a capacity of 76 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 130°F.

2. Models: BA2010
    A. Rinnai's RC80HP condensing tankless WHU with a capacity of 157 kBtu/h, plus a Rinnai AHB45 AHU with delivered water at 140°F

B. AO Smith's Vertex condensing storage WHU with a capacity of 76 kBtu/h, plus a Rinnai AHB45 AHU with delivered water at 135°F.

For the hot-climate models (Houston), four representative 24-h Vintage and BA2010 datasets containing the load profiles were selected as shown in Table 6. The group of datasets includes at least 1 day in each month between December and March and comprises days with mean temperatures between about 30°F and 60°F. The following combo system configurations were tested against each of the datasets:

1. Models: Vintage
    A. Rinnai's RC80HP condensing tankless WHU with a capacity of 157 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 135°F
    B. AO Smith's Vertex condensing storage WHU with a capacity of 76 kBtu/h, plus a Rinnai AHB90 AHU with delivered water at 130°F.
2. Models: BA2010
    A. Rinnai's RC80HP condensing tankless WHU with a capacity of 157 kBtu/h, plus a Rinnai AHB45 AHU with delivered water at 140°F
    B. AO Smith's Vertex condensing storage WHU with a capacity of 76 kBtu/h, plus a Rinnai AHB45 AHU with delivered water at 135°F.

Table 6. Representative Hot-Climate Days

Month/Day	Category	Mean Temperature (°F)	Supply Water (°F)
February 11	BA2010	30.0	64.7
January 11	BA2010	41.0	64.6
December 9	BA2010	50.0	67.5
March 7	Vintage	60.0	66.7

Performance of the two representative combo system configurations was evaluated for each of the discrete 24-h operating conditions listed in Table 4, Table 5, and Table 6. For each of those tests, the research team focused on differences in operation between the tankless and storage configurations, such as the following:

1. Load response (both time and prioritization of space versus water heating)
2. Supplied water temperature
3. Energy use and resulting efficiency.

Efficiencies were calculated on a 24-h test basis by dividing the total energy produced as DHW and space heating air by the total electric and gas energy consumed by the WH and the AHU.

2.3 Measurements

A key goal for this project was to determine how the combined equipment performed against combined and coincidental space and hot water loads. As such, the test setup is unique. The 24-h tests were not conducted to standardized test methods. Those methods require the WH and the AHU to be tested separately at predefined steady-state conditions.

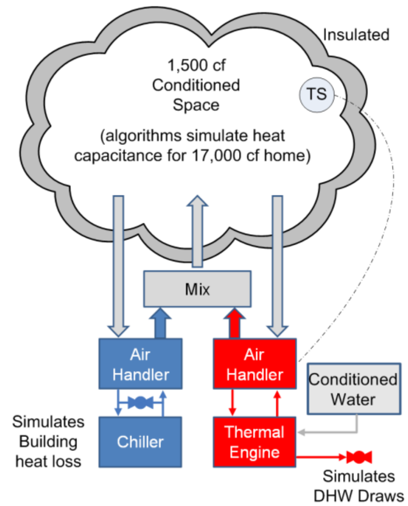


Figure 5. Simple test diagram

Figure 5 shows a conceptual diagram of the test setup. A 1,500-cf environmental chamber was used to simulate the 17,000-cf home. The combo system hot WH and the AHU delivered heat to the space as called on by the thermostat. At the same time, a chiller and a "cold-side" AHU modulated cooling to simulate building heat loss. Algorithms in the chiller modulation control were applied to account for the difference in heat capacitance of air resulting from the difference in volume. DHW draws were simulated with a modulating control valve that dumped hot water to a drain. Laboratory supply water was chilled to the modeled supply water temperature.

The test plan consisted of two boundaries as shown in Figure 6. The System Boundary bounds all but the necessary interconnections including power, fuel, city water, exhaust ventilation, and DHW drainage. The Product Boundary includes all of the equipment supplied by the manufacturers to make up the matched packaged products. For this testing, a package included the WH and the AHU. Conditions for testing within the System Boundary were consistent with ambient living conditions.

The test setup consisted of two air streams that were mixed in an air ASHRAE 41.1 mixing device and delivered to an enclosed 1,500-cf space (Conditioned Space). The combo system AHU resided in the Test Lab and delivered the "heat-side" air. A second AHU with a chilled water cooling coil also resided in the Test Lab and delivered the cool-side air. Cool air delivery simulated building heat loss and was controlled on an energy-unit basis tracking the minute-by-minute space heating load model data. A three-way modulating bypass valve was used in the chilled water loop for air temperature control from the cool-side AHU. Cool-side air inlet and outlet temperatures along with air flow measurements were used to determine the energy input needed to simulate the building heat loss. Heat-side air inlet and outlet temperatures along with air flow measurements were used to determine the energy delivered to the Conditioned Space. Energy delivered to Conditioned Space was also calculated using the liquid side for validation, and was found to correspond within about 2% of the air-side calculations. All duct work was tightly sealed and heavily insulated so that heat loss and air leakages were negligible.

The combo system space conditioning was operated based on calls from the thermostat in the Conditioned Space. The BA prototype model used for the BA2010 models does not incorporate thermostat setback. Similarly, the Vintage models do not incorporate thermostat setback. As such, a fixed thermostat set point was used for those profile tests. The two Max EE test profiles conducted for Chicago do incorporate simple thermostat setback, and the energy models were used to account for makeup capacity and proper system sizing.

Hot water flow through a modulating control valve was used to simulate DHW draws and was controlled on an energy basis tracking the minute-by-minute DHW load model data. City water inlet and DHW outlet temperatures along with water flow measurements were used to determine the energy delivered to DHW. City water temperature was controlled with a 250-gal storage tank that was maintained at the corresponding supply water temperature for the test day using a separate apparatus that incorporated a chiller and a WH.

Natural gas consumed by the water heater was measured and corrected for pressure and temperature to determine the fuel energy delivered to the Product Boundary. GTI measures the caloric value of gas coming into the campus on a monthly basis. Power consumed by the WH and the AHU was measured with watt meters to determine the electrical energy delivered to the Product Boundary.

Temperature in the Test Lab was maintained at 75°F via thermostat control, but was not recorded.

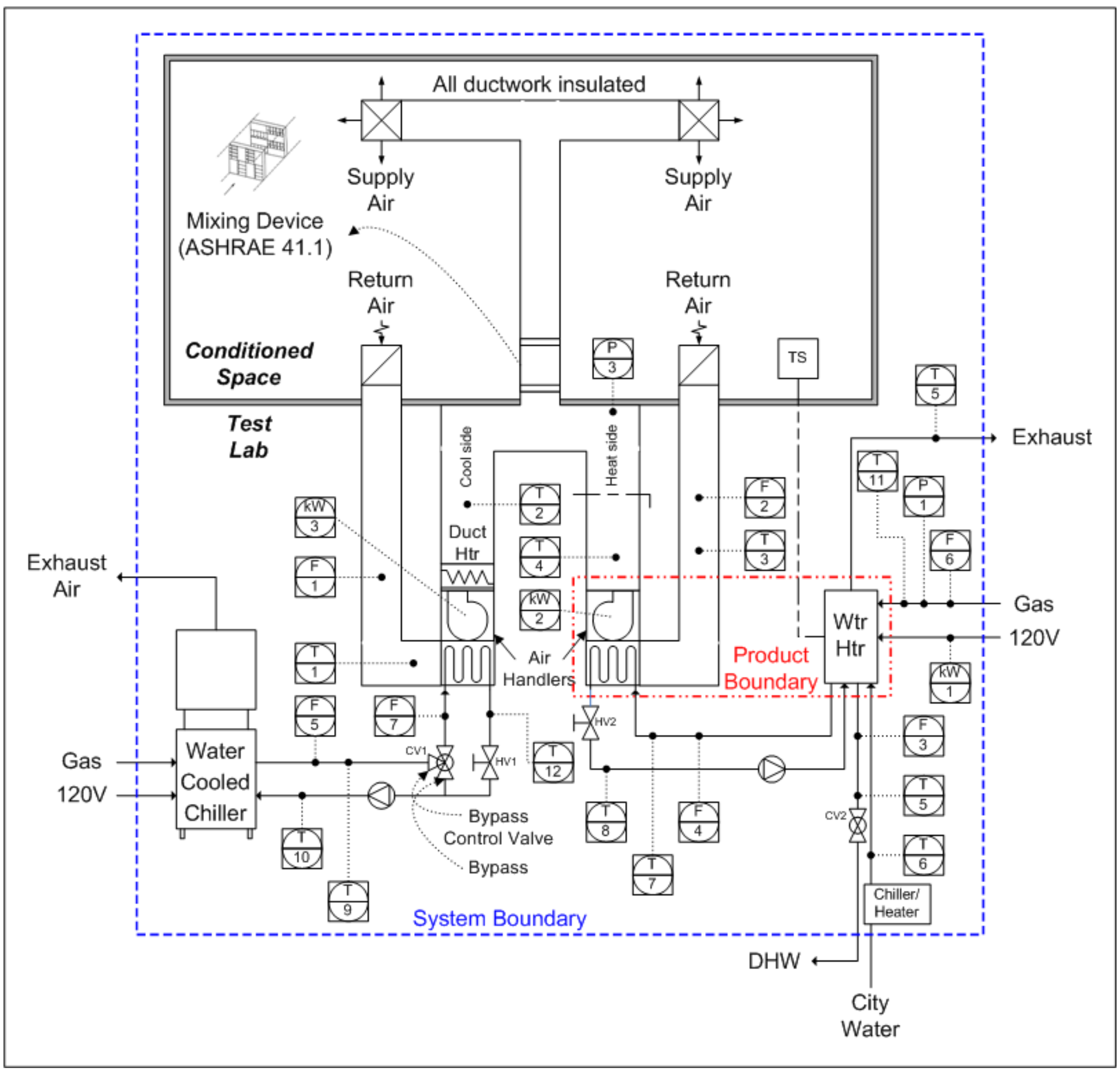


Figure 6. Test boundaries

2.4 Measurement Equipment

Equipment and materials used to conduct the tests, as described in Section 2.3, are listed in Table 7.

Table 7. Test Instrumentation

Tag	Process Measurement	Instrument	Accuracy	Quantity
T1	Cool-side return air	Thermocouples (averaged)	± > of 1.0°C or 0.75%	9
T2	Cool-side supply air	Thermocouples (averaged)	± > of 1.0°C or 0.75%	9
T3	Heat-side return air	Thermocouples (averaged)	± > of 1.0°C or 0.75%	9
T4	Heat-side supply air	Thermocouples (averaged)	± > of 1.0°C or 0.75%	1
T5	WH exhaust gas	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T6	WH city supply	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T7	Hydronic heat loop supply	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T8	Hydronic heat loop return	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T9	Water chiller supply	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T10	Water chiller return	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
T12	Cool-side chilled water return	Ultra precise fast response RTDs	±1/10 (0.3 + 0.005 |t|)°C	1
F1	Cool-side air flow	Air flow station	± 2%	1
F2	Heat-side air flow	Air flow station	± 2%	1
-	Flow Pressure	Low Range Differential Pressure Transmitter	± 0.5% of full span	2
F3	DHW flow	Water flow meter	± 1% of full span	1
F4	Hydronic heat loop flow	Water flow meter	± 1% of full span	1
F5	Water chiller flow	Water flow meter	± 1% of full span	1
F6	Gas flow	Gas meter, P/T compensated	< ± 1%	1
F7	Cool-side chilled water supply	Water flow meter	± 1% of full span	1
P3	Supply air static pressure	Static Pressure	± 1% of full span	1
KW1	Electric Energy Use	Electric Wattmeter	± 0.5% of full span	1
KW2	Electric Energy Use	Electric Wattmeter	± 0.5% of full span	1
-	Electric Energy Use	Current Transformer	± 0.05% of full span	2

Notes: RTD, resistance temperature device; P/T, Pressure/Temperature

3 Analysis

The tests were intended to characterize key operational attributes for condensing storage and tankless combo system configurations and to differentiate the performance of the two combo approaches. Each system was tested against the loads to determine how well their capacities matched with the model home and how well the systems responded to demands.

Efficiencies were calculated on a 24-h test basis by dividing the total energy produced as DHW and space heating air by the total electric and gas energy consumed by the WH and the AHU.

$$\text{Efficiency} = (Q_W + Q_A)/Qin$$

where

Q_W = Energy produced as DHW (Btu/h)

$$Q_W = 499.8 \times F3 \times (T_{DHW} - T_{CW})$$

where

F3 = DHW flow (gal/min)

T_{DHW} = Water heater DHW outlet temperature (°F)

T_{CW} = City water supply temperature (°F)

Q_A = Energy produced as warm air (Btu/h)

$$Q_A = 14.46 \times F2 \times \rho_a \times (T_{in} - T_{out})$$

where

F2 = AHU air flow (cfm)

ρ_a = Density of air = $1.325 \times P2 / (T3 + 459.7)$

T_{in} = Coil inlet temperature (°F)

T_{out} = Coil outlet temperature (°F)

Q_{in} = Fuel input (Btu/h)

$$Q_{in} = F6 \text{ x } \rho_g \times HHV_g$$

where

F6 = Gas flow (cf/h)

ρ_g = Density of gas

HHV_g = Higher heating value of natural gas.

4 Results

In all, thirty-six 24-h tests were conducted. The Rinnai tankless combo system and the AO Smith storage combo system were tested against each of the 18 daily load profiles. For each test day, the same AHU was used—one test with the tankless and one test with the storage. For all tests, the combo systems were configured per the manufacturer's instructions. Additionally, for all tests the WH set points and hot water flows to the AHUs were adjusted to maintain appropriate heating capacities, delivered air temperatures, and return water temperatures. Table 8 summarizes the key system parameters. The parametric adjustments were made with one goal in mind: to minimize the return water temperature and still achieve comfortable supply air delivery (110°F–120°F).

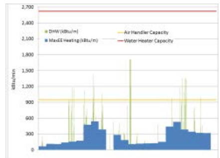
Supply air and return water temperatures were found to be significantly higher with the storage system than with the tankless. This accounted for the 5°F temperature set point differential between the two systems. The reason for the higher storage temperatures is that water is drawn off the top of the tank where the stacking effect makes it hotter than the set point.

Table 8. Key Test Parameters

Water Heater	AH	WH Set Point (°F)	Hot Water Flow to AH (gpm)	DHW Tempering (°F)	AH Air Flow (cfm)
Tankless	AHB90	135	~3.5	120	~1,250
Storage	AHB90	130	~3.5	120	~1,250
Tankless	AHB45	140	~2.1	120	~775
Storage	AHB45	135	~2.1	120	~775

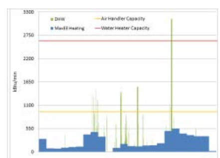
Detailed results for each of the tests, including space heating and DHW load matching, temperature profiles, and performance results are given in Appendix C. The following tables (Table 9 through Table 26) summarize the daily performance results. It is important to restate that the purpose of this project was not to conduct replicated certification tests against standardized test procedures. Instead, the testing focused on subjecting the systems to coincidental loads and letting them function in an as-installed setting. That approach provided the opportunity to evaluate the real-world attributes of the systems, and it also allowed for greater variability across tests that could not be fully controlled. For example, modulating swinging cooling loads across a 24-h test period and applying them to a small test volume (simulate building heat loss) introduces significant variables that are difficult to calibrate and control. High-resolution, wide-ranged, and frequent hot water draws across a 24-h test period are also difficult to calibrate and control. The test methods used to control the parameters, however, allowed for two very different systems (tankless and storage) to be run across separate 24-h test periods to get within about 15%, and often significantly better, in terms of space heating and DHW energy loads. That type of comparison cannot be done for in-field testing.

Table 9. Chicago MaxEE Model Test Performance Results, January 6

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: –2.0°F /+12.0°F		Applied heat loss (Btu)	447,845	369,101
City Supply Water: 44.6°F		Applied DHW draws (gal)	75.2	81.0
Max Heat Loss Rate: ~32,500 Btu/h		Energy consumed (Btu)	497,629	430,387
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	439,508	357,812
Max DHW Draw: ~2.7 gpm/7 min		HHV efficiency (%)	88	83

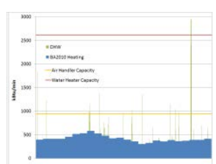
See Appendix C for details (Figure 10 through Figure 27).

Table 10. Chicago MaxEE Model Test Performance Results, January 26

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: –2.9°F /+19.9°F		Applied heat loss (Btu)	362,929	361709
City Supply Water: 44.2°F		Applied DHW draws (gal)	108.4	116.5
Max Heat Loss Rate: ~33,100 Btu/h		Energy consumed (Btu)	442,178	447,336
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	383,198	381,585
Max DHW Draw: ~4.0 gpm/7 min		HHV efficiency (%)	87	85

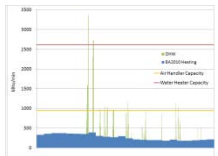
See Appendix C for details (Figure 28 through Figure 45).

Table 11. Chicago BA2010 Model Test Performance Results, January 5

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 5.0°F/26.1°F		Applied heat loss (Btu)	623,192	609,712
City Supply Water: 46.7°F		Applied DHW draws (gal)	53.4	60.5
Max Heat Loss Rate: ~34,800 Btu/h		Energy consumed (Btu)	681,692	687,978
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	632,866	624,320
Max DHW Draw: ~4.0 gpm/5 min		HHV efficiency (%)	93	91

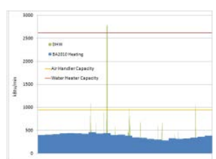
See Appendix C for details (Figure 46 through Figure 63).

Table 12. Chicago BA2010 Model Test Performance Results, December 3

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 18.0°F/39.9°F		Applied heat loss (Btu)	490,967	464,986
City Supply Water: 52.1°F		Applied DHW draws (gal)	106.2	119.1
Max Heat Loss Rate: ~23,300 Btu/h		Energy consumed (Btu)	558,168	566,915
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	500,914	490,591
Max DHW Draw: ~4.5 gpm/3 min		HHV efficiency (%)	90	87

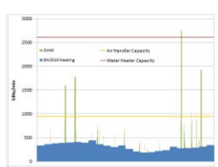
See Appendix C for details (Figure 64 through Figure 81).

Table 13. Chicago BA2010 Model Test Performance Results, November 27

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 18.0°F/28.0°F		Applied heat loss (Btu)	609,804	610,887
City Supply Water: 53.3°F		Applied DHW draws (gal)	46.2	52.2
Max Heat Loss Rate: ~27,500 Btu/h		Energy consumed (Btu)	649,749	669,538
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	604,948	608,752
Max DHW Draw: ~4.0 gpm/7 min		HHV efficiency (%)	93	91

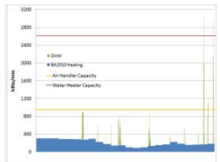
See Appendix C for details (Figure 82 through Figure 99).

Table 14. Chicago BA2010 Model Test Performance Results, December 11

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 17.1°F/32.0°F		Applied heat loss (Btu)	544,228	534,080
City Supply Water: 50.6°F		Applied DHW draws (gal)	108.1	121.0
Max Heat Loss Rate: ~26,700 Btu/h		Energy consumed (Btu)	631,765	633,693
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	573,633	562,924
Max DHW Draw: ~4.0 gpm/6 min		HHV efficiency (%)	91	89

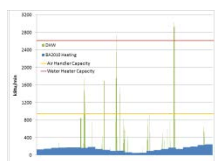
See Appendix C for details (Figure 100 through Figure 121).

Table 15. Chicago BA2010 Model Test Performance Results, February 22

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 33.1°F/53.1°F		Applied heat loss (Btu)	338,738	306,218
City Supply Water: 44.2°F		Applied DHW draws (gal)	97.8	108.8
Max Heat Loss Rate: ~18,300 Btu/h		Energy consumed (Btu)	409,704	391,547
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	342,864	317,946
Max DHW draw: ~4.0 gpm/4 min		HHV efficiency (%)	84	81

See Appendix C for details (Figure 122 through Figure 139).

Table 16. Chicago BA2010 Model Test Performance Results, March 29

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 35.1°F/55.9°F		Applied heat loss (Btu)	338,050	361,884
City Supply Water: 47.3°F		Applied DHW draws (gal)	139.7	158.5
Max Heat Loss Rate: ~14,700 Btu/h		Energy consumed (Btu)	433,315	479,571
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	368,408	405,535
Max DHW Draw: ~4.2 gpm/8 min		HHV efficiency (%)	85	85

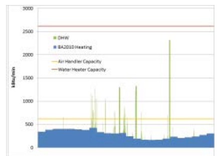
See Appendix C for details (Figure 140 through Figure 157).

Table 17. Atlanta BA2010 Model Test Performance Results, February 3

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 16.0°F/35.1°F		Applied heat loss (Btu)	528,493	538,676
City Supply Water: 56.2°F		Applied DHW draws (gal)	58.3	62.3
Max Heat Loss Rate: ~30,200 Btu/h		Energy consumed (Btu)	623,102	640,823
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	552,058	567,382
Max DHW Draw: ~2.0 gpm/8 min		HHV efficiency (%)	89	89

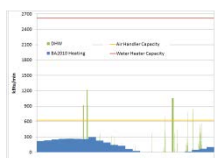
See Appendix C for details (Figure 158 through Figure 175).

Table 18. Atlanta BA2010 Model Test Performance Results, January 26

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 21.9°F/36.0°F		Applied heat loss (Btu)	485,469	491,210
City Supply Water: 56.3°F		Applied DHW draws (gal)	103.4	111.3
Max Heat Loss Rate: ~25,500 Btu/h		Energy consumed (Btu)	598,007	615,974
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	525,516	539,212
Max DHW Draw: ~4.0 gpm/8 min		HHV efficiency (%)	88	88

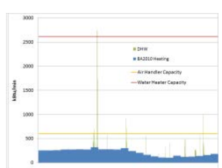
See Appendix C for details (Figure 176 through Figure 193).

Table 19. Atlanta BA2010 Model Test Performance Results, December 3

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 25.0°F/44.1°F		Applied heat loss (Btu)	237,614	266,762
City Supply Water: 62.0°F		Applied DHW draws (gal)	81.3	83.9
Max Heat Loss Rate: ~17,500 Btu/h		Energy consumed (Btu)	277,828	323,871
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	232,389	272,571
Max DHW Draw: ~2.1 gpm/12 min		HHV efficiency (%)	84	84

See Appendix C for details (Figure 194 through Figure 215).

Table 20. Atlanta BA2010 Model Test Performance Results, February 6

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 32.0°F/44.1°F		Applied heat loss (Btu)	400,602	411,699
City Supply Water: 56.3°F		Applied DHW draws (gal)	41.0	45.8
Max Heat Loss Rate: ~19,000 Btu/h		Energy consumed (Btu)	442,489	470,029
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	379,183	401,160
Max DHW Draw: ~4.5 gpm/4 min		HHV efficiency (%)	86	85

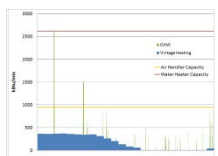
See Appendix C for details (Figure 216 through Figure 234).

Table 21. Atlanta Vintage Model Test Performance Results, April 6

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 32.0°F/60.1°F		Applied heat loss (Btu)	309,081	295,182
City Supply Water: 62.6°F		Applied DHW draws (gal)	71.6	75.2
Max Heat Loss Rate: ~31,100 Btu/h		Energy consumed (Btu)	349,895	360,149
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	305,445	298,032
Max DHW Draw: ~1.5 gpm/14 min		HHV efficiency (%)	87	83

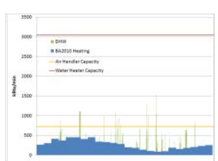
See Appendix C for details (Figure 235 through Figure 252).

Table 22. Atlanta Vintage Model Test Performance Results, March 23

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 41.0°F/64.9°F		Applied heat loss (Btu)	236,894	271,582
City Supply Water: 60.3°F		Applied DHW draws (gal)	74.3	75.1
Max Heat Loss Rate: ~22,200 Btu/h		Energy consumed (Btu)	276,339	318,840
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	236,145	265,406
Max DHW Draw: ~3.5 gpm/5 min		HHV efficiency (%)	85	83

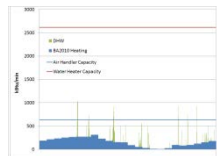
See Appendix C for details (Figure 253 through Figure 270).

Table 23. Houston BA2010 Model Test Performance Results, February 11

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 21.0°F/39.0°F		Applied heat loss (Btu)	469,495	474,407
City Supply Water: 64.7°F		Applied DHW draws (gal)	79.7	82.9
Max Heat Loss Rate: ~27,100 Btu/h		Energy consumed (Btu)	566,579	585,523
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	492,477	504,984
Max DHW Draw: ~2.0 gpm/3 min		HHV efficiency (%)	87	86

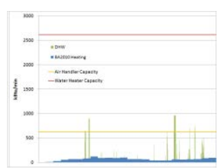
See Appendix C for details (Figure 271 through Figure 288).

Table 24. Houston BA2010 Model Test Performance Results, January 11

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 30.0°F/52.0°F		Applied heat loss (Btu)	297,513	304,799
City Supply Water: 64.6°F		Applied DHW draws (gal)	53.9	55.5
Max Heat Loss Rate: ~18,700 Btu/h		Energy consumed (Btu)	331,061	358,595
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	274,610	291,182
Max DHW Draw: ~1.8 gpm/1 min		HHV efficiency (%)	83	81

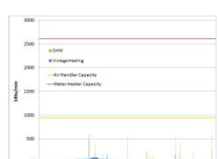
See Appendix C for details (Figure 289 through Figure 306).

Table 25. Houston BA2010 Model Test Performance Results, December 9

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 46.0°F/54.0°F		Applied heat loss (Btu)	186,130	176,746
City Supply Water: 67.5°F		Applied DHW draws (gal)	76.9	79.7
Max Heat Loss Rate: ~7,200 Btu/h		Energy consumed (Btu)	214,151	217,643
Approx. AH Capacity: ~37,400 Btu/h		Energy delivered (Btu)	163,282	156,205
Max DHW Draw: ~2.0 gpm/13 min		HHV efficiency (%)	76	72

See Appendix C for details (Figure 307 through Figure 324).

Table 26. Houston Vintage Model Test Performance Results, March 7

Test Day Summary	Model Profile	Daily Results	Tankless	Storage
Min/Max Temperatures: 48.0°F/72.0°F		Applied heat loss (Btu)	47,355	55,860
City Supply Water: 66.7°F		Applied DHW draws (gal)	12.3	11.7
Max Heat Loss Rate: ~6,200 Btu/h		Energy consumed (Btu)	45,995	69,640
Approx. AH Capacity: ~56,700 Btu/h		Energy delivered (Btu)	31,940	40,603
Max DHW Draw: ~1.0 gpm/1 min		HHV efficiency (%)	69	58

See Appendix C for details (Figure 325 through Figure 342).

5 Key Findings and Recommendations

The following general findings and recommendations were derived from the laboratory evaluations of tankless- and storage-based combo systems:

1. The tankless combo system maintained more stable DHW and space heating temperatures than the storage combo system. Most notably, temperature stratification in the storage tank was found to cause supply air temperature instability. As water is drawn from the tank, it comes off the top where, in some cases, the stacking effect causes the water to be hotter than the average tank temperature. The stacking effect occurs because the hot water is less dense and rises to the top of the hot water tank. As water is drawn down lower in the tank, the delivered temperature gets cooler. For long space heating draws, or periods where space heating and DHW are needed, the temperature decay is enough to create uncomfortable drafty conditions from the AHU. Those conditions could occur when air is delivered from the AHU at less than 110°F as was seen at times during the laboratory tests.

   Further testing is appropriate to determine if alternative tap positions would stabilize delivered water temperature for storage-based combo systems.

2. The storage combo system delivered DHW at the tempered setting (120°F) faster than the tankless combo system. The tankless system reached 115°F, however, nearly as fast (i.e., within 10 s) as the storage system.

3. The tankless combo system consistently achieved better daily efficiencies (i.e., 84%–93%) than the storage combo system (i.e., 81%–91%) when the AHU was sized adequately and adjusted properly to achieve significant condensing operation. To achieve more consistent condensing operation, it was necessary to minimize the return water temperatures by adjusting the water heater set point down and reducing the water flow. These adjustments were governed by comfort in terms of air temperature and air flow delivered. When condensing operation was not achieved, the tankless and storage systems performed with lower efficiencies than when condensing was achieved. In those noncondensing cases, the tankless and storage systems performed with about the same daily efficiencies (i.e., 75%–88%).

4. AHUs currently packaged with combo systems are not designed to optimize condensing operation for condensing WHs. To achieve overall system efficiencies greater than 90%, the WH must condense while delivering DHW and space heating. While delivering DHW, cold water enters the heat exchanger and cools the exhaust sufficiently for condensing operation. While delivering space heating, however, water returns to the system at temperatures well above 100°F. If the AHU was sized large enough (as was generally the case with the AHB90), enough energy was removed from the hot water (e.g., <107°F) to cool exhaust gas down to condensing temperatures. For the AHB45 to maintain heating capacities, the WH set point needed to be increased. To minimize the return water temperature, the water flow to the coils was reduced to 2 gpm. Even at that low flow, the return water temperature was greater than 107°F and resulted in efficiencies less than 90% for all of the tests with the AHB45.

   More research is needed to develop AHUs specifically designed for condensing WHs.

5. System efficiencies greater than 90% were achieved only on days where continuous and steady space heating loads were required. For days where heating was required only at night or the space heating loads were "peaky," the system efficiencies fell below 90%.
6. For DHW draws, temperature stratification in the storage tank goes relatively unnoticed because the water temperature is generally maintained higher than the tempered valve setting. Only during very long DHW draws (>15 min) do temperatures dip below the setting.

Appendix A: Detailed Modeling Parameters

Building America 2010 Residential Prototype Building Site and Geometry		
Home Type = Single Family Detached		**1**
Finished Floor Area of unit, Above Grade	ft^2	**2250**
Num Floors of unit (Above Grade)	#	**2**
Building Aspect Ratio (Width/Depth)	ratio	**1**
Foundation Type (slab, basement, crawlspace, exposed floor)	Basement	**Basement + Slab**
Basement Floor Area	sq ft	**900**
Basement Finished?	YES/NO	**NO**
Conditioned Floor Area	ft^2	**2250**
Total Floor Area (conditioned+unconditioned)	ft^2	**3150**
Attic Vented or Unvented	Vented/Unvented	**Vented**
Number of Bedrooms	#	**3**
Number of Bathrooms	#	**2**
Garage Depth	ft	**20**
Garage Protrusion	ft	**10**
Total Garage Floor Area	sq ft	**400**
Floor-to-floor Height	ft	**8**

- Residential building models were constructed per BA2010 residential prototype recommendations and modified to reflect climate conditions in three geographical locations. See Table 27.
- The high-efficiency version of residential models upgrades BA2010 with high-efficiency envelope, glazing, and ENERGY STAR appliances. See Table 27.

The Vintage version of residential models downgrades the BA2010 prototype using envelope recommendations per work at LBNL (see footnote 2). See Table 27. Residential DHW loads were generated using data from the National Renewable Energy Laboratory's Standard DHW Event Schedules Spreadsheet Tool (01/05/2011). Multievent load data from the spreadsheet were postprocessed and aggregated to minute-by-minute annual load profiles for the climate conditions in three geographical locations. For details see "Tool for Generating Realistic Residential Hot Water Event Schedules."[6] Table 27 – Residential Building Model Details

CASE		BA2010	BA2010 + Max. Envelope/Ducts/Controls EE	Vintage
GEOMETRY	Total Finished Floor Area	2250	2250	2250
	Beds	3	3	3
	Baths	2	2	2
SITE				
	Location	USA_IL_Chicago-OHare.Intl.AP.725300_TMY3	USA_IL_Chicago-OHare.Intl.AP.725300_TMY3	USA_IL_Chicago-OHare.Intl.AP.725300_TMY3
Building				
	Orientation	North	North	North
	Neighbors	None	None	None
Operation				
	Heating Set Point	71 F no setback	71 F/65 F setback during weekdays	71 F no setback
	Cooling Set Point	76 F no setback	76 F/85 F setback during weekdays	76 F no setback
	Misc Electric Loads, kWh/year	1, 3279, gas/elec house	1, 3279, gas/elec house	1, 3279, gas/elec house
	Misc Gas Loads, therms/year	1, 7.8	1, 7.8	1, 7.8
	Misc Hot Water Loads	Benchmark, sink 25, shower 27, bath. 7 gal/day	Benchmark, sink 25, shower 27, bath. 7 gal/day	Benchmark, sink 25, shower 27, bath. 7 gal/day
	Natural Ventilation	Benchmark, Jan-Dec31	Benchmark, Jan-Dec31	Benchmark, Jan-Dec31
Walls				
	Wood Stud	R13 batts, 2x4, 16"o.c. + R5 foam, Framing 0.25, Comp. R 17	R21 batts, 2x6, 24"o.c. + 1" foam, framing 0.218, comp R 24.2	R11 batts, 2x4, 16"o.c. , Framing 0.25, Comp. R 10.5
	Exterior Finish	Stucco, R 0.2	Stucco, R 0.2	Stucco, R 0.2
	Interzonal Walls	R13 batts, 2x4, 16"o.c. + R5 foam	R13 batts, 2x4, 16"o.c. + R5 foam	R11 batts, 2x4, 16"o.c., Comp. R 10.1
Ceilings/Roofs				
	Unfinished Attic	Ceiling R38 Cellulose Blown-In, Vented, Comp R 28.9	Ceiling R60 Cellulose Blown-In, Vented, Comp R61	Ceiling R11 fiberglass blown-in, Vented, Celing Comp R12.5
	Roofing Material	Asphalt Shingles, White or cool colors, Abs. 0.75,Emiss.0.91	Asphalt Shingles, White or cool colors, Abs. 0.75,Emiss.0.91	Asphalt Shingles, Dark, Abs. 0.92,Emiss.0.91
	Radiant Barrier	None	Radiant Barrier	None
Foundation/Floors				
	Slab	2-ft R-10	2-ft R-10	Uninsulated
	Unfinished Basement	Wall 8ft R10 Rigid	Wall 8ft R10 Rigid	Uninsulated, Comp. R2.58
	Interzonal Floor	R-23.0	R-23.0	R13, fibergalss
	Exposed Floor	20% Exposed	20% Exposed	20% Exposed
Thermal Mass				
	Floor Mass	Wood Surface	Wood Surface	Wood Surface
	Ext Wall Mass	1/2" Drywall	1/2" Drywall	1/2" Drywall
	Partition Wall Mass	1/2" Drywall	1/2" Drywall	1/2" Drywall
	Ceiling Mass	1/2" Ceiling Drywall	1/2" Ceiling Drywall	1/2" Ceiling Drywall
	Furniture Mass	Light-Weight, 8 lbs/sqft	Light-Weight, 8 lbs/sqft	Light-Weight, 8 lbs/sqft
Windows & Shading				
	Window Areas	15.0% F25 B25 L25 R25/290-72/72/72/72	15.0% F25 B25 L25 R25/290-72/72/72/72	15.0% F25 B25 L25 R25/290-72/72/72/72
	Window Type	U.35_SHGS.35	Low-e v. high SHGC arg (U .325_SHGS.511)	Double clear U.447_SHGS.547
	Interior Shading	Benchmark, cooling 0.7, heating 0.7	Benchmark, cooling 0.7, heating 0.7	Benchmark, cooling 0.7, heating 0.7
	Eaves	2 ft	2 ft	2 ft
	Overhangs	None	None	None
Airflow				
	Infiltration	Tight, SLA 0.00036	Tightest, SLA 0.00009	Leaky, SLA 0.00070
	Mechanical Ventilation	Exhaust, 100% of A-62.2, 52.5 cfm	Exhaust, 100% of A-62.2, 52.5 cfm	Exhaust, 100% of A-62.2, 52.5 cfm
Major Appliances				
	Refrigerator	Standard, Bottom Mount Freezer, 668 kWh/year	EnergyStar, Bottom Mount Freezer, 452 kWh	Standard, Bottom Mount Freezer, 668 kWh/year
	Cooking Range	Electric, Conventional, 500 kWh/year	Electric, Conventional, 500 kWh/year	Electric, Conventional, 500 kWh/year
	Dishwasher	Standard 175 kWh	Energy Star	Standard 175 kWh
	Clothes Washer	Standard, Mod EF 1.41, 78 kWh	Energy Star	Standard, Mod EF 1.41, 78 kWh
	Clothes Dryer	Electric, 2.26 kWh/cycle, 1076 kWh	Electric, 2.26 kWh/cycle, 1076 kWh	Electric, 2.26 kWh/cycle, 1076 kWh
Lighting				
	Lighting, Liv 1554, Grg 40, Ext 326 kWh	B10 Benchmark, 1738 kWh/year, CFL 21, LED 0, LFL 13	B10 Benchmark, 1738 kWh/year, CFL 21, LED 0, LFL 13	B10 Benchmark, 1738 kWh/year, CFL 21, LED 0, LFL 13
Space Conditioning				
	Air Conditioner	SEER 13, EER 11.09	SEER 13, EER 11.09	SEER 10, EER 9.31
	Furnace	Gas, AFUE 78%, 1.242 Btu/Btu	Gas, AFUE 78%, 1.242 Btu/Btu	Gas, AFUE 78%, 1.242 Btu/Btu
	Ducts	Typical, Uninsulated, LF 0.150	Tight, R8 Insulation, LF 0.075	leaky, Uninsulated, LF 0.300
	Ceiling Fans	Benchmark	Benchmark	Benchmark
Water Heating				
	Water Heater	Gas Standard, EF 0.59, Tank 40 gal, burner 40200 Btu/h	Gas Standard, EF 0.59, Tank 40 gal, burner 40200 Btu/h	Gas Standard, EF 0.59, Tank 40 gal, burner 40200 Btu/h
	Distribution	R-0, TrunkBranch, Copper	R-0, TrunkBranch, Copper	R-0, TrunkBranch, Copper

[6] Hendron, B.; Burch, J.; Barker, G. (2010). "Tool for Generating Realistic Residential Hot Water Event Schedules." Paper presented at SimBuild 2010, New York, August 15–19. Accessed January 8, 2013: http://www.ibpsa.us/pub/simbuild2010/technicalPresentations/SB10-PPT-TS06B-01-Hendron.pdf.

