Condensing Boilers--Are They Cost Effective?

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ABSTRACT

High-efficiency condensing boilers have been available in the residential market for many years, but consumer acceptance and market penetration has remained low. Furthermore, there is a lack of confidence by many contractors and utilities about the energy savings attributable to this technology over a non-condensing version-particularly in the retrofit market.

To address these concerns and uncertainty, our research team monitored thirteen condensing boilers in Minnesota homes to characterize installed performance. Six of these were installed up to seven years prior to the project and seven were installed using a Quality Installation protocol developed during the project.

We have data on supply and return water temperature, flow rates, incidence of condensing, and energy usage for all thirteen systems. These systems represent a variety of single family residential installations with various brands, emitter types, zone set-ups, and outdoor reset control installation and set points. These homes also represent a range of house types and heating loads in Minnesota.

In this paper, we will discuss the usage and performance findings from this monitoring and the impact of installation and recommissioning procedures on boiler performance. We will show that condensing boilers in Minnesota homes are generally achieving high performance without requiring a specialized site-specific installation. We will discuss the results of our market analysis, including HVAC contractor and homeowner surveys and cost comparisons on over 70 installation bids. We will also include our recommendations for easy to implement Quality Installation activities to improve system performance.

Introduction

This paper reports on Center for Energy and Environment's (CEE) recently completed *Quality Installation and Retrocommissioning of High-Efficiency Condensing Boilers* that was supported by a grant from the Minnesota Department of Commerce, Division of Energy Resources through the Conservation Applied Research and Development (CARD) program (Olson and Schoenbauer Upcoming). Findings presented are from thirteen sites monitored during the 2015-2016 and 2016-2017 heating seasons.

Background

There have been a few research projects aimed at understanding condensing boiler operation and optimization. These studies have examined several potential issues and industry concerns and have provided a technical basis for condensing boiler optimization measures. Much of this work focuses on laboratory testing, house characteristics (including load and distribution designs), and system types that do not directly apply to Minnesota's residential market. This work was used as a starting point to identify potential solutions, test them under Minnesota conditions, and develop best practices.

Cost Effectiveness

One of the common concerns of HVAC contractors and potential customers is whether the large cost difference between condensing and non-condensing boilers is recouped in energy savings. This question requires an analysis of both the efficiency of these systems as well as a look at the incremental cost difference between condensing and non-condensing boilers.

Installation costs for condensing boilers tend to vary significantly by home, contractor, and equipment manufacturers. This cost variability is far greater with boilers than it is with forced air furnaces. Since cost effectiveness is a barrier to market transformation, we needed to look at both the efficiency of the equipment and the variables that go into the installation costs.

Condensing Boiler Operation

Understanding the market concerns for actual efficiency versus rated efficiency, and the potential opportunities for optimization, requires a discussion of the differences between condensing and non-condensing boilers.

Condensing boilers are more efficient because they transfer more heat out of the combustion gases and into the circulating water than non-condensing boilers. They do this by utilizing a secondary heat exchanger that harnesses and effectively handles the energy from the condensation process. Due to this design, it is optimal to have the combustion gases condense as much as possible. In order to do this, the return water coming back from the room convectors (radiators) must be low enough to allow significant heat transfer out of the gases below the condensation point and into the circulating water.

In order to ensure low return water temperatures (<130˚), there needs to be significant heat transfer from the radiators into the home and/or low enough supply water temperatures. This is not an issue in condensing forced air furnaces because the returning air temperature is always below 130˚. Much of the skepticism around the real energy efficiency of condensing boilers has to do with these details and whether or not the systems are set up in a way to allow condensation to occur on a regular basis.

In non-condensing boilers, it is very important to prevent condensation from occurring inside a heat exchanger that is not designed or equipped to handle condensate due to corrosion issues. Therefore, most supply water temperatures are set very high (180˚F or more) in order to keep return water temperatures from bringing the combustion gases below the condensation point. This is in direct contrast to the goal for condensing boilers. Because of this, the theory is that if an installation contractor sets the supply water temperatures or flow for a condensing boiler the same as a non-condensing boiler (in other words, too high), the savings will be small or non-existent.

Many HVAC contractors have concerns that if they lower the supply water temperature of a condensing boiler system below the traditional 180˚F in a retrofit from a non-condensing system, the heating load won't be met by the existing radiators. To have confidence in meeting the heating load, it is much easier as an installation contractor to keep the supply temperature high and sacrifice efficiency, than it is to do calculations on emitter capacity and heat load.

Methodology

First, we did market research to investigate barriers to wide market adoption. We did this through in-depth interviews with HVAC companies as well as homeowners. These interviews focused on installation costs, and, individual perceptions regarding system performance, reliability, and operations and maintenance. In addition to the interviews, we also analyzed condensing boiler rebate data from utilities as well as installation costs across multiple contractors and programs.

Next, we conducted field research in two phases. The first phase included homes that had replaced their non-condensing boiler with a condensing boiler within the last five years (Phase I). The second focused on customers interested in replacing their current non-condensing boiler with a condensing boiler (Phase II). Although the data collection and analysis for these two phases were very similar, we gleaned unique market insights and installation procedure details by conducting the two phases. It also allowed us to perform detailed monitoring of systems before and after optimization.

