Expanded Scope Commercial Boiler Tune Ups

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Executive Summary

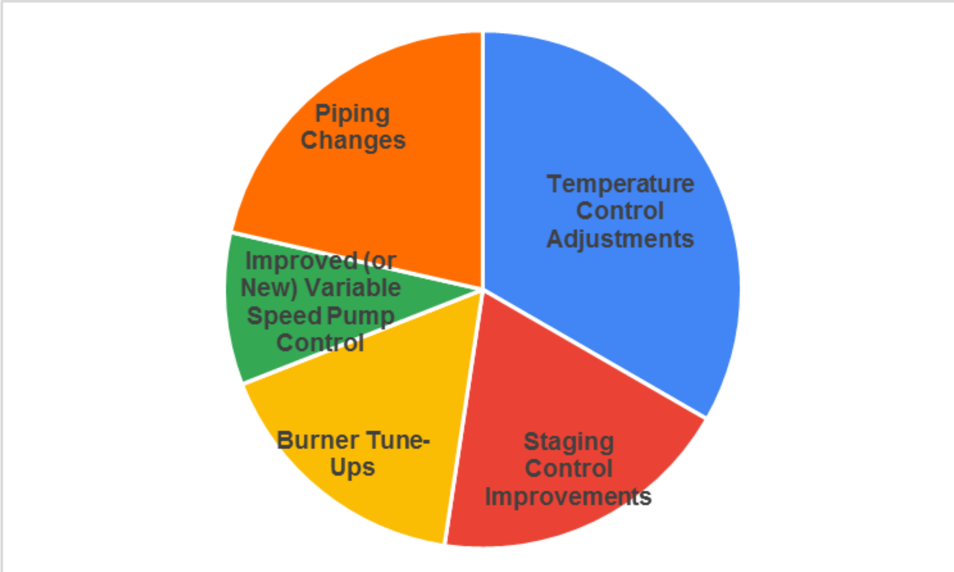
This study clearly demonstrated a large potential for cost-effective savings and increased Conservation Improvement Program (CIP) impact by adding boiler temperature and staging control optimization to the scope of traditional commercial boiler tune-up programs, which have historically focused on energy savings only through burner adjustments. This expanded scope of service requires a more detailed protocol and data collection form than traditional burner tune-up programs, as well as significant technician training and technical support to reliably achieve savings. However, for buildings with condensing boilers, this scope expansion cost-effectively provided savings of about 7% of pre-tune-up gas use, in addition to the roughly 2% savings typically assumed for burner tune-ups alone. While there is some drop off in savings over time, the persistence appears to be at least as good as for traditional burner tune-ups. The combination of savings, market size, and cost-effectiveness makes this an attractive option for expanding current CIP offerings.

Context of This Study

The goal of this project was to develop and field test an expanded-scope commercial boiler tune-up protocol that goes beyond burner adjustments to provide a comprehensive review and adjustment of boiler control settings to increase energy savings — especially for buildings with condensing boilers. More specifically, the scope was expanded to include the optimization of boiler temperature and staging controls. Field tests were implemented to evaluate costs, savings, operations, persistence, and market and implementation issues for the protocol. In short, the study aimed to provide information that utilities can use to plan CIP program additions or modifications that achieve more boiler tune-up savings toward their program savings goals, and that can also be used to add boiler control adjustment measure(s) to the Technical Resource Manual (TRM).

At the onset of the study, commercial boiler tune-up programs that were narrowly focused on burner air–fuel ratio adjustments provided about 8% of total CIP portfolio savings for natural gas utilities in Minnesota. Boiler tune-up programs have a long history of achieving savings by fine-tuning the burner air–fuel ratio, but these programs have not addressed optimization of boiler temperature and staging controls. A recent CARD-funded study suggested that, for commercial condensing boilers in Minnesota, making adjustments to boiler control settings alone can provide substantially more savings than burner air–fuel ratio adjustments (Center for Energy and Environment [CEE] 2016). Figure 1 shows the relative amount of savings that the previous study showed could be achieved through various improvements to existing condensing boiler systems. While the combination of temperature and staging control improvements were estimated to represent more than half of the possible savings, burner tune-ups were estimated to only capture about one-sixth of the possible savings. Therefore, enhancing boiler tune-ups by including controls optimization appeared to have the potential both to dramatically increase the per-participant savings for boiler tune-up programs when condensing boilers are encountered and to potentially expand the pool of buildings that would realize cost-effective benefits.

Figure 1. Relative Potential Savings from Improvements to Existing Condensing Boiler Systems



The current study looked at the substantially larger market of existing non-condensing boilers as well as condensing boilers. The following adjustments were included in part of the enhanced tune-up protocol:

- settings for outdoor reset control (which automatically reduces boiler temperature in mild weather); and
- staging control settings that affect the on/off cycling, part-load control, and coordination among multiple boilers.

The potential to achieve savings through boiler temperature and staging control adjustments has been amplified in the last few years by boiler industry trends that have made it simultaneously more difficult and more important to optimize these settings. Condensing boilers with about 10% rated efficiency improvements over non-condensing boilers have begun to dominate the market for new boilers and account for about one-fourth of existing boilers. However, their actual operating efficiency can drop off significantly if the boiler system water temperatures and staging controls are not optimized. Even in buildings without condensing boilers, outdoor reset controls have been widely recognized as a cost-effective savings opportunity for decades, but suboptimal settings often cause overheating and excess pipe heat losses.

Study Methodology

After conducting a market study to inform the protocol and targeting of test sites so that they would be representative of key building types and boiler controllers, the research team selected 17 sites for long-term pre-post monitoring and implementation of the boiler controls tune-up protocol. The goal was to monitor for at least half of a heating season before and after the controls tune-up at each site. The test sites were identified by working through key local boiler service contractors. A summary of key participant site characteristics can be seen in Table 1.

Table 1. Summary of Research Site Key Characteristics

Characteristic	Category A	Participants A	Category B	Participants B	Category C	Participants C
Building Type	Education	11	Multifamily	6	Other	0
Control Type	Local Staging with Temperature from BAS	10	All Local	7	All BAS	0
Number of Boilers	1 Boiler	0	2 Boilers	8	3 or 4 Boilers	9
Size of Each Boiler[a]	200–800 MBH[b]	5	801–1,950 MBH[b]	2	1,950–3,000 MBH[b]	9[a]
Make of Boiler[c]	Aerco	4	Fulton	6	Lochinvar	2

a) A lower priority was given to the selection of up to four buildings with boilers larger than 3,000 MBH, and one such building participated.

b) 1 MBH = 1,000 BTU per hour.

c) A high priority was also given to the selection of 1–5 buildings with KN boilers, and one such building participated.

For each of the participating sites, an indicator of whole-building or boiler gas use was monitored, along with boiler system supply temperature. Gas use was measured by either a whole-building meter or boiler plant submeter for eleven sites, and Building Automation System (BAS) trend data on boiler firing rates at the other six sites. The use of boiler firing rate alone proved problematic at three sites because of a misunderstanding regarding the interpretation of 0% firing rate for many of the ModSync controllers. However, the use of burner on status data for at least a portion of the time prevented a complete failure of the firing rate approach to measure the controls tune-up impacts. Additional measurements of boiler cycling, boiler system return temperature, and individual boiler temperatures were also made at most sites.

For the school sites, the changes in operations in response to the COVID-19 pandemic limited the ability to make as robust of a pre-post tune-up comparison as for the multifamily building sites. For the multifamily buildings, gas savings was estimated by conducting change-point linear regression analysis of daily average gas use against outdoor temperature. The change-point model was used to determine the limits of the heating season, and the linear models were applied at the heating season average temperature for each site. A similar approach was planned for the school buildings, but the limited amount of post-tune-up data prevented adequate regression modeling of the post-tune-up data set. To provide a fair comparison between the pre- and post-tune-up data, each school site's savings was estimated by conducting a regression of pre-tune-up over the range of outdoor temperatures experienced in the post-tune-up period (prior to school shutdowns), then averaging the difference between the pre-tune-up model and the individual days of post-tune-up data.

Tune-Up Protocol

The research team developed and refined a commercial condensing boiler controls tune-up protocol with input and feedback from a variety of local trade allies. The protocol both documents existing boiler control conditions and guides technicians in making and documenting control setting changes focused on optimal outdoor reset control and optimal staging control of the boilers. Although it was meant to cover a variety of possible variations, special efforts were made to ensure that the protocol was comprehensive for and representative of the most common condensing boiler brands in Minnesota. Quick-reference guides were also prepared for the three most common controllers (Aerco, ModSync for Fulton boilers, and Lochinvar) to help technicians quickly navigate through the control menu structure to reach the items addressed by the protocol.

The field protocol was broken up into the following main sections:

1. Site-level summary information.
2. Detailed observations of the operation and setup for each boiler.
3. Observations of potential issues with the controller's outdoor temperature sensor.
4. Key system temperature and setpoint observations and temperature setting optimization.
5. Staging control settings and optimization.

The second and third sections were intended to both provide more detailed documentation of the current operation to inform the optimization of settings, and to identify issues beyond simple temperature setting adjustments that need correcting. The first four sections were developed to have one version of the protocol cover all variations of boiler and controller brands, as well as the outdoor reset logic being used at either the local controller or BAS system level. On the other hand, the large variations of basic staging control logic and parameter names led to the customization of staging control forms for specific makes of boiler controllers.

The most critical item with regard to the energy savings achieved by the protocol was the choice of target boiler system temperatures, given that the optimal temperature can vary from building to building. The most important variable is whether the building heating system was designed for the lower operating temperatures that are ideal for condensing boilers, temperatures that are generally avoided with non-condensing boilers. In close consultation with numerous trade allies, researchers chose moderately aggressive target temperatures. It was anticipated that these settings would lead to about one in four participants having moderate underheating issues that would require a callback to fine-tune the temperature settings.

The field trails of the protocol led to further refinement, with the most important changes being the addition of:

- spot observations of system pressure before any changes and after systems cooled down to lower temperature setpoints, and subsequent addition of fluid to the system in critically low-pressure situations; and
- on-site observations of boiler system behavior over the course of at least one on and off cycle or until system temperatures and firing rates settled into a new, stable operating condition — especially after moderate staging control changes or significant temperature control changes.

The pressure observation was needed to prevent problems when lowering the system temperature settings would further reduce already low system pressures. The boiler system operations were valuable both to provide for better optimization of staging controls and to prevent possible callbacks in cases of unexpected system responses.

Representative contractor costs to implement the protocol at the test sites are shown in Table 2. These costs include repeat site visits at four sites to conduct temperature setting fine-tuning adjustments; implement a staging control upgrade; and restart boilers after a combination of temperature reduction, low system pressures, and an improper control sensor location that led to the lockout of all boilers. However, the costs did not include the engineering support provided to contractors by the research team on-site during the tune-up visits, or via remote direction to school district staff for fine-tuning adjustments at two buildings (which prevented contractor fine-tuning revisits).

Table 2. Contractor Cost to Conduct Controls Tune-Ups

Cost Basis	Average	Median
Cost per Site	$737	$750
Per Boiler Cost at Each Site	$288	$224

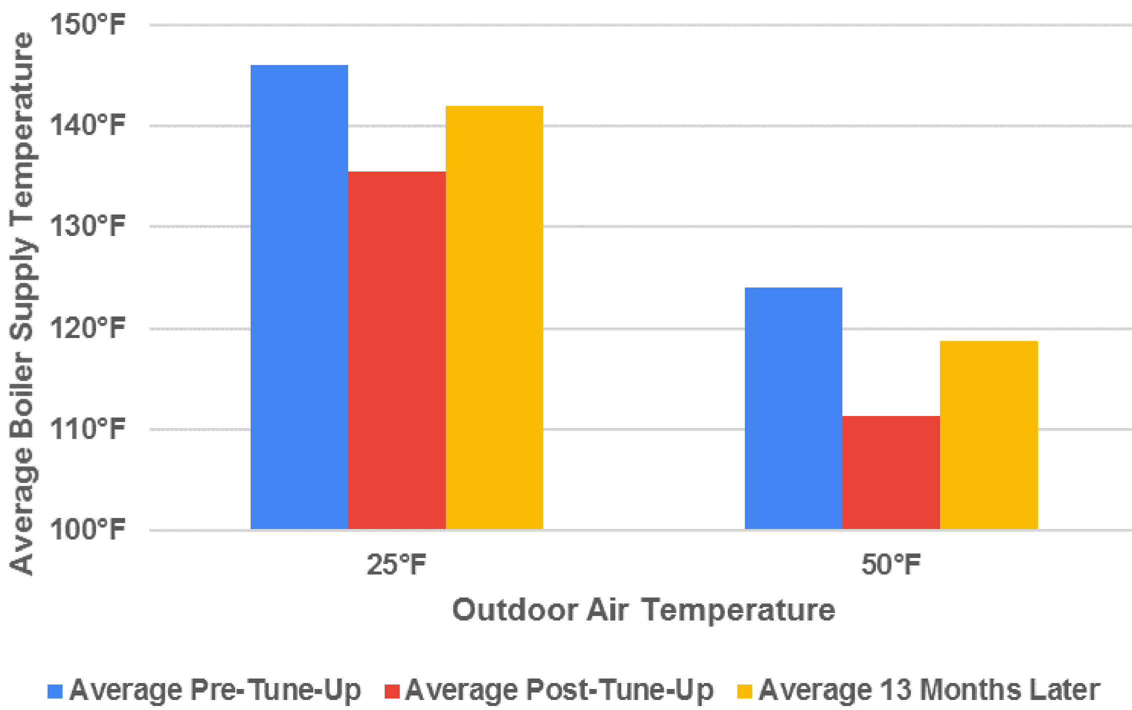
Key observations from the field trial that have implications for CIP program development were:

1. **Training and Support.** Contractor technicians leaned heavily on expert coaching through the first few sites, even with the detailed protocol and quick-reference materials.
2. **Frequency of Adjustments Called For.** Temperature control changes were made at all sites, while staging control changes were made at about three-fourths of the sites.
3. **Screening for Control Problems.** The protocol's diagnostics identified control problems beyond controls settings for one-third of the sites, including both staging and temperature sensor problems. In most cases, these problems were resolved at the time of the initial controls tune-up visit.
4. **Persistence of Aggressive Changes.** A somewhat higher frequency of controls being changed back to near as-found settings occurred at sites with the most aggressive temperature reductions. This suggests that a maximum limit of about 20°F on the change of setting would be useful, in addition to the target temperature setting guidance provided by the protocol.
5. **BAS Control Changes.** The contractor technicians and researchers were able to work with building owners' staff to make immediate temperature control changes at all 11 sites with BAS systems. This required special efforts ahead of time to communicate the need for this to building owners' staff, and three sites required additional follow-up with school district staff to make a temporary override effective an on ongoing basis. It appears that these "permanent" overrides were later reset to the original defaults as part of a system-wide reset to defaults.
6. **Design Temperature Variations.** Review of mechanical plans was important to identify optimal target temperatures for a number of buildings with HVAC systems designed with condensing boilers in mind.
7. **Fine-Tuning Adjustments.** Four of the 17 sites needed fine-tuning adjustments within the first month, and fine-tuning adjustment was needed several months later at a fifth site. Repeat contractor site visits were needed for two of these, while researchers talked school district staff through fine-tuning adjustments at the other three.

Boiler System Temperature and Staging Impacts

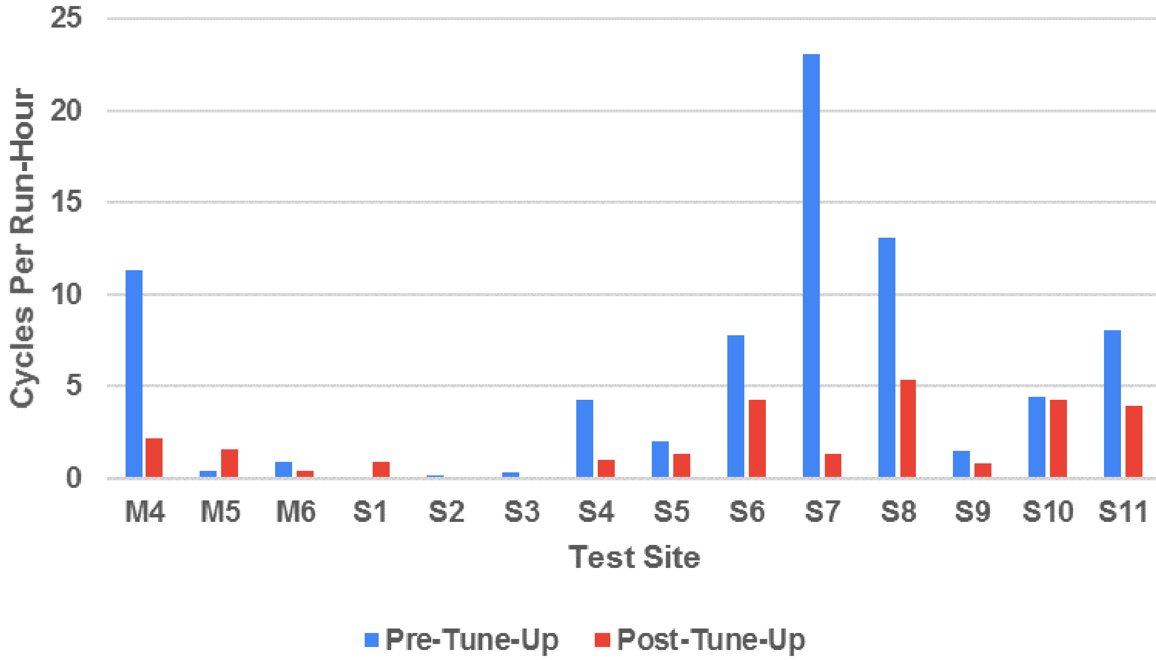
The boiler control tune-ups initially reduced boiler system temperatures by about 12°F, and subsequent adjustments far into the post-tune-up monitoring period led to a net average 5°F reduction 13 months after the initial tune-up. The average system changes are shown in Figure 2 at representative outdoor air temperatures of 25°F and 50°F. The site-to-site differences in system temperature reduction and persistence of that reduction were dramatic. It was noteworthy that sites tended either to maintain all of their temperature reduction over time or to have temperature settings returned to very near their original settings. None of the sites made moderate changes that were only partway back toward the pre-tune-up setpoints. It was also noteworthy that correcting staging control problems was critical to reducing heating season average boiler supply temperatures at two sites.

Figure 2. Impact of Tune-Up on Boiler System Temperatures



Boiler short-cycling was at a level of concern for nearly half of the boiler systems, and the control tune-ups were very effective at reducing short-cycling. Across the 13 sites where boiler cycling data was available, the median reduction in cycling rate was 48%, and it was 58% among the eight sites that have pre-tune-up short-cycling at a level of concern (two or more cycles per run-hour). The control tune-up impacts on cycling behavior for the individual sites can be seen in Figure 3. While engineering estimates that considered the energy impact of the burner pre- and post-purge cycles suggested that reductions in cycling were generally small (1.3%, 0.5%, and 0.4% of pre-tune-up gas use for the three most significant sites), industry trade allies and building owners consider the cycling reduction to be valuable for both reduced maintenance requirements and energy savings.

Figure 3. Boiler Cycling Behavior Changes by Site



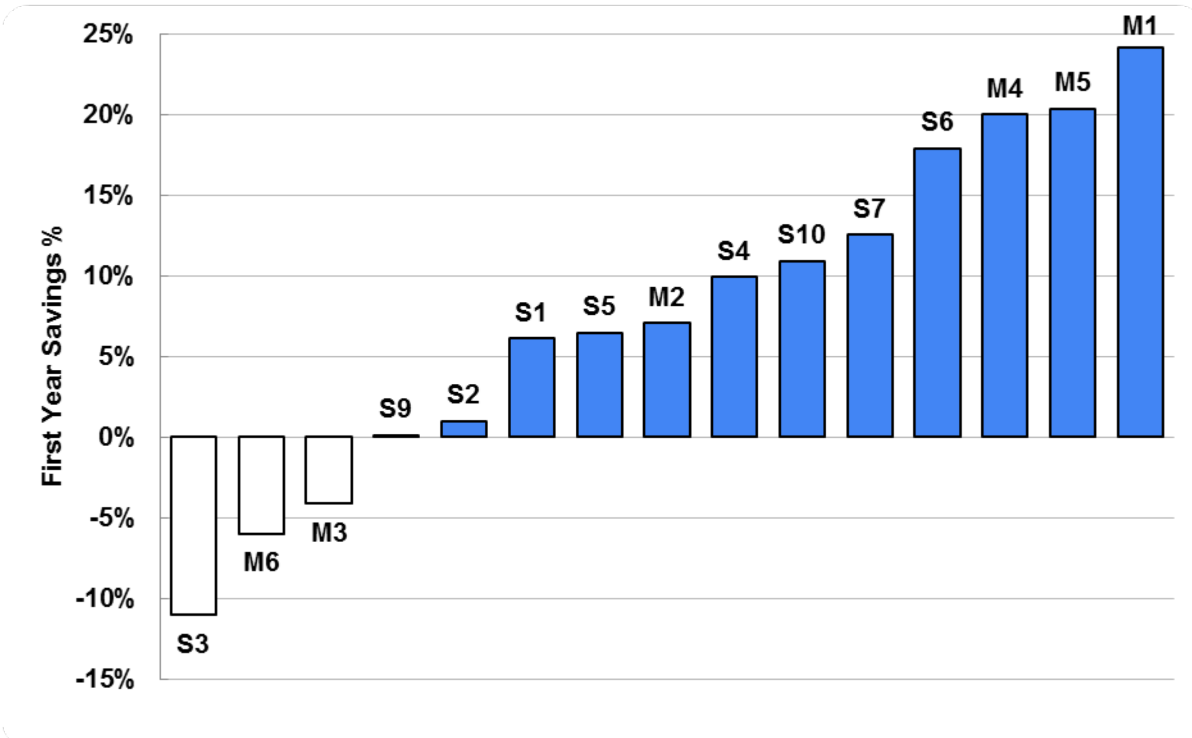
The few results available on the impact of staging control changes aimed at improving the load sharing among multiple boilers suggested less impact than had been hoped. It appeared that significant changes in the part-load threshold for bringing on the next boiler led to changes of only a few percentage points in the average boiler firing rate over a limited portion of the outdoor temperature range encountered over the heating season. Therefore, the efficiency gain from improved efficiency at low part-load operation compared to high part-load operation appeared to be minimal.

It was clear that all boiler staging control changes made persisted over the entire post-tune-up monitoring period. This was true both for changes aimed at reducing short-cycling and those aimed at improving load sharing to reduce the average firing rate of boilers.

Energy Savings Results, Persistence, and Program Potential

The 15 sites that had a representative measurement of observed savings achieved an average savings of 7.7% and median savings of 7.1%. The ranked savings for individual sites is shown in Figure 4. Note that the sites with M in the label are multifamily buildings, and those with S in the site label are schools. Due to COVID-19 shutdowns shortly after the controls tune-ups, the savings at the school sites is based on a comparison with much fewer data points and over a more limited range of outdoor temperatures that were representative of a cooler portion of the heating season. A summary of the results by building type and for all 15 buildings is shown in Table 3. This shows that the observed percent savings for multifamily buildings was roughly double the percent savings for schools. However, the tendency for the sample of school buildings to have higher gas use to begin with makes the magnitude of gas savings per site larger for the school sites.[1]

Figure 4. First-Year Percent Savings by Site*



*These 15 sites with representative, direct measurement exclude one site with an engineering estimate of savings and one with a major operational change unrelated to the tune-up that are included in analysis within the main report.

Table 3. Summary of Savings by Building Type

Sample	Mean Percent	Median Percent	Mean Gas	Median Gas
Multifamily Buildings (N=6)	10.3%	13.6%	152 Dth	67 Dth
School Buildings (N=9)	6.0%	6.5%	187 Dth	148 Dth
Both Building Types (N=15)	7.7%	7.1%	173 Dth	137 Dth

Engineering estimates of savings based on observed temperature and cycling changes tended to underpredict savings by nearly 40%. These engineering calculations also suggested that the changes in boiler efficiency with operating temperature that is unique to condensing boilers only contributed about one-fourth of the total savings results from the controls tune-ups. This suggests that the application of a

[1] Note that the gas savings are reported here by site (with a sample average of three boilers per site), whereas participants in utility CIP programs are often treated as individual boilers at a site.

similar protocol at sites with non-condensing boilers could achieve that majority of the savings realized at the research study test sites.

Observations of controller temperature setpoints at the end of the monitoring period suggested that, on average, 66% of the initial savings from boiler control tune-ups persist into the second year. It appears that only a fraction of the reverting back to near pre-tune-up temperature settings was in response to underheating, but were rather part of changes made when other boiler service work was performed or when BAS system setpoints were restored to defaults system-wide. Individual sites tended to either maintain all of their initial savings into the second year (60% of sites) or have the settings reverted back to very near the pre-tune-up settings (35% of sites).

The sum of full-scale program achievable potential for the three largest natural gas investor-owned utilities (IOUs) in Minnesota was estimated at 196,500 Dth per year, which is equivalent to 10% of the current commercial and industrial portfolio savings for these utilities. Societal benefit–cost ratios were estimated at 1.4 to 1.85 and utility benefit–cost ratios were estimated at 1.5 to 2.1. Boiler service contractors were very optimistic that virtually all current burner tune-up customers would pay the additional cost for a more expensive combined package of burner tune-up and boiler control optimization. The significant savings of controls tune-ups could allow for cost-effective expansion into market sectors that have not traditionally had large participation in boiler tune-up programs, such as multifamily buildings.

CIP Program Recommendations

We recommend that natural gas utilities in Minnesota take steps toward full-scale integration of boiler control tune-ups into existing boiler efficiency programs. Because of the complexity of this offering, the need to further optimize a number of program processes, and the need to develop contractor technician expertise and habits, we recommend a moderately slow approach to scaling up this program.

The study results have also led researchers to make a number of recommendations for CIP program development and delivery that are enumerated below and expanded upon in the main report:

1. Plan for extensive contractor training and on-demand technical support.
2. Conduct additional market research among end users.
3. Work closely with boiler industry trade allies during program planning.
4. Institute a robust quality control program.
5. Leverage boiler service contractors to promote the controls tune-up service.
6. Provide clear expectations of customer requirements to have staff authorized to make BAS setpoint changes on-site and to make the mechanical plans available (whenever possible).
7. Ensure that the technician has the knowledge necessary to appropriately adjust control settings for the make and model of boiler controller that will be encountered at each particular site.
8. Develop and test appropriate follow-up activities aimed at maximizing persistence over time in a cost-effective manner.

Background

Introduction

This project investigated the savings achievable through a protocol that systematically optimizes settings for boiler temperature and burner staging control in commercial, multifamily, and institutional buildings — especially those with condensing boilers. Boiler tune-up programs have a long history of achieving savings by fine-tuning the burner air–fuel ratio, but these programs have not addressed optimization of boiler temperature and staging controls. A recent CARD-funded study suggested that, for commercial condensing boilers in Minnesota, making adjustments to boiler control settings alone can provide substantially more savings than burner air-fuel ratio adjustments (Center for Energy and Environment [CEE] 2016). The study described in this report subsequently looked at the substantially larger market of existing non-condensing boilers as well as condensing boilers. The following adjustments were part of the enhanced tune-up protocol:

- settings for outdoor reset control (automatically reduces boiler temperature in mild weather);
- on/off staging;
- part-load control (i.e., firing rate modulation); and
- sequencing of boilers in multiple boiler systems.

The potential to achieve savings through boiler temperature and staging control adjustments has been amplified in the last few years by boiler industry trends that have simultaneously made it more difficult and more important to optimize these settings. The population of boilers in Minnesota's commercial buildings has been trending toward systems with high-efficiency condensing boilers. These condensing boilers have much more sophisticated built-in controls than conventional boilers, and there are many complex variations in how the control of multiple boilers is coordinated, making it more difficult for technicians and operators to optimize the myriad of boiler control configurations and settings. At the same time, the operating efficiencies of these condensing boilers are much more sensitive to boiler water temperature and boiler part-loading control than the efficiencies of conventional boilers. So much so that while condensing boilers often have a 10%–15% rated efficiency advantage over conventional boilers, they commonly only achieve only about half of this efficiency advantage in Minnesota buildings (CEE 2016). The Consortium for Energy Efficiency has published two reports highlighting the impact of control settings on the achieved annual efficiency of condensing boilers (CEE 2001 & 2011). This is a relatively low-cost approach with broad applicability, and the achievable market impact on Conservation Improvement Program (CIP) programming could be significant.

Even in buildings without condensing boilers, optimizing boiler control settings — especially temperature control — was expected to produce significant savings. This is because boiler outdoor reset controls have historically achieved significant savings by reducing the amount of heating the boiler system has to do rather than by improving boiler efficiency. Although limited to a small number of multifamily buildings that primarily have non-condensing boilers with simpler controls, CEE had achieved savings recognized through a CIP program in Minnesota by coaching operators to adjust outdoor reset controls in multifamily buildings. (The simultaneous installation of other energy conservation measures makes it impractical to use data from these program participants to validate the kind of savings anticipated here.) Having been rebated for more than 30 years, outdoor reset controls are used on the vast majority of commercial boilers in Minnesota, and optimizing their settings was expected to provide substantial savings in buildings with either condensing or conventional boilers. These control setting adjustments can also yield savings in buildings not reached by traditional tune-up programs because natural draft boilers (which tend to be most prevalent in small to midsize buildings) cannot have their secondary air flow rates adjusted but can achieve savings through outdoor reset control optimization.

While there did not appear to be other examples of protocols specifically addressing boiler control settings, a number of similar examples did exist when this study began. In CEE's search for other program precedents, we inquired with ESource and found no prescriptive rebates specifically associated with boiler control setting adjustments in their database of more than 6,000 demand-side management (DSM) programs in North America. However, there were other related DSM program precedents for recognizing savings from control adjustments. Common examples include the programming of thermostats in direct-install programs and the implementation of building automation system (BAS) setting changes as part of recommissioning programs. One closer parallel to commercial boiler setting changes was the prescriptive rebate offered by Focus on Energy's EBTU program for the adjustment of chiller temperature control setpoint.

While the previous CARD study identified the potential for savings through boiler control changes, it left a number of unresolved issues. The most important of these were:

1) what detailed protocols are needed to optimize control settings in a large-scale utility program;
2) whether a full-scale program is best dovetailed with existing boiler tune-up program services;
3) how interactions with BASs impact the trade allies that need to be involved in program delivery;
4) what protocol-specific training or other technician certification is needed for effective program delivery;
5) what the implementation costs are;
6) how much savings could be achieved by a production-scale program; and
7) how common variations in building and boiler system characteristics impact costs and savings.

Commercial Boiler Efficiency and Load Issues

This section provides technical background for in-depth understanding of the mechanisms by which the boiler control temperature and staging adjustments can provide savings, as well as the interaction with burner tune-up adjustments. The discussion focuses mainly on commercial condensing boilers because of their growing market impact and the implications that has for their unique sensitivity to operating conditions. Unlike most natural gas–fired equipment, the operating efficiency of condensing boilers can change significantly with operating conditions. Unfortunately, the optimal conditions for maximizing condensing boiler efficiency are the exact conditions that designers and operators have rightly tried to avoid with conventional boilers. This means that optimizing boiler efficiency is often most challenging when replacing conventional boilers in existing buildings and when boilers are operated by seasoned facilities staff. This makes the importance of recognizing the following condensing boiler efficiency implications all the more critical.

How Condensing Boilers are More Efficient

The steam that can typically be seen forming at the chimneys of boiler systems during cold weather is the key to the efficiency advantages of condensing boilers. When natural gas and air burn together (as is the case for the majority of commercial boilers in Minnesota), water vapor is one of the natural products that occurs, representing about 12% of the gases that exit a boiler system chimney. This water vapor is actually diluted steam that packs a big punch when it comes to heating energy potential, as each pound can theoretically heat about six gallons of water. While the design of conventional boilers intentionally allows all of the steam in the combustion gases to escape out the chimney, condensing boilers are able to capture a portion of the valuable heat in the steam by condensing it to water before it leaves the boiler.

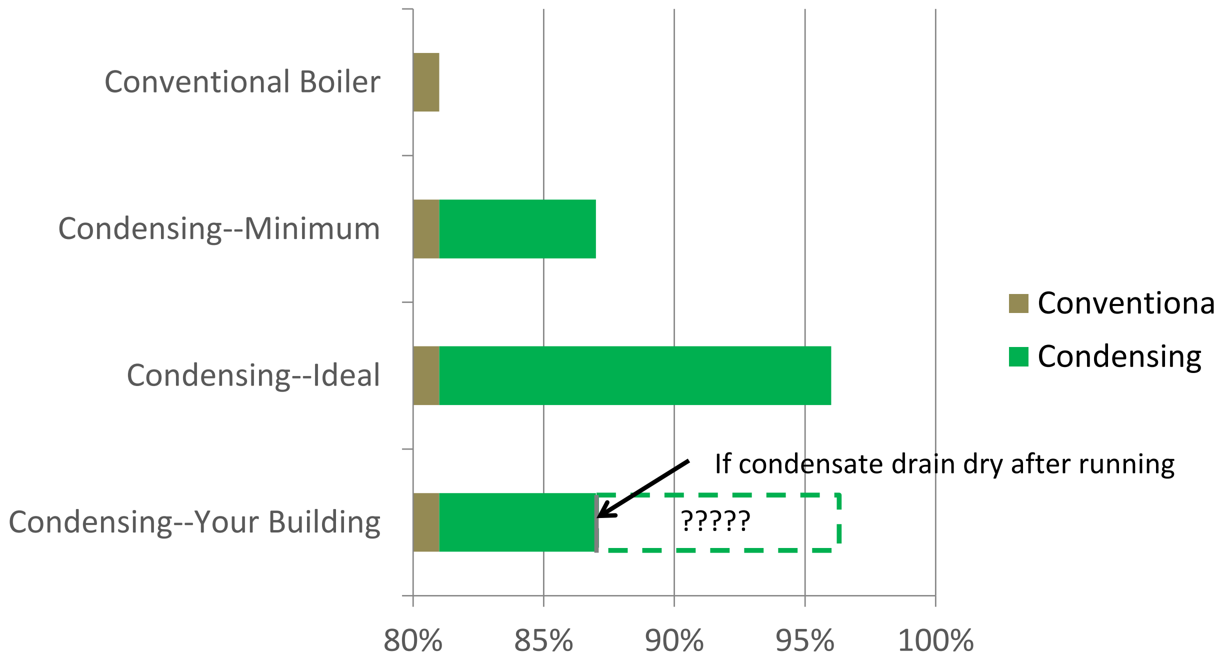
Boiler efficiencies of 90% or higher are only achieved when a boiler is condensing part of the steam in the flue gases. However, a boiler's ability to condense this steam varies greatly with the actual operating conditions that are imposed upon a boiler in a building. Regardless, condensing boilers are generally at least a few percentage points more efficient than conventional boilers under all conditions. This is primarily because the safety factors built into conventional boilers to avoid the potential for condensation of water vapor inside the boiler are not needed in the design of the heat exchangers for condensing boilers. Higher insulation levels and much smaller water tanks are also typical in condensing boilers, and they provide secondary efficiency benefits.

These two design aspects that allow condensing boilers to achieve efficiencies 5%–15% greater than conventional boilers are highlighted below.

- Actual condensation (allows 90%+ efficiency)
- No safety factors to prevent condensation (gives a few percentage point gain — from the 81%–84% range to the 86%–89% range)

Figure 5 below shows their impact in typical boiler situations.

Figure 5. Range of Efficiency Gain with Condensing Boilers



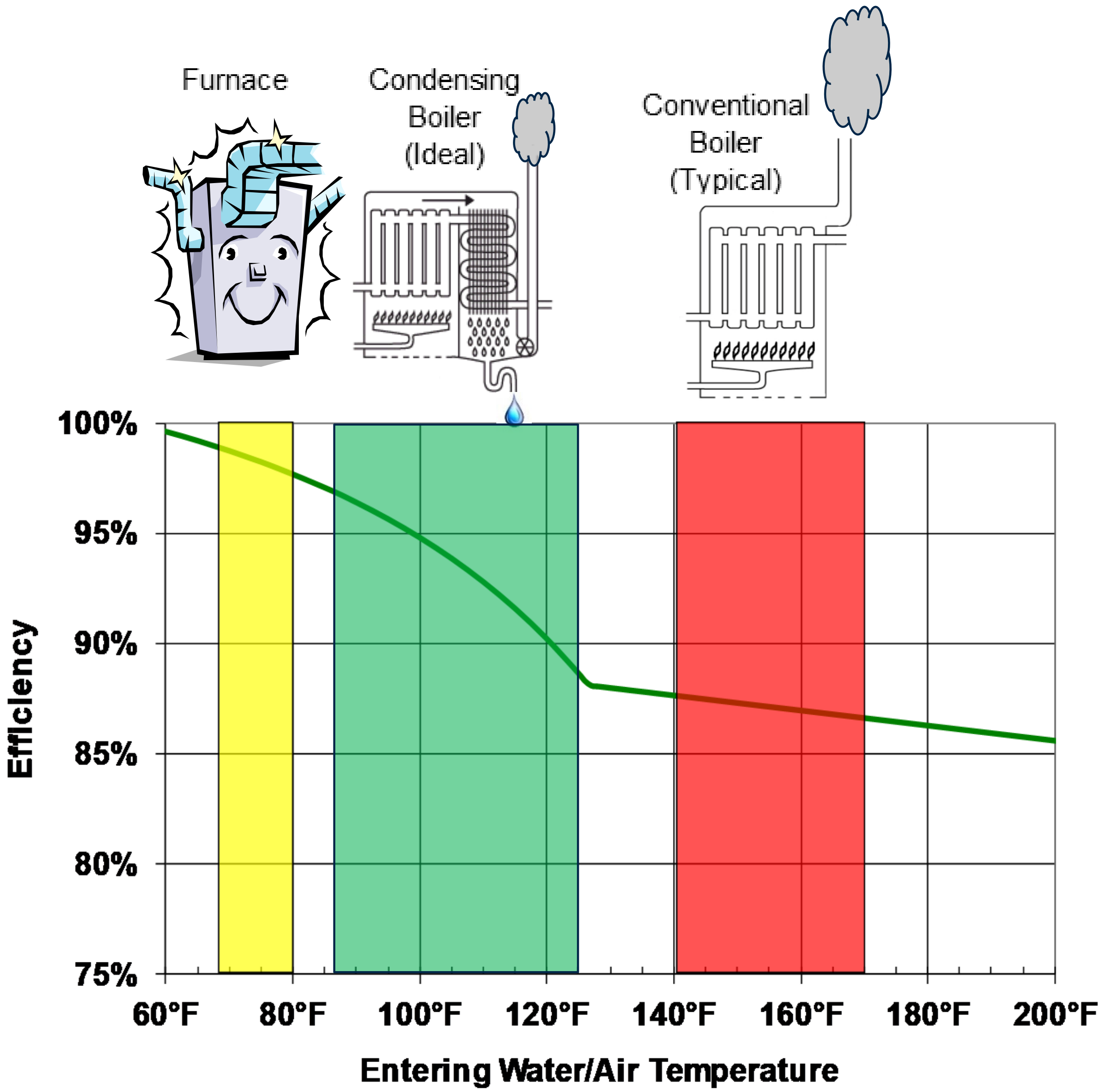
Factors Uniquely Impacting Condensing Boiler Efficiency

Unlike most natural gas–fired equipment, the operating efficiency of condensing boilers can change significantly with operating conditions. As noted in the previous section, much of the potential efficiency benefit of condensing boilers is associated with the extra heat captured when a portion of the water vapor generated by combustion is condensed instead of lost out the vent. The following operating variables can each have a significant impact both on whether and how much a boiler condenses.

Entering Water Temperature

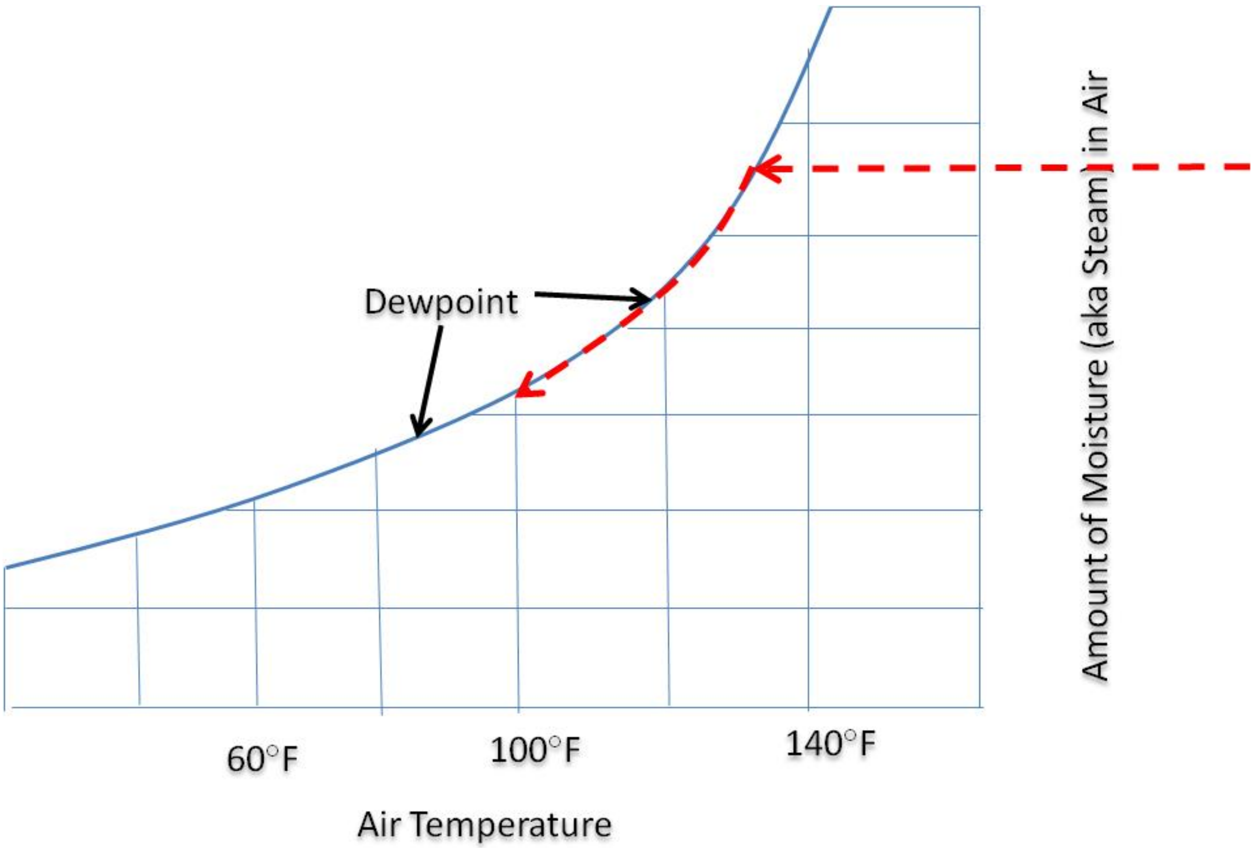
By far, the most important operating factor affecting condensing boiler efficiency is the temperature of the water entering the boiler (before it is heated). The line in Figure 6 shows how the efficiency of a condensing boiler changes with the temperature of the entering water. The efficiency begins to increase sharply as the entering water temperature drops below the temperature at which condensation starts, and it continues to increase as the entering water temperature drops. Note that the red bar shows the typical entering water temperature range for conventional boiler systems (140°F to 170°F), and the green bar shows the ideal entering water temperature range for condensing boilers (80°F to 125°F). On the other hand, the yellow bar shows that condensing furnaces don't have much of a temperature sensitivity issue because the temperature of the air they heat (70°F to 80°F) is always well below the typical point of condensation.

Figure 6. Boiler and Furnace Efficiency Dependence on Entering Water or Air Temperature



The sharp gains in efficiency that come with decreasing entering water temperature occur as the water entering the boiler gets far enough below the dewpoint of the flue gas mixture (downstream of the burner) to condense water vapor from the flue gas mixture. Just like how the moisture in the air condenses on a cold can of soda when the water vapor in the air is cooled down to the air's dewpoint temperature, the moisture within a boiler's flue gasses condenses when it is cooled down to the flue gas dewpoint. Figure 7 shows how flue-gas condensation starts and increases as the temperature drops below the dewpoint. The dewpoint is the curve at the top of the psychrometric chart where the air is saturated and holds as much water as it can for a given (dry bulb) temperature. Cooler air simply has a lower capacity to hold water vapor, so the moisture condenses (giving off a large amount of heat) as the flue gases are cooled below the dewpoint temperature. While a cold can of soda is usually well below the dewpoint of indoor air, the temperature of the water that enters a boiler is often above the dewpoint of the flue gases — especially in systems designed for conventional boilers where condensation is to be avoided.

Figure 7. Flue Gas Condensation Below Dewpoint



When condensing boilers are installed in buildings that are designed for conventional boilers, numerous factors can limit the ability to bring the entering water temperature down into the ideal operating temperature range. Boiler plant considerations such as boiler controls, boiler piping, and pump controls are some of those factors. The various devices used to heat the building (e.g., radiators, hot water heating coils in air handling units, and VAV reheat coils) can also be factors. These had historically been sized to provide adequate heat (in very cold weather) for boiler water temperatures maintained at 160°F when entering the boiler and 180°F when leaving the boiler. While hydronic (hot water) boiler systems typically do use outdoor reset controls to automatically reduce boiler temperature as the outside temperature rises, the sizing of these heating devices still places a lower limit on the degree to which the entering boiler water temperature can be reduced in mild weather.