Appendix B: Load Duration Graphs

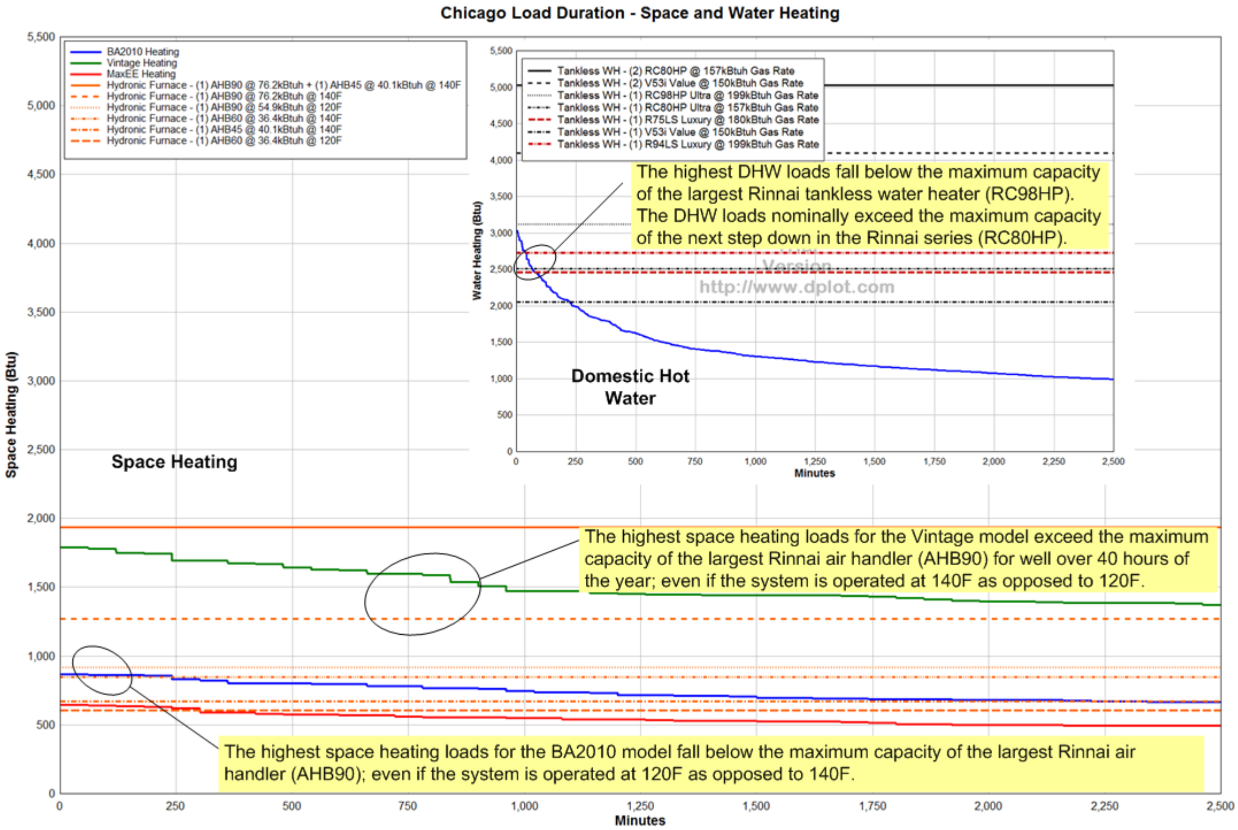


Figure 7. Chicago load durations

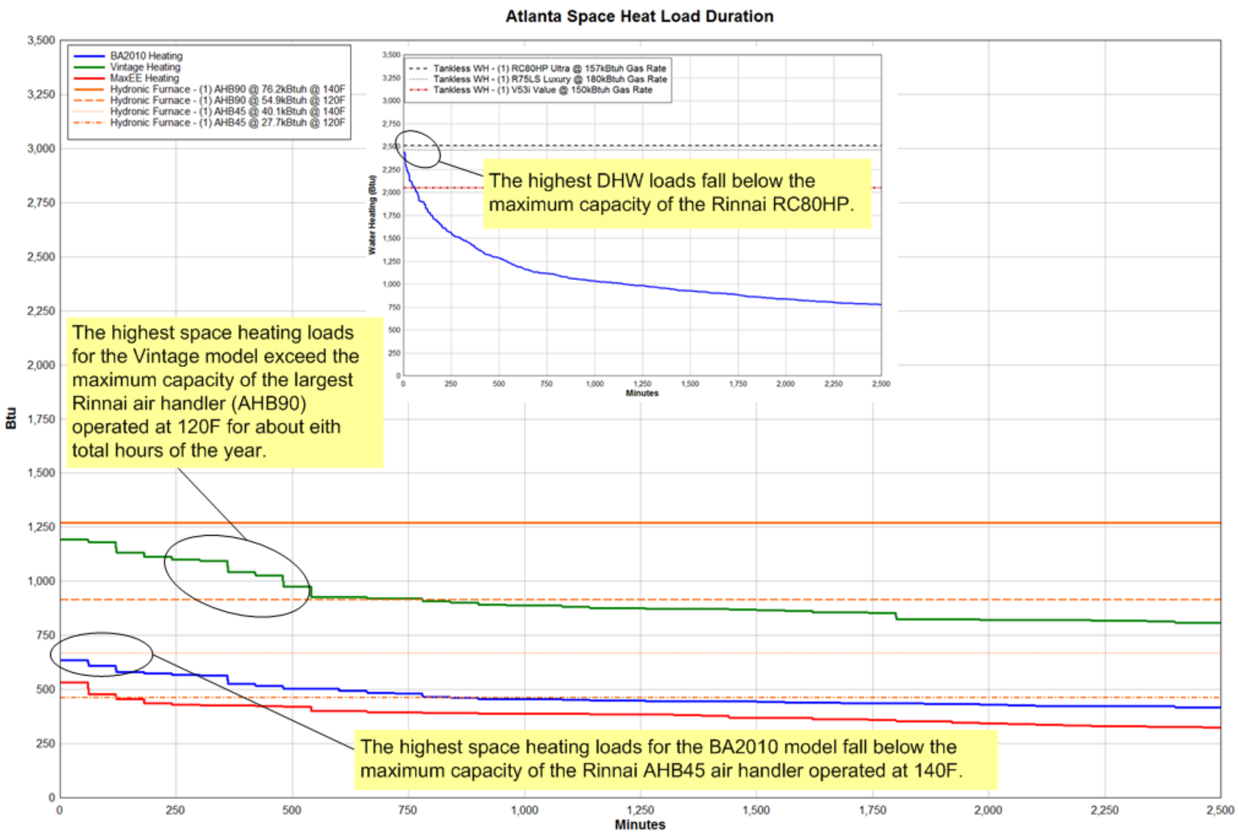


Figure 8. Atlanta load durations

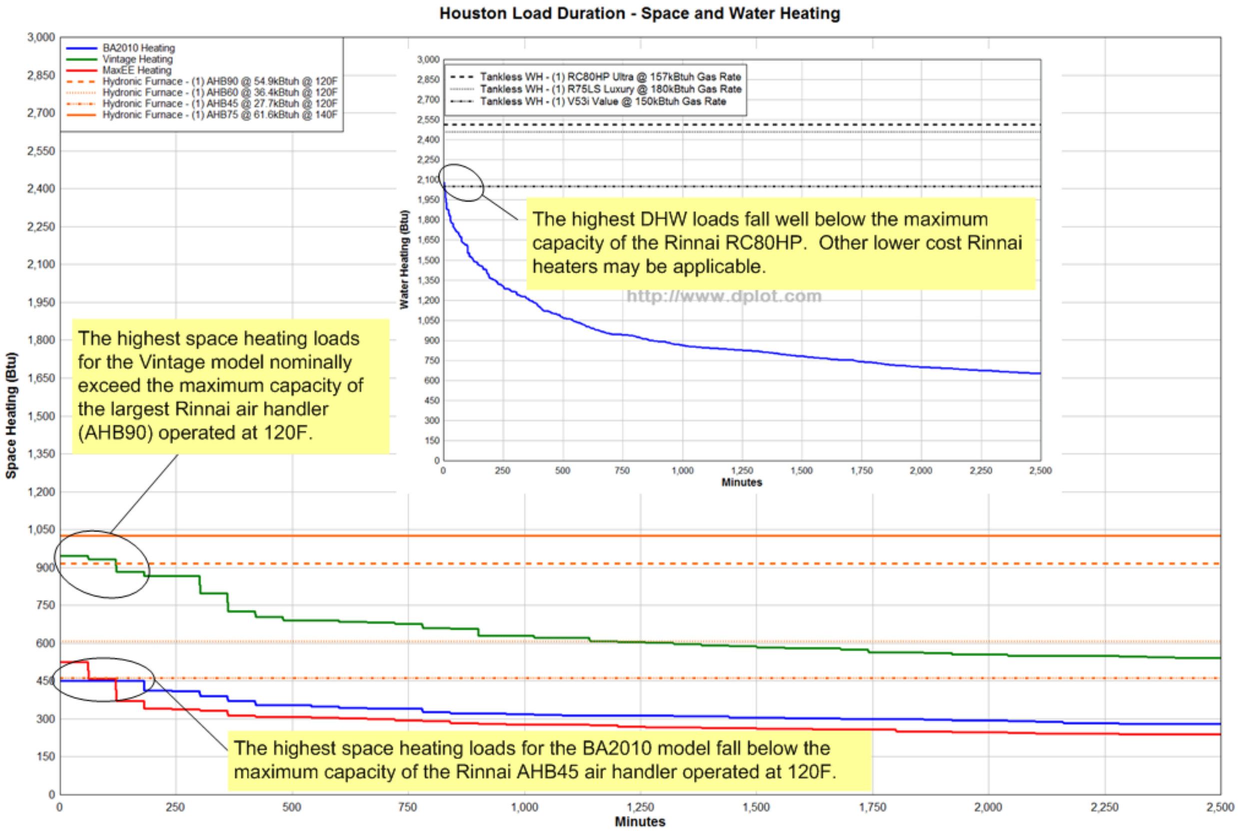


Figure 9. Houston load durations

Appendix C: Daily Profile Graphs

Chicago, MaxEE Model, Rinnai Test With RC80HP/AHB90, January 6

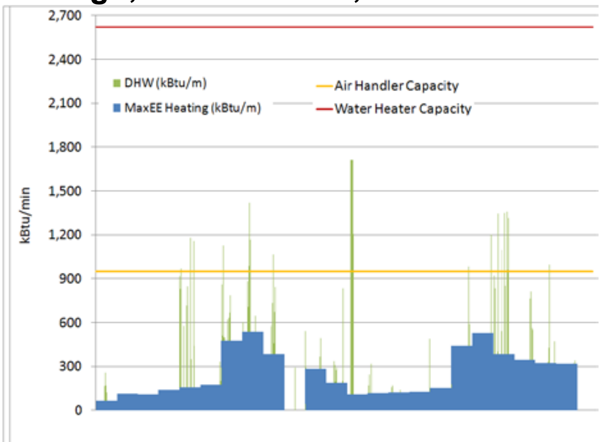


Figure 10. As-modeled space/DHW loads

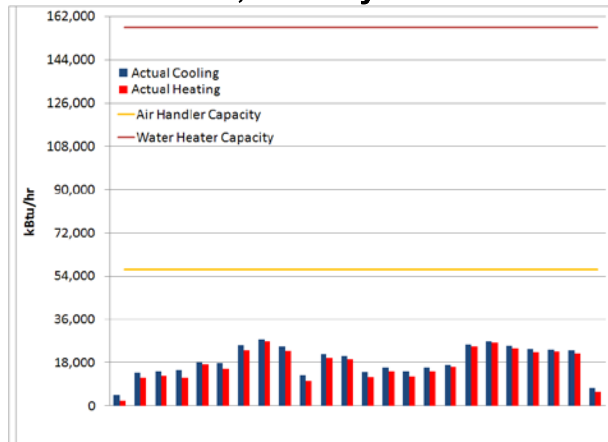


Figure 11. Actual space heating

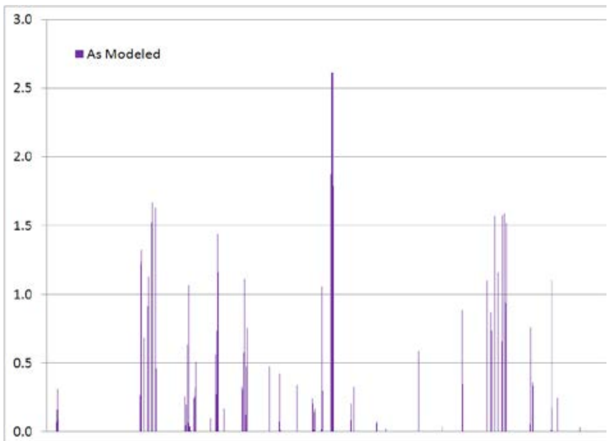


Figure 12. As-modeled DHW draws

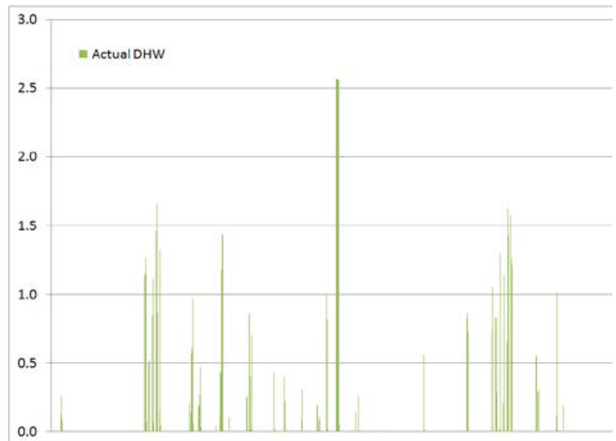


Figure 13. Actual DHW draws

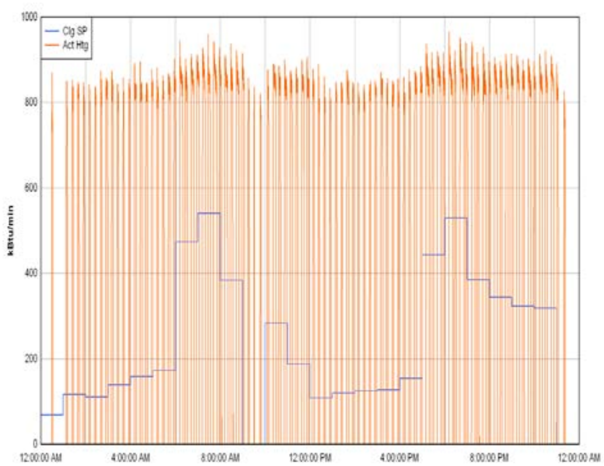


Figure 14. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	337,005
Actual heat loss applied (Btu/day)	447,845
Total daily DHW as modeled (gal/day)	73.5
Actual daily DHW (gal/day)	75.2
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	475,463
Gas consumed LHV (Btu)	467,333
Combo Air Handler power consumed (Btu)	22,015
Water heater power consumed (Btu)	151
Space heating Energy (Btu)	410,826
DHW energy (Btu)	28,682
HHV System Efficiency	88%
LHV System Efficiency	90%

Figure 15. Performance results

Chicago, MaxEE Model, Vertex Test With RC80HP/AHB90, January 6

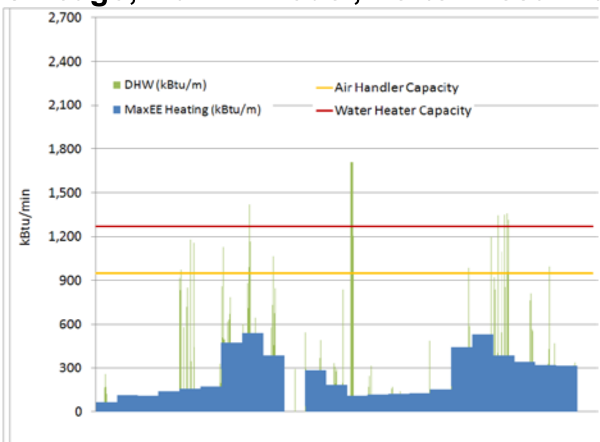


Figure 16. As-modeled space/DHW loads

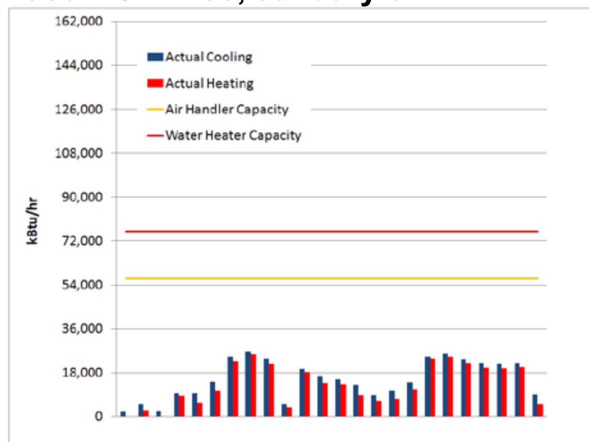


Figure 17. Actual space heating

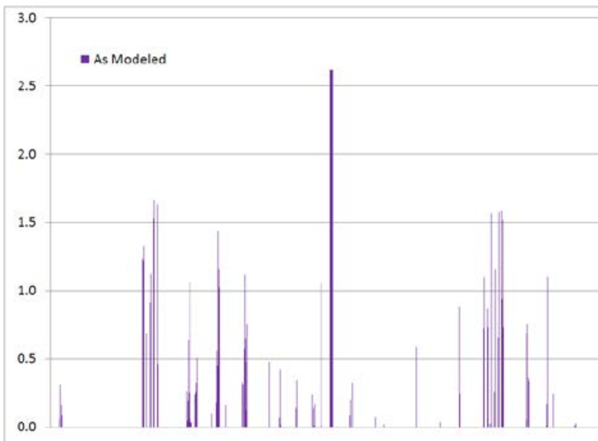


Figure 18. As-modeled DHW draws

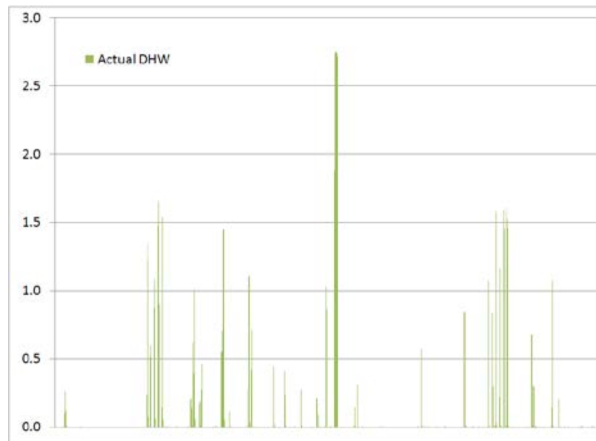


Figure 19. Actual DHW draws

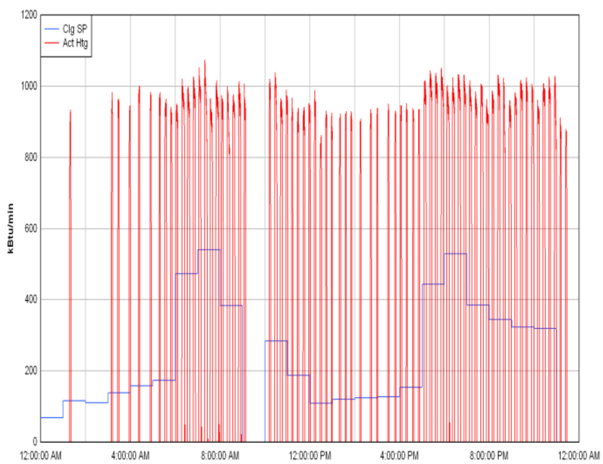


Figure 20. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	337,005
Actual heat loss applied (Btu/day)	369,101
Total daily DHW as modeled (gal/day)	73.5
Actual daily DHW (gal/day)	81.0
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	415,114
Gas consumed LHV (Btu)	408,016
Combo Air Handler power consumed (Btu)	15,155
Water heater power consumed (Btu)	118
Space heating Energy (Btu)	315,306
DHW energy (Btu)	42,506
HHV System Efficiency	83%
LHV System Efficiency	85%

Figure 21. Performance results

Chicago, MaxEE Model, Tankless Versus Storage Temperature Stability, January 6

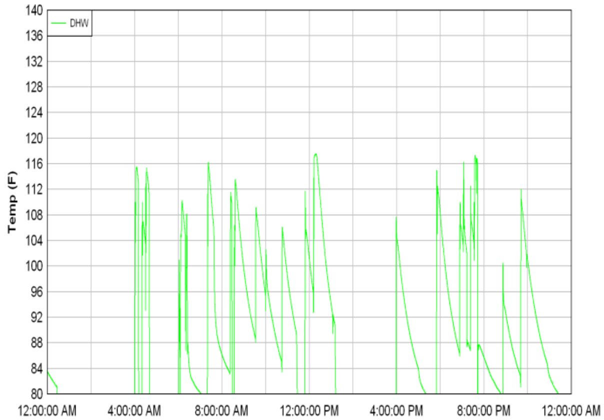


Figure 22. Tankless DHW temperatures

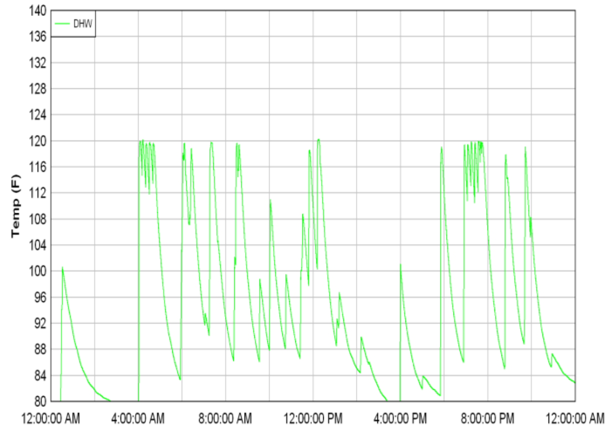


Figure 23. Storage DHW temperatures

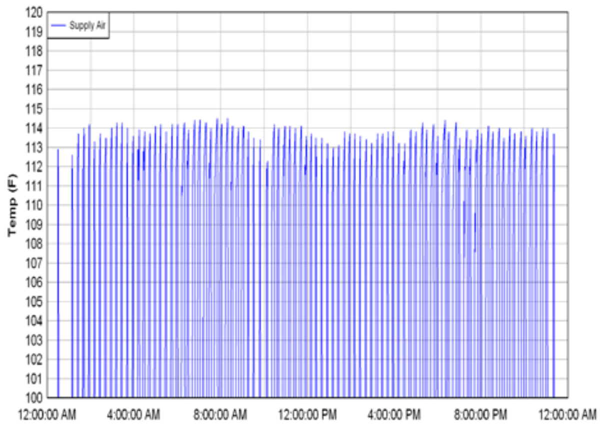


Figure 24. Tankless supply air temperatures

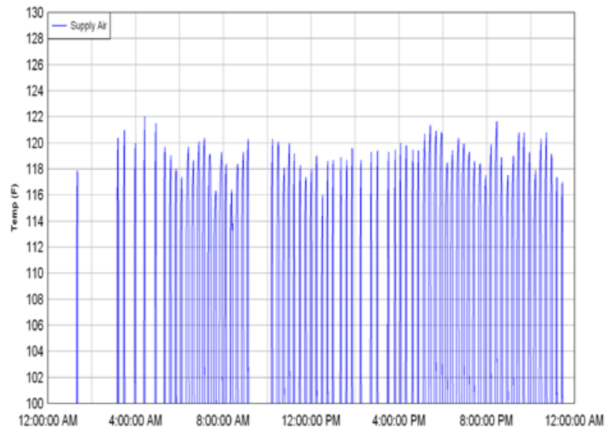


Figure 25. Storage supply air temperatures

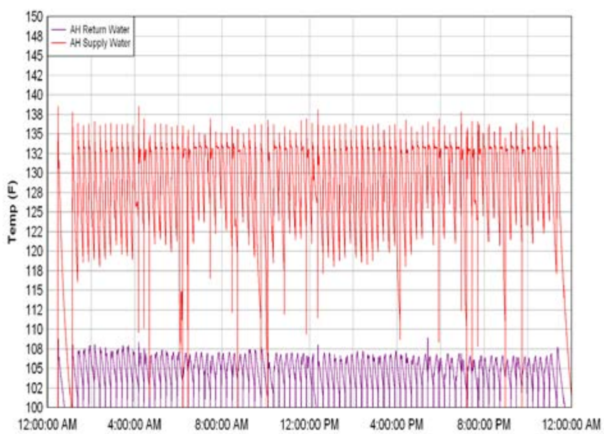


Figure 26. Tankless AH water temperatures

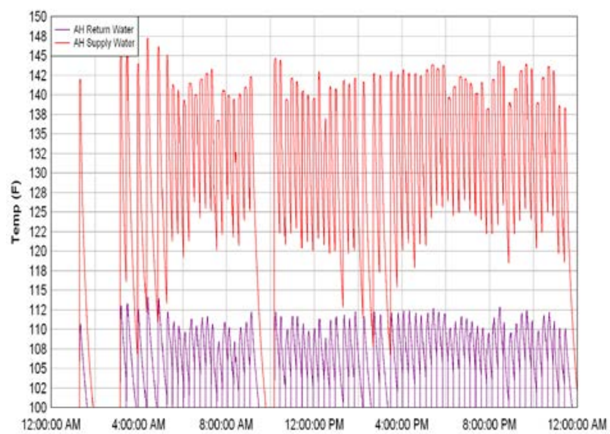


Figure 27. Storage AH water temperatures

Chicago, MaxEE Model, Rinnai Test With RC80HP/AHB90, January 26

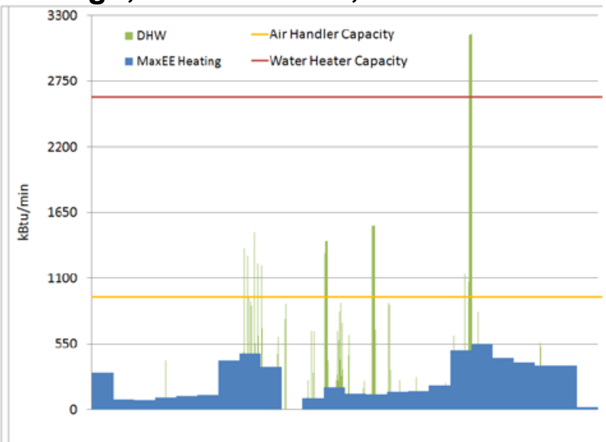


Figure 28. As-modeled space/DHW loads

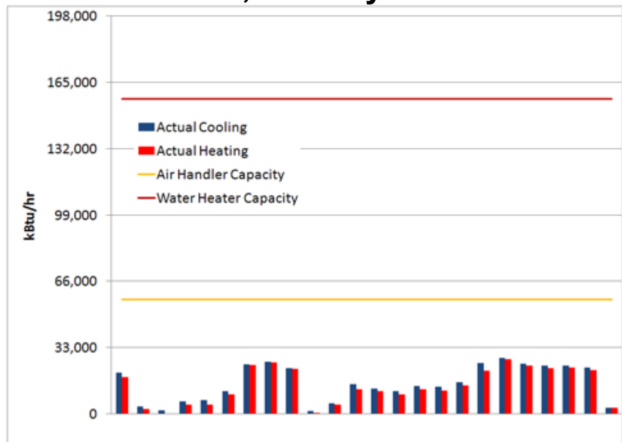


Figure 29. Actual space heating

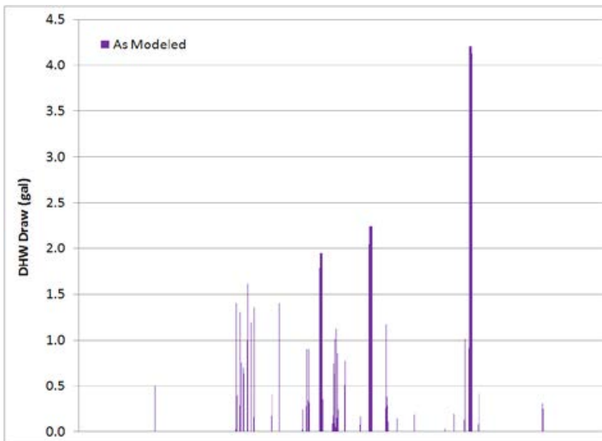


Figure 30. As-modeled DHW draws

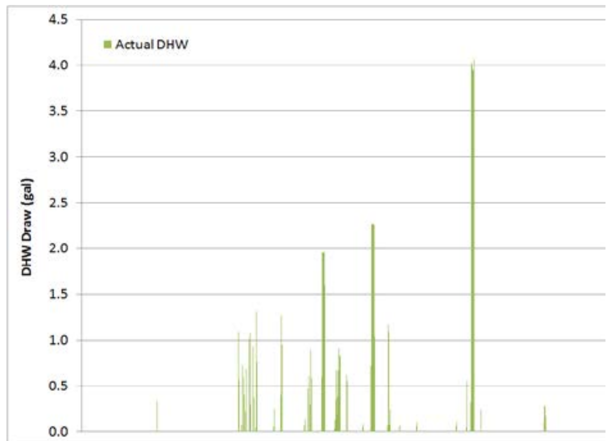


Figure 31. Actual DHW draws

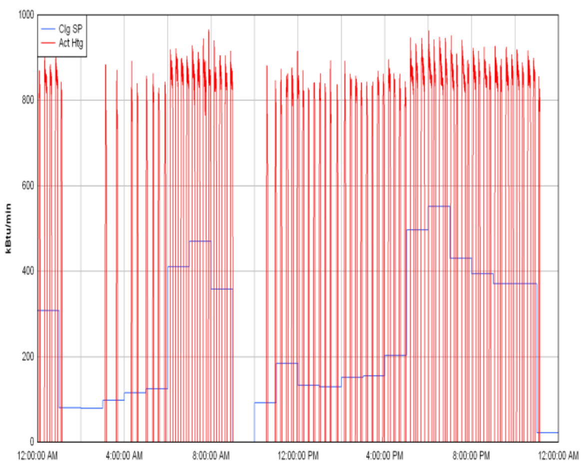


Figure 32. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	344,074
Actual heat loss applied (Btu/day)	362,929
Total daily DHW as modeled (gal/day)	104.4
Actual daily DHW (gal/day)	108.4
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	424,348
Gas consumed LHV (Btu)	417,092
Combo Air Handler power consumed (Btu)	17,705
Water heater power consumed (Btu)	125
Space heating Energy (Btu)	330,382
DHW energy (Btu)	52,816
HHV System Efficiency	87%
LHV System Efficiency	88%

Figure 33. Performance results

Chicago, MaxEE Model, Vertex Test With RC80HP/AHB90, January 26

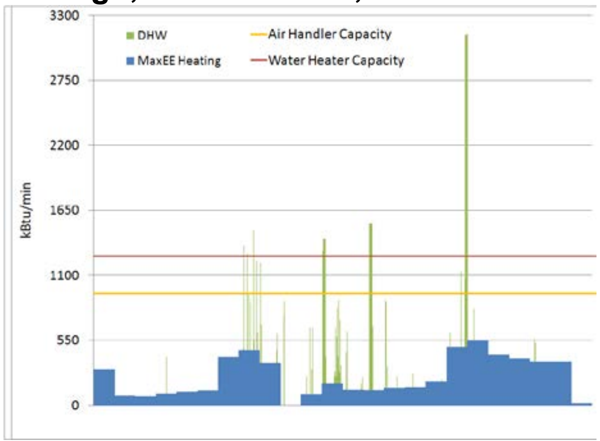


Figure 34. As-modeled space/DHW loads

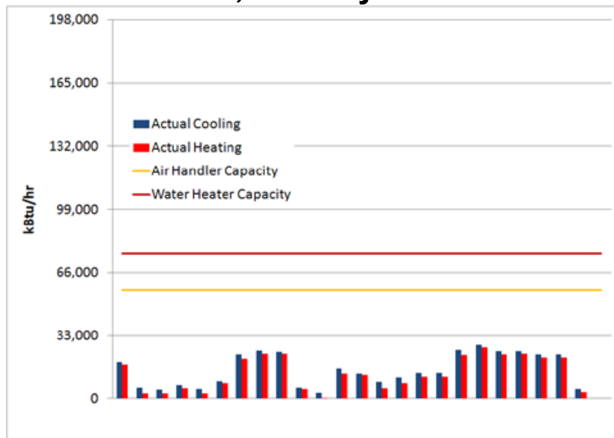


Figure 35. Actual space heating

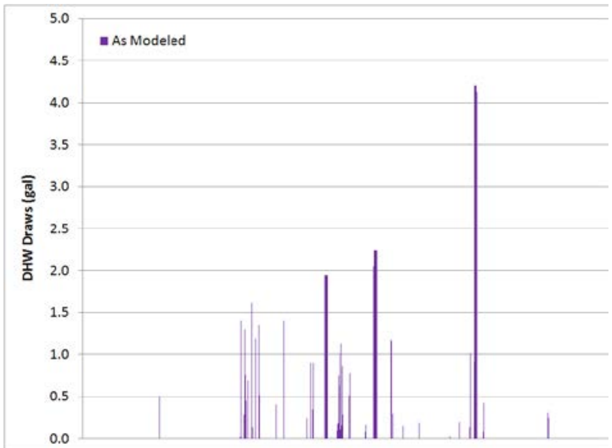


Figure 36. As-modeled DHW draws

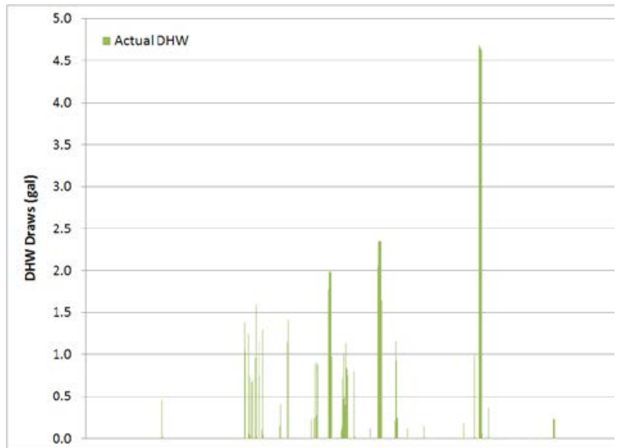


Figure 37. Actual DHW draws

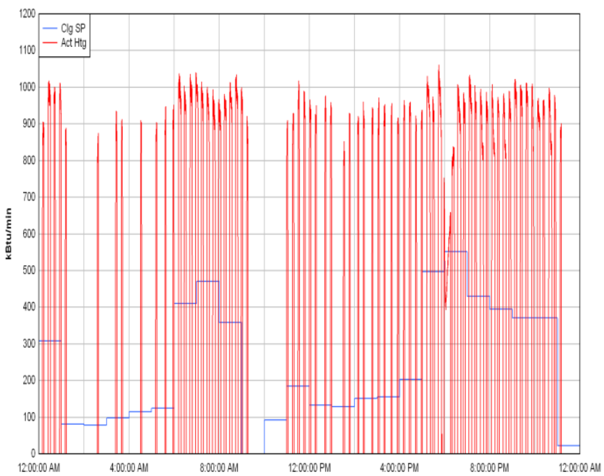


Figure 38. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	344,074
Actual heat loss applied (Btu/day)	361,709
Total daily DHW as modeled (gal/day)	104.4
Actual daily DHW (gal/day)	116.5
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	431,856
Gas consumed LHV (Btu)	424,472
Combo Air Handler power consumed (Btu)	15,361
Water heater power consumed (Btu)	119
Space heating Energy (Btu)	315,543
DHW energy (Btu)	66,042
HHV System Efficiency	85%
LHV System Efficiency	87%

Figure 39. Performance results

Chicago, MaxEE Model, Tankless Versus Storage Temperature Stability, January 26

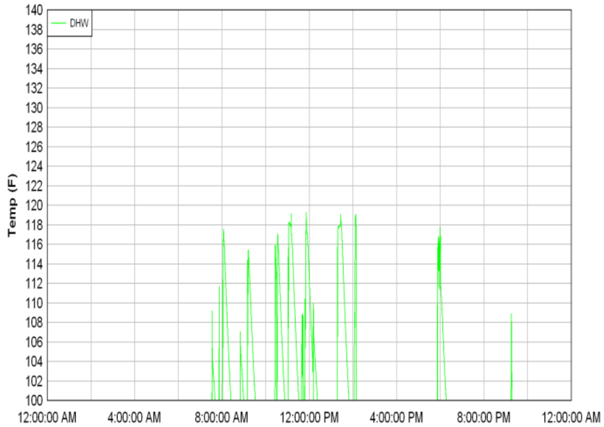


Figure 40. Tankless DHW temperatures

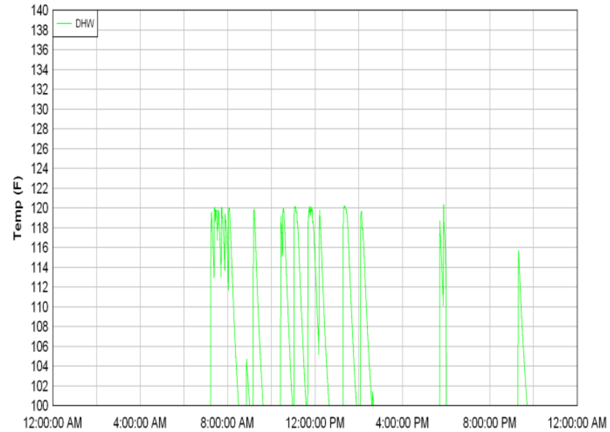


Figure 41. Storage DHW temperatures

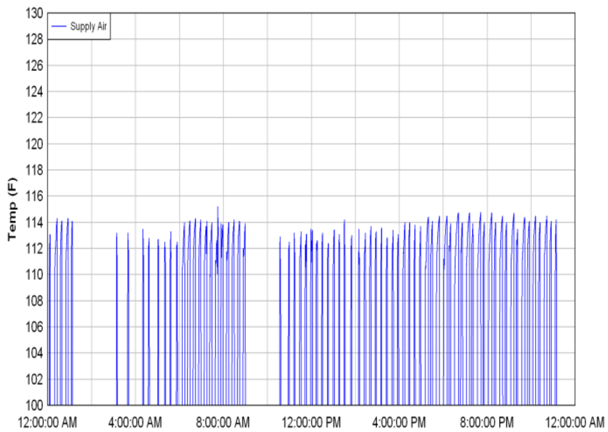


Figure 42. Tankless supply air temperatures

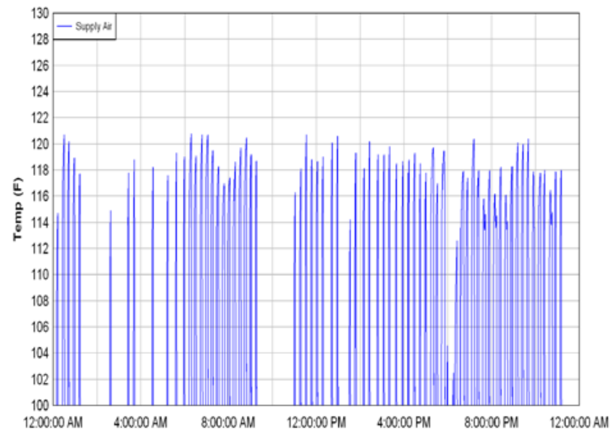


Figure 43. Storage supply air temperatures

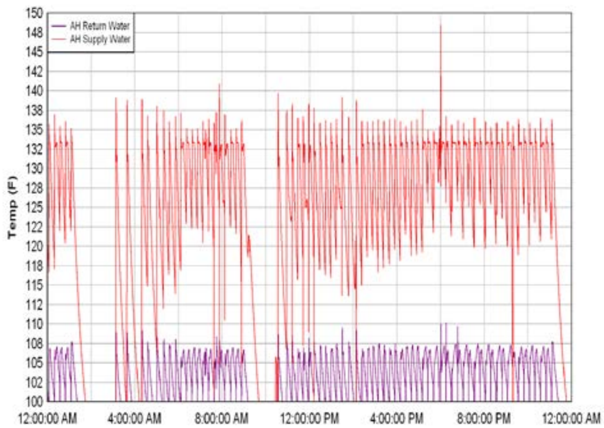


Figure 44. Tankless AH water temperatures

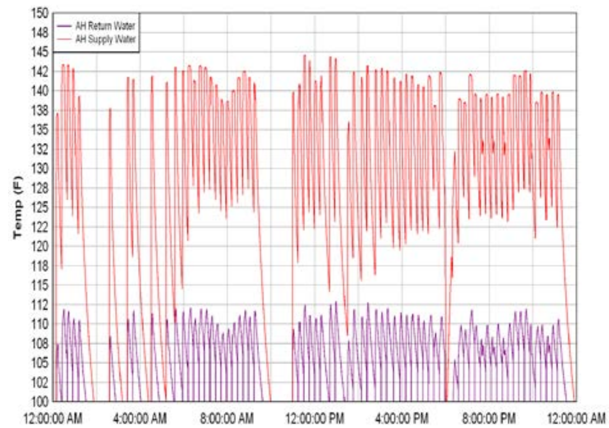


Figure 45. Storage AH water temperatures

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, January 5

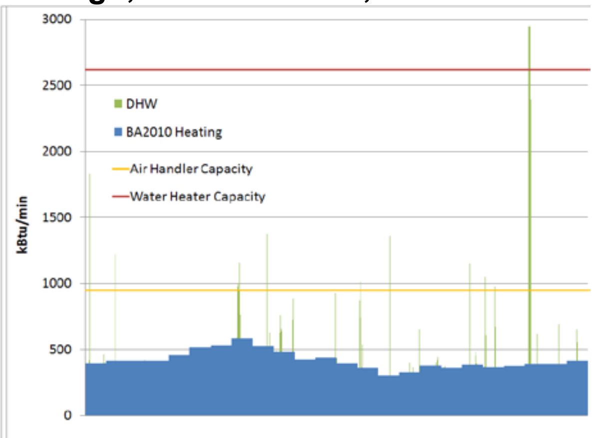


Figure 46. As-modeled space/DHW loads

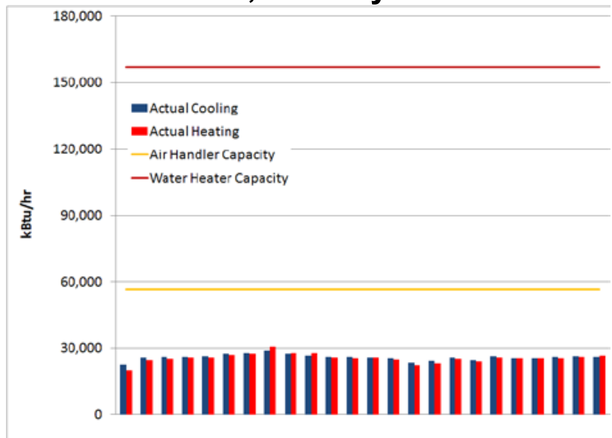


Figure 47. Actual space heating

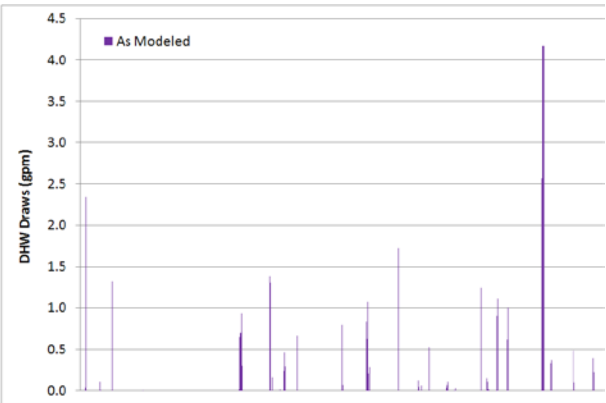


Figure 48. As-modeled DHW draws

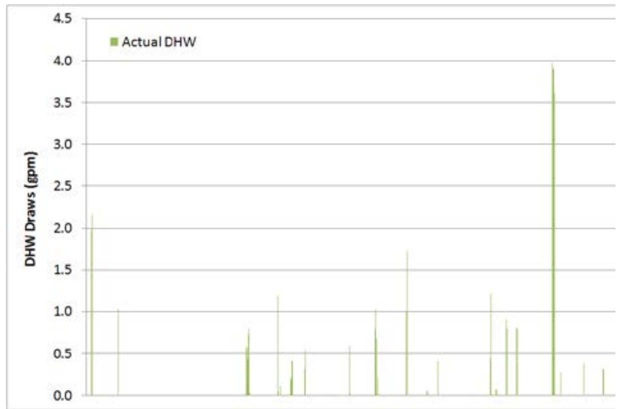


Figure 49. Actual DHW draws

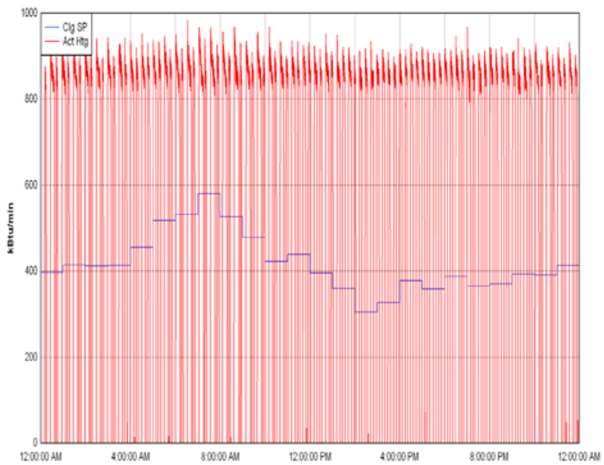


Figure 50. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	601,833
Actual heat loss applied (Btu/day)	623,192
Total daily DHW as modeled (gal/day)	54.0
Actual daily DHW (gal/day)	53.4
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	650,499
Gas consumed LHV (Btu)	639,376
Combo Air Handler power consumed (Btu)	31,010
Water heater power consumed (Btu)	183
Space heating Energy (Btu)	613,003
DHW energy (Btu)	19,863
HHV System Efficiency	93%
LHV System Efficiency	94%