Field Research Site Selection

The project team developed site selection criteria for the field characterization. The goal of the criteria was to select sites representative of Minnesota homes. Selection criteria were developed around seven specific areas that have been shown to have the largest impact on boiler performance and savings from increased boiler efficiency. For each category, an estimation of the demographics in Minnesota was determined and the criteria in Table 1 (below) were set to ensure that typical conditions were represented.

Table 1. Boiler site selection criteria

Desired Criteria	Target Selection	Actual Selection
Heating loads	Select sites from a mix of the heating load range expected in Minnesota.	1st Quartile: 5 homes (38%) 2nd Quartile: 3 homes (23%) 3rd Quartile: 4 homes (31%) 4th Quartile: 1 home (8%)
DHW integration	Minimum of 4 homes with integrated DHW	Phase 1: With 3 of 6 (50%) Phase 2: With 1 of 7 (14%)
Emitter types	A mix of cast iron radiators, in-floor heating, low-mass radiators, and baseboards	4 of 13 cast iron radiator only 9 of 13 mix of emitters
Installers	No more than 3 sites per installer, max installers for phase I	Phase I: 5 installers Phase II: 4 installers Max 3 sites for a single installer
Major manufacturers	At least 4 of the top 5 manufactures	All tier 1 manufacturers 2 of 3 tier 2 All of tier 3
Controls	Sites without outdoor resets (if possible)	1 of 13 sites (phase I)
Sizing	Sites with a range of emitter to design load sizing ratios	Ratios selected were between 1.1 and 3.6 (none with capacities below 1)

Field Characterization

During the first heating season, we monitored the as-found performance of existing condensing boilers in six sites (Phase I). This data helped determine the baseline performance of condensing boilers installed without specific requirements in addition to the manufacturer's requirement and/or general installation practice.

Once the as-found condition was fully characterized, a trained contractor and/or project staff performed retro-commissioning on each boiler using a checklist based on existing research (Arena 2013) (Landry et al. 2016), the as-found data analysis, and engineering calculations (ASHRAE 2013, 2015) , in order to optimize performance. The optimization focused on reducing the water temperature returning from the heating loop by optimizing the outdoor reset curve and lowering supply temperature set points, modifying the water flow rate (as applicable), and adjusting the supply water temperatures in the DHW loop, if present. We conducted the optimization at these sites with an “adjust and measure” approach and, as more optimization visits were conducted, the guidelines were finalized. The monitoring continued until we were able to fully characterize the impacts of the retro-commissioning visit.

During the second heating season, we worked with seven different households and four contractors to replace non-condensing boilers with condensing boilers (Phase II) using quality installation (QI) guidelines developed in Phase I. These QI guidelines again focused on minimizing return water temperature through distribution set points and outdoor reset controls. Once installed following these guidelines, we monitored the replacement condensing boilers for at least one heating season. This phase allowed us to work with installation contractors more closely to implement a quality installation and set-up procedure as a way to test the protocol for ease of use. It also gave us the opportunity to look at multiple bids on the same home to see if there were trends based on contractor, equipment choice, or home details.

Once both phases were complete, we compared data from the sites in Phase II to the as-found and optimized conditions in Phase I sites.

Data Collection

Each home was fully instrumented with a residential HVAC data acquisition system that was developed by CEE and successfully used on other field test projects. The system utilizes a Campbell Scientific acquisition system customized to collect energy use, temperature, water flow, runtime, and other system data. A high-resolution data collection interval was used (one second) to capture short time-scale events. This logging interval strategy allows for efficient use of short-term storage on the data logger with daily transmission by cellular modem or internet connection each night. Table 2 details the data and instrumentation used at each site.

Table 2. Instrumentation deployed in field monitoring sites

Instrument	Measurement Type	Measurement Location
Immersion RTDs	Immersion water temperature	Heating supply water Heating return water DHW supply water (if applicable) DHW return water (if applicable)
Nutating disk flow meter	Water flow rate	Primary loop flow DHW loop flow (if applicable)
Diaphragm gas meter	Gas flow rate	Boiler gas inlet
Surface mount thermocouples	Hydronic pipe temperature (as an approximation of water temperature)	Individual zone supplies Individual zone returns Individual emitter supplies Individual emitter returns
Thermocouples	Air temperatures	Ambient near boiler

		Ambient in conditioned space Ambient outdoors (if possible)
Current Transformers	Runtime and Current measurements	Circulation pumps Boiler
Status switch	On/off status	Zone valves
NOAA weather data	Data collected from nearest weather station	Outdoor air temperature

Retro-commissioning of Condensing Boilers

In all sites in Phase I, a retro commissioning process was used to identify opportunities in system installation or operation for improved performance. At all sites, except site exist_06, there were opportunities for retro commissioning. The commissioning process sought to identify operational settings that led to higher delivered capacities than necessary. Increased capacities result in higher water temperatures and shorter run times, less condensing, lower efficiency, and increased energy usage.