Strategies to reduce the flow of boiler system water through the building can often improve efficiency by reducing the temperature of the water entering the boiler without significantly impacting the ability to provide adequate heat. For example, reducing the flow rate without changing the boiler plant supply temperature might provide a 15°F reduction in boiler return water temperature while only reducing the average water temperature in a radiator or air handler by 7.5°F. Variable speed pumping is the most common strategy to reduce entering boiler water temperature and still maintain a temperature drop though the building heating loop as the load drops in mild conditions. However, optimizing the control of boiler system variable speed pump controls typically requires the involvement of a controls contractor (in addition to a boiler service contractor). Moreover, this was noted by the previous CARD-funded commercial boiler study as having significantly less savings potential than the savings associated with outdoor reset control and improved staging and part-load control (CEE 2016). For these reasons, the research team decided to omit variable speed pumping optimization from the pilot study's streamlined boiler tune-up protocol.

Part-Load Operation

Unlike many types of heating equipment, condensing boilers tend to have a moderate increase in efficiency, instead of an energy penalty, as the load drops down into low part-load conditions. This is because at low part-loads, the flue gases travel through the heat exchanger slower and, therefore, get cooled down to a lower temperature (which means that more water vapor is condensed out of the flue gases). Since most condensing boiler systems in multifamily or commercial applications have multiple boilers, the way in which the boiler system controller manages the staging and balancing of heating load between multiple boilers is another variable that can impact operating efficiency.

Figure 8. Secondary Impact of Part-Load on Efficiency (Lochinvar, LLC, 2013)

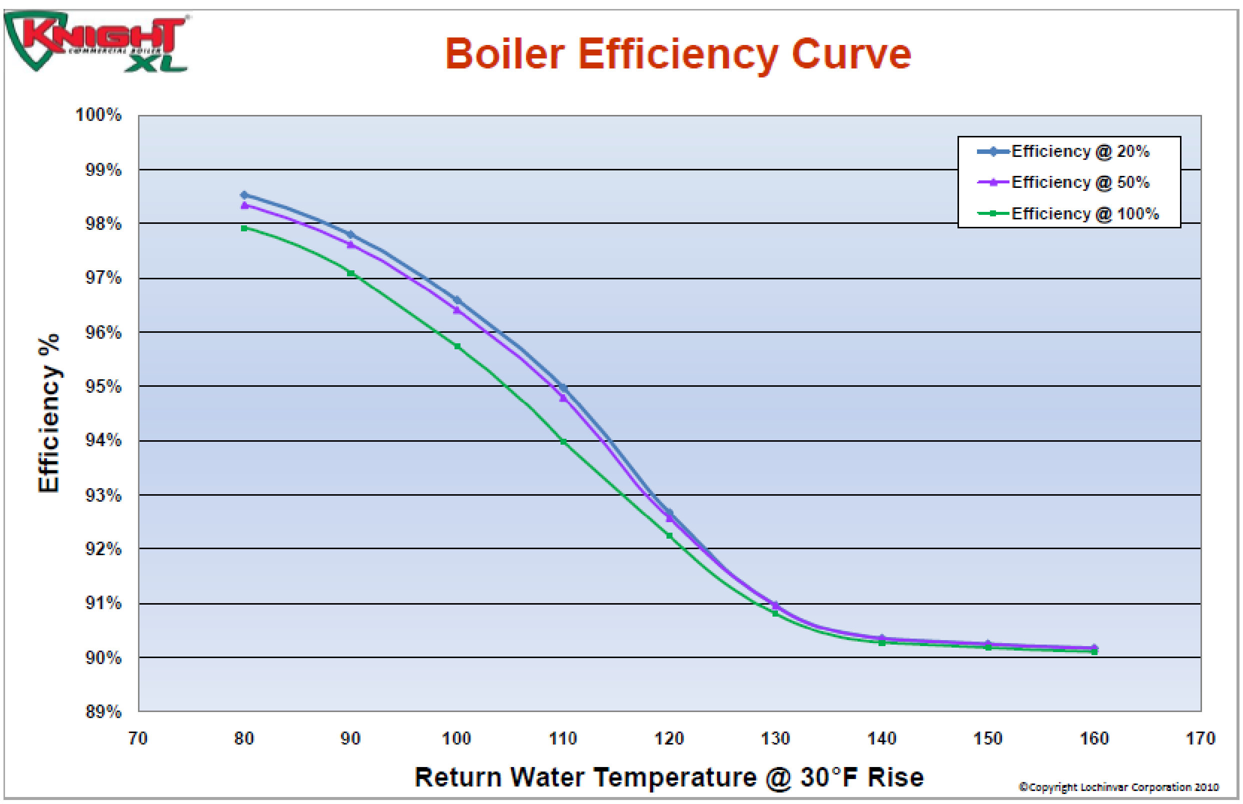


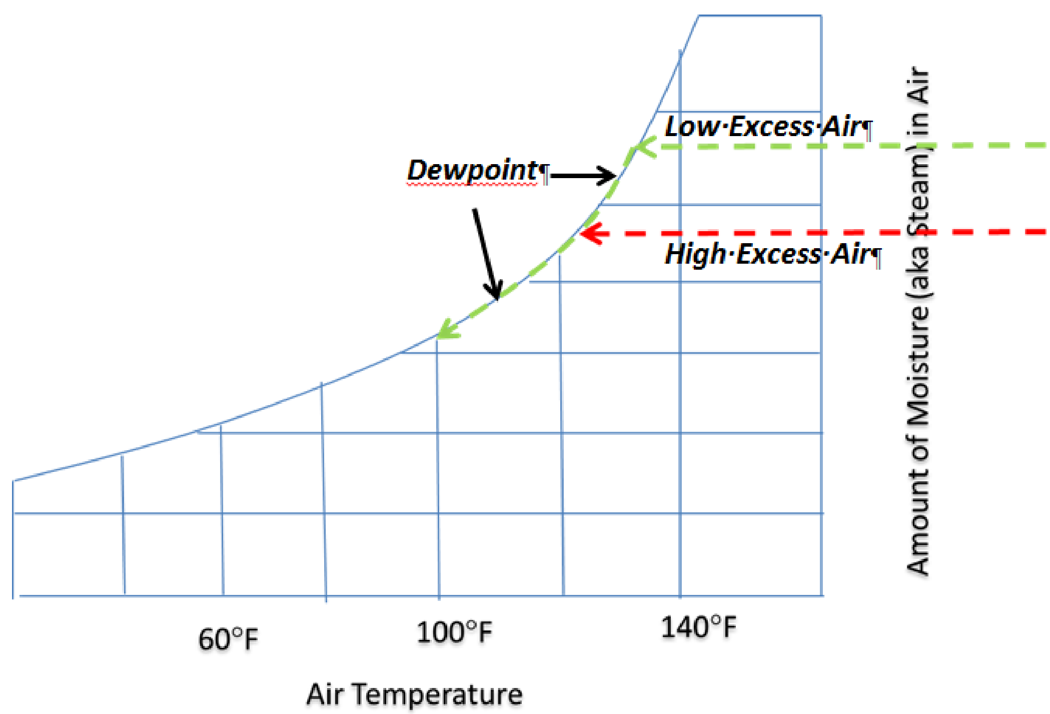
Figure 8 shows how part-load conditions (% firing rate) have an impact on efficiency that is secondary to (and varies with) the entering return water temperature. Note that this secondary impact is negligible when the entering water temperature is too high for condensation and tends to be largest once the entering water temperature is significantly below the temperature where condensation begins.

Unfortunately, this theoretical benefit of lower part-load operation is offset in some specific condensing boilers by the much less exacting control of air–fuel ratio at low firing rates. This factor has the potential for a dramatic increase in the percentage of excess air (and air–fuel ratio) at low part-loads. (See section below on classic burner tune-up and excess air issues for further explanation of the efficiency impact of excess air.) Besides some models with designs that allow for variations in air–fuel ratio at different firing rates, some specific models recommend adjustments at low firing rates that would reduce the efficiency much more than can be achieved by having the flue gases flow through the boiler heat exchanger more slowly.

Classic Burner Tune-Up and Excess Air Issues

While burner air–fuel ratio adjustments made during boiler tune-ups help optimize the efficiency of any boiler, the efficiency impact on condensing boilers is amplified. Tune-up savings for conventional boilers are achieved by reducing the amount of excess air that flows through the boiler and carries heat out the vent (i.e., the chimney). In condensing boilers, this excess air also dilutes the water vapor, thereby reducing the temperature at which condensation starts (i.e., the dewpoint) and the amount of water that can be condensed at any given entering water temperature below the dewpoint. The impact of the dilution of the water vapor by excess air on dewpoint and condensation is depicted in Figure 9.

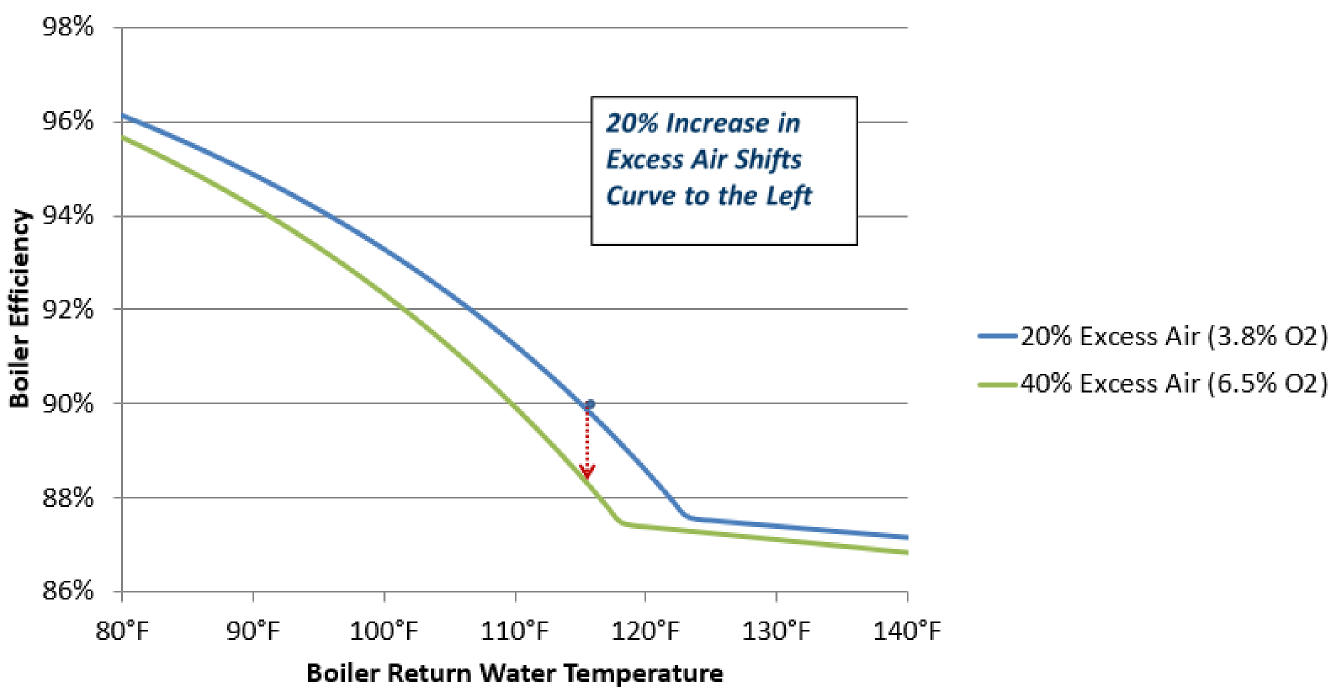
Figure 9. Excess Air Impact on Dewpoint & Condensation



An example of the resulting efficiency impact is shown in Figure 10. Note that having excess air beyond the minimum required effectively shifts the efficiency curve to the left, which indicates reduced efficiency at any given entering water temperature. When the entering water temperature is in the range of possible condensation (80°F to 125°F), this has a much bigger impact because of the reduction in the ability to condense.

Manufacturers' literature provides varying guidelines for the amount of excess air. For most products, there is a limited range of values as would be expected given the impact on efficiency. Some have guidelines that suggest more than a 2:1 variation in the amount of excess air is okay, and most larger boilers have guidelines for the measuring and fine-tuning of the amount of excess air at different part-load ranges, besides at 100% firing rate. As noted in the above section, some specific condensing boiler models have recommended increases in excess air at low firing rates that are high enough to dramatically reduce the operating efficiency below what it would be at full firing rate (with the lower excess air percentage).

Figure 10. Excess Air/Burner Tuning Impact on Efficiency



Although there appears to be significant savings potential associated with upgrading burner tune-up program protocols to better address the above issues for condensing boilers, the research team ultimately decided to omit such protocol changes from the scope of this study. The previous CARD-funded study on commercial condensing boilers suggested that the potential savings from updating burner tune-up protocols is less than half of potential from optimizing reset controls and comparable to the savings from optimizing staging controls.

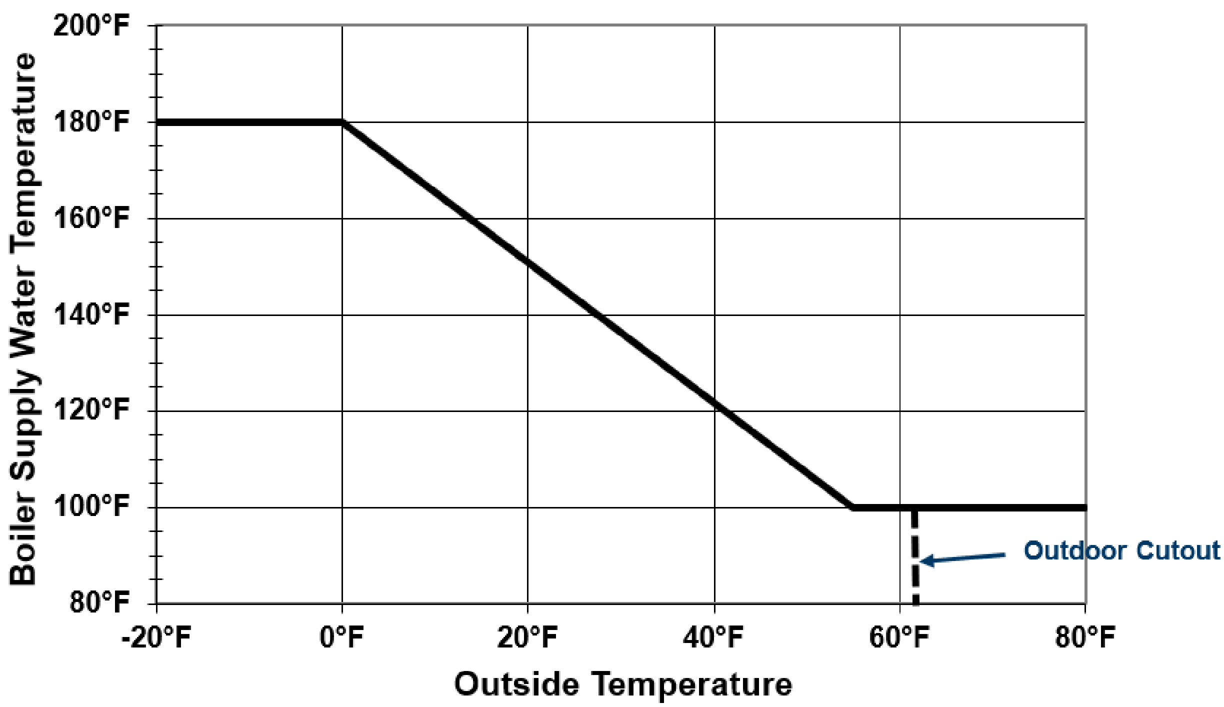
Key factors in the decision to exclude this from the project scope included the following:

- It appeared that the savings potential would vary dramatically between different makes and models of boilers.
- It appeared that the optimal tune-up protocol would also vary dramatically between different makes and models.
- The degree of technician specialization needed to perform detailed make and model specific burner tune-up procedures would likely limit the number of buildings within which each participating contractor could full employ the pilot protocol.
- The persistence of savings from burner tune-ups was expected to be significantly different than the persistence from temperature and staging control changes.

Outdoor Reset Control Impact on Load and Efficiency

After more than 30 years of utility rebate programs and 20 years of energy code requirements, the use of outdoor air reset controls has become nearly universal in commercial boilers used for space heating in hot water (hydronic) systems. A sample of how an outdoor reset control varies the boiler supply water temperature in response to the outdoor temperature can be seen in Figure 11.

Figure 11. Sample Outdoor Rest Control Curve



As the outdoor air warms significantly above the cold outdoor design conditions, the boiler supply water temperature is gradually brought down to a minimum temperature that can still adequately heat air during low load periods with mild outdoor temperatures. The dashed line indicates that an outdoor cutout (also called a warm weather shutdown) feature is often used in conjunction with an outdoor reset control to shut down the boiler system completely in warm weather. Although most boiler reset controls use outdoor temperature as the indicator of when and how much to reduce the boiler water temperature, some commercial buildings with BASs will use feedback from the heating valves to decide when the boiler system temperature can be reduced and still provide adequate heat to all HVAC systems. Whether they are controlled based on outdoor temperature or valve positions, boiler reset controls ideally provide significant heating load reduction on heating plants in all systems, and can increase the operating efficiency of condensing boilers in systems that can provide adequate heat at low boiler temperatures.

Load Reduction with Outdoor Reset Control

The most significant savings from boiler outdoor reset controls is generally from reducing the amount of overheating of the conditioned space — both intentional and unintentional. Intentional overheating is when an occupant chooses to heat a space to a temperature above what the building owner considers to be the highest heating season indoor temperature needed to accommodate reasonable occupant expectations for comfort (e.g., 72°F), and a thermostat or other control device is set to do so. Reducing the boiler system water temperature in mild weather will put an upper limit a system's ability to heat above the owner's intended comfort range. Unintentional overheating occurs when a failed control device or poor design causes a space to get heated above the temperature that the building owner and occupant intend. The following are common situations that yield unintentional overheating:

- An individual apartment unit's zone valve sticks open and has hot water flowing through it continuously.
- Water leaks by a "closed" valve on an air handler or variable air volume box so that heating is provided when it is not needed.

Increases in energy use associated with unintentional overheating can often be greatly amplified by the occupant's or HVAC system's response to the unintentional overheating. If excessing overheating occurs in an apartment unit, a common occupant response is to open windows to compensate, which can cause an even higher heat loss from the radiators that are heating continuously. Similarly, a leaky valve in a commercial building can cause a cooling system to run harder to compensate, so the problem leads to increases in both space heating and space cooling energy use. Lower boiler system temperatures will also reduce heat loss from boiler system piping to unconditioned spaces and through exterior walls, but this impact tends to be much lower than the savings associated with reducing overheating.

Outdoor Reset Control Impact on Condensing Boiler Efficiency

While the load reductions from boiler reset controls have long been recognized as beneficial for all boiler types, the savings are often amplified for condensing boilers because they are able to condense water from the flue gases more when the boiler temperature is reduced in ranges below around 120°F. This condensing boiler sensitivity to the entering water temperature was already detailed above in the Entering Water Temperature subsection. In older buildings with heating elements designed for high boiler water temperatures, this amplification of efficiency might only occur during very mild portions of the heating season, while newer systems that are designed with low condensing boiler water temperatures in mind can see this additional condensing boiler efficiency improvement throughout most of the heating season.

Staging Control Impacts on Boiler System Efficiency

Optimized boiler staging control is a balance between trying to operate the boiler system so that it provides the highest theoretical efficiency under steady-state conditions and not overreacting in a way that leads to wasteful transient behavior. The two aspects of this balance are outlined within the two subsections below. Note that while these issues apply to all boilers, the impacts on efficiency tend to be exaggerated for condensing boilers because their operating efficiency is more sensitive to operating conditions. The tendencies of condensing boilers to operate more efficiently at part-load — as well as their tendency to have lower thermal mass and react much faster than traditional boilers — also changes the way that controls should be optimized for condensing boilers versus non-condensing boilers.

Staging for Optimal Steady-State Efficiency

For buildings with multiple boilers, the most efficient way to stage condensing boilers to handle a continuous, steady heating load is generally to have as many boilers as possible operating at a time with each at or near its minimum load. This maximizes the part-load efficiency gain that was demonstrated in Figure 8. This staging strategy to optimize a condensing boiler plant is the opposite of the traditional, optimum approach for staging multiple non-condensing boilers. A non-condensing boiler system generally is optimized by staging on as few boilers as possible, with each operated at or near its full-load capacity. Although real building heating loads are not constant over longer time frames, the general goal of optimizing a condensing boiler system by staging on a higher number of boilers and operating each at a firing rate that is a fraction of its full capacity is a key consideration in optimizing the control of commercial condensing boilers.

Staging Impact on Transient Inefficiencies

While aiming for optimum steady-state operation is an important consideration as noted in the previous subsection, the real variations in boiler system heating load over the course of a day brings added challenges. A boilers system's staging controls overreaction to sudden or short-term changes in heating load can lead to boiler cycling inefficiencies that offset the efficiency gains made by trying to stage the boilers to provide the optimal efficiency for the load at each moment in time. Three key inefficiencies associated with staging boilers on and off are noted in each of the following subsections. Optimal boiler system operation requires a balance between providing staging that optimizes operation for the load at each moment while avoiding excessive cycling that can accelerate wear on equipment and cause the energy inefficiencies described below.

Purge Losses

Each boiler on/off cycle has a certain amount of energy losses associated with purging the combustion chamber. This purging is done as a safety measure both before and after each boiler on/off cycle. The boiler's combustion air fan blows air through the combustion chamber and boiler heat exchanger for a fixed amount of time before the gas burner is started, then again for a different fixed amount of time after the gas burner is turned off. As the cold combustion air is blown through the boiler, it absorbs heat from boiler's heat exchanger before being exhausted outside through the vent. These pre- and post-purge energy losses have a very small impact on overall efficiency when a boiler runs for an hour or longer each time its burner is cycled on, but those losses can bring down the efficiency a modest amount when severe short-cycling occurs.

Thermal Mass Effects

The energy initially needed to heat up a boiler and its dedicated piping poses an inefficiency that negatively impacts a system each time another boiler is activated. Most condensing boiler systems (and large non-condensing boiler systems) stop the flow of boiler system water through idle boilers and allow them to cool down so that they eventually reach the boiler room temperature after being off for a long time. As a boiler is started up, its heat exchanger metal and all of the water in both the heat exchanger and the idle part of the piping must be heated back up to the current boiler system operating temperature before it can contribute to useful heating of the building. This impact on system efficiency tends to be much large for non-condensing boiler systems because they tend to have a much higher weight of water and heat exchanger metal for the same amount of heating capacity. However, the effect can also significantly impact condensing boiler system efficiency in certain situations. One such example observed in a recent study (CEE 2016) is the daily cycling on of all six boilers during the morning warm-up (i.e., the time when all air handlers were turned on at once to bring a building back up to temperature after the temperature was set back substantially overnight). In this case, only one or two boilers were needed to handle the heat load throughout most of the day, but the staging controls overreaction to the sudden morning warm-up load required the boiler system to heat up four or five boilers that were then left idle for nearly 24 hours until the next morning's warm-up period.

Start Up Load Adjustments

Many boiler controls — especially electronic on-board boiler controls — force operation at a certain part-load level for a period of time before the staging control can optimally adjust the firing rate to the most efficient level. Again, this impact is generally minimal when boiler cycling is reasonable (i.e., fewer than two cycles per run-hour), but this impact can become larger when short-cycling occurs and when the fixed start-up time period is a large percentage of the boiler's on-time. However, the negative impact of this effect is limited by the difference in efficiencies at the optimal part-load condition and the part-load condition that occurs during the fixed start-up period. Documented examples of this inefficiency occurring (CEE 2016) include a single boiler that short-cycled severely enough that many on/off cycles were shorter than the high firing rate start-up period, and a system that had three successive boiler stages cycle on before even the first boiler had completed its high firing rate start-up period (then all three stages would cycle off again within a few minutes). The presence and potential severity of such fixed firing rate start-up periods varies dramatically by boiler make and model, but appears to generally be more of a concern in systems with boilers with firing rates below 1,000,000 Btu/hour each. These smaller boilers are more likely to have a high fixed firing rate at start-up, while larger boilers tend to have a lower fixed firing rate at start-up.

Project Objectives and Relevance to CIP Goals

The goal of this project was to develop and field test an expanded scope commercial boiler tune-up protocol that goes beyond burner adjustments to provide a comprehensive review and adjustment of boiler control settings to increase energy savings. More specifically, the scope was expanded to include the optimization of boiler temperature and staging controls. The field tests were implemented to evaluate costs, savings, operations, persistence, and market and implementation issues for the protocol. In short, the study aimed to provide information that utilities can use to plan CIP program additions or modifications that achieve more boiler tune-up savings toward their savings goals, and that can also be used to add boiler control adjustment measure(s) to the Technical Resource Manual (TRM).

At the onset of the study, commercial boiler tune-up programs that were narrowly focused on burner air–fuel ratio adjustments provided about 8% of total CIP portfolio savings for natural gas utilities in Minnesota. Enhancing boiler tune-ups by including controls optimization appeared to have the potential both to dramatically increase the per-participant savings for these programs and to expand the pool of buildings that could benefit. Any significant increase in boiler tune-up program savings would have a positive impact on gas utilities’ ability to meet program energy savings goals.

Market Assessment

Researchers began by conducting a market study to guide the project and provide a basis for using field results to estimate the potential impact of subsequent program offerings. The market assessment goals were to evaluate market issues related to the general commercial boiler/building stock, the portion of the boiler/building stock that has participated in boiler tune-up programs, possible program delivery approaches, and expected end-user acceptance. These market findings were used to establish goals for the mix of boiler system characteristics to target in test sites and to help determine the range of characteristics to be addressed by the tune-up protocol. After the test sites' tune-up savings were quantified, the market study data was also used to project the potential impact and cost-effectiveness of a large-scale program.

Methodology

The market study consisted of a combination of interviews and a review of quantitative boiler market data.

Industry Interviews

Interviews with local industry contacts were a critical part of the market study. Information was gathered through discussions and follow-up correspondence targeting 20 local market players including the following: 3+ utility program representatives; 5+ boiler manufacture representatives or wholesale distributors; 3+ contractors; 6+ building owners or managers; and 3+ energy program or recommissioning providers. While some questions were consistent across multiple types of contacts, there was also a significant degree of specialization of the questionnaires to the expected level of knowledge and perspective of each group. The actual number of organizations of each type that had a contact interviewed are summarized in Table 4. These interviews provided information, insights, and impressions from a variety of market player perspectives.

Table 4. Summary of Industry Contacts Interviewed in Market Assessment

Industry Segment	Number of Organizations Represented in Interviews
Natural Gas Utilities	3
Boiler Manufacturer Representatives[a]	5
Boiler Service Contractors	4
Building Owners & Operators	6
Recommissioning Providers & BAS Contractors	3

a) This category included one local boiler distributor, who tends to deal with smaller boilers than the manufacturer's representatives.

Review of State Boiler and Pressure Vessel Database

In addition to interviews, the project team analyzed quantitative data, including information from the state boiler inspection database and utility tune-up program progress reports. These sources provided valuable information to assist in projecting the prevalence of boiler makes and types that could impact the cost-effectiveness of boiler tune-ups. Along with the information from interviews, these sources provided information for estimating the potential participation associated with adding the new service to current boiler tune-up programs, as well as any possible market opportunities beyond the end users that have historically participated in these programs.

The state boiler and pressure vessel database proved to be the most useful source of data on the existing stock of hot water heating boilers in Minnesota. However, the database was not as precise as identifying condensing boilers — the primary focus of this pilot project. While "condensing" was an option that could be selected to characterize a boiler, it was an option within a field that included numerous other descriptive options that were not mutually exclusive (e.g., "fire-tube" or "water tube"). Close review of the data made it clear that the "condensing" option was seldom (or, at best, inconsistently) chosen, even for makes of boilers that are exclusively condensing boilers. Therefore, researchers used boiler make as an alternative way to estimate the number of condensing boilers. For those manufacturers that make both condensing and non-condensing boilers, information from trade ally interviews was used to estimate the percentage of each boiler make that could be assumed to be condensing.

Market Assessment Results and Discussion

High-Level Market Issues

The market study's interview responses from trade allies were very encouraging regarding both the level of interest and expected market size for expanded scope commercial boiler tune-ups. Seven out of nine trade ally respondents rated their interest at a 6 on a scale of 1 to 6, while the other two chose a rating of five. There was also a nearly universal expectation among the trade allies that the number of participants in a full-scale expanded scope boiler tune-up service program would be about the same as the current number of burner tune-up program participants.

The level of building owner interest in the expanded scope tune-up service was not clearly determined from the market study. Six on-site operators gave an average level of interest of 2 on a scale of 1 to 6, but the one building owner interviewed did not report a level of interest.

Boiler service contractors were overwhelmingly in favor of combining the enhanced scope with traditional burner tune-ups. Contractors also overwhelmingly favored the name "Complete Boiler Optimization" for this combined burner tune-up and controls optimization service. On the other hand, manufacturer representatives and recommissioning providers expressed some interest in the controls tune-up portion of work being available as a separate service that could be performed by a recommissioning provider, HVAC contractor, or BAS contractor. These same industry representatives expressed some interest in having the word "recommissioning" in the service name. One contractor interviewed does high volumes of both BAS system work and boiler service work and agreed with boiler service contractors that it would be best to provide a combined service with the name “Complete Boiler Optimization” or “Boiler Optimization.” The contractor also expressed concern about confusion in the market if the burner and control tune-up services were packaged separately, and felt that the combined service was much more “sellable.”

Interview responses did not provide a clear, consistent idea of the expected added cost for the expanded boiler tune-up scope. One contractor reported already including that within their current price, while a second estimated two additional hours at $150 per hour for a three-boiler system. The two other boiler service contractors were less committal, with one indicating at least an additional hour per boiler, and the other not giving any specific time estimate. These same contractors generally expected the controls tune-up service to take about four hours if it was done as a separate trip. Manufacturer representatives — many of whom have their own service staff — gave very inconsistent estimates of the added time for the additional controls tune-up work. For a system with three boilers, their time estimates ranged from under 30 minutes to as much as a full day. Most answers were in the 1–2 hour range. These varying reports made cost estimation difficult, but most seemed to give a clear indication that the costs for the intended new controls tune-up scope would be less than, or at most comparable to, the cost of tradition burner tune-ups.

Table 5. Estimates of Condensing Boiler Share of the Commercial Hot Water Heating Boiler Market in Minnesota

Data Source	Market	Percent Condensing
Manufacturer Representatives	New Boilers	82%[a]
Distributor (typically smaller boilers)	New Boilers	60%
MN DLI Inspections List[b]	New Boilers	79%
Boiler Contractors (weighted average)	Existing Boilers	36%
CARD Potential Study[c]	Existing Boilers	54%
MN DLI Inspections List[b]	Existing Boilers	23%[c]

a) The 85% value reported represents the median of four responses. Individual responses ranged from 75% to 99%.

b) This list nominally includes all boilers or boiler systems in Minnesota with a total input rate of ≥ 750,000 Btu per hour. The value for new boilers is based on the percentage of boilers manufactured in 2016 or 2017, which were the most recent two years in the database at the time of analysis.

c) This information was self-reported by contacts for 84 existing buildings in Minnesota with hot water space-heating boilers (CEE 2018).

Another key market consideration is how much inroads condensing boilers have made into the commercial boiler market in Minnesota. Table 5 summarizes a number of estimates of the percent market share of commercial boilers among both new boiler installations and existing buildings. The Minnesota Department of Labor and Industry’s Inspections List is generally considered the most reliable estimate for each portion of the market, and it estimates that 79% of new boilers and 23% of existing boilers are condensing (DLI 2018). However, this source does tend to miss small boiler plants. Also, note that the 36% of existing boilers reported by boiler service contractors is likely to be more representative of boiler tune-up program participants than DLI’s comprehensive list of larger boilers throughout Minnesota.

The database also showed that about 44% of existing hot water space heating boilers are in multifamily or education buildings. All four of the contractors interviewed noted that they service education buildings, with most indicating at least one other building type, and only one of the four servicing multifamily buildings. Additional, minor building categories that each represents from 7% to 11% of the hot water heating boiler market in Minnesota are: government, places of worship, hospitality, and healthcare.

Detailed Findings Relevant to Tune-Up Protocol Design and Implementation

Differences in control interfaces and control logic across boiler brands impact the protocol form and reference materials needed, so understanding the importance of different brands of boilers in the local market was an important consideration in developing the protocol. Based on the DLI data, it appears that three condensing boiler brands dominate every other brand, with each of the following having at least 20% of the market share:

- Aerco
- Fulton
- Lochinvar

Others that were noted as having a market presence in Minnesota but appear to each represent 7% or less of the market are as follows:

- KN (currently under ATH brand, but previously Hydrotherm)
- Laars
- Parker
- Patterson Kelley
- RBI
- Viessman
- Weil McLain

It will be most important to have forms and reference materials that work well for Aerco, Fulton, and Lochinvar boilers, which together appear to represent about three-fourths of the existing commercial boiler market (except for boiler plants with input rates less than 750,000 Btu per hour). However, consideration should also be given to having the protocol and reference materials support several other boiler control brands.

While most industry contacts favored having the expanded scope controls tuning include multiple site visits with at least a month between visits (or one visit and remote follow-up through BAS) to verify optimization over a range of outdoor temperatures, some contractors were less insistent on the need for more than one visit. Burner tune-ups are generally carried out with a single site visit, so the additional trip would add significantly to the additional cost associated with expanding the scope to include boiler controls. There were also some indications that not all technicians who perform burner tune-ups would be fully capable of performing the boiler controls tune-ups, although this varied among the industry contacts, and it was noted that specific program training could be very important in this regard. Having a protocol that only specialized technicians can perform could both limit the ability to quickly scale up the service and could lead to a loss of savings if a different technician responds to a callback for a controls tune-up site.

The market study findings were mixed in regard to a couple of possible barriers to successful implementation: BAS access and boiler control passwords. Some contractors and manufacturer representatives indicated that a different technician, or even a BAS contractor, would be needed for BAS boiler temperature setpoint changes, while a number of responses suggested that the boiler service technician could typically work with an on-site operator who would make BAS temperature control changes for the boiler system. Interviews suggested that about 75%–80% of boiler systems have their temperature setpoint passed down from a BAS system,[2] so barriers that would prevent BAS system boiler temperature setpoints from being changed at the time of the site visit could be a serious problem. Some contacts noted that this can typically be prevented by making it clear to the building owner that they need to have staff that are capable an authorized to make BAS setpoint changes on-site at the time of the controls tune-up. For boiler controls with password lock capability, most indications were that only a small percentage of boiler controllers ever have the password changed from the factory default. Contractor technicians can easily access key boiler tune-up control settings whenever factory default passwords are retained. On the other hand, one or two interviews suggested that more than half of controllers may have had their passwords changed by a contractor to limit operator access or to make it more difficult for other contractors to service. These two issues were considered in the protocol development and could be important considerations for how large-scale program delivery will be carried out most efficiently.

Most industry contacts reported that of buildings with condensing boilers, less than 5% are hybrid, which is a combination of one or more condensing boilers with one or more non-condensing boilers. While a previous CARD study found very significant opportunities for operational improvements in hybrid systems, their increasing scarcity and complexity suggests that the scope of this program should not address them. It appears that the low number of these hybrid systems would generally be better served by more comprehensive recommissioning services than by this pilot program's protocol.

High-level contacts within boiler service contractors had mixed preferences regarding the media for the controls tune-up protocol form and any reference materials. Most said that a paper form would be okay, with one of four having a strong preference for a paper form. Three of the four said a tablet computer would be okay, and two strongly preferred the tablet computer. The one contractor that was not okay with a tablet computer mentioned the possibility of technicians taking pictures with their cell phones, but noted the importance of having a system that files the pictures right away. Only one of four contractors noted that a laptop computer would be okay. There were similar responses to a question about the format for reference materials, with three of four contractors being okay with paper forms. However, all four were okay with at least one form of electronic media with three noting tablet

[2] One large BAS and boiler service contractor also reported often using the BAS to directly control the staging and firing rates of individual boilers, while all other local contacts indicated that it is rare to use anything other than an onboard boiler controller or dedicated boiler controller in the boiler room to control the staging and firing rates of individual boilers.

computers as acceptable, two noting cell phones as acceptable, and one noting a laptop computer as acceptable.

Field Study Methodology

Research Questions

This project primarily set out to address the following research questions:

- How much savings can be achieved by adding boiler temperature and staging control optimization to the scope of condensing boiler tune-ups?
- What is the expected cost and cost-effectiveness of adding this scope?
- What is the persistence of savings from boiler temperature and staging control adjustments?

The development, implementation, and verification of the pilot controls tune-up services also provided insights related to a number of secondary program design and implementation issues that are noted below:

- What settings should be targeted for typical buildings, and when should those targets be customized?
- Should the service be limited to a one-time visit or potentially include follow-up fine-tuning?
- How can tune-up changes be reliably documented, and their energy impacts reliably estimated, from data collected during larger-scale program implementation?
- How do the savings and first-cost variations between sites correlate to characteristics that could be used for program screening or targeting?
- How often can the controls tune-up be fully carried out by a boiler service technician in conjunction building operations staff, and how often is a separate BAS contractor needed?
- What training for on-site staff or “leave-behind” materials could help maximize savings and persistence?
- How much of the above savings could be expected for systems with only non-condensing boilers?
- What program requirements, processes, guidance documents, contractor training, and contractor certification requirements are needed?
- How much customization for various boiler controllers is needed to provide useful direction to technicians?

Control Tune-Up Protocol Development

Background Research & Guidance

Researchers looked at protocol design issues from a number of perspectives. This began with review existing protocols with similar goals to identify the most effective elements to use in the new protocol. This included reviews of:

- Protocols for existing utility burner tune-up programs;
- Boiler manufacturers’ literature outlining initial start-up procedures;
- Boiler commissioning checklists;

- Contractor training materials;
- Operator training materials; and
- Contractors' boiler servicing checklists.

Secondly, researchers consulted with a number of manufacturers' representatives, distributors, and other trade allies regarding both the general design of the tune-up protocol and its technical details. We sought guidance on issues such as: controller makes, models, and boiler configurations that should be covered; recommended control setpoints; the look and feel of the protocol; the primary media for the protocol (e.g., hard copy or tablet computer); the level of detail for various portions of the protocol; and items to include within the form versus those better made available as "handy" reference material.

Finally, researchers considered the market study results outlined previously in the Market Assessment Results and Discussion to guide the scope of the controls tune-up protocol. They balanced the desirability of a protocol that can be used in as wide a range of situations as possible against the limited funding to conduct this field research. While the general goal of the boiler tune-up protocol is applicable to any situation, it was generally expected to be most effective in practice if it included detailed guidance that was specific to the controllers and configurations encountered at the pilot tune-up test sites. Although there is a multitude of boiler and controller makes and models available, this field study focused on a limited number of specific makes and models that are representative of common systems in Minnesota's commercial buildings based on the market assessment results.

Development of Draft Protocol

The team developed a draft protocol that both documents existing boiler control conditions and guides technicians in making and documenting control setting changes. The protocol was broken up into the following main sections:

1. Site level summary information, including make, model, and number of boilers; indications of over- or under-heating; loads served by the boiler; and type of boiler temperature controller.
2. Detailed observations of the operation and set-up each boiler.
3. Observations of potential issues with the controller's outdoor temperature sensor.
4. Key system temperature observed values, observed controller settings, optimal setting recommendations, and final "tuned-up" settings.
5. Key staging control observed controller settings, optimal setting recommendations, and final "tuned-up" settings.

The control tune-up protocol did not include any direction regarding burner air–fuel ratio adjustments. While control tune-ups were expected to eventually be conducted at the same time as burner tune tune-ups when they reach large-scale program deployment, this project aimed to evaluate only the additional savings that temperature and staging control optimization can achieve (without any confounding effects from burner tune-up savings).

Due to inconsistencies in preferred media form between contractor (and in some cases within the same organization), the draft was developed in the form of a Google Sheet that could be used in any of the following ways:

- Shared in its native format to be electronically filled out using a wide variety of devices;
- Converted to a PDF or Microsoft Excel spreadsheet and shared with organizations that wish to use an electronic form but do not have seamless access to Google Sheets; or
- Printed out to be used as a paper form.

The first draft protocol was a combination checklist and form developed with a high degree of emphasis on ease of use in electronic form for a particular make and model of boiler controller. Interactive features included in this design included the following:

- After the necessary inputs were entered for an item, its checkbox would be checked off and the entire row would be reformatted with gray text and italicized so that outstanding items would stand out in comparison to those that had been completed;
- Items that are not applicable based on the inputs for previous items would be automatically checked off and grayed out (e.g., if the system has two boilers, no observations for a third boiler would be requested); and
- Input label names would change based on the nomenclature and abbreviations used in the display for the specific make and model of boiler controller.

This last feature was not yet interactive within the draft protocol, but the input labels (and their order) were highly customized to the make and model of boiler controller at the initial field trial site.

Field Trial, Feedback, and Refinement

The initial draft protocol went through extensive editing as it was adapted to work for a wider variety of boilers and edited in response to feedback from a variety of sources. Key feedback sources included the researchers' industry partner, the initial field trial experience, reviews by participating contractors, reviews by manufacturers' representatives, and the experiences with implementation across all tune-up sites. While much of the core content of the original draft protocol was maintained throughout subsequent rounds of revision, there were significant high-level changes to the primary target media and approach to customization for various boiler controllers, as well as the addition of a few key observations.

The initial field trial provided two key insights that informed changes to both the formatting and content. Although organizational leaders for the contractor performing the initial field trial had indicated a strong preference for the protocol to be employed using tablet computers, the field technician had a strong preference for using a paper version of the form. Inconsistent mobile network access form mechanical rooms and limited capabilities beyond the organization's work order tracking software were reported as key factors preventing the routine use of tablet computers in an interactive manner while servicing equipment. This was a key factor in the decision to focus on a format that can be readily used in paper form in lieu of efforts to make a user-friendly electronic protocol form. The second key finding in the initial field trial was the discovery of a lack of staging coordination between the two boilers at this site. This highlighted the importance of verifying both the outdoor temperature sensor and the proper staging control setup. This led to additional items being included in the form, as well as the inclusion of more specific direction regarding the correction of these issues within the protocol.

As researchers started refining the protocol for application across all of the participating sites, they conducted in-depth evaluations of the temperature and staging control logic and settings for a number of BAS systems and three more of the most common boiler controllers. It became clear that, although there were different conventions for the naming of key temperature programming parameters and logistics for accessing these parameters, the basic temperature control logic for the vast majority of cases is virtually the same. Therefore, the approach to customization was changed to the development of single protocol form that could be used across all different controllers (including BAS systems), with separate supplemental documents providing quick-reference guides for each different make of controller. These supplemental guides were developed to provide clear direction on navigating the controller menus and correlating the names within the controller menus to the standardized parameter names used in the protocol form. The subsequent working drafts that were developed for field trial use standardized the temperature control parameters for nearly all situations, but were more limited in terms of boiler staging control characterization. This was because of the wide variety of staging and part-load control logic across the different controllers. Review from a limited number of industry contacts at this time led to additional minor refinements before the protocol was applied to all field test sites in February of 2020.

The larger scale use of the protocol on the 17 test sites also provided some lessons that led to some key additions. As the first tune-ups were performed, the importance of comprehensively addressing staging and cycling control became clearer, and controller-specific versions of a form for addressing staging and cycling control settings were quickly developed as separate tabs within the worksheet that housed the main protocol form. Close on-site consultation with a manufacturer's representative technician was also very helpful in narrowing the focus of staging variables to adjust for one specific controller that has an unusually extensive array of staging control variables.[3] Other key items that were added to the protocol during the course of moving through the 17 sites were:

- Observation of system pressure and direction to see that low pressure situations were addressed before lowering boiler system temperature settings; and
- Observations of current boiler cycling and staging behavior, and post-tune-up observations for a period of time in cases where tune up changes are expected to lead to either significant temperature reductions or significant changes to staging and cycling behavior.

Following the implementation of the controls tune-up protocol at the test sites and subsequent refinements based on field experiences, researchers circled back to several local industry contacts to get feedback on the updated, complete protocol. This feedback led to additional minor refinements that were incorporated into the project's final protocol, which is further detailed in the Results section of this report.

[3] This technician happened to be scheduled to visit the site to address a boiler problem unrelated to the boiler controls tune-ups.

Site Recruitment and Selection

The field study site recruitment challenge for this project was complicated by the importance of working closely with a limited number of boiler service technicians to implement a complex new service concept. This consideration, along with need to match the program concept's focus on providing the controls tune-up as an expansion of regular burner tune-up services, pointed to a two-step recruitment process that would involve:

1. Recruiting contractors with significant buy-in into testing the controls tune-up service; and
2. Leveraging the contractors to recruit from amongst each one's existing customer base.

Each of these steps is described further in the following sections.

Contractor Recruitment

Researchers originally planned to work very closely with two or three contractors who would provide the control tune-up service. These target numbers were chosen to balance the need for a high level of consistency and quality control with the need to obtain results representative of a range of contractors. It was also important to have multiple contractors, as there is a tendency for each contractor to work with a limited number of boiler makes and models. Therefore, having more contractors would help the study cover wider range of boilers as well as protect against the results being overly skewed by the performance of one individual contractor's technician.

Contractor recruitment began early in the project so that the participating contractors could assist with both the development of the control tune-up protocol and the recruitment of test sites. Researchers drew on their own experience with local mechanical contractors and the market assessment results to find a limited number of quality contractors to work with research staff on this project. Contractors were targeted based on a combination of recommendations from other local industry contacts, level interest in the controls tune-up service, volume of customer base, and the type(s) of both buildings and boilers that each primarily served.