Figure 51. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, January 5

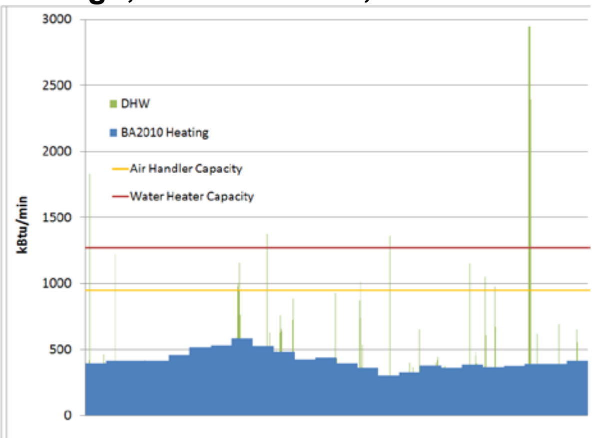


Figure 52. As-modeled space/DHW loads

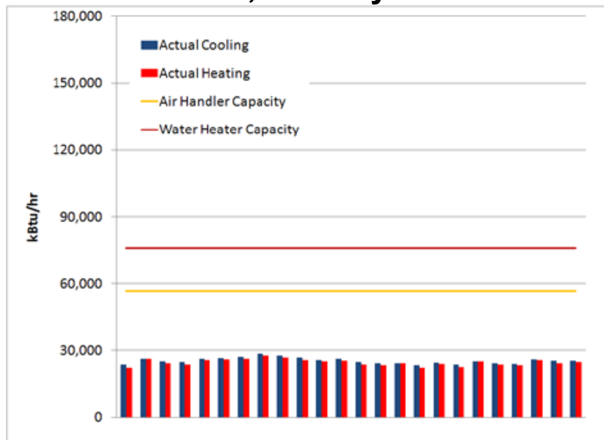


Figure 53. Actual space heating

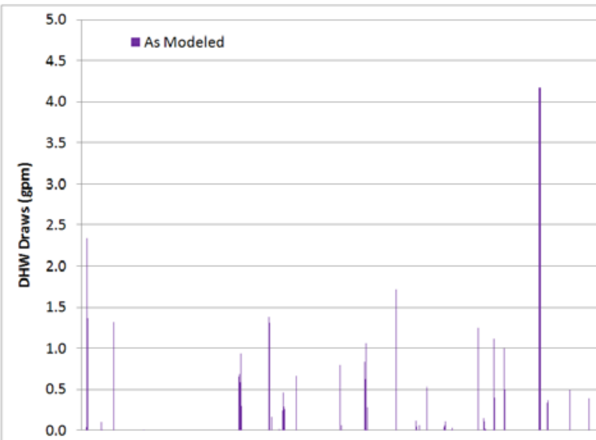


Figure 54. As-modeled DHW draws

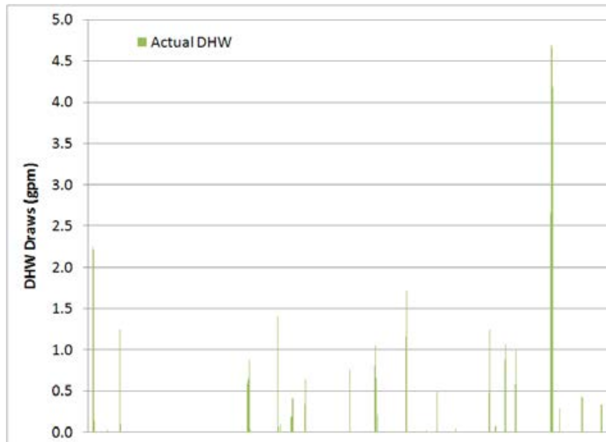


Figure 55. Actual DHW draws

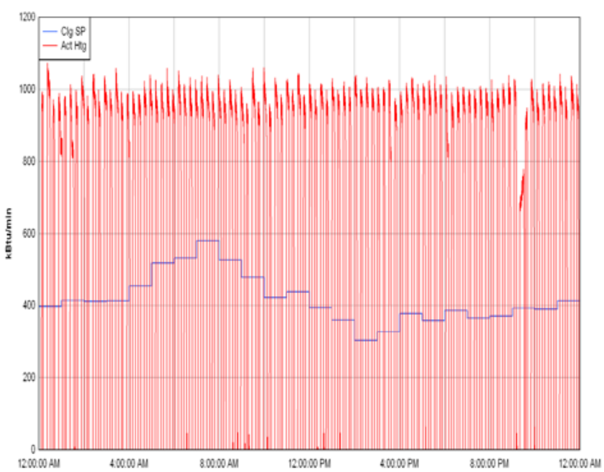


Figure 56. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	601,833
Actual heat loss applied (Btu/day)	609,712
Total daily DHW as modeled (gal/day)	54.0
Actual daily DHW (gal/day)	60.5
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	660,265
Gas consumed LHV (Btu)	648,976
Combo Air Handler power consumed (Btu)	27,541
Water heater power consumed (Btu)	172
Space heating Energy (Btu)	593,574
DHW energy (Btu)	30,746
HHV System Efficiency	91%
LHV System Efficiency	92%

Figure 57. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, January 5

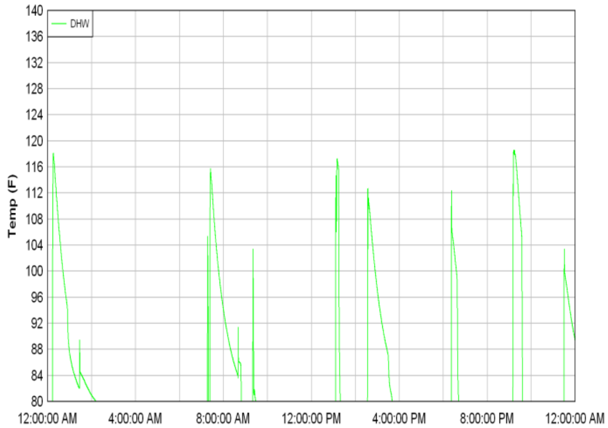


Figure 58. Tankless DHW temperatures

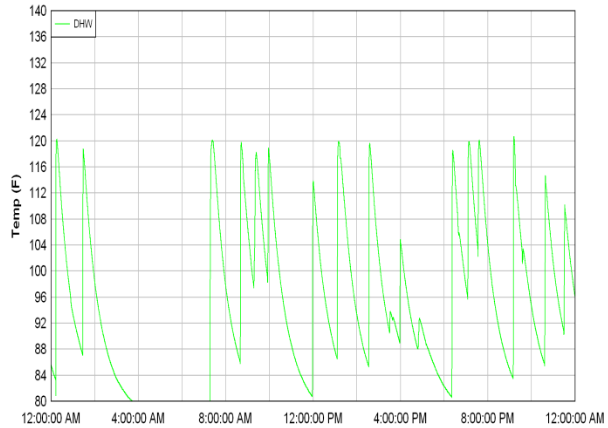


Figure 59. Storage DHW temperatures

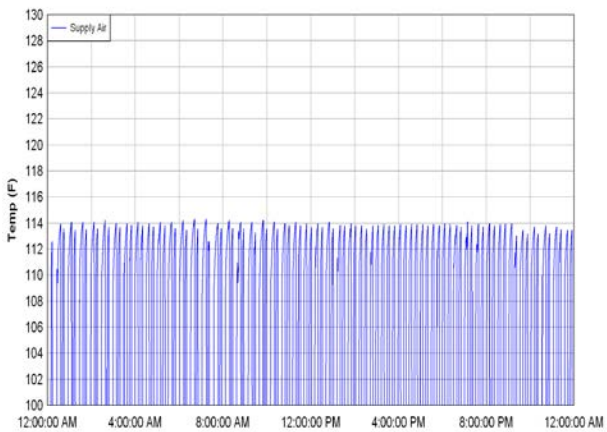


Figure 60. Tankless supply air temperatures

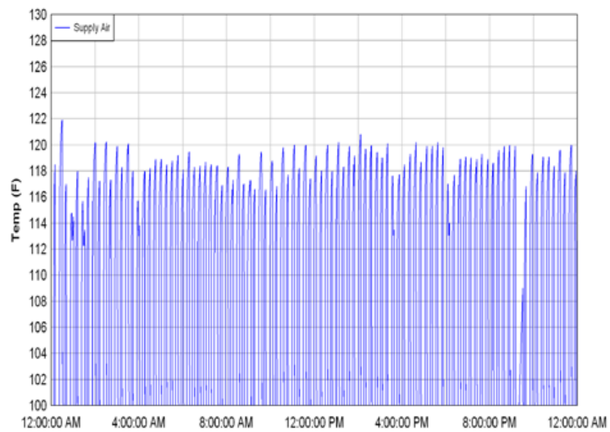


Figure 61. Storage supply air temperatures

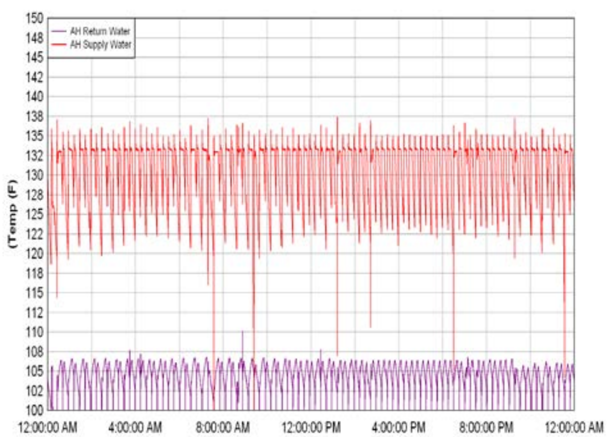


Figure 62. Tankless AH water temperatures

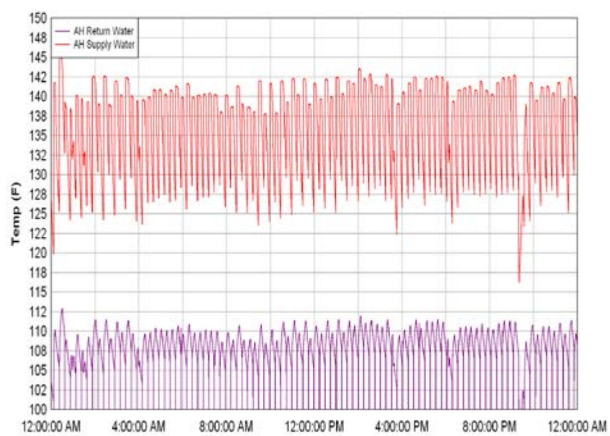


Figure 63. Storage AH water temperatures

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, December 3

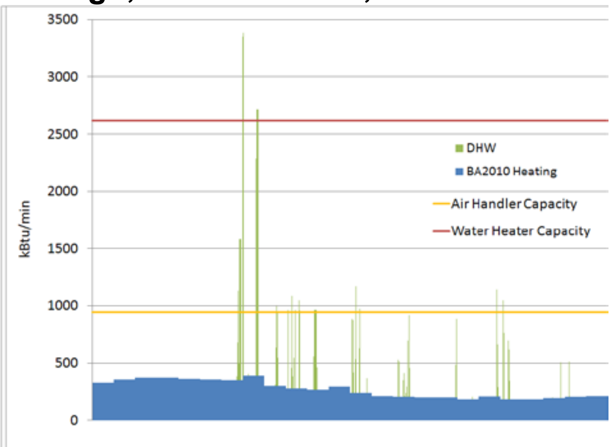


Figure 64. As-modeled space/DHW loads

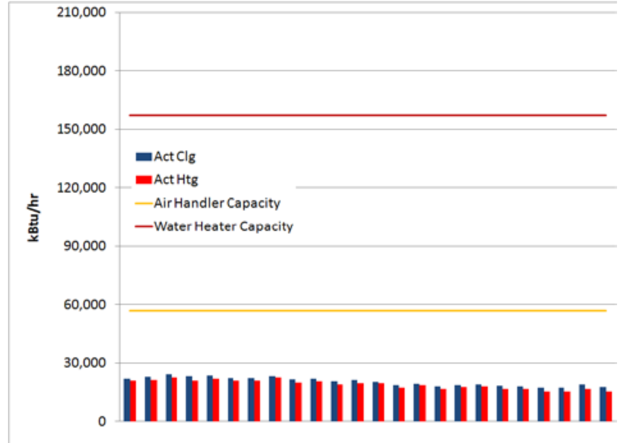


Figure 65. Actual space heating

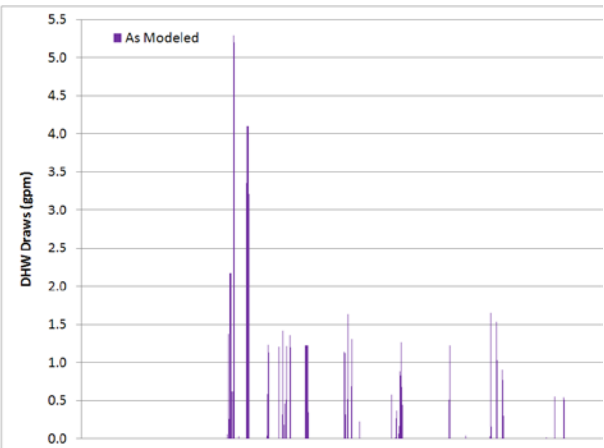


Figure 66. As-modeled DHW draws

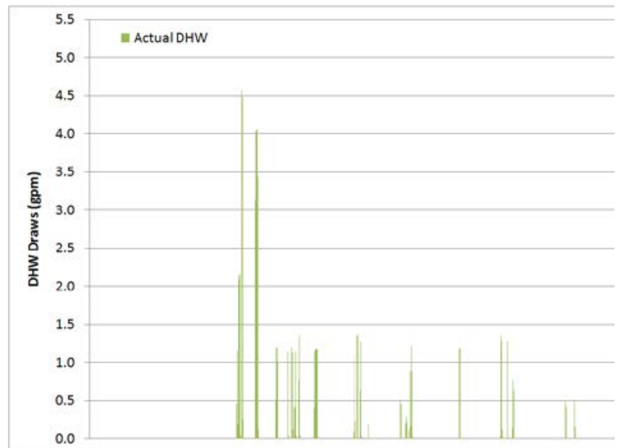


Figure 67. Actual DHW draws

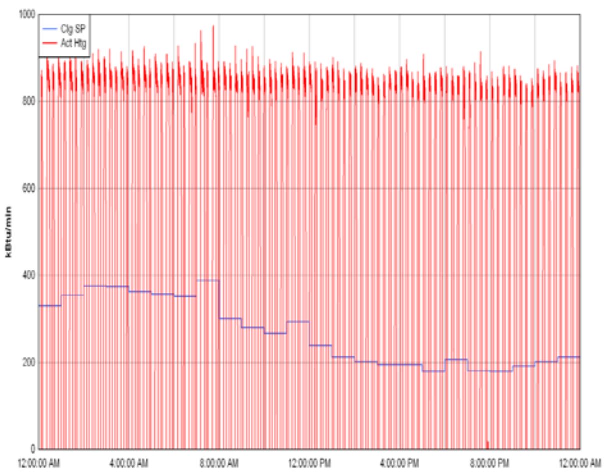


Figure 68. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	386,192
Actual heat loss applied (Btu/day)	490,967
Total daily DHW as modeled (gal/day)	106.2
Actual daily DHW (gal/day)	106.2
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	533,834
Gas consumed LHV (Btu)	524,706
Combo Air Handler power consumed (Btu)	24,177
Water heater power consumed (Btu)	157
Space heating Energy (Btu)	455,878
DHW energy (Btu)	45,036
HHV System Efficiency	90%
LHV System Efficiency	91%

Figure 69. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, December 3

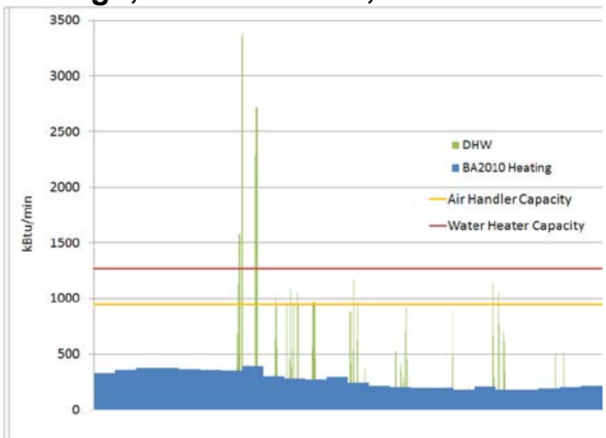


Figure 70. As-modeled space/DHW loads

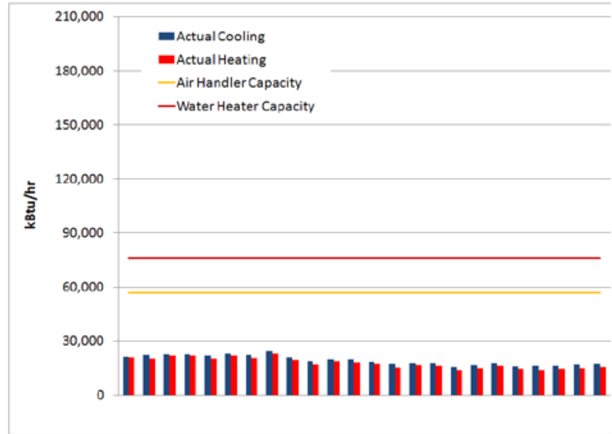


Figure 71. Actual space heating

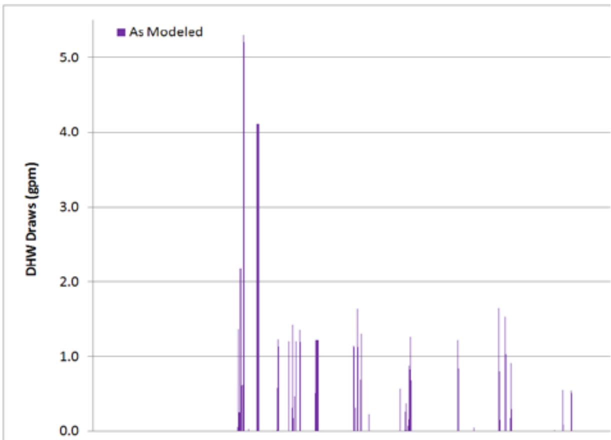


Figure 72. As-modeled DHW draws

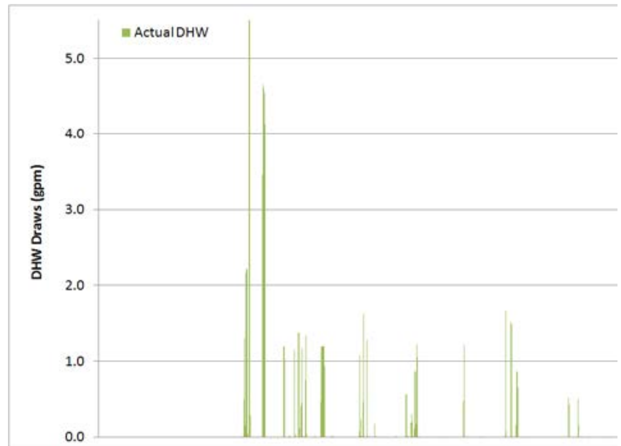


Figure 73. Actual DHW draws

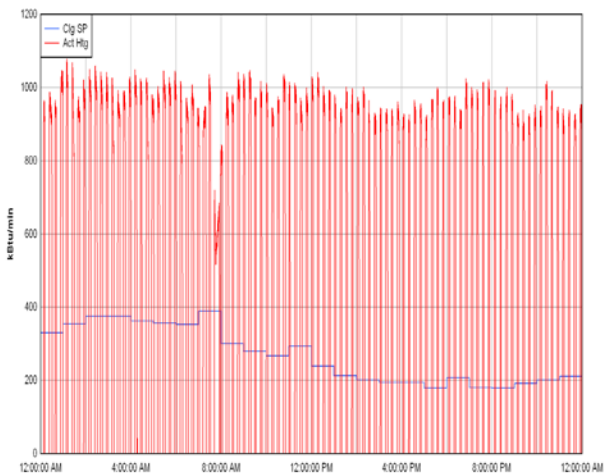


Figure 74. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	386,192
Actual heat loss applied (Btu/day)	464,986
Total daily DHW as modeled (gal/day)	106.2
Actual daily DHW (gal/day)	119.1
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	546,137
Gas consumed LHV (Btu)	536,799
Combo Air Handler power consumed (Btu)	20,635
Water heater power consumed (Btu)	143
Space heating Energy (Btu)	428,246
DHW energy (Btu)	62,345
HHV System Efficiency	87%
LHV System Efficiency	88%

Figure 75. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, December 3

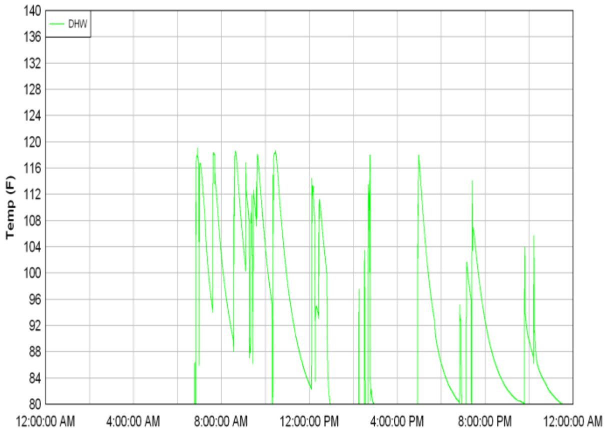


Figure 76. Tankless DHW temperatures

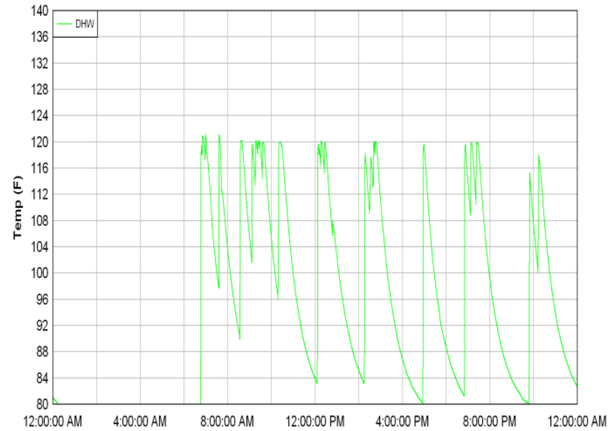


Figure 77. Storage DHW temperatures

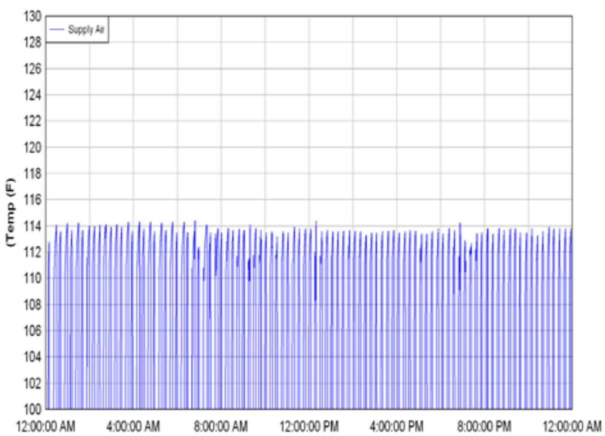


Figure 78. Tankless supply air temperatures

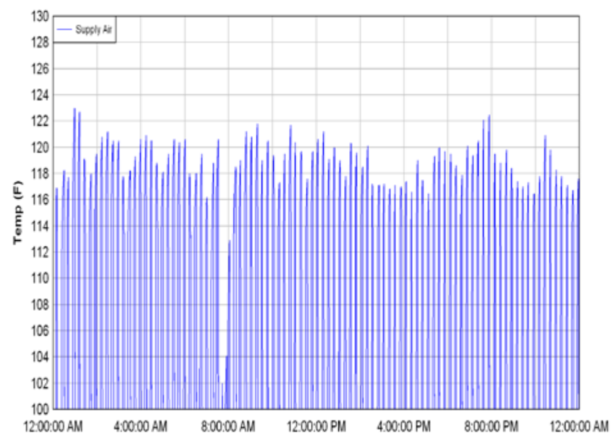


Figure 79. Storage supply air temperatures

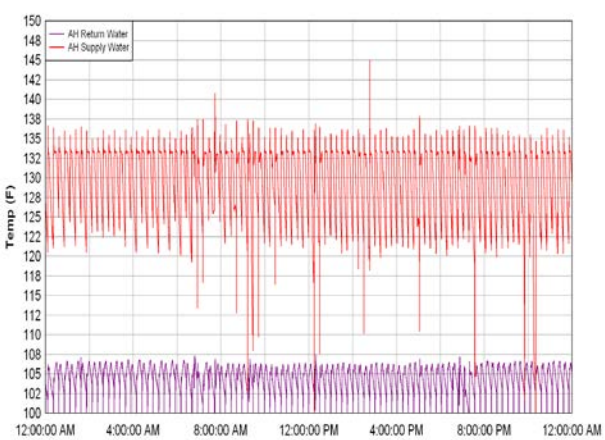


Figure 80. Tankless AH water temperatures

Figure 81. Storage AH water temperatures

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, November 27

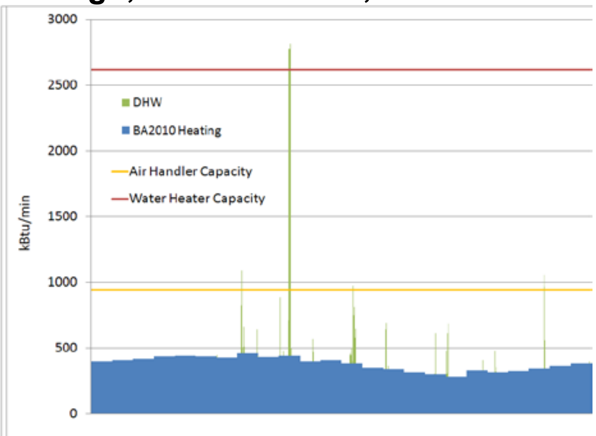


Figure 82. As-modeled space/DHW loads

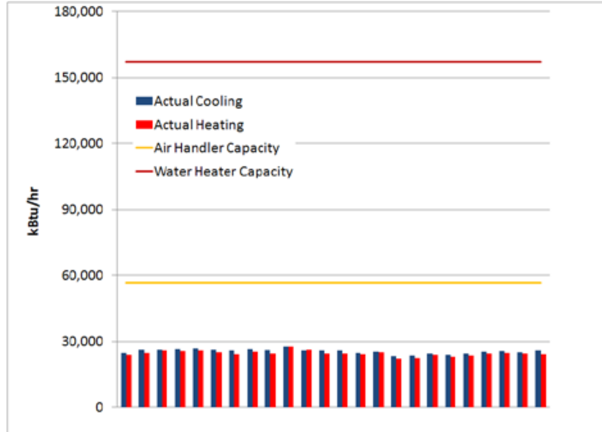


Figure 83. Actual space heating

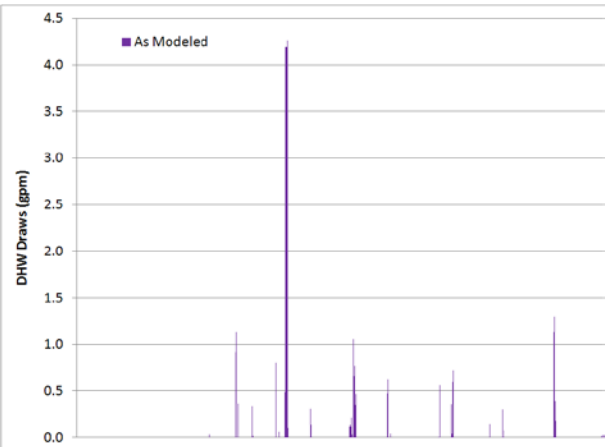


Figure 84. As-modeled DHW draws

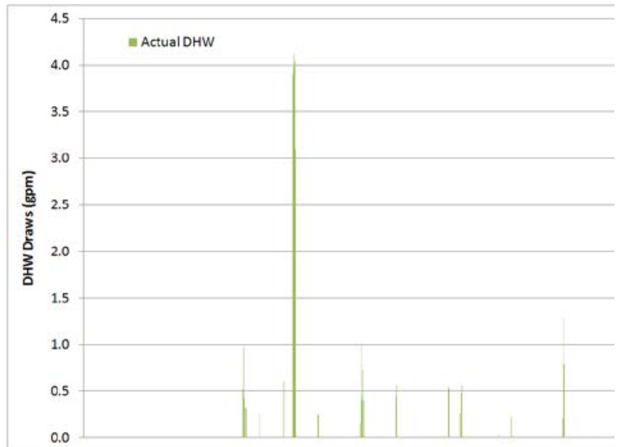


Figure 85. Actual DHW draws

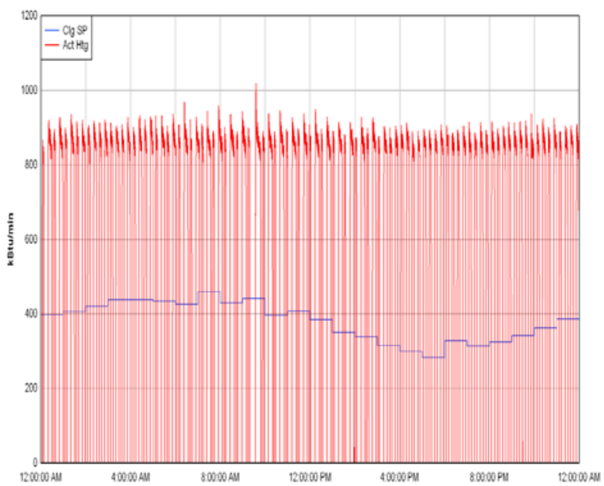


Figure 86. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	547,236
Actual heat loss applied (Btu/day)	609,804
Total daily DHW as modeled (gal/day)	47.0
Actual daily DHW (gal/day)	46.2
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	620,159
Gas consumed LHV (Btu)	609,555
Combo Air Handler power consumed (Btu)	29,412
Water heater power consumed (Btu)	178
Space heating Energy (Btu)	585,895
DHW energy (Btu)	19,053
HHV System Efficiency	93%
LHV System Efficiency	95%

Figure 87. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, November 27

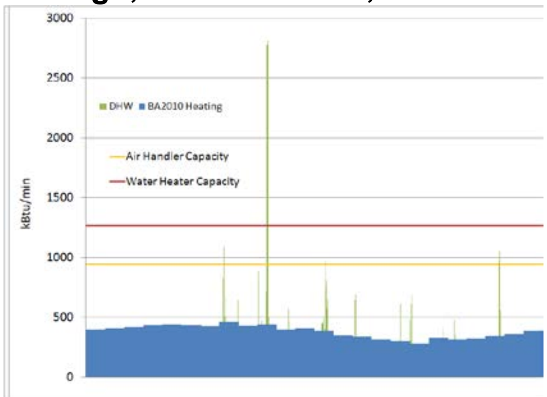


Figure 88. As-modeled space/DHW loads

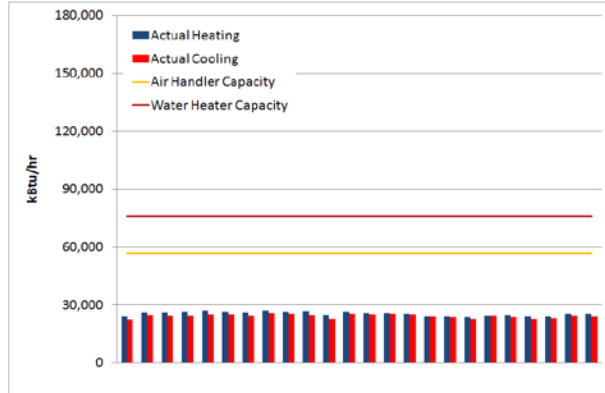


Figure 89. Actual space heating

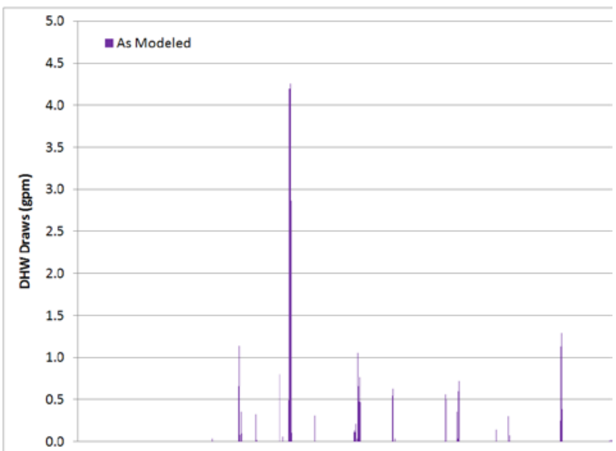


Figure 90. As-modeled DHW draws

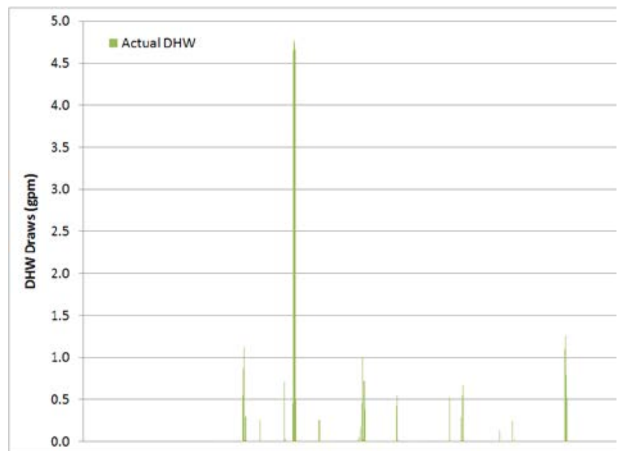


Figure 91. Actual DHW draws

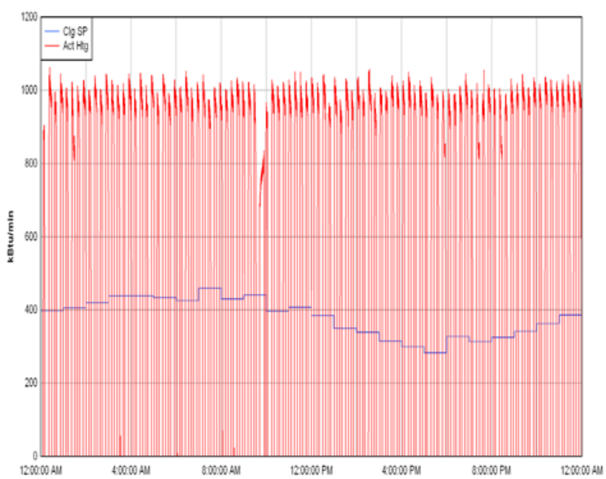


Figure 92. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	547,236
Actual heat loss applied (Btu/day)	610,887
Total daily DHW as modeled (gal/day)	47.0
Actual daily DHW (gal/day)	52.2
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	642,889
Gas consumed LHV (Btu)	631,896
Combo Air Handler power consumed (Btu)	26,485
Water heater power consumed (Btu)	164
Space heating Energy (Btu)	584,221
DHW energy (Btu)	24,531
HHV System Efficiency	91%
LHV System Efficiency	92%

Figure 93. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, November 27

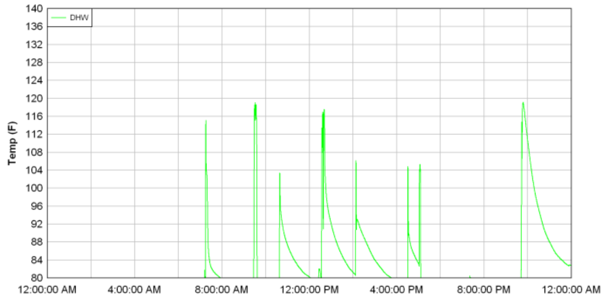


Figure 94. Tankless DHW temperatures

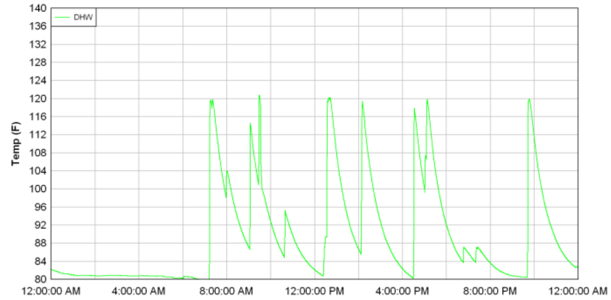


Figure 95. Storage DHW temperatures

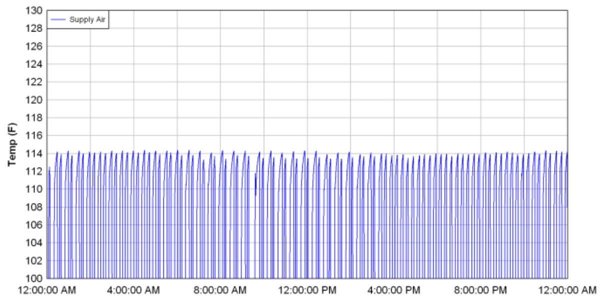


Figure 96. Tankless supply air temperatures

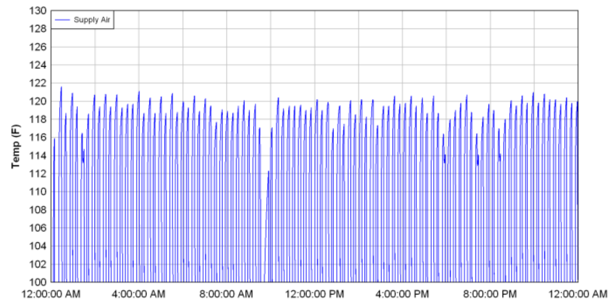


Figure 97. Storage supply air temperatures

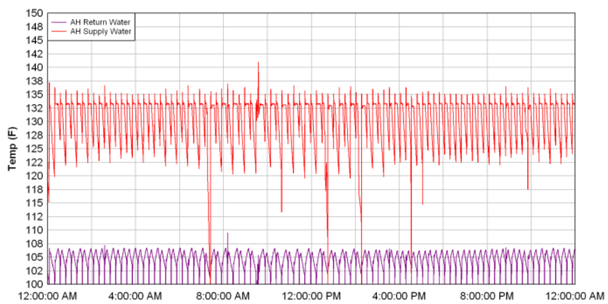


Figure 98. Tankless AH water temperatures

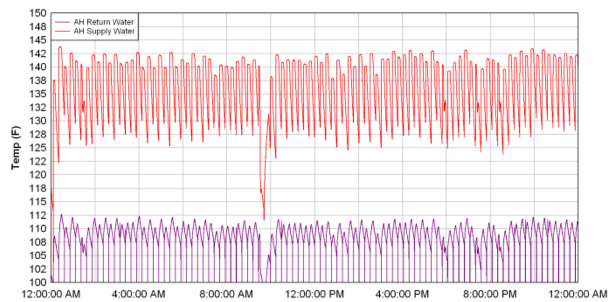


Figure 99. Storage AH water temperatures

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, December 11

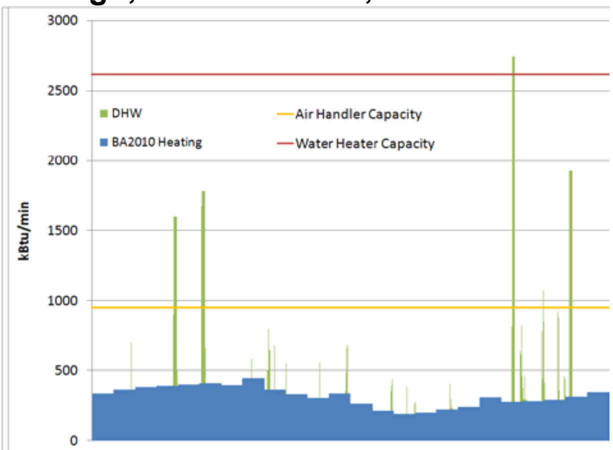


Figure 100. As-modeled space/DHW loads

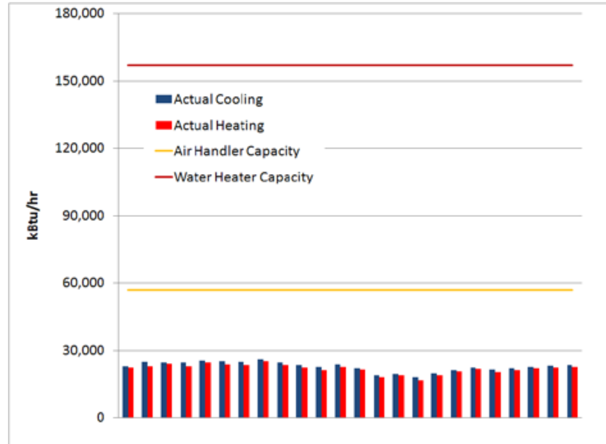


Figure 101. Actual space heating

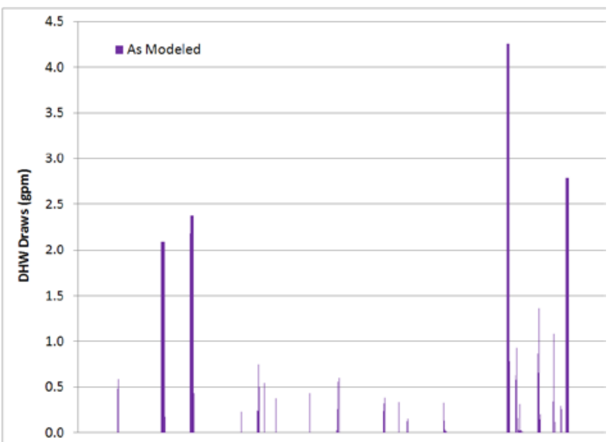


Figure 102. As-modeled DHW draws

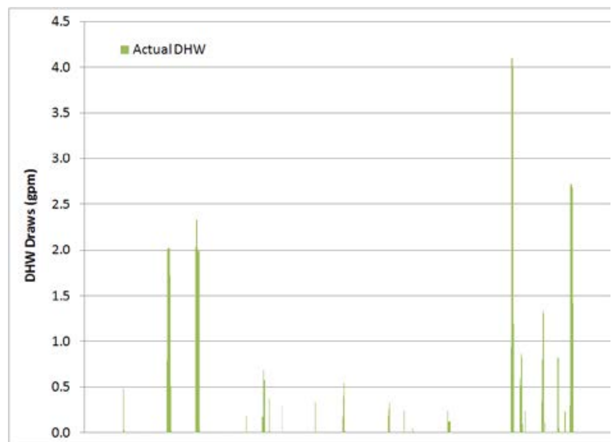


Figure 103. Actual DHW draws

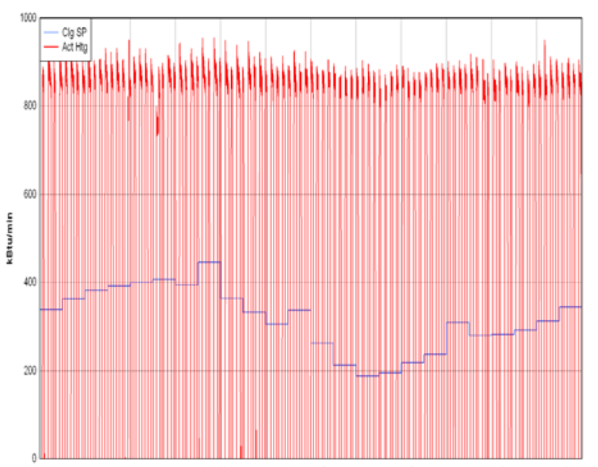


Figure 104. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	455,709
Actual heat loss applied (Btu/day)	544,228
Total daily DHW as modeled (gal/day)	112.2
Actual daily DHW (gal/day)	108.1
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	604,685
Gas consumed LHV (Btu)	594,346
Combo Air Handler power consumed (Btu)	26,908
Water heater power consumed (Btu)	172
Space heating Energy (Btu)	520,416
DHW energy (Btu)	53,217
HHV System Efficiency	91%
LHV System Efficiency	92%