The first opportunity was to adjust the outdoor reset curve, which sets the boiler supply water temperature based on the outdoor air temperature. Matching the emitter capacity to the house heating load over the full range of outdoor air conditions ensures minimum water temperatures while also ensuring the house heating needs are met.

The second opportunity was for boilers designed and installed as combined systems to meet heating and DHW loads. In these systems, the DHW system often operated at efficiencies lower than optimal. By assessing the delivery heating capacity of the DHW heat exchanger and knowing the storage volume of the system, a boiler DHW system can be sized as a standard water heater. Following this procedure, opportunities were found to reduce the DHW capacity, thus lowering water temperatures and flow rates leading to improved efficiency.

Analysis

Data from both phases was analyzed to determine annual energy consumption and seasonal operating efficiency. Annual performance was compared between operation modes (as-found and optimized), between phases, as well as to an estimated baseline (82% AFUE) boiler. We also compared annual energy performance, runtimes, and installed efficiencies.

For the annual energy consumption analysis, we used an input/output method to compare the performance of the systems and modes of operation. CEE used this method in previous projects to compare annual energy use and the installed efficiencies of each system (Bohac et al. 2010; Schoenbauer 2013).

The data collection included additional parameters, such as boiler water temperatures, outdoor air temperatures, and the temperature in conditioned space. These parameters were anlyzed and used to refine the retrocommisioning tune up and quality installation guidelines, and to deterime the impacts of various factors (runtime, water temperature, outdoor air temperature, firing rate, etc) on cycle efficiency.

Results

Market Assessment

Heating professional interview results. We conducted in-depth, in-person interviews with five HVAC contractors and one prominent Minnesota equipment distributor about distribution of forced air versus hydronic replacements, market trends, utility programs and current design, installation, and set-up procedures by contractors.

The HVAC companies we interviewed primarily serve the Twin Cities metro area with roughly 2% to 30% of the companies' retrofit business being replacement hydronic systems ranging from 15-50 installations per year. Condensing boiler replacements make up about 15% to 50% of all hydronic installations by HVAC companies interviewed. All contractors reported choosing replacement equipment brands based on reliability, affordability, and installer familiarity.

All contractors stated the practice of using some form of whole house sizing calculation method (only a few used an official Manual J). Most contractors sited use of outdoor reset control as an external control device installed on condensing boilers. In addition, most contractors stated some sort of adjustment to the reset curve at installation either according to manufacturers' recommendations or their own experience. None of the contractors sited using emitter capacity calculations on a regular basis, unless there was a reason to be concerned about under capacitance. No particular attempt was made by installers to ensure condensing occurs most often.

Some contractors stated that they mostly encourage condensing boiler replacements on non-condensing equipment, but others have concerns about payback and performance or are indifferent, so the lower priced non-condensing option often wins the customer over. When asked about customer satisfaction, most contractors stated a high level of customer satisfaction with condensing boiler replacements—with only a few callback issues. All contractors stated some level of concern and/or questions in terms of efficiency and payback. One contractor stated that a lower price for condensing boiler installations would really help in their ability to sell this technology.

Homeowner interview results. In addition to the contractor surveys, all 13 homeowner participants completed an in-person or phone interview about their experience with the installed condensing boilers. These systems were all replaced either within seven years of our project start or as part of our project.

Most systems were replaced at the time of failure or as part of a larger remodel/retrofit. Some homeowners were motivated by energy savings potential while others were sold by contractors on advantages of condensing, including sealed combustion safety. Most participants had expectations of energy/cost savings and improved comfort.

Two participants had minor issues with performance, and these have been remedied since installation, including an issue with a side arm tank sensor and a gas pressure issue. All other participants sited no issues with system performance.

Around half of the participants sited annual or semiannual maintenance practices, while some participants sited no maintenance activities at all.

All participants that had experience with the older system said they had a sense that they are saving energy and money with the condensing boiler. Four participants stated they've analyzed their bills and have savings between 10% and 40%.

Comfort was either improved or the same as the previous system in all sites where participants had experience with both systems. Eleven participants rated their overall satisfaction as 5 on a scale from 1-5 (5 being the most satisfied). And all participants stated they would recommend a condensing boiler to others based on the energy savings, home re-sale value, reliability, and safety.

Installation cost analysis. We looked at 73 bids/invoices (45 non-condensing and 38 condensing) for 32 homes, including internal CEE loan data and research project bids. On average, the difference in cost between condensing and non-condensing boiler installation is around $2,300. This is taking all 73 bids/invoices and comparing the average non-condensing price--$6,658 and the average condensing price--$8,944. We also looked at the price difference when both were bid by the same contractor on the same job (10 homes) and this average price difference was around $2,500. However, the range in price difference when looking at cost comparison in this way was between $550 and $5,000.

We found that the ranges were much wider spread than that of their forced air counterparts. The installation cost range for non-condensing boilers was $3,700-$13,000, and for condensing boilers it was $5,700-$17,000. In examining these cost ranges, we excluded additional costs for asbestos abatement, additional radiator installs and indirect water heater tanks.