Contractor recruitment efforts were primarily carried out by the principal investigator, with an on-staff professional salesperson making initial contacts with a limited number of the targeted contractors. To secure adequate provider commitment, field study funding was offered to pay for the contractors' time to review the protocol during development and to train a technician in the protocol, in addition to time paid for providing the control tune-up service to individual test sites.

To get close to the number and variety of sites that were targeted, researchers successfully recruited a total of five contractors, three of which provided the overwhelming majority of participating sites. The other two contractors recruited multiple potential sites, but most of these potential sites did not participate because they were screened out by the site selection criteria or because of inadequate end-user interest and follow-through.

Owner and Site Recruitment

The researchers worked almost exclusively through the participating contractors to recruit appropriate test sites from amongst buildings where the contractors have long-term service contracts. The one exception to this was researchers' direct recruitment of a multifamily building owner who controls a large number of buildings, but these efforts did not successfully recruit any test sites. To aid contractors with recruitment, researchers provided a one-page flyer outlining the benefits and commitments associated with participation and a website link to project information. Based on the contractor and the end user, CEE's principal investigator was also involved to varying degrees in discussions with end users' key decision makers about the boiler controls tune-up service benefits. Once an end user noted significant interest in the project, the contractors' knowledge of the end users' buildings was used to identify the buildings that would most likely fit the researchers target characteristics.

Researchers then conducted on-site screening visits to gather extensive information about the buildings, boiler systems, and gas metering to further evaluate each site. For most sites, this on-site information was supplemented with utility billing history data and the gas utility's evaluation of the ability and cost to retrofit a pulse counter output onto the existing gas meter. Contractor estimates of the cost to install gas submeters were also taken into consideration for some sites.

The findings from site candidate evaluations were compared to a detailed set of target numbers within several categories of key characteristics that the research team had developed based on a combination of the market study findings and practical field monitoring considerations. The researchers' goal was to recruit approximately 30 potential sites that would allow final selection of approximately 20 sites that provided the best matches for targets among a wide variety of key site and system characteristics. A total of 32 buildings were selected for screening through site visits, and researchers selected a total of 18 sites for participation, one of which ultimately did not participate because of the building owner's failure to be able to provide adequate access to BAS system trend data.

After narrowing down the screening to appropriate sites, test site participants entered into a written research participation agreement whereby they received the control tune-up service at no charge and agreed to certain items that would facilitate successful field study results. Besides allowing the addition of the pulse output to the utility gas meter and allowing other monitoring, each test site participant was asked to not make any unnecessary changes to HVAC system equipment or control settings, and to report any subsequent boiler issues or other HVAC system issues or setting changes to research staff.

The site selection target counts for categories within the seven key boiler system characteristics are summarized in Table 6, along with the count of participating buildings fitting into each of the target categories.[4].

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[4] This table does not include monitoring logistics–related characteristics that were also used for screening, but only those key characteristics that were focused on getting adequate representation of key system variations that are most likely to be encountered during large-scale program implementation in the Minnesota market.

Table 6. Summary of Site Selection Targets and Participants by Key Characteristics and High Priority Categories

Characteristic	Category A	Target A	Participants A	Category B	Target B	Participants B	Category C	Target C	Participants C
Building Type[a]	Education	5–12	11	Multifamily	4–9	6	N/A[a]	N/A[a]	N/A[a]
Control Type[b]	Local Staging with Temperature from BAS	7–15	10	All Local	4–11	7	N/A[b]	N/A[b]	N/A[b]
Number of Boilers	1 Boiler	3–8	0	2 Boilers	4–11	8	3 or 4 Boilers	5–14	9
Size of Each Boiler[c]	200–800 MBH[d]	4–13	5	801–1,950 MBH[d]	3–12	2	1,950–3,000 MBH[d]	5–14	9[c]
Make of Boiler[e]	Aerco	5–8	4	Fulton	4–7	6	Lochinvar	3–7	2
Summer Operation	None	6–16	9	For HVAC Only[f]	4–14	6	N/A[g]	N/A[g]	N/A[g]
Service Contractor[h]	Contractor A	4–7	5	Contractor B	4–7	4	Contractor C	4–7	7

a) Selection was also open to as many as four buildings within six other building categories, but none participated from other building categories.

b) A lower priority was given to the selection of 1–4 buildings with direct BAS control of boiler staging, but none participated from other building categories.

c) A lower priority was given to the selection of up to four buildings with boilers larger than 3,000 MBH, and one such building participated.

d) 1 MBH = 1,000 BTU per hour.

e) A high priority was also given to the selection of 1–5 buildings with KN boilers, and one such building participated.

f) HVAC denotes for heating, ventilating, and air conditioning, which is primarily reheat within variable air volume boxes in the summer.

g) A lower priority was also given to the selection of up to three buildings with non-HVAC summer loads (e.g., pool or service water heating), and two such buildings participated.

h) A lower priority was given to additional contractors with up to seven buildings per contractor, and one building serviced by another contractor participated.

The characteristics in Table 6 are generally listed in order from highest priority to lowest priority. The participating site counts fit within the target ranges for 15 of the 19 categories. These deviations were within the third through fifth priority characteristics, and three of the four deviations were only one site shy of the target range for the category. The deviations in the third priority category, number of boilers per building, is due to the sample of buildings screened having a much higher number of boilers per building than had been assumed, as well as an original desire to oversample buildings with one boiler (because they were expected to have significantly different opportunities for optimizing boiler staging control than other buildings). With the relatively minor deviations noted above, the sample of participating buildings provided a very close overall match to the variations in key characteristics that the researchers hoped to achieve.

The key characteristics for each participating site are detailed in Table 7. The six multifamily sites all had fully local control of boiler temperature and staging, while all but one of the 11 school sites had BAS control of the boiler system supply temperature matched with local control of boiler staging. The local control of staging was through on-board boiler controls for the sites with Aerco or Lochinvar boilers, while all of the sites with Fulton boilers used a separate ModSync controller to stage the boilers. (S8 also used the ModSync to control the boiler system supply temperature.) The multifamily buildings also tended to have smaller boilers and a wide variety of boiler makes. The school sites tended to have larger boilers and more consistency in makes, with all but one of them using either Fulton or Aerco boilers.

Table 7. Detail of Key Characteristics by Site

Site ID	Building Type	Control Type	# of Boilers	Boiler Size[a]	Boiler Make	Summer Loads	Service Contractor
M1	Multifamily	All Local	2	1,000 MBH[a]	KN	None	Contractor A
M2	Multifamily	All Local	4	214 MBH[a]	Buderus	SWH[b]	Contractor A
M3	Multifamily	All Local	3	399 MBH[a]	Viessmann	None	Contractor A
M4	Multifamily	All Local	2	285 MBH[a]	Laars	None	Contractor A
M5	Multifamily	All Local	4	1,000 MBH[a]	Cleaver Brooks	None	Contractor A
M6	Multifamily	All Local	4	399 MBH[a]	Lochinvar	None	Contractor D
S1	Education	Temperature from BAS; Local Staging	2	2,000 MBH[a]	Aerco	None	Contractor B
S2	Education	Temperature from BAS; Local Staging	4	3,000 MBH[a]	Aerco	Pool & SWH[b]	Contractor B
S3	Education	Temperature from BAS; Local Staging	2	2,000 MBH[a]	Aerco	None	Contractor B
S4	Education	Temperature from BAS; Local Staging	4	800 MBH[a]	Lochinvar	None	Contractor B
S5	Education	Temperature from BAS; Local Staging	4	4,000 MBH[a]	Fulton	HVAC[c]	Contractor C
S6	Education	Temperature from BAS; Local Staging	2	3,000 MBH[a]	Fulton	HVAC[c]	Contractor C
S7	Education	Temperature from BAS; Local Staging	2	3,000 MBH[a]	Fulton	HVAC[c]	Contractor C
S8	Education	All Local	3[d]	2,000 MBH[a]	Fulton	None	Contractor C
S9	Education	Temperature from BAS; Local Staging	2	3,000 MBH[a]	Aerco	HVAC[c]	Contractor C
S10	Education	Temperature from BAS; Local Staging	3	2,000 MBH[a]	Fulton	HVAC[c]	Contractor C
S11	Education	Temperature from BAS; Local Staging	2	3,000 MBH[a]	Fulton	HVAC[c]	Contractor C

a) 1 MBH = 1,000 BTU per hour.

a) SWH denotes service water heating (hot water for faucets, showers, etc.)

b) HVAC denotes for heating, ventilating, and air conditioning, which is primarily reheat within variable air volume boxes in the summer.

c) S8 was a hybrid boiler system that also had two large, non-condensing boilers that nominally take over heating when the outdoor temperature drops below 10°F, so that the three condensing boilers nominally only operate above 10°F.

Conducting Control Tune-Ups

The boiler control tune-up protocol was applied to 18 test sites in February of 2020 after at least half a heating season of detailed pre-tune-up monitoring. The following items were part of the tune-up enhancements that focused on boiler control temperature and staging controls:

- Settings of outdoor reset controls that automatically reduce boiler temperature in mild weather;
- Settings that impact the on/off staging of each boiler and sequencing of multiple boilers;
- Settings that impact the part-load control (i.e., firing rate modulation) of each boiler;
- Correction of problems with the outdoor temperature sensor;
- Correction of problems with the coordination between the different levels of controls and the individual boilers; and
- Addition of fluid to the boiler system as needed to relieve any unusually low system pressures observed.

Technicians were specifically directed not to make any burner air–fuel ratio adjustments, as those are within the scope of traditional boiler tune-ups. The full control tune-up protocol is detailed in Appendix A: Primary Control Tune-Up Protocol Form and Appendix B: Tune-Up Reference Documents and Make-Specific Staging Forms.

Research staff originally planned to train technicians ahead of time and observe the tune-ups of at least five of the sites before transitioning to promptly review the control setpoint and adjustment information captured for each tune-up, as well as to quickly identify and deal with any unexpected situations or quality issues before they were repeated at additional test sites. Contractors strongly preferred to only review the forms ahead of the control tune-ups, then have a researcher present for at least the first few sites for each contractor. For the one contractor that did have a pre-tune-up meeting to discuss the forms in detail, this discussion was with the field supervisor rather than the technician that performed the tune-ups. While the technician level of independence grew with each visit, there was ultimately a research staff member present at each of the boiler control tune-ups to provide support as needed, to better understand how the protocol matches the workflow habits of each technician, and to collect supplemental documentation of data.

Technicians were told to closely track the time it took to perform the tune-ups to help researchers understand delivery costs and their variations. Contractor agreements had time and materials billing arrangements to provide further incentive for detailed tracking of technician time.

Other Site Changes: Burner Tune-Ups and Addition

Despite the researchers' goal to have no other boiler system changes impacting load carried out during the monitoring period, a few sites did have some confounding system changes. Burner tune-ups were carried out at sites S8–S11, and a small addition and renovation were carried out at site S5. These changes are summarized in Table 8. Note that all of the burner tune-ups affected the average boiler steady-state efficiency for each site by less than one-half of one percentage point, and half of the sites actually had a reduction in average steady-state efficiency as a result of the burner tune-ups. These burner tune-ups were carried out despite the participation agreement's clear commitment not to perform such tune-ups during the monitoring period, and were only reported to researchers after the fact. On the other hand, the renovation and addition at S5 was known to researchers ahead of time, and BAS system trending for this site including close monitoring of loads for impacted spaces so that any significant impacts on boiler system load could be subtracted from the post gas use analysis.

Table 8. Summary of Confounding Burner Tune-Ups and Building Addition

Site	Change	Impact	Date
S5	Renovation & Addition	Undetermined[a]	Summer 2019
S8	Burner Tune-Ups	Efficiency down 0.35 percentage points[b]	12/13/2019
S9	Burner Tune-Ups	Efficiency up 0.4 percentage points[b]	12/16/2019
S10	Burner Tune-Ups	Efficiency up 0.4 percentage points[b]	12/18/2019
S11	Burner Tune-Ups	Efficiency down 0.2 percentage points[b]	01/03/2020

a) Other data-quality issues at this site made a detailed evaluation of this secondary impact irrelevant.

b) The average boiler steady-state efficiency impacts are based on steady-state combustion efficiency changes (without considering secondary impacts on the amount of condensing that would occur) as documented in detailed reports provided by the contractor that performed the burner tune-ups. It was not the school district's regular service contractor that participated in the program and performed the boiler control tune-ups.

Operational changes in response to the COVID-19 pandemic also had a dramatic impact on all schools, as is further described in the *COVID-19 Impact* section, starting on page 47.

Field Data Collection

Site Observations

Boiler plant, water heater, and gas meter observations were generally made through direct observations by research staff through on-site visual observation or remote access to monitored data and control settings. For most sites, the on-site observations included each boiler's running counters of run-hours and burner on/off cycles. Beyond the boiler plant, other building information (e.g., occupancy schedule, HVAC equipment throughout the building) was typically based on secondhand information (e.g., site staff, school calendars, and mechanical system plans) that was often spot-checked by observation of a sample of HVAC equipment or monitored data. The notable exceptions to direct observations by research staff were:

- Pre-tune-up control settings and tune-up control changes by contractors at some sites (researchers verified through direct observation for most sites);
- For control changes that were made outside of the tune-up event, the circumstances and subsequent control changes were often reported through building staff or contractors (researchers generally verified the new control settings at some point after the change was made);
- On-site logs of boiler operators' daily observations and notes about service events.

Long-Term Monitoring

The research team's intent was to monitor both the pre- and post-tune-up operation for at least one-half of a heating season to obtain data over the full range of heating season outdoor temperatures. A secondary goal was to monitor an adequate amount of pre- and post-tune-up summertime operations for those sites that used boilers in the summer.

Each multifamily site had one or more dataloggers installed to capture time-averaged and pulse-count data and allow for regular remote data downloading via cellular modems. One multifamily site had such poor cell service that less frequent, manual on-site data retrieval was required. For the other multifamily sites, data was generally automatically downloaded daily, then run through range-checking routines regularly.

All of the school sites had instantaneous, fixed time interval measurements (and pulse count data, where applicable) stored on BASs so that researchers could regularly download data via remote access. Researchers were generally granted remote access to these BAS systems. While some systems were already collecting many trend data points, researchers generally had to set up new trend points or modify trending time intervals at all schools, either directly or through requests to school district staff. Most of these sites had data downloaded on regularly scheduled intervals ranging from weekly to monthly, depending on the BAS trend data storage and downloading capabilities. Researcher remote access problems at two of the schools prevented convenient downloading of data, so it was less frequently downloaded through researcher visits to the school district office and school staff who transmitted the data to researchers.

Long-term monitoring began during the second half of the 2018–2019 heating season, and pre-tune-up monitoring continued until the control tune-ups were performed in February of 2020, except for temporary holds on data collection in the summer for most sites. The intent was to generally limit post-tune-up data collection to the remainder of the 2019–2020 heating season to capture the full range of outdoor temperatures encountered during a normal heating season. This was because of the project's originally planned end date and the research team's expectation — prior to carrying out the control tune-ups — that the majority of savings would occur in mild and moderate heating season temperatures (with little savings expected during very cold weather). When the project end date was extended (for reasons outlined in the following COVID-19 Impact section), post-tune-up monitoring continued for multifamily sites into February of 2021. Sporadic post tune-up monitoring of school sites also occurred, as detailed in this next section.

COVID-19 Impact

Unfortunately, abrupt shutdowns of schools in response to the COVID-19 pandemic began shortly after all boiler control tune-ups were performed in February of 2020. This severely impacted the post-tune-up data for all monitored schools. The changes in occupancy and operation of HVAC systems severely affected heating energy use such that it was unfair to compare data after shutdowns began to the "typical" occupancy and HVAC operations that occurred before the pandemic. Even when students returned to schools, the occupancy was still significantly lower than pre-pandemic levels, and some buildings had changed their HVAC system operations.

In some schools, the heating load actually increased because the HVAC systems operated as usual while the school was minimally occupied to provide day care for the children of essential workers and to distribute food. The systems continued to bring in enough outdoor air for a fully occupied school, while there was not nearly as much heat given off by building occupants to partially offset the heating energy needed to bring the cold outdoor air up to normal room temperatures.

At the same time, other schools completely shut down and set back the indoor temperatures significantly. These schools had much lower heating loads. Even comparisons to pre-tune-up weekend data were problematic for these schools because of periodic weekend activities in many schools pre-pandemic.

For a limited number of schools, researchers attempted to augment the truncated pre–post comparisons by monitoring during alternating mode tests during the fall of the 2020–2021 school year. A subset of the schools established four-day-a-week hybrid learning schedules that were expected to be maintained for an extended period of time. Each district established this pattern at a different date after the normal start of the school year. During this time period, the boiler controls settings were alternately changed between the “tuned up” settings and the “as-found” (i.e., pre-tune-up) settings every few weeks, depending on the range of outdoor temperatures experienced each week. These changes were made on Fridays, which was the one day of the week that no students were in school. These alternating mode tests were ended with all schools left in “tuned up” settings by Thanksgiving of 2020. By this time, all schools had switched to all-distance learning, and schools reopening in early 2021 did not follow the same hybrid occupancy schedules that were used in the fall of 2020.

Gas Use for Empirical Savings Analysis

The research team used one of two different approaches for each test site to measure gas use in both the pre- and post-monitoring periods. Gas meters with pulse outputs were used at 11 sites, while BAS trend logging of each boiler’s percent firing rate was used at six sites. Table 9 details the type of measurement approach used at each site, along with site-specific information relevant to the choice and accuracy of the measurement approaches.

All meters (except for the existing paddlewheel submeter at S9) were utility grade, positive displacement gas meters. The meter pulse outputs used at 11 sites were generally believed to lack temperature and pressure compensation. Researchers adjusted usage for the pressure level settings of pressure regulators, but did not make any adjustments based on direct measurements of temperature and pressure over time. While this was known to introduce some biases — especially in the calculated gas use at different outdoor temperatures — they were presumed to be fairly consistent for a given outdoor temperature such that biases in pre–post comparisons and regression analysis would be small compared to other daily variations in load and other factors.

At the four multifamily sites with separate service water heaters included in the meter, researchers also monitored water heater burner on-time to supplement the metered information. The intent was to subtract out the service water heater usage from the metered gas use to isolate the boiler system gas use.

Table 9. Key Gas Use Measurement Information by Site

Site	Gas Use Measurement Type	Data Collecting Device[a]	Non-Boiler Use Included	Loads On Boiler In Addition to Space Heating
M1	Utility Meter	Logger	Water Heaters and Dryers (18% of Heating Season Use)	None
M2	Utility Meter	Logger	None	Service Water Heating
M3	Utility Meter	Logger	Water Heaters and Dryers (19% of Heating Season Use), Plus Make-Up Air Unit	None
M4	New Submeter	Logger	None	None
M5	Utility Meter	Logger	Water Heaters 25% of Heating Season Use	None
M6	Utility Meter	Logger	Water Heaters and Dryers (10% of Heating Season Use), Plus Rooftop Unit	None
S1	Utility Meter	BAS[a]	Water Heaters (6% of Heating Season Use)	None
S2	Firing Rates	BAS every 60 seconds	None	Service Water Heating and Seasonal Pool Heating
S3	Utility Meter	BAS	Water Heaters (8% of Heating Season Use)	None
S4	New Submeter	BAS	None	None
S5	Firing Rates	BAS every 10 seconds	None	Pool Heating in Very Cold Weather
S6	Firing Rates	BAS every 20 seconds	None	None
S7	Firing Rates	BAS every 20 seconds	None	None
S8	Utility Meter	BAS	None	None
S9	Existing Submeter	BAS	None	None
S10	Firing Rates	BAS every 60 seconds	None	None
S11	Firing Rates	BAS every 60 seconds	None	None

a) BAS denotes a Building Automatic System that the building owner already had in place.

At most schools, researchers were able to obtain direct indications of the individual boiler firing rate command signals through the BAS. Because the BAS trend data is a series of snapshots captured at fixed time intervals, one drawback is that high-frequency data capture was needed to minimize the missing of any short boiler cycles or short-term spikes in values. To minimize errors from these factors, researchers chose the shortest time intervals that were practical given the limitations of the exiting BAS at each school (e.g., minimum system time interval of one minute or limited BAS data storage that would require onerously frequent downloading of data). The frequency of staging control variations observed during site-selection visits was also taken into consideration in determining the appropriate time interval of firing rate data sampling at each site. As with the gas meters, some error was introduced by the lack of variable temperature or pressure corrections, but this was presumed to be fairly consistent for a given outdoor temperature such that biases in pre–post comparisons and regression analysis would be small compared to other daily variations in load and other factors.

Hourly outdoor temperatures used for correlating variations in gas use (and other variables) was downloaded from the National Weather Service for the nearest major weather station where data was available.

Long-Term Monitoring of Other Key Variables

In addition to direct indicators of boiler plant gas use, researchers monitored key boiler system operating parameters to provide further insight into correlations that could be used to develop recommendations for TRM calculations. The most critical additional measurements were the temperature of water that the boiler system supplied to the building, the temperature of water returning to the boilers, and boiler cycling. A summary of which sites had each of these measurements, as well as a few additional measurements, is presented in Table 10.

Wherever practical, this data was collected via dataloggers at the multifamily sites using thermocouples to measure temperature on the outside of pipes (with insulation covering the pipe and sensor) and current transformers on one of the wires powering each boiler's gas valve. This data captured by dataloggers was a true average based on rapid sampling throughout the time periods. Because it was not practical to run a cable from the gas meter to the boiler room at four of the multifamily sites, this temperature and cycling data was captured with a separate datalogger than the one that was used to capture gas meter pulse output.

Measurements of these additional variables for the school sites was collected through BASs at the school sites for each key variable was available. The BAS temperature probes were inserted into the pipes, and each boiler's on/off status was based on BAS system indications of status or the burner firing rate value (assuming a non-zero value meant the burner was on and a zero value meant that the burner was off). Most BAS data recorded was a snapshot at an instant in time recorded at fixed intervals ranging from 1 to 15 minutes. Wherever possible, burner on/off status was recorded at the shortest possible interval (typically once every minute) to try to avoid "missing" short boiler cycles.

Table 10. Summary of Additional Key Variables Monitored by Site

Site	Boiler System Supply Temperature[a]	Boiler Return Temperature[b]	Boiler Cycling	System Pump VFD Speed[c]	Boiler Temperature Settings[d]
M1	Yes (surface)	Yes (surface)	No	No	No
M2	Yes (surface)	Yes (surface)	No	No	No
M3	Yes (surface)	Yes (surface)	Yes	No	No
M4	Yes (surface)	Yes (surface)	Yes	No	No
M5	Yes (surface)	Yes (surface)	Yes	No	No
M6	Yes (surface)	Yes (surface)	Yes	No	No
S1	Yes (probe)	Yes (probe)	No	Yes	Yes
S2	Yes (probe)	Yes (probe)	Yes (1 minute intervals)	No	Yes
S3	Yes (probe)	Yes (probe)	No	Yes	Yes
S4	Yes (probe)	Yes (probe)	Yes[e] (1 minute intervals)	Yes	Yes
S5	Yes (probe)	Yes (probe)	Yes (10 second intervals)	Yes	Yes
S6	Yes (probe)	Yes (probe)	Yes (exact on/off times recorded)	Yes	Yes
S7	Yes (probe)	Yes (probe)	Yes (exact on/off times recorded)[f]	Yes	Yes
S8	Yes (probe)	Yes (probe)	No	No	No
S9	Yes (probe)	Yes (probe)	Yes (5 minute intervals)	Yes	No
S10	Yes (probe)	Yes (probe)	Yes (1 minute intervals)	Yes	No
S11	Yes (probe)	Yes (probe)	Yes (1 minute intervals)	Yes	No

a) Building system supply temperature is the temperature of the water that the boiler plant sends to the building.
b) Boiler return temperature is the temperature of the water flowing into operating boilers.
c) This refers to the percentage of maximum speed for a variable speed drive on the main system pump supplying heating water to the building (as opposed to any pumps on individual boilers).
d) These sites either captured instantaneous boiler temperature setpoint or the outdoor reset settings used to calculate the setpoint from outdoor air temperature.
e) The cycling data at site S4 was based on the operation of each boiler’s dedicated primary pump rather than the boiler/burner itself. Each pump would start shortly before a burner cycling and for longer after the burner stops.
f) Boiler on and off cycle times at this site were only capture during the post-tune-up period and during alternating mode tests.

Data Processing and Analysis

Long-Term Monitored Data

Researchers used both R software and CEE's own TRAVIS software to generate and combine data and time-sync data from multiple sources for each site (e.g., hourly National Weather Service data with BAS trend data or data from multiple dataloggers). R range checking routines were used to spot data anomalies, and R was also used to convert short-interval data into daily averages for regression analysis. These routines were very similar for each of the multifamily sites, but required significant customization for the school sites due to the wide variety of trend data points available, wide variety of data file formats from different BAS systems, and periodic overlapping of time periods in different data files. The school sites also had the added complication of separation of data into weekdays when school was in session and "weekends," which included holidays and weekdays when school was not in session. For the school sites, researchers performed analysis on both the weekday and weekend data sets, but then abandoned attempts to compare pre- and post-tune-up weekend data sets due to COVID-19 impacts on the amount of data, weekend activity schedules, and the general variability in weekend activity and system operations schedule. Therefore, all data and analysis presented in this report for schools is based only on weekdays.

Estimations of Savings from Tune-Up Changes

While researchers focused on direct, empirical indications of gas use as the primary means of verifying savings from the boiler control tune-ups, engineering estimation was also carried out to develop and verify a TRM calculation approach that could be applied to future program participants (when research grade empirical measurements are not available). For a limited number of sites, these secondary engineering estimates became the most reliable savings estimate available due to a combination of data collection issues and a monitoring period that was abbreviated by school operational changes in response to the COVID-19 pandemic.

Empirical Gas Use Analysis

Researchers estimated savings at each site from empirical gas use data (i.e., gas meter pulse output or boiler firing rate data from short-interval BAS trends) by seeing how the gas use at various outdoor temperatures after the control tune-up compared to gas use at the same temperatures before the control tune-up. The pre- and post-tune-up behavior was generally modeled by performing standard least-squares regression analysis to the data sets from before and after the tune-ups. Heating season gas use was then determined by applying each data set's regression model to its heating season average temperature. This heating season average outdoor temperature for each data set was determined by taking an average of typical meteorological year data below the outdoor temperature at which the regression line shows no space heating energy use.[5]

[5] For a very limited number of sites, summer boiler usage was also included as either a flat value or based on a regression or BIN relationship.

The analysis at each site began by visually reviewing plots of gas use against outdoor temperature and initial change-point regression model lines. These reviews spotted a number of data points that were very different from the trend, and additional efforts were undertaken to determine whether there was a clear reason for this inconsistency (e.g., a boiler system problem or unusual operating conditions), and a small number of such spurious data points were removed from the data sets for a number of sites.

The visual review also spotted data patterns that might skew the results, which led to most sites having the final models for savings estimates based on least-squares regressions performed over a specific range of outdoor temperatures. For example, many sites showed data splitting into two different groups as the outdoor temperature warmed near the point at which there was no real need for space heating. Some of these mild weather days fell in line with the trend of cooler weather data, while some had zero boiler gas use. Including all of the data from these time periods in the regression analysis could easily cause the models skew in a way that causes a poor representation of the trend over the wider range of cooler outdoor temperatures. Sites that showed this pattern to a substantial degree had their use over this very mild temperature range determined via a regression model based on lower temperature data combined with BIN data analysis from this limited, mild temperature range. The BIN analysis looked at the percentage of zero-use days within a mild weather bin (e.g., 65°F to 70°F) during the pre- and post-tune-up data sets. These percentages were then applied to the number of hours and extrapolation of the regression model through this outdoor temperature range to calculate the gas use for time periods when the outdoor temperature fell within the bin.

While the school sites had data broken out into weekdays with school in session and weekends (which included other unoccupied days), all savings was reported based on analysis of only weekdays with school in session. The more limited number of weekend days and inconsistencies in weekend activities made regression models of weekend data much less reliable than the regressions of weekday operations.

Due to very limited post-tune-up data monitoring prior to occupancy and operational changes made in response to the COVID-19 pandemic, most schools sites had savings based on a comparison of post-tune-up data point to the pre-tune-up regression model. Besides having far fewer data points, the post data sets at these schools also had a much lower range of outdoor temperatures. To prevent any bias from pre-tune-up boiler system behavior outside of the post-tune-up data set outdoor temperature range, researchers closely examined the consistency between the pre-tune-up regression models and pre-tune-up data points over the limited post-tune-up data set ranges. For a fraction of the sites, significant patterns of bias over this data range were noted, and the pre-tune-up regression was updated to only include data over the range of data that was observed within the post-tune-up data set. Once the pre-tune-up regressions were finalized, the average deviation of the post data points from the pre-regression model was used to estimate the average savings at these sites.

Engineering Estimation

A spreadsheet calculator was used to make engineering estimates of boiler control tune-up savings at each site. A previous version of this calculator has been routinely used for CIP program savings estimates, but it was updated as part of this project. This calculator takes into account tune-up impact on three factors affecting the energy use of a condensing boiler system over the heating season range of outdoor temperatures as outlined in Table 11. Note that two of the factors — heating load reduction and purge cycle performance penalty — would apply consistently across all types of commercial boilers, while the steady-state boiler efficiency change (with return water temperature variations) is unique to condensing boilers.

Table 11. Summary of Three Key Factors Impacting Engineering Savings Estimator

Factor Item	Heating Load Reduction	Steady-State Boiler Efficiency Change[a]	Purge Cycle Performance Penalty[b]
Savings Mechanism Description	Lowering the temperature of water supplied to the building reduces overheating and pipe losses	Lowering the temperature of a condensing boiler's return water temperature increases its efficiency	Lowering the frequency of burner cycling reduces heat losses from purging air through the boiler before and after each cycle
Ideal Input Variable(s)	Relationship of boiler system supply water temperature to outdoor air temperature	Relationship of boiler system return water temperature to outdoor air temperature (or system supply temperature)	Relationship of boiler cycling rate to outdoor air temperature
Inputs Used in Reported Estimates	Linear, change-point models of above based on long-term temperature monitoring	Linear model of above based on long-term temperature monitoring	Average cycles per run-hour observed over the pre- and post-tune-up periods
Readily Available Inputs for Program Use	Boiler system temperature control setpoints plus spot and logged observation	Spot and logged observation of difference between supply and return temperature	Pre-tune-up long-term average of cycles per run hour

a) The secondary impact of part-load fraction was not included in this iteration of the calculator.
b) The cycling impact associated with bringing a boiler up to temperature was not included in this iteration of the calculator.

The spreadsheet used to make engineering estimates of savings uses a binned calculation approach with TMY3 data to estimate the impact of the three factors outline in Table 11. The load reduction savings is estimated by comparing the expected system temperature reductions from the controls tune-up to the ideal case of going from no outdoor reset to the outdoor reset curve used in a field study that documented outdoor reset control energy savings in multifamily buildings in Minnesota (MEO 1984). The ideal and expected temperature reductions expected for each 5°F outdoor temperature are weighted by the number of heating season hours in each bin. These factors are added up over the heating season and the expected savings is calculated as a percentage of the ideal savings observed in the previous field study. A similar approach is used to account for any changes in the warm weather shutdown settings. The impact of temperature on condensing boiler steady state efficiency is calculated by combining the estimated load in each bin with estimates of the change in boiler efficiency between the pre- and post-tune-up temperature control settings. The efficiency change is based on applying one boiler manufacturer's curve of efficiency variation with return water temperature to the pre- and post-tune-up control settings. Each bin's combination of load factor and efficiency change is summed over the heating season and used to estimate a percent change in gas use for condensing boiler steady-state efficiency changes. A similar load factor approach is also used to estimate the savings from reduced purge losses. The load factor for each bin is combined with the percentage efficiency penalty from pre- and post-purge heat losses and the pre- and post-tune-up average cycles per run-hour.

Correlation of Results to Key Characteristics

Various exploratory data analysis techniques were used to look for important correlations of cost and percent savings to key system characteristics. Exploratory approaches included scatter plots, box and whisker plots of various groups within categories, and least squared regression analysis. While the limited number of data points and cross-correlations (e.g. multifamily buildings did not have BAS systems) limited the effectiveness to draw broad conclusions, some important trends were observed and highlighted in the results and discussion sections.

Cost-Effectiveness and Program Potential

The control tune-up cost-effectiveness was evaluated via contractor costs billed to the research project, along with each site's best available annual energy cost savings estimate. A representative natural gas price of $0.76 per therm ($7.60 per Mcf or $0.76 per Ccf) was used to evaluate individual site simple payback based on initial savings (after any fine-tuning within the first month).

Program-level cost-effectiveness was estimated using the Societal Cost Test (SCT) and Utility Cost Test (UCT) in a manner consistent with Department of Commerce's approved practice for Minnesota utilities. The general assumptions used within this framework were drawn from the Commerce Decision: CIP Gas and Electric Utilities 2021–2023 Cost-Effectiveness Review, EIA state-level energy price data, and the 2018 Minnesota DSM Potential Study. These assumptions are all statewide averages and were not customized by utility service territory. The details of these assumptions are presented in Appendix C: Assumed Inputs for Cost-Effectiveness Evaluation. This appendix also shows the assumptions used for administration, program, and participant rebate costs. These assumptions were based on a review of Minnesota investor-owned utility 2021–2023 CIP filings, with two scenarios for the program implementation costs: (1) the same as current boiler tune-up programs; and (2) increased by 25% (relative to incentive costs) to account for the higher level of protocol development, contractor training and technical oversight required than for burner tune-up rebate programs.

Two separate sources of potential participation estimates were used to a provide a conservative estimate of the technical potential and an estimate of the annual achievable potential of a mature program. The conservative technical potential estimate was based on the number of hot water heating boilers listed in the Minnesota boiler and pressure vessel inspection databased (DLI 2018), which nominally only includes boiler in plants with an input rate of 750,000 Btu/hr or larger. The research study's average savings per boiler was scaled up by 9% to account for a higher average input rate of boilers in the DLI database. Savings for non-condensing boilers (estimated at 77% of the boilers in the database) was scaled down to about 77% of the study's savings for condensing boiler sites based on engineering estimates of the amount of savings associated with condensing boiler steady-state efficiency changes at the test sites. These efficiency benefits would not be realized for non-condensing boilers, which would only achieve savings through load reduction and reduced short-cycling. The achievable potential was estimated based on the total number of annual participants in current boiler burner tune-up programs for the three largest natural gas IOUs in Minnesota (CenterPoint Energy, 2020; Xcel Energy 2020; and MERC 2020), and the per site savings found at the research study test sites. The savings values weren't scaled for boiler plant size because there was consistent information about boiler plant size for program participants.

Results

Control Tune-Up Protocol Implementation

Document & Procedure

The final version of the main tune-up protocol document appears in Appendix A: Primary Control Tune-Up Protocol Form. Supplemental reference documents and worksheet tabs that address staging control for specific makes of controls are detailed in Appendix B: Tune-Up Reference Documents and Make-Specific Staging Forms. While technicians are generally expected to complete the form and procedure in the order on the form, some variations occurred based on the availability of on-site staff and each technician's preference for assessing various items. In all cases, the temperature and staging control adjustments were only made after the rest of the form was completed, then post-control change observations were carried out to ensure that the system responded to the control change as expected.[6]

Contractors' technicians completed the protocol forms with an engineer from CEE on-site to observe and provide support as needed. While the intent was to have contractors' technicians be able to conduct many of the control tune-ups without any on-site support, the number of unexpected issues and complications that were encountered at the first few sites ultimately led to presence of at least one CEE research staff person at every tune-up. Direct research staff involvement decreased dramatically as the technicians dealt with new sites that were very similar to previous sites, but some level of staff support or intervention was still valuable at most sites. This was especially true for the multifamily sites, as each of these had a different make of boiler controller. The most common researcher interventions were:

1) providing direction on staging control adjustments;
2) reviewing mechanical system plans to determine the design water temperature (and intended outdoor reset settings in some cases);
3) providing a second opinion on proposed temperature control changes;
4) assisting with BAS temperature setting changes; and
5) translating between nonstandard temperature controller settings and the protocol's temperature setting recommendations for the most common temperature control logic.

Control changes to local boiler controls were made by the contractors' technicians, while BAS temperature setpoint changes were made with the assistance of building operations staff. In some cases, building operations staff made the control changes directly, while in other cases, the staff provided on-site terminal access for the technician or engineer to make the change. These variations were generally dictated by the comfort level of the operations staff involved. The operations staff were generally site-level staff, while a district-level lead was present for a small minority of the control tune-ups at school sites. Contractors left a site one-page document (see sample in Appendix B: Tune-Up

[6] The post-control adjustment observations were expanded based on experience with the first few control tune-ups.

Reference Documents and Make-Specific Staging Forms) with the on-site or district-level staff, which described the tune-up service and had blanks filled in indicating the specific control setting adjustments that were made. The form also included contact information for research staff and the boiler service contractor, with instructions to contact both in the event of underheating issues.

The contractors provided the research team with a copy of the completed protocol forms at a later date. Most technicians completed paper forms and with scans of those forms provided, with the exception of one technician who completed the form electronically in a spreadsheet while conducting the tune-ups.

Fine-tuning follow-up was expected to be needed for roughly one out of every four sites. The school sites generally reached out to researchers who coached the operations staff through appropriate fine-tuning adjustments, and informed the boiler service contractor. Multifamily sites generally reached out to their service contractor first, with one contractor reaching out to researchers for coaching, and the other making adjustments without consulting with or informing researchers.

Field Application

The most important observations from the field application of the protocol are listed below.

1. A high level of technician training and support was needed — especially for the first one or two sites with a particular control configuration.
2. Both temperature and staging control recommendations were made at nearly every site, with the exception of a few sites where no staging control adjustments were made.
3. Significant problems with temperature sensors were found at three sites, and significant controller to boiler coordination issues were also found at two sites. Resolving these issues required the application of knowledge beyond the protocol.
4. After significant control changes are made, the system operation should be observed until stable operation with the new settings is verified. This is especially true when addressing severe short-cycling issues, as a second round of fine-tuning was needed for some sites.
5. The system pressure should be observed, and low pressure problems resolved (by adding water [and glycol for some systems], as needed) before reducing temperature settings.
6. For all sites with BAS systems, a school operations staff person was able to assist with or carry out recommended temperature setting changes without involving a separate BAS contractor, which would add considerably to the tune-up cost.
7. Out of 17 sites, three (M3, S1, and S3) had callbacks that required fine-tuning of temperature settings within eight days of the control tune-up date, and a fourth (M6) had a similar callback within the first month. Then, it was eight months before a fifth site (S5) had a similar low-temperature callback.
8. While contractors' technicians generally provided the vast majority of information called for by the protocol forms, there were notable exceptions for documentation of some key pre- and post-setting values for multiple technicians, and across numerous items for one technician.
9. All seven sites with a password on the boiler controls still had the factory default password.

Numbers 4 and 5 above are based on both the best optimization of settings for efficiency and to avoid having to make a return visit to address issues that are not directly related to the efficacy of the new control settings. At site S2, research staff and the contractor's technician were called back within an hour of completing the tune-up because all boilers failed to fire due to a combination of: (1) low pressure prior to the control changes; (2) poor system temperature sensor location; and (3) a significant reduction in temperature. Resetting of lock-outs and the addition of fluid to the boiler system to bring up the pressure were needed to get the system operating reliably with the new settings. Fluid was also added at M1 and S7 to increase the pressure and prevent any similar issues at these sites.

Realized Cost

The contractors' reported costs for performing the control tune-ups and submitting the completed protocol forms to researchers is summarized in Table 12, along with some key site characteristics that were likely to impact cost. The per site costs ranged from $350 to $1,752 with a median of $750 and average of $737. The highest-cost site for each contractor was either their first site or a site that required a repeat visit. Three of these repeat site visits were related to protocol updates and would not have been needed in a mature program. The per boiler costs ranged from $105 to $876 with a median cost of $224.

Figure 12 is the first of a series of box-and-whisker plots showing the range of control tune-up costs within various categories of characteristics. The lines in the middle of the boxes represent the median value for each group, while the "X" represents the average, and the top and bottom of each box represent approximately one standard deviation above and below the average. Where there is a line extending above or below the box, this represents the extension of the 95% confidence interval in that direction. Where the very low number of data points in some of the categories prevents calculation of a 95% confidence interval, these extension lines are omitted. This first box-and-whisker plot demonstrates one of the most noteworthy observations of the variations in controls tune-up costs — there does not seem to be a consistent trend of the cost per site increasing as the number of boilers at a site goes up.

Since the control tune-up cost at a site does not change much with the number of boilers, the cost per boiler tends to go down significantly as the number of boilers at a site goes up. Figure 13 shows both the individual site data points and regression line trending down as the number of boilers per site goes from two to four. The regression line estimates of cost are: $292 per boiler for two boilers at a site; $232 per boiler for three boilers at a site; and only $172 per boiler for four boilers at a site.

Table 12. Control Tune-Up Costs by Site

Site ID	Control Type	# of Boilers	Local Controller	Service Contractor	Tune-Up Cost	Cost Per Boiler
M1	All Local	2	Heat-Timer MultiMod Platinum	A	$448	$224
M2	All Local	4	Buderus CM10 and AM10	A	$448	$112
M3	All Local	3	Viessmann Vitotronic 300-K, MW2C series	A	$750[a]	$250
M4	All Local	2	On Board; Laars Neotherm NTH series	A	$1,752[b, c]	$876
M5	All Local	4	On Board; Cleaver Brooks CFC-700 series	A	$575	$144
M6	All Local	4	On Board; Lochinvar KBN400	D	$895[a, c]	$224
S1	Temperature from BAS; Local Staging	2	On Board; Aerco BMK series	B	$350	$175
S2	Temperature from BAS; Local Staging	4	On Board; Aerco BMK series	B	$750[a]	$188
S3	Temperature from BAS; Local Staging	2	On Board; Aerco BMK series	B	$350	$175
S4	Temperature from BAS; Local Staging	4	On Board; Lochinvar KBN801	B	$420[c]	$105
S5	Temperature from BAS; Local Staging	4	ModSync and Fulton	C	$922[d]	$230
S6	Temperature from BAS; Local Staging	2	ModSync &Fulton	C	$1,121[c, d]	$560
S7	Temperature from BAS; Local Staging	2	ModSync &Fulton	C	$976[d]	$488
S8	All Local	3	ModSync &Fulton	C	$633	$211
S9	Temperature from BAS; Local Staging	2	On Board; Aerco BMK series	C	$868	$434
S10	Temperature from BAS; Local Staging	3	ModSync &Fulton	C	$777	$259
S11	Temperature from BAS; Local Staging	2	ModSync &Fulton	C	$488[d]	$244
Median	n/a	3	n/a	n/a	$750	$224

a) The cost at these sites includes a repeat technician visit to fine-tune settings or correct a low pressure problem.
b) Costs for site M3 included three site visits, with the first visit as the very first field trial, the second visit to add a system level sensor and other control wiring to coordinate staging of the two boilers, and the third visit to step through the control setting part of the protocol with the new control scheme in place.
c) These sites were the first control tune-ups for the contractor.
d) These sites required two site visits because of significant tune-up protocol updates for the ModSync controller.

