NAVIGANT

ILLUME cadeo bellomy research LEXICON ENERGY CONSULTING INCORPORATED

HEHE Condensing Equipment Barriers

Draft Final Report

Prepared for:

The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

Submitted by:
Navigant Consulting, Inc.
Laura Tabor
Lindsay Willman
Justin Spencer
Chris Newton
Ryan Tanner
Jane Hummer
Ken Seiden

1375 Walnut Street
Suite 200
Boulder, CO 80302

303.728.2500
navigant.com

Reference No.: 183406
Residential Study 16
March 31, 2017

TABLE OF CONTENTS

Executive Summary iii

Program Background and Study Objectives iii
Methodology iv
Results vi
Savings from Optimized Outdoor Reset (OR) Controls vi
Customer Behavior and Thermostat Use ix
Cost Analysis x
Contractor Surveys xi
Manufacturer Interviews xi
Program Implications and Conclusions xi

1. Program Background and Study Objectives 1

1.1 Research Questions 2
1.2 Structure of this Report 2

2. Methodological Approach 3

2.1 Overview 3
2.2 Site-Specific Analysis of Data from 2014 HEHE Impact Evaluation 6
2.3 Field Data Collection Approach 7
2.3.1 Initial Site Visit 8
2.3.2 Long-Term Metering for Controls-Only Sites 8
2.4 Field Data Analysis 9
2.4.1 Logger Data Processing and QC 9
2.4.2 Development of Efficiency Models 10
2.4.3 Calculation of Seasonal Efficiency Improvements 12
2.4.4 Smart Thermostat Analysis 12
2.4.5 Moderate Outdoor Reset Curve Analysis 13
2.5 Cost Analysis 13
2.6 Contractor Surveys 14
2.7 Manufacturer Interviews 14

3. Results 16

3.1 Savings from Optimized Outdoor Reset (OR) Controls 16
3.2 Site Results Case Studies 19
3.3 Customer Behavior and Thermostat Use 23
3.4 Cost Analysis 25
3.5 Contractor Surveys 26
3.5.1 Installation Practices 26
3.5.2 Barriers to efficient controls configuration 28
3.5.3 Possible solutions to improve outdoor reset control implementation 30
3.6 Manufacturer Interviews 30
3.6.1 Importance of indoor temperature feedback 31
3.6.2 Optimal start features 31
3.6.3 Barriers to advanced controls 32
3.6.4 Strategies for increasing US adoption 32

4. Program Considerations and Conclusions 33

©2017 Navigant Consulting, Inc.

4.1 Moderate outdoor reset control improvements 34
4.2 Smarter supply temperature modulation technologies 35
4.3 Simultaneous envelope and control upgrades 36

Appendix A. Detailed Methodology A-1

A.1 Site-Specific Analysis of Data from the 2014 High-Efficiency Heating Equipment (HEHE) Impact Evaluation A-1
A.2 Field Data Analysis A-2

Appendix B. Thermostat Data Visual QC B-1

B.1 Daily Setpoints and System Performance B-1
B.2 Setpoint Schedules B-2
B.3 Actual vs. Setpoint B-3
B.4 Morning Setup B-4

©2017 Navigant Consulting, Inc.

EXECUTIVE SUMMARY

Program Background and Study Objectives

The Massachusetts High-Efficiency Heating Equipment (HEHE) Rebate Program offers prescriptive rebates for the installation of new high-efficiency natural gas heating and water heating equipment. The 2014 HEHE Impact Evaluation[1] showed that condensing boilers were not achieving maximum energy savings, in part due to installation practices and controls configuration. In the 2014 study, over 50% of metered boilers showed no evidence of effectively programmed outdoor reset controls. The average operating efficiency of the metering sample (standard and combination systems) was 88.4%, almost six percentage points below the average rated new efficiency of 94%. Metered data showed that over 80% of boilers operated with high return water temperatures for the majority of heating hours, resulting in lower than rated operating efficiency. The 2014 study estimated that this difference in operating efficiency resulted in lost savings of over 60 therms per year for the average high-efficiency boiler relative to the rated efficiency.[2] While capturing the full 60 therms of missing savings is not possible in most retrofit applications in Massachusetts (standard test conditions do not reflect typical installation characteristics for a well-designed Massachusetts retrofit), the evaluation team estimated that improved outdoor reset controls might be able to recapture as much as 33 therms in first year savings by improving operating efficiency by 3%.