Additionally, we investigated just the difference in equipment costs between non-condensing and condensing boilers. We did this by searching online for supplier product cost data on equipment for six of the homes where non-condensing and condensing boilers were both bid. This showed that the average equipment cost difference was around $1,000.

When looking at installations that included indirect water heaters, the average price for including DHW was around $2,800. However, this price may be less in the future. The side-arm tanks in this analysis were all double-walled tanks, which have been required by code in Minnesota until recently. Single-wall-tanks are now being allowed in most Minnesota cities. Interviewed contractors stated that double-walled tanks are about $1,000 more than single walled tanks.

This analysis leads us to believe that pricing for boiler replacements is highly irregular from contractor to contractor, system to system and household to household, whether or not the bid is for condensing or non-condensing, but especially for condensing replacements. It also indicated that the bulk of the average price difference is in soft costs, including labor.

Field Study Performance

As-found performance. The system performance was calculated from the measured data continuously through the monitoring period. The first analysis of the project was to determine the as-found performance of the Phase I boilers. Figure 1 shows the daily efficiencies from each of the phase I boilers in the as-found condition. Each of the six sites had daily data collected through a full calendar year. All boilers provided heat for space heating in each home and sites exist_01, exist_03, and exist_05 also provided heat for domestic hot water (DHW) through the use of indirect water heaters. Operation for DHW had significantly lower efficiencies than the space heating operation. DHW efficiency was lower than space heating operation due to higher water temperatures and flow rates. DHW systems were designed to ensure maximum capacity with simple systems, which limited the temperature drop and increased the return water temperature. Sites with combined space and water heat had daily efficiencies that dropped below

80% when outdoor temperatures were warm enough that no space heating was required. DHW loads are smaller than design heating conditions. On very cold days lower DHW efficiencies had only a small impact on the overall system efficiency, while in warmer weather, the impact was greater.

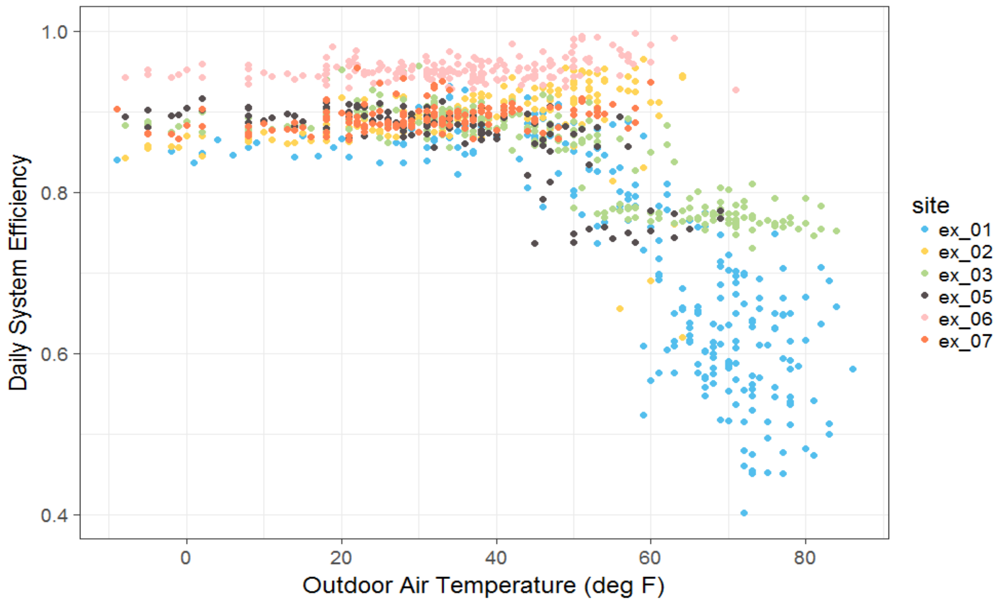

Figure 1. Daily efficiency of the as-found boilers (phase I)

Overall the as-found operation had better than expected space heating performance. The vast majority of days had space heating efficiencies of 85% and above. Table 3 shows the annual performance of as-found operation for the previously installed boilers in Phase I. The space heating efficiencies were between 86% and 95%, with an average annual efficiency of 90%. While slightly lower than the rated AFUE (average AFUE was 94%) these installed efficiencies are in line with the expected efficiencies of well installed systems. Actual measured efficiencies are different than ratings specifications that are measured in controlled laboratory environments (Hoeschele and Weitzel 2013). Based on these finding the as-found condensing boilers would expect to save 14% annual heating energy consumption over a baseline boiler installation.