Figure 12. Control Tune-Up Cost Variation with Number of Boilers

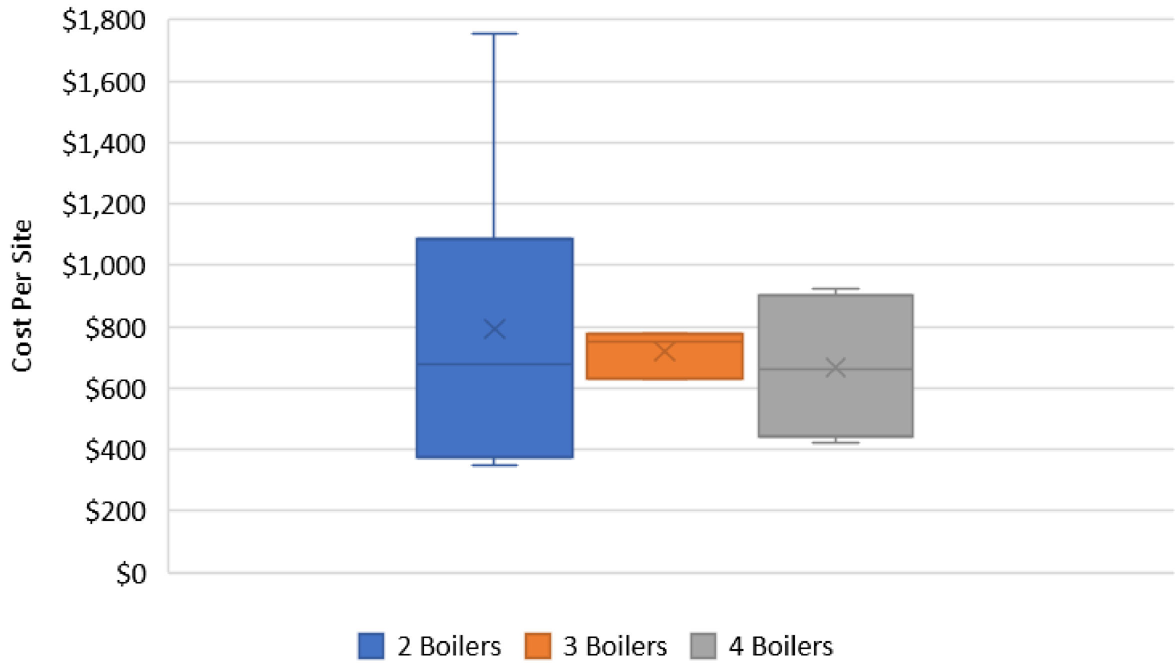
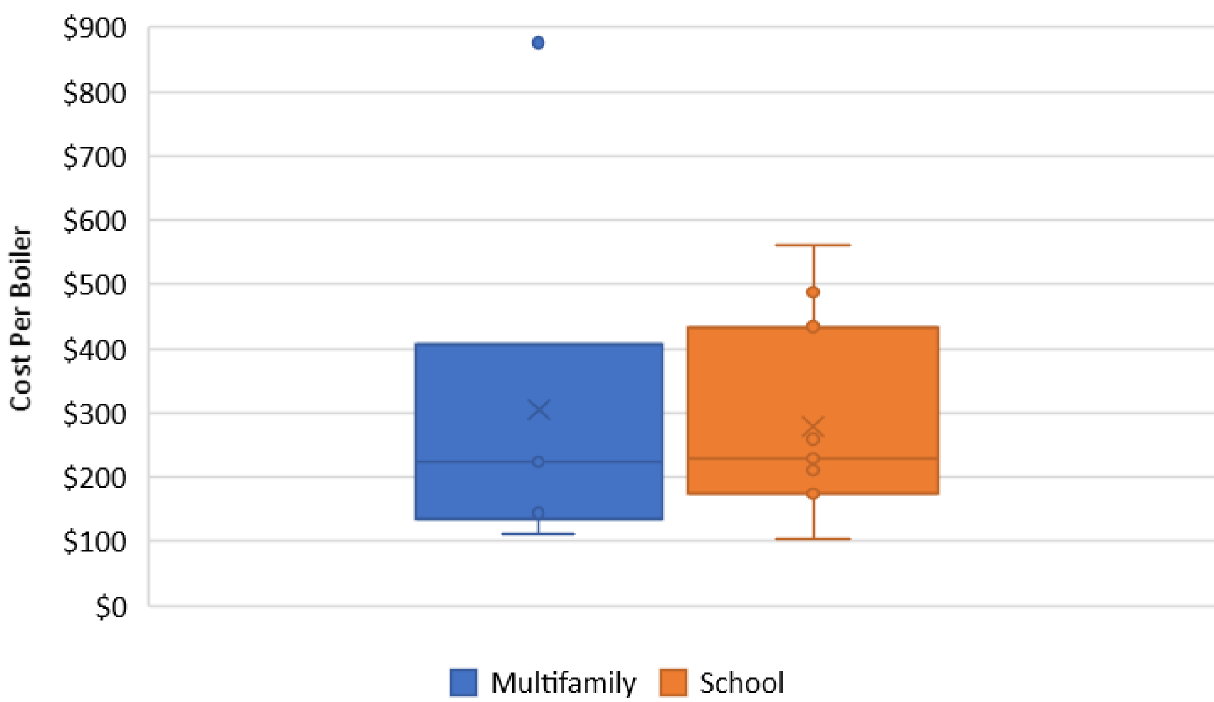


Figure 13. Downward Trend in Cost Per Boiler as the Boilers Per Site Increases

The box-and-whisker plot in Figure 14 shows the range of per boiler control tune-up costs for the two types of buildings monitored — multifamily buildings and school buildings. The wide ranges of per boiler cost variations within each building category appear to be much larger than any systematic difference between the two building types. This also suggests that there is not a consistent trend in cost variation with size of boiler because of the strong correlation between building type and size of boiler (as detailed in Table 7). Six of the seven smallest boiler sizes in the study are in multifamily buildings, including the four smallest boiler sizes. Similarly, this comparison between the multifamily and school buildings also strongly indicates that the use of a BAS system to dictate a temperature setpoint versus having a local controller determine the boiler temperature setpoint did not have a consistent impact on controls tune-up cost. This is because six of the seven buildings with local temperature control settings were multifamily buildings, while 10 of the 11 school buildings used a BAS system to reset the boiler system temperature setpoint. Therefore, the comparison between building types in Figure 14 suggests that for this limited data set, the controls tune-up cost per boiler does not vary substantially based on: (1) whether the building is multifamily or a school; (2) whether the boiler system temperature is set by a BAS system; or (3) boiler size.

Figure 14. Cost per Boiler Variations by Building Type



On the other hand, Figure 15 and Figure 16 appear to show significant differences in cost between different brands of controllers and different contractors.

Figure 15. Cost per Boiler Variations by Local Boiler Controller Brand

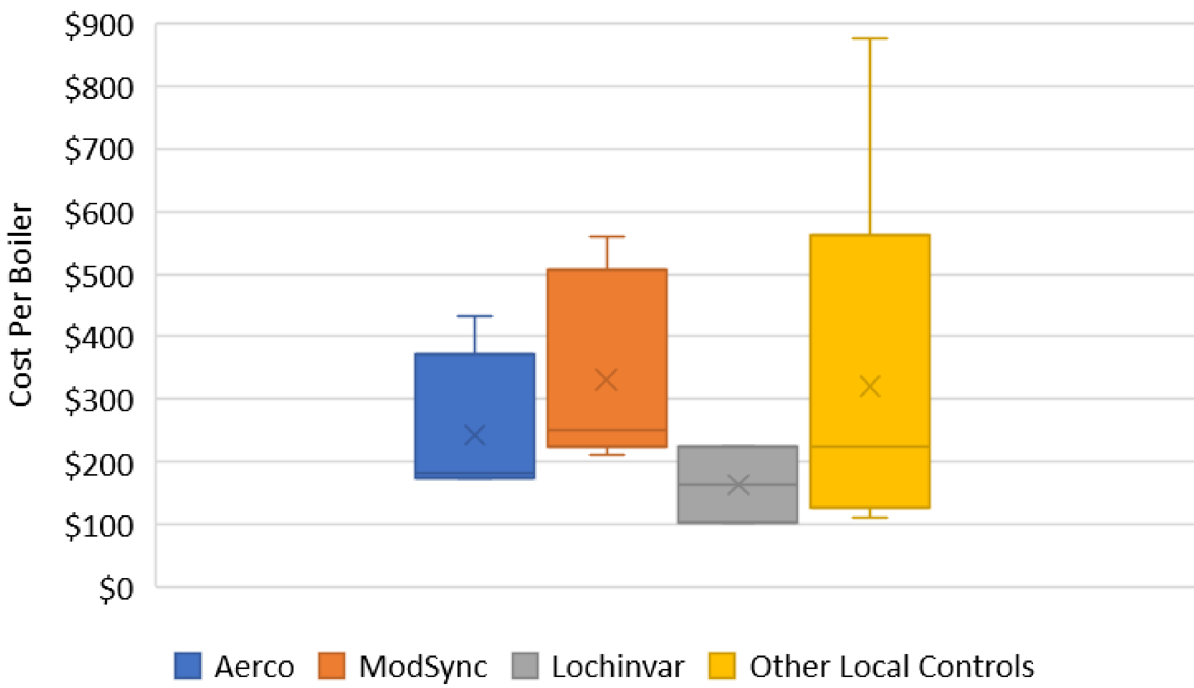
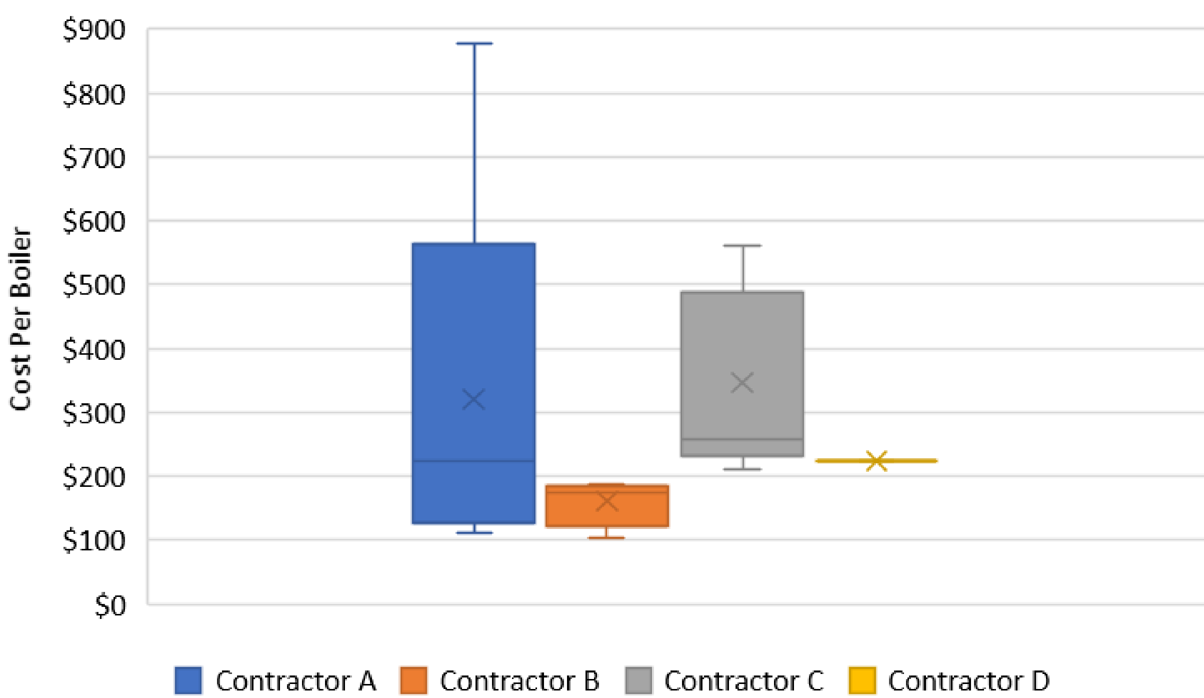


Figure 16. Cost per Boiler Variations by Contractor Performing Controls Tune-Up



However, strong cross-correlations between the controller brand and contractor make it difficult to determine whether most of this variation is due to controller brand variations or variations between contractors. These cross-correlations include:

- Contractor A did all of the control tune-ups at sites with controllers that fell into the other local controls category, and did not work on any sites with the other three brands of controllers.
- Contractor B did three of the four control tune-ups at sites with Aerco controllers and one of the two with Lochinvar controllers.
- Contractor C tuned up all six sites with ModSync controllers, plus one site with an Aerco controller.
- Contractor D only tuned up one of the two sites with Lochinvar controllers.

There was controller-specific guidance and quick-reference information provided for the sites with Aerco, ModSync, and Lochinvar controllers, so researchers expected somewhat higher costs for the sites with other local controllers. At these sites, the technician (with support from a research engineer) had to translate the general outdoor reset setting guidance into the model-specific logic of these various controllers, and work through the programming logic without a program quick-reference guide. These sites ended up having the widest range of costs with both the highest cost per boiler and some of the lowest costs per boiler within this group. For the sites with model-specific guidance and quick-reference documents, the Lochinvar controls tended to provide the lowest cost per boiler, with Aerco controllers also having relatively low costs per boiler for most sites. On the other hand, the sites with ModSync controllers tended to have somewhat higher costs per boiler. It is noteworthy that somewhat higher costs were expected for some for the ModSync sites because the protocol guidance for that controller was updated based on lessons learned from the first few sites. The mean and median for the ModSync sites was comparable to the mean and median for the sites with other local controls, despite the larger site-to-site variations among that group.

Details of Control Changes

Control Setting Changes

The temperature and staging control changes made at each site during the controls tune-ups are summarized in Table 13. These changes represent the net changes from the combination of the initial controls tune-up site visits, and any subsequent fine-tuning callback visits that were necessary within the first month. After this initial fine-tuning period, the new setpoints were generally maintained for at least the next several months spanning the milder weather portions of two heating seasons. Every site had a change to at least one setting that defines the outdoor reset curve, with all but one of those seeing decreases in boiler system temperatures for at least part of the range of heating season outdoor temperatures. On the other hand, only three sites had changes to outdoor cutout controls, with two sites having significant reductions in boiler system on-time and one site having a modest increase in boiler system on-time. Of the 18 sites, 12 also had changes made to boiler staging control settings. Three-fourths of the staging control setting changes were expected to reduce the occurrences of short-cycling issues, while the other one-fourth of the staging control setting changes had the goal of increasing the time at low boiler part-load conditions by bringing on another boiler stage sooner.

Table 13. Control Tune-Up Setting Changes by Site

Site	Outdoor Temp. at Boiler Max.	Max. Boiler Temp.	Outdoor Temp. at Boiler Min.	Min. Boiler Temp	Warm Weather Shutdown	Staging Control Changes
M1[a]	Down 22°F[b]	n/c[c]	n/a[d]	Down 22°F[b]	n/c	Increased off-delay
M2[a,e]	n/c	Down 38°F	n/a	Down 25°F	n/c	n/a
M3[a,f]	Down 32°F	n/c	n/a	Up 4°F	n/c	n/a
M4[a]	Down 40°F	n/c	n/c	Down 34°F	n/c	Established coordination between boilers
M5	Changed from manually adjusted setpoint to automatic outdoor reset via programming and sensor changes				Manual to Auto 55°F	Increased interstage delay from 3 to 5 minutes
M6[f]	n/c	n/c	Up 10°F	Up 15°F	Down 25°F	n/c
S1[f]	n/c	n/c	n/c	Down 20°F	n/c	Lowered 2nd-stage threshold from 70% to 40%
S2	n/c	Down 30°F	n/c	Down 15°F	n/c	Lowered 2nd-stage threshold from 60% to 50% and lowered demand offsets on two boilers
S3[f]	n/c	n/c	n/c	Down 10°F	n/c	Lowered 2nd-stage threshold from 70% to 40%
S4	Down 20°F	n/c	n/c	Down 10°F	n/c	Cascade offset from 10°F to 12°F; Differential from 20°F to 24°F; Min. on/off time from 30 seconds to 5 minutes; Min. next on time from 1 to 5 minutes
S5	n/c	Down 10°F	n/c	Down 10°F	n/c	n/c
S6[g]	Down 10°F	Up 5°F	n/c	Down 20°F	n/c	`Increased lag boiler start delay from 1 to 5 minutes; Increased lead off differential by 5°F; Increased threshold for starting 2nd boiler
S7	Changed Sensor; Down 10°F	Up 5°F	Up 10°F	Down 20°F	n/c	Removed local manual override of one boiler; Increased lag boiler stop delay from 1 to 5 minutes; Increased differentials by 4°F–5°F; Increased threshold for starting 2nd boiler; Increased integral time
S8	n/c	Down 5°F	n/c	Down 20°F	Up 5°F	Increased lead differential from 6°F to 15°F
S9	n/c	Down 20°F	n/c	Down 10°F	n/c	Lowered 2nd-stage threshold from 60% to 45%
S10	n/c	Down 20°F	Down 10°F	Down 10°F	n/c	Increased lag boiler start delay from 1 to 5 minutes; Increased lead off differential by 3°F; Increased threshold for starting second boiler
S11[a]	n/a	n/c	n/a	Down 10°F	n/c	Increased lag start delay from 1 minute to 5 minutes; Increased lead off differential by 5°F; Increased threshold for starting second boiler

a) The outdoor reset control logic at these sites differed from the standard, four-parameter end-points outlined in the protocol, and the reported changes in this table provide an approximate representation of how the setting changes would have equated to changes in a standard, four-parameter end point control situation.
b) An offset in the temperature setting was accidentally realized at this site due to a misunderstanding of staging versus setpoint logic.
c) "n/c" indicates that no change was made.
d) "n/a" indicates that the control does not have any settings that can be adjusted for this parameter.
e) These setpoint changes only affected the heating mode setting for a portion of the boilers, but not the service hot water heating control for two of the four boilers.
f) These sites had fine-tuning adjustments made within one month, with a non-program-trained technician performing the follow-up adjustment at M6.
g) This site's temperature control was switched from BAS to local controller.

Four of the sites had fine-tuning temperature setting adjustments made within the first month. At the two multifamily sites, this fine-tuning required a repeat contractor site visit. On the other hand, the building operations staff were able to make the adjustments at the school sites with remote coaching from research staff. The settings changes made during the initial tune-up at these sites are detailed in Table 14. (The values after fine-tuning are in Table 13.) The fine-tuning at sites M3, S1, and S3 was done in consultation with the research team and appears to have been necessary to provide adequate heating. On the other hand, the adjustment at M6 was done without consultation with researchers by a technician that had no involvement in the original tune-up and was not familiar with the protocol. At this site, instead of backing off on the largest and most relevant change made during the controls tune-up — the outdoor cutout setting reduction — the technician increased the boiler system temperature throughout the heating season, including bumping it up to a level that was significantly higher than the pre-tune-up settings in mild weather.

While the boiler staging control setting changes outlined in Table 13 were maintained throughout the post-tune-up monitoring period, nearly half of the sites underwent subsequent boiler temperature setting changes before the end of the 13-month post-tune-up monitoring period. The impact of these unexpected temperature setting changes are documented in the Boiler System Temperatures subsection within the Measured Impacts on Boiler System Temperature and Staging section.

Table 14. Initial Setting Changes for Sites with Fine-Tuning Revisits

Site	Outdoor Temp. at Boiler Max.	Max. Boiler Temp.	Outdoor Temp. at Boiler Min.	Min. Boiler Temp	Warm Weather Shutdown	Reason for Fine-Tuning
M3[a]	Down 32°F	n/c[b]	n/a[c]	Down 14°F	n/c	Underheating
M6	Down 9°F	Down 15°F	Up 10°F	n/c	Down 25°F	Unknown — likely underheating in mild weather
S1[d]	Down 20°F	Down 10°F	n/c	Down 20°F	n/c	Underheating
S3[d]	Down 20°F	Down 10°F	n/c	Down 10°F	n/c	Underheating

a) The outdoor reset control logic at these sites differed from the standard, four-parameter end-points outlined in the protocol, and the reported changes in this table provide an approximate representation of how the setting changes would have equated to changes in a standard, four-parameter end point control situation.
b) "n/c" indicates that no change was made.
c) "n/a" indicates that the control does not have any settings that can be adjusted for this parameter.
d) The very low setpoints at these two sites were based on plans clearly indicating a design intent for the system to run at lower temperatures than the commissioning report indicated for settings at the end of commissioning.

Tune-Up Changes Beyond Setpoints

The scope of control work at four of the sites included work beyond setting changes. The additional scope of needed work identified through application of the protocol at each of these sites is outlined in Table 15. Only the work at site M4 was not able to be completed during the initial tune-up visit because of the need to order specific parts. It is also noteworthy that three of the sites — M1, S2, and S7 — had water or water and glycol added to the system to alleviate extremely low pressure conditions. While the addition of glycol was accomplished at S2 with material that was available on-site, it was done on a callback return visit the same day that the control tune-up was performed. The low pressure contributed to a condition that kept the boilers from firing for a time until manual restarts were performed and fluid was added to ensure that the boilers would keep operating reliably.

Table 15. Individual Site Control Changes beyond Simple Controller Settings

Site	Scope Beyond Setting Changes
M4	Wired cascade control link between the two boilers; added a system supply temperature sensor
M5	Rewired controller to an existing outdoor temperature sensor; changed from manual constant temperature setpoint to outdoor reset
S2*	Changed the BAS sensor used to control the boiler system supply temperature from within the boiler plant piping to the building loop*
S6	Set local controller to determine its own system temperature setpoint instead of using temperature control setting from BAS
S7	Changed individual boiler from manual override (with a constant temperature setpoint) back to automatic staging by ModSync controller; switched from BAS outdoor temperature sensor to the ModSync's outdoor temperature sensor

*This change was recommended to the school district, but implemented at a later time by a BAS contractor. This contributed to the same-day callback of boilers not firing and likely causes issues during low load conditions.

Measured Impacts on Boiler System Temperature and Staging

Boiler System Temperatures

Table 16 and Figure 17 summarize the impact of the boiler control tune-ups on boiler system supply temperature across all sites. The outdoor temperatures of 25°F and 50°F were chosen to represent performance during the colder and warmer portions of the heating season. These temperatures are representative of an outdoor temperature range with a sizeable combination of heating load and operating hours during a typical heating season in Minnesota.

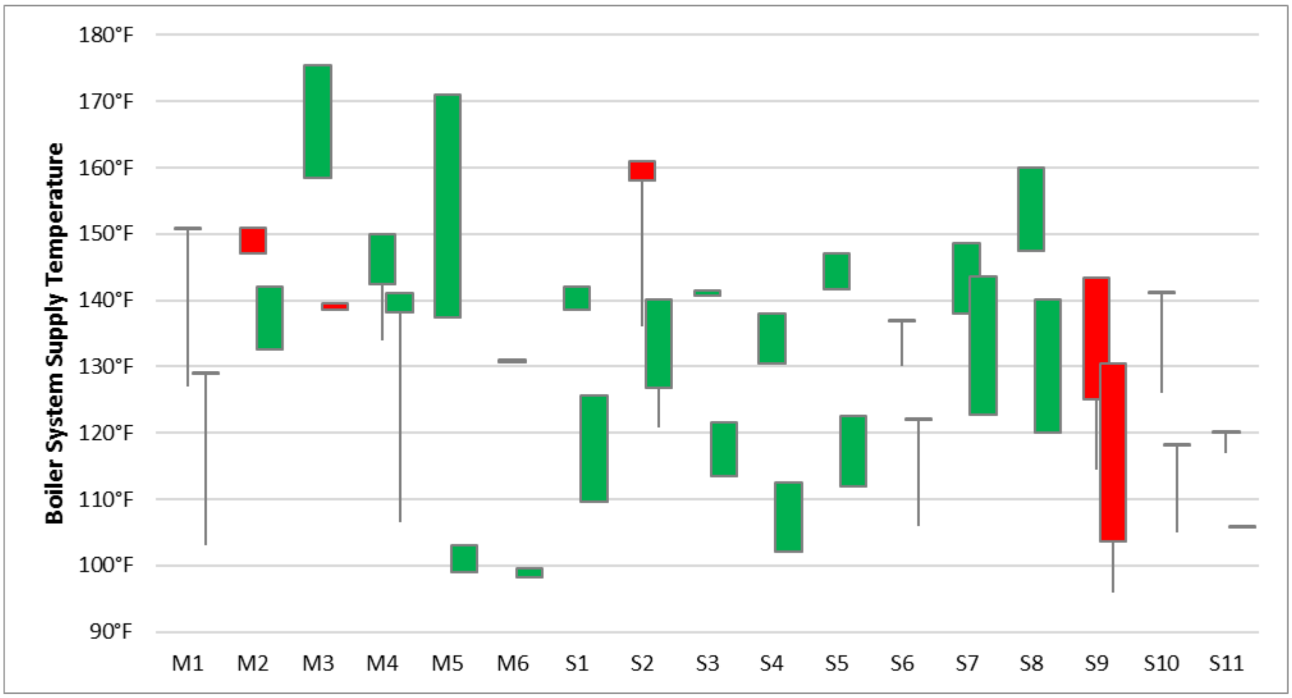
The average boiler system supply temperatures were lowered by 11°F–13°F during the first several months after the control tune-ups, and, on average, maintained a 4°F–5°F lower average temperature after 13 months. The green bars in Figure 17 show that 11 of the 17 sites maintained at least a moderate reduction at 25°F, 50°F, or both. Five of the sites ended up reverting back to near pre-tune-up values, while one site had significantly higher settings at the end of the monitoring period.

The eight sites that had documented changes in temperature settings after the initial tune-up (and first few weeks of fine-tuning) are outlined in Table 17. It is noteworthy that only two of the eight sites were very likely to have had settings adjusted because of underheating issues. For sites S9 and S10, researchers strongly suspect that BAS system temperature setpoints reverted back to previous defaults as part of BAS system default setpoint resets for each entire school. This could not be confirmed due to the changeover of multiple key staff at the district level, but on-site staff had no recollection of changing boiler temperature settings due to any underheating issues.

Table 16. Summary of Boiler System Supply Temperature Changes

	At 25°F Outdoor Air Temperature	At 50°F Outdoor Air Temperature
Average Pre-Tune-Up	146.1°F	124.0°F
Average Post-Tune-Up	135.4°F (10.7°F < Pre)	111.4°F (12.6°F < Pre)
Average 13 Months Later	141.9°F (4.3°F < Pre)	118.8°F (5.2°F < Pre)

Figure 17. Boiler System Supply Temperature Changes by Site at 25°F and 50°F Outdoor Air Temperatures*



***Key:**

- The tops and bottoms of the boxes and horizontal lines show the observed supply temperatures for the pre-tune-up period and at the end of the monitoring period. A green box indicates a reduction (end of monitoring value less than pre-tune-up) and red indicating an increase (end of monitoring period higher than pre-tune-up). Where there is a gray horizontal line instead of a box, that indicates that the pre-tune-up and end-of-monitoring temperatures were the same.
- The bottom of each vertical line indicates the supply temperatures observed during the first several months of the post-tune-up period. When no vertical line is shown, that indicates that the initial post-tune-up temperature reductions observed over the first several months were maintained until the end of the monitoring period (or lowered further in two cases).
- For each site, the left-hand box, or bar and line, are based on observations around 25°F outdoor air temperatures and the right-hand box, or bar and line, are based on observations around 50°F outdoor air temperature. (Due to data monitoring problems, the temperatures reported for S8 were estimated from control settings rather than monitored observations.)

Table 17. Apparent Reason for Boiler System Temperature Changes Long after Control Tune-Ups

Site	Apparent Reason
M1	Reset by contractor while replacing a pump; may have been underheating issues
M4	Operator manual adjustment due to incomplete understanding of outdoor reset programming
M5	Temperatures reduced further; likely in response to overheating in mild weather
S5	Underheating in moderately cold weather, but was later set back to tuned-up settings
S6	Confusion regarding the intent to use BAS settings in summer only and local controller settings during heating season
S9	School wide reset of BAS setpoints to default values
S10	School wide reset of BAS setpoints to default values
S11	Operator and contractor technician misunderstanding of expected cycling operation

Examples of the changes in observed boiler system supply temperature trends can be seen in Figure 18 through Figure 24 for a number of the sites. The general expectations were that:

- boiler system supply water temperature will start with its maximum at low outdoor temperatures and drop along a line until it reaches a set minimum at high outdoor temperatures;
- post-tune-up data sets will generally have lower temperatures for at least part of the range of outdoor temperatures; and
- in mild weather, manual or automatic warm weather shutdown control causes the boiler supply temperature to drop to room temperature on some days.

Note that various boiler staging coordination issues or manual setpoint changes caused the pre-tune-up relationship between supply water temperature and outdoor temperature to differ significantly from this expectation for sites M4, M5, and S7. Summer boiler use for reheat also caused the boiler supply temperature to ramp back up in hot weather at site S5.

Figure 18. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site M4

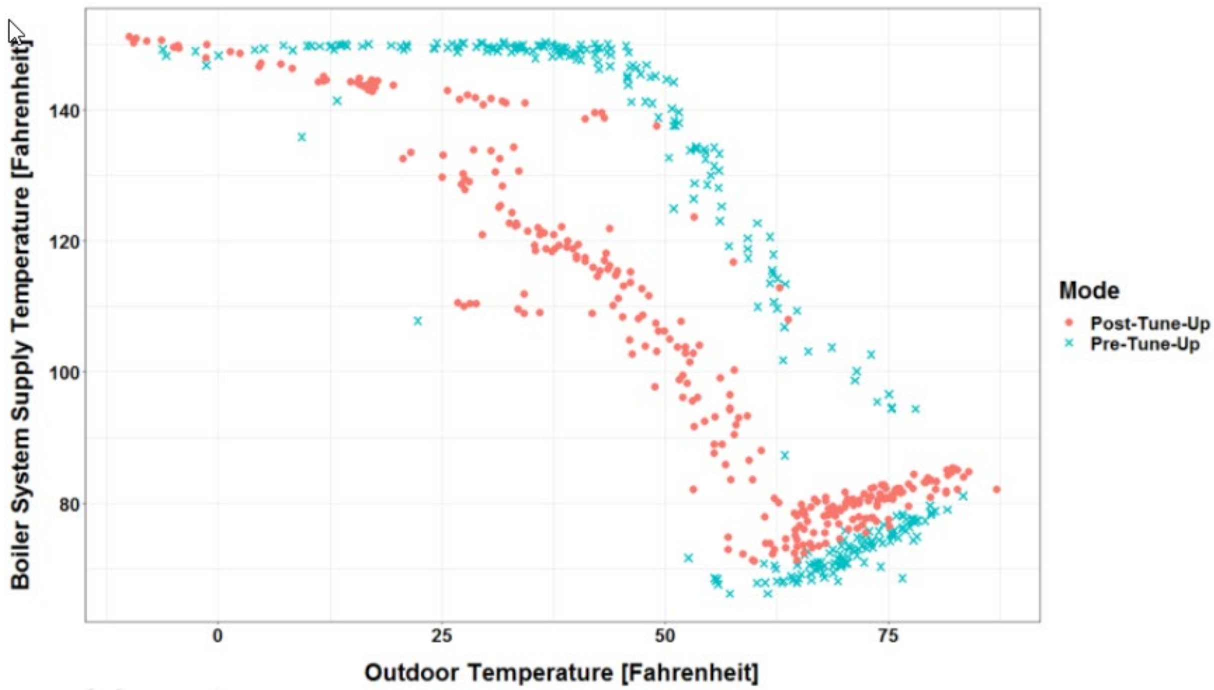


Figure 19. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site M5

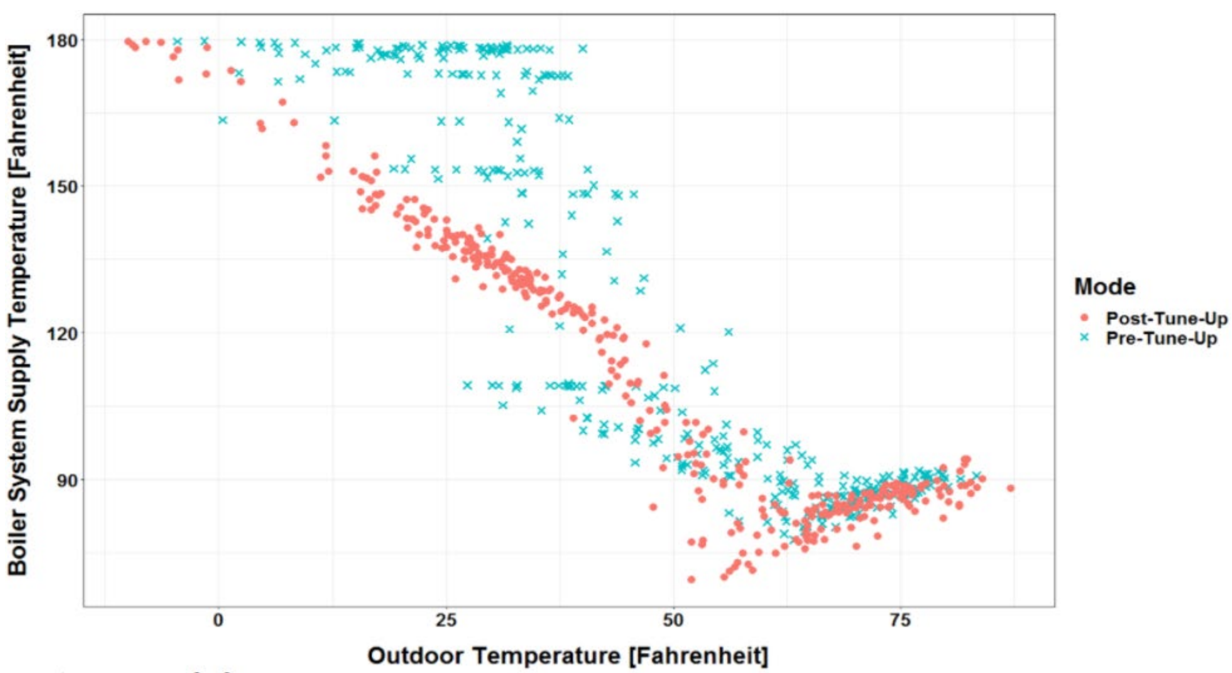


Figure 20. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site S1

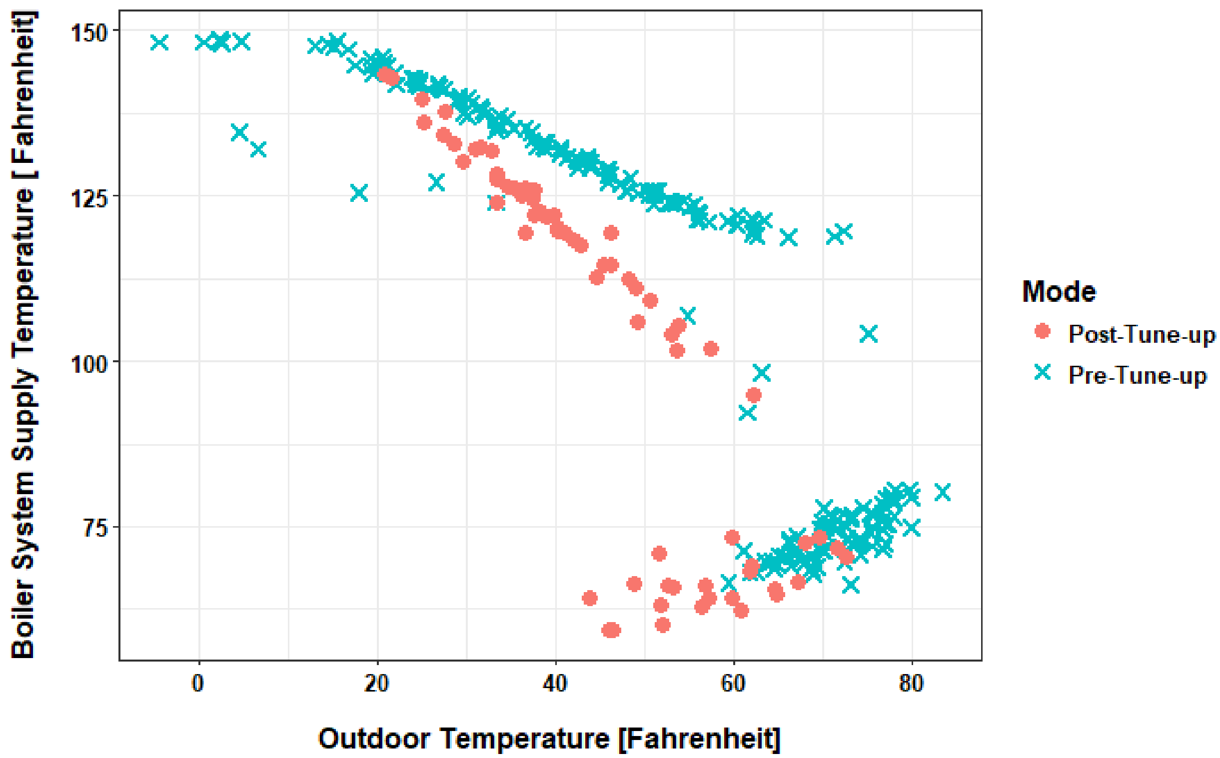


Figure 21. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site S5

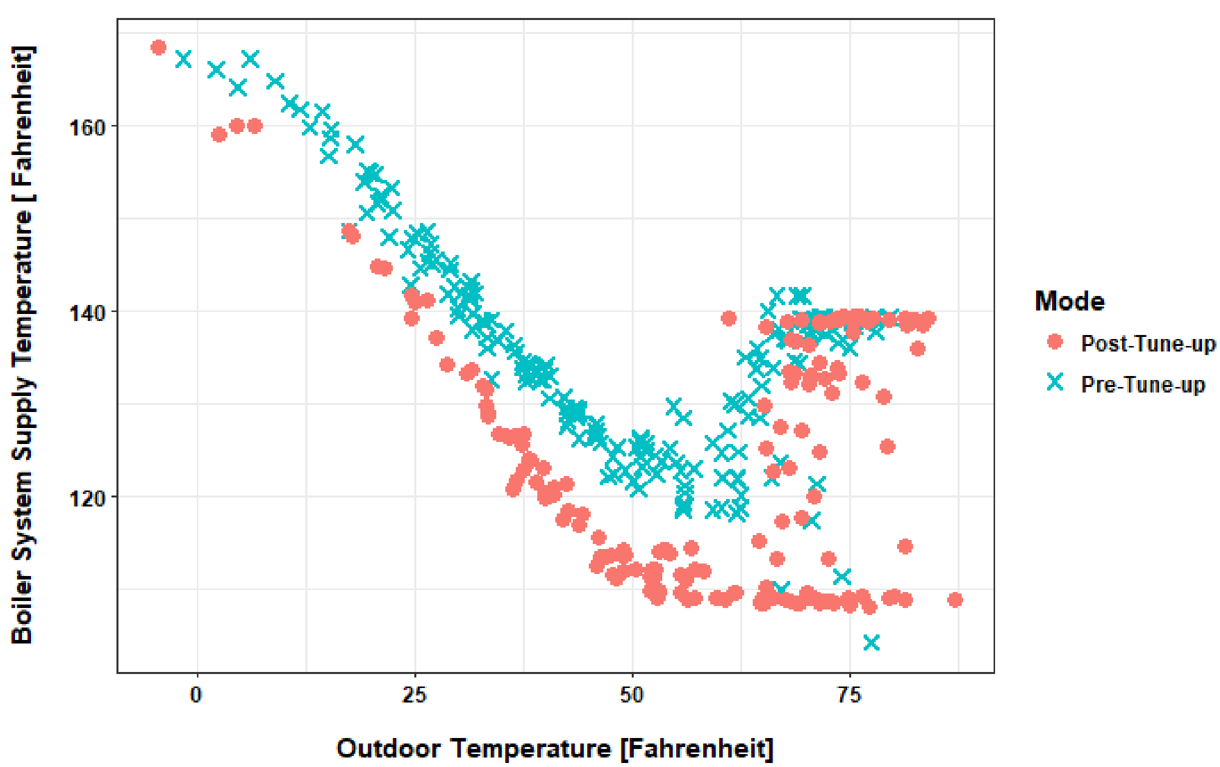


Figure 22. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site S6

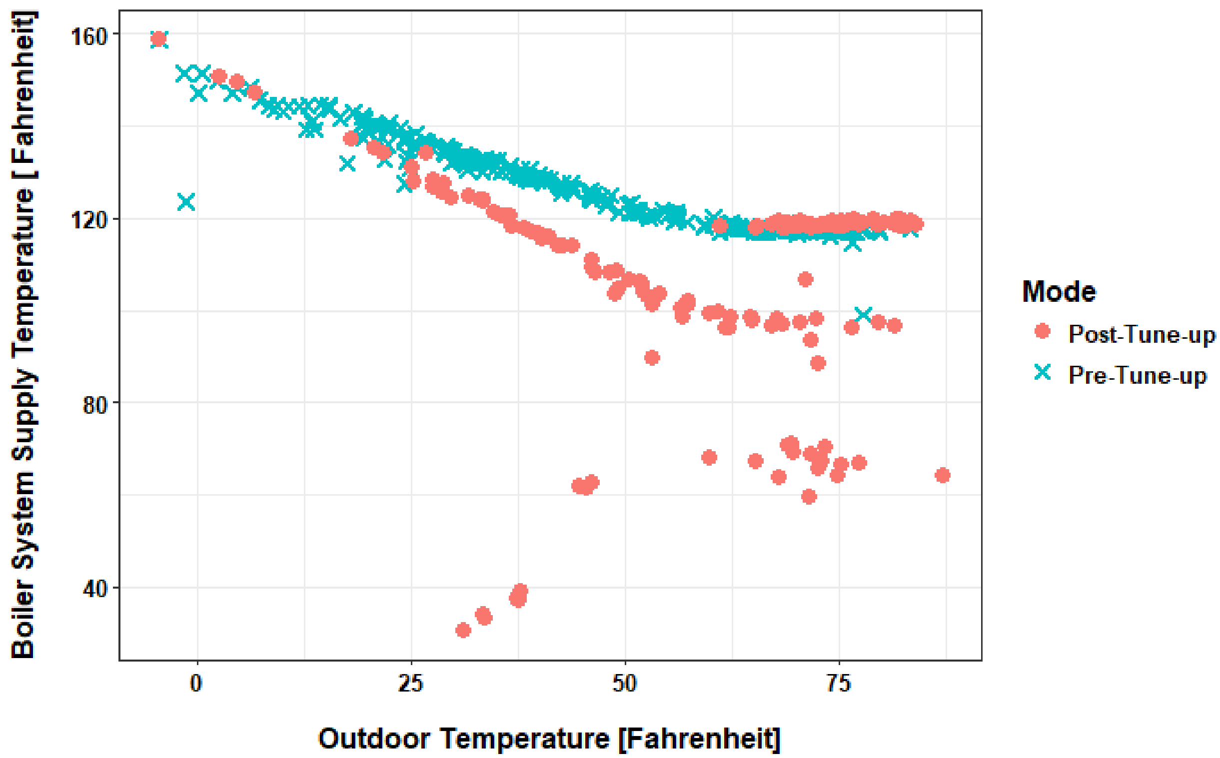


Figure 23. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site S7

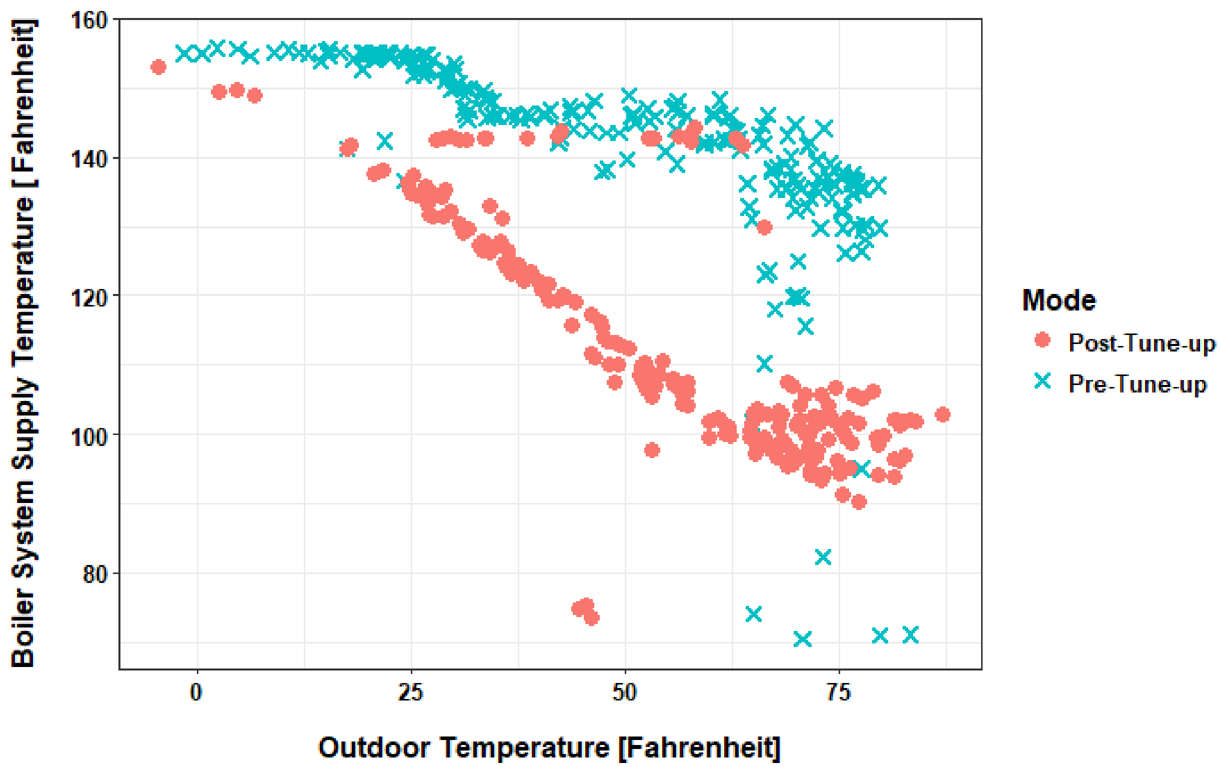
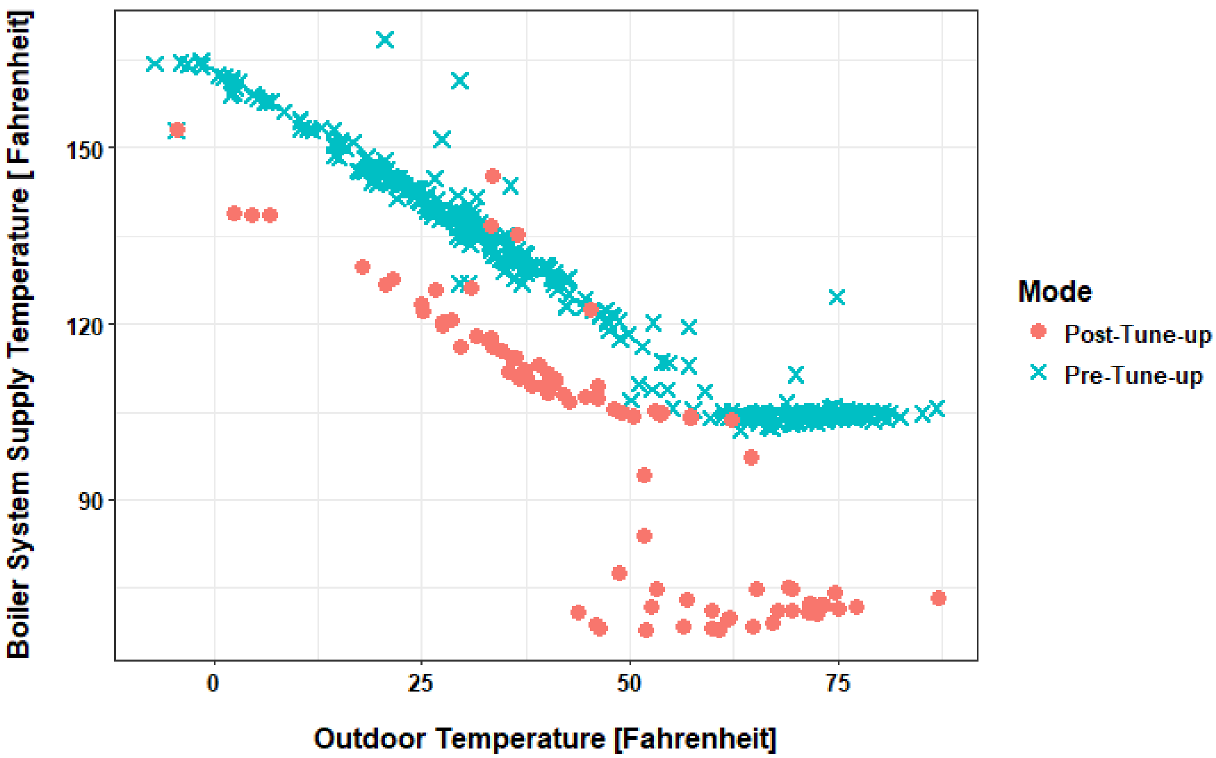


Figure 24. Daily Average Boiler Supply Temperature versus Outdoor Temperature: Site S10



Measured Boiler Staging Changes

Observations of changes in boiler cycling between pre-tune-up and post-tune-up periods are detailed in Table 18 for 14 of the 17 sites that had control tune-ups performed. No boiler cycling behavior data was available for sites M1, M2, and M3. The table also indicates the local controller make and product series, with all of these controllers being built into the boilers, except for the ModSync controllers that were used in connection with Fulton boilers. The median boiler cycles per run-hour dropped from 3.13 to 1.32, with a median per-site reduction in average cycles per run-hour of 48%. For the seven sites that had cycles per run-hour of about two or greater, which is considered excessively high by boiler representatives, a similar median reduction of 51% was realized between the pre-tune-up operation and post-tune-up operation. Five of the six sites with ModSync controllers had excessive pre-tune-up cycling rates, while none of the four Aerco sites had high cycling rates. While two sites had significant increases in cycling, the post-tune-up values were still under the 2.00 cycles per run-hour threshold of concern. One of the two sites with Lochinvar boilers had a high pre-tune-up cycling rate. Problems with staging control beyond setting changes contributed to pre-tune-up short-cycling at sites M4 and S7, and these two sites had the highest percent reduction in cycles per run-hour. The cycling reductions at the other sites were accomplished with only changes to settings such as on- and off-stage delays and differentials.