The primary objective of this follow-on study was to evaluate the energy savings and costs associated with installing outdoor reset controls to determine the extent to which these and other controls could mitigate the non-condensing problem identified in the earlier study. The evaluation team chose to focus the field portion of this study on outdoor reset controls because they are the most common control strategy for modulating boiler supply temperature in the U.S. Most condensing boilers ship with controls and sensors; the lack of effectively programmed controls observed in the previous study suggested that simply installing and adjusting outdoor reset controls properly could yield additional savings with relatively low effort. Other control strategies (described in more detail in sections 3.6 and 4.2) would require more expensive and invasive configuration and might not be compatible with all systems.

Navigant, along with field work partner Lexicon Energy Consulting (the evaluation team) developed the HEHE Condensing Equipment Barriers study to answer the following questions:

- What are current best practices around implementing optimized outdoor reset controls, and how often do HEHE contractors currently use these practices? What training and financial support would contractors need to implement these practices more often?
- What are the specific actions contractors need to take in order to apply optimized outdoor reset controls during condensing boiler installations?
- Do customers need to use different thermostats and thermostat settings in order to maintain expected comfort while using optimized outdoor reset controls?
- What are the costs associated with taking these actions?

[1] *High-Efficiency Heating Equipment Impact Evaluation*, Final Report, March 2015. http://ma-eeac.org/wordpress/wp-content/uploads/High-Efficiency-Heating-Equipment-Impact-Evaluation-Final-Report.pdf.

[2] As mentioned in the body of the report, capturing the full 60 therms of missing savings is not possible in most retrofit applications in Massachusetts – standard test conditions do not reflect typical installation characteristics for a well-designed Massachusetts retrofit.

©2017 Navigant Consulting, Inc.

- What is the range of savings associated with optimized outdoor reset controls?
- How often can optimized outdoor reset controls make a significant impact on savings?
- How often do customer comfort complaints arise from using an optimized outdoor reset control?
- What is the prevalence of non-controls barriers (i.e., not enough baseboard length, undersized piping) that limit the implementation of optimized outdoor reset controls?

Methodology

Figure 1 summarizes installation improvement options for homes with condensing boilers. The evaluation team sought to evaluate energy savings associated with the following controls-only solution installation improvements:

- Implementing optimized and aggressive outdoor reset control settings
- Reducing/optimizing thermostat setbacks
- Providing homeowners with instructions on how to program their thermostats
- Educating homeowners on what to expect from their boiler