Figure 105. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, December 11

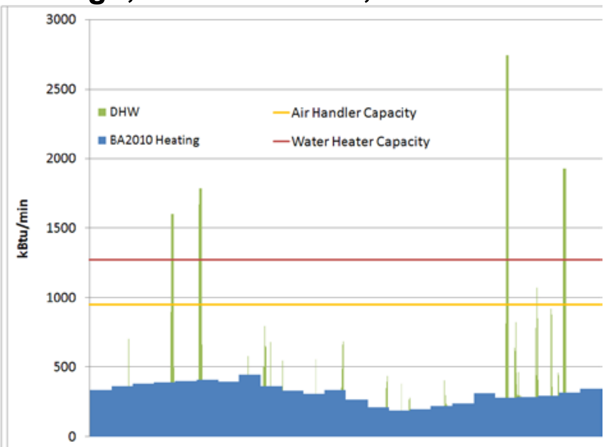


Figure 106. As-modeled space/DHW loads

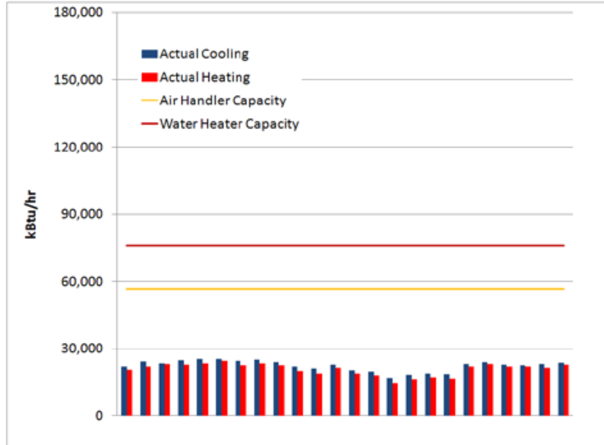


Figure 107. Actual space heating

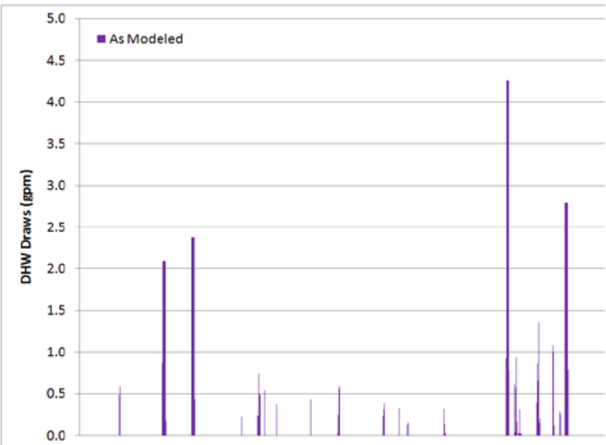


Figure 108. As-modeled DHW draws

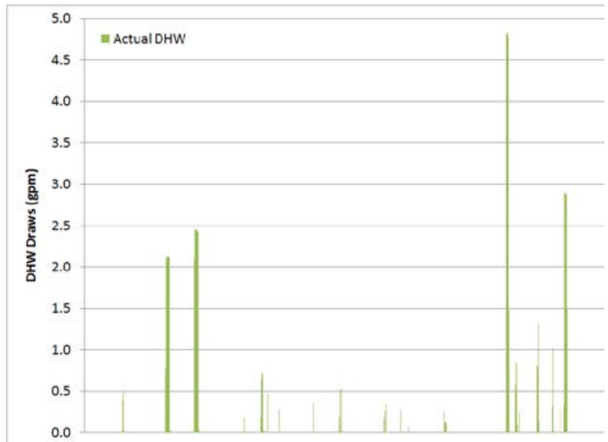


Figure 109. Actual DHW draws

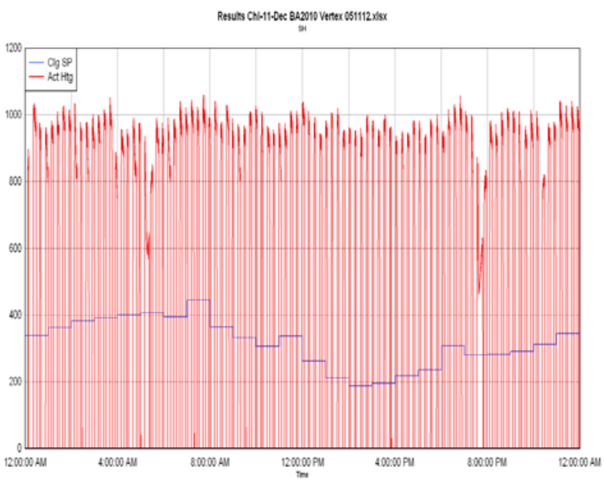


Figure 110. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	455,709
Actual heat loss applied (Btu/day)	534,080
Total daily DHW as modeled (gal/day)	112.2
Actual daily DHW (gal/day)	121.0
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	609,429
Gas consumed LHV (Btu)	599,008
Combo Air Handler power consumed (Btu)	24,107
Water heater power consumed (Btu)	157
Space heating Energy (Btu)	498,267
DHW energy (Btu)	64,657
HHV System Efficiency	89%
LHV System Efficiency	90%

Figure 111. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, December 11

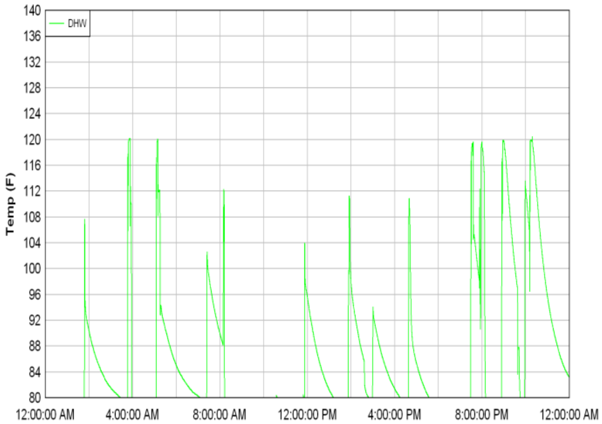


Figure 112. Tankless DHW temperatures

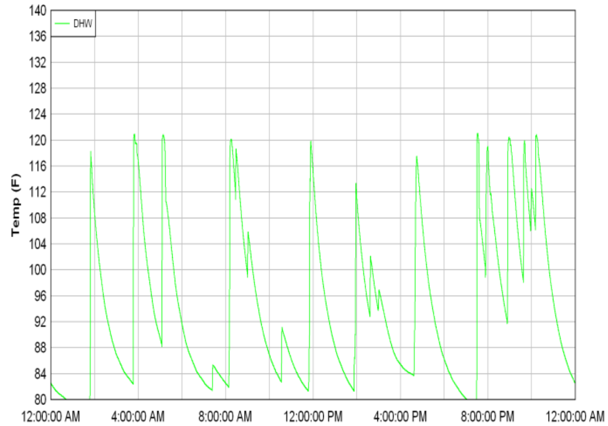


Figure 113. Storage DHW temperatures

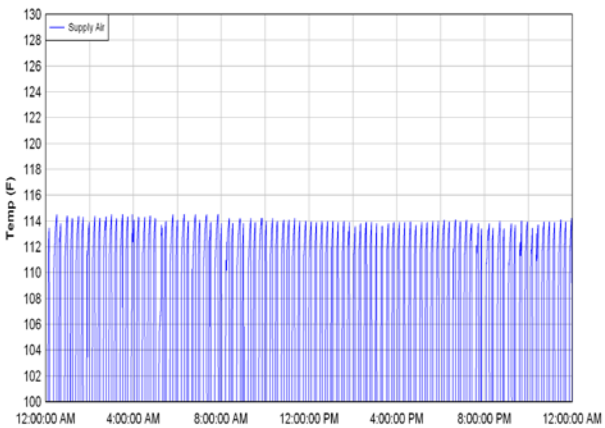


Figure 114. Tankless supply air temperatures

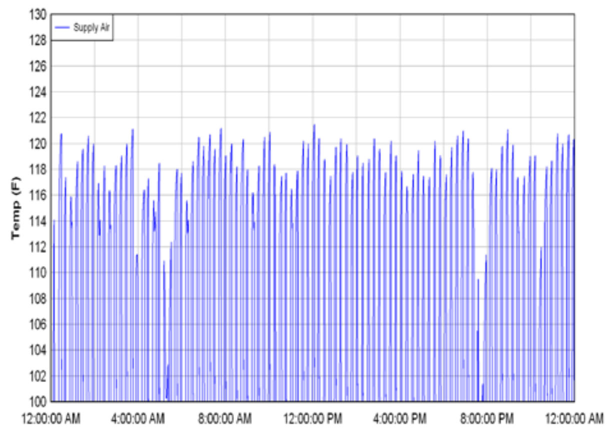


Figure 115. Storage supply air temperatures

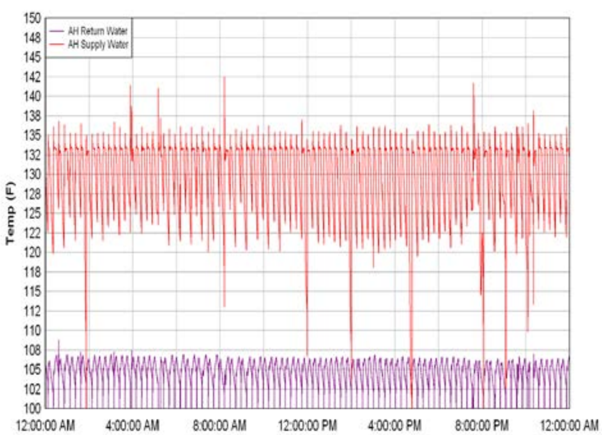


Figure 116. Tankless AH water temperatures

Figure 117. Storage AH water temperatures

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability Detail, December 11

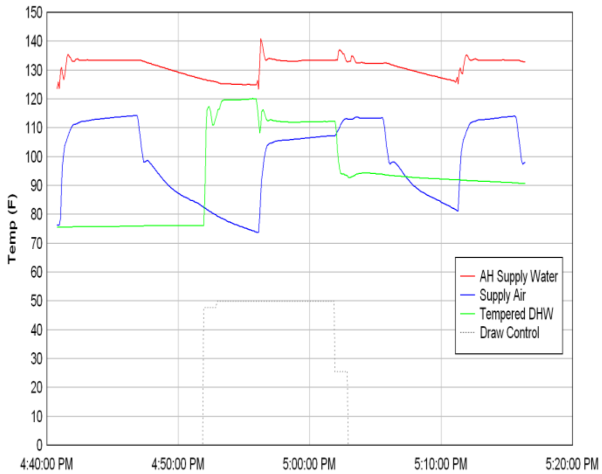


Figure 118. Tankless, three thermostat cycles with coincidental DHW draw

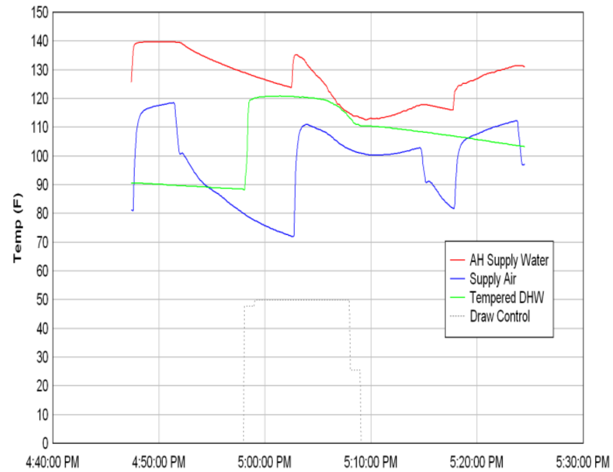


Figure 119. Storage, three thermostat cycles with coincidental DHW draw

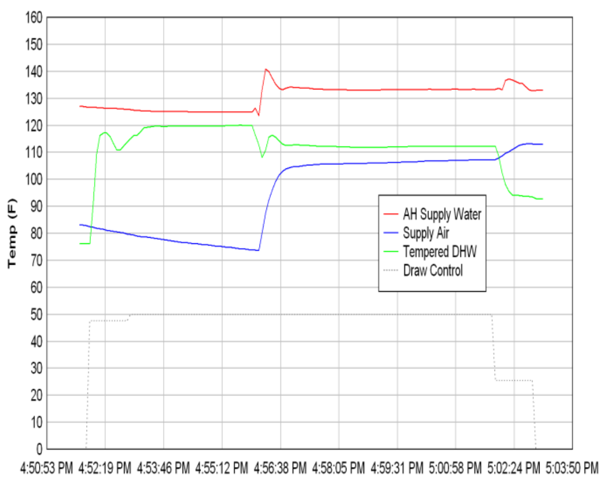


Figure 120. Tankless, one thermostat cycles with coincidental DHW draw

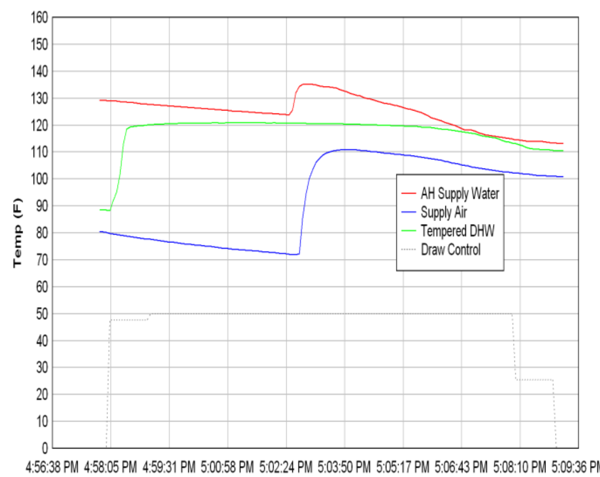


Figure 121. Storage, one thermostat cycle with coincidental DHW draw

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, February 22

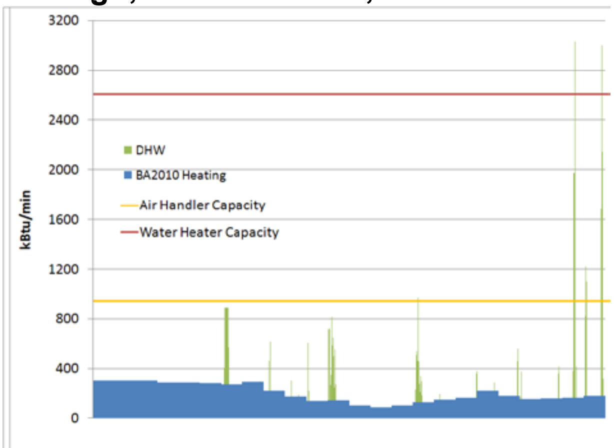


Figure 122. As-modeled space/DHW loads

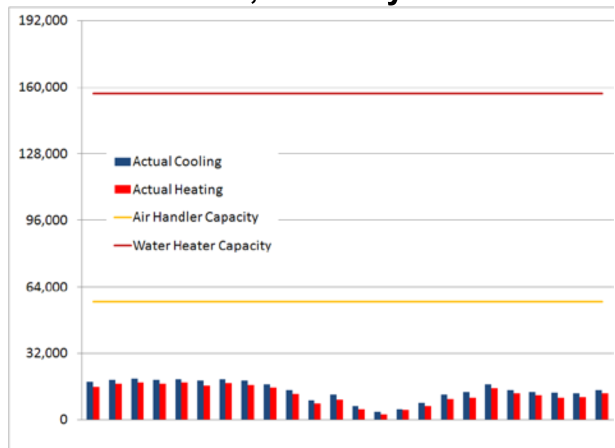


Figure 123. Actual space heating

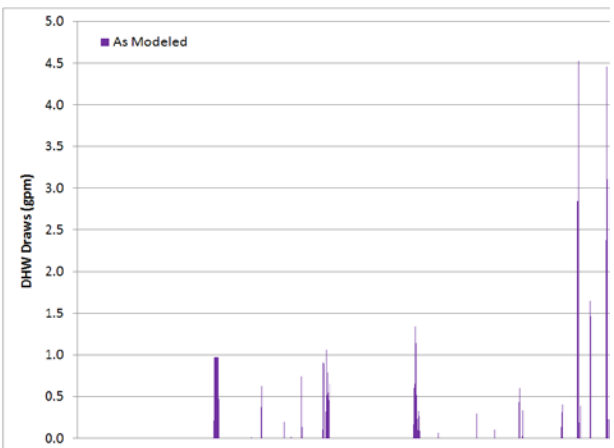


Figure 124. As-modeled DHW draws

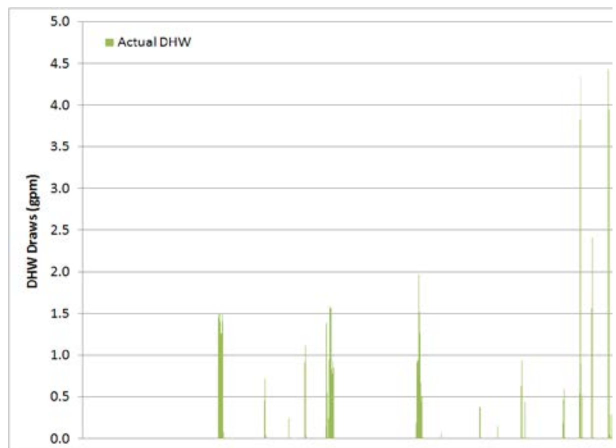


Figure 125. Actual DHW draws

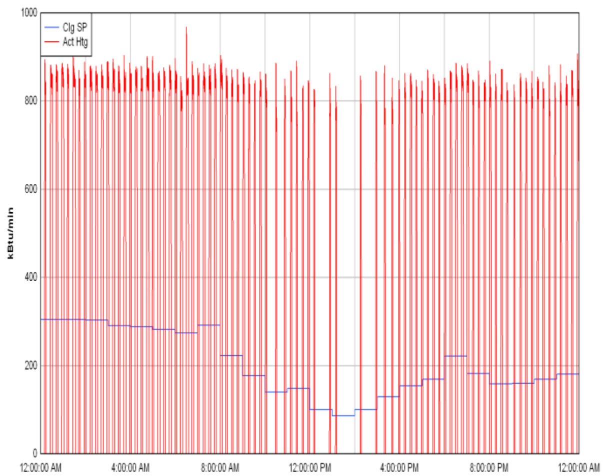


Figure 126. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	290,388
Actual heat loss applied (Btu/day)	338,738
Total daily DHW as modeled (gal/day)	64.7
Actual daily DHW (gal/day)	97.8
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	393,196
Gas consumed LHV (Btu)	386,473
Combo Air Handler power consumed (Btu)	16,389
Water heater power consumed (Btu)	119
Space heating Energy (Btu)	295,795
DHW energy (Btu)	47,069
HHV System Efficiency	84%
LHV System Efficiency	85%

Figure 127. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, February 22

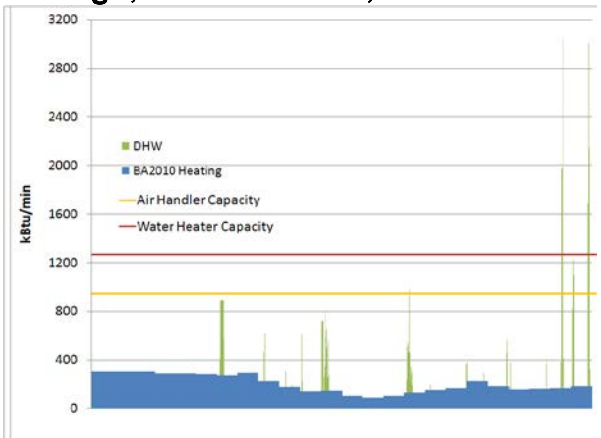


Figure 128. As-modeled space/DHW loads

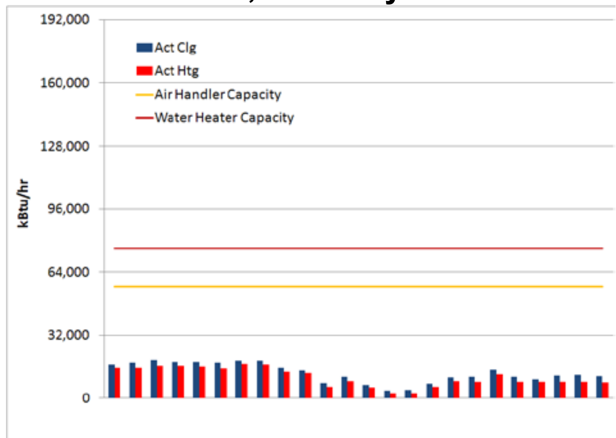


Figure 129. Actual space heating

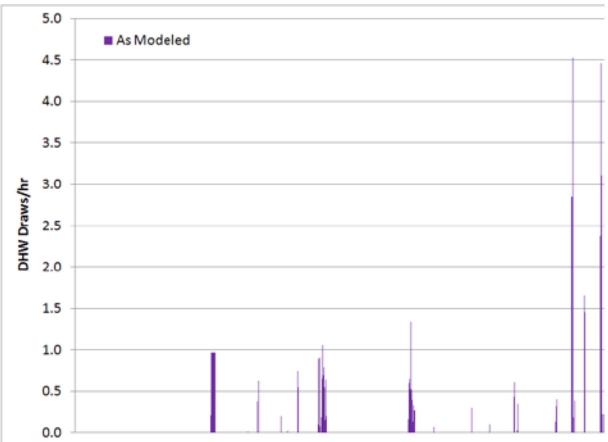


Figure 130. As-modeled DHW draws

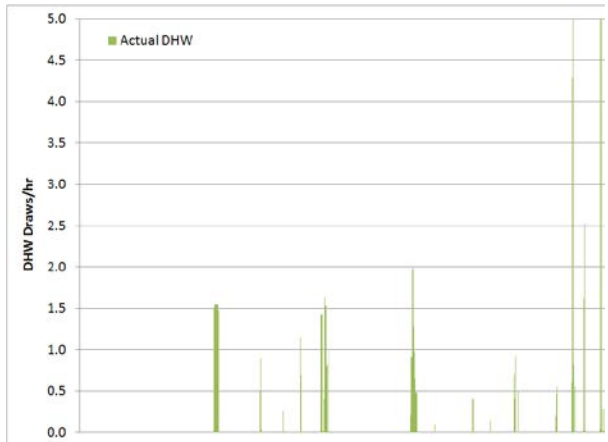


Figure 131. Actual DHW draws

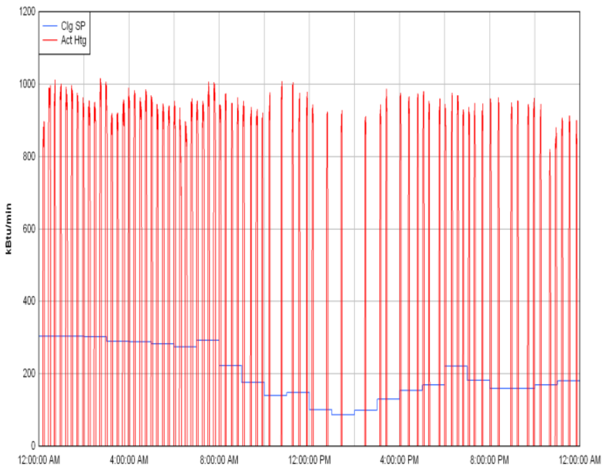


Figure 132. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	290,388
Actual heat loss applied (Btu/day)	306,218
Total daily DHW as modeled (gal/day)	64.7
Actual daily DHW (gal/day)	108.8
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	378,382
Gas consumed LHV (Btu)	371,912
Combo Air Handler power consumed (Btu)	13,062
Water heater power consumed (Btu)	103
Space heating Energy (Btu)	255,490
DHW energy (Btu)	62,456
HHV System Efficiency	81%
LHV System Efficiency	83%

Figure 133. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, February 22

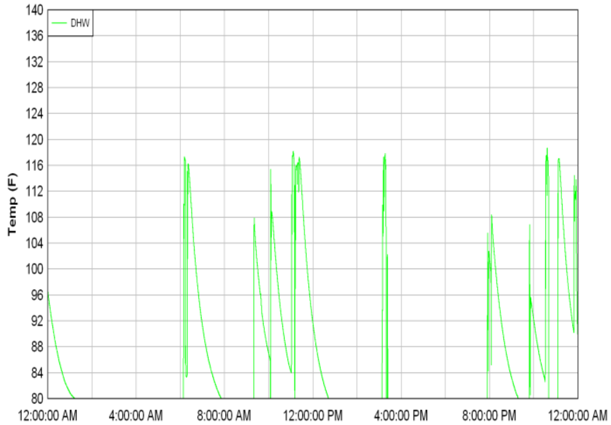


Figure 134. Tankless DHW temperatures

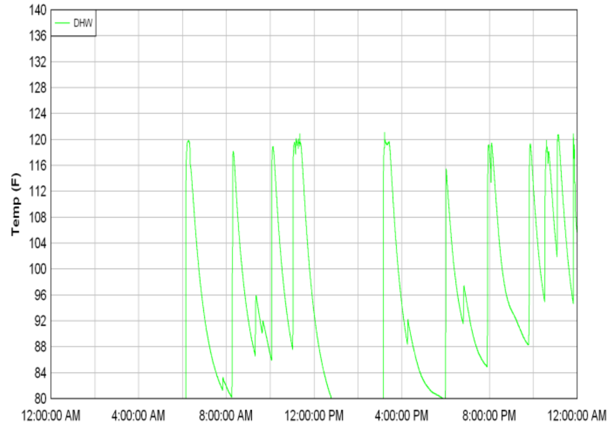


Figure 135. Storage DHW temperatures

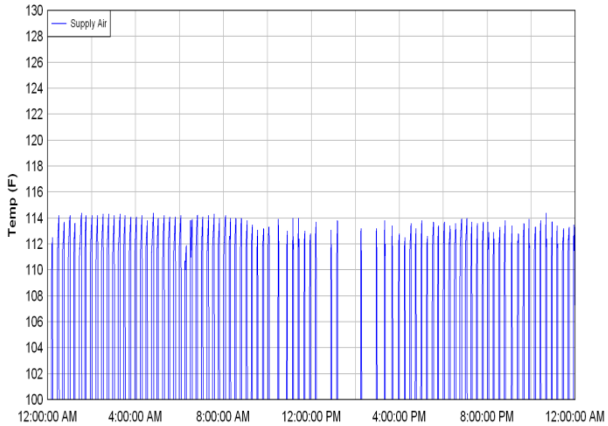


Figure 136. Tankless supply air temperatures

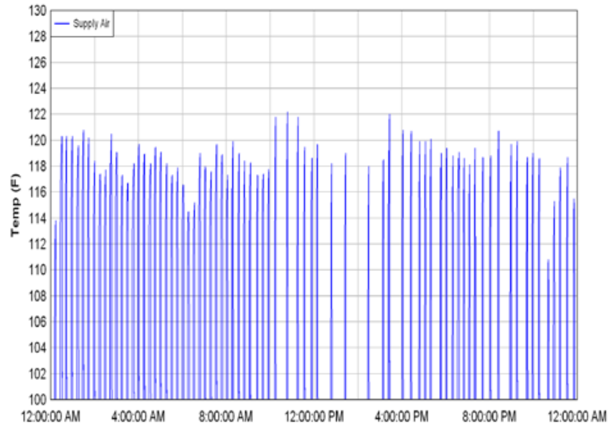


Figure 137. Storage supply air temperatures

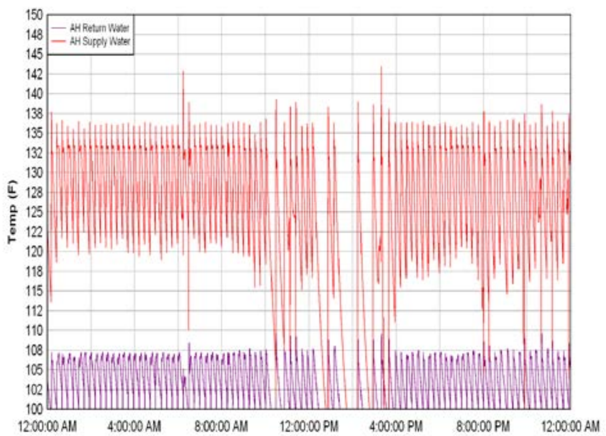


Figure 138. Tankless AH water temperatures

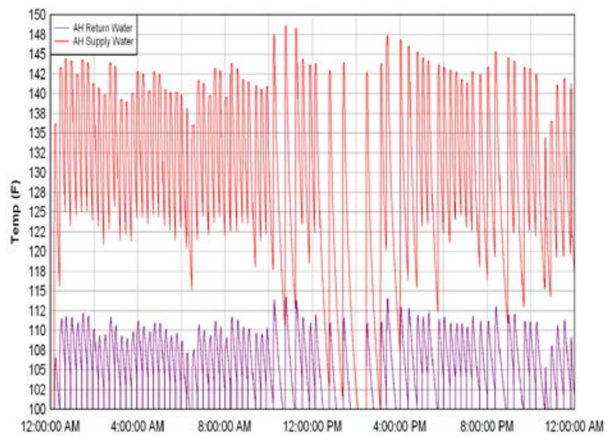


Figure 139. Storage AH water temperatures

Chicago, BA2010 Model, Rinnai Test With RC80HP/AHB90, March 29

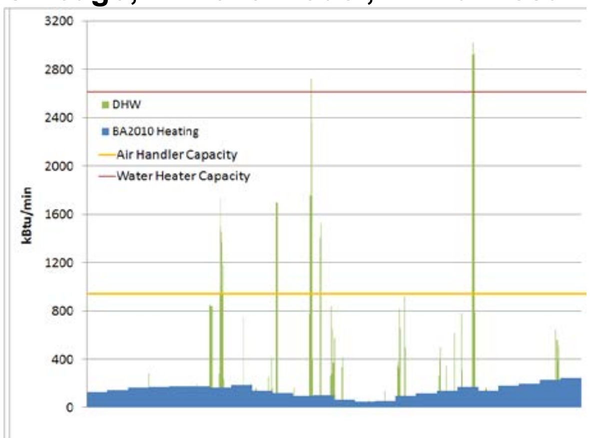


Figure 140. As-modeled space/DHW loads

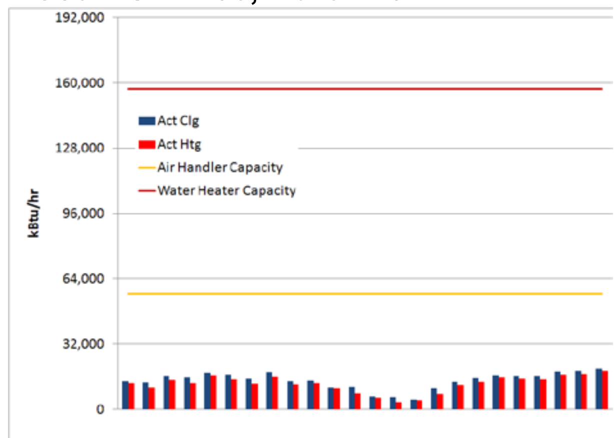


Figure 141. Actual space heating

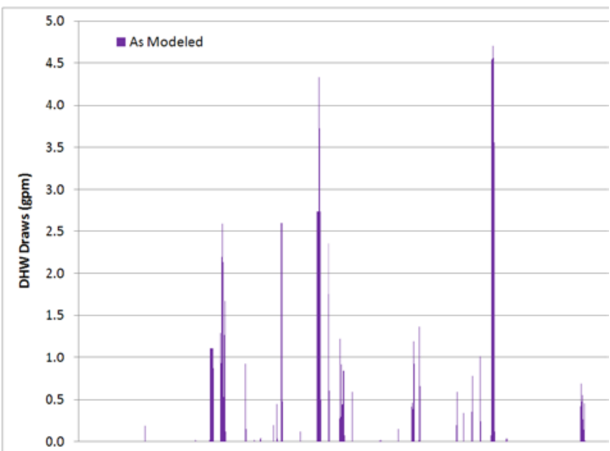


Figure 142. As-modeled DHW draws

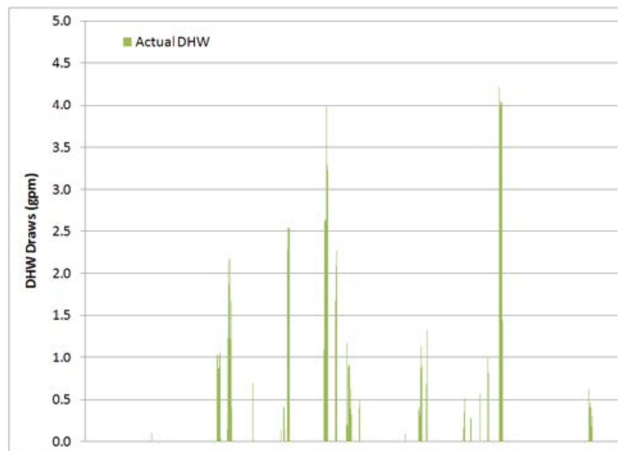


Figure 143. Actual DHW draws

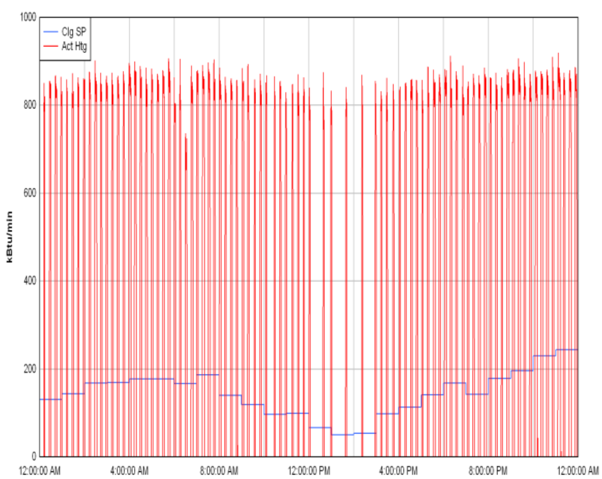


Figure 144. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	207,316
Actual heat loss applied (Btu/day)	338,050
Total daily DHW as modeled (gal/day)	138.7
Actual daily DHW (gal/day)	139.7
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	416,534
Gas consumed LHV (Btu)	409,412
Combo Air Handler power consumed (Btu)	16,655
Water heater power consumed (Btu)	126
Space heating Energy (Btu)	298,147
DHW energy (Btu)	70,261
HHV System Efficiency	85%
LHV System Efficiency	86%

Figure 145. Performance results

Chicago, BA2010 Model, Vertex Test With RC80HP/AHB90, March 29

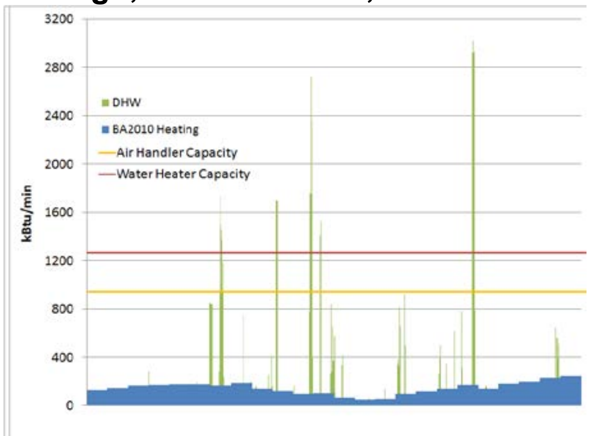


Figure 146. As-modeled space/DHW loads

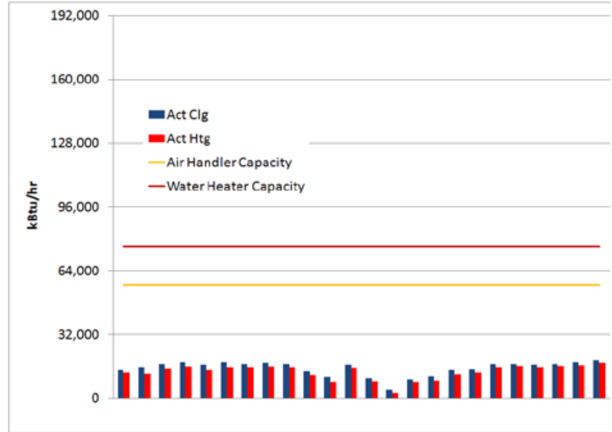


Figure 147. Actual space heating

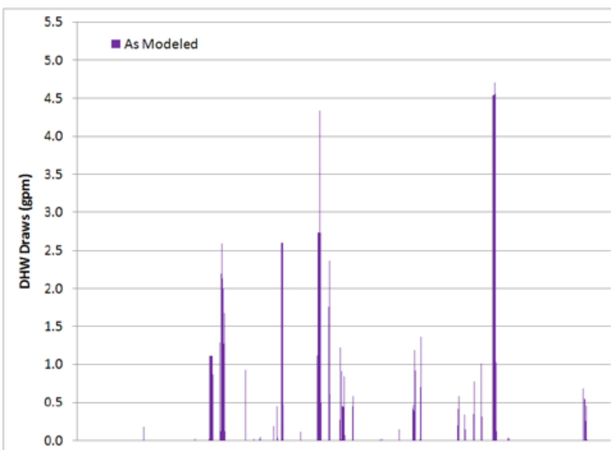


Figure 148. As-modeled DHW draws

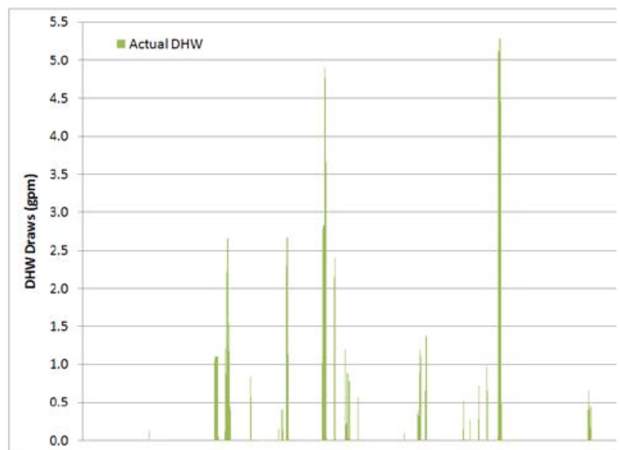


Figure 149. Actual DHW draws

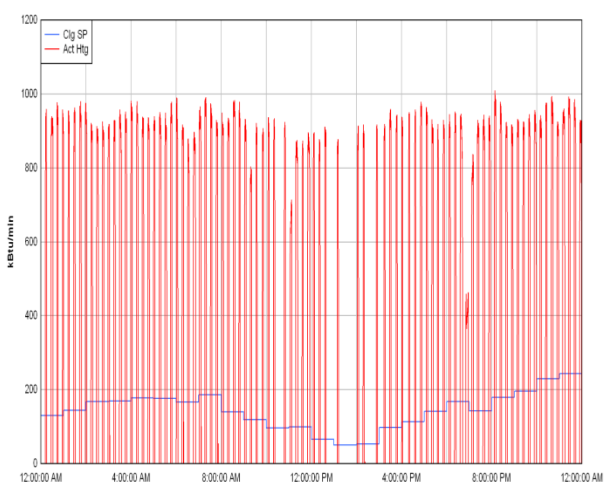


Figure 150. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	207,316
Actual heat loss applied (Btu/day)	361,884
Total daily DHW as modeled (gal/day)	138.7
Actual daily DHW (gal/day)	158.5
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	463,033
Gas consumed LHV (Btu)	455,116
Combo Air Handler power consumed (Btu)	16,410
Water heater power consumed (Btu)	128
Space heating Energy (Btu)	317,794
DHW energy (Btu)	87,741
HHV System Efficiency	85%
LHV System Efficiency	86%