Table 18. Observed Number of Boiler Cycles per Run-Hour Pre- and Post-Tune-Up

Site ID	Local Controller	Since Boiler Installation or Counter Reset	Pre-Tune-Up Monitoring Period	Post-Tune-Up Period	Percent Reduction[a]
M4	Laars Neotherm NTH	n/a[b]	11.34[c]	2.16[c]	81%[c]
M5	Cleaver Brooks CFC-700 series	n/a	0.34[c]	1.54[c]	-360%[c]
M6	Lochinvar KBN400	0.76	0.92 (3.00 monitored)[c]	0.39 (0.52 monitored)[c]	58% (83% monitored)[c]
S1	Aerco BMK	0.29	0.04	0.86	-2,050%
S2	Aerco BMK	0.10	n/a	0.08	20%
S3	Aerco BMK	0.32	n/a	0.08	75%
S4	Lochinvar KBN801	4.27	n/a	0.95	78%
S5	ModSync	1.38	1.98	1.31	34%
S6	ModSync	4.62 (4.87 Boiler 1)	6.52 (7.75 Boiler 1)	n/a (4.27 Boiler 1)	45%
S7	ModSync	8.93	23.11	1.32	94%
S8	ModSync	2.05	13.06	5.33	59%
S9	Aerco BMK	1.45	1.48	0.82	45%
S10	ModSync	4.41[e]	n/a	4.27	3%
S11	ModSync	8.06[e]	n/a	3.93	51%
Median		3.13[f]		1.32	48%

a) Percent reduction is based on a comparison of the post-tune-up period to either the pre-tune-up period (whenever available) or the boiler history since installation or counter reset.

b) "n/a" indicates that data was not available due to there not being counters for the boilers or no reading being taken.

c) Data reported for multifamily buildings is based on monitoring of burner on-time and cycling via a current transformer on a gas burner lead wire.

d) Median values were reported because the average was overly skewed by a few very high count data points that were probably caused by field data quality issues or burner ignition problems, rather than temperature control cycling.

e) These values are based on observations at the time of the controls tune-up.

f) The median reported here is based each site's best estimate of the pre-tune-up condition that can be directly compared to post-tune-up data is reported.

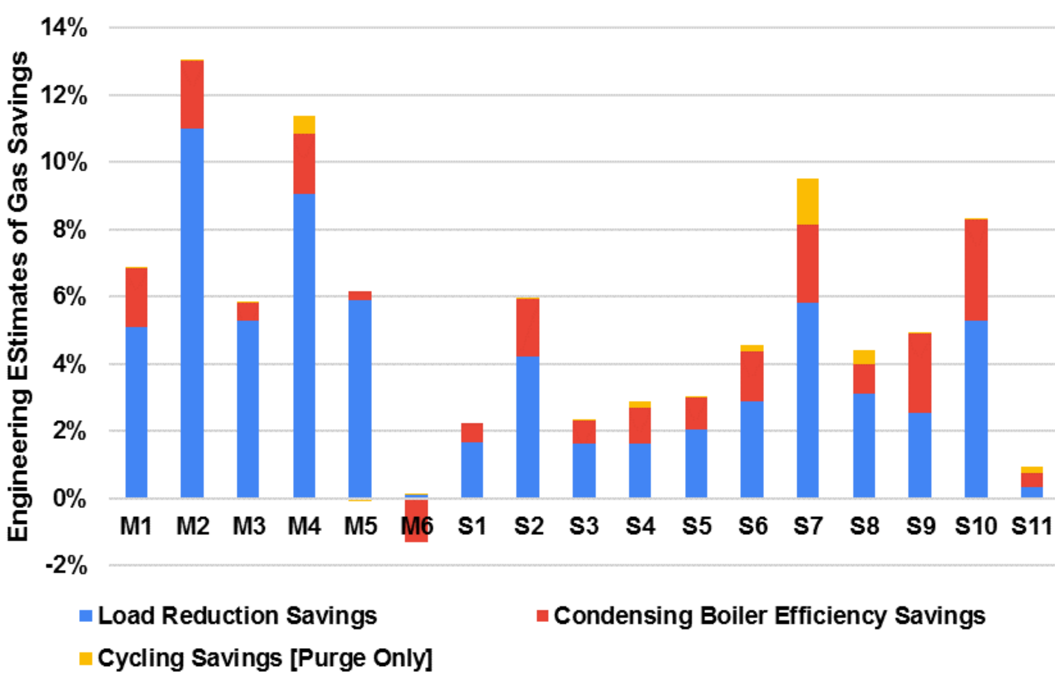
There are no conclusive findings regarding the effectiveness of staging control setting changes at the four sites with Aerco boilers. These changes had the goal of having more boilers run at lower average firing rates. Researchers were only able to measure boiler firing rates at two of these four sites, and the limited amount of post-tune-up data with comparable school operation made it hard to draw conclusions. The limited data for these two sites suggested that in some outdoor temperature ranges the average boiler firing rate decreased 2–5 percentage points, with the range of temperatures where this appeared to occur inconsistent between the two sites. It is noteworthy that, even before the control tune-ups, the median of daily average firing rates at around 0°F was already less than 25% for site S9 and less than 40% for site S2. These low average firing rates suggest that boilers spend most of their time operating at firing rates well below the thresholds for bringing on additional boilers.

The staging control settings were generally not altered by building operators or contractors after the initial tune-up site visits. Therefore, the improvements to cycling behavior or average firing rates made from control tune-up adjustments are expected to have a very high degree of persistence over time.

Savings Predictions from Setting Changes

Engineering estimates of percent savings for each site are shown in Figure 25. The different colors of stacked bars indicate how much of each site's savings is associated with load reduction (from lower building loop temperatures); condensing boiler efficiency increases (from lower boiler water return temperatures); and reduced cycling purge losses. The average projected savings is 5.4%. On average, the load reduction savings accounts for 74% of the savings with the condensing boiler efficiency gain accounting for most of the remainder of the savings (23% of the total savings). The purge reduction savings from reducing short-cycling was estimated to account for only about 3% of the total savings across all sites, and at most 14% of the savings at any individual site.

Figure 25. Engineering Estimates of Savings for Each Site



Monitored Energy Savings

Annual Savings from Tune-Up Changes

Table 19 details the annual energy savings observed at the boiler control tune-up sites. This table also includes the analysis basis for each site's savings estimate and the pre-tune-up annual gas use for each site. However, the most important metrics in this table are the observed first-year savings and the estimated persistence of this savings beyond the first year. The observed first-year savings is based on field monitoring between any fine-tuning adjustments made within the first month of the initial tune-up visit, and any known dates of later control setting adjustments that occurred after the first several months (but before the end of the 13-month monitoring period). The estimated persistence of this savings beyond the first year is based on a comparison of boiler control settings observed at the end of the 13-month monitoring period to those before and after the controls tune-ups. The ranked percent savings by site is also shown in Figure 26.

The observed savings over the limited post-tune-up period at the only hybrid boiler site, S8, was believed to be strongly biased by an atypical operating condition that occurred in response to a failure of the normal service hot water system. While the observed value is reported here, the dramatic increase in gas use is believed to be unrelated to the boiler controls tune-up. Therefore, the research team believes that summary values that exclude the observed gas use results from this site are more representative of program expectations than those that include this usage change. Therefore, the most representative summaries of the savings achieved at these pilot boiler controls tune-up sites are the 6.5% median savings and 7.3% average without site S8, or 1,343–1,646 therms per site.

The persistence of savings was encouraging — over time, it appeared that 10 of the 17 sites will maintain the full amount of first-year savings into the second year. The average persistence of savings at the end of the first year (with the -250% value included as a zero value) was 66%. There was a pattern of sites generally either maintaining 100% of their savings through the first year or having the savings reduced to a small fraction of the initial savings. None of the sites had a persistence into the second year between 30% and 100%.

Table 19. Measured Energy Savings from Boiler Control Tune-Ups

Site	Savings Basis	Pre-Tune-Up Gas Use (therms/ccf)	First-Year Tune-Up Savings (therms/ccf)	First-Year Tune-Up Savings	Persistence Beyond First Year[a]
M1	Pre/Post Regressions	9,861[b]	2,381	24.1%	5%
M2	Pre/Post Regressions	10,091[b]	716	7.1%	100%
M3	Pre/Post Regressions	34,439[b]	-1,421	-4.1%	100%
M4	Pre/Post Regressions	3,077	616	20.0%	30%
M5	Pre/Post Regressions	37,911[b]	7,732	20.4%	115%
M6	Pre/Post Regressions	15,132[b]	-907	-6.0%	100%
S1	Pre Regression/Post Residuals[c]	27,610[b]	1,699	6.2%	100%
S2	Pre Regression/Post Residuals[c]	132,584	1,343	1.0%	15%
S3	Pre Regression/Post Residuals[c]	24,603[b]	-2,713	-11.0%	100%
S4	Pre Regression/Post Residuals[c]	13,729	1,367	10.0%	100%
S5	Pre Regression/Post Residuals[c,d]	62,381[d]	4,047[d]	6.5%[d]	100%
S6	Pre Regression/Post Residuals[c]	37,927	6,799	17.9%	20%
S7	Alternating Mode Regressions[c]	22,160	2,783	12.6%	100%
S8	Pre Regression/Post Residuals[c]	121,068[b]	-57,494[e]	-47.5%[e]	100%
S9	Pre Regression/Post Residuals[c]	21,433[b]	29	0.1%	-250%
S10	Pre Regression/Post Residuals[c]	13,540	1,482	10.9%	5%
S11	Engineering Estimate	40,997[f]	379	0.9%	25%
Median	All Sites	24,603	1,343	6.5%	100%
Average	All Sites	36,973	-1,833	4.1%	66%[g]
Average	Excluding Site S8	31,717	1,646	7.3%	63%[g]

a) The persistence into second year is estimated based on boiler control settings after 13 months and engineering estimates.

b) The pre-tune-up gas use at these sites includes end uses that are not served by the boiler plant.

c) The post-tune-up residuals were generally limited to observations made at outdoor temperatures below 40°F, with minimum temperatures ranging from -5°F to 5°F for seven sites and at about 20°F for two sites (S1 and S3).

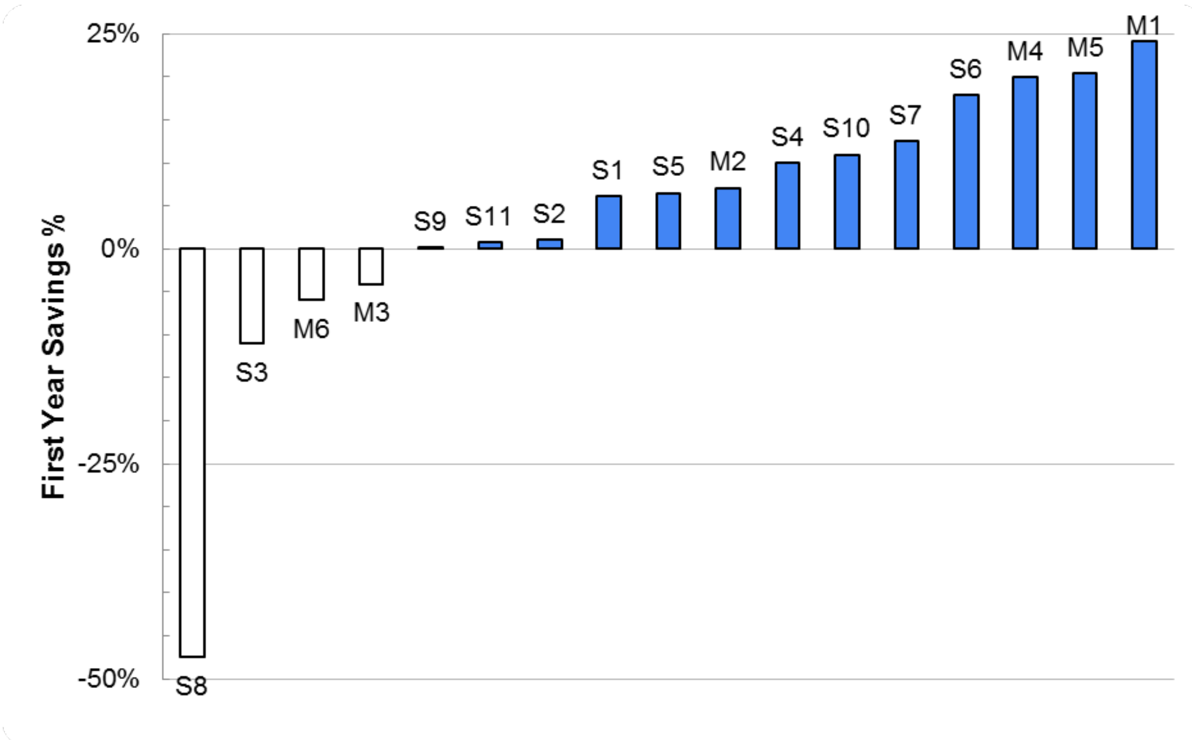
d) Data for S5 could not be fully corrected for inadequate boiler on-time information. The nature of the error was not expected to differ significantly between the pre- and post-data sets, and more detailed review for a portion of the post-tune-up data period suggests that energy usage is underestimated by about 8%.

e) The post-tune-up gas use and a limited amount of the pre-tune-up gas use at site S8 is believed to be dramatically impacted by the extended manual override of the switchover between the two large non-condensing boilers and the three condensing boilers, which normally occurs at around 10°F. Site staff reported that the non-condensing boilers were forced on at high boiler temperatures so that a service hot water heat exchanger could be used while the normal service hot water system was in need of service.

f) Pre-tune-up usage for site S11 was estimated by applying the average ratio of annual usage to boiler plant size for the other 10 schools.

g) These averages are based on using a value of 0% for S9 instead of -250% since the increase is expected to have taken place whether there was the program intervention or not.

Figure 26. Ranked First Year Savings for Each Site



Examples of the pre- and post-tune-up gas use data and regressions for the multifamily sites can be seen in Figure 27 and Figure 28. The shaded areas in these plots show the bounds of 95% confidence interval of each model's estimate of daily average gas use.

Examples of the pre-tune-up data and regression models for the schools can be seen in Figure 29, Figure 31, Figure 33, and Figure 35, while the corresponding comparison of the limited amount of post-tune-up data to the pre-tune-up regression lines (based on regressions over a similar limited range of outdoor temperature in most cases) are shown in Figure 30, Figure 32, Figure 34, and Figure 36. Lastly, the alternating mode testing data comparison for site S7 is shown in Figure 37.

Figure 27. Pre- and Post-Tune-Up Daily Average Gas Use: Site M4

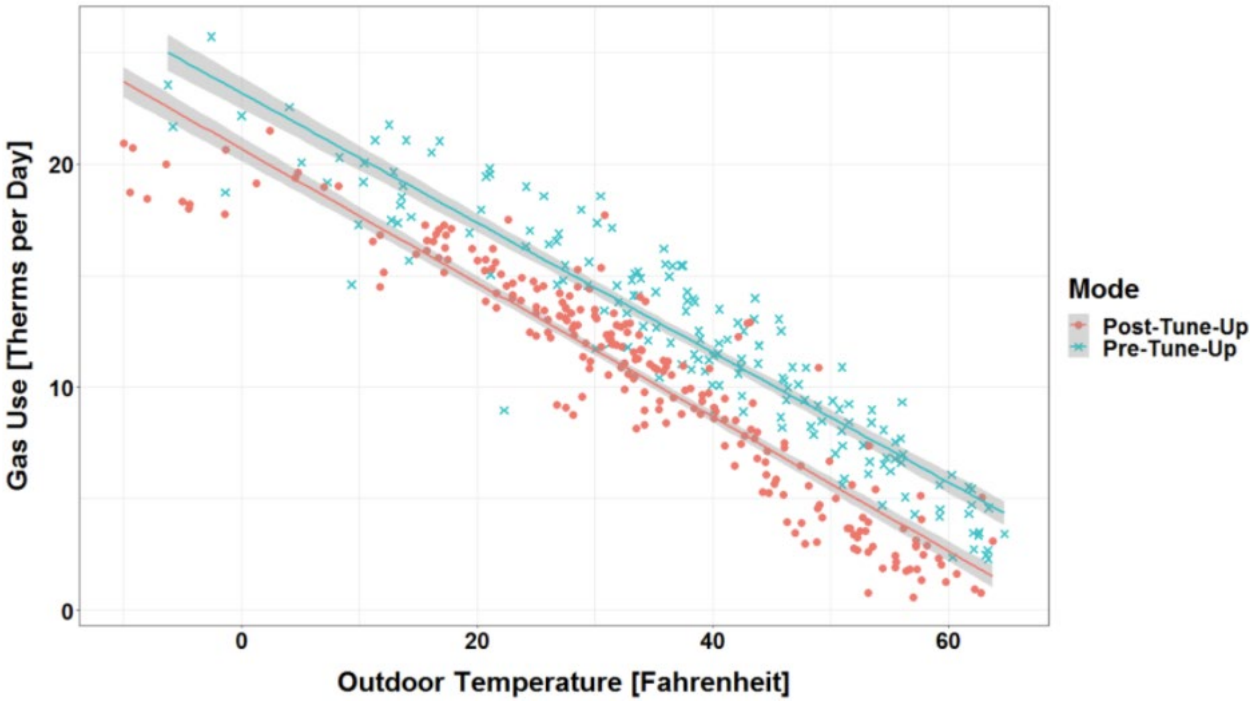


Figure 28. Pre- and Post-Tune-Up Daily Average Gas Use: Site M5

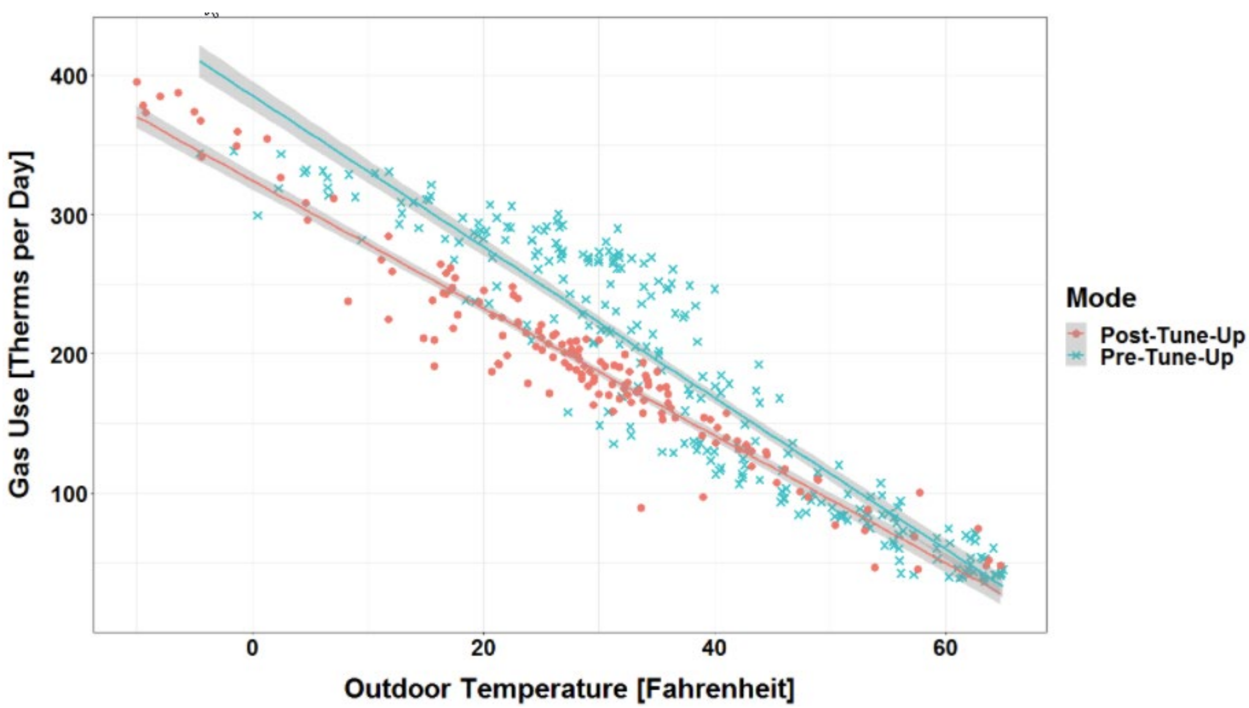


Figure 29. Pre-Tune-Up Daily Average Gas Use: Site S1

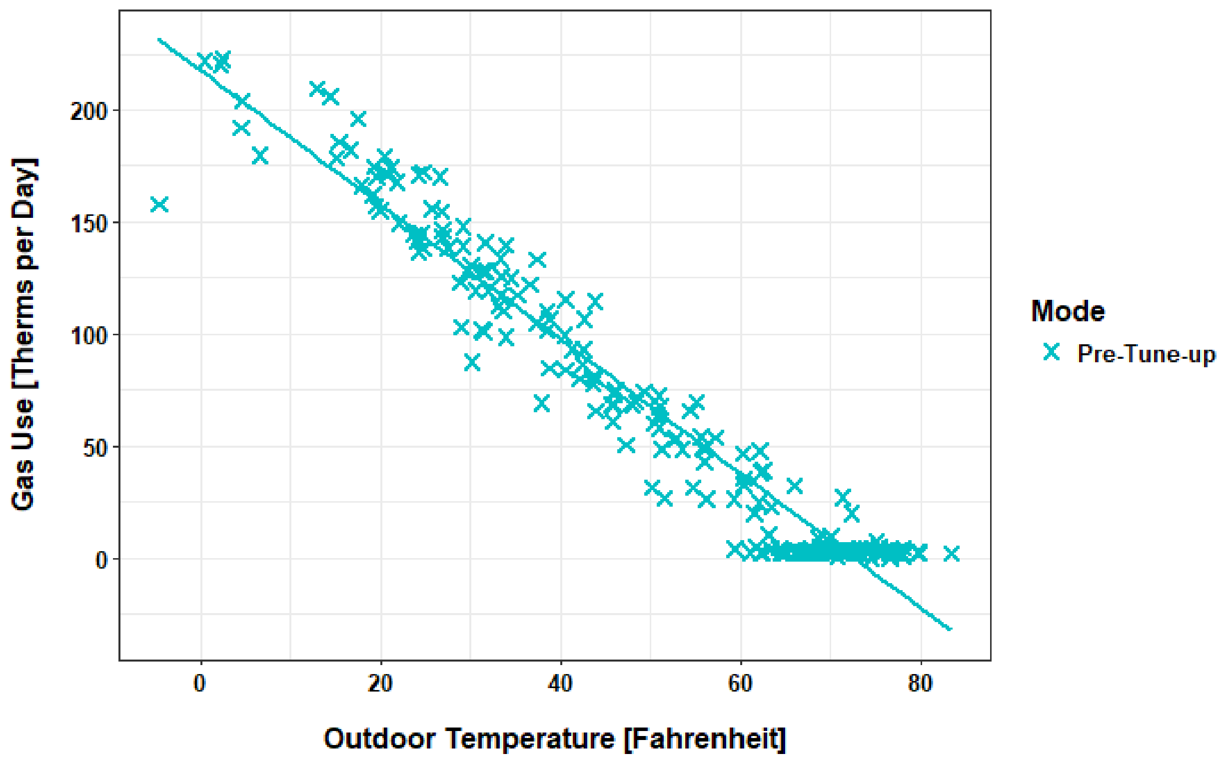


Figure 30. Post-Tune-Up Daily Average Gas Use Comparison to Pre-Tune-Up Regression: Site S1

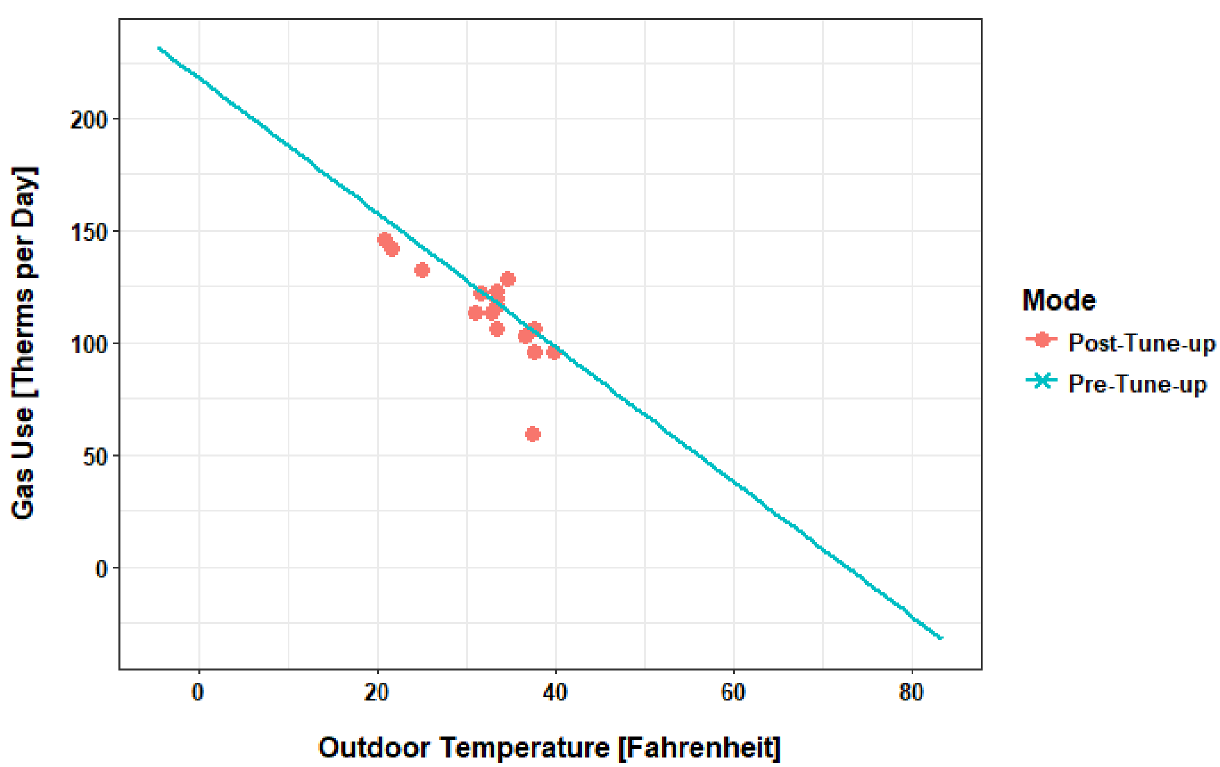


Figure 31. Pre-Tune-Up Daily Average Gas Use: Site S5

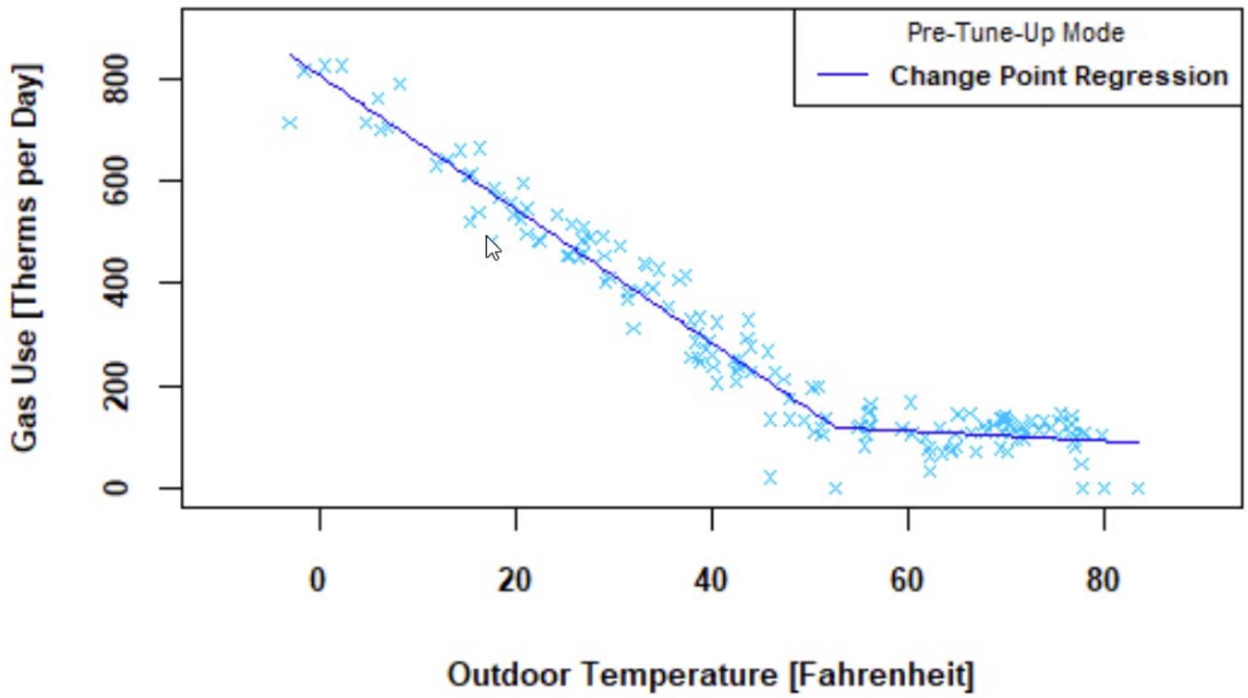


Figure 32. Post-Tune-Up Daily Average Gas Use Comparison to Pre-Tune-Up Regression: Site S5

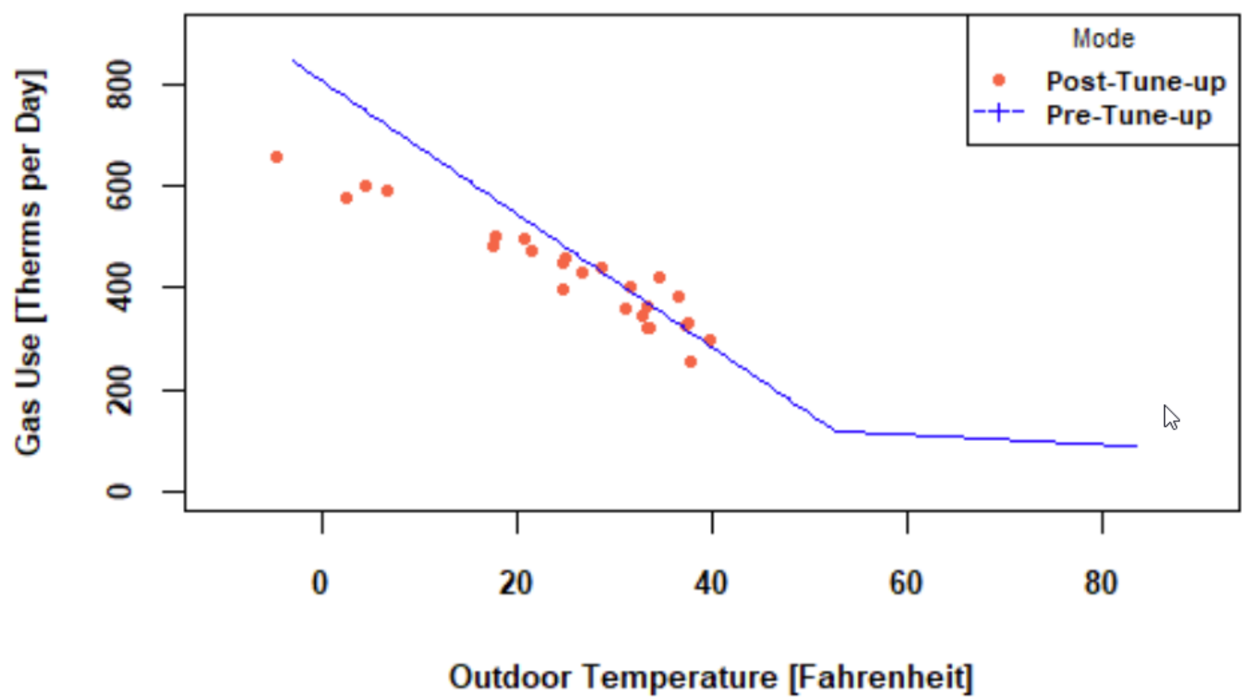


Figure 33. Pre-Tune-Up Daily Average Gas Use: Site S6

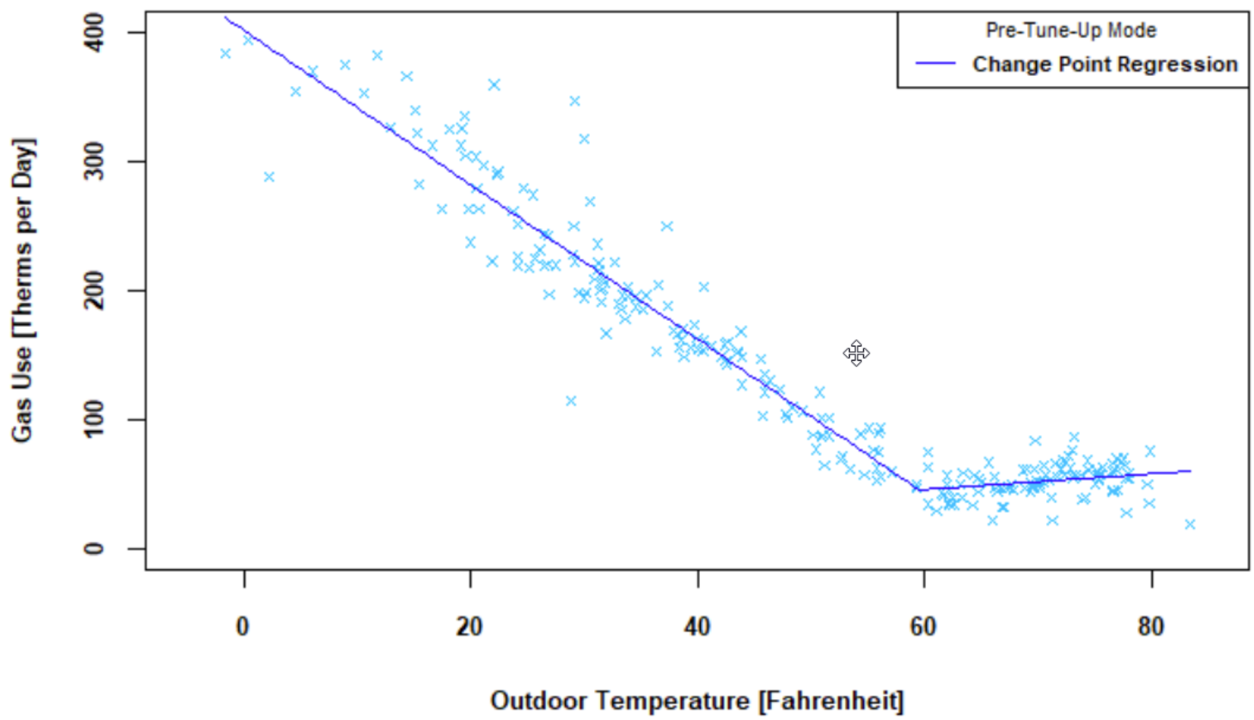
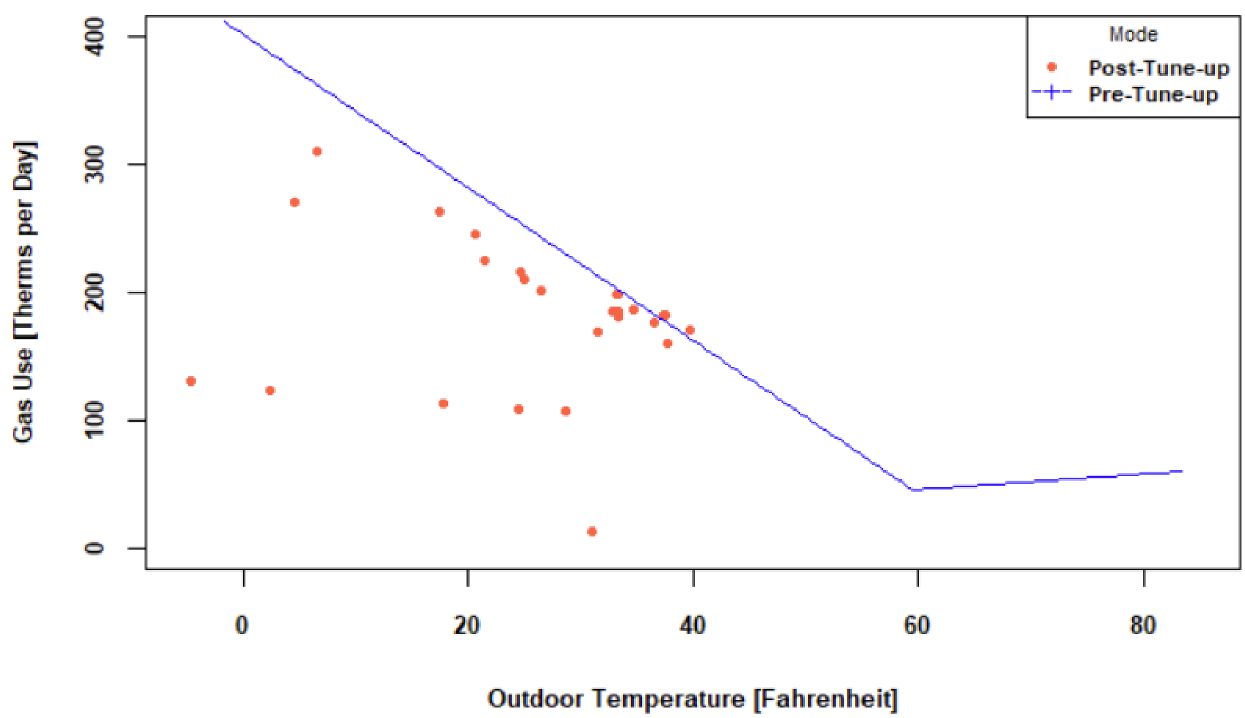


Figure 34. Post-Tune-Up Daily Average Gas Use Comparison to Pre-Tune-Up Regression: Site S6*



*The savings analysis for site S6 excluded the three post-tune-up data points that had the highest model residuals (i.e., the lower use points at -5°F, 2°F, and 31°F outdoor air temperatures). Exclusion of three additional low data points between 18°F and 25°F outdoor air temperatures would have reduced the savings from 17.9% to 11.2%.

Figure 35. Pre-Tune-Up Daily Average Gas Use: Site S10

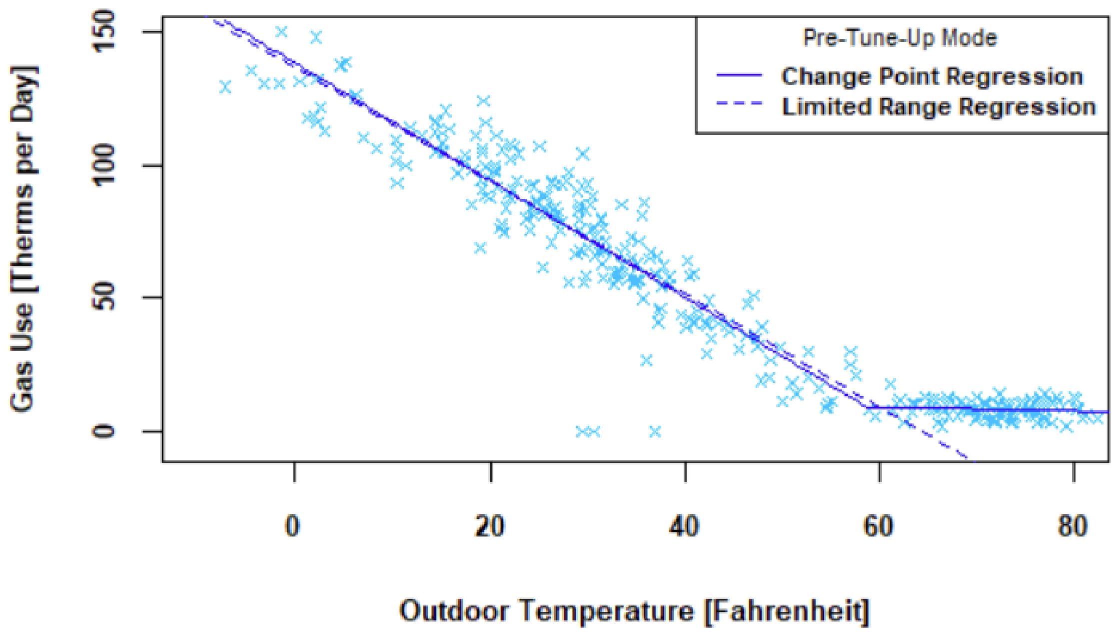


Figure 36. Post-Tune-Up Daily Average Gas Use Comparison to Pre-Tune-Up Regression: Site S10

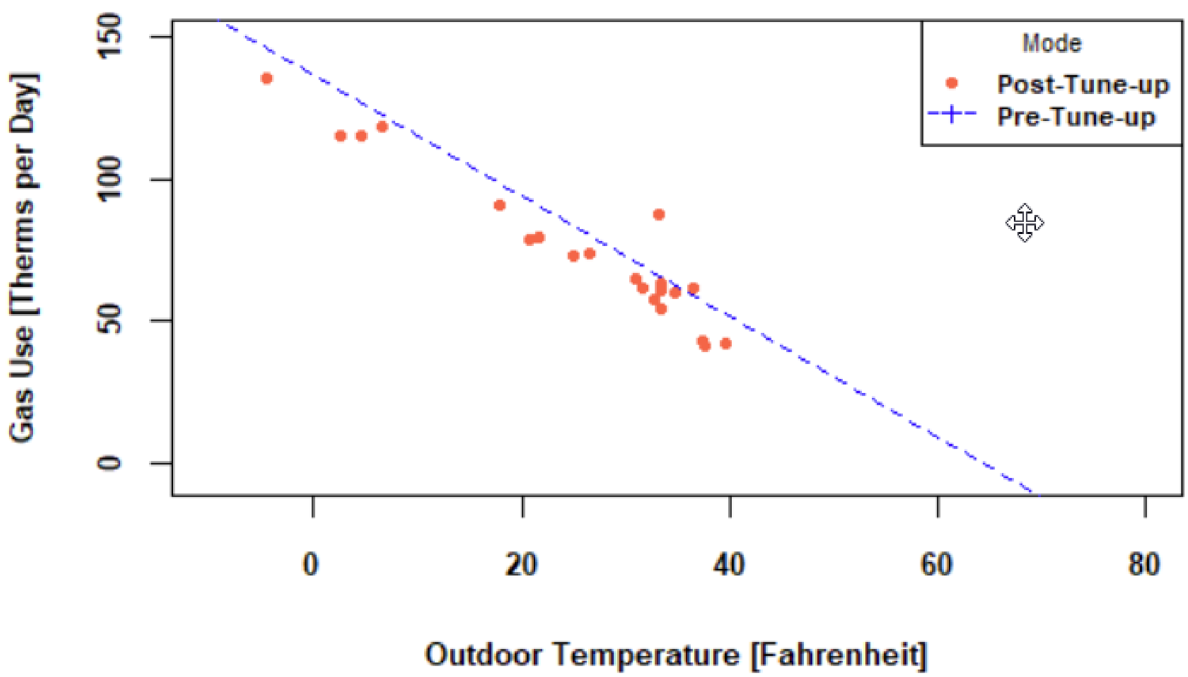
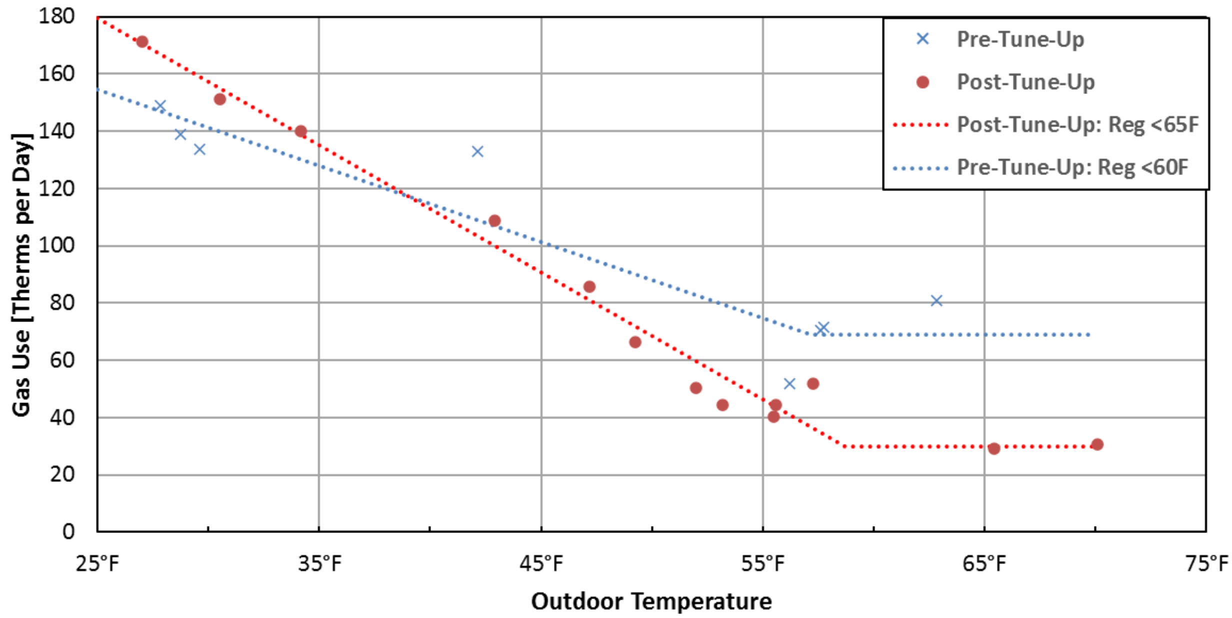


Figure 37. Alternating Mode Daily Average Gas Use Comparison: Site S7



Correlation of Savings Variations to Basic System Characteristics

The difference in observed savings between multifamily buildings and schools is one of the most important comparisons. Note that besides variations in the HVAC system types and operating schedules, the multifamily buildings all had local controls for boiler system temperature, while the schools generally had BAS systems dictating the boiler system temperature setpoint. Table 20 compares the median and average percent savings, gas use savings, and pre-tune-up usages for multifamily and school buildings. While the observed percent savings in multifamily buildings tended to be about double the percent savings for schools, the per-site gas savings for multifamily buildings was less than the savings for school buildings. When looking at the median, the multifamily buildings only saved about half as much, while the average per-site savings was only slightly less for multifamily buildings. The lower per-site savings was observed for the multifamily buildings in the sample because the schools tended to have much larger pre-tune-up energy usage. The persistence of savings was very similar between these two building types, with four of six multifamily buildings having full persistence after 13 months and six of eleven schools also having full persistence after 13 months.