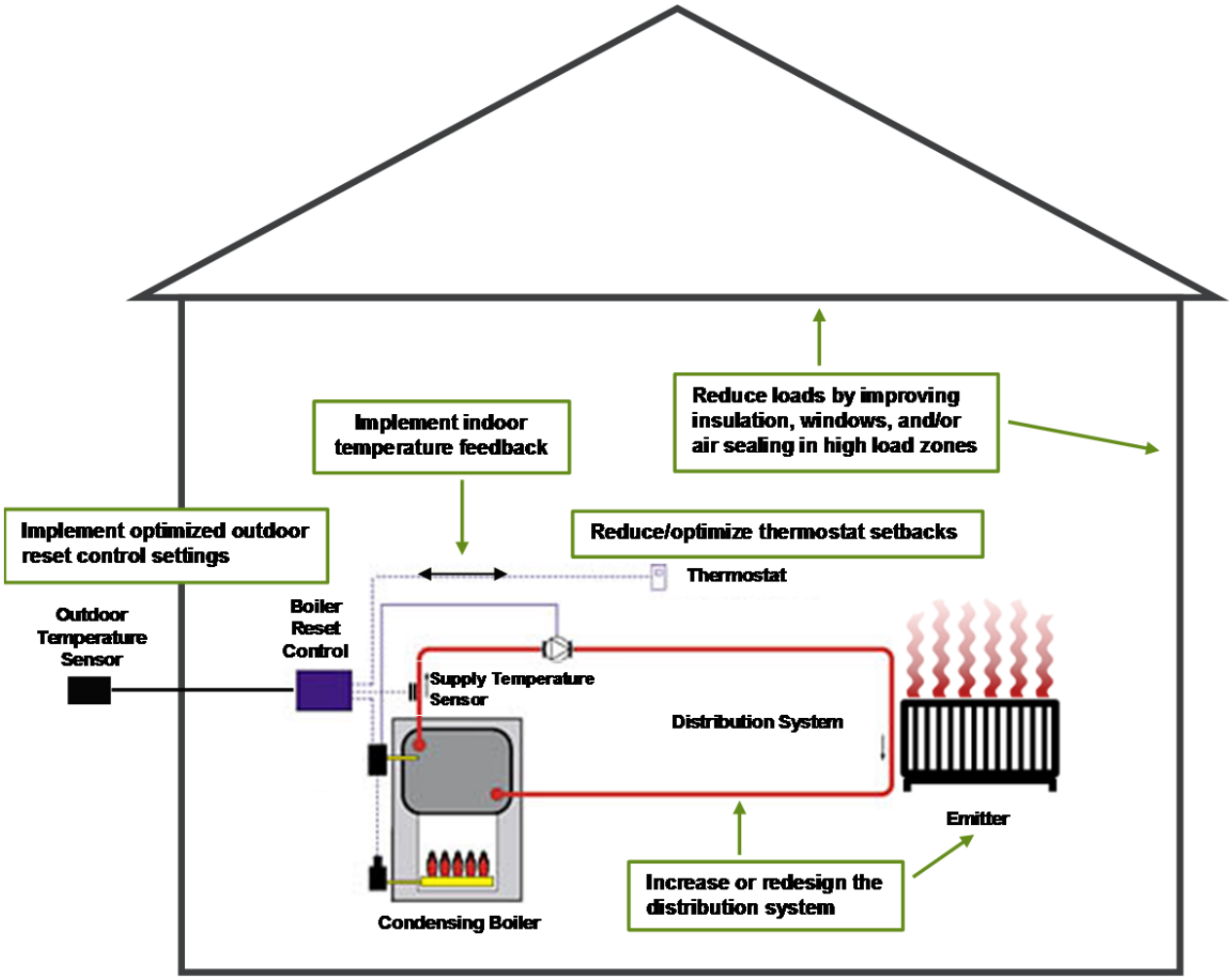
The field work for this study focused on the controls-only solutions as the lowest-cost option, while the evaluation team conducted research on costs and other barriers associated with the following non-controls distribution/envelope solution installation improvements:

- Increasing or redesigning the distribution system
- Reducing loads by improving insulation, windows, and/or air sealing in high load zones

The evaluation team also conducted interviews with boiler and controls manufacturers to better understand existing technology available in Europe and the U.S. for one additional strategy to improve boiler efficiency: ***implementing indoor temperature feedback*** to allow the boiler to reduce supply temperatures when space temperatures are close to customers' thermostat set points.

©2017 Navigant Consulting, Inc.

Figure 1. Installation Improvements for Homes with Condensing Boilers[3]



[3] Adapted from: Siegenthaler, John, P.E. PM Engineer Magazine, "Outdoor Reset Control--No Quality Hydronic System Should Be Without It." 2/27/01, Accessed 2/27/17. http://www.pmengineer.com/articles/86699-outdoor-reset-control-no-quality-hydronic-system-should-be-without-it

©2017 Navigant Consulting, Inc.

Table 1 describes the scope and rationale for each evaluation activity.

Table 1. Evaluation Activities

Activity	Rationale
Analysis of existing and secondary data (pre-analysis)	Use site-specific data to inform data collection needs and assign initial likelihood of controls-only solution viability for each site. Screen out sites with load constraints due to non-controls barriers (not enough insulation and/or distribution). Review manufacturing installation documents and related literature to confirm optimal outdoor reset control strategies. Develop site-specific optimized outdoor reset controls for controls-only sites and estimates of efficiency improvement as a result of optimized outdoor reset controls.
Installation site visits and solution viability assessment	Determine if the optimized outdoor reset control settings should be adjusted prior to implementation, install metering equipment at controls-only sites, conduct audit, and develop a list of solutions for sites that are not candidates for optimized outdoor reset controls.
Retrieval site visits	Retrieve metering equipment from controls-only solution sites.
Analysis of boiler metering data	Determine the new efficiency curves for each site and estimate the percentage improvement in performance resulting from optimized outdoor reset controls.
Cost estimates	Develop a list of solutions (emitter/envelope improvements) and cost estimates for sites that are not candidates for optimized outdoor reset controls.
Contractor surveys and analysis	Assess current installation practices, barriers to implementing optimized controls, and possible program solutions.
Manufacturer interviews	Better understand advanced control strategies for boilers used in Europe and what barriers these technologies face in the United States.