Table 3. Summary results from as-found performance of existing condensing boiler installations

Sites	Heating Load (therms/yr)	DHW Load (therms/yr)	Space Heating Efficiency	DHW Efficiency	Operating Cost* ($/year)
exist_01	1111	135	86.2%	62.6%	$1,001
exist_02	745	N/A	88.4%	N/A	$669
exist_03	485	85	90.5%	76.1%	$429
exist_05	421	66	90.3%	74.6%	$372
exist_06	636	N/A	95.1%	N/A	$535
exist_07	644	N/A	89.0%	N/A	$579

*This table assumes a natural gas cost of $0.80 per therm

Further analysis of the as-found boilers identified three main contributing factors to the energy efficient operation. Those factors were emitter types and sizes, outdoor reset, and boiler water temperature control.

Emitters. Most boiler installations occur in existing homes with hydronic heating systems that were designed to work before condensing boilers were available. These systems typically relied on high water temperatures to achieve the necessary heating capacities. In the Minnesota metro areas, these distribution systems typically relied on large cast iron radiators. Newer hydronic distribution systems typically have emitters that rely on lower water temperatures, such as radiant panels and in-floor heat (Figure 2).

High-efficiency boiler operation requires return water temperatures to be less than 130^{o}F. Emitter characterization for this project found that the older cast iron radiators were typically sized with a large safety factor to ensure they could meet the heating needs of the home. Additionally, homes with hydronic heating are typically older. Therefore, when the distribution was designed, it relied on less efficient equipment. Over time rising equipment efficiencies, improvements to the home, and the conservative design resulted in the radiator systems being over-sized. For these reasons, the water temperatures can reliably be reduced and still meet the load of the home.

In addition, newer emitter types (radiant panels and in-floor heating) are designed to work at lower operating temperatures, which allow the boiler to operate at high efficiency.

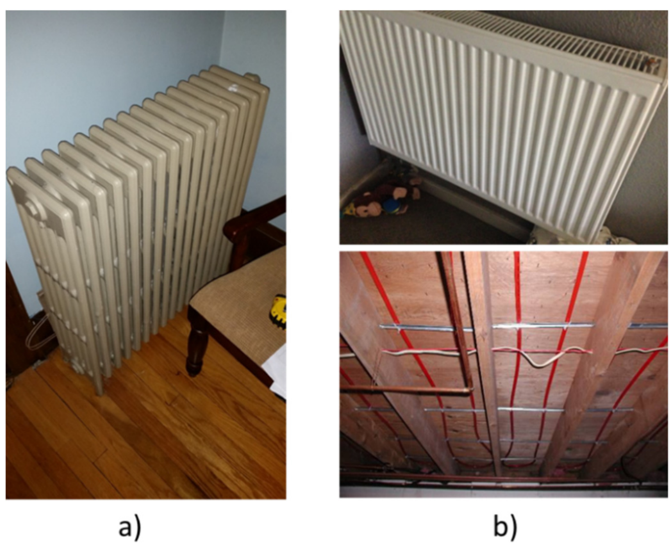

Figure 2. Most common emitters found in Minnesota homes include a) cast iron radiators and b) low temperature radiant panels and in floor heat

Outdoor reset control. The reset is a control strategy for condensing boilers that reduces the target boiler supply temperature based on the outdoor air temperature measured by the system. The capacity of the boiler scales with the house heating load. Reducing the target supply water temperature also reduces the return water temperature, increasing boiler efficiency.

Figure shows a typical reset curve and the four operational parameters that can be changed and optimized for individual installations. The four control points allow the installer to set the coldest and warmest days, as well as the corresponding target water temperature at those outdoor temperatures.

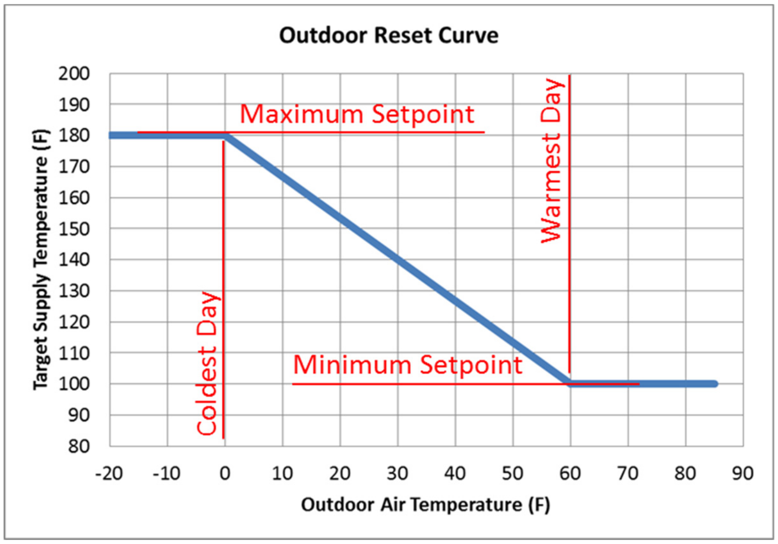

Figure 3. Typical boiler reset curve

Water temperature control. The analysis also showed that condensing boilers had operational controls and methodologies that helped ensure high performance. Figure 4 shows a time-series plot of the supply water temperature for individual heating cycles at site exist_7. The plot shows that for each heating cycle the supply water temperature started at temperatures below 100 ^{o}F and then slowly ramped up to the target set point temperature. At an outdoor temperature of 30^{o}F, the boiler took about 30 minutes to reach the target temperature. At 0^{o}F, it took over 100 minutes to reach the target. Additionally, the chart shows that for lots of events, the boiler turned off before reaching the target temperature. This control strategy means that the system was meeting the load of the home at lower water temperatures than if the temperatures quickly went to the target. This strategy results in lower return water temperatures and high efficiencies.