Table 20. Savings Comparison by Building Type

Building Type	Median Percent Savings	Average Percent Savings*	Median Savings [Therms]	Average Savings [Therms]*	Median Pre Usage [Therms]	Average Pre Usage [Therms]*
Multifamily	13.6%	10.3%	666	1,519	12,611	18,419
School	6.3%	5.5%*	1,367	1,715	27,610	39,696

*All school averages reported here omit site S8, which was impacted by a major short-term operations change.

Most of the exploratory analysis that looked for correlations in percent savings or persistence of savings to basic system characteristics did not find any obvious tendencies. The notable exceptions where there appear to be correlations are shown in a series of box-and-whisker plots beginning with Figure 38. The lines in the middle of the boxes represent the median value for each group, while the “X” represents the average, and the top and bottom of each box represent approximately one standard deviation above and below the average. Where there is a line extending above or below the box, this represents the extension of the 95% confidence interval in that direction. Where the very low number of data points in some of the categories prevents calculation of a 95% confidence interval, these extension lines are omitted.

Figure 38 shows that, among sites with the target brands of local controls, those with Aerco boiler controls tended to have the lowest savings, while sites with Lochinvar local controls had the next highest savings, and sites with the ModSync local controllers tended to have the most savings. However, sites with other local controllers tended to show an even higher percent savings than the sites with ModSync controls, albeit with a higher variability of savings between sites. Because of lower per-site energy use for sites with Lochinvar controls or other local controls, the relative magnitude of the per-site savings for these two control types tended to be lower than the percent savings alone would suggest, as shown in Figure 39.

Figure 38. Percent Savings Variations by Local Boiler Controller Brand

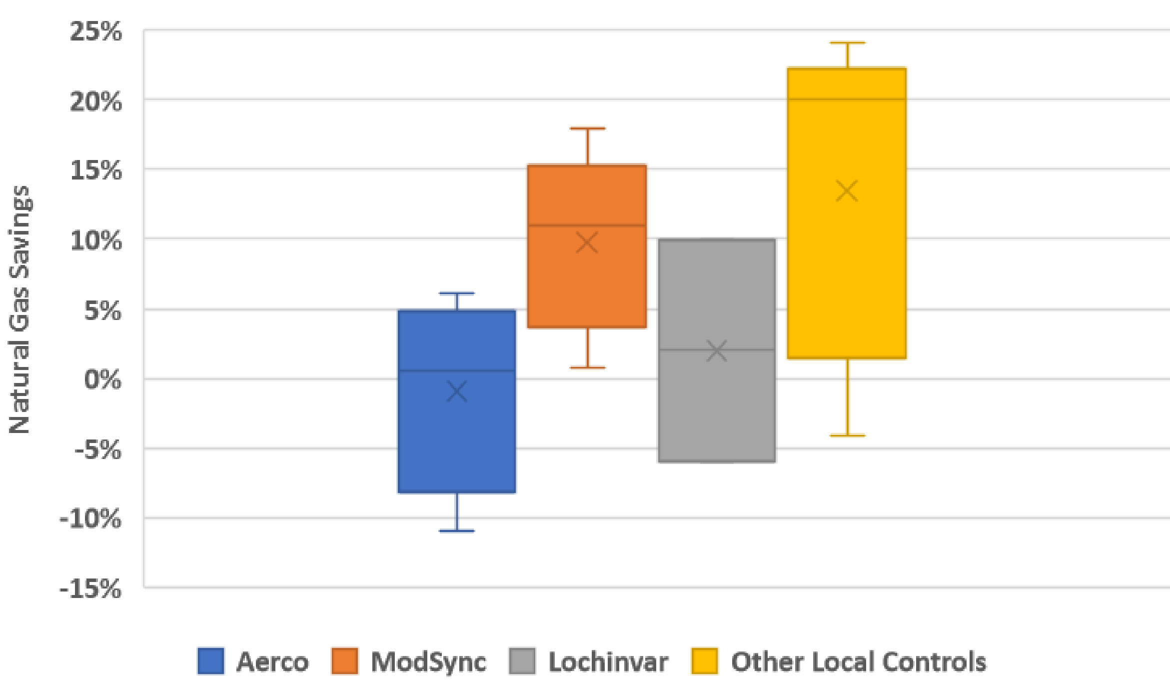
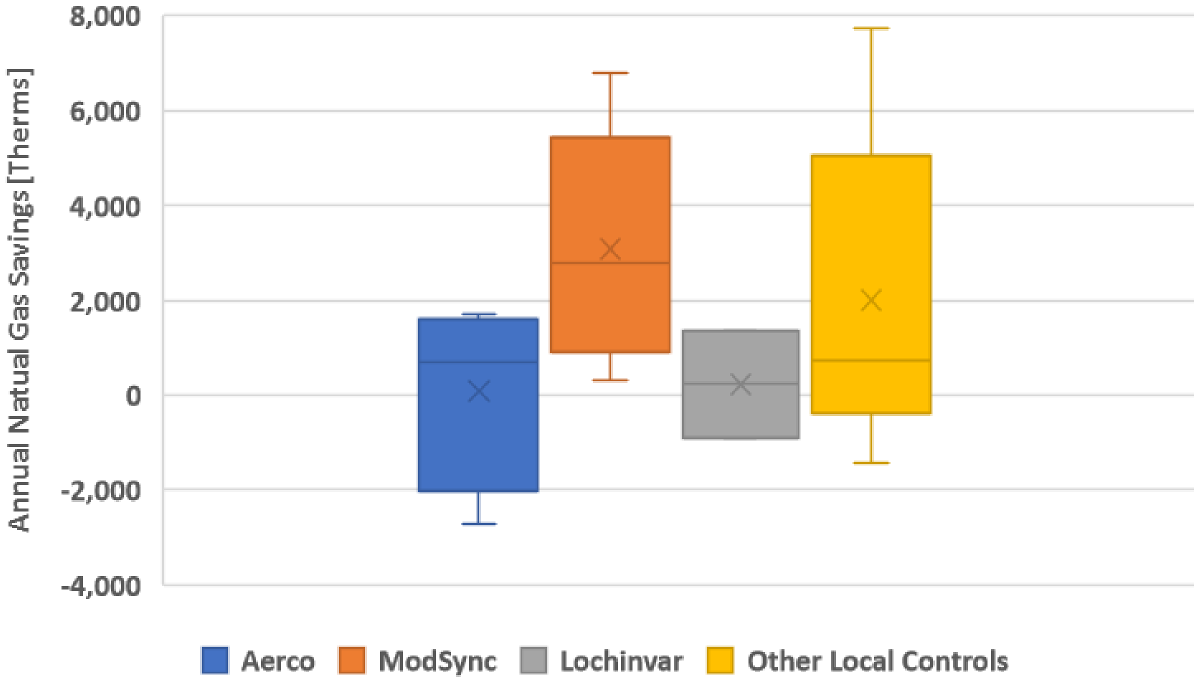


Figure 39. Per-Site Gas Savings Variations by Local Boiler Controller Brand



Other noteworthy trends suggested by this sample were differences between smaller and larger boiler plants. First of all, the variability in percent savings tended to be lower for larger boiler plants. This is demonstrated by the box-and-whisker plot in Figure 40, which shows the nine smallest boiler plants in the left-hand size category and the seven largest in the right-hand size category. While each group has nearly identical median and average percent savings, the site-to-site variability in savings appears to be much lower for the larger boiler plants, which ranged in size from 6,000 MBH to 16,000 MBH (i.e., 6,000,000 Btu/hr to 16,000,000 Btu/hr). The other key observation related to plant size was a much higher tendency for smaller boiler plants, compared to larger boiler plants, to have savings persist. This is shown in Figure 41 for the same two categories of boiler plant size. The findings shown in these two figures suggest that larger boiler plants tend to have more consistent initial percent savings than smaller plants, but that the savings in the smaller boiler plants tends to persist better over time.

Figure 40. Percent Savings Variations by Boiler Plant Size

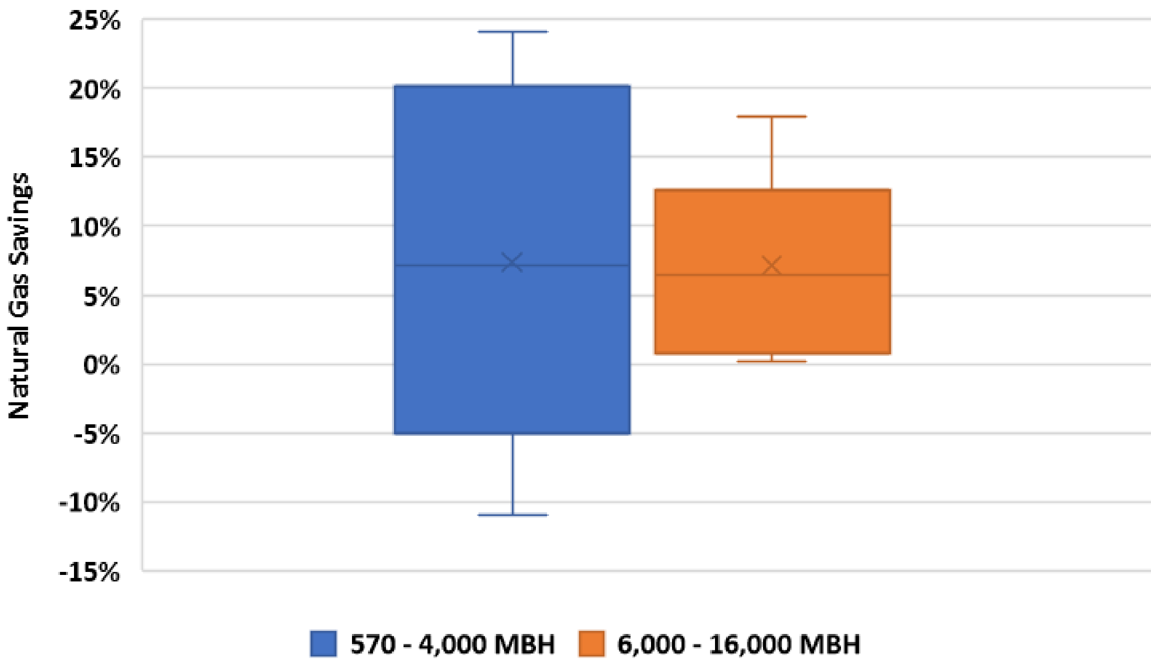
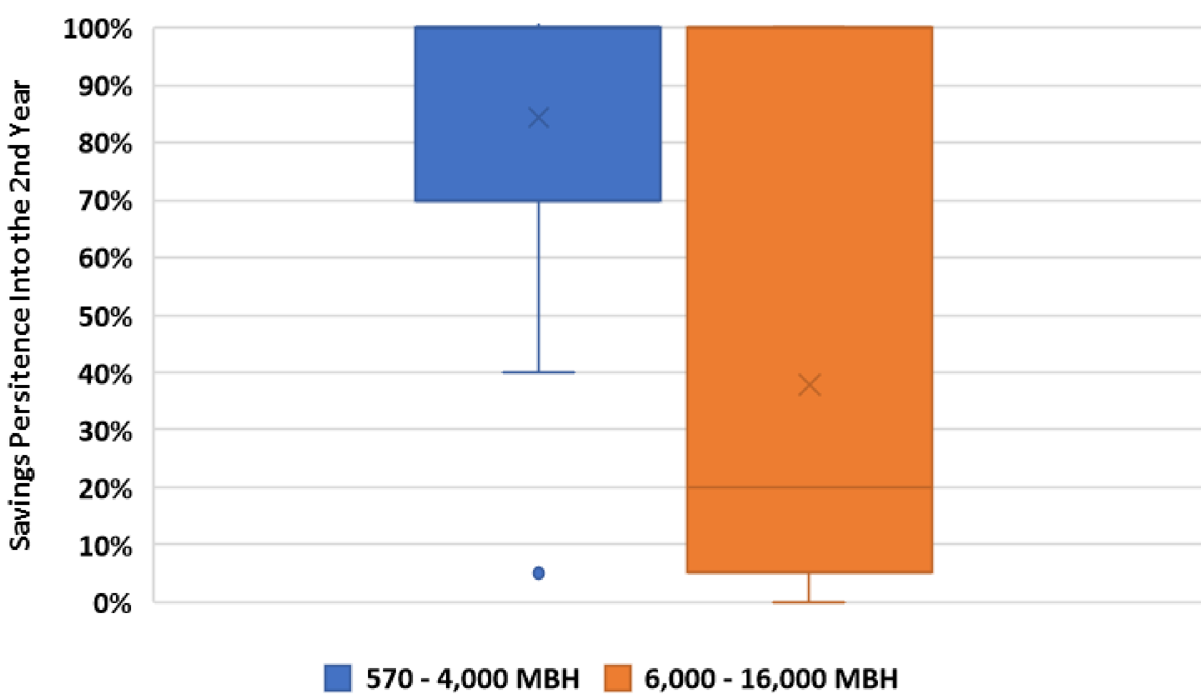
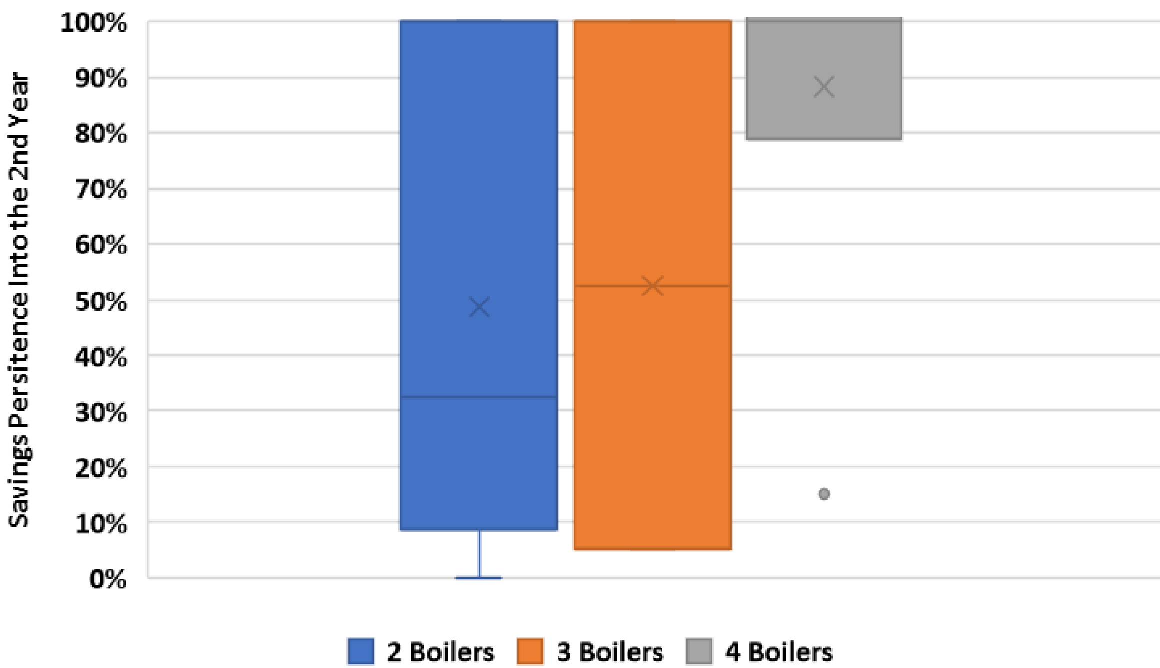


Figure 41. Persistence of Savings Variations by Boiler Plant Size



The last noteworthy correlation observed was much more consistent persistence of savings for systems with four boilers than for those with fewer boilers. This is shown in Figure 42. Five of the six systems with four boilers maintained all of their initial savings into the second year. On the other hand, of the systems with three boilers, only two of three maintained those savings — and of the systems with two boilers, only three of eight did so.

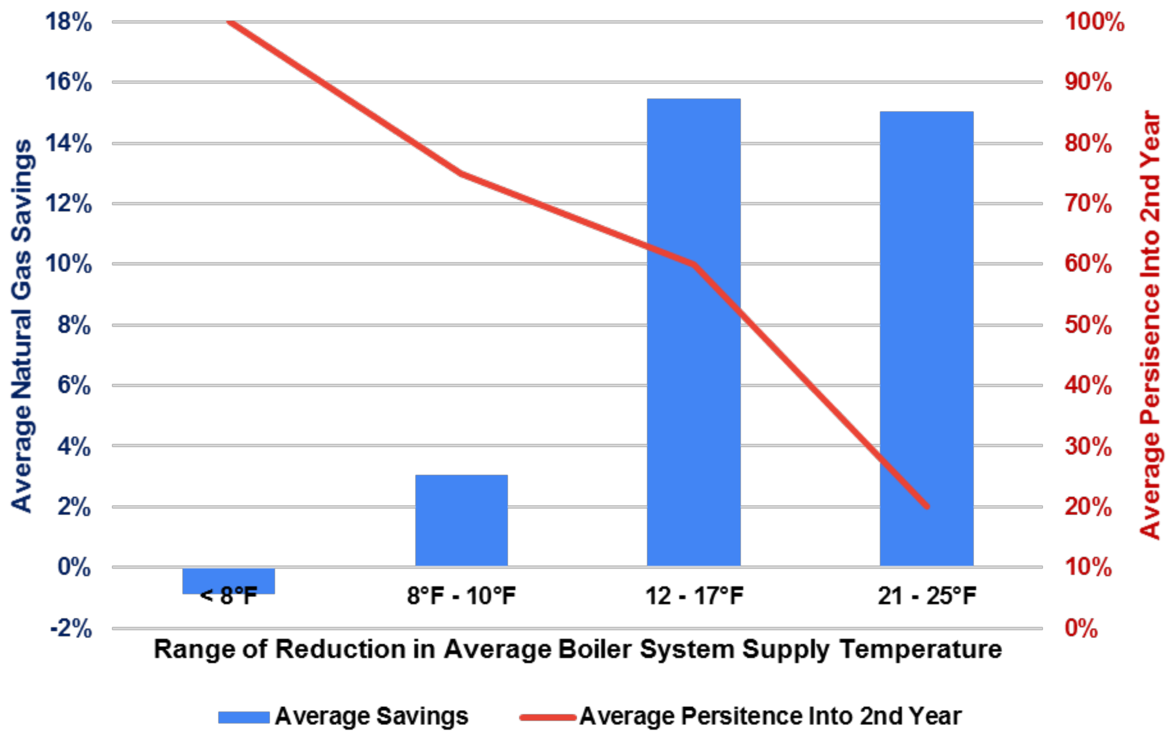
Figure 42. Persistence of Savings Variations by Number of Boilers



Correlation of Savings Variations to Controls Tune-Up Details

The most striking relationships observed for savings and persistence variations with tune-up details were related to the reductions in boiler system supply temperatures. Regressions of percent savings against the average of the reductions in boiler system temperatures at 25°F and 50°F outdoor temperatures at each site had an r-square of 0.51 with all data points (except site S8), and an r-squared of 0.67 when site S2 was also omitted. This latter regression had a slope of 1.17% per °F and an F-value of 25, indicating a very high probability that this correlation is not random. This trend of percent savings increasing as the boiler system supply temperature goes up can also be seen by looking at the blue bars in Figure 43. These show the average savings among the three or four sites that fell within different ranges of average boiler system temperature reduction. Also note that the red line shows that persistence of savings into the second year tended to fall off as the temperature reduction at the sites increased (and the initial savings increased). This suggests a trade-off in that aggressive temperature reductions can provide high initial savings, but with the apparent drawback of reducing the persistence of that savings into the second year (and beyond).

Figure 43. Savings and Persistence Variations with Temperature Reduction



While the data suggested a possible correlation between extra actions taken at the time of the control tune-ups and the savings achieved, it is not clear if this provides initial savings beyond the temperature reductions that the changes helped achieve. There was a strong cross-correlation between these extra staging or sensor actions and the average temperature reduction achieved. All five sites with an extra action achieved an average temperature reduction of at least 12°F. In addition to the large temperature reductions, these sites tended to have better persistence than other sites with large temperature reductions (18 and 8 percentage points higher than averages shown in Figure 43 for the last two ranges of temperature reduction).

Similarly, the data hints at correlations between cycling behavior and percent savings that are difficult to separate from the primary correlation of percent savings to temperature reduction. The strongest hints are for a positive correlation between historic cycles per run-hour and percent savings with an r-square of 0.34, but when historic cycling was added as a second variable to the regression of savings against boiler system temperature reduction, there was no improvement in the regression modelling of savings.

Strong correlations between the contractor performing the tune-up and other items — most notably brand of local boiler control — made it difficult to isolate savings variations for each contractor. This is shown in a box-and-whisker plot in Figure 44. However, one trend that stands out by contractor is that contractor C had the full savings persist into the second year at only two of six sites they serviced, while each of the other three contractors had full savings persistence into the second year for the majority of sites they serviced. Figure 45 shows how the persistence into the second year varies by contractor.

Figure 44. Savings Variation by Contractor

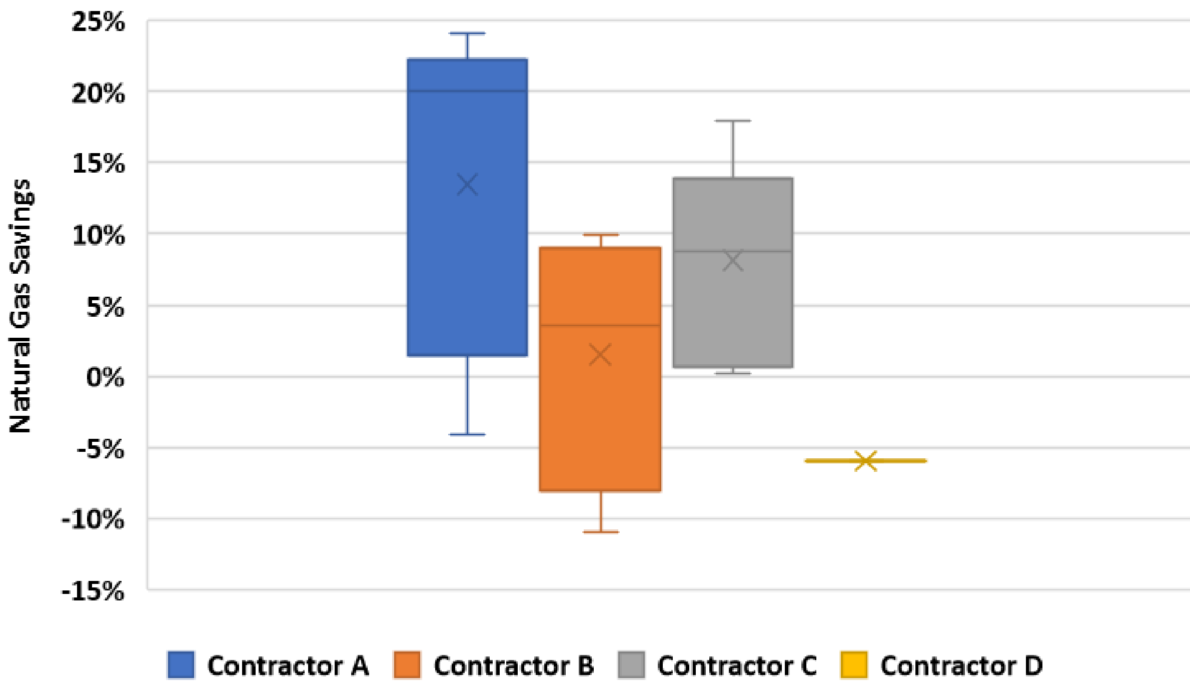
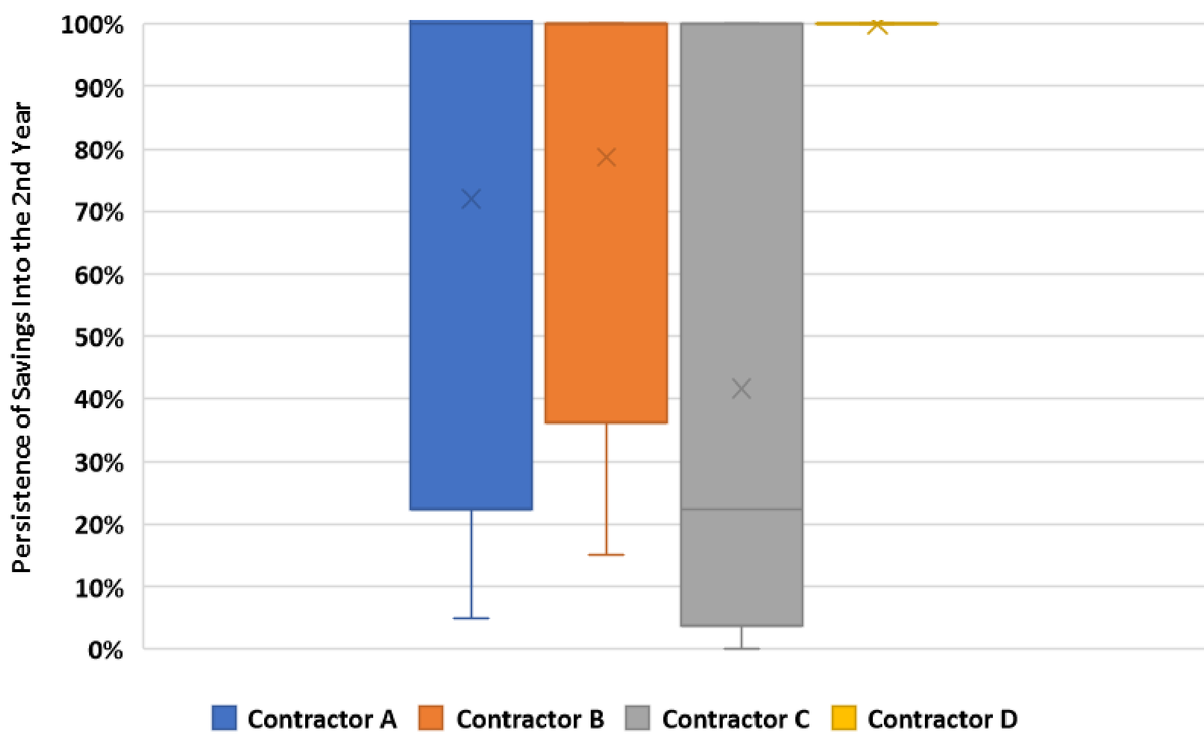


Figure 45. Persistence of Savings Variation by Contractor



Cost-Effectiveness and Program Potential

The individual site economics are outlined in Table 21.

Table 21. Site-Level Economics of Control Tune-Ups

Site	Savings Basis	Controls Tune-Up Cost	First-Year Tune-Up Savings (therms/ccf)	First Year Energy Cost Saving[a]	Simple Payback Period	Savings Persistence Beyond First Year[b]
M1	Pre/Post Regressions	$448	2,381	$1,810	0.2 years	5%
M2	Pre/Post Regressions	$448	716	$544	0.8 years	100%
M3	Pre/Post Regressions	$750	-1,421	-$1,080	n/a[c]	100%
M4	Pre/Post Regressions	$1,752	616	$468	3.7 years	30%
M5	Pre/Post Regressions	$575	7,732	$5,876	0.1 years	115%
M6	Pre/Post Regressions	$895	-907	-$689	n/a	100%
S1	Pre Regression/Post Residuals[d]	$350	1,699	$1,291	0.3 years	100%
S2	Pre Regression/Post Residuals[d]	$750	1,343	$1,021	0.7 years	15%
S3	Pre Regression/Post Residuals[d]	$350	-2,713	-$2,062	n/a	100%
S4	Pre Regression/Post Residuals[d]	$420	1,367	$1,039	0.4 years	100%
S5	Pre Regression/Post Residuals[d]	$922	4,047	$3,076	0.3 years	100%
S6	Pre Regression/Post Residuals[d]	$1,121	6,799	$5,167	0.2 years	20%
S7	Alternating Mode Regressions[d]	$976	2,783	$2,115	0.5 years	100%
S8	Pre Regression/Post Residuals[d]	$633	-57,494[e]	-$43,695[e]	n/a	100%
S9	Pre Regression/Post Residuals[d]	$868	29	$22	39.4 years	-250%
S10	Pre Regression/Post Residuals[d]	$777	1,482	$1,126	0.7 years	5%
S11	Engineering Estimate	$488	379	$288	1.7 years	25%
Median	All Sites	$750	1,343	$1,021	0.73 years	100%
Average	All Sites (except S8 savings)	$737	1,646	$1,251	0.59 years	66%[f]

a) Energy cost savings is based on an assumed natural gas price of $0.76 per therm.

b) The persistence into second year is estimated based on boiler control settings after 13 months and engineering estimates.

c) The increased usage leads to no payback for the four sites with an "n/a". When calculating the median payback value, the payback was assumed to be 50 years for these sites.

d) The post-tune-up residuals were generally limited to observations made at outdoor temperatures below 40°F, with minimum temperatures ranging from -5°F to 5°F for seven sites and at about 20°F for two sites (S1 and S3).

e) The post-tune-up gas use and a limited amount of the pre-tune-up gas use at site S8 is believed to be dramatically impacted by the extended manual override of the switchover between the two large non-condensing boilers and the three condensing boilers, which normally occurs at around 10°F. Site staff reported that the non-condensing boilers were forced on at high boiler temperatures so that a service hot water heat exchanger could be used while the normal service hot water system was in need of service.

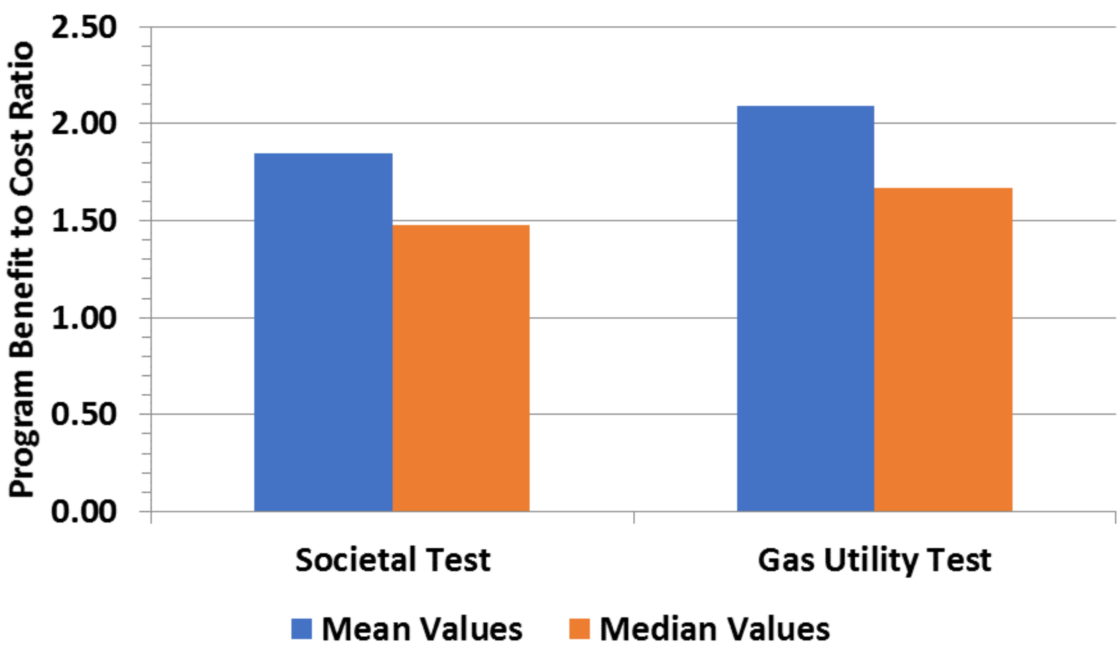
f) The average value of 66% for persistence beyond the first year is based on using a value of 0 for site S9.

The median payback was 0.73 years, and 10 of the 17 sites had paybacks under one year. The three additional sites with savings had simple paybacks of 1.7 years, 3.7 years, and 39 years, while four sites had no payback due to net increases in gas use. Despite the lack of savings at four sites, the very low paybacks for those sites with significant savings makes the representative economics for the average per-site cost and per-site savings look very good — with a 0.59 year payback.

Estimates of utility program–level cost-effectiveness are summarized in Figure 46 and Figure 47, with a 2-year measure life assumption. The plots show ranges of cost-effectiveness based on the following ranges of assumptions:

- Benefit—cost ratios based on the combination of mean (average) cost and savings, and the combination of median cost and savings are presented as separate side-by-side bars in each figure.
- Benefit—cost ratios based on applying existing boiler tune-up program cost to incentive ratios are shown in Figure 46, while Figure 47 shows values based on 25% higher program costs to account for greater training, technical support, and quality control requirements.

Figure 46. Projected Program Cost-Effectiveness: Existing Boiler Tune-Up Administration Costs

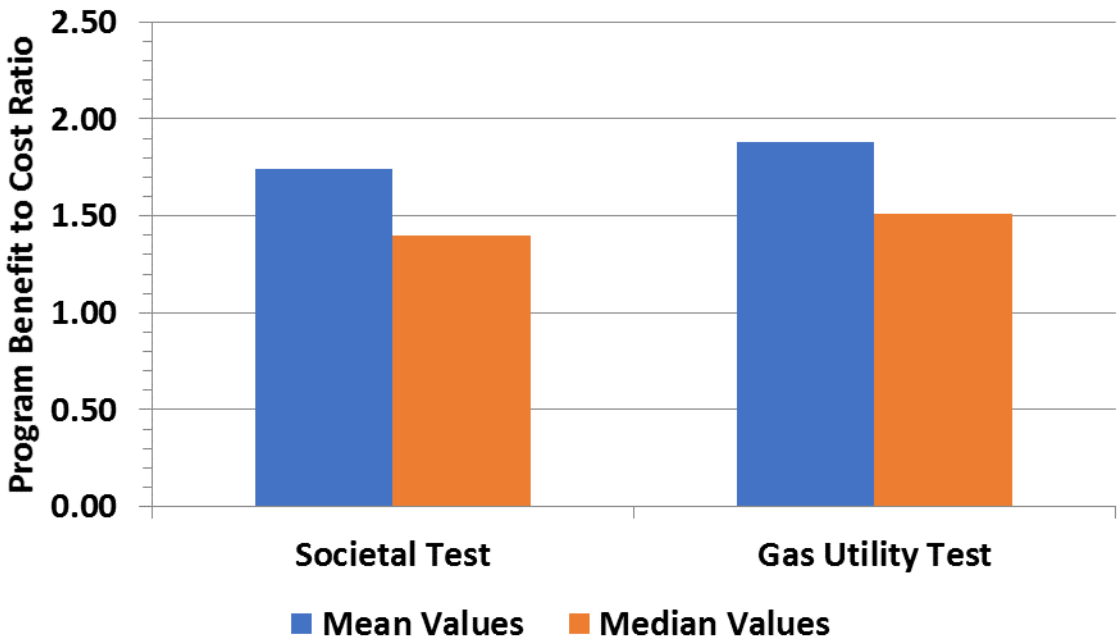


For each of these approaches, the cost-effectiveness using both the mean costs and savings values (with site S8 savings omitted) and the median costs and savings values are shown.[7] The most conservative estimate of cost-effectiveness suggests a 1.40 societal benefit–cost ratio and 1.51 utility benefit–cost

[7] The ratio of program implementation to incentive costs was assumed to be 25% larger than for traditional burner tune-up programs.

ratio using the median cost, medians savings, and 25% higher program costs. On the other hand, the most optimistic estimate based on mean cost, mean savings, and the same program costs suggests a 1.85 societal benefit–cost ratio and a 2.09 utility benefit–cost ratio.

Figure 47. Projected Program Cost-Effectiveness: 25% Higher Administration Costs



Statewide potential program impacts are shown in Table 22, which includes both technical potential and the estimated achievable annual potential savings for a mature program. Achievable potential is based on an estimated 1,445 participants (buildings) per year, which is based on burner tune-up program projections of three largest natural gas IOUs in Minnesota. The 300,200 Dth technical potential and 196,500 Dth achievable potential represent about 15% and 10%, respectively, of total annual commercial and industrial CIP program savings for the three largest gas IOUs in Minnesota.

Table 22. Program Potential Estimates

Potential	Time Period	Participants Condensing	Participants Non-Condensing	Savings Per Condensing	Savings Per Non-Condensing	Potential
Technical	Multiyear to Include All Boilers in MN	2,678	8,964	62.4 Dth	48.3 Dth	600,400 Dth
Technical	One Year with Half of All Boilers	1,339	4,482	62.4 Dth	48.3 Dth	300,200 Dth
Achievable	One Year	332	1,113	164.6 Dth	127.4 Dth	196,500 Dth

a) Participants and savings per participant for the technical potential are reported as number of boilers.
b) Participants and savings per participant for the achievable potential are reported as number of buildings with an average of 2.9 boilers per building as observed in the study test sites.

Discussion of Results

Market Issues

Contractors are very optimistic about their ability to sell the control service as part of a package that includes the traditional tune-ups that have focused primarily on burner adjustments. They generally expect that they would be able to sell a combined burner and expanded scope controls tune-up to the same number of customers to which they currently sell burner tune-ups. On the other hand, it appears likely to be more challenging to get customers to understand the scope expansion and to interest them enough to pay an additional cost for a service that they may have thought they were already receiving. Possible approaches to overcome these barriers are:

- Use contractors to market the service to customers with whom they have a long-term relationship.
- Develop a marketing campaign that resonates with key decision makers among building owners and operators.
- Develop separate target messaging for market sectors with different decision-making processes and business models — especially schools and multifamily buildings, which are by far the two largest market sectors. Other sectors (e.g., government, places of worship, hospitality, and health care) might also be effectively reached through targeted outreach at industry events or targeted advertising.
- Use local case studies.
- Promote non-energy benefits of reduced short-cycling and improved comfort from reduced overheating.

Owners of condensing boilers are another niche for which it may be easy to make initial inroads because of the higher per-site savings, as well as those owner's tendency to have a greater interest in energy efficiency than the general population of boiler owners. It is also likely that condensing boilers will realize lower savings from traditional burner tune-ups than other boilers. A limited sample of four participant sites that had burner tune-ups performed during the course of monitoring showed combustion boiler efficiency improvements averaging only 0.1%, with a site average range of -0.4% to +0.4%. Condensing boilers account for at least 23% of the market, with their market share continually growing. After establishing good experiences for multi-site building owners at condensing boiler sites, it may be easier to expand to sites with non-condensing boilers.

A combination burner and controls tune-up, or a controls-only tune-up, may also be able to reach segments of the market that are underserved by burner tune-up programs with much higher savings than can normally be achieved with burner tune-ups alone. This would include smaller boilers and atmospheric draft boilers that tend to have lower savings from burner tune-ups (CEE 1995).

The relative dominance of Aerco, Fulton, and Lochinvar suggests that it would be worthwhile for a full-scale program to undertake special efforts to get local manufacturer representatives and distributors familiar and comfortable with the control tune-up services before approaching a large number of contractors or end users. It is also important for tune-up protocol forms and quick-reference materials to support these three boiler makes.

Based on varied preferences about the format of the forms, it appears that a full-scale program should have forms and reference materials in both paper and electronic format to maximize the number of contractors that could participate in a way that works well with their normal procedures.

Complete Boiler Optimization is a favorite name among trade allies for a combined burner and expanded scope controls tune-up. However, with the relative importance of making the service appealing to end users, the researchers suggest conducting more market research among key decision makers for end users before settling on a program name for this combined service.

Field Protocol Application

Lessons Learned

The following list details some of the key lessons learned from this field application of the controls tune-up protocol as well as from consideration of the savings and persistence results.

1. **Training and Support.** Contractors strongly preferred on-site coaching through the protocol over extensive training ahead of time. Most technicians needed much more support through the first few sites than researchers had expected, even after contractors carefully selected technicians to work on the controls tune-up implementation.
2. **Prioritization of Temperature vs. Staging Setting Changes.** Temperature control changes appeared to provide much more of an energy benefit than staging control changes, and these were easier to address within the protocol for a variety of makes and models of boilers. Some level of temperature reduction was accomplished at all 17 sites. However, dramatic reductions in short-cycling did have an important energy impact for a small percentage of sites, besides preventing accelerated wear of the boilers. Staging control changes aimed at reducing short-cycling were carried out at about half of the sites, with another one-fourth having staging control adjustments aimed at reducing the average firing rate across multiple boilers.
3. **Screening for Control Problems.** The protocol's diagnostics identified control problems beyond controls settings for one-third of the sites. This included two sites with staging control problems that impacted system temperatures; both of these sites had saving far above the average and median of all study sites. Most of these problems were corrected during a single controls tune-up visit.
4. **Persistence of Aggressive Changes.** There appears to be a somewhat higher frequency of controls being changed back to near as-found settings among those sites with the most aggressive temperature reductions. This suggests that in addition to the protocol including target temperature settings, it may be worthwhile to include a maximum amount of change for each setting (e.g., no more than 20°F).
5. **Post–Control Change Observation.** It was important to observe boiler behavior after significant changes were made. The most common value in this was confirming that the expected control change occurred — especially for staging control changes. However, this also could have

prevented a repeat site visit at one site where only significant temperature control changes were made, and the system's cascading response led to all of the boilers locking out and no heat available to the building.

6. **Low-Pressure Issues.** The importance of checking system pressures became apparent as a number of systems ran at very low system pressures before the tune-up. This caused one system to lock out after temperature settings were reduced as part of the tune-up, and fluid was added to two other systems to prevent similar problems.
7. **BAS Control Changes.** The contractor technicians and researchers were able to work with building owners' staff (either on-site or higher level multi-site staff) to make temperature control changes at all 11 sites with BAS systems. This required special efforts ahead of time to communicate the need for this to building owners' staff.
8. **Design Temperature Variations.** A number of the sites had the building systems designed for lower boiler system temperatures than traditional systems. Asking if the boiler was installed at the same time as all HVAC equipment was helpful in identifying these sites, but a review of building plans to identify the design intent for outdoor reset control settings was also very helpful to get a more precise indication of what temperature settings should be ideal. This review was generally conducted by a researcher, so it is not yet clear how effectively this could be worked into the standard contractor technician protocol.
9. **Fine-Tuning Adjustments.** Four of the 17 sites needed fine-tuning adjustments within the first month of the February tune-ups (most of those within the first week). Only one of these sites showed significant measured savings. The pilot cost for fine-tuning was minimized at schools, where researchers were able to coach district staff through appropriate fine-tuning adjustments. It is likely that these issues would otherwise have resulted in contractor technician revisits with additional researcher technical support.