Figure 151. Performance results

Chicago, BA2010 Model, Tankless Versus Storage Temperature Stability, March 29

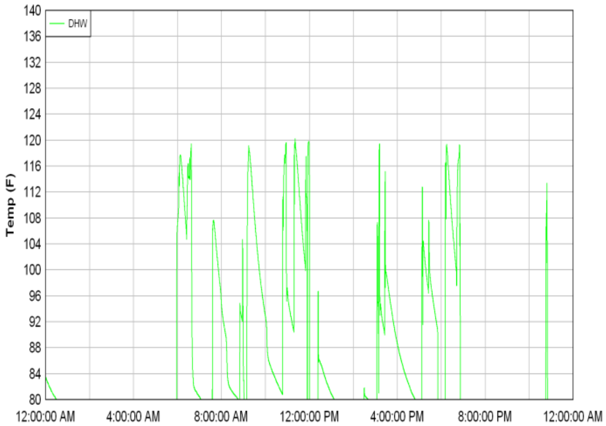


Figure 152. Tankless DHW temperatures

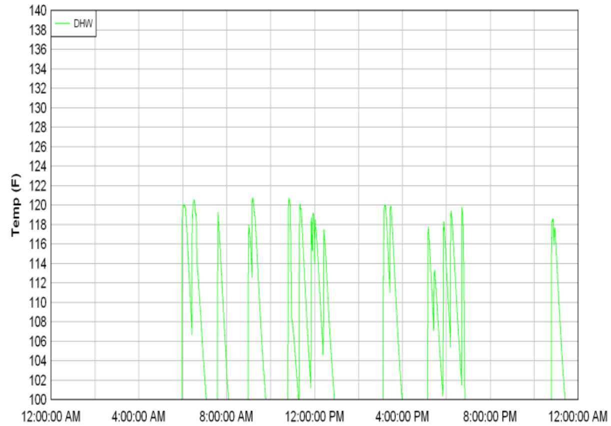


Figure 153. Storage DHW temperatures

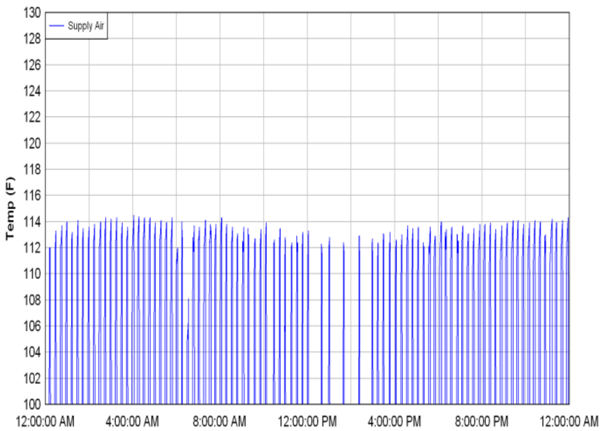


Figure 154. Tankless supply air temperatures

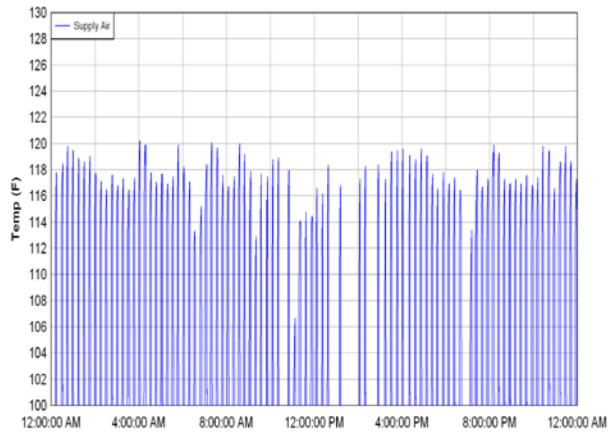


Figure 155. Storage supply air temperatures

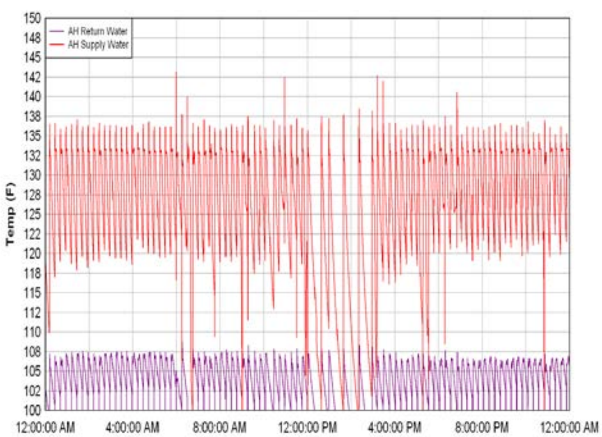


Figure 156. Tankless AH water temperatures

Figure 157. Storage AH water temperatures

Atlanta, BA2010 Model, Rinnai Test With RC80HP/AHB45, February 3

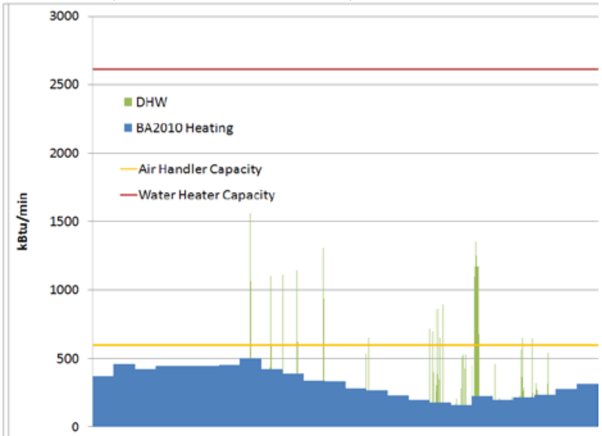


Figure 158. As-modeled space/DHW loads

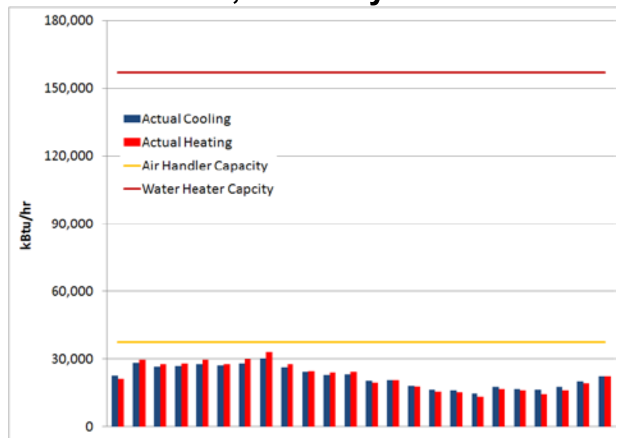


Figure 159. Actual space heating

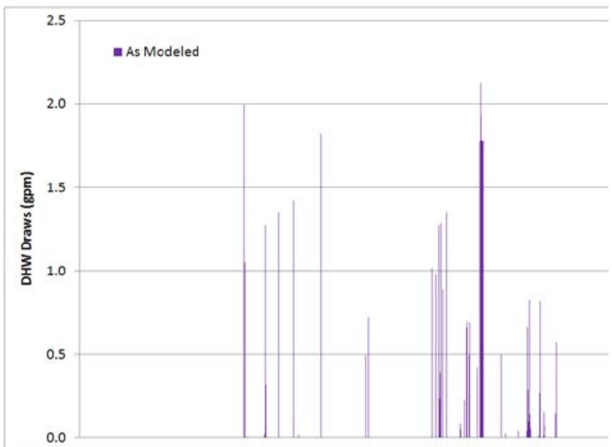


Figure 160. As-modeled DHW draws

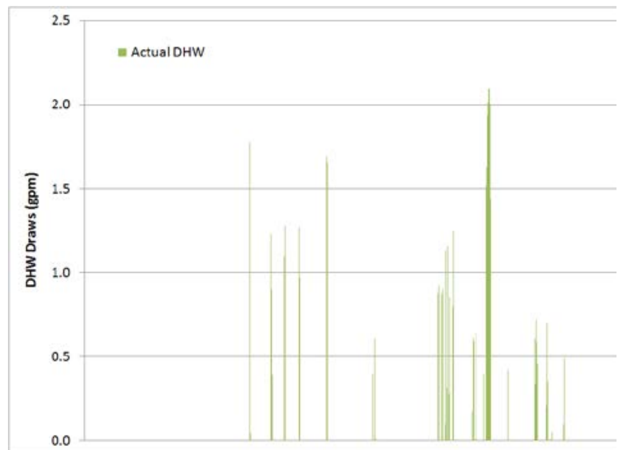


Figure 161. Actual DHW draws

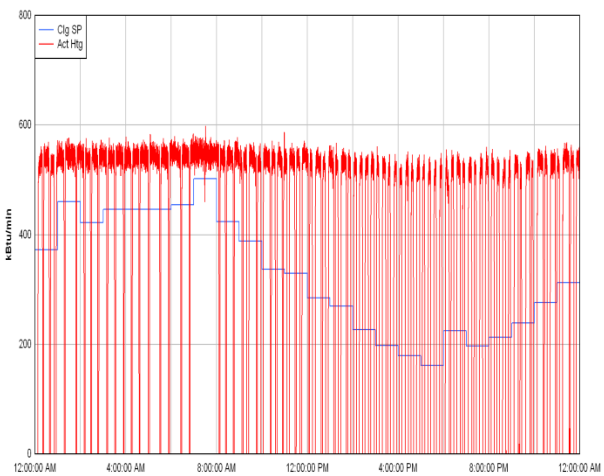


Figure 162. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	468,866
Actual heat loss applied (Btu/day)	528,493
Total daily DHW as modeled (gal/day)	53.2
Actual daily DHW (gal/day)	58.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	599,028
Gas consumed LHV (Btu)	588,786
Combo Air Handler power consumed (Btu)	23,837
Water heater power consumed (Btu)	237
Space heating Energy (Btu)	531,425
DHW energy (Btu)	20,633
HHV System Efficiency	89%
LHV System Efficiency	90%

Figure 163. Performance results

Atlanta, BA2010 Model, Vertex Test With RC80HP/AHB45, February 3

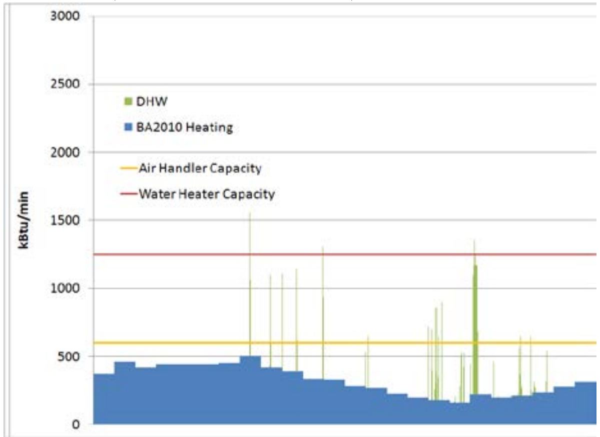


Figure 164. As-modeled space/DHW loads

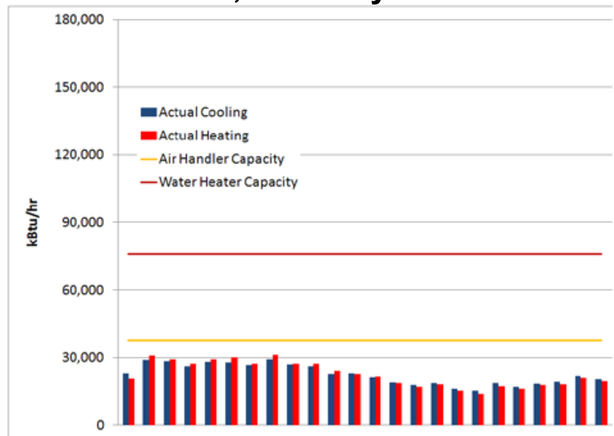


Figure 165. Actual space heating

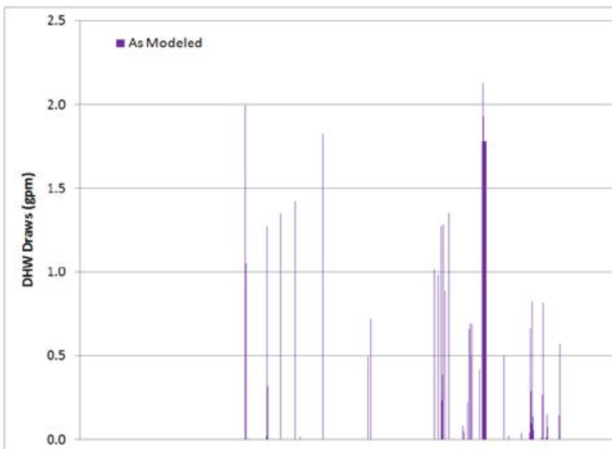


Figure 166. As-modeled DHW draws

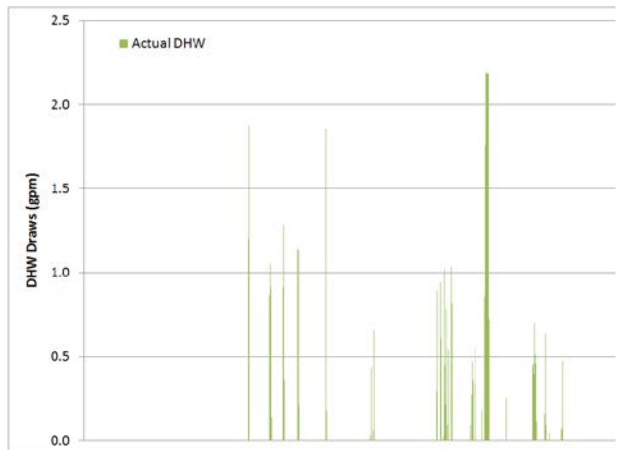


Figure 167. Actual DHW draws

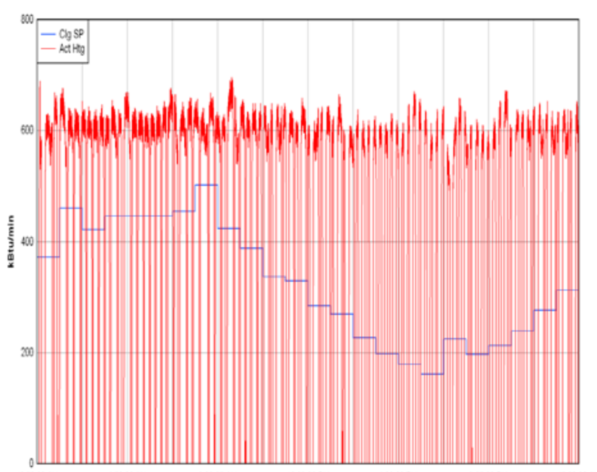


Figure 168. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	468,866
Actual heat loss applied (Btu/day)	538,676
Total daily DHW as modeled (gal/day)	53.2
Actual daily DHW (gal/day)	62.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	618,891
Gas consumed LHV (Btu)	608,309
Combo Air Handler power consumed (Btu)	21,709
Water heater power consumed (Btu)	223
Space heating Energy (Btu)	539,743
DHW energy (Btu)	27,639
HHV System Efficiency	89%
LHV System Efficiency	90%

Figure 169. Performance results

Atlanta, BA2010 Model, Tankless Versus Storage Temperature Stability, February 3

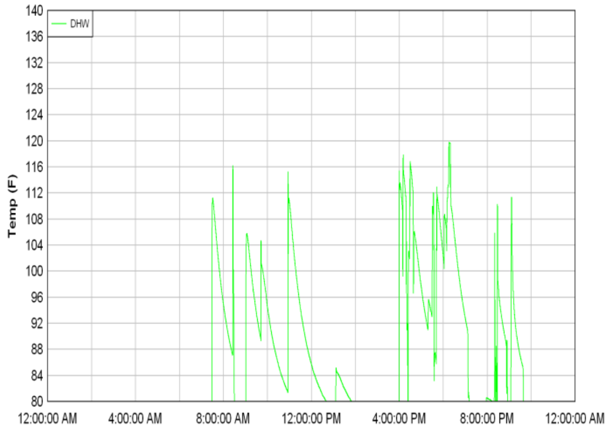


Figure 170. Tankless DHW temperatures

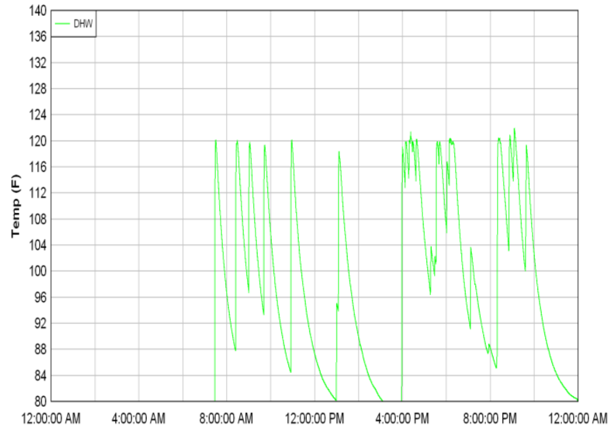


Figure 171. Storage DHW temperatures

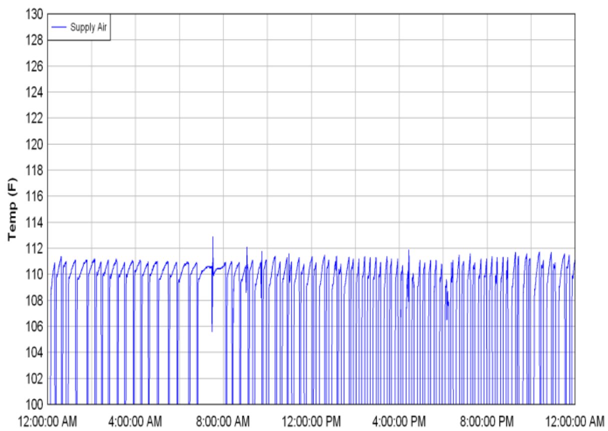


Figure 172. Tankless supply air temperatures

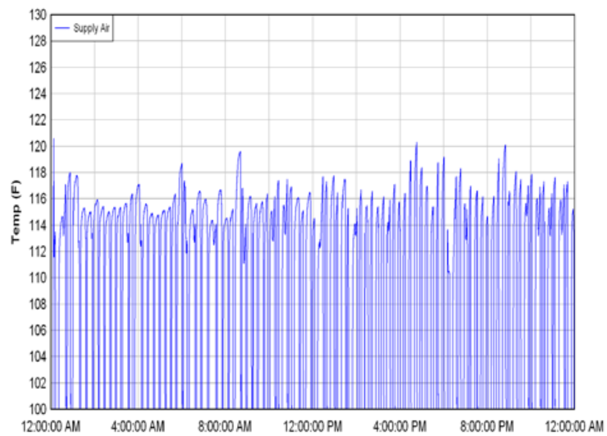


Figure 173. Storage supply air temperatures

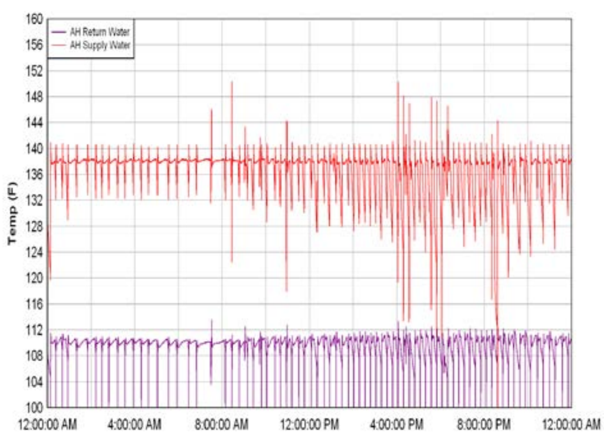


Figure 174. Tankless AH water temperatures

Figure 175. Storage AH water temperatures

Atlanta, BA2010 Model, Rinnai Test With RC80HP/AHB45, January 26

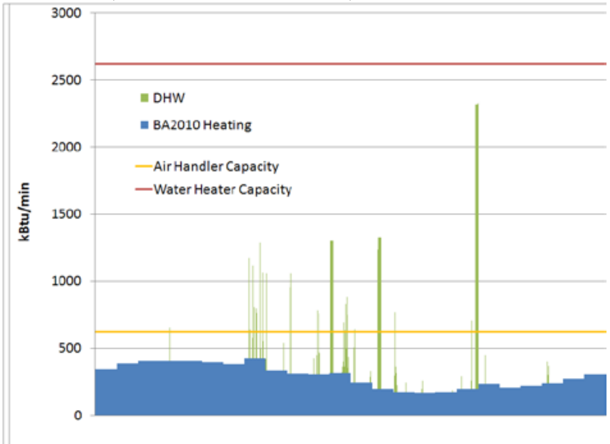


Figure 176. As-modeled space/DHW loads

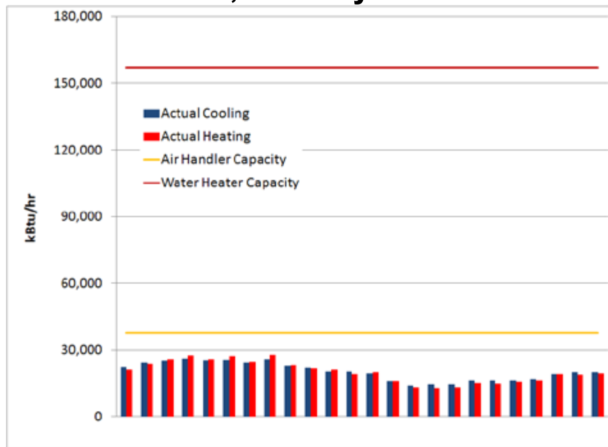


Figure 177. Actual space heating

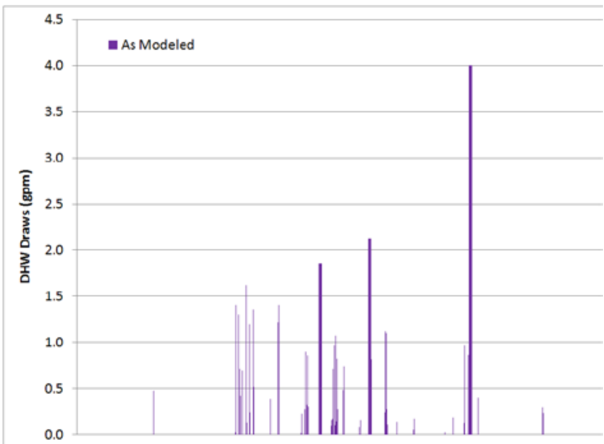


Figure 178. As-modeled DHW draws

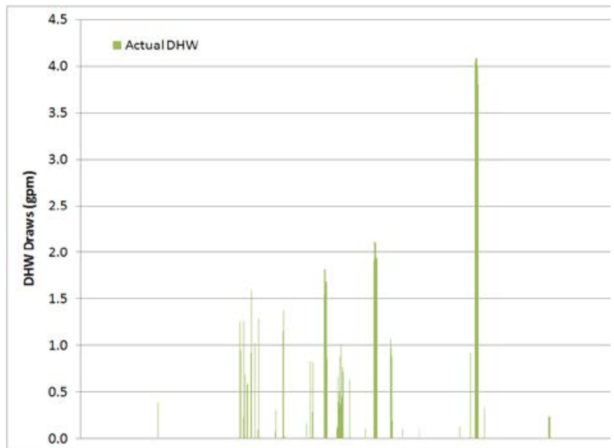


Figure 179. Actual DHW draws

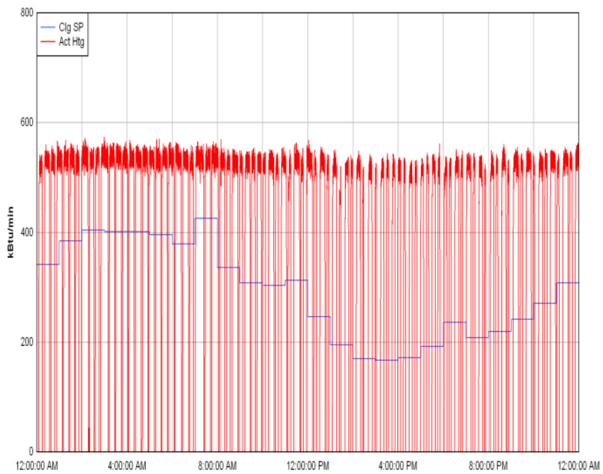


Figure 180. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	421,270
Actual heat loss applied (Btu/day)	485,469
Total daily DHW as modeled (gal/day)	100.0
Actual daily DHW (gal/day)	103.4
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	575,614
Gas consumed LHV (Btu)	565,772
Combo Air Handler power consumed (Btu)	22,166
Water heater power consumed (Btu)	227
Space heating Energy (Btu)	481,344
DHW energy (Btu)	44,172
HHV System Efficiency	88%
LHV System Efficiency	89%

Figure 181. Performance results

Atlanta, BA2010 Model, Vertex Test With RC80HP/AHB45, January 26

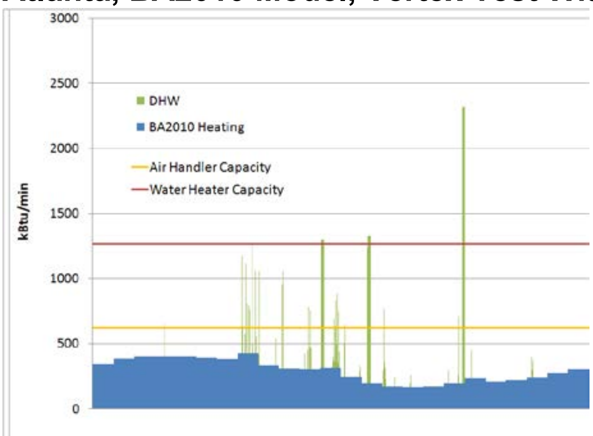


Figure 182. As-modeled space/DHW loads

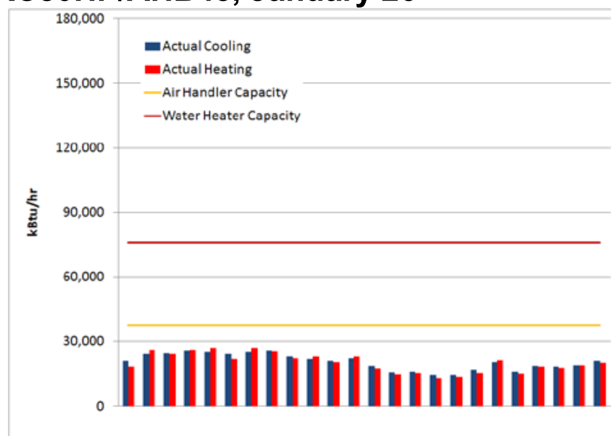


Figure 183. Actual space heating

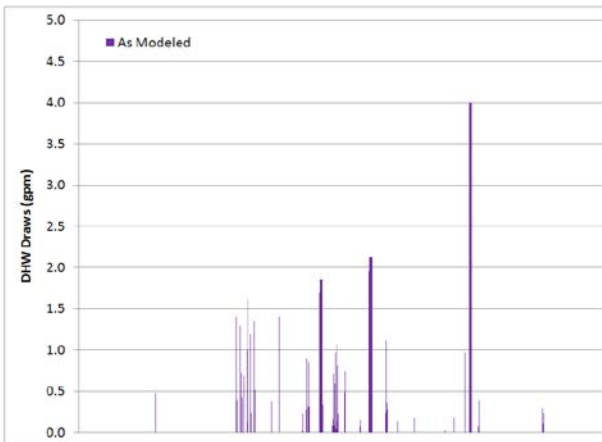


Figure 184. As-modeled DHW draws

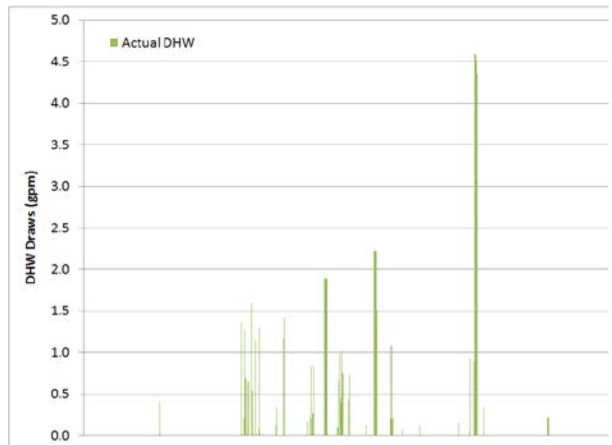


Figure 185. Actual DHW draws

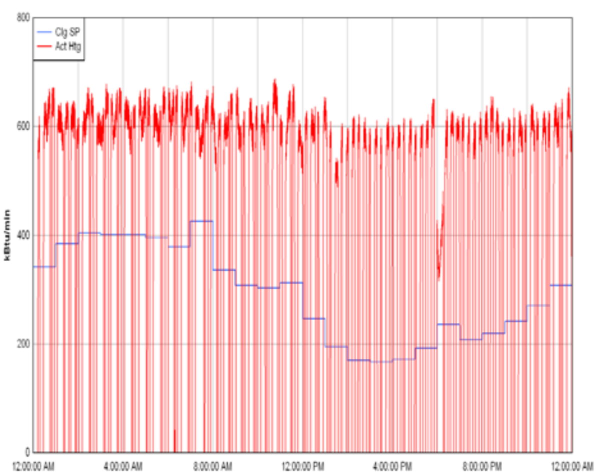


Figure 186. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	421,270
Actual heat loss applied (Btu/day)	491,210
Total daily DHW as modeled (gal/day)	100.0
Actual daily DHW (gal/day)	111.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	596,086
Gas consumed LHV (Btu)	585,893
Combo Air Handler power consumed (Btu)	19,681
Water heater power consumed (Btu)	207
Space heating Energy (Btu)	484,352
DHW energy (Btu)	54,860
HHV System Efficiency	88%
LHV System Efficiency	89%

Figure 187. Performance results

Atlanta, BA2010 Model, Tankless Versus Storage Temperature Stability, January 26

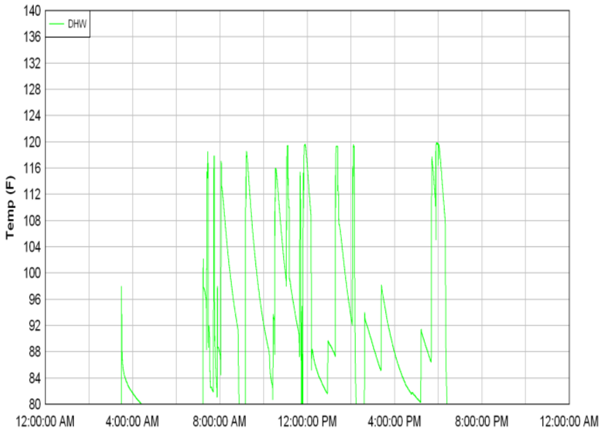


Figure 188. Tankless DHW temperatures

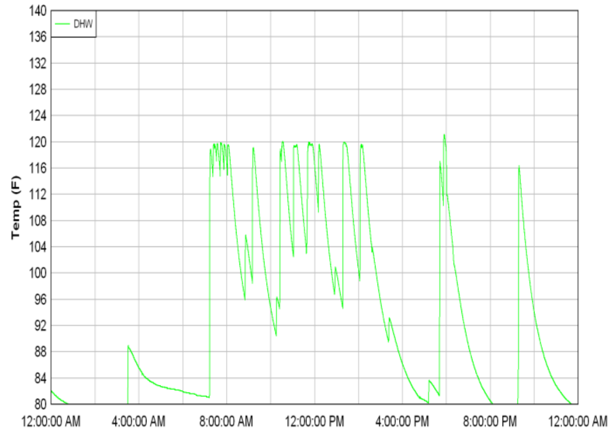


Figure 189. Storage DHW temperatures

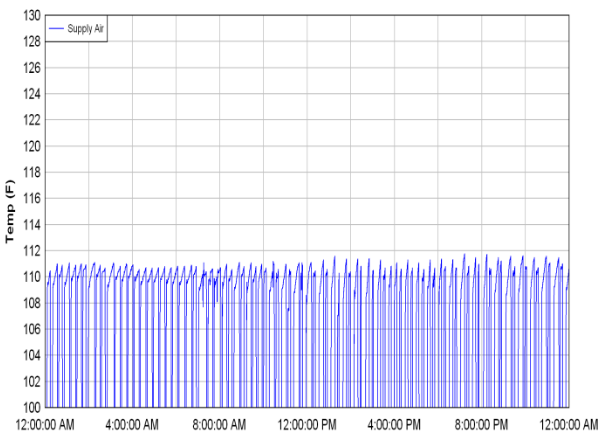


Figure 190. Tankless supply air temperatures

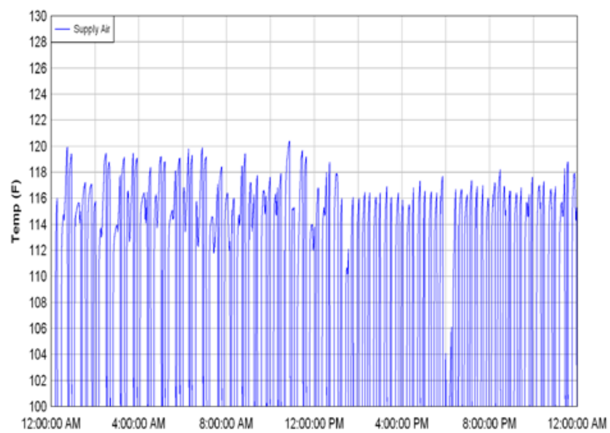


Figure 191. Storage supply air temperatures

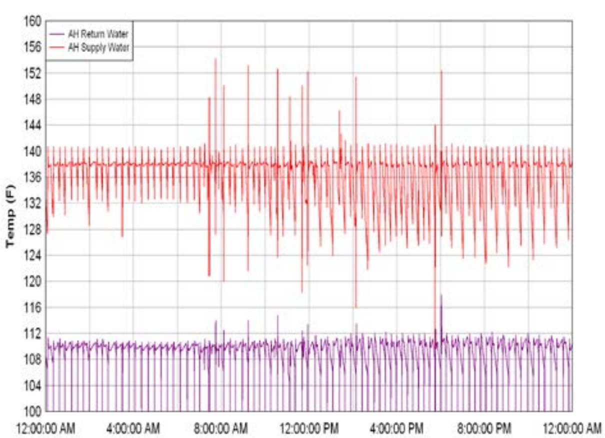


Figure 192. Tankless AH water temperatures

Figure 193. Storage AH water temperatures

Atlanta, BA2010 Model, Rinnai Test With RC80HP/AHB45, December 3

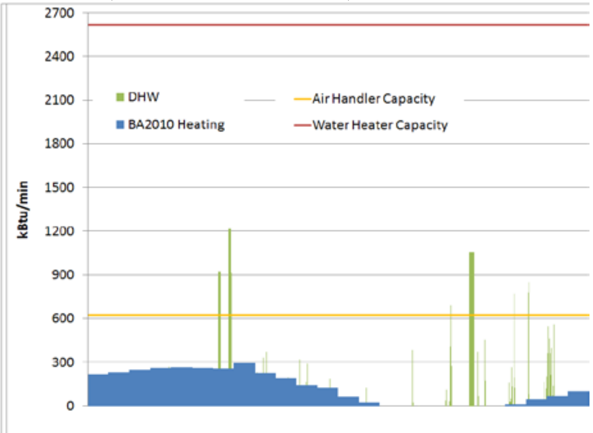


Figure 194. As-modeled space/DHW loads

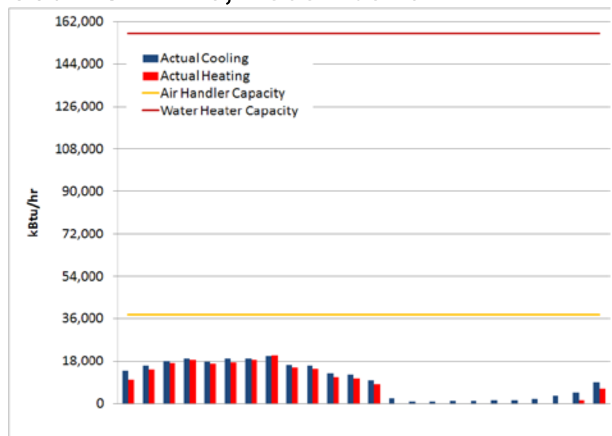


Figure 195. Actual space heating

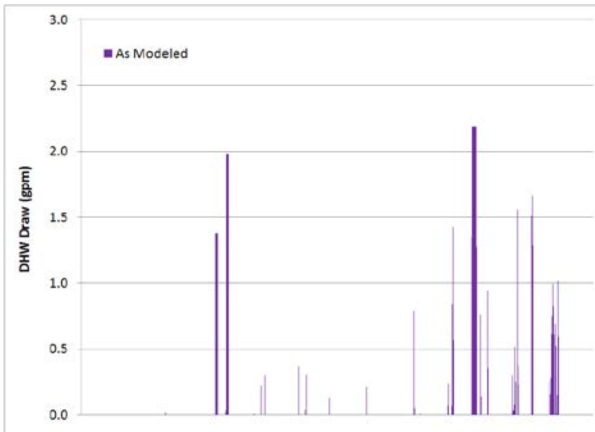


Figure 196. As-modeled DHW draws

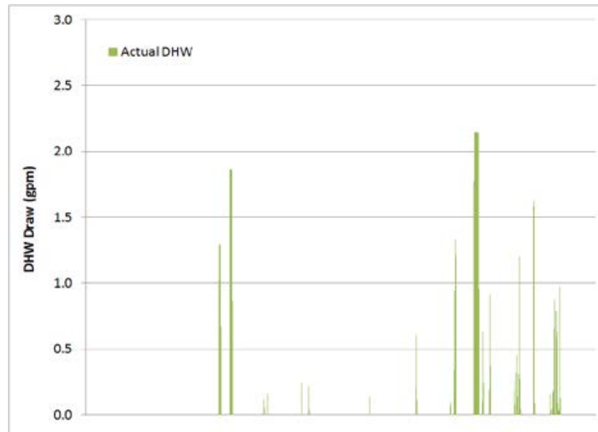


Figure 197. Actual DHW draws

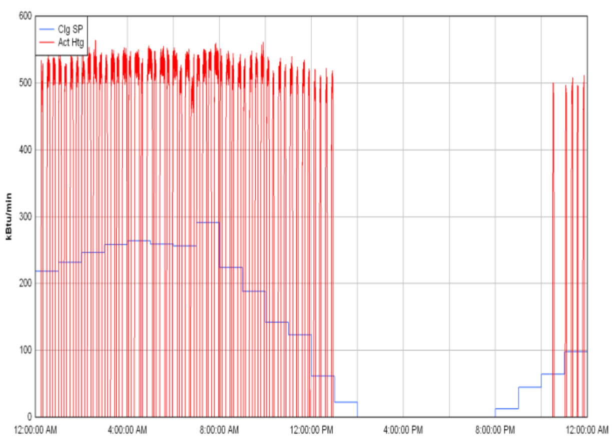


Figure 198. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	180,416
Actual heat loss applied (Btu/day)	237,614
Total daily DHW as modeled (gal/day)	78.8
Actual daily DHW (gal/day)	81.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	267,957
Gas consumed LHV (Btu)	263,375
Combo Air Handler power consumed (Btu)	9,750
Water heater power consumed (Btu)	121
Space heating Energy (Btu)	200,259
DHW energy (Btu)	32,130
HHV System Efficiency	84%
LHV System Efficiency	85%