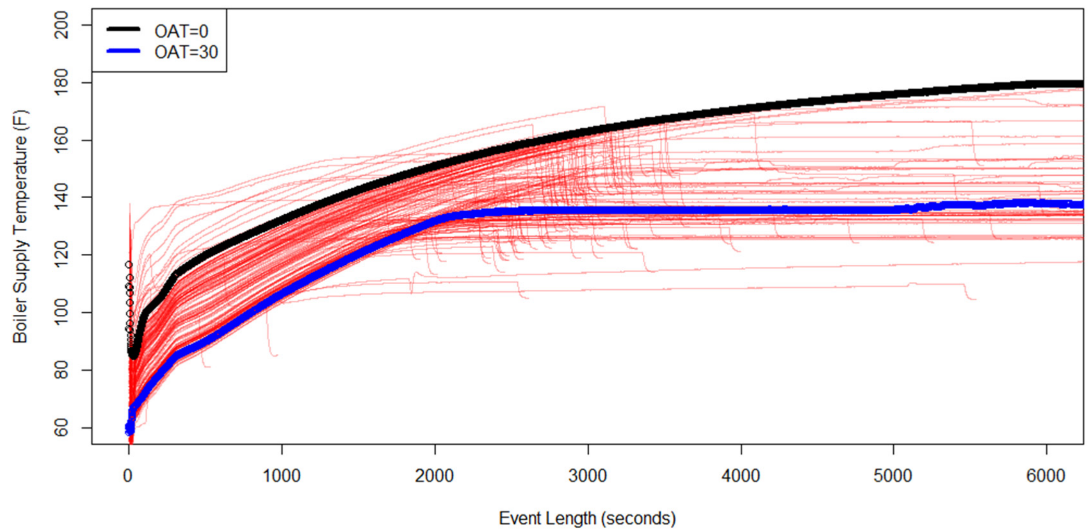

Figure 4 Time-series plot of the supply water temperature for each heating event of site exist_07

The combination of the emitter sizing, outdoor reset, and supply water control lead to low return water temperatures in each of the as-found Phase I boilers. The low water temperatures resulted in the high space heating efficiencies shown in Figure 1and Table 3. Figure 2 shows the average performance across the range of return water temperatures for exist_7, a typical site. At the lowest return temperatures, between 80 and 90 ^{o}F, the boiler saw its highest efficiencies of 97.5%. These low heating return water temperatures were found across all of the Phase I boilers (Figure 3).

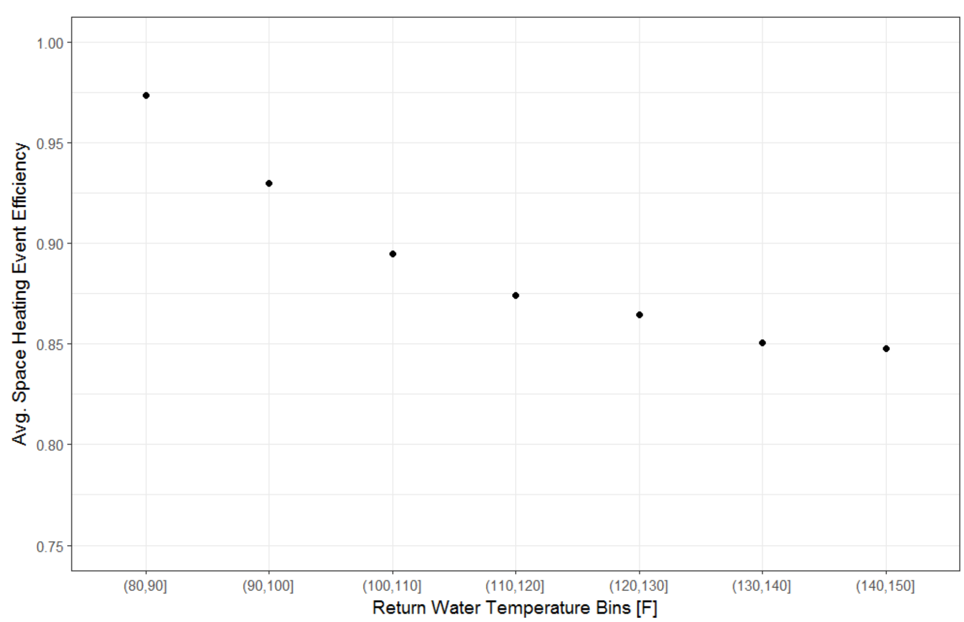

Figure 2. Average heating efficiency per return water temperature bins at Site exist_7