Cost

The average $750 contractor cost per site (with the sites having an average of three boilers) experienced during this pilot project is expected to be higher than for a larger-scale program. However, the higher level of technical support that appears to be needed by a program implementer is expected to increase implementation costs per participant above those for traditional burner tune-up programs.

Application to Non-Condensing Boilers

Application beyond the pilot program target of condensing boilers is an important opportunity. It appears that about three-fourths of the savings could be achieved among non-condensing boilers. Protocol development that would be needed to support non-condensing boilers includes:

1. The establishment of non-condensing boiler target temperature settings, and
2. The development of staging control guidance and other quick-reference materials for the boiler control makes that are most common among likely participants.

Observed Temperature and Staging Changes

Measured system supply temperature changes for most sites were in line with expectations from pre- and post-tune-up control settings, with a small number of notable exceptions where pre-tune-up control issues prevented operation consistent with typical outdoor reset control. On average, the boiler control tune-ups reduced the boiler system operating temperatures by about 12°F. At the end of the 13-month monitoring period, the average reduction in boiler system temperature was about 5°F.

While it was not clear at all sites why the temperatures returned toward pre-tune-up settings over time, it appears that it may have happened in response to inadequate heating issues for a minority of these sites. Staff for a majority of the sites that had changes made late in the monitoring period reported no recollection of underheating issues leading to control changes, and a number of sites with one school district appeared likely to have had settings changed as part of a system-wide reset to default setpoints. This suggests that some type of follow-up check-in with sites could greatly improve the persistence over time. For sites with BAS systems, remote checking of settings or operating temperatures could be an especially cost-effective way to follow up. The use of mobile phone remote video applications could also be an effective way to spot-check the maintenance of setting changes for any boiler control system. A higher-cost and longer-term approach would be monitoring of boiler system temperature with a datalogger or other device (New Ecology 2018).

Of the eight sites that had pre-tune-up short-cycling measured at a level of concern (about two cycles per run-hour or higher), seven had significant reductions in short-cycling achieved with an average 56% reduction in cycles per run-hour. Short-cycling was a pre-tune-up issue for all six sites that had a combination of ModSync controls and Fulton boilers, as well as both sites with Lochinvar boilers. On the other hand, none of the Aerco boiler sites had short-cycling issues. Control changes at the four Aerco boiler sites instead aimed to reduce the average firing across multiple boilers. The limited data on the effectiveness of those efforts were mixed on only suggested a few percentage point average firing rate reduction over a limited range of conditions. Based on the study findings, it appears that it is much more important to address staging control issues at sites with Fulton or Lochinvar boilers than at those with Aerco boilers.

Savings, Persistence & Variations

The study's representative savings of around 7% for the controls tune-ups gives a clear indication that this service has very promising potential for inclusion in natural gas CIP programs in Minnesota. While the site-to-site variations in savings are not completely understood, it appears that two key factors are differences between multifamily buildings and school buildings and the amount of boiler system temperature reduction achieved.

Building Type Impact

Multifamily buildings had percentage savings about double those of school buildings, while their much lower average pre-tune-up gas usages led to school buildings still having higher dekatherm savings per site. Factors like cross-correlations between building type, boiler control manufacturer, contractor, and the use of local control versus BAS for boiler temperatures make it difficult to fully understand the reason for the higher savings in multifamily buildings among the buildings studied. However, the research team's history with multifamily buildings suggests that the extensive overheating and load increase that occur with high boiler system temperatures in multifamily buildings is likely much larger than overheating in school buildings. The roughly 12% savings for multifamily buildings could make this service much more cost-effective for multifamily buildings than traditional burner tune-ups that have deemed savings of 2.2% (COM 2021). Even the roughly 6% savings for school sites is well over double the savings for burner tune-ups.

Temperature Reduction Impact

It is also clear that the amount of boiler system temperature reduction is a key factor in the amount of savings achieved. Sites that had their average boiler system temperature reduced by 12°F or more averaged savings of about 15% compared to an average of about 1% savings for those sites where the boiler system temperature reduction was less than 10°F. Unfortunately, these sites with larger temperature reductions also tended to lose more of their savings over time due to control settings being reset to near the pre-tune-up values. It may be worthwhile to target these participants with follow-up efforts to maximize persistence, examples of which are noted in the Field Protocol Application subsection within the Discussion section.

Controller Brand Impact

There are also some apparent secondary savings correlations to boiler control make, but cross-correlations between boiler make, contractor, and school district make it hard to draw conclusions about possible patterns in a wider population of buildings. Nevertheless, it appears that the highest savings tended to be among systems with ModSync controllers (used exclusively with Fulton boilers in the study sample) or controllers other than those associated with the top three boiler makes in existing Minnesota buildings (i.e., makes other than Aerco, Lochinvar, and Fulton).

Number of Boilers Impact on Persistence

Other than the correlations of persistence to items already mentioned in the preceding paragraphs, the only noteworthy trend observed was the change in persistence with the number of boilers at a site. There was a clear pattern in sample buildings of savings persisting over time in five of the six buildings with four boilers, and less often in buildings with fewer boilers. The researchers developed two competing theories for this trend: (1) The larger number of boilers gets operators feeling more "out of their depth," and they are therefore less likely to make control changes unless absolutely necessary; and (2) Property owners assign their best operations staff to oversee these more complex systems. The first appears to be more likely for multifamily buildings while the second may be more likely in schools.

Program Scale and Maturity Impact on Persistence

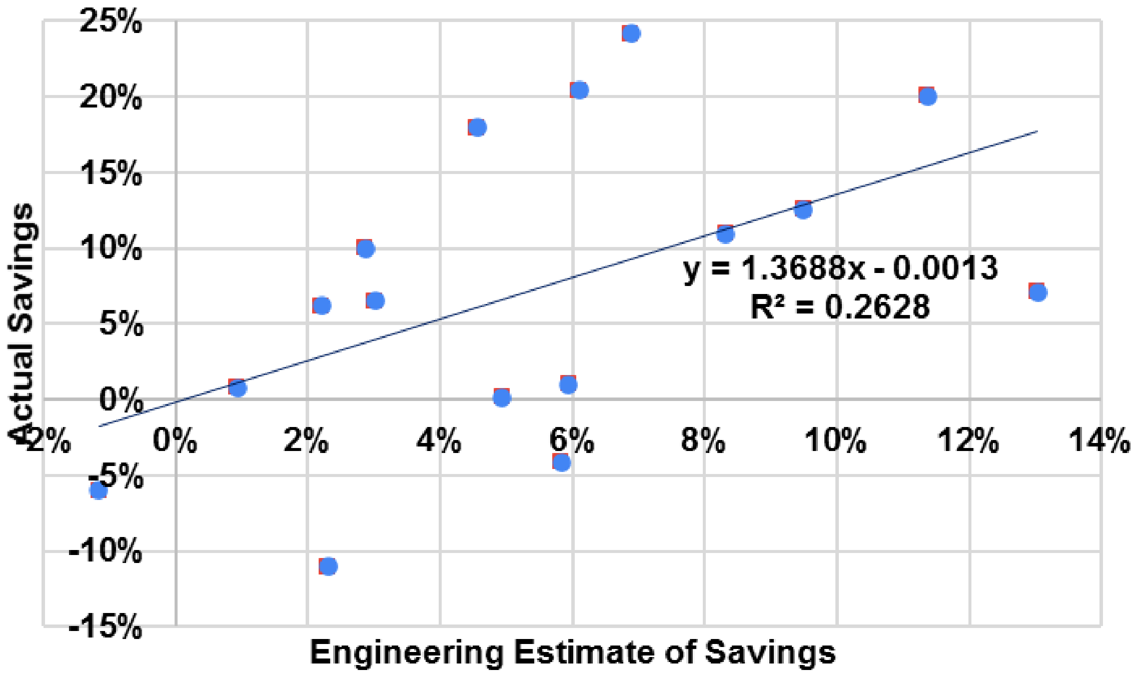
Some observations suggest that maintaining significant savings through fine-tuning and long-term persistence of savings might be notably improved after this service ramps up its volume to a point where the majority of technicians are familiar with the program and comfortable with the program's target boiler system temperatures. Two possible indications of this are: (1) multiple examples of contractor technicians not involved in the initial controls tune-up making dramatic changes during serving instead of fine-tuning changes; and (2) a pattern of much lower persistence of savings over time for one contractor in particular. These both suggest that one or more of the contractor's technician(s) is not comfortable with the target temperatures. For larger boiler plants, education and leave-behind materials for on-site and building portfolio-level operations staff may also be a key factor in maintaining savings over time. It appears that boiler plants larger than 6,000 MBH (6,000,000 Btu per hour) are much less likely to maintain their savings over an extended time period than boiler plants of 4,000 MBH (4,000,000 Btu per hour) or smaller. It seems likely that a reason for this is that the increased attention paid to larger boiler systems provides more opportunities for contractor technicians or building operations staff to makes changes back to what they are used to. This pattern was also further complicated by the apparent resetting of BAS setpoints to default values at multiple schools within one district.

TRM Implications

The detailed engineering estimates of savings based on site-specific control changes made in the research study buildings appear to underestimate savings and do not come close to fully taking into account the site-to-site variations observed in the sample. Figure 48 shows a plot of how the actual savings observed varied from the engineering-estimated savings based on observed boiler system temperature and cycling changes, along with the regression line equation and r-squared value. While the site-to-site savings differ often differ substantially from the regression line, there appears to be a decent overall correlation with an F-value of 5.0 and standard error of savings estimates of about 9%. The slope of the regression and near-zero intercept regression indicates that the engineering estimates tend to underestimate savings by about 37%.

While scaling these engineering calculations of savings could be useful on a limited scale to verify patterns of achieved savings among program participants, a more useful TRM calculation for estimating the impact of future programs would be to assume savings at the per-site dekatherm values observed, with separate values for multifamily buildings and schools. Another reasonable option is to simply add the percent savings of this measure as another option within Table 2 of the *Commercial HVAC — Boiler Modifications, Space Heating Only* measure, with a roughly 12% savings for multifamily buildings and roughly 6% savings for other buildings.

Figure 48. Correlation between Engineering Estimates and Observations



Questions Answered & Raised

While this research project provided a solid basis for projecting the program-level savings and economics of expanding the scope of boiler tune-ups to including boiler temperature and staging controls, it did not fully answer the following questions raised related to the next steps of program development:

- What is the most effective and efficient way to train contractor technicians and provide technical support for large-scale program implementation?
- How receptive will building owners be to the service, and how should it be packaged and promoted to maximize market uptake among traditional boiler burner tune-up program participants?
- What is the best way to package and promote a boiler controls tune-up service for additional buildings that could benefit but have been underserved by traditional burner tune-up programs?

Another technical question that has not yet been fully addressed: How well do the initial program savings persist after the second year?

Conclusions and Recommendations

Study Results

This study clearly demonstrated a large potential for cost-effective savings and increased CIP program impact by adding boiler temperature and staging control optimization to the scope of traditional commercial boiler tune-up programs, which have historically focused on energy savings only through burner adjustments. This expanded scope of service would require a more detailed protocol and data collection form than traditional burner tune-up programs, as well as significant technician training and technical support to reliably achieve savings. However, for buildings with condensing boilers, this scope expansion provided savings of about 7% of pre-tune-up gas use, in addition to the roughly 2% savings typically assumed for burner tune-ups. The representative simple payback before incentives is from seven to nine months. In buildings with non-condensing boilers, the savings is expected to be about three-fourths of that achieved in condensing boiler sites. While there is some drop off in savings over time, the persistence appears to be at least as good as for traditional burner tune-ups. The combination of savings, market size, and cost-effectiveness makes this an attractive option for expanding current CIP program offerings.

The sum of full-scale program achievable potential for the three largest natural gas IOUs in Minnesota was estimated at 196,500 Dth per year, which is equivalent to 10% of the current commercial and industrial portfolio savings for these utilities. Societal benefit–cost ratios were estimated at 1.4 to 1.85, and utility benefit–cost ratios were estimated at 1.5 to 2.1. Boiler service contractors were very optimistic that virtually all current burner tune-up customers would pay the additional cost for a more expensive combined package of burner tune-up and boiler control optimization. The significant savings of controls tune-ups could allow for cost-effective expansion into market sectors that have not traditionally had large participation in boiler tune-up programs, such as multifamily buildings.

CIP Program Recommendations

We recommend that natural gas utilities in Minnesota take steps toward full-scale integration of boiler control tune-ups into existing boiler efficiency programs. Because of the higher complexity of developing and delivering this service on a large scale (compared to burner tune-ups and most other program offerings), it may be prudent to pilot the scope expansion on a moderate scale before ramping up to full-scale program implementation. This would give utilities the opportunity to further develop, test, and refine various program aspects such as: the controls tune-up protocol, contractor training material and approaches, approaches to providing large-scale technical support for technicians, quality control, sales and marketing approaches, and follow-up approaches to maximizing longer-term persistence of savings. A slower ramp-up approach is likely to avoid any bad customer experiences with the program that could be a significant barrier to the long-term market penetration of this service.

The study results have led researchers to make the following recommendations for CIP program development and delivery:

1. Plan for extensive contractor training and on-demand technical support — especially at the start of the program and as the program ramps up in a way that will require new contractors and technicians to get up to speed.
2. Conduct additional market research among end users to determine the most effective service packaging, marketing, and sales approaches (e.g., starting with condensing boiler sites in multifamily and school buildings, then leveraging early success to encourage building owners to expand the service to non-condensing boilers).
3. Work closely with boiler service contractors, manufacturer representatives and distributors in program planning, further development and refinement of the controls tune-up protocol, and planning for marketing. This will be especially important for the logistics of implementing the tune-up protocol and documenting both pre- and post-tune-up control settings.
4. Develop and implement a robust quality control program that includes program certification of contractors (or individual technicians); reviews of tune-up documentation; and random measurement and verification (e.g., review of available BAS trends logs covering at least a week of time before and after the controls tune-up).
5. Leverage boiler service contractors to promote the controls tune-up service through their long-term relationships with end users.
6. Before the on-site visit, make special efforts to be sure that: (1) buildings with BAS control of boiler system temperatures will have staff available that can make BAS setpoint changes at the time of the controls tune-up; and (2) mechanical plans will be available on-site or provided to the boiler service technician ahead of time — especially for buildings that had condensing boilers installed at the same time that all HVAC equipment was installed (or changed out).
7. Encourage (or require) pre-visit information about the makes and models of boilers and controllers so that contractors can plan to use a technician familiar with the specific tune-up control issues, or at least ensure that appropriate quick-reference materials will be available.
8. Further develop and test approaches to maximize the persistence of savings over time, such as: operator training, operator leave-behinds, low-cost monitoring, and remote check-ins on settings.

TRM Recommendations

While a detailed calculator was used to make engineering estimates of savings for the research project test sites, a much simpler TRM approach is recommended for large-scale program planning and reporting. The engineering estimate approach used by researchers could be valuable for the evaluation of the savings for a sample of program participants, with the savings scaled up by 37% to account for the difference between observed and predicted savings. However, the engineering estimate calculations were based on detailed, site-specific information that will generally not be available during program planning. Therefore, the research team recommends that program savings generally be estimated by using the same calculation procedure used for commercial boiler tune-ups and other boiler system modifications, with percent savings value in the TRM Measure Table 2 of 11.9% for multifamily buildings and 5.9% for schools.

References

Aerco. (n.d.). Benchmark 2500 & 3000 Overview. Retrieved 02 18, 2013, from Aerco Website (http://www.aerco.com/Products/Boilers/Benchmark-Boilers/Benchmark-Series).

CEE 1995. Lobenstein, Mary Sue and Martha Hewett. The Best Boiler and Water Heating Retrofits. Center for Energy and Environment. *Published in Home Energy Magazine, September/October 1995*. Berkeley, CA.

CEE 2016. Landry et. al. Commercial Condensing Boiler Optimization. Center for Energy and Environment, Minneapolis, MN.

CEE 2018. Minnesota Energy Efficiency Potential Study: 2020–2029. Center for Energy and Environment. Minneapolis, MN.

CEE 2001. Consortium for Energy Efficiency. A Market Assessment for Condensing Boilers in Commercial Heating. Consortium for Energy Efficiency. Boston, MA.

CEE 2011. Consortium for Energy Efficiency. High Efficiency Commercial Boiler. Consortium for Energy Efficiency. Boston, MA.

CenterPoint Energy 2020. CenterPoint Energy's 2021-2023 Natural Gas Conservation Improvement Program Triennial Plan, Compliance Filing ,Docket No. G-008/CIP-20-478. CenterPoint Energy.

COM 2021. State of Minnesota Technical Reference Manual for Energy Conservation Improvement Programs, Version 3.2. Minnesota Commerce Department.

DLI 2018. Boiler and Pressure Vessel Database Snapshot; Downloaded in 2018. Minnesota Department of Labor and Industry.

Lochinvar, LLC. (2013, 7 9). Knight XL Efficiency Curve. Retrieved 2014, from Lochinvar High Efficiency Boilers and Water Heaters (http://www.lochinvar.com/_linefiles/Knight%20XL%20Efficiency%20Curve-2013.pdf)

MEO 1984. Hewett, Martha and George Peterson. Minneapolis Energy Office (predecessor to Center for Energy and Environment). Measured Energy Savings from Outdoor Resets in Modern, Hydronically Heated Apartment Buildings. MEO/TR84-2-MF. Also published in Proceeding of the American Council for an Energy Efficient Economy 1984 Summer Study, Vol. C, pp. 135-152. Washington, CD: ACEEE.

MERC 2020. Minnesota Energy Resources Corporation (MERC) 2021-2023 Triennial Conservation Improvement Program Plan, Docket No. G011/CIP-20-479. Minnesota Energy Resources.

New Ecology 2018. Continuous Monitoring: A Low-Cost Path to Improved Performance. New Ecology. Boston, MA.

Xcel Energy 2020. 2021-2023 CIP Triennial Plan: Minnesota Electric and Natural Gas Conservation Improvement Program, , Docket No. E,G002/CIP-20-473. Xcel Energy.

Appendix A: Primary Control Tune-Up Protocol Form

Pilot Condensing Boiler Control Tune-Up Form							
Prepared by Center for Energy and Environment		*Site:*					
	Name:		*Date:*				
	Company:		*Start Time:*				
		End Time:					
	Question	**Response**					
	Preliminary Assessment	**Circle or Provide Comments**					
	Building						
1	Does site have a BAS?	**Yes**	**No**				
2	Which control parameters of the boiler plant are controlled via BAS? (circle all that apply)	**Heating Water Supply Setpoint**	**Boiler Enable/Disable**	**Boiler Sequencing**	**Boiler Pump Speed**	**Boiler Control Valve Position**	**Other:**
3	What is the design heating water supply temperature of the building? (if unknown, circle unknown)						**Unknown**
4	What is the building type? (Office, Education, Municipal, Multi-Family, Senior Living, etc) (circle all that apply)	**Office**	**Education**	**Municipal**	**Multi-Family**	**Senior Living**	**Other:**
5A	What type of terminal units are being utilized? (Fan Coil Units, VAVs, FTR, etc.) (circle all that apply)	**Fan Coil Units**	**VAVs**	**FTR**	**Duct Reheat Coil**	**No reheat**	**Other:**
5B	Was the HVAC equipment installed at the same time as the condensing boilers?	**Yes or After Boilers**	**No--Before Boilers**	*If Yes or After boilers, ask to see plans and find EWT for heating coils, etc. on Mechanical Schedule pages.*		**HVAC EWT & LWT:**	
6	Are spaces generally overheated, underheated, or conditioned appropriately? (circle all that apply)	**Overheating**	**Underheating**	**Conditioned Appropriately**	**Mixed**	**Other:**	
7	If spaces are **overheating** - describe severity and areas of concern (i.e. do occupants open windows, what outdoor air temperatures does this occur?)						
8	If spaces are **underheating** - describe severity and areas of concern (cold corridors/rooms, what outdoor air temperatures does this occur? etc.)						
9	Approximately what percent of terminal units have 2-way and 3-way valves?	**2-Way:**		**3-Way:**			
10	Other Comments						
	Boiler System						
11	Number of Boilers?	**1**	**2**	**3**	**4**		
12	Boiler Manufacturer?	**Aerco**	**Fulton**	**Lochinvar**	**KN**	**Patterson Kelley**	**Other:**
13	Piping system? (primary/secondary, variable primary, etc.)	**Constant Primary / Variable Secondary**		**Variable Primary / Variable Secondary**		**Variable Primary**	
14	Glycol? (circle) If so, what percentage and type?	**Yes**	**No**	**Glycol Type:**		**% Glycol:**	
15	If building circulation pump is installed with VFD, indicate the speed in which the pump is operating.	**Operating Speed (Hz):**		*(Note: <50 Hz when occupied suggests that boiler temeperature can be lowered.)*			
16	If boiler pump has a VFD, does the boiler pump speed reset with the burner firing rate?	**Yes**	**No**				
17	Note if there are any atypical building equipment/loads (e.g. service hot water, pool, ice arena, etc.)						
18	Observe minimum of 1-2 boiler cycles or 30 minutes of boiler operation, whichever is greater, ***before*** parameters are changed and comment on any abnormalities or potential issues						

	Outdoor Air Sensor Assessment	Check Box or Circle		Comments		
19	Is there an outdoor temperature sensor located at the building?	Yes	No (Add Sensor & Reset)			
20	If local outdoor reset, confirm outdoor temperature sensor wiring					
21	Describe outdoor temperature sensor location.					
22	Is outdoor temperature sensor shaded?	Yes	No (Move or Add Shading)			
23	What approximate direction is outdoor temperature sensor facing if on a wall?	North	South (Shade or Move)	East (Shade or Move)	West (Shade or Move)	
24	Is the sensor near any exhaust/relief air or condensing units that could be effecting it?	Yes (Move)	No			
25	Is the sensor installed a minimum of 4'-0" above the ground/roof?	Yes	No (Move)			
26	Corrective Action for Outdoor Sensor*	Not Needed Was Taken	Rec'd Boiler Contracor Follow-UP	Rec'd BAS Contractor Follow-UP	*Describe (& Note Cost if Available):*	
27	Other Comments					
	*See the Outdoor Air Sensor Assessment Appendix for suggested corrective actions based on the documented information. Then circle if action was taken or not, who was contacted, if necessary, and describe the action taken.					

	Current System Operation Assessment	Check Box	Comments
28	If applicable, confirm BAS input wiring to Lead Boiler or other local boiler controller. (check box)		
29	Confirm wiring between local/master/BAS and each lag boiler. (check box if correct)		
30	Interlocks and communication to building automation system connected and functional, including system enable/disable, supply water set point determination, pump speed control and isolation valve control (where applicable), etc. (check box if correct)		
31	Confirm each boiler is properly programmed to take direction from lead boiler or other master controller. (check box if correct)		

	Current Boiler Information during Assessment	Current Value		Comments
	Boiler 1			
32	Boiler Model & Year Made			
33	Boiler Input Rate (MBH)			
34	Outlet Temperature (°F)			
35	Firing Rate (%)			
36	Runtime Hours			
37	# of Cycles			
38	# of Cycles/Runtime Hour Ratio (Manually calculate and document value)			*(If >1.5 cycles/run hour look at possible staging/sequencing changes.)*
39	Properly Setup as Master or Slave?	Master	Slave	

	Boiler 2			
40	Boiler Model & Year Made			
41	Boiler Input Rate (MBH)			
39	Outlet Temperature (°F)			
40	Firing Rate			
41	Runtime Hours			
42	# of Cycles			
43	# of Cycles/Runtime Hour Ratio (Manually calculate and document value)			*(If >1.5 cycles/run hour look at possible staging/sequencing changes.)*
44	Properly Setup as Master or Slave?	**Master**	**Slave**	
	Boiler 3	**Current Value**		**Comments**
45	Boiler Model & Year Made			
46	Boiler Input Rate (MBH)			
47	Outlet Temperature (°F)			
48	Firing Rate			
49	Runtime Hours			
50	# of Cycles			
51	# of Cycles/Runtime Hour Ratio (Manually calculate and document value)			*(If >1.5 cycles/run hour look at possible staging/sequencing changes.)*
52	Properly Setup as Master or Slave?	**Master**	**Slave**	
	Boiler 4			
53	Boiler Model & Year Made			
54	Boiler Input Rate (MBH)			
55	Outlet Temperature (°F)			
56	Firing Rate			
57	Runtime Hours			
58	# of Cycles			
59	# of Cycles/Runtime Hour Ratio (Manually calculate and document value)			*(If >1.5 cycles/run hour look at possible staging/sequencing changes.)*
60	Properly Setup as Master or Slave?	**Master**	**Slave**	

	Current and Final Boiler Plant Parameters Assessment	Current Value	Final Value	Comments	
61	Outdoor Temp from a Weather App (°F)				
62	Outdoor Temp From Controls/Sensor (°F) [note source]				
63A	System Supply Temperature Setpoint--from BAS (°F)				
63B	System Supply Temperature Setpoint--from Local/On-Board Controller (°F)				
64	System Loop Supply Temperature (°F) (Note if controlling temperature sensor is in the boiler loop or building loop)				
65	System Loop Return Temperature (°F) (Note if temperature sensor is in the boiler loop or building loop)				
65P	Boiler System Pressure (note guage location [e.g. at expansion tank or at boiler 1]			***Note if: Water/glycol added? Recommendation to watch and/or add fluid?***	
OA Reset? If so, record the following information.				***Suggested Value****	
66	High Boiler Setpoint Temperature (°F)			*170°F apt./165°F schools (140°F if design HVAC EWT=140°F)*	
67	Low Boiler Setpoint Temperature (°F)			*100°F (90°F if design HVAC EWT=140°F)*	
68	High Outdoor Temperature (°F)			*60°F or lower*	
69	Low Outdoor Temperature (°F)			*-10°F (or lower)*	
70	High Outdoor Shutdown Temperature (°F)			*60°F or lower (except for reheat)*	
If OA Reset from BAS, confirm allowed setpoint range on local controller					
71A	Maximum system setpoint (°F)			*180°F*	
71B	Minimum system setpoint (°F)			*90°F or lower*	
	Describe boiler sequencing observations and settings within				
	*Suggested values are based on research and experience with similar systems. If the suggested values are not realistic for your building because of underheating/other issues, please refer to the general guide for further suggested values.				
	**See appropriate Appendix for specific boiler manufacturer on documenting and tuning sequencing parameters.				

Appendix B: Tune-Up Reference Documents and Make-Specific Staging Forms

Pilot Condensing Boiler Control Tune-Up General Guide – Template

This guide is intended for use along with the Tune-Up Protocol Form. The tables and charts that follow are CEE's recommended operating guidelines for the Boiler Tune-Up Protocol. Recommended initial settings are based on a combination of our actual field experiences and input from local manufacturers' representatives, contractors, and end-users.

CEE recognizes that each building is unique and may require additional modifications to the recommended settings. However, the final optimized controller settings are expected to lie within the adjustment ranges noted in the tables and charts for the vast majority of multifamily and commercial buildings in Minnesota.

Preliminary Assessment

The intent of the preliminary assessment is to gain information and context of the building and heating system. Please fill out the form to the best of your ability – most information can be found in the boiler room, by talking to building staff, or by having the building staff show you the BAS system graphics pages.

Outdoor Air Sensor Assessment

The purpose of the outdoor air sensor assessment is to determine if the sensor has been installed correctly and in a proper location to provide an accurate reading of the outside air temperature. The following are corrective actions for the outdoor air sensor based on the documented information in the Pilot Condensing Boiler Control Tune-Up Form.

Assessment Question #	Assessment Response	Suggested Corrective Action
19	Yes	No action required
	No	Install an OA sensor to allow for an OA Reset.
22	Yes	No action required
	No	Install a sun shield on sensor.
23	North	No action required
	South	Ensure there's a sunshield and/or relocate to north wall
	East	Ensure there's a sunshield and/or relocate to north wall
	West	Ensure there's a sunshield and/or relocate to north wall
24	Yes	Relocate sensor minimum of 10'-0" away from heat source.
	No	No action required
25	Yes	No action required
	No	Relocate sensor a minimum of 4'-0" above ground/roof.

Current System Operation Assessment and Boiler Information

The purpose of the current system operation section is to record existing information on the setpoints and parameter settings of the heating system. This information will be used as a starting point for making adjustments and as a baseline in order to estimate savings.

Typically, the values required in this section can be found on each boiler's user interface or the boiler plants central controller if one was installed. Most boilers have arrows to scroll through various values such as Outlet/Inlet Temperature, Firing Rate, Runtime Hours, Boiler Control and # of Cycles.

Fill in the current values to the best of your ability, and add any additional comments that stand out.

If you are having issues finding certain values, see the boiler/controller user interface guide for the specific boiler being worked on.

Current and Final Boiler Plant Parameters Assessment

The purpose of this section is to change key parameters in order to optimize the boiler system temperatures, staging, and part-load control. The parameters listed in this section of the form can be found within each boiler's user interface or on the boiler plants central controller if one was installed.

If you are having issues finding/changing the key parameters, see the boiler user interface guide for the specific boiler being worked on.

Suggested Outside Air Reset Schedules for Overheating/Under heating and Unusual Loads

Below are recommended values different than the suggested values in the Pilot Condensing Boiler Control Tune-Up Form for buildings with overheating/underheating or unusual loads.

A) Outdoor Air Reset Suggested Values for Overheating/Underheating

Outdoor Temperature during Problem	Under Heating Problem	Over Heating Problem
Below 0°F	1. Increase High Boiler Setpoint Temp by 5°F more than suggested value ***OR*** 2. Increase Low Outdoor Temperature to -5°F.	1. Decrease High Boiler Setpoint Temp by 5°F less than suggested value ***OR*** 2. Decrease Low Boiler Setpoint Temp by 5°F less than suggested value.
0°F to 30°F	1. Increase High Boiler Setpoint Temp by 5°F more than suggested value	1. Decrease High Boiler Setpoint Temp by 5°F less than suggested value. 2. Decrease Low Boiler Setpoint Temp by 5°F less than suggested value.
30°F to 60°F	1. Increase Low Boiler Setpoint Temp by 5°F more than suggested value	1. Decrease Low Boiler Setpoint Temp by 10°F less than suggested value.
All Temperatures	1. Perform all of the modifications listed above.	1. Perform all of the modifications listed above.

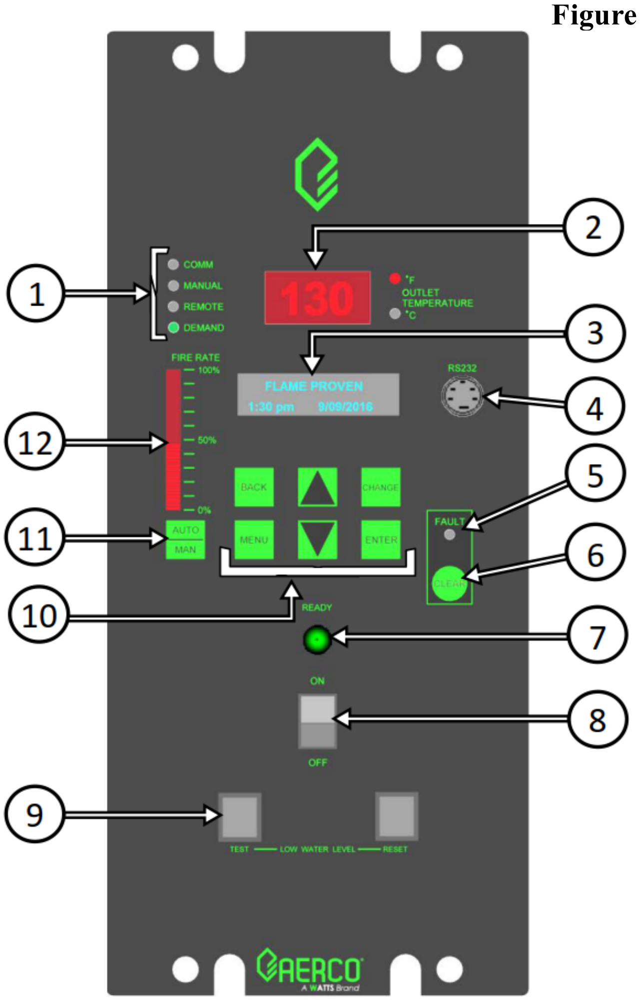
B) Outdoor Air Reset Suggested Values for Service/Unusual Loads

Type of Load	Suggested Supply Water Temperatures
Domestic Hot Water Heating (Domestic Hot Water Setpoint of 120°F)	1. Minimum Low Boiler Setpoint Temp of 140°F
Domestic Hot Water Heating (Domestic Hot Water Setpoint of 140°F)	1. Minimum Low Boiler Setpoint Temp of 160°F
Fuel Oil used as Fuel	1. Minimum Low Boiler Setpoint Temp of 160°F

Center for Energy and Environment

AERCO Control Tune-Up Guide

Figure 1



#	Item on Controller Display
1	Boiler Status
2	Outlet Temperature
3	Display
4	RS232 Port
5	Fault Indicator
6	Clear
7	Ready Indicator
8	On/Off Switch
9	Low Water Level Test + Reset
10	Keypad
11	Auto/Manual Switch
12	Fire Rate

- **General Navigation**
  1. The ▲ and ▼ arrow keys will display the available information on the screen.
  2. To scroll between different menu types (Operating, Setup, Configuration, Tuning, and BST (Boiler Sequencing Technology), select **MENU** until desired menu is displayed.
  3. Once the desired menu is displayed the arrow keys will scroll through the menu options.
  4. To change the value of a setting that is displayed, select **CHANGE**.
  5. Use arrow keys to change value to desired value, and then save by selecting **ENTER**.

  Password check
  1. Select **MENU** on the keypad (10) to show the *Setup* menu. Select ▲ until *Password* is displayed.
  2. Select **ENTER** to enter the default level 2 Password **6817 (unless otherwise noted)** by selecting the ▲ and **CHANGE** keys for each digit.
  3. This will permit access to all menus.

- **Navigation to Individual Boiler Information**

The following steps should be completed for each individual boiler.

1. Select **MENU** on the keypad until the OPERATING Menu is displayed.
2. Scroll through OPERATING Menu items by selecting ▼ to find Outlet Temperature, Run Hours, # of Run Cycles, Outdoor Temp. See chart below for list of points shown within the OPERATING Menu.

MENU ITEM DISPLAY		AVAILABLE CHOICES OR LIMIT		Appears Only If Enabled in:
		Minimum	Maximum	
1	Active Setpoint	40°F (4.4°C)	240°F (116°C)	
2	Outlet Temp	30°F (-1.1°C)	240°F (116°C)	Configuration Menu
3	Inlet Temp	30°F (-1.1°C)	240°F (116°C)	
4	Air Temp	-70°F (-56.7°C)	245°F (118°C)	
5	Outdoor Temp	-70°F (-56.7°C)	130°F (54.4°C)	Configuration Menu
6	Valve Position In	0%	100%	
7	Valve Position Out	0%	100%	Configuration Menu
8	FFWD Temp	30°F (-1.1°C)	240°F (115.6°C)	
9	Exhaust Temp	Displays current exhaust temperature		
10	Flame Strength	0%	100%	
11	Min Flame Str	Not Used		
12	O2 Monitor	Enable	Disable	O2 Monitor = Enabled
13	Oxygen Level	0%	21%	
14	Ignition Time	0.00	10.00	
15	SSOV Time to OPN	0.00	10.00	
16	Spark Current	0 amps	2.5 amps	
17	Run Cycles	0	999,999,999	
18	Run Hours	0	999,999,999	
19	Fault Log	0	19	

3. Fire Rate can be found on the keypad to the left of the display (See #12 in Figure 1).
4. Outlet temperature can be found on the boiler above the display (See #2 in Figure 1).
5. To determine a lead/lag boiler status, select **MENU** to navigate to the BST Menu.
6. Select ▼ to find the "1 BST Units 8" menu item. Refer to the following to find the lead/lag status of each boiler.

*** NOTE**:
The **1 BST Units 8** menu item shows the current status for each unit controlled by BST, up to a maximum of 8 units. The possible characters displayed are:

- \- = Off Line
- * = Not Available (fault, etc.)
- 0 = Off
- 1 = On,
- A = Lead On
- a = Lead Off
- B = Lag On
- b = Lag Off
- S = Setpoint Limit Active

The following example shows the status of 5 units being controlled by BST where:

Unit 1 & 3 are **On**
Unit 2 is **Off**
Unit 4 is **Not Available**
Unit 5 is **Lead On**
Unit 6 is **Lag Off**

1 BST Units 8

1	0	1	*	A	b		

- **Navigation to Boiler System Supply Temperature Setpoint**
    1. On the lead boiler, select **MENU** until the BST Menu is displayed.
    2. Select ▼to find Row 52 System Supply Temperature Setpoint (BST Setpoint).
    3. Rows 53 and 54 can be found on the BAS.

	MENU ITEM DISPLAY	AVAILABLE CHOICES OR LIMIT			DEFAULT
		Minimum		Maximum	
1	**BST Mode**	Off	BST Client	BST Manager	Off
2	BST Setpoint	BST Setpt Lo Limit		BST Setpt Hi Limit	130°F (54.4°C)
3	Header Temp	Read Only – current Header temperature in °F			N/A
4	BST Fire Rate	0		100%	Fire rate %
5	BST Ave Fire Rate	0		100%	Avg Fire Rate %
6	BST Outdoor Temp	Read Only – current outdoor temperature in °F			N/A
7	Units Available	0		8	Units Present
8	Units Ignited	0		8	Units firing
9	BST Valve State	0 (CLOSED)		1 (OPEN)	0
10	1 BST Comm Errors 8	0		9	0
11	1 BST Units 8	0 – 8 (see * NOTE below)			0
12	***BST SETUP MENU***	Disabled		Enabled	Disabled
13	BST Setpoint Mode	Constant Setpoint	Remote Setpoint	Outdoor Reset	Constant Setpt
14	BST Remote Signl	4-20 mA/1-5 VDC	0-20 mA/0-5 VDC	Network	Network
15	Head Temp Source	Network		FFWD Temp	FFWD Temp
16	Mdbus Temp Units	Degrees C or Degrees F			Degrees C
17	Header Temp Addr	0		255	240
18	Header Temp Point	0		255	14
19	BST Outdoor Sens	Disabled		Enabled	Disabled
20	Outdr Tmp Source	Outdoor Temp		Network	Outdoor Temp
21	Outdoor Tmp Addr	0		255	240
22	Outdoor Tmp Pnt	0		255	215
23	BST Auto Mstr	No		Yes NOTE! A Modbus temperature transmitter must be installed in conjunction with this feature.	No
24	BST Auto Timer	10 sec		120 sec	30 sec
25	Remote Intlk Use	Boiler Shutdown		System Shutdown	System Shutdown
26	One Boiler Mode	Off	On-Outlet Temp	On-Avg Temp	Off
27	1 Blr Threshold	10		35	25
28	Setpoint Setback	Disable		Enable	Disable
29	Setback Setpoint	BST Setpt Lo Limit		BST Setpt HI Limit	130°F (54.4°C)
30	Setback Start	12:00am		11:59pm	12.00am
31	Setback End	12:00am		11:59pm	12.00am
32	Rate Threshold	1°F (0.55°C)		30°F (16.5°C)	15°F (8.25°C)

33	***OPERATE MENU***	Disabled	Enabled	Disabled
34	BST Next On VP	16%	100%	50%
35	BST Max Boilers	1	8	8
36	BST On Delay	30 sec	300 sec	60 sec
37	BST On Timeout	15 sec	300 sec	60 Sec
38	Valve Override	Off	Closed / Open	Off
39	Valve Off Delay	0	15 min	1 min
40	BST Sequencing	Run Hours	Unit Size / Select Lead	Run Hours
41	Select Lead Unit	0	127	0
42	Select Lag Unit	0	127	0
43	Lead/Lag Hours	25 hours	225 hours	72 hours
44	***TEMP CTRL MENU***	Disabled	Enabled	Disabled
45	BST Temp Hi Limit	40°F (4.4°C)	210°F (98.9°C)	210°F (98.9°C)
46	BST Setpt Lo Limit	40°F (4.4°C)	BST Setpt HI Limit	60°F (15.5°C)
47	BST Setpt HI Limit	BST Setpt Lo Limit	220°F (104.4°C)	195°F (90.6°C)
48	BST Prop Band	1°F (-17.2°C)	120°F (48.9°C)	100°F (37.8°C)
49	BST Intgral Gain	0.00	2.00	0.50
50	BST Deriv Time	0.00 Min	2.00 Min	0.10 Min
MENU ITEM DISPLAY		**AVAILABLE CHOICES OR LIMIT**		**DEFAULT**
		Minimum	**Maximum**	
51	BST Deadband Hi	0	25	1
52	BST Deadband Lo	0	25	1
53	Deadband En Time	0	120 Sec	30 Sec
54	BST FR Up Rate	1	120	20
55	BST Bldg Ref Tmp	40°F (4.4°C)	230°F (110°C)	70°F (21.1°C)
56	BST Reset Ratio	0.1	9.9	1.2
57	System Start Tmp	30°F (-1.1°C)	120°F (48.9°C)	60°F (15.6°C)
58	***BST COMM MENU***	Disabled	Enabled	Disabled
59	Comm Address	0	127	0
60	BST Min Addr	1	128	1
61	BST Max Addr	1	128	8
62	SSD Address	0	250	247
63	SSD Poll Control	0	1000	0
64	Err Threshold	1	9	5
65	SSD Temp Format	Degrees	Points	Degrees
66	BST Upld Timer	0	9999 sec	0

- **Navigation to Outside Air Reset Parameters**
  1. If supply water temperature setpoint is calculated by the BAS and written to the BST controller through the communication protocol, confirm outside air reset parameters on BAS. Otherwise, follow the next steps.
  2. On the lead boiler, select **MENU** until the BST Menu is displayed.
  3. Select ▼to find the *OPERATE MENU*.
  4. Select ▼ to find the BST Setpt Low Limit and BST Setpt Hi Limit for rows "High Boiler Setpoint Temperature" and Low Boiler Setpoint Temperature", respectively.
  5. Select ▼to find the *TEMP CTRL MENU*.
  6. Select ▼to find the "BST Reset Ratio", record this value on the form. This value is how AERCO calculates the OA reset curve. Refer to the "OA Reset Information" on page 5.
  7. Select ▼to find the "System Start Tmp", record this value in the "High Outdoor Shutdown Temperature" row on the form.

- **Navigation to Boiler Sequencing and Firing Rate Parameters (AERCO Sequencing Appendix)**
  1. On the BST Manager boiler (flashing red outlet temperature), select **MENU** until the BST Menu is displayed.
  2. Select ▼to find and document the values under the BST Operating Menu portion of the AERCO Sequencing Appendix form.
  3. Select **MENU** to find the CALIBRATION Menu and then▼ to find and document the Stop and Start Levels. This must be done on each individual boiler. **NOTE:** This will shut off the boiler until the CALIBRATION Menu is exited.
  4. Select **MENU** to find the CONFIGURATION Menu and then ▼ to find and record the Shutoff Delay Temp and the Demand Offset Temp.

- **OA Reset Information**

Indoor / Outdoor Setup Instructions

1. Refer to the Indoor/Outdoor reset ratio charts in Appendix E.
2. Choose the chart corresponding to the desired Building Reference Temperature.
3. Go down the left column of the chart to the coldest design outdoor air temperature expected in your area.
4. Once the design outdoor air temperature is chosen, go across the chart to the desired supply header temperature for the design temperature chosen in step 3.
5. Next, go up that column to the RESET RATIO row to find the corresponding reset ratio.
6. Access the *Configuration* menu and scroll through it until the display shows ***BLDG REF TEMP*** (Building Reference Temperature). If necessary, refer to Section 2.3: *C-More Controller Menus*, above, for detailed instructions on navigating the menus.
7. Press the **CHANGE** key. The display will begin to flash.
8. Use the ▲ and ▼ arrow keys to select the desired Building Reference Temperature.
9. Press **ENTER** to save any changes.
10. Next, scroll through the *Configuration* menu until the display shows ***RESET RATIO***.
11. Press the **CHANGE** key. The display will begin to flash.
12. Use the ▲ and ▼ arrow keys to select the Reset Ratio determined in step 5.
13. Press **ENTER** to save the change.