Figure 199. Performance results

Atlanta, BA2010 Model, Vertex Test With RC80HP/AHB45, December 3

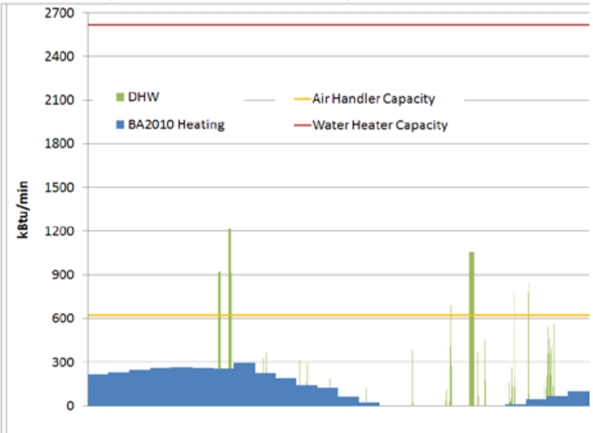


Figure 200. As-modeled space/DHW loads

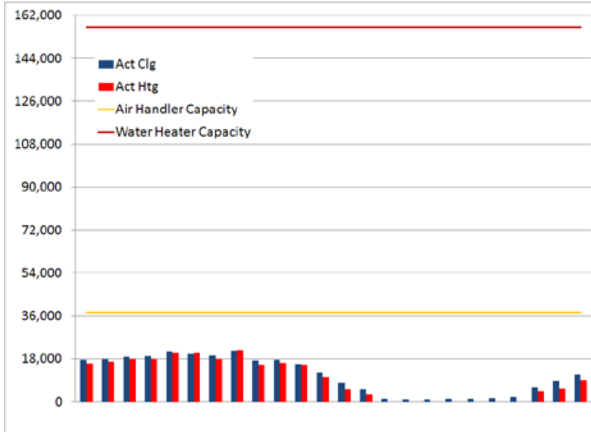


Figure 201. Actual space heating

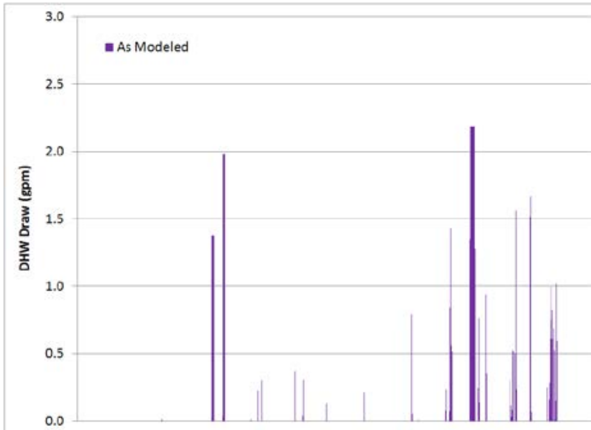


Figure 202. As-modeled DHW draws

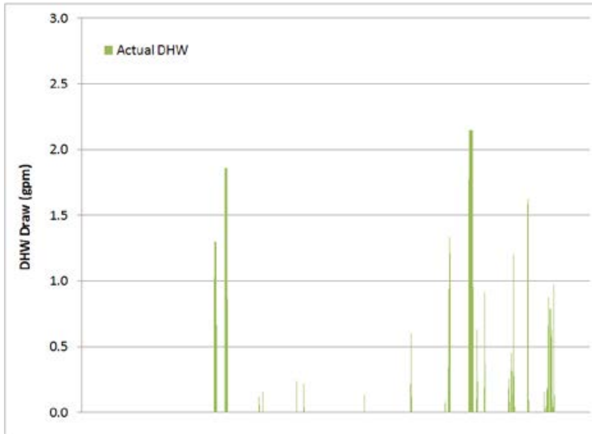


Figure 203. Actual DHW draws

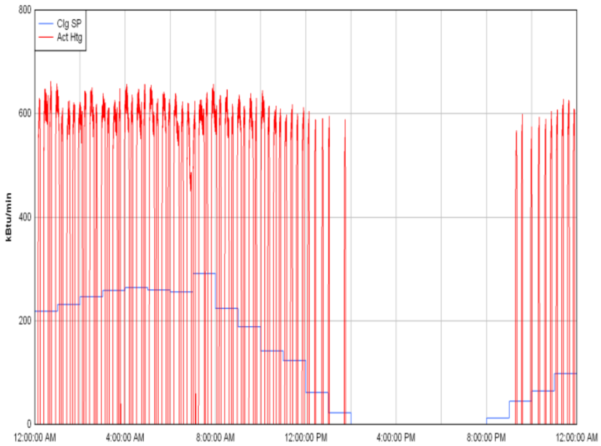


Figure 204. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	180,416
Actual heat loss applied (Btu/day)	266,762
Total daily DHW as modeled (gal/day)	78.8
Actual daily DHW (gal/day)	83.9
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	313,821
Gas consumed LHV (Btu)	308,455
Combo Air Handler power consumed (Btu)	9,926
Water heater power consumed (Btu)	124
Space heating Energy (Btu)	235,355
DHW energy (Btu)	37,216
HHV System Efficiency	84%
LHV System Efficiency	86%

Figure 205. Performance results

Atlanta, BA2010 Model, Tankless Versus Storage Temperature Stability, December 3

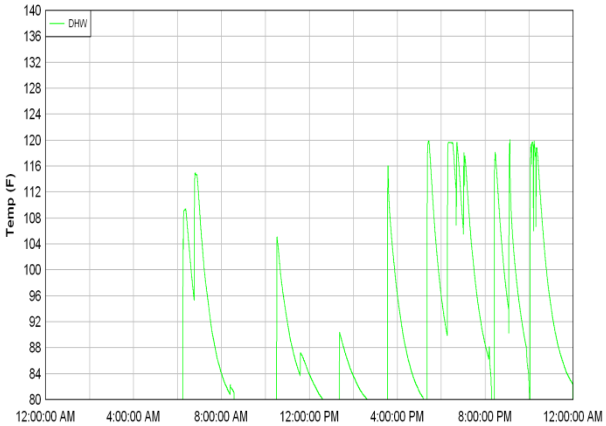


Figure 206. Tankless DHW temperatures

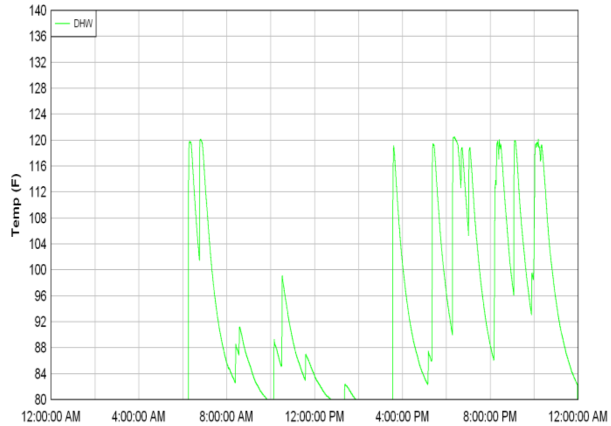


Figure 207. Storage DHW temperatures

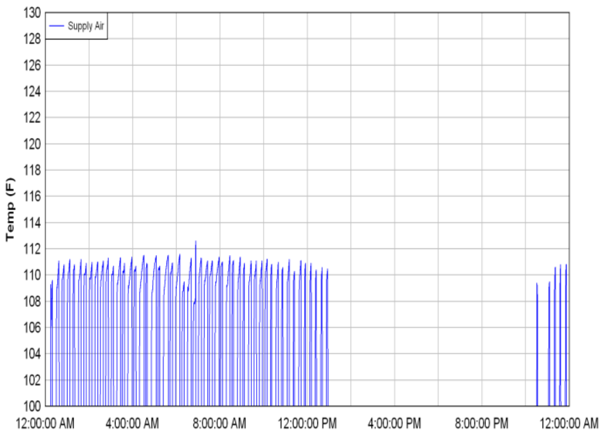


Figure 208. Tankless supply air temperatures

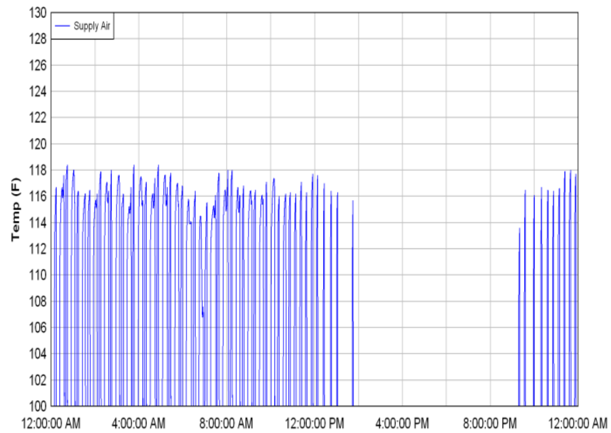


Figure 209. Storage supply air temperatures

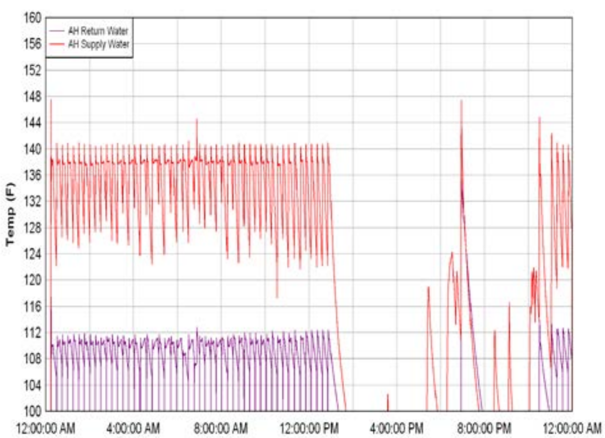


Figure 210. Tankless AH water temperatures

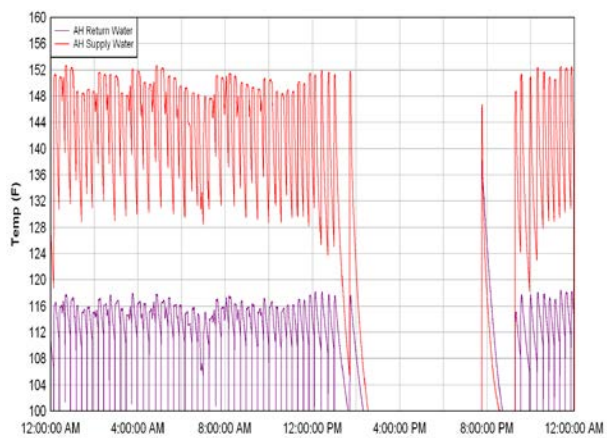


Figure 211. Storage AH water temperatures

Atlanta, BA2010 Model, Tankless Versus Storage DHW Temperatures, December 3

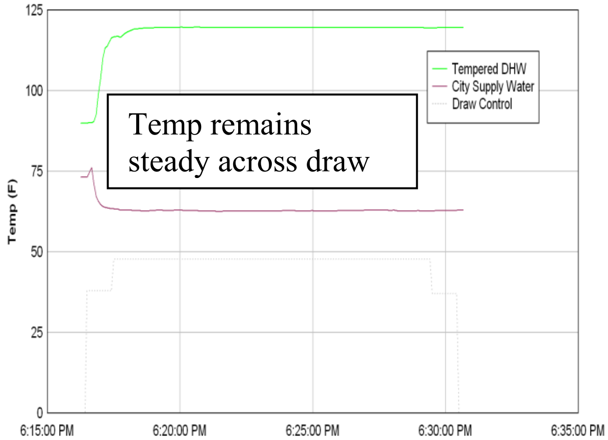


Figure 212. Tankless 12-min DHW draw

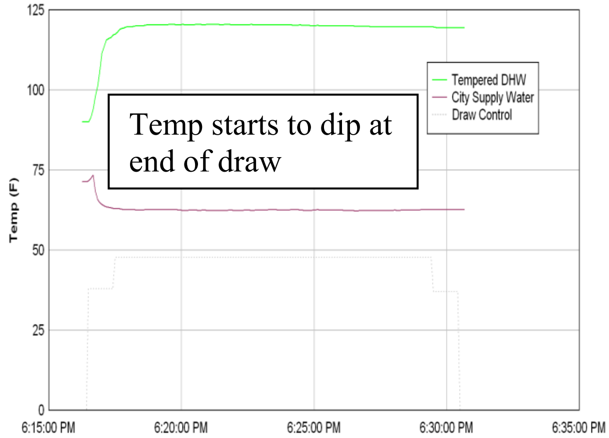


Figure 213. Storage 12-min DHW draw

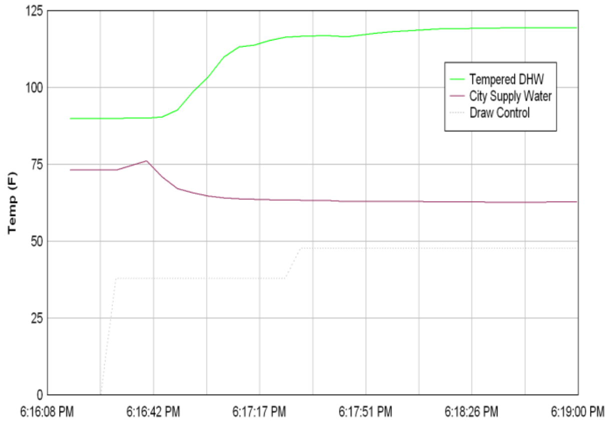


Figure 214. Tankless 12-min DHW warm-up

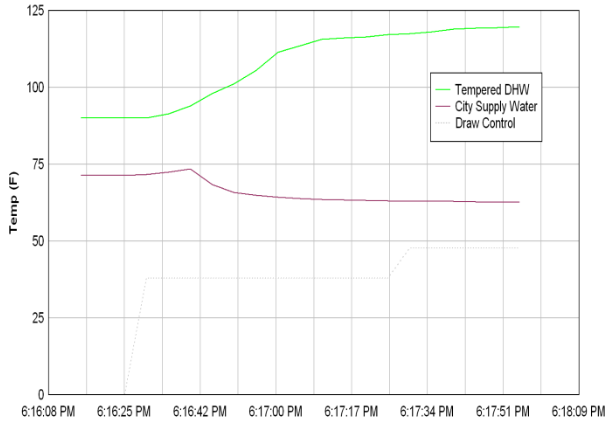


Figure 215. Storage 12-min DHW warm-up

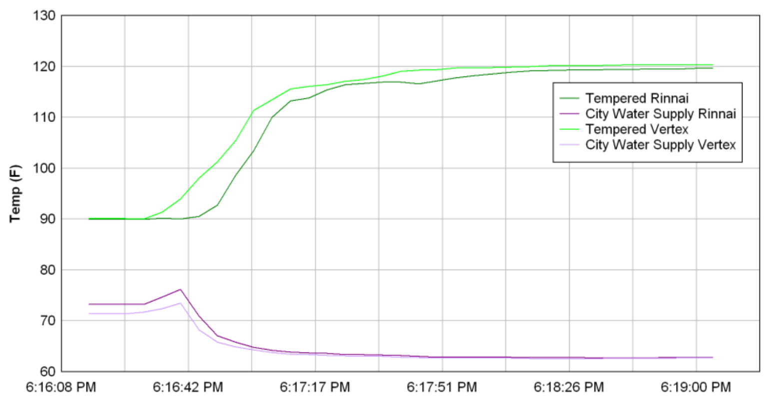


Figure 216. 12-min DHW draw comparison

Atlanta, BA2010 Model, Rinnai Test With RC80HP/AHB45, February 6

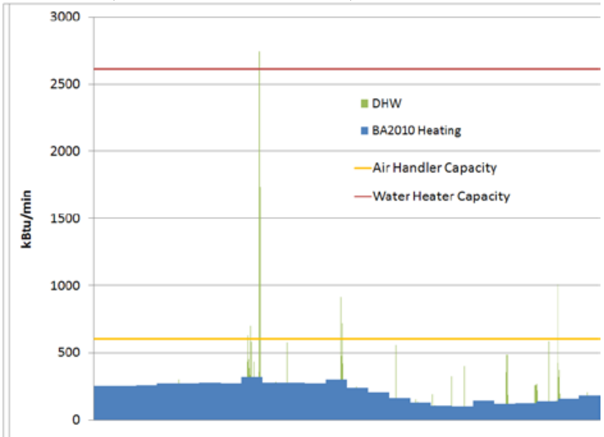


Figure 217. As-modeled space/DHW loads

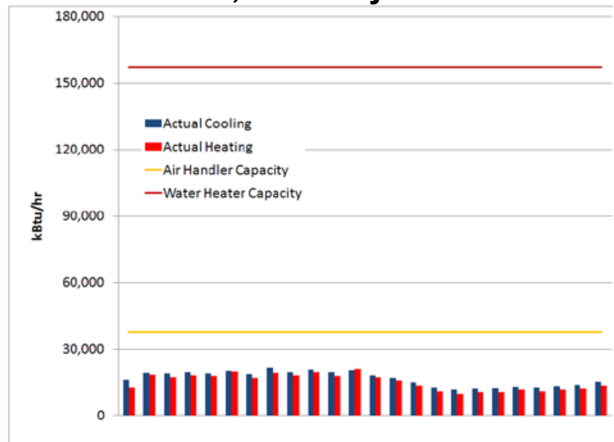


Figure 218. Actual space heating

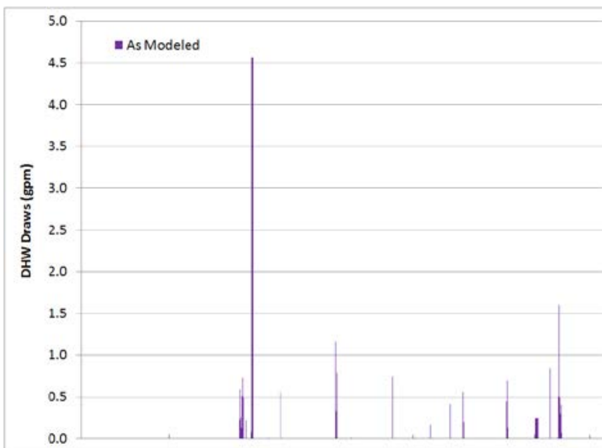


Figure 219. As-modeled DHW draws

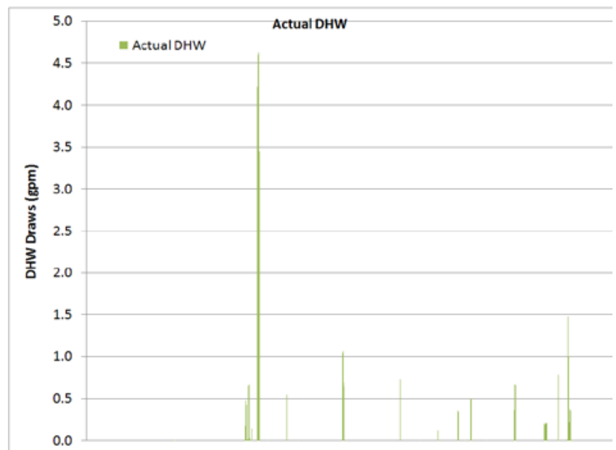


Figure 220. Actual DHW draws

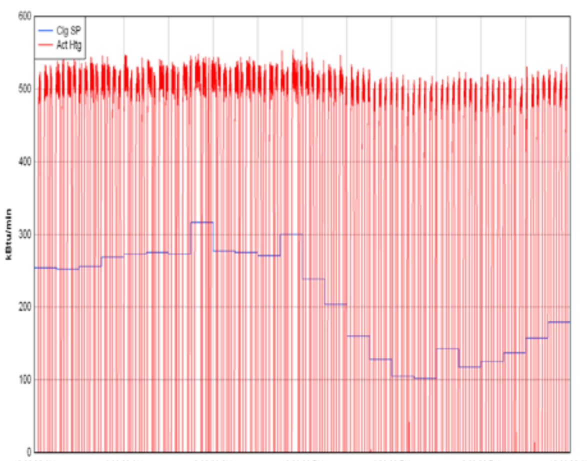


Figure 221. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	305,440
Actual heat loss applied (Btu/day)	400,602
Total daily DHW as modeled (gal/day)	39.5
Actual daily DHW (gal/day)	41.0
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	424,449
Gas consumed LHV (Btu)	417,192
Combo Air Handler power consumed (Btu)	17,853
Water heater power consumed (Btu)	187
Space heating Energy (Btu)	364,343
DHW energy (Btu)	14,840
HHV System Efficiency	86%
LHV System Efficiency	87%

Figure 222. Performance results

Atlanta, BA2010 Model, Vertex Test With RC80HP/AHB45, February 6

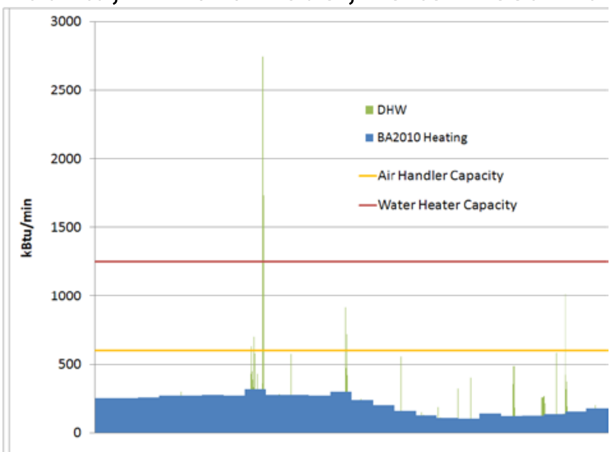


Figure 223. As-modeled space/DHW loads

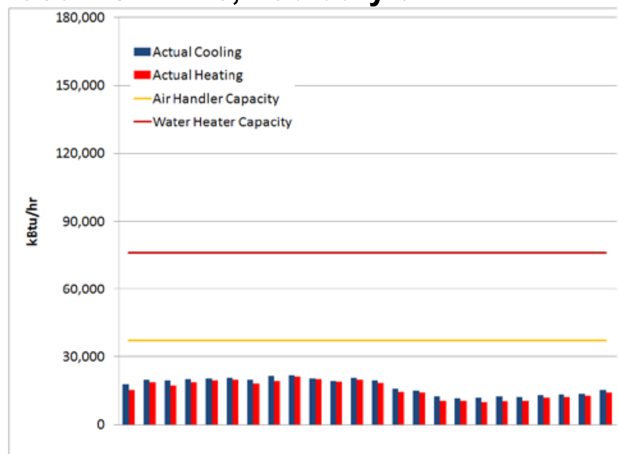


Figure 224. Actual space heating

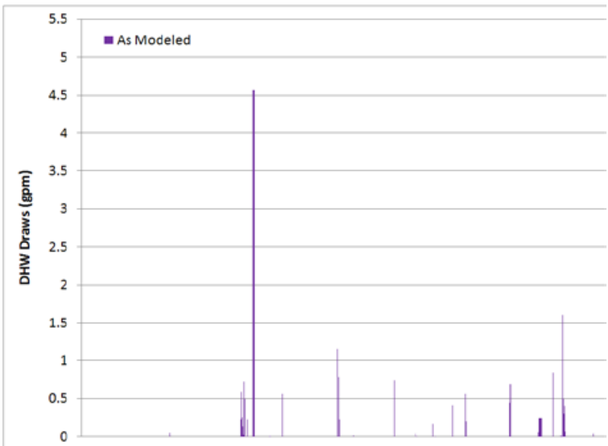


Figure 225. As-modeled DHW draws

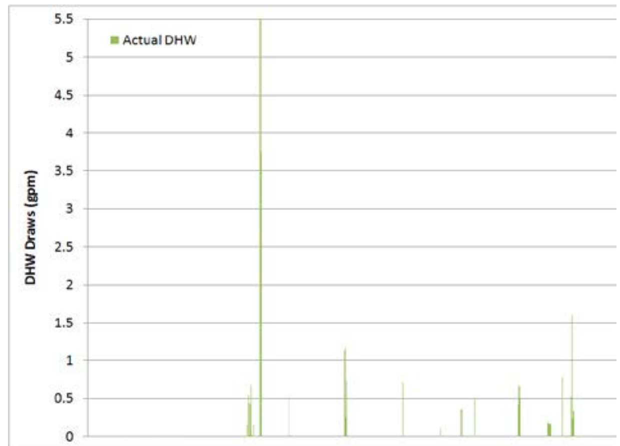


Figure 226. Actual DHW draws

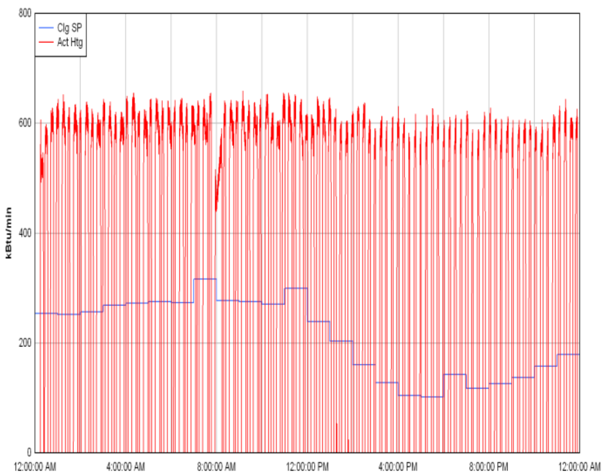


Figure 227. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	305,440
Actual heat loss applied (Btu/day)	411,699
Total daily DHW as modeled (gal/day)	39.5
Actual daily DHW (gal/day)	45.8
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	453,951
Gas consumed LHV (Btu)	446,189
Combo Air Handler power consumed (Btu)	15,905
Water heater power consumed (Btu)	173
Space heating Energy (Btu)	379,813
DHW energy (Btu)	21,347
HHV System Efficiency	85%
LHV System Efficiency	87%

Figure 228. Performance results

Atlanta, BA2010 Model, Tankless Versus Storage Temperature Stability, February 6

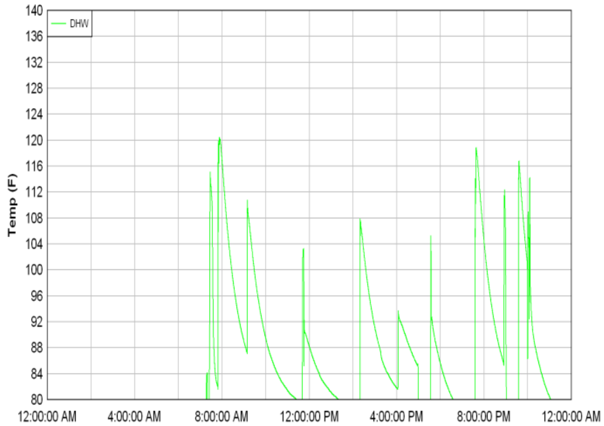


Figure 229. Tankless DHW temperatures

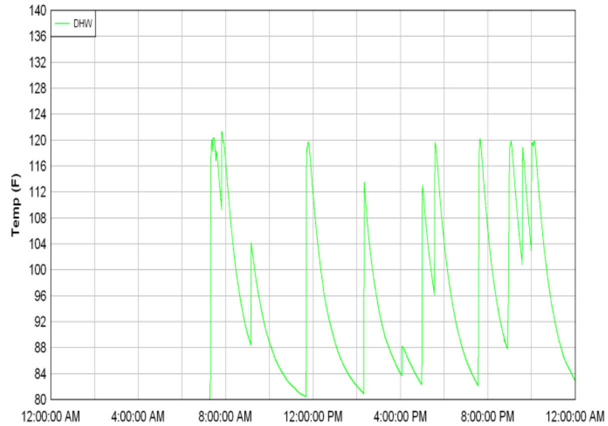


Figure 230. Storage DHW temperatures

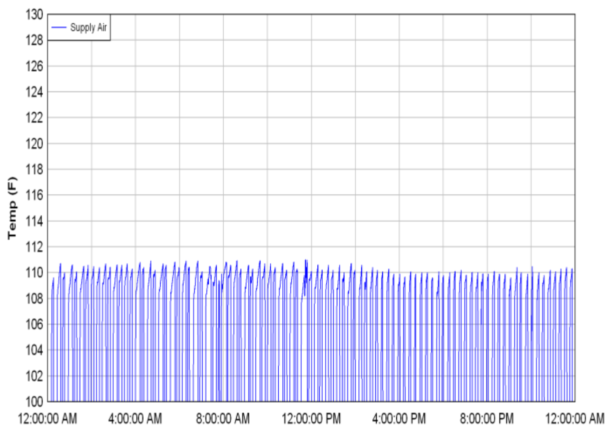


Figure 231. Tankless supply air temperatures

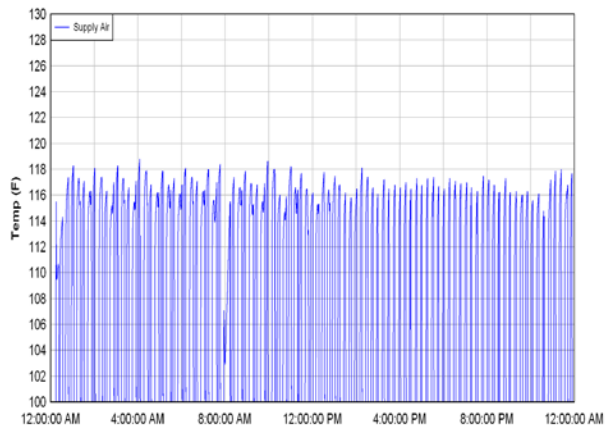


Figure 232. Storage supply air temperatures

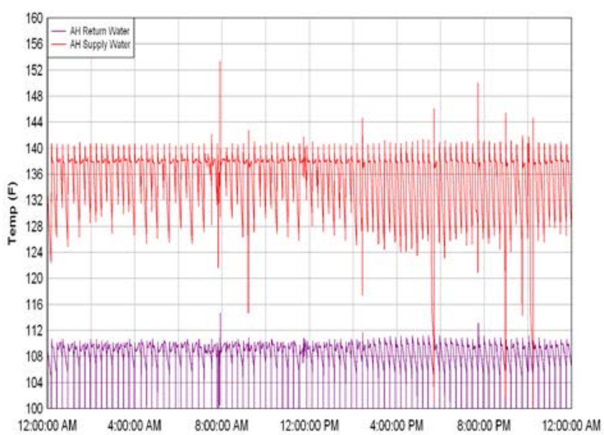


Figure 233. Tankless AH water temperatures

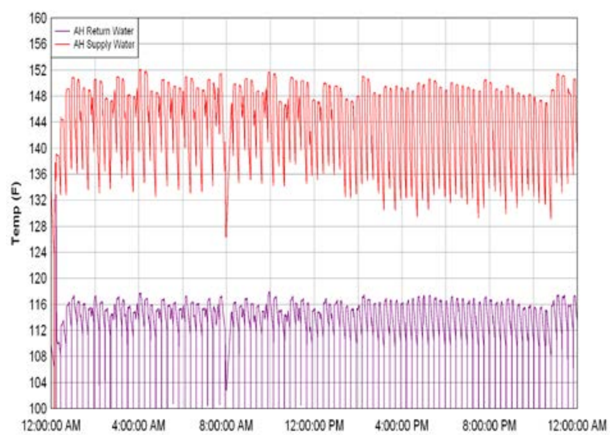


Figure 234. Storage AH water temperatures

Atlanta, Vintage Model, Rinnai Test With RC80HP/AHB90, April 6

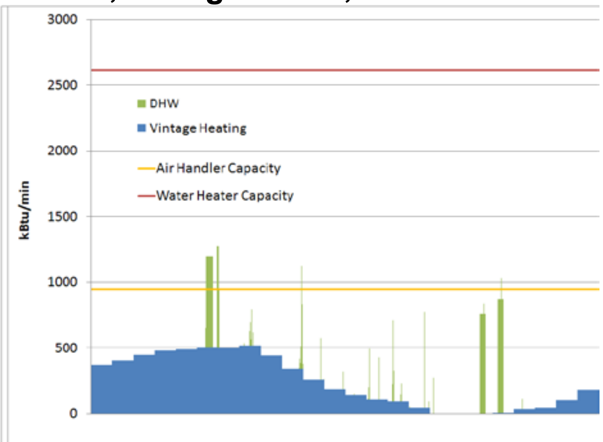


Figure 235. As-modeled space/DHW loads

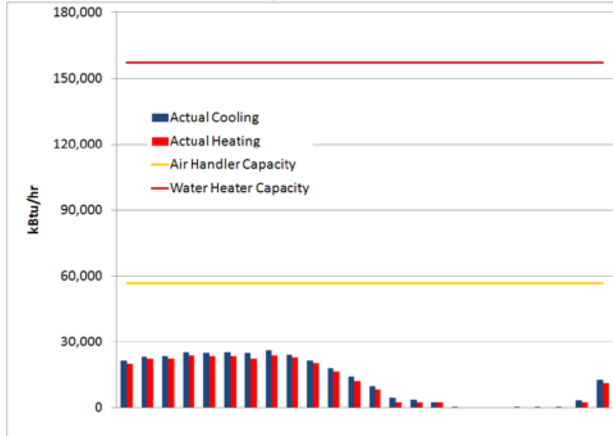


Figure 236. Actual space heating

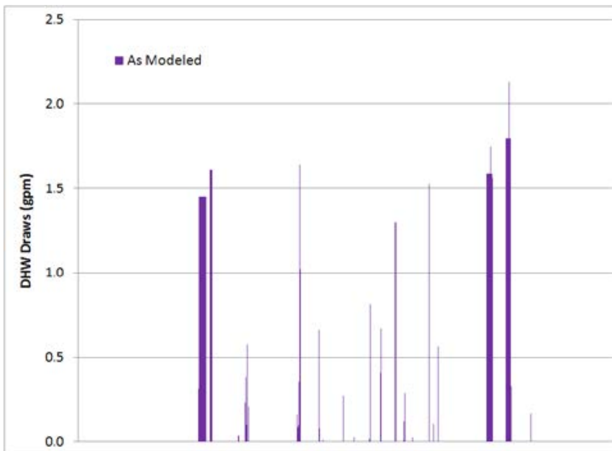


Figure 237. As-modeled DHW draws

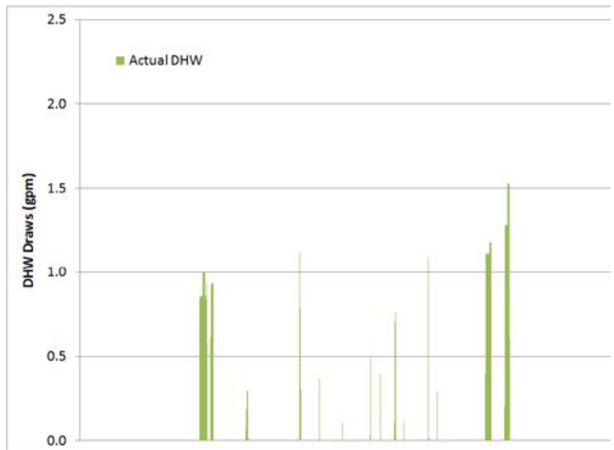


Figure 238. Actual DHW draws

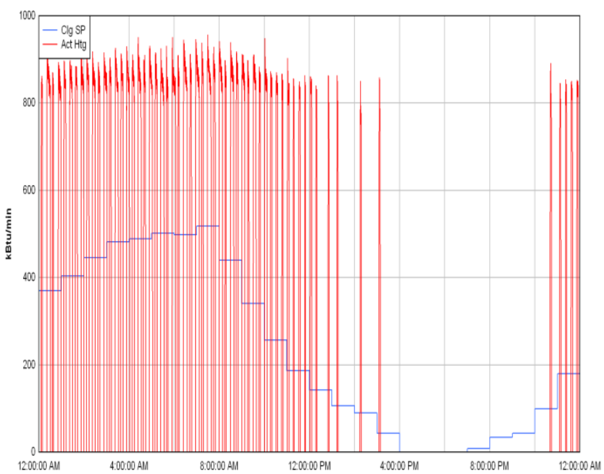


Figure 239. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	340,796
Actual heat loss applied (Btu/day)	309,081
Total daily DHW as modeled (gal/day)	104.3
Actual daily DHW (gal/day)	71.6
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	335,206
Gas consumed LHV (Btu)	329,475
Combo Air Handler power consumed (Btu)	14,582
Water heater power consumed (Btu)	107
Space heating Energy (Btu)	282,817
DHW energy (Btu)	22,628
HHV System Efficiency	87%
LHV System Efficiency	89%

Figure 240. Performance results

Atlanta, Vintage Model, Vertex Test With RC80HP/AHB90, April 6

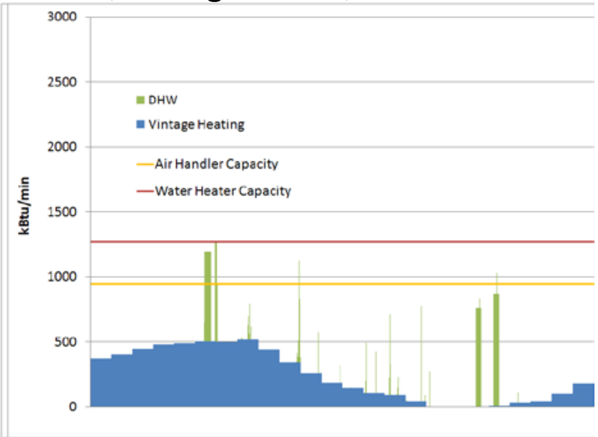


Figure 241. As-modeled space/DHW loads

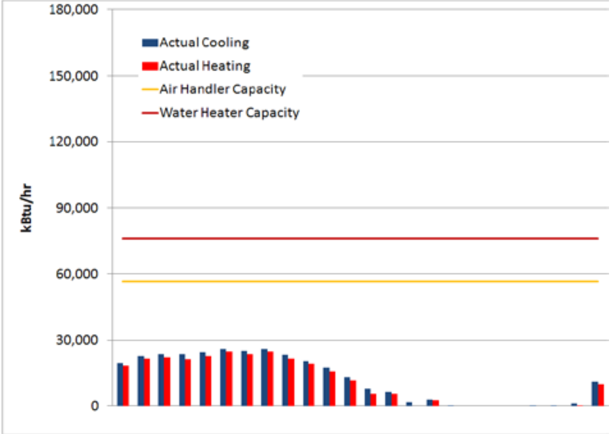


Figure 242. Actual space heating

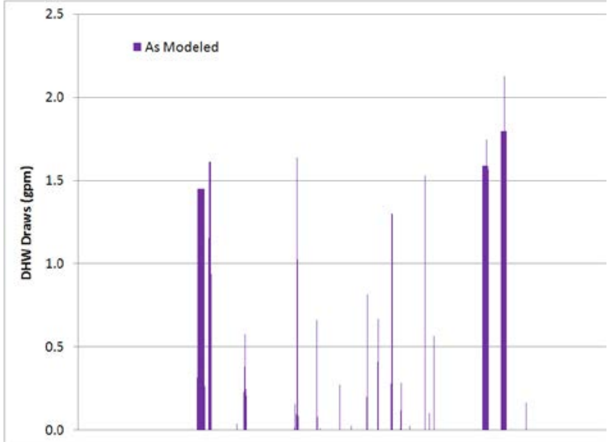


Figure 243. As-modeled DHW draws

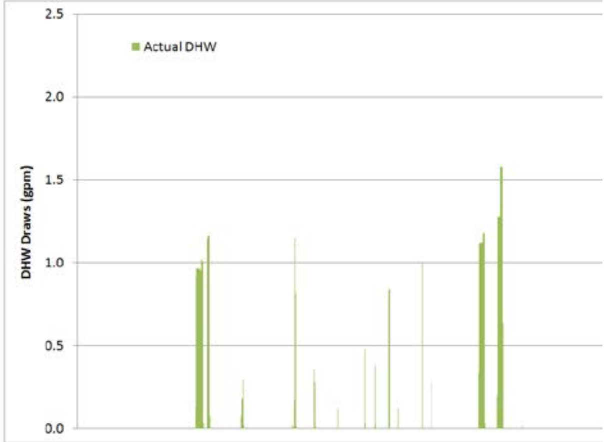


Figure 244. Actual DHW draws

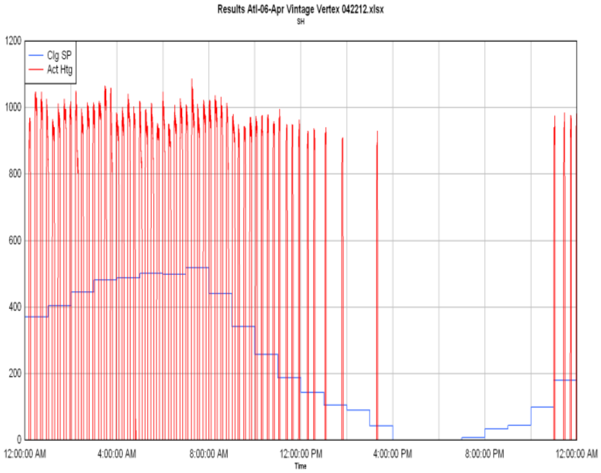


Figure 245. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	340,796
Actual heat loss applied (Btu/day)	295,182
Total daily DHW as modeled (gal/day)	104.3
Actual daily DHW (gal/day)	75.2
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	347,383
Gas consumed LHV (Btu)	341,443
Combo Air Handler power consumed (Btu)	12,667
Water heater power consumed (Btu)	99
Space heating Energy (Btu)	269,225
DHW energy (Btu)	28,807
HHV System Efficiency	83%
LHV System Efficiency	84%

