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# Definitions

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<tr>
<td>AFUE</td>
<td>Annual fuel utilization efficiency</td>
</tr>
<tr>
<td>AH</td>
<td>Air handler</td>
</tr>
<tr>
<td>BA</td>
<td>Building America</td>
</tr>
<tr>
<td>BEopt</td>
<td>Building Energy Optimization</td>
</tr>
<tr>
<td>Btu</td>
<td>British thermal unit</td>
</tr>
<tr>
<td>CEE</td>
<td>Center for Energy and Environment</td>
</tr>
<tr>
<td>cf</td>
<td>Cubic foot</td>
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<tr>
<td>cfm</td>
<td>Cubic feet per minute</td>
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<tr>
<td>DHW</td>
<td>Domestic hot water</td>
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<tr>
<td>EE</td>
<td>Energy efficiency</td>
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<tr>
<td>EF</td>
<td>Energy factor</td>
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<tr>
<td>EIA</td>
<td>Energy Information Administration</td>
</tr>
<tr>
<td>gpm</td>
<td>Gallons per minute</td>
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<tr>
<td>GTI</td>
<td>Gas Technology Institute</td>
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<tr>
<td>h</td>
<td>Hour</td>
</tr>
<tr>
<td>HHV</td>
<td>Higher heating value</td>
</tr>
<tr>
<td>kBtu</td>
<td>Thousand Btu</td>
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<tr>
<td>LBNL</td>
<td>Lawrence Berkley National Laboratory</td>
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<tr>
<td>LHV</td>
<td>Lower heating value</td>
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<tr>
<td>MMBtu</td>
<td>Million Btu</td>
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<tr>
<td>RTD</td>
<td>Resistance temperature detector</td>
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<tr>
<td>s</td>
<td>Second</td>
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<tr>
<td>WH</td>
<td>Water heater</td>
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<td>yr</td>
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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-ft² 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-ft², single-family house (see Figure 2) with three bedrooms and two bathrooms. The Energy Plus models were designed to BA2010 standards¹ or better, and standards based on Lawrence Berkeley National Laboratory (LBNL) work² 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

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As an order of magnitude, 2.9 million two-story single-family homes that were 2,250 ft² 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>
<thead>
<tr>
<th>Gas Price $/MMBtu</th>
<th>Vintage</th>
<th>BA2010</th>
<th>Max EE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago</td>
<td>9.10</td>
<td>25.7</td>
<td>13.7</td>
</tr>
<tr>
<td>Atlanta</td>
<td>15.09</td>
<td>12.8</td>
<td>9.3</td>
</tr>
<tr>
<td>Houston</td>
<td>10.44</td>
<td>6.8</td>
<td>5.6</td>
</tr>
</tbody>
</table>

---


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

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

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

<table>
<thead>
<tr>
<th></th>
<th>Vintage (%)</th>
<th>BA2010 (%)</th>
<th>Maximum EE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago</td>
<td>9</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Atlanta</td>
<td>9</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Houston</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Phoenix</td>
<td>5</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

---

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.
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

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

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

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

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>
<thead>
<tr>
<th>Month/Day</th>
<th>Category</th>
<th>Mean Temperature (°F)</th>
<th>Supply Water (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>February 11</td>
<td>BA2010</td>
<td>30.0</td>
<td>64.7</td>
</tr>
<tr>
<td>January 11</td>
<td>BA2010</td>
<td>41.0</td>
<td>64.6</td>
</tr>
<tr>
<td>December 9</td>
<td>BA2010</td>
<td>50.0</td>
<td>67.5</td>
</tr>
<tr>
<td>March 7</td>
<td>Vintage</td>
<td>60.0</td>
<td>66.7</td>
</tr>
</tbody>
</table>

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

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.

Efficiency = \( \frac{Q_W + Q_A}{Q_{in}} \)

where

\[ Q_W = \text{Energy produced as DHW (Btu/h)} \]
\[ Q_W = 499.8 \times F_3 \times (T_{DHW} - T_{CW}) \]

where

\[ F_3 = \text{DHW flow (gal/min)} \]
\[ T_{DHW} = \text{Water heater DHW outlet temperature (°F)} \]
\[ T_{CW} = \text{City water supply temperature (°F)} \]

\[ Q_A = \text{Energy produced as warm air (Btu/h)} \]
\[ Q_A = 14.46 \times F_2 \times \rho_a \times (T_{in} - T_{out}) \]

where

\[ F_2 = \text{AHU air flow (cfm)} \]
\[ \rho_a = \text{Density of air} = \frac{1.325 \times P_2}{T_3 + 459.7} \]
\[ T_{in} = \text{Coil inlet temperature (°F)} \]
\[ T_{out} = \text{Coil outlet temperature (°F)} \]
\[ Q_{in} = \text{Fuel input (Btu/h)} \]
\[ Q_{in} = F_6 \times \rho_g \times \text{HHV}_g \]

where

\[ F_6 = \text{Gas flow (cf/h)} \]
\[ \rho_g = \text{Density of gas} \]
\[ \text{HHV}_g = \text{Higher heating value of natural gas} \].
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