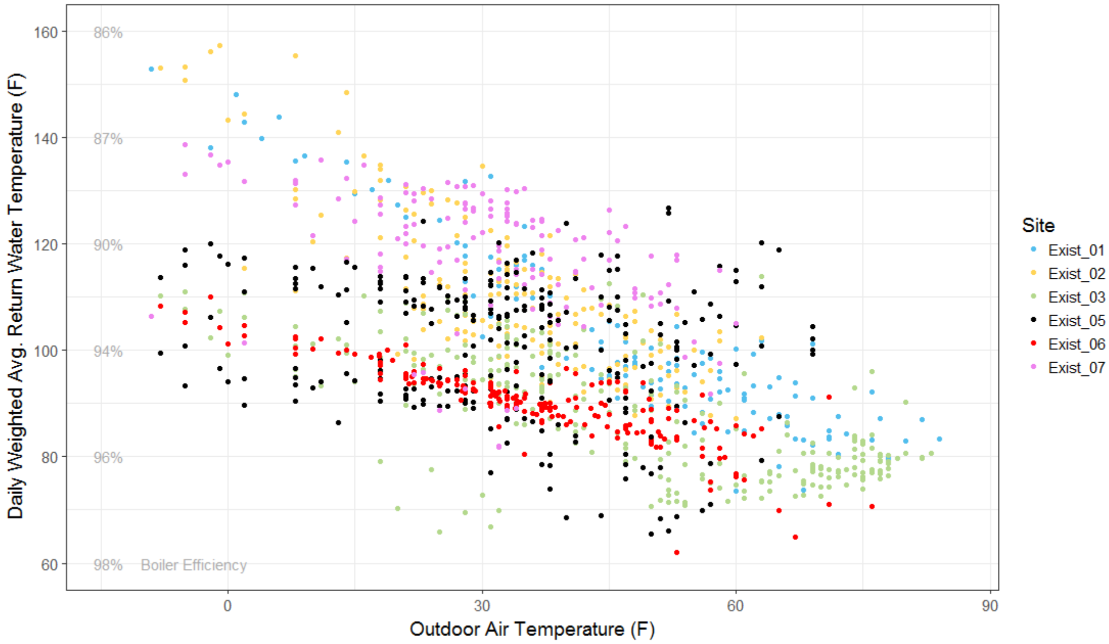

Figure 3. Outdoor air temperature and its impact on heating water temperatures.

Optimization Performance

Opportunities for both space heating and water heating performance improvements were evaluated as part of Phase I of this project (Olson and Schoenbauer Upcoming). In general the identification and optimization process were time consuming and required specific knowledge or measurement of parameters in each system. For example, the space heating optimization required a full measurement and calculation of the emitter capacity at a range of operating conditions. These measurements and calculations are not difficult, but are time consuming.

While difficult to do, the optimization did show improved efficiency and reduced energy consumption in all cases. However, the effort, time, and measurements needed to make these optimizations did not justify the amount of energy savings they delivered. This was because the improvement was relatively small at 2% to 3%, but also because these systems already had very good energy efficiency performance without optimization, limiting the opportunity for impact.

Phase II: Quality Installation Performance

Seven sites were selected and had condensing boilers installed following a QI procedure based on the lessons learned from Phase I of this project. The same instrumentation and data collection package used for Phase I was also used in Phase II. Data was collected and analyzed for one full heating season and the performances of the newly installed boilers were compared to the results from Phase I and baseline systems.

The quality installation procedure was developed based on the as found and optimized performance of the boilers from Phase I. The project team found that the best practice would be to follow the manufacturer's installation requirements and ensuring that:

- The maximum firing rate of the boiler should be sized according to ACCA Manual J (Rutkowski and Air Conditioning Contractors of America 2006), while minimizing the minimum firing rate. This should be achieved by selecting a boiler with a reasonable turn-down rate.

- The outdoor reset control has been installed to the manufacturer's specifications. Specifically ensuring that the exterior temperature sensor has the required clearances and is installed so that it will make a reasonable measurement of the outdoor temperature.
- The outdoor reset curve is set for the appropriate distribution system in the home. Figure 4 shows a generic version of the outdoor reset guidance used for this project. The coldest day set point should be based on the installation location and design temperatures and the minimum and maximum supply water temperatures should be set according to the emitter type. Most manufacturers provide specific guidance in the installation documentation.