Figure 246. Performance results

Atlanta, Vintage Model, Tankless Versus Storage Temperature Stability, April 6

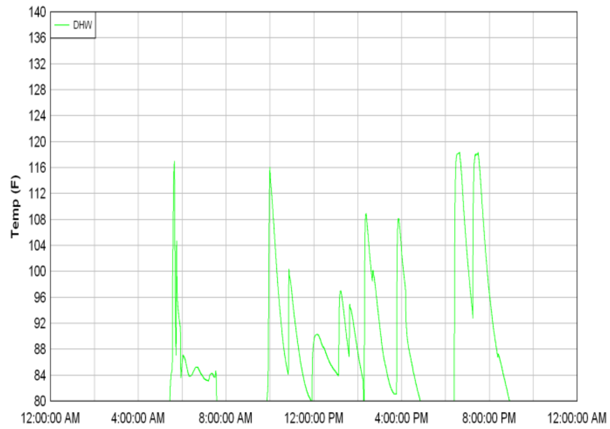


Figure 247. Tankless DHW temperatures

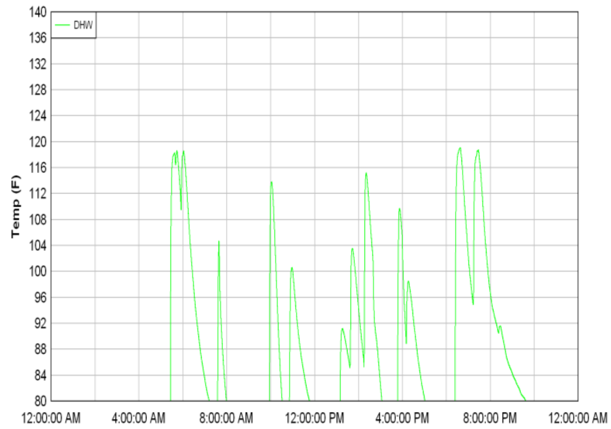


Figure 248. Storage DHW temperatures

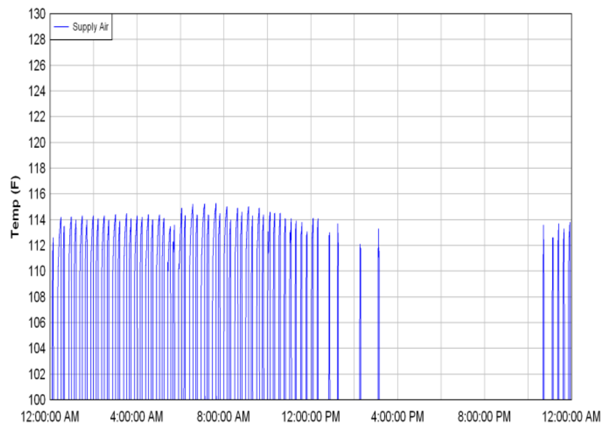


Figure 249. Tankless supply air temperatures

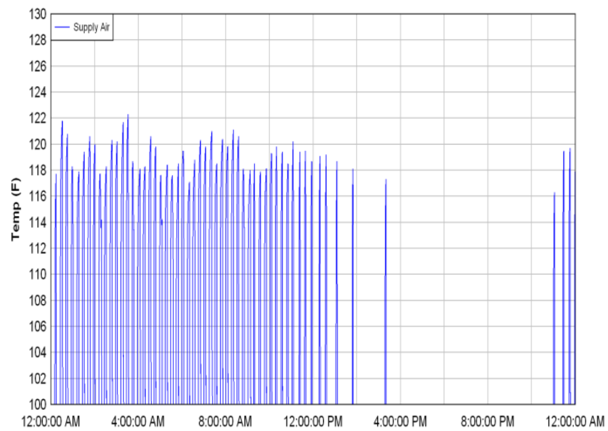


Figure 250. Storage supply air temperatures

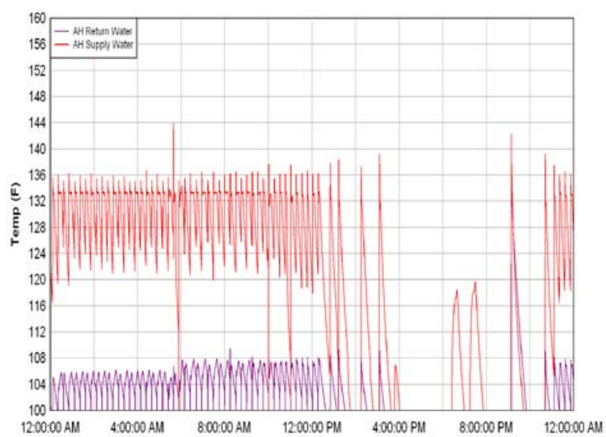


Figure 251. Tankless AH water temperatures

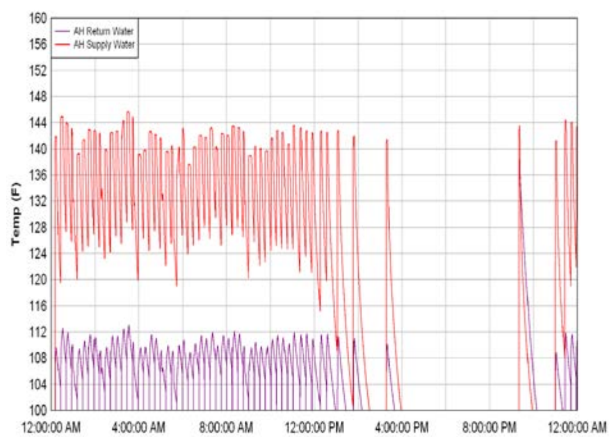


Figure 252. Storage AH water temperatures

Atlanta, Vintage Model, Rinnai Test With RC80HP/AHB90, March 23

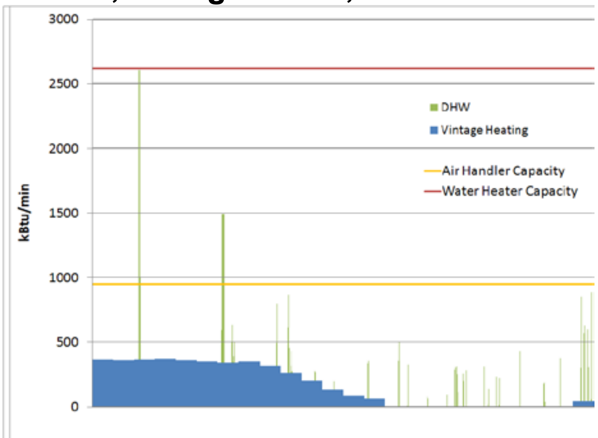


Figure 253. As-modeled space/DHW loads

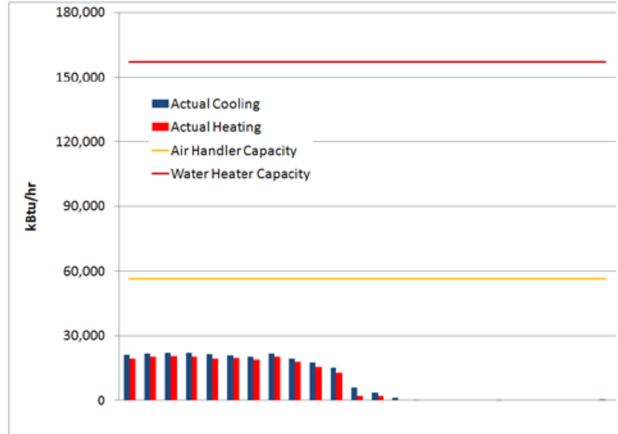


Figure 254. Actual space heating

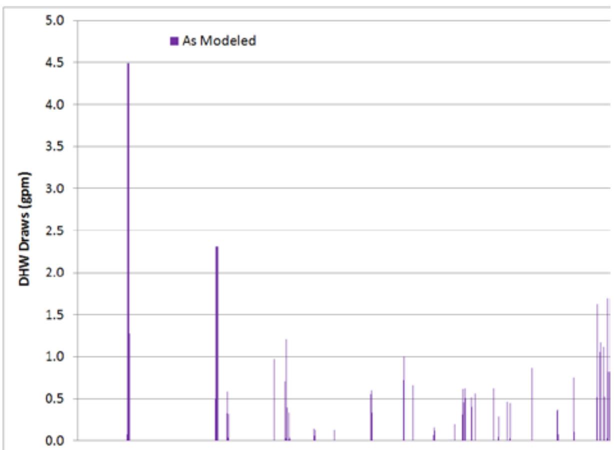


Figure 255. As-modeled DHW draws

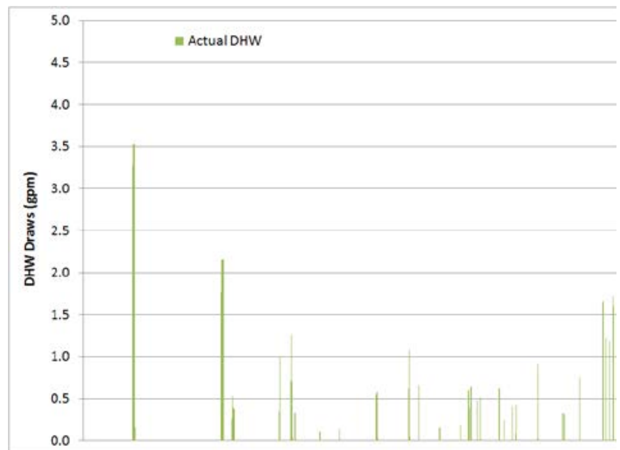


Figure 256. Actual DHW draws

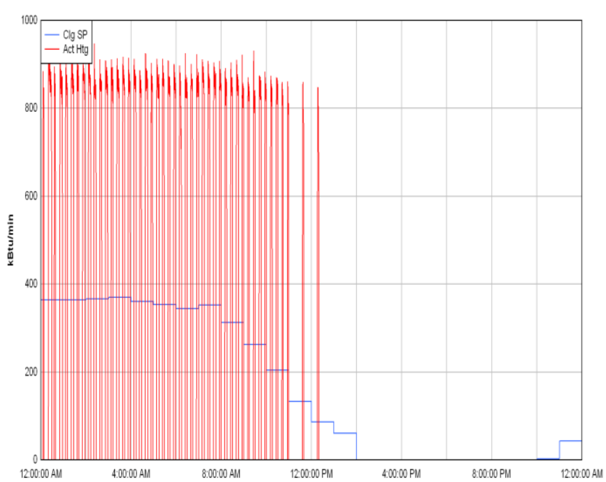


Figure 257. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	238,858
Actual heat loss applied (Btu/day)	236,894
Total daily DHW as modeled (gal/day)	71.2
Actual daily DHW (gal/day)	74.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	265,369
Gas consumed LHV (Btu)	260,832
Combo Air Handler power consumed (Btu)	10,875
Water heater power consumed (Btu)	95
Space heating Energy (Btu)	210,500
DHW energy (Btu)	25,645
HHV System Efficiency	85%
LHV System Efficiency	87%

Figure 258. Performance results

Atlanta, Vintage Model, Vertex Test With RC80HP/AHB90, March 23

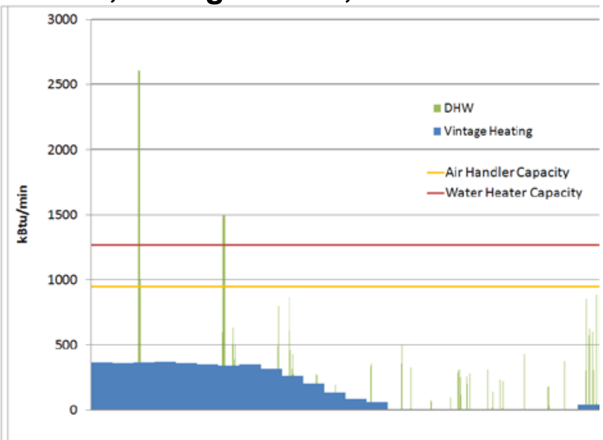


Figure 259. As-modeled space/DHW loads

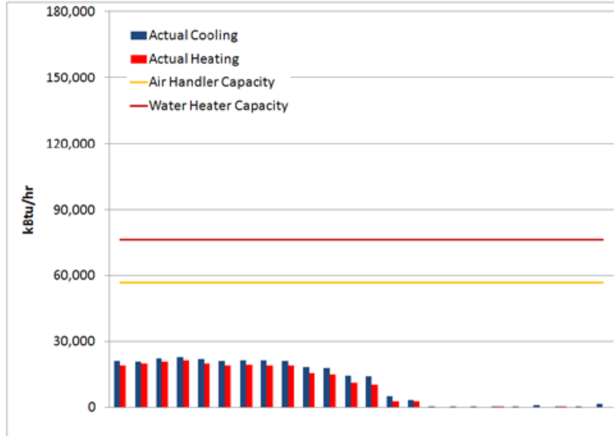


Figure 260. Actual space heating

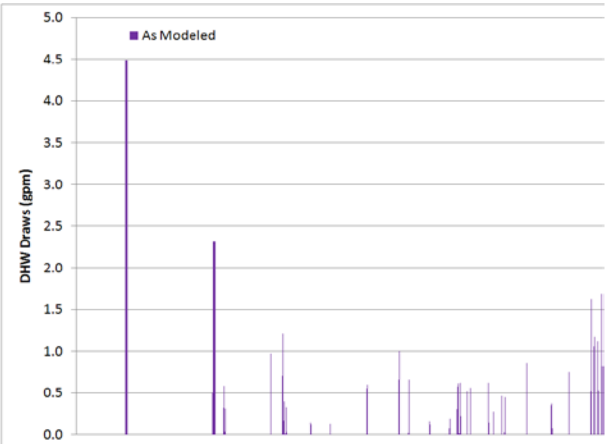


Figure 261. As-modeled DHW draws

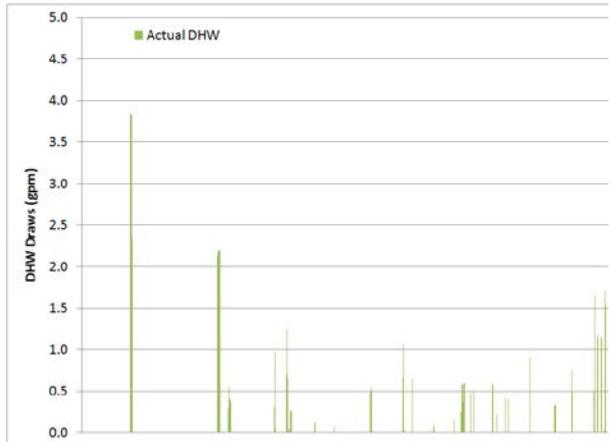


Figure 262. Actual DHW draws

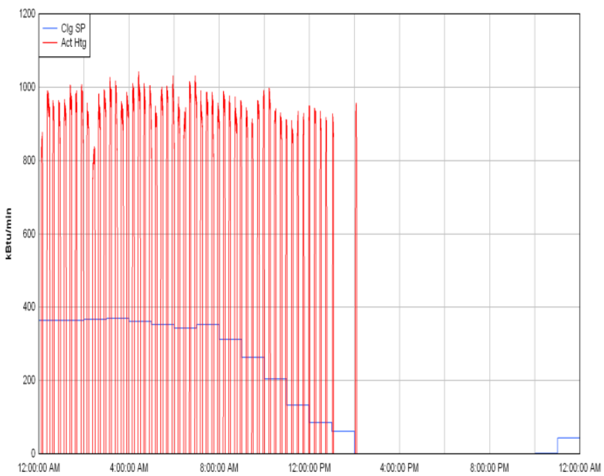


Figure 263. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	238,858
Actual heat loss applied (Btu/day)	271,582
Total daily DHW as modeled (gal/day)	71.2
Actual daily DHW (gal/day)	75.1
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	307,556
Gas consumed LHV (Btu)	302,297
Combo Air Handler power consumed (Btu)	11,185
Water heater power consumed (Btu)	99
Space heating Energy (Btu)	234,348
DHW energy (Btu)	31,058
HHV System Efficiency	83%
LHV System Efficiency	85%

Figure 264. Performance results

Atlanta, Vintage Model, Tankless Versus Storage Temperature Stability, March 23

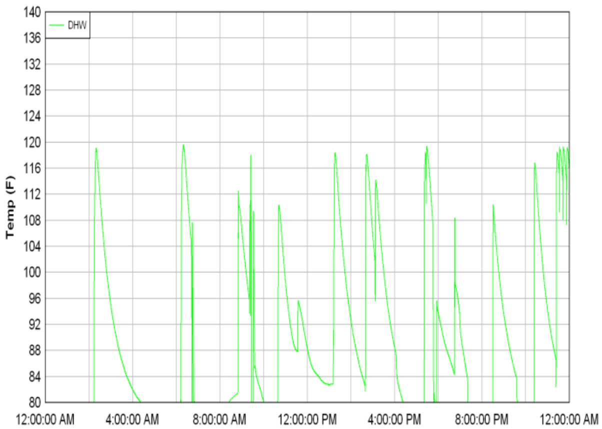


Figure 265. Tankless DHW temperatures

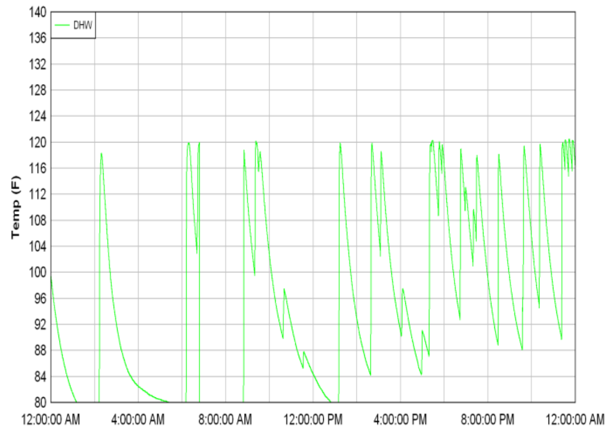


Figure 266. Storage DHW temperatures

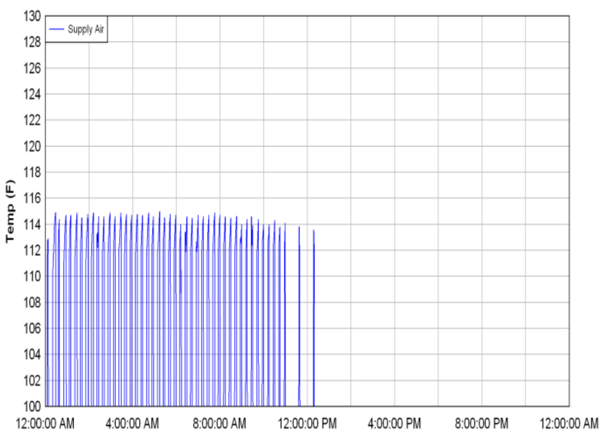


Figure 267. Tankless supply air temperatures

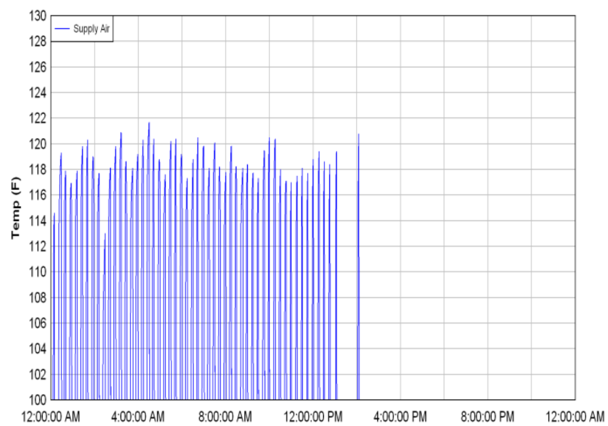


Figure 268. Storage supply air temperatures

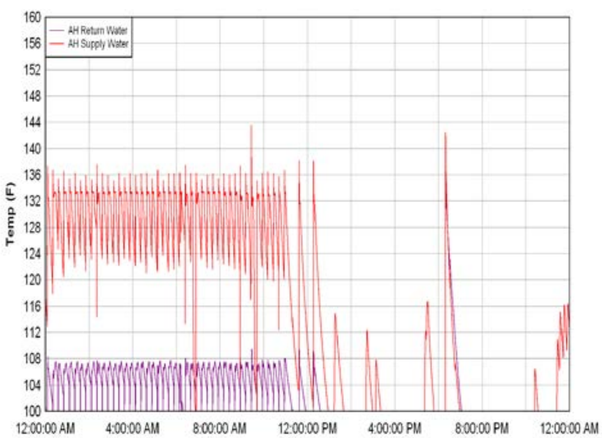


Figure 269. Tankless AH water temperatures

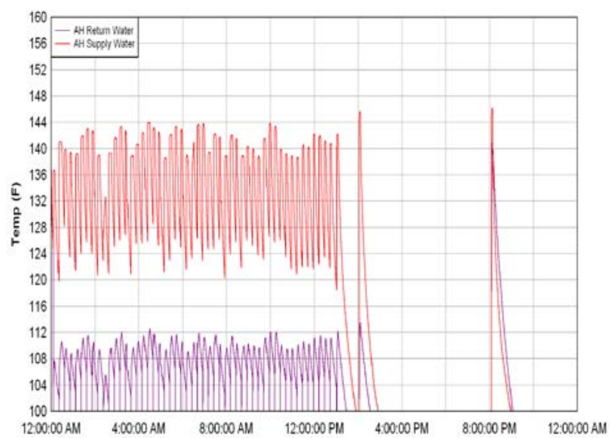


Figure 270. Storage AH water temperatures

Houston, BA2010 Model, Rinnai Test With RC80HP/AHB45, February 11

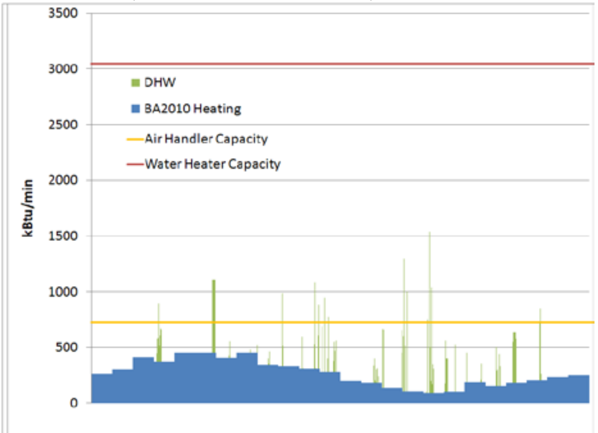


Figure 271. As-modeled space/DHW loads

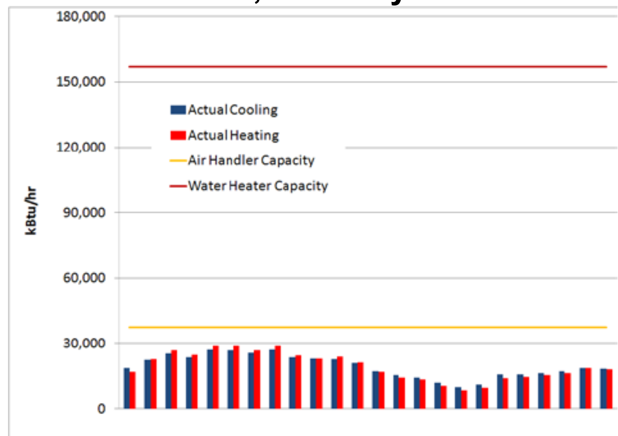


Figure 272. Actual space heating

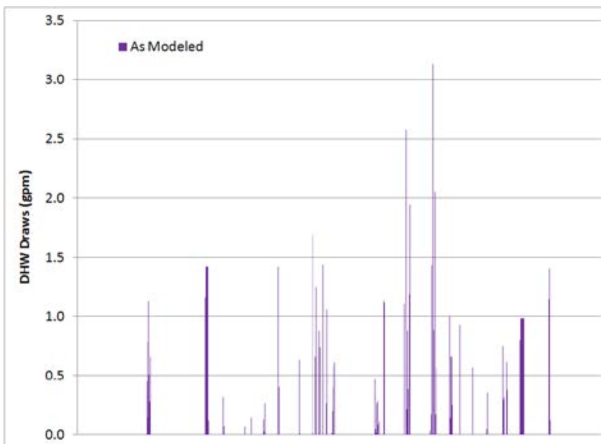


Figure 273. As-modeled DHW draws

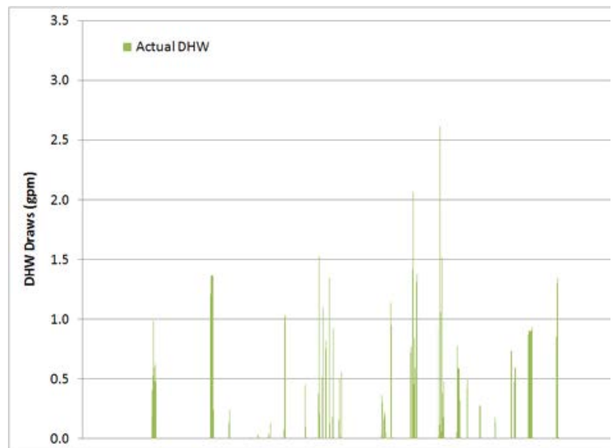


Figure 274. Actual DHW draws

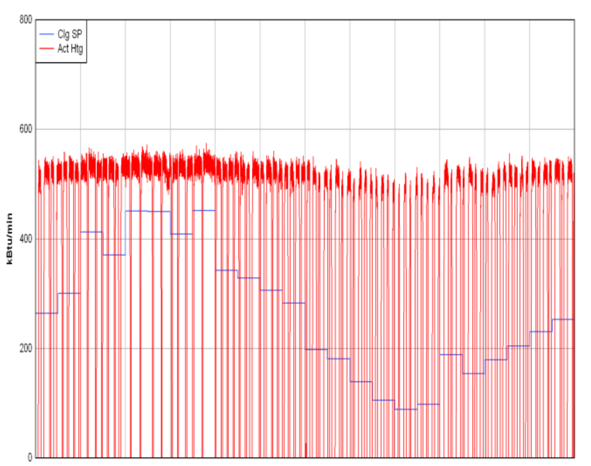


Figure 275. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	383,314
Actual heat loss applied (Btu/day)	469,495
Total daily DHW as modeled (gal/day)	77.5
Actual daily DHW (gal/day)	79.7
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	544,539
Gas consumed LHV (Btu)	535,228
Combo Air Handler power consumed (Btu)	21,817
Water heater power consumed (Btu)	223
Space heating Energy (Btu)	468,237
DHW energy (Btu)	24,240
HHV System Efficiency	87%
LHV System Efficiency	88%

Figure 276. Performance results

Houston, BA2010 Model, Vertex Test With RC80HP/AHB45, February 11

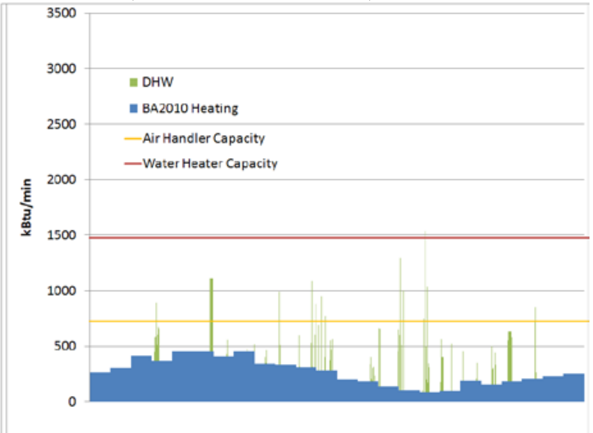


Figure 277. As-modeled space/DHW loads

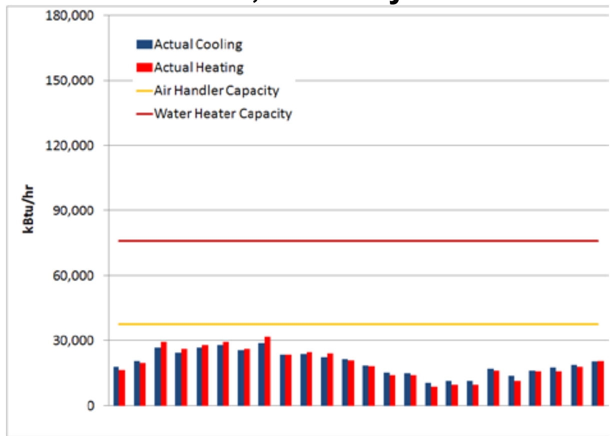


Figure 278. Actual space heating

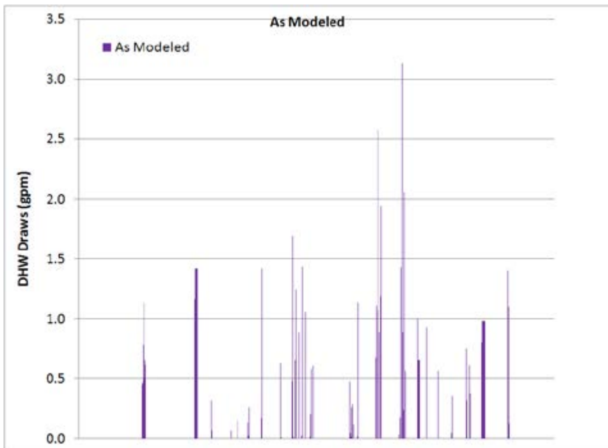


Figure 279. As-modeled DHW draws

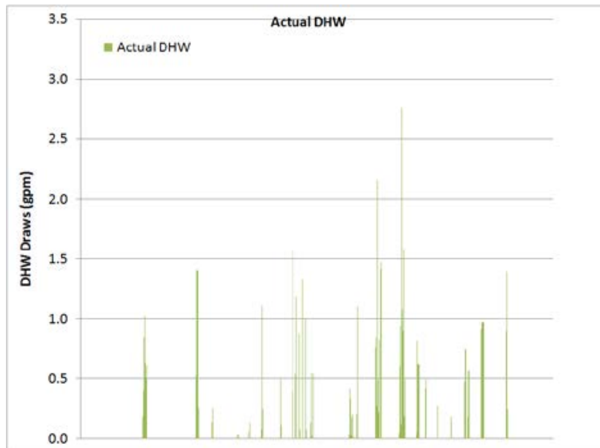


Figure 280. Actual DHW draws

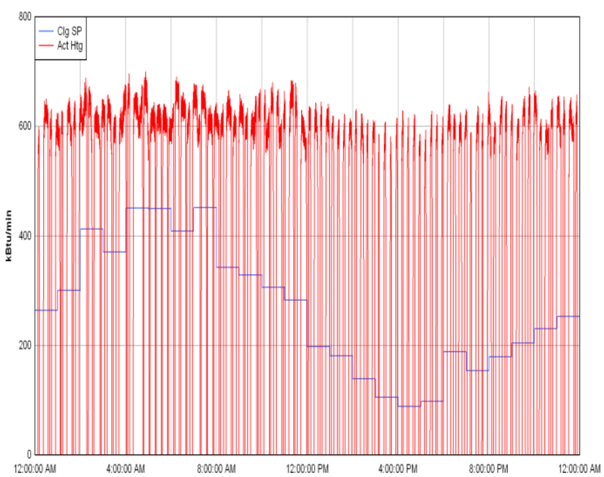


Figure 281. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	383,314
Actual heat loss applied (Btu/day)	474,407
Total daily DHW as modeled (gal/day)	77.5
Actual daily DHW (gal/day)	82.9
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	566,406
Gas consumed LHV (Btu)	556,721
Combo Air Handler power consumed (Btu)	18,913
Water heater power consumed (Btu)	204
Space heating Energy (Btu)	471,160
DHW energy (Btu)	33,824
HHV System Efficiency	86%
LHV System Efficiency	88%

Figure 282. Performance results

Houston, BA2010 Model, Tankless Versus Storage Temperature Stability, February 11

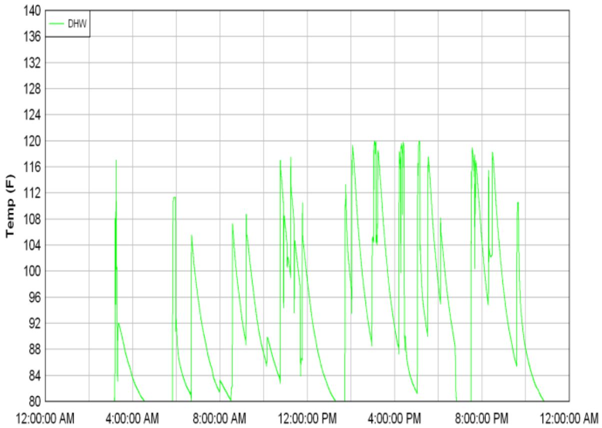


Figure 283. Tankless DHW temperatures

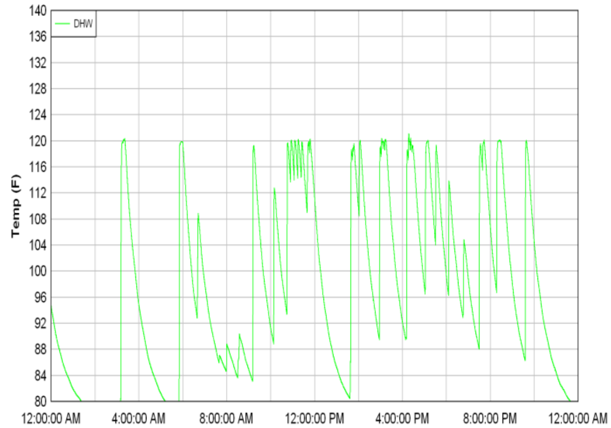


Figure 284. Storage DHW temperatures

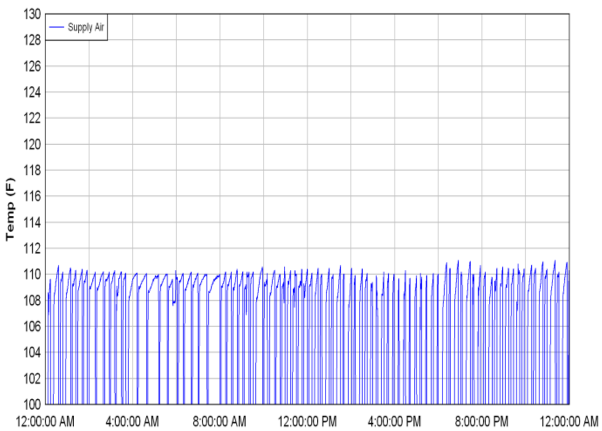


Figure 285. Tankless supply air temperatures

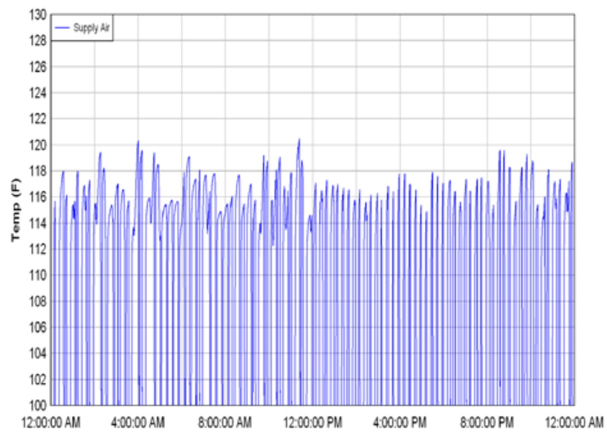


Figure 286. Storage supply air temperatures

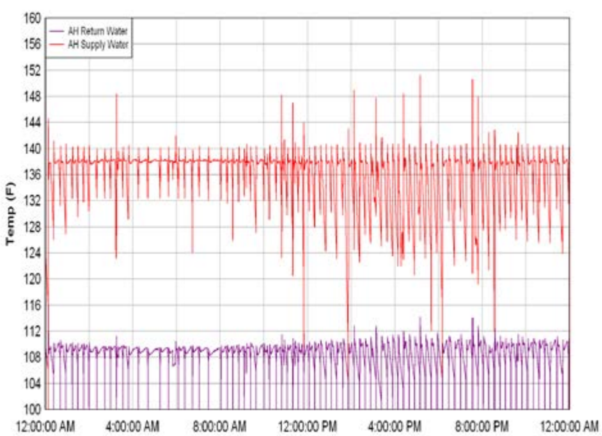


Figure 287. Tankless AH water temperatures

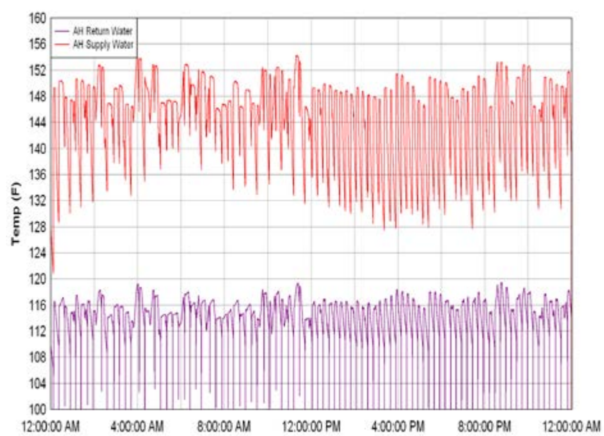


Figure 288. Storage AH water temperatures

Houston, BA2010 Model, Rinnai Test With RC80HP/AHB45, January 11

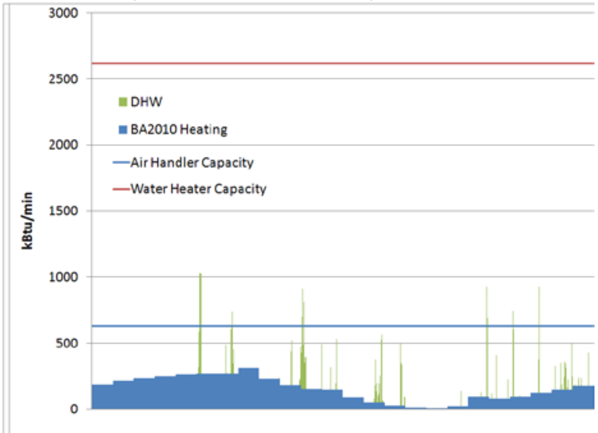


Figure 289. As-modeled space/DHW loads

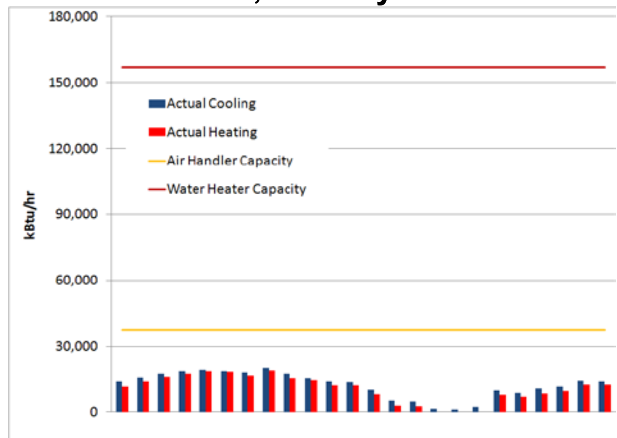


Figure 290. Actual space heating

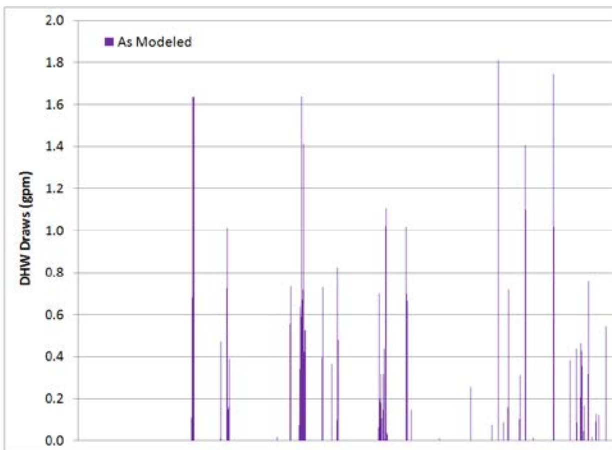


Figure 291. As-modeled DHW draws

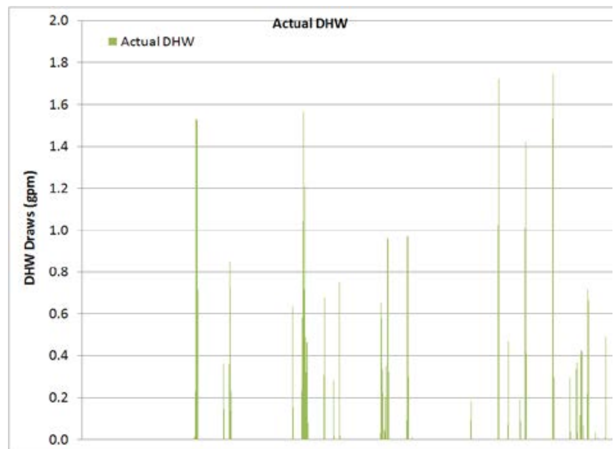


Figure 292. Actual DHW draws

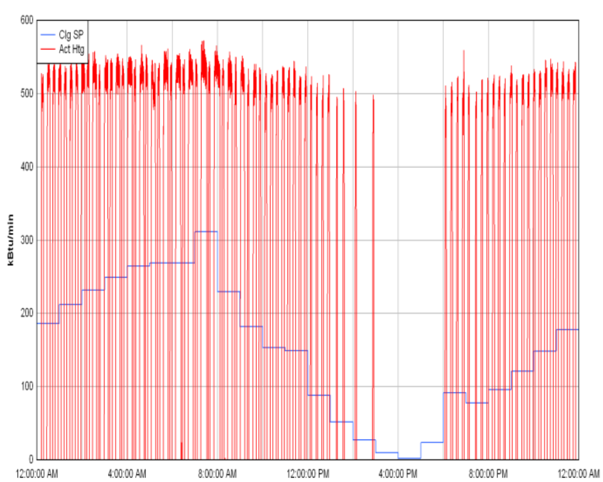


Figure 293. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	217,373
Actual heat loss applied (Btu/day)	297,513
Total daily DHW as modeled (gal/day)	50.2
Actual daily DHW (gal/day)	53.9
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	318,387
Gas consumed LHV (Btu)	312,943
Combo Air Handler power consumed (Btu)	12,525
Water heater power consumed (Btu)	149
Space heating Energy (Btu)	258,691
DHW energy (Btu)	15,919
HHV System Efficiency	83%
LHV System Efficiency	84%