<table>
<thead>
<tr>
<th>Water Heater</th>
<th>AH</th>
<th>WH Set Point (°F)</th>
<th>Hot Water Flow to AH (gpm)</th>
<th>DHW Tempering (°F)</th>
<th>AH Air Flow (cfm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tankless</td>
<td>AHB90</td>
<td>135</td>
<td>~3.5</td>
<td>120</td>
<td>~1,250</td>
</tr>
<tr>
<td>Storage</td>
<td>AHB90</td>
<td>130</td>
<td>~3.5</td>
<td>120</td>
<td>~1,250</td>
</tr>
<tr>
<td>Tankless</td>
<td>AHB45</td>
<td>140</td>
<td>~2.1</td>
<td>120</td>
<td>~775</td>
</tr>
<tr>
<td>Storage</td>
<td>AHB45</td>
<td>135</td>
<td>~2.1</td>
<td>120</td>
<td>~775</td>
</tr>
</tbody>
</table>

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

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

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

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

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

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

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

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

See Appendix C for details (Figure 46 through Figure 63).
### Table 12. Chicago BA2010 Model Test Performance Results, December 3

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

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

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

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

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

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

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

See Appendix C for details (Figure 100 through Figure 121).
### Table 15. Chicago BA2010 Model Test Performance Results, February 22

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

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

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

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

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

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

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

See Appendix C for details (Figure 158 through Figure 175).
Table 18. Atlanta BA2010 Model Test Performance Results, January 26

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

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

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

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

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

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

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

See Appendix C for details (Figure 216 through Figure 234).
Table 21. Atlanta Vintage Model Test Performance Results, April 6

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

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

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

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

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

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

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

See Appendix C for details (Figure 271 through Figure 288).
Table 24. Houston BA2010 Model Test Performance Results, January 11

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

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

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

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

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

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

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

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

<table>
<thead>
<tr>
<th>Building America 2010 Residential Prototype Building Site and Geometry</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Type = Single Family Detached</td>
<td>1</td>
</tr>
<tr>
<td>Finished Floor Area of unit, Above Grade</td>
<td>ft²</td>
</tr>
<tr>
<td>Num Floors of unit (Above Grade)</td>
<td>#</td>
</tr>
<tr>
<td>Building Aspect Ratio (Width/Depth)</td>
<td>ratio</td>
</tr>
<tr>
<td>Foundation Type (slab, basement, crawlspace, exposed floor)</td>
<td>Basement</td>
</tr>
<tr>
<td>Basement Floor Area</td>
<td>sq ft</td>
</tr>
<tr>
<td>Basement Finished?</td>
<td>YES/NO</td>
</tr>
<tr>
<td>Conditioned Floor Area</td>
<td>ft²</td>
</tr>
<tr>
<td>Total Floor Area (conditioned+unconditioned)</td>
<td>ft²</td>
</tr>
<tr>
<td>Attic Vented or Unvented</td>
<td>Vented/Unvented</td>
</tr>
<tr>
<td>Number of Bedrooms</td>
<td>#</td>
</tr>
<tr>
<td>Number of Bathrooms</td>
<td>#</td>
</tr>
<tr>
<td>Garage Depth</td>
<td>ft</td>
</tr>
<tr>
<td>Garage Protrusion</td>
<td>ft</td>
</tr>
<tr>
<td>Total Garage Floor Area</td>
<td>sq ft</td>
</tr>
<tr>
<td>Floor-to-floor Height</td>
<td>ft</td>
</tr>
</tbody>
</table>

- 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

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Appendix B: Load Duration Graphs

Figure 7. Chicago load durations
The highest space heating loads for the Vintage model exceed the maximum capacity of the largest Rinnai air handler (AH850) operated at 120°F for about 0.5% total hours of the year.

The highest space heating loads for the BA2010 model fall below the maximum capacity of the Rinnai AH45 air handler operated at 140°F.

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

Figure 15. Performance results

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 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

Figure 21. Performance results

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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

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 38. Thermostat cycling

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

Figure 51. Performance results

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

Figure 57. Performance results

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%
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
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
Figure 69. Performance results

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%
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

Figure 75. Performance results

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%
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
Figure 87. Performance results

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%
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

Figure 93. Performance results

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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

Figure 105. Performance results

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%
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

Figure 111. Performance results

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%
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
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

Figure 127. Performance results

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%
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

Figure 133. Performance results

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

Figure 145. Performance results

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%
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

Figure 151. Performance results

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

Figure 163. Performance results

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 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

Figure 169. Performance results

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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
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

Figure 181. Performance results

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 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

Figure 187. Performance results

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%
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

Figure 199. Performance results

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%
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%
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

**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
Figure 222. Performance results

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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%
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

Figure 240. Performance results

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/ft³) 1,015
Gas heat value LHV (Btu/ft³) 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%
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

Figure 246. Performance results

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%
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

Figure 258. Performance results

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%
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

Figure 264. Performance results

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 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

Figure 276. Performance results

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%
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

Figure 282. Performance results

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%
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

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 293. Thermostat cycling

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

Figure 300. Performance results

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%
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

Figure 312. Performance results

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 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

Figure 318. Performance results

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%
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
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

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**

**Figure 336. Performance results**

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%
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