Header Temperature for a Building Reference Temperature = 70°F (21.1°C)

AIR TEMP		RESET RATIO									
°F	°C	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
70	21.1	70	70	70	70	70	70	70	70	70	70
65	18.3	73	74	75	76	77	78	79	80	81	82
60	15.6	76	78	80	82	84	86	88	90	92	94
55	12.8	79	82	85	88	91	94	97	100	103	106
50	10.0	82	86	90	94	98	102	106	110	114	118
45	7.2	85	90	95	100	105	110	115	120	125	130
40	4.4	88	94	100	106	112	118	124	130	136	142
35	1.7	91	98	105	112	119	126	133	140	147	154
30	-1.1	94	102	110	118	126	134	142	150	158	166
25	-3.9	97	106	115	124	133	142	151	160	169	178
20	-6.7	100	110	120	130	140	150	160	170	180	190
15	-9.4	103	114	125	136	147	158	169	180	191	202
10	-12.2	106	118	130	142	154	166	178	190	202	214
5	-15.0	109	122	135	148	161	174	187	200	213	
0	-17.8	112	126	140	154	168	182	196	210		
-5	-20.6	115	130	145	160	175	190	205			
-10	-23.3	118	134	150	166	182	198	214			
-15	-26.1	121	138	155	172	189	206				
-20	-28.9	124	142	160	178	196	214				

Center for Energy and Environment

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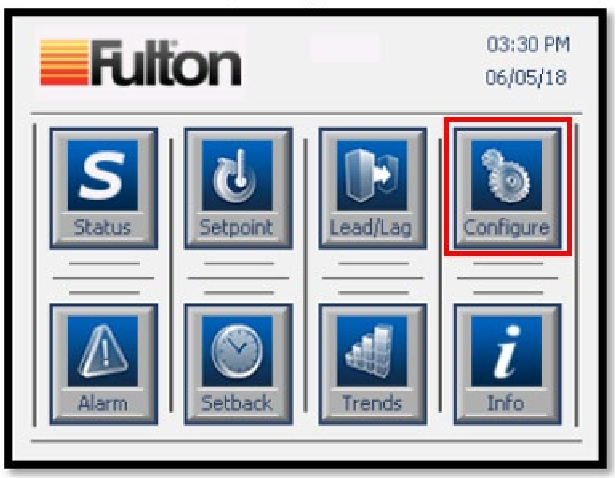
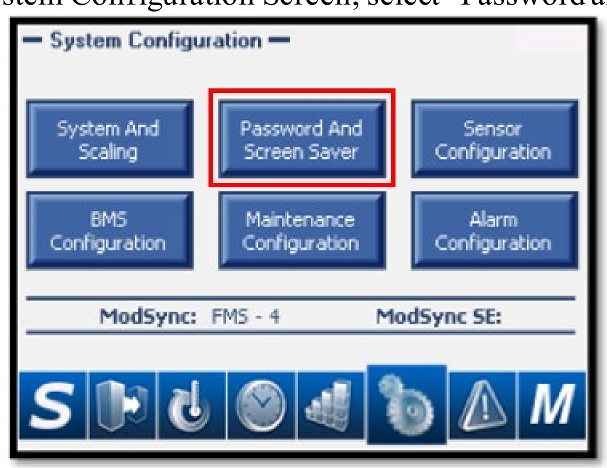
- **Modsync Controller Password Input**

1. If a password is required to access the Modsync screens, obtain password from owner and enter on screen.
2. Once entered, select "Configure".



3. On the System Configuration Screen, select "Password and Screen Saver."

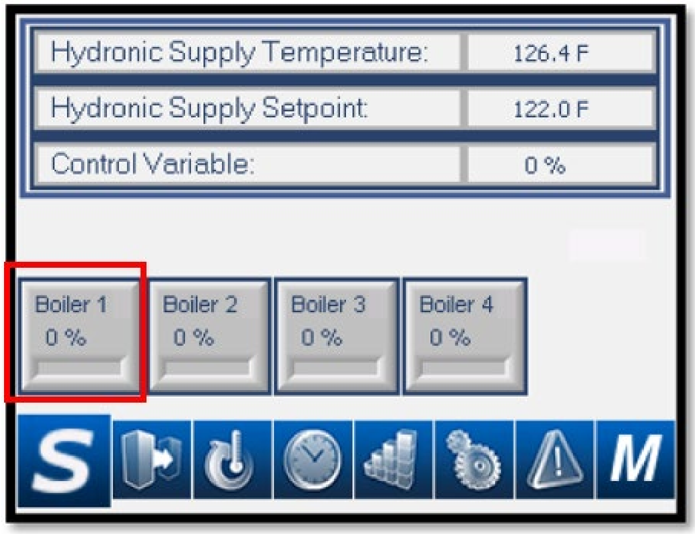


4. Change the "Bypass Timer" value, if needed, to the approximate length of time required to record all the data. Typical value is 20 minutes. Select the "M" button on the bottom right corner of the screen to return to the Main Menu.
   - *This Bypass Timer should be reverted back to its original value after the tune-up.*

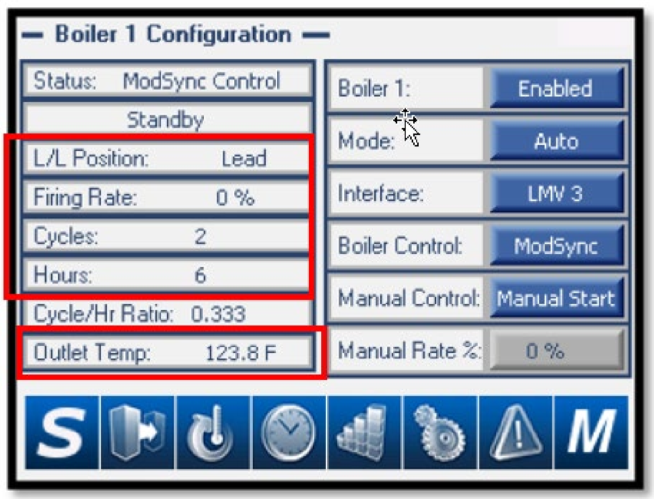
➢ **Navigation to Individual Boiler Information (Rows 32-60)**

5. On the Modsync Main Menu, select "Status".

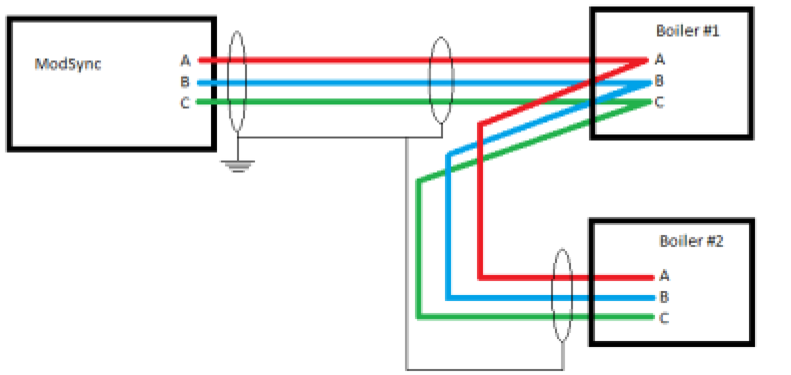
6. On the Status Menu select the boiler you want to view.



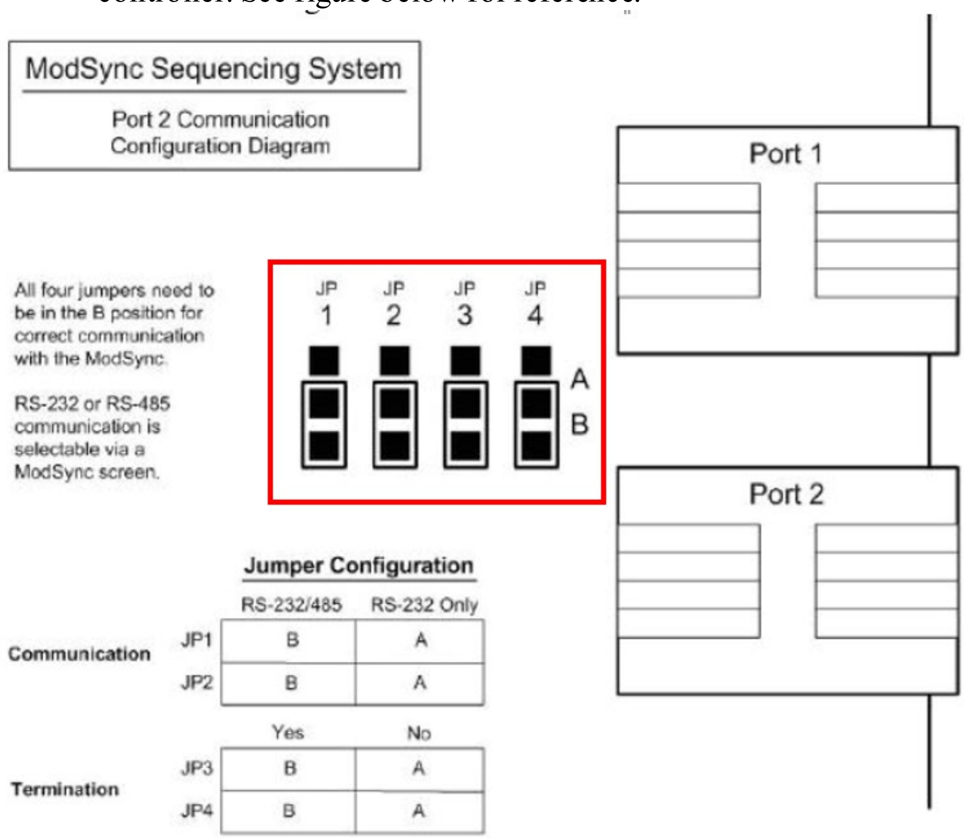
7. Information on the boilers current **outlet temperature, firing rate**, **runtime hours**, **# of cycles**, and **Lead/Lag position** can be found on the Boiler Configuration Screen as shown in the figure below.



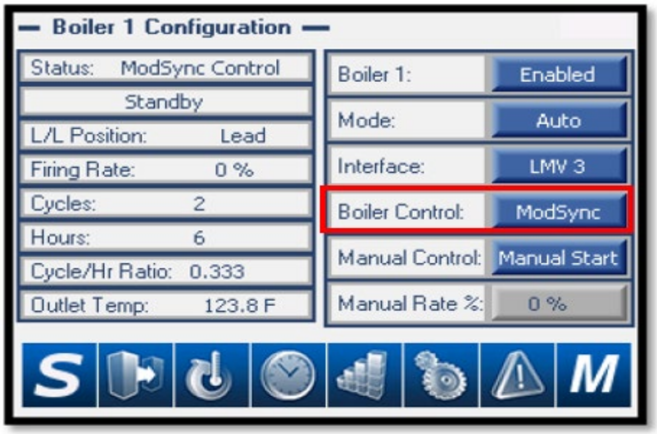
- **Confirm control wiring/communication between Modysnc and boiler plant (Row 31)**
  1. *Control Wiring Verifiction:* The communication wiring should be done in a daisy chain configuration. The wiring should be three-wire shielded. The shield should be connected at one end only and to earth ground at the Modsync only as shown in figure below.



  2. *Communication Verification:* Confirm the boilers are setup per the information in both of the following bullet points.
     - All four jumpers, located on port 2 of the Modsync controller, must be in the B possition for correct communication between the boilers and Modsync controller. See figure below for reference.



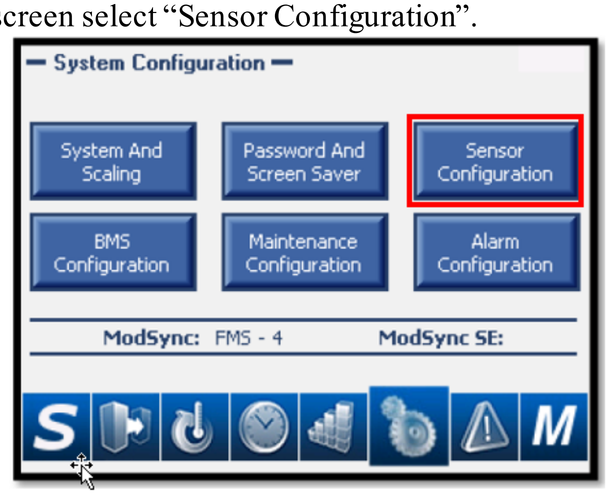
- On the Modsync Controller, navigate to each individual boiler configuration page as described in the section "Navigation to Individual Boiler Information". On each boiler configuration page verify **Boiler Control** is set as Modsync as shown in figure below.



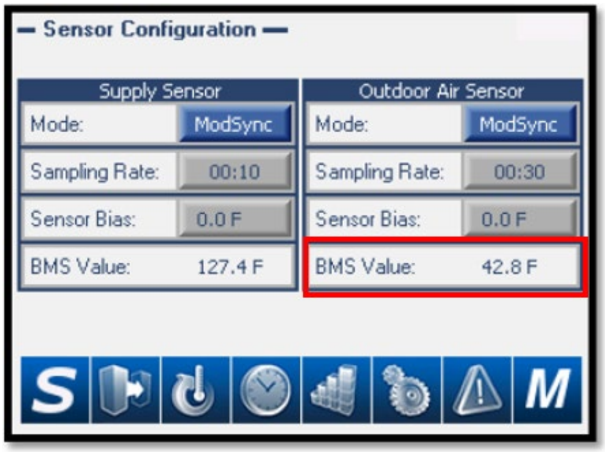
➢ **Navigation to Outdoor Temperature from Controls/Sensor (Row 62)**

3. On the Main Menu select "System Configuration".

4. On the next screen select "Sensor Configuration".



5. The outdoor temperature can be found as shown in the figure below. Note the source of the value.

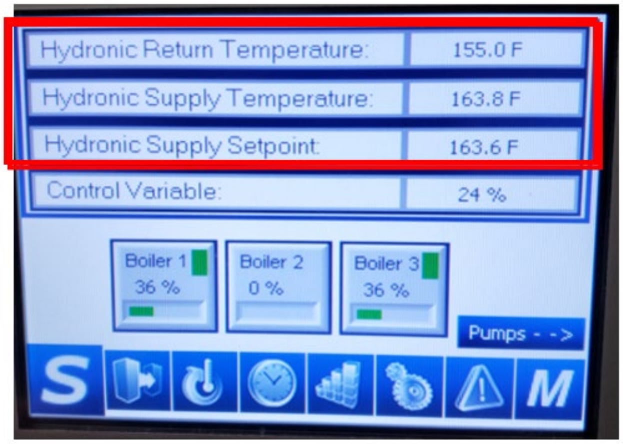


- **Navigation to Boiler Plant Information (Rows 63-65)**

6. For system supply temperature setpoint and system supply/return temperature, select "Status" on the Main Menu.

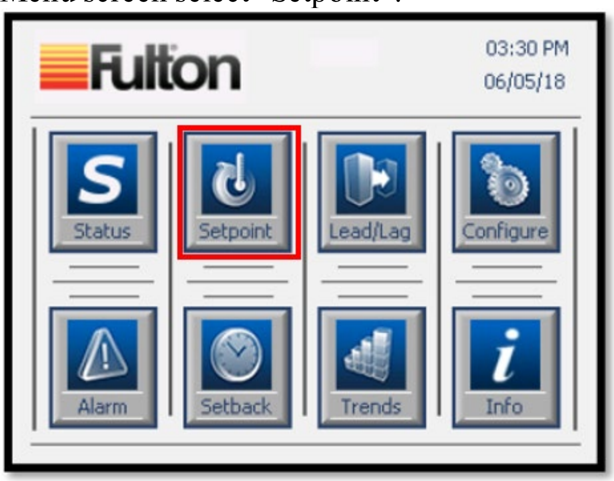
7. The system supply temperature setpoint, system supply temperature and system return temperature can be found as shown below.

- *If the system return temperature can not be found as shown in the Figure below, locate and document the return temperature from the BAS.*

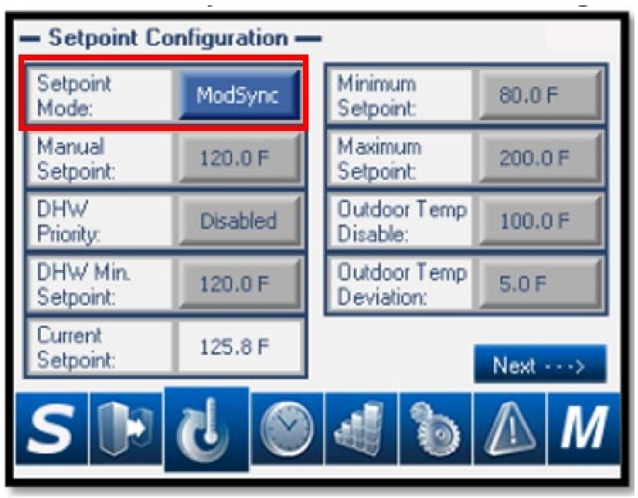


- **Navigation to Outside Air Reset Parameters (Rows 66-70)**

8. *If supply water temperature setpoint is calculated by the BAS and written to the Modsync controller through the communication protocol, confirm outside air reset parameters on BAS. If not see the following steps to locate reset on the Modsync Controller.*
9. On the Main Menu screen select "Setpoint".

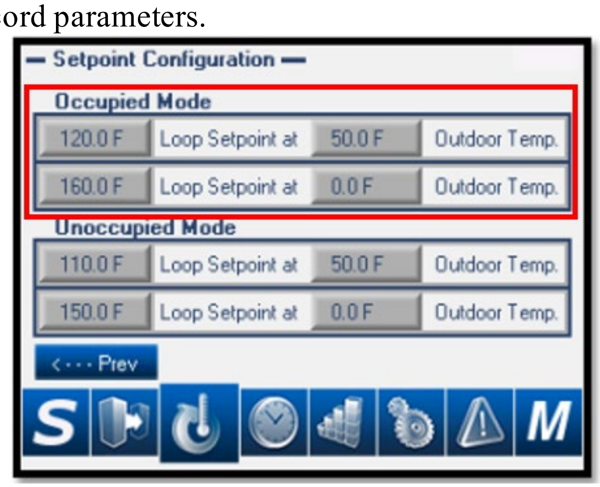


The Setpoint Configuration Screen should be similar as shown below. The Setpoint Mode should be in Modsync if the Modsync Controller is calculating the OA Reset.



10. Select "Next" on the Setpoint Configuration screen.

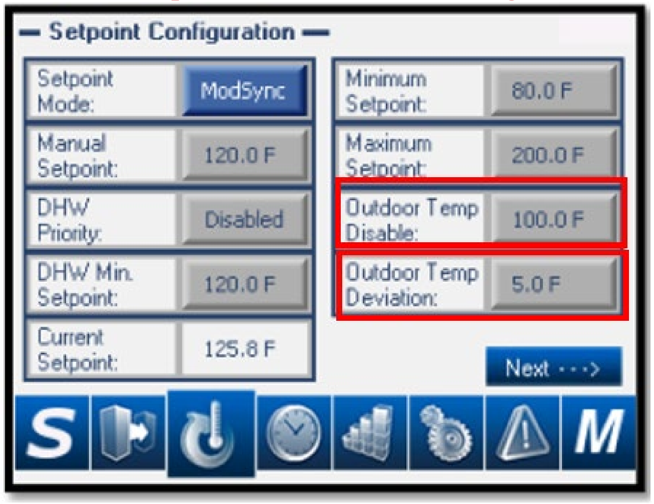
11. The outdoor air reset parameters can be found as shown below. If an unoccupied mode reset is programmed, note this in the Pilot Condensing Boiler Control Tune-Up Form and record parameters.



12. The High Outdoor Shutdown Temperature can be found on the first Setpoint Configuration screen as shown below. Record the Outdoor Temp Deviation setpoint

in the comments section of Row 70 in the Pilot Condensing Boiler Control Tune-Up Form.

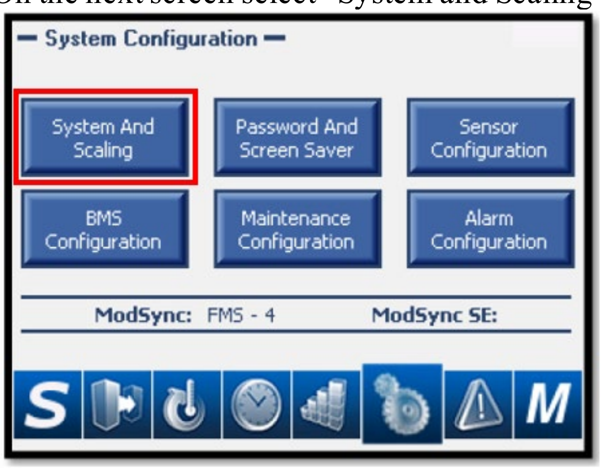
- *The Outdoor Temp Deviation should be no greater than 5°F*



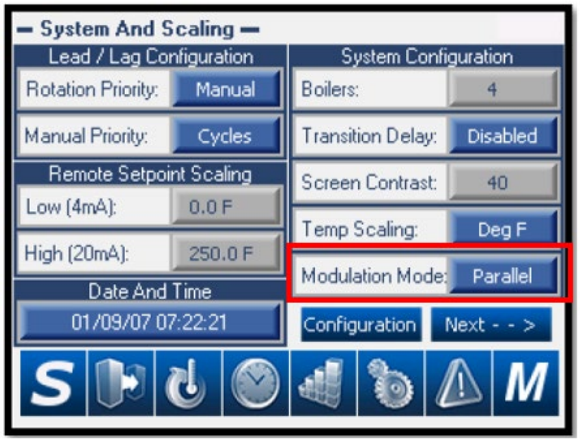
➢ **Navigation to Boiler Sequencing Parameters (Fulton VTG Sequencing Appendix)**

13. To locate the sequencing control method used by the boiler plant, first on the Main Menu screen select "Configure".

On the next screen select "System and Scaling".

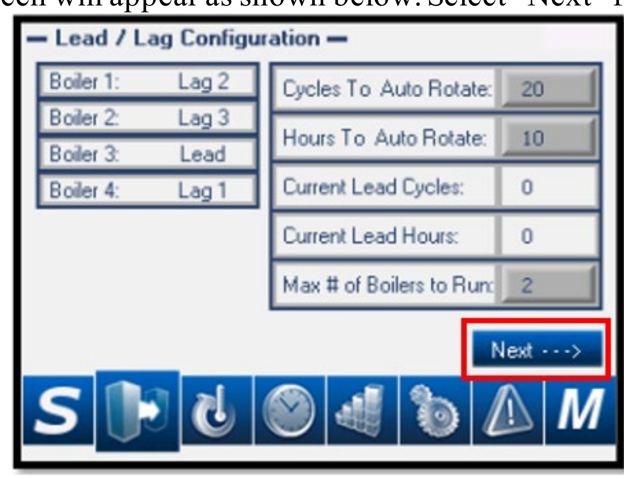


14. The sequencing control method used by the boiler plant can be found as shown in the figure below.

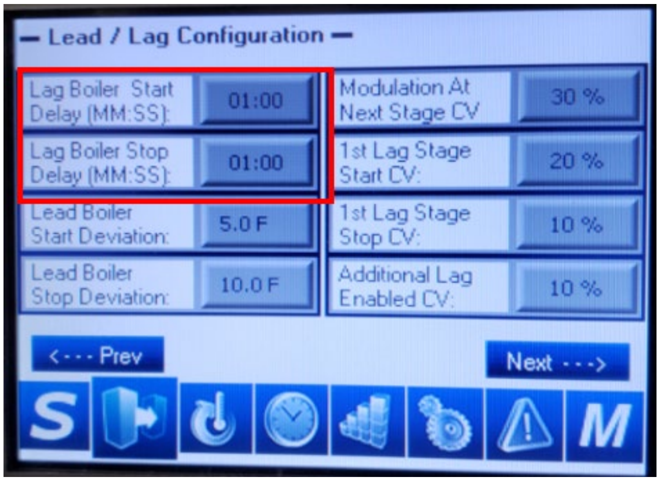


15. To locate the lead/lag and sequencing parameters of the boilers, on the Main Menu screen select "Lead/Lag".

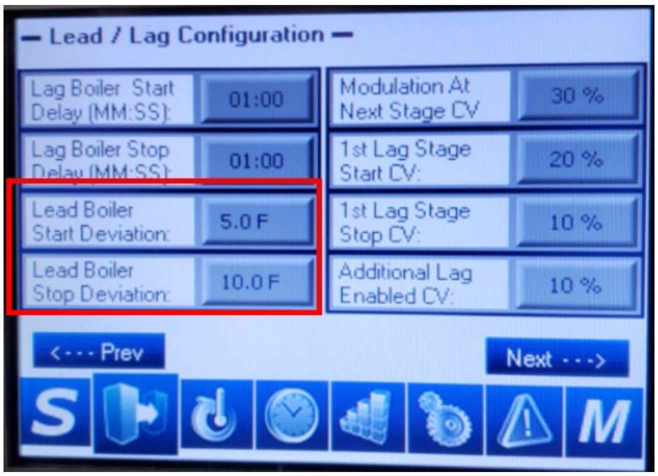
16. The first screen will appear as shown below. Select "Next" for the next screen.



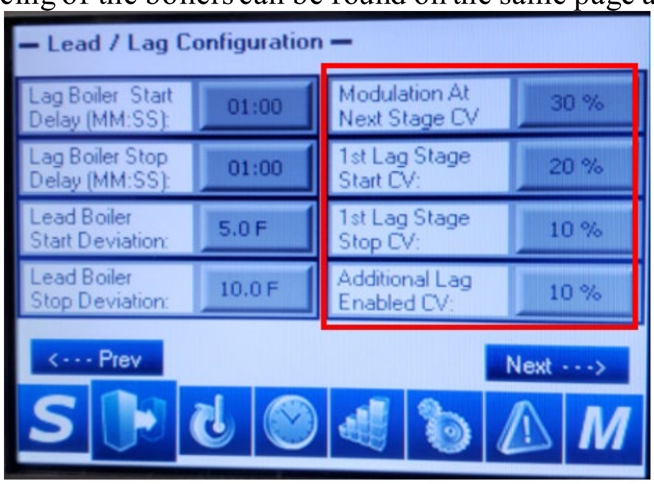
17. The lag boiler start/stop delay can be found on the second Lead/Lag Configuration screen as shown below.



18. The Lead Boiler Start and Stop Deviation setpoints can be found on the same page as shown below.



19. The sequencing of the boilers can be found on the same page as shown below.



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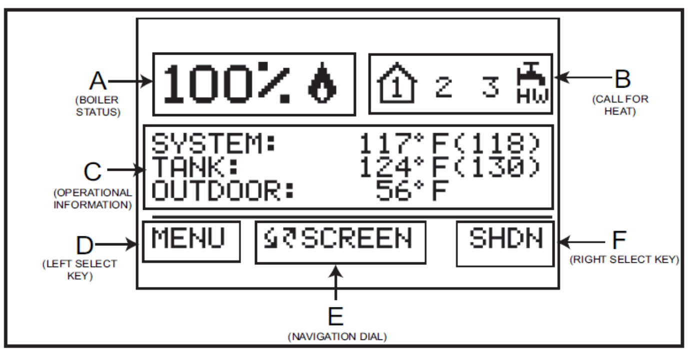
1. **Navigation to Individual Boiler Information (Rows 34-37, 39-42, 47-50, 55-58)**
   See following section for Lead/Lag identification.

   The **outlet temperature** and **firing rate** are displayed on the home screen shown. "A" displays the firing rate. The outlet temperature is displayed further down as the "outlet temp". The navigation dial can be used to scroll through the operational information.



   The runtime and # of Cycles are listed under the operational information. **Runtime** is labeled as SH Run hours and **# of Cycles** is labeled as SH Cycles.

2. Navigation to Master/Slave Boiler identification (Rows 39, 44, 52, 60)

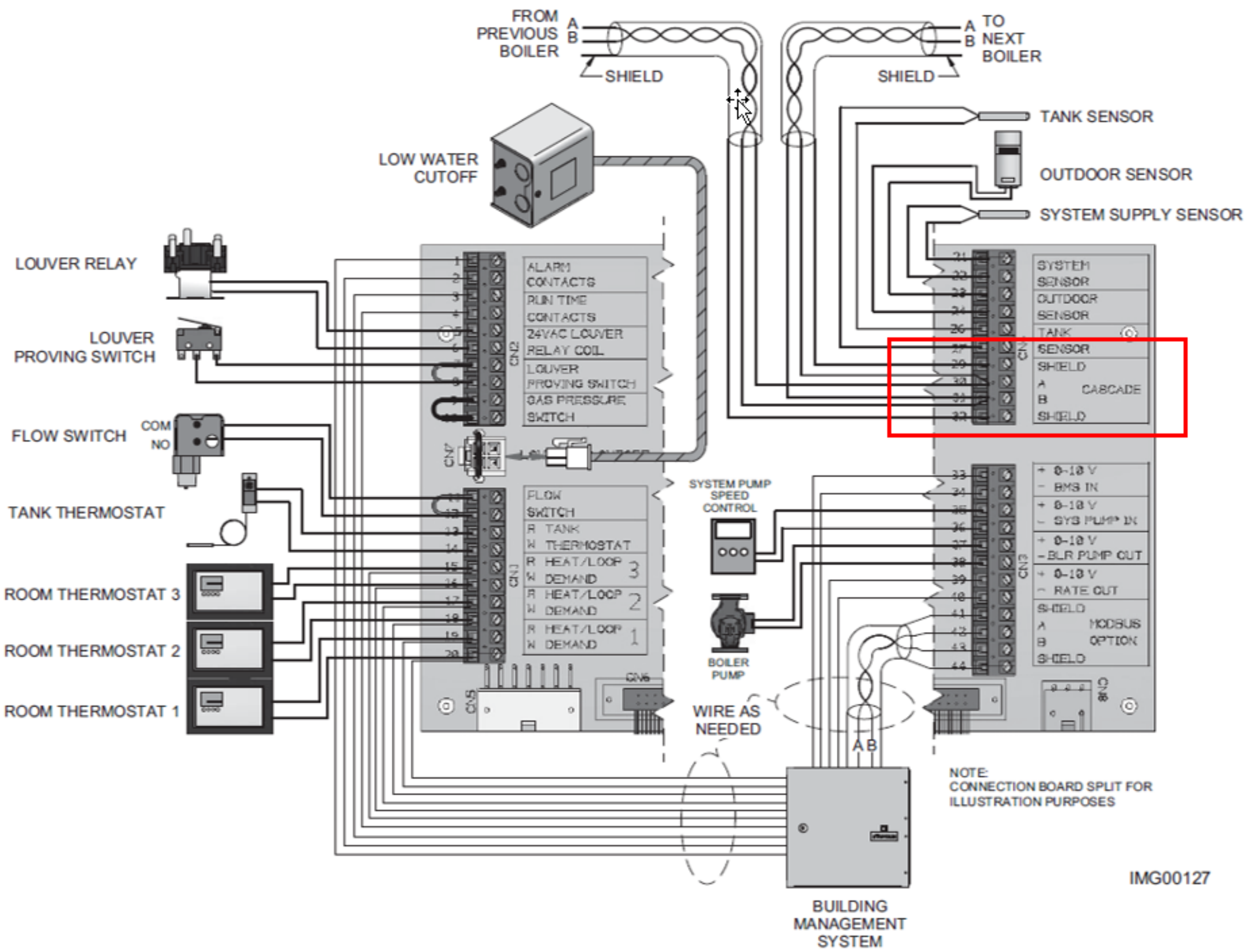
Lochinvar uses a cascade address to designate the **Lead** boiler. If the address is 0 the boiler is the lead. If the address is 1-7 the boiler is lagging.

The installer password needs to be entered to access the controller modes screen where the cascade address is listed. Follow the steps below to enter the installer password **5309**.

BUTTON	SCREEN STATUS	OPERATION	DISPLAY
	[MENU]	Press and hold the LEFT SELECT soft key [MENU] for five (5) seconds.	STANDBY OUTLET 117°F INLET 128°F MENU ↓SETPOINTS SHDN
		Rotate the NAVIGATION dial clockwise until 5 is displayed (first digit on the left).	SHUTDOWN PASSWORD 0000 EXIT ↓NEXT SAVE
		Press the NAVIGATION dial to select the next digit. Rotate the NAVIGATION dial clockwise until 3 is shown in the display.	SHUTDOWN PASSWORD 5000 EXIT ↓NEXT SAVE
		Press the NAVIGATION dial 2 times to move to the last digit. Rotate the NAVIGATION dial counterclockwise until 9 is displayed.	SHUTDOWN PASSWORD 5300 EXIT ↓NEXT SAVE
	[SAVE]	Press the RIGHT SELECT soft key [SAVE].	SHUTDOWN PASSWNRD 5309 EXIT ↓NEXT SAVE
		Rotate the NAVIGATION dial counterclockwise to select a category.	SHUTDOWN >GENERAL TEMPERATURE SETTINGS DATA LOGGING FUNCTIONS HOME ↺↻ SCROLL

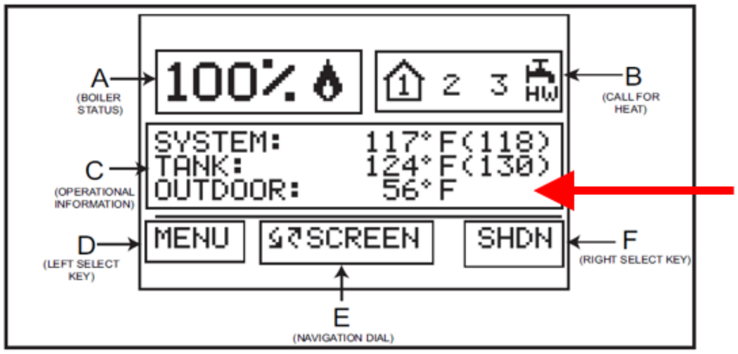
3. Confirming control wiring/communications between multiple Lochinvar boilers (Row 31)

Communication between the Leader boiler and the Member boilers is accomplished by using a shielded, 2-wire twisted pair communication cable. If the Leader is connected to the Member boilers a twisted pair wire will be connected to the Cascade terminal A on each of the Low Voltage Connection boards, and the other wire of the twisted pair will be connected to Cascade terminal B on each of the Low Voltage Connection Boards (see image below).



4. Navigation to Outdoor Temperature from Controls/Sensor (Row 62)

The **Outdoor Temp From Controls/Sensor** can be found in the operational information on the home screen.



5. Navigation to Outdoor Air Reset settings (Row 66-70)
Installer access required. See section 2 for how to enter the installer password.

After entering the installer password (5309) use the navigation dial to get to the "Outdoor Reset" option using the dial. Here you will find the outdoor air reset and warm weather shutdown settings.

The table below shows the menu labels that align with the tune-up form and the recommended default setting.

Boiler Control Tune-up Form Label	Lochinvar Label	Recommended Setting
High Boiler Setpoint Temperature (°F)	Set Point 1 at Low Outdoor Temp 1	170°F
Low Boiler Setpoint Temperature (°F)	Set Point 1 at High Outdoor Temp 1	100°F
High Outdoor Temperature (°F)	Outdoor 1 High	60°F
Low Outdoor Temperature (°F)	Outdoor 1 Low	-10°F
High Outdoor Shutdown Temperature (°F)	Outdoor Air Shutdown SH1	60°F (except for reheat)

6. Navigation to Boiler Sequencing and programming to EFF (Rows 71-75)
Installer access required. See section 2 for how to enter the installer password.

After entering the installer password (5309) use the navigation dial to get to the “Control Modes” option using the dial. Here you will find the boiler sequencing information.

The responses entered in rows 59 – 63 of the tune-up form depend on the cascade type. If the cascade type is “L/L” the boiler is set to lead/lag. This method is used when it is desired to have the least amount of total flow through the boilers. When the last boiler reaches 100% and the calculated load is still increasing, it will start the next boiler at 20% and reduce the previous boiler to 80%.

If the cascade type is set to “L/L” the following is true:

Boiler Control Tune-up Form Label	Default Setting
Lead boiler initial firing rate	Max rate of 100%
Firing rate that triggers enabling of 2nd boiler	Boiler 1 @ 100%
Firing rate that triggers enabling of 3rd boiler	Boiler 2 @ 100%
Firing rate that triggers enabling of 4th boiler	Boiler 3 @ 100%
Firing rate at which a boiler stage is dropped off	Next to last at 40% and last at 20%

If the current cascade type is currently “L/L” it should be changed to to Efficiency Optimization or “EFF”. This is the recommended and more efficiency method. When the first boiler reaches a certain rate (default = 90%), it lowers its rate to 45% and turns on the next boiler at 45%. The two (2) boilers then modulate at the same rate. If the cascade type is set to “EFF” the following is true:

Boiler Control Tune-up Form Label	Default Setting
Lead boiler initial firing rate	Max rate at 90%
Firing rate that triggers enabling of 2nd boiler	Boiler 1 @ 90%
Firing rate that triggers enabling of 3rd boiler	Boiler 1 @ 90%
Firing rate that triggers enabling of 4th boiler	Boiler 1 @ 90%
Firing rate at which a boiler stage is dropped off	Boiler 1 @ 30%

7. Navigation to Anti Short Cycle Timer (Row 76)
Installer access required. See section 2 for how to enter the installer password.

After entering the installer password (5309) use the navigation dial to get to the "Anti-Cycling" option using the dial.

The **Anti Short Cycle Timer Setting** is labeled as the "Anti-Cycling Time" in the Lochinvar menu.

8. Troubleshooting Short Cycling Issues
Installer access required. See section 2 for how to enter the installer password.

If your boiler is short cycling consider increasing the **minimum next on time** to 5 minutes or more. This parameter defines the minimum time after one unit is started before the next unit may be started. Increasing the time from the default of 0 to 5 minutes gives the lead boiler time to adjust to the setpoint temperature before turning on the next boiler and can prevent lag boilers from short cycling. The minimum next time on is labeled "min on/off time" and located in the control modes screen.

Adjusting the **cascade offset** and **cascade differential** may also prevent short cycling. The cascade offset determines how much the temperature must go above set point before the lead boiler will turn off. The cascade differential determines how much the temperature must go below the turn off temperature (Set point + Offset) before the lead boiler turns on. Both parameters require installer access and can be adjusted by through the control modes screen.

9. Saving Parameters

If changes are made to the parameters they can be saved by pressing the RIGHT SELECT [SAVE] key and then pressing the RIGHT SELECT [HOME] key.

Center for Energy and Environment

Pilot Condensing Boiler Control Tune-Up Program: Work Site Document

As part of a state-funded study* to pilot a controls tune-up program to save on gas energy use in buildings the ***boiler temperature and/or staging control settings have been adjusted*** by:

_________________________________ of

__________________________________ on ______________________

The control programming changes included:

☐ Boiler Temperature Settings in BAS

☐ Boiler Temperature Settings in Local or Onboard Boiler Controller

☐ Boiler Staging, Cycling, and/or Sequencing Control in BAS

☐ Boiler Staging, Cycling, and/or Sequencing Control in Local or Onboard Boiler Controller

☐ Other

____

____

If there is any apparent need for boiler control changes, please consult with the above contractor. If the tune-up adjustments caused any under-heating or other problems, the cost to have corrective boiler control adjustments made within 90 days of the initial boiler control tune-up will be covered by Center for Energy and Environment (the organization running the pilot program). Contact your above regular service contractor and/or Russ Landry of CEE at 612-327-1817 (rlandry@mncee.org) if further control adjustments are required.

If you would like additional information about the study, please contact Russ Landry or visit https://www.mncee.org/resources/projects/commercial-boiler-control-tune-ups/

Also note that this site's study participation agreement asks that other boiler system and HVAC upgrade work should be avoided during the monitoring period (boiler use through July of 2020). Where unavoidable, such work and major tenant changes are to be reported to researchers.

AERCO Sequencing					
Sequencing options are located in the Configuration, Calibration and the BST (Boiler Sequencing Technology) Menus.					
	Current Value	**Final Value**	**Range**	**Default**	**Suggested Value (if overcycling)**
BST - Operating Menu					
BST Next on VP (Valve Position/Firing Rate)*			16% - 100%	50%	*40%*
BST Deadband High*			0°F-25°F	1-5°F, depending on model	*3°F or less*
BST Deadband Low*			0°F-25°F	1-5°F, depending on model	*3°F or less*
BST Prop Band			1°F-120°F	70°F	Changing the PID values is not recommended. Contact the local AERCO boiler representative if assistance is needed
BST Integral Gain			0.00 - 2.00	1.00	
BST Derivitive Time			0.00 Min - 2.00 Min	0.0min	
	Current value for each boiler	**Final value for each boiler**	**Range**	**Default**	**Suggested Value (if overcycling)**
Calbration Menu					
Stop Level**			0% - Start Level	16%	
Start Level**			Stop Level - 40%	22%	
Configuration Menu					
Boiler Op Mode*			Parallel or Sequential	Parallel	*Parallel*
Shutoff Delay Temp**			0°F-25°F	10°F	*10°F*
Demand Offset**			0°F-25°F	10°F	*10°F*
Observe 1-2 boiler cycles or 30 minutes of boiler operation, whichever is greater, ***after*** parameters have been modified and note observations in Comments section below.					
*This option must be changed on the master boiler					
**These options must be changed on each individual boiler					

Fulton VTG Sequencing							
Sequencing Parameters and PID Settings are found under the Lead/Lag Configuration Menu. Remote Scaling settings are found under the System and Scaling Configuration Menu.							
Parameters	**Current Value**	**Final Value**	**Suggested Value based on Number of Boilers if Cycles/Hour > 1.5**			**Parameter Definitions**	**Comments**
			2 Boilers	**3 Boilers**	**4 Boilers**		
Sequencing Parameters							
Modulation Mode			*The Modulation Mode should always be in "Parallel".*			Defines how the boilers will modulate as additional boilers are enabled.	
Modulation at Next Stage CV			*40%*	*30%*	*30%*	This value defines the firing rate the lead boiler will modulate up to before the 1st Lag boiler is enabled.	
1st Lag Stage Start CV			*40%*	*30%*	*30%*	This value defines the Control Variable (CV), calculated by the PID settings, that will enable the 1st lag boiler.	
1st Lag Stage Stop CV			*10%*	*10%*	*10%*	This value defines the CV the disables the 1st Lag Boiler.	
Additional Lag Enable CV			*10%*	*10%*	*10%*	This value defines the additional CV percent that is added to the 1st Lag Stage Start CV and 1st Lag Stage Stop CV to enable/disable additional boilers.	
Lag Boiler Start Delay			*5 min.*	*5 min.*	*5 min.*	Defines the time required before a lag boiler begins firing after it has reached its enable CV.	
Lag Boiler Stop Delay			*1 min.*	*1 min.*	*1 min.*	Defines the time required before a lag boiler is disabled after it has reached its disable CV.	
Lead Boiler Start			*5°F*	*5°F*	*5°F*	Defines how many degrees below setpoint the supply temperature must be before enabling the lead boiler.	
Lead Boiler Stop			*10°F*	*10°F*	*10°F*	Defines how many degrees above setpoint the supply temperature must be before disabling the lead boiler.	
Observe 1-2 boiler cycles or 30 minutes of boiler operation, whichever is greater, ***after*** parameters have been modified and note observations in Comments.							
Parameters	**Current Value**	**Typical Value**	**Additional Notes**				**Comments**
PID Settings							
Proportional Band		20%	***Changing the PID values is not recommended. Contact the local Fulton boiler representative if assistance is needed or current values vary significantly from typical values.***				
Integral Time		60					
Derivatime Time		0					
Parameters	**Current Value**	**OA Reset Temperature Values**	**Additional Notes**				**Comments**
Remote Setpoint Scaling							
Low (4mA)			***If the Low and High scaling setpoints do not encompass the final outside air reset temperature values from the BAS, contact the Controls Contractor that performed the original calibration to modify the scaling setpoints for the new OA reset schedule.***				
High (20mA)							

Lochinvar Sequencing					
Sequencing options are located in the Control Modes Menus of the lead boiler (cascade address = 0). The control modes menu requires the Installer Access code to be entered.					
	Current Value	**Final Value**	**Suggested Value**	**Default**	**Parameter Definitions**
Control Modes					
Cascade Type			*The Cascade Type should always be in "EFF".*	EFF	This cascade method is the most efficient option. When the first boiler reaches a certain rate (default = 90%), it lowers its rate to 45% and turns on the next boiler at 45%. When the two boilers reach a 90% firing rate a third boiler is turned on and the load is split evenly among the 3.
Minimum Next Time On			5 minutes	30 seconds	Defines the minimum time delay from starting one unit until the next unit may be started
Cascade Offset			10°F	10°F	Determines how much the temperature must go above set point before the lead boiler will turn off
Cascade Differential			20°F	20°F	Determines how much the temperature must go below the turn off temperature (Set point + Offset) before the lead boiler turns on. If the building has a water to air heat pump for heating and cooling the offset and differential may need to be lowered from the suggested values shown here since heat pumps are sensitive to temperature swings.
Observe 1-2 boiler cycles or 30 minutes of boiler operation, whichever is greater, ***after*** parameters have been modified and note observations in Comments.					

Appendix C: Assumed Inputs for Cost-Effectiveness Evaluation

Description	Assumed Value	Annual escalation rate	Source
Avoided costs (Gas)			
Commodity cost ($/Dth)	$ 3.250	4.69%	Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Demand cost ($/Dth/year)	$ 0.540	4.69%	Xcel Energy 2021-23 Triennial Plan Filing (General Inputs for the Gas CIP BENCOST Model)
Variable O&M ($/Dth)	$ 0.041	4.69%	Xcel Energy 2021-23 Triennial Plan Filing (General Inputs for the Gas CIP BENCOST Model)
Environmental damage factor ($/Dth)	$ 2.070	2.30%	Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Other inputs (Gas)			
Retail gas rate ($/Dth)	$ 5.03	4.69%	Xcel Energy 2021-23 Triennial Plan Filing (General Inputs for the Gas CIP BENCOST Model)
Peak reduction factor (%)	1.00%	N/A	Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Discount Rates			
Gas Utility	5.34%	N/A	(Xcel Gas) Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Societal	3.02%	N/A	Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Gas CIP Program Information			
Participant Incentive	40% of Cost	N/A	(Xcel Gas) Commerce Decision: CIP Gas and Electric Utilities - 2021-2023 Cost-Effectiveness Review (2/11/2020, Docket Nos. G999/CIP-18-782 and E999/CIP-18-783)
Other Program and Admin Costs	1) 95% of Incentive Cost; 2) 125% of (1)	N/A	1) Average ratio of 2021-2023 Heating Program Costs to Incentive Costs (CenterPoint Energy, Xcel Energy, and Minnesota Energy Resources); 2(Assumed 25% increase for training, technical support & quality control.
Peak Reduction Gas Factor	0%	N/A	Assumed.