Figure 294. Performance results

Houston, BA2010 Model, Vertex Test With RC80HP/AHB45, January 11

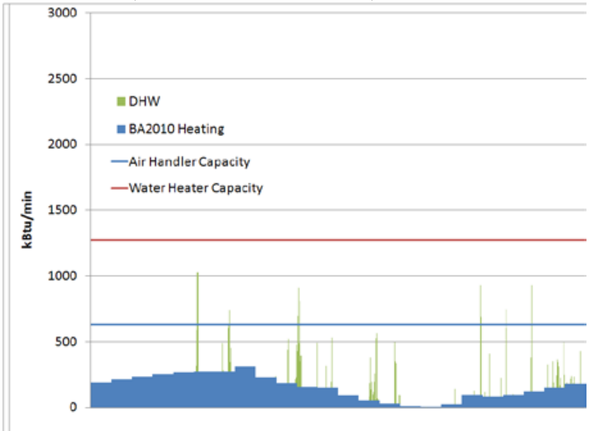


Figure 295. As-modeled space/DHW loads

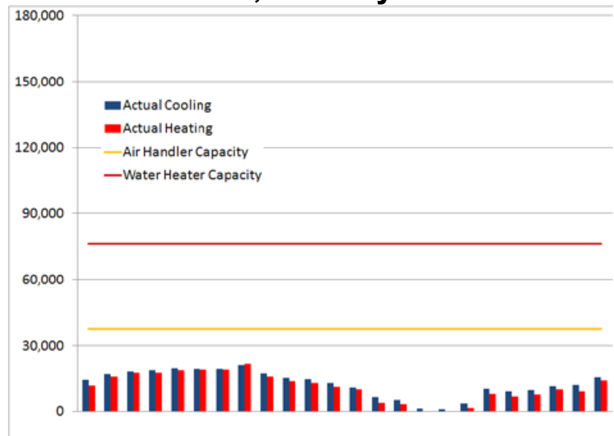


Figure 296. Actual space heating

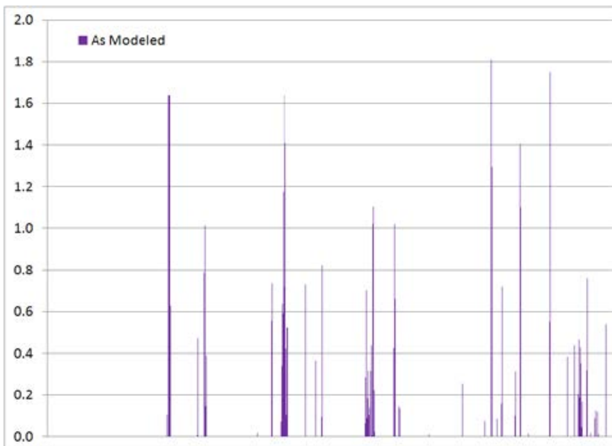


Figure 297. As-modeled DHW draws

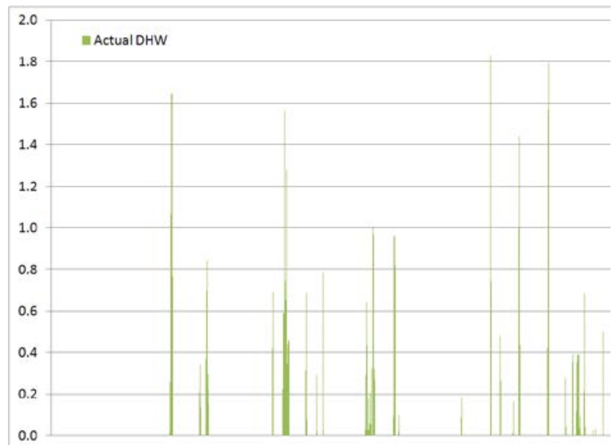


Figure 298. Actual DHW draws

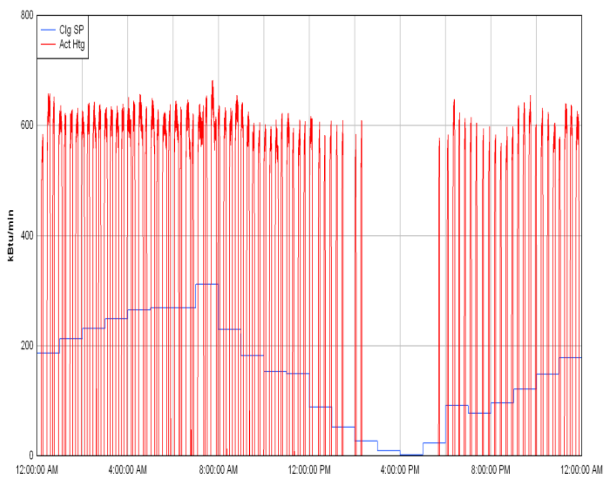


Figure 299. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	217,373
Actual heat loss applied (Btu/day)	304,799
Total daily DHW as modeled (gal/day)	50.2
Actual daily DHW (gal/day)	55.5
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	346,977
Gas consumed LHV (Btu)	341,044
Combo Air Handler power consumed (Btu)	11,473
Water heater power consumed (Btu)	145
Space heating Energy (Btu)	269,511
DHW energy (Btu)	21,671
HHV System Efficiency	81%
LHV System Efficiency	83%

Figure 300. Performance results

Houston, BA2010 Model, Tankless Versus Storage Temperature Stability, January 11

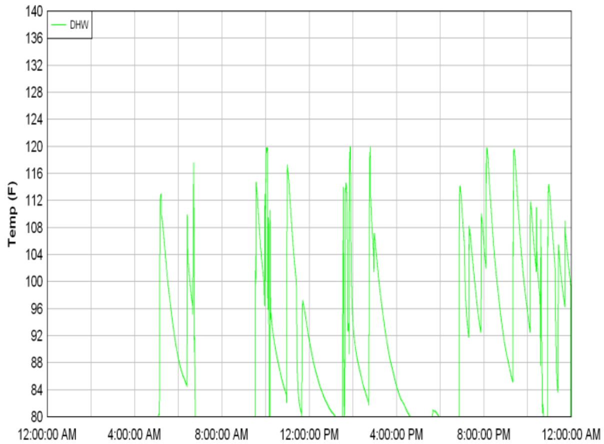


Figure 301. Tankless DHW temperatures

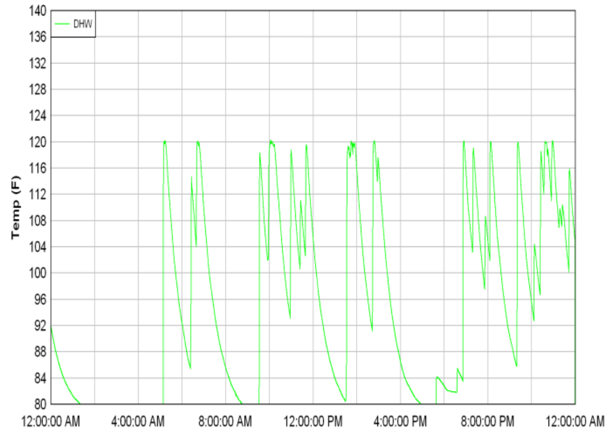


Figure 302. Storage DHW temperatures

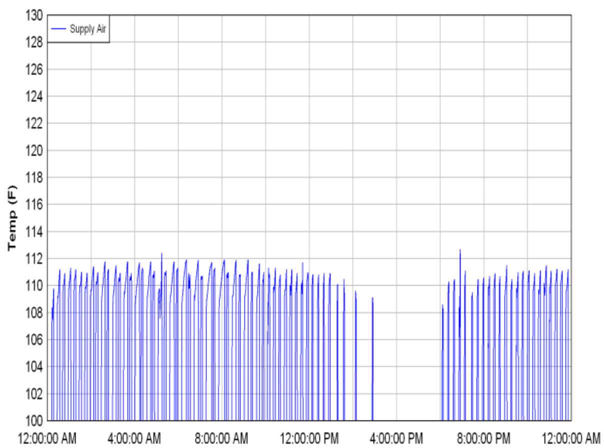


Figure 303. Tankless supply air temperatures

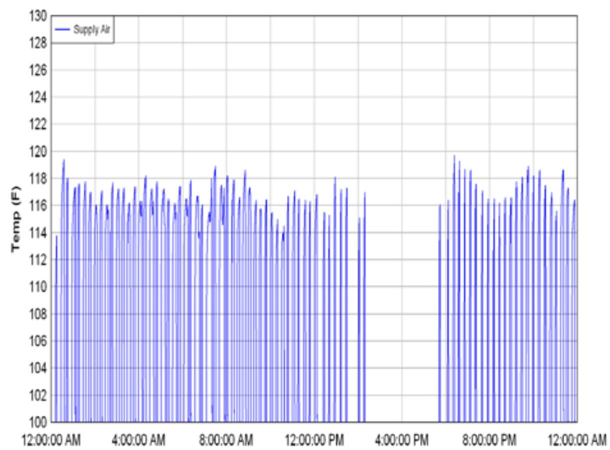


Figure 304. Storage supply air temperatures

Figure 305. Tankless AH water temperatures

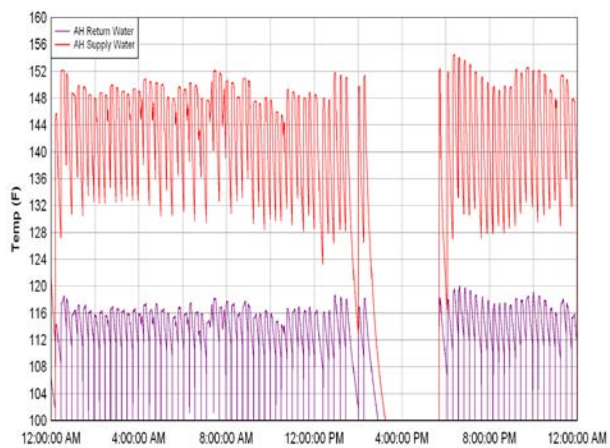


Figure 306. Storage AH water temperatures

Houston, BA2010 Model, Rinnai Test With RC80HP/AHB45, December 9

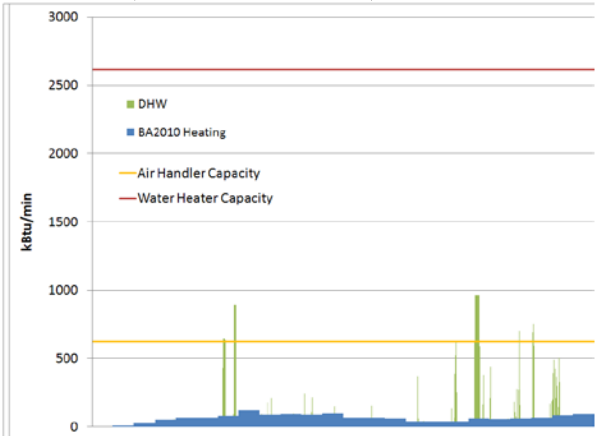


Figure 307. As-modeled space/DHW loads

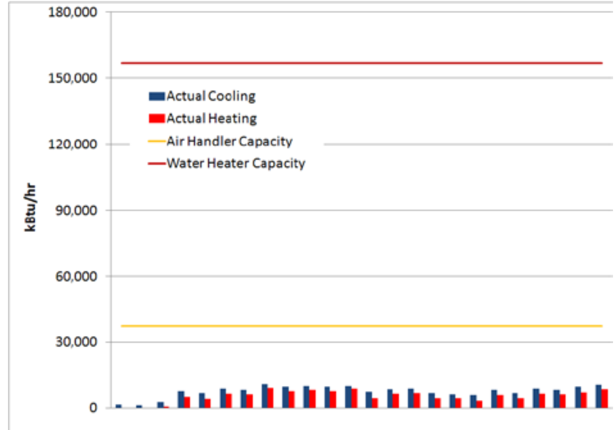


Figure 308. Actual space heating

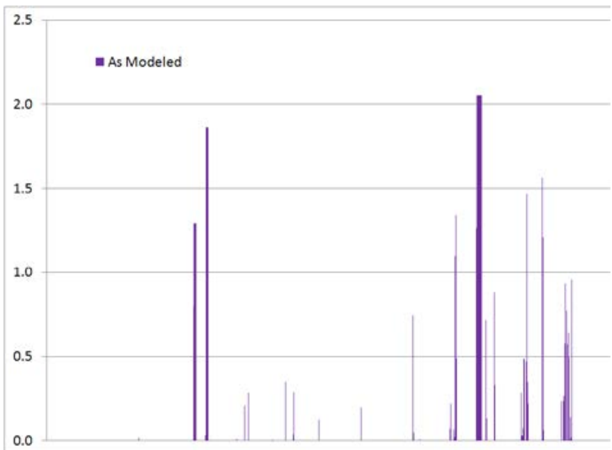


Figure 309. As-modeled DHW draws

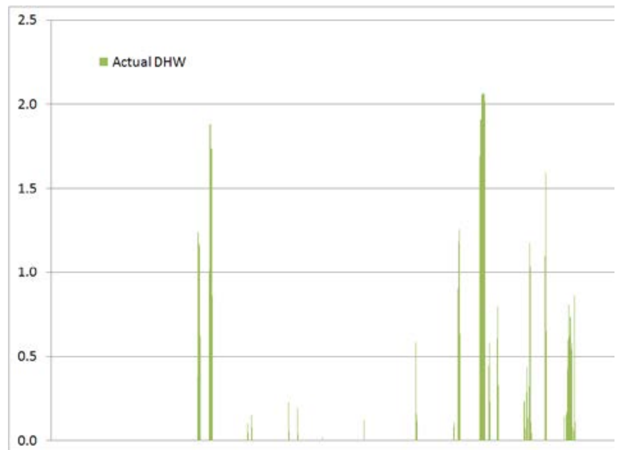


Figure 310. Actual DHW draws

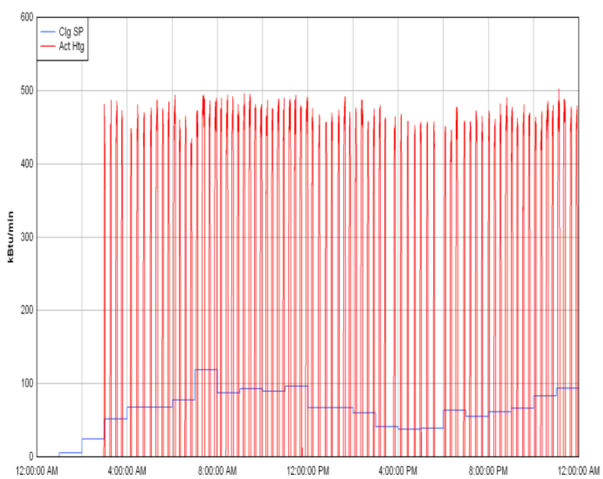


Figure 311. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	91,112
Actual heat loss applied (Btu/day)	186,130
Total daily DHW as modeled (gal/day)	74.0
Actual daily DHW (gal/day)	76.9
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	206,086
Gas consumed LHV (Btu)	202,562
Combo Air Handler power consumed (Btu)	7,957
Water heater power consumed (Btu)	108
Space heating Energy (Btu)	134,961
DHW energy (Btu)	28,321
HHV System Efficiency	76%
LHV System Efficiency	78%

Figure 312. Performance results

Houston, BA2010 Model, Vertex Test With RC80HP/AHB45, December 9

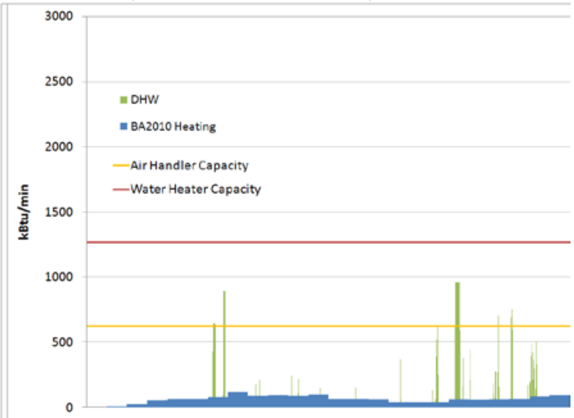


Figure 313. As-modeled space/DHW loads

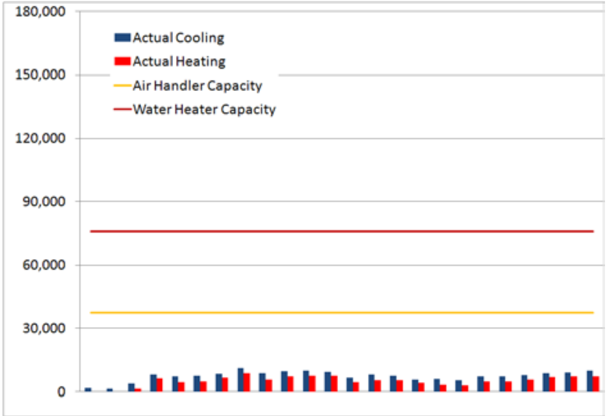


Figure 314. Actual space heating

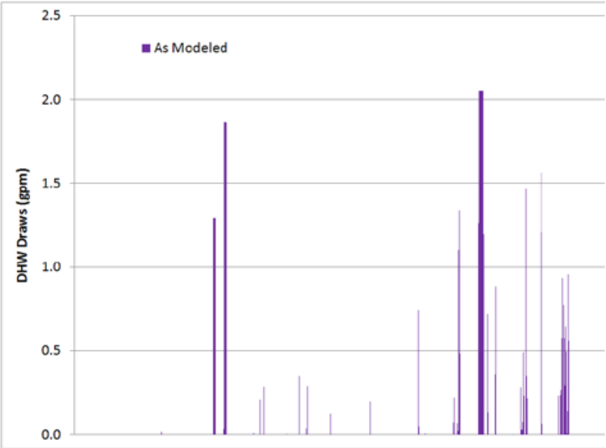


Figure 315. As-modeled DHW draws

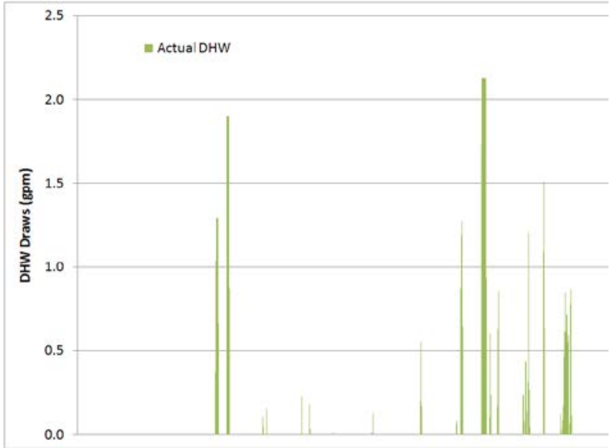


Figure 316. Actual DHW draws

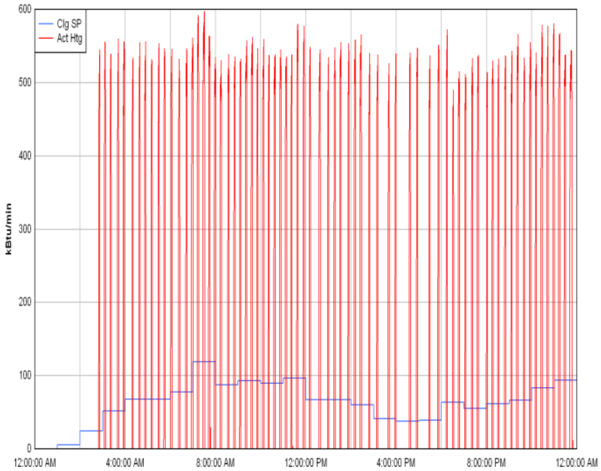


Figure 317. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	91,112
Actual heat loss applied (Btu/day)	176,746
Total daily DHW as modeled (gal/day)	74.0
Actual daily DHW (gal/day)	79.7
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	211,184
Gas consumed LHV (Btu)	207,573
Combo Air Handler power consumed (Btu)	6,362
Water heater power consumed (Btu)	97
Space heating Energy (Btu)	122,525
DHW energy (Btu)	33,680
HHV System Efficiency	72%
LHV System Efficiency	73%

Figure 318. Performance results

Houston, BA2010 Model, Tankless Versus Storage Temperature Stability, December 9

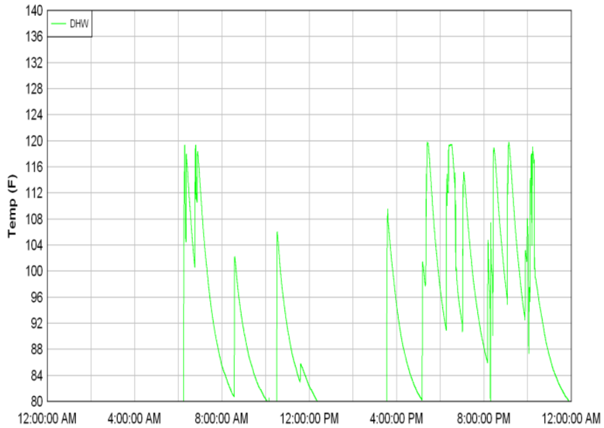


Figure 319. Tankless DHW temperatures

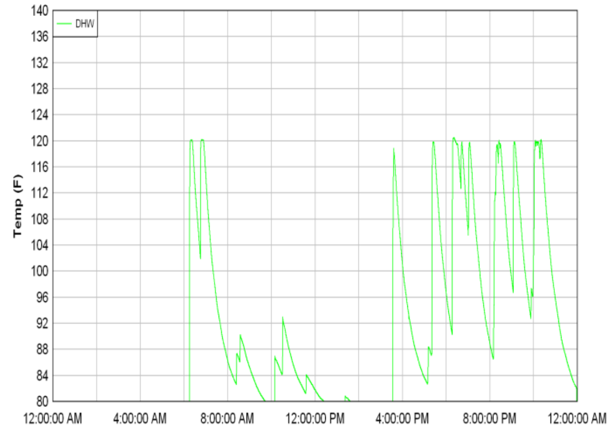


Figure 320. Storage DHW temperatures

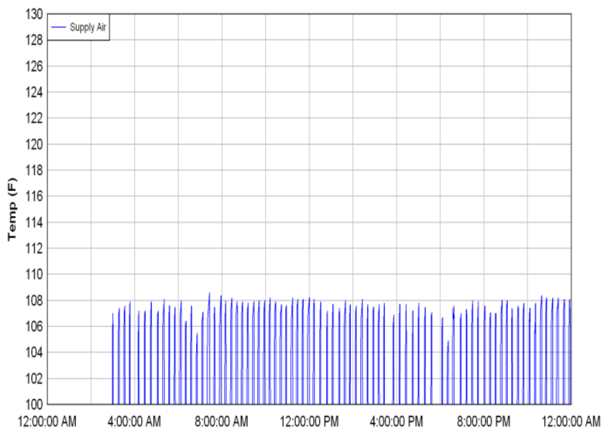


Figure 321. Tankless supply air temperatures

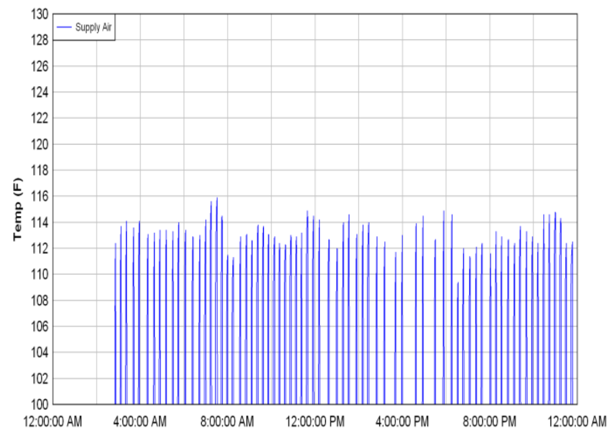


Figure 322. Storage supply air temperatures

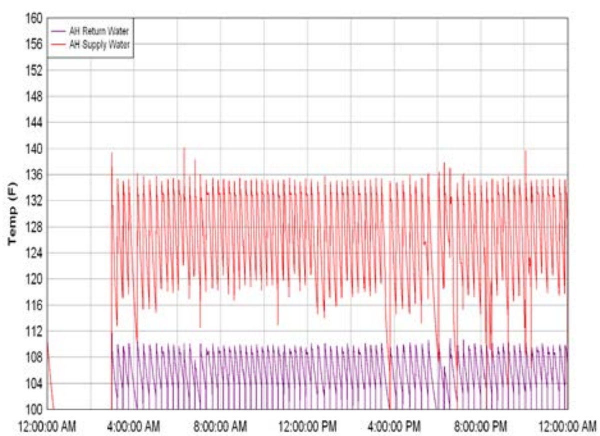


Figure 323. Tankless AH water temperatures

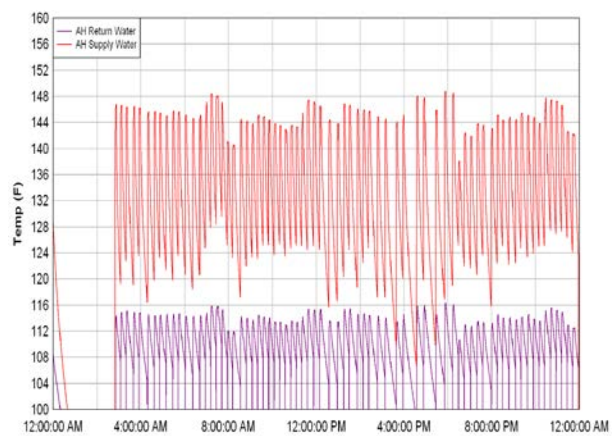


Figure 324. Storage AH water temperatures

Houston, Vintage Model, Rinnai Test With RC80HP/AHB90, March 7

Figure 325. As-modeled space/DHW loads

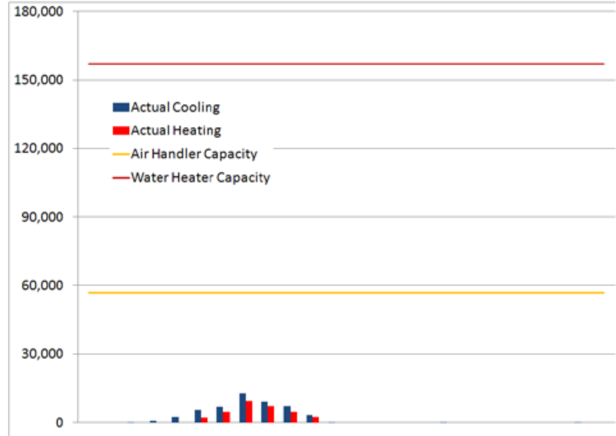


Figure 326. Actual space heating

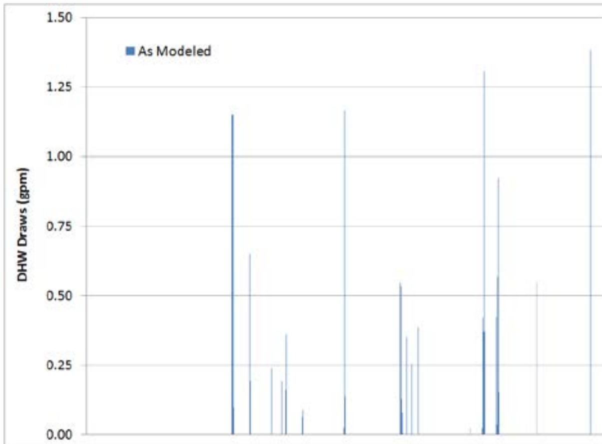


Figure 327. As-modeled DHW draws

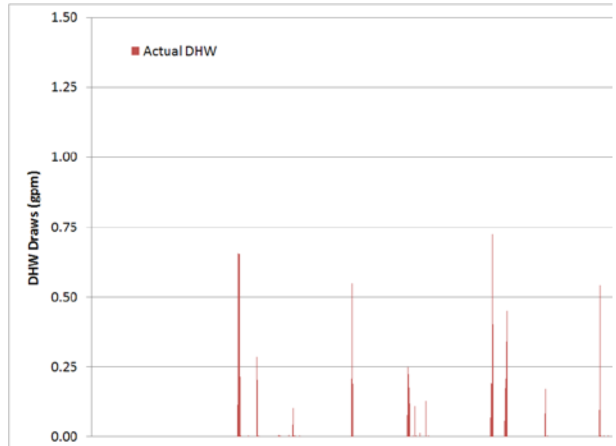


Figure 328. Actual DHW draws

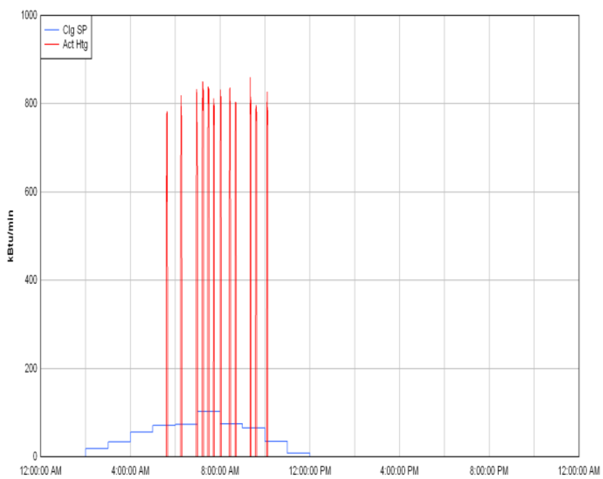


Figure 329. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	32,283
Actual heat loss applied (Btu/day)	47,355
Total daily DHW as modeled (gal/day)	18.9
Actual daily DHW (gal/day)	12.3
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	44,139
Gas consumed LHV (Btu)	43,385
Combo Air Handler power consumed (Btu)	1,821
Water heater power consumed (Btu)	35
Space heating Energy (Btu)	29,717
DHW energy (Btu)	2,223
HHV System Efficiency	69%
LHV System Efficiency	71%

Figure 330. Performance results

Houston, Vintage Model, Vertex Test With RC80HP/AHB90, March 7

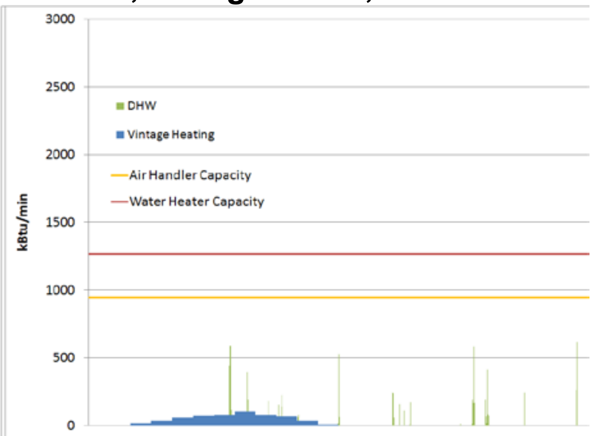


Figure 331. As-modeled space/DHW loads

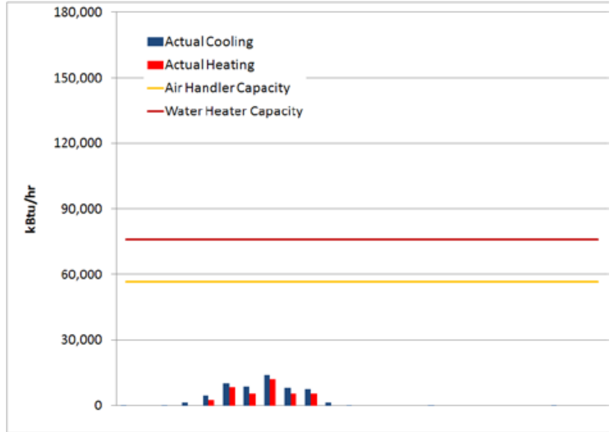


Figure 332. Actual space heating

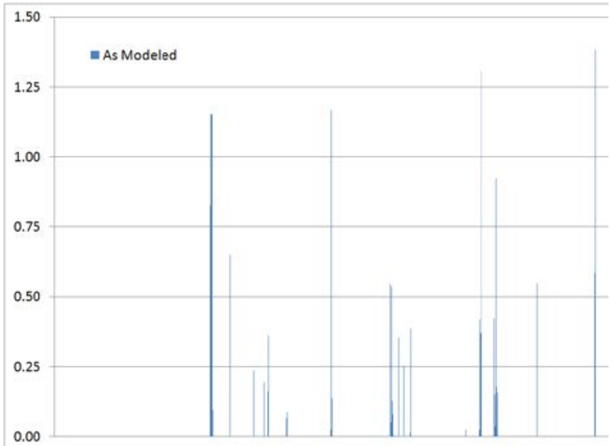


Figure 333. As-modeled DHW draws

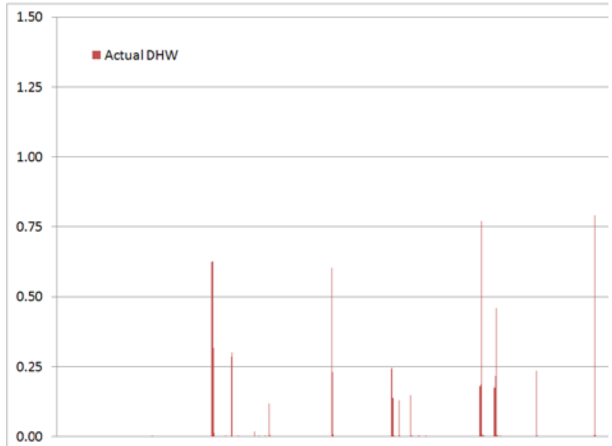


Figure 334. Actual DHW draws

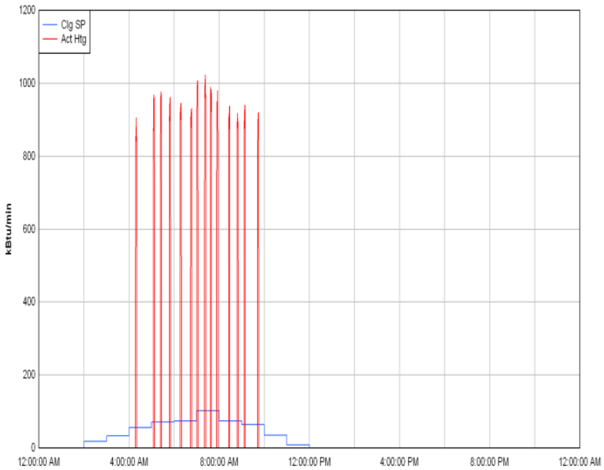


Figure 335. Thermostat cycling

Total daily heat loss as modeled (Btu/day)	32,283
Actual heat loss applied (Btu/day)	55,860
Total daily DHW as modeled (gal/day)	18.9
Actual daily DHW (gal/day)	11.7
Gas heat value HHV (Btu/cf)	1,015
Gas heat value LHV (Btu/cf)	997
Gas consumed HHV (Btu)	67,579
Gas consumed LHV (Btu)	66,424
Combo Air Handler power consumed (Btu)	2,027
Water heater power consumed (Btu)	34
Space heating Energy (Btu)	39,228
DHW energy (Btu)	1,375
HHV System Efficiency	58%
LHV System Efficiency	59%

Figure 336. Performance results

Houston, Vintage Model, Tankless Versus Storage Temperature Stability, March 7

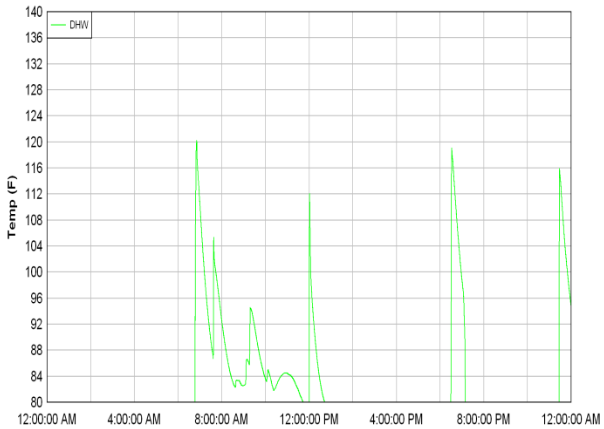


Figure 337. Tankless DHW temperatures

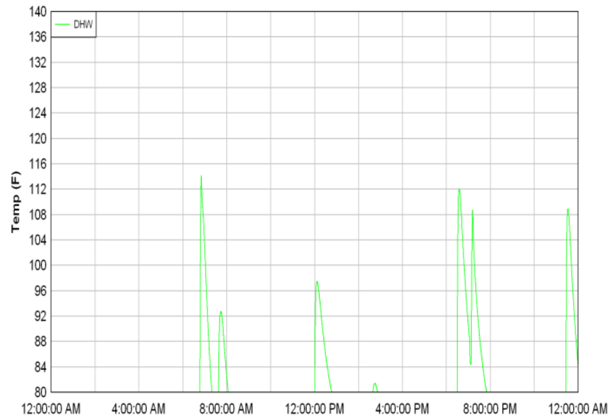


Figure 338. Storage DHW temperatures

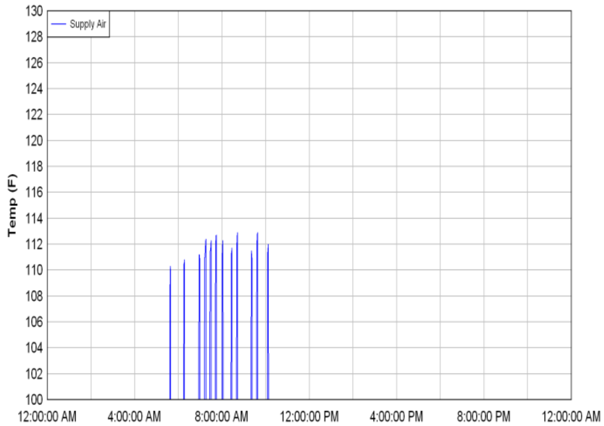


Figure 339. Tankless supply air temperatures

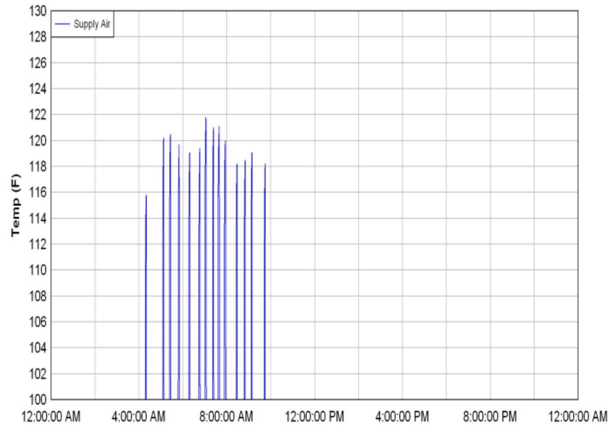


Figure 340. Storage supply air temperatures

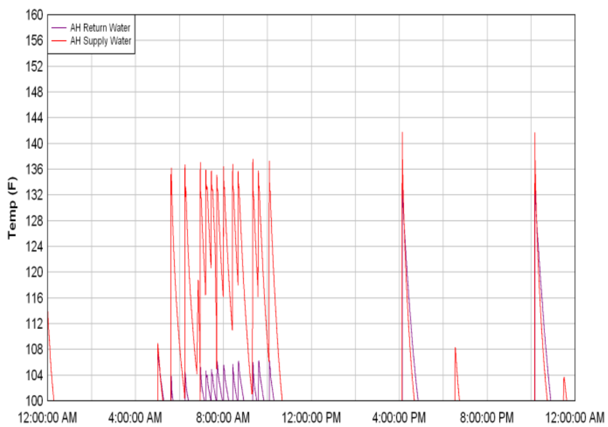


Figure 341. Tankless AH water temperatures

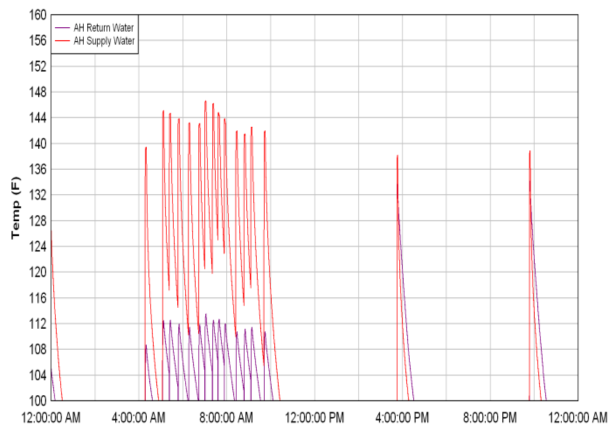


Figure 342. Storage AH water temperatures

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