Results

The following sections summarize the findings from the controls-only metering sites, non-controls sites, and contractor surveys.

Savings from Optimized Outdoor Reset (OR) Controls

Table 2 summarizes the final disposition of the 17 metering sites.

©2017 Navigant Consulting, Inc.

Table 2. Summary of Metering Site Dispositions

Final Disposition	Number of Sites
Clean, usable data	10
Metering equipment failure	3
Customer altered outdoor reset control settings	1
Dropped out of study	2
Inexplicable data trends	1
Total metering sites	**17**

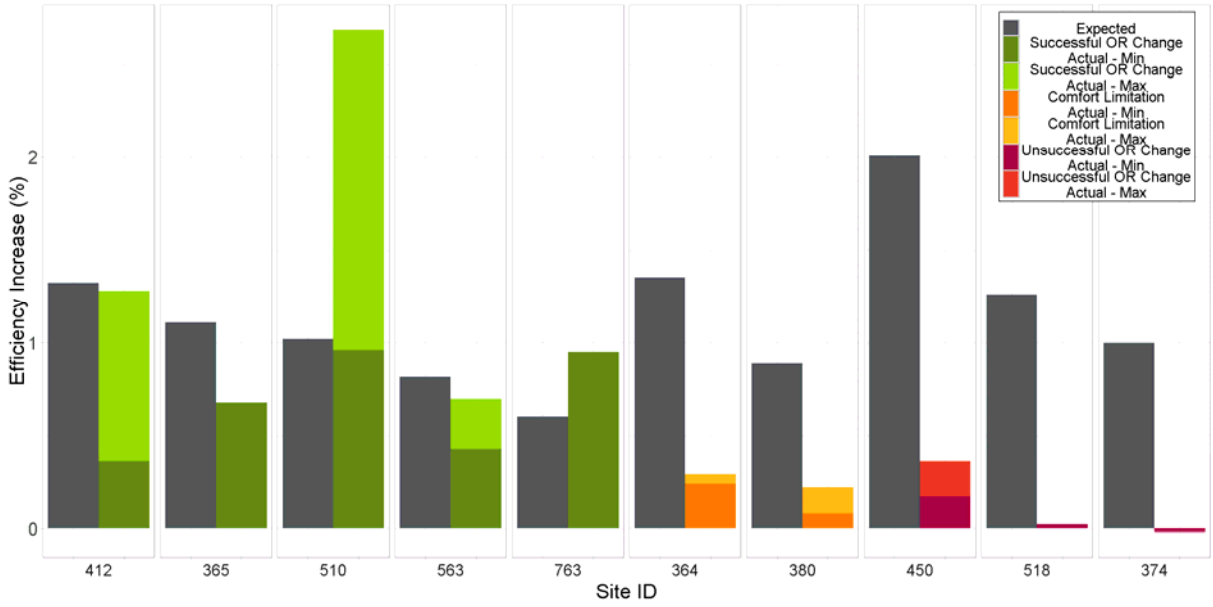
The evaluation team grouped the 10 sites with clean, usable data into three results categories:

- **Successful:** At five sites, the evaluation team implemented the reset curves as planned in the pre-analysis and boiler operation changed as predicted. These sites showed energy savings comparable to the pre-analysis estimates, although some were higher and some were lower.
- **Comfort Limitations:** At two sites, the evaluation team could not implement the planned reset curve due to comfort limitations. One site's audit showed enough capacity constraint to warrant a less aggressive curve. At the second site, the customer requested that the evaluation team adjust the settings shortly after the installation. These sites yielded lower savings.
- **Unsuccessful:** Although the evaluation team implemented the optimal reset curve at the remaining three sites, it did not work as intended. At one site, the data suggested that the outdoor air sensor may have been broken. At another site, the control changes did not stay programmed. At the third site, the boiler's minimum supply temperature of 145°F limited the reset curve effectiveness.

Figure 2 illustrates the range of efficiency increase across controls-only sites with usable data as compared to the expected savings estimated in the pre-analysis. The efficiency increase is the number of percentage points the seasonal efficiency changed due to the controls adjustments. For example, a 1.