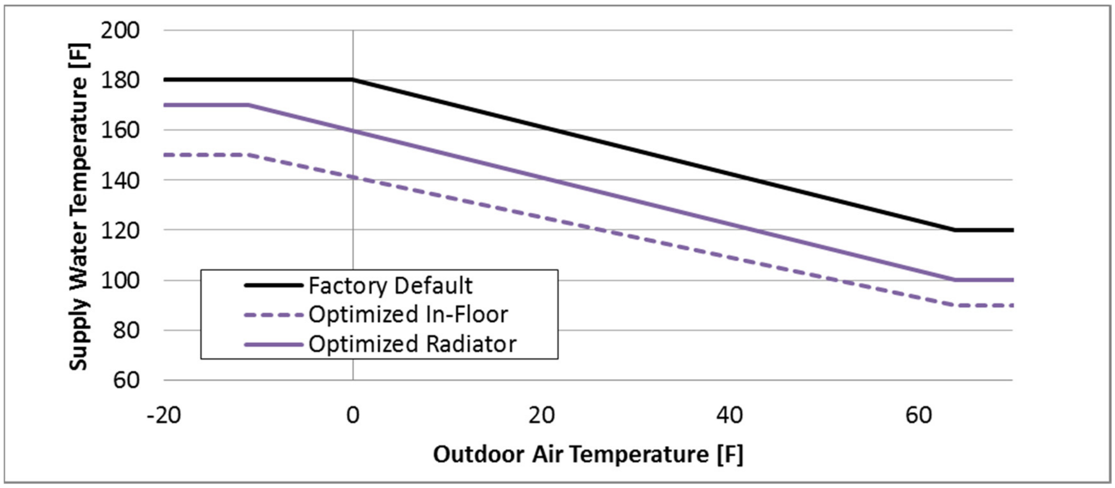

Figure 4. Generic outdoor reset curve guideline

Phase II monitoring and results had nearly identical performance to Phase I boilers. For Phase II, the average annual space heating efficiency was 89.3% compared to 90.0% for Phase I. This characterization validates the QI measures for ensuring installed performance capable of achieving the expected savings above baseline. Table shows the measured results for each newly installed boiler. As expected, the operating costs increase proportionally with the homes' load, but efficiency remains consistent.

Table 4. Annual performance results from Phase II monitoring (new installations)

Sites	Heating Load (therms/yr)	DHW Load (therms/yr)	Space Heating Efficiency	DHW Efficiency	Operating Cost* ($/year)
new_01	1033	N/A	89.0%	N/A	$938
new_05	616	N/A	89.5%	N/A	$551
new_08	656	44	88.2%	76.8%	$641
new_10	549	N/A	89.9%	N/A	$488
new_11	740	N/A	88.2%	N/A	$671
new_12	778	N/A	89.1%	N/A	$699
new_16	1259	N/A	91.1%	N/A	$1,106

Comparing All Modes

Both as-found and optimized boiler space heating performance was compared to the installed performance of the Phase II newly installed systems. Figure 5 compares the efficiency for all these systems. The figure shows that all the measured efficiencies were fairly consistent, ranging from 86% to 96% with an average annual efficiency of 90%. Additionally the performance of a typical baseline system was also included for comparison. This baseline was created from the average estimated performance of the typical baseline system and validated against a billing analysis for the systems prior to the Phase II installations.

Only three of the as-found systems were optimized. Both Exist_05 and Exist_06 were already set up for the lowest return water temperatures possible. Exist_06 had the highest annual efficiency (95.1%) measured across all sites. Exist_05 had slightly higher return water temperatures than Exist_06, but emitter capacity, existing supply temperature settings and house load were such that further optimization was unlikely to result in significant changes in system performance. Exist_03 was optimized for DHW performance and not space heating performance.

Figure 5 . Space heating efficiency for all sites

Savings Results

All of these systems had space heating efficiencies near 90% and showed annual energy savings between 10% and 18% over a baseline boiler. Table 5 shows the annual cost and percentage savings.

Table 5. Summary of annual results

Site	Design Load (BTUs/HR) (Outdoor Temp of -11 ^{0}F)	Annual Savings over Baseline ($/year)	Percent Savings
exist_01 – as found	49,123	$108	10%
exist_02 – as found	32,581	$95	12%
exist_03 – as found	23,606	$69	14%
exist_05 – as found	19,762	$59	14%

exist_06 – as found	29,490	$117	18%
exist_07 – as found	27,670	$82	12%
new_01	46,230	$122	12%
new_05	25,492	$81	13%
new_08	26,397	$88	12%
new_10	25,727	$74.	13%
new_11	31,746	$88	12%
new_12	32,354	$100	12%
new_16	43,332	$185	14%

Cost Effectiveness Conclusions

According to our savings analysis above, the average heating savings for the participant households with condensing systems over non-condensing systems is 13%, with an average yearly cost savings of $97.54. So, in order to have a simple payback of 25 years or less (typical lifetime of boilers), the price difference between condensing and non-condensing boilers needs to be around $2,500. In order to have a 10 year payback, the price difference needs to be around $1,000

This cost analysis shows that, on average, the difference in installation price is close to the 23 year simple payback mark, but an individual bid for a particular homeowner may prove to be a shorter or longer payback, due to the wide range of the price difference in the market.

Research on supplier cost data shows the cost differences between non-condensing and condensing boilers (just equipment costs) points to a fairly small hard cost difference of $1,000 and also suggests that the larger cost difference is in the labor/soft costs side of things.

Our savings results for side arm or integrated DHW over a baseline power vented DHW unit is quite small if present at all. So, as long as the side arm or integrated tank cost is similar to a power vented unit (around $2,000 installed), it may make sense to replace an existing separate DHW with a combined unit for space saving or venting reasons. However, this does not appear to be cost effective for energy savings at the current average cost of $2,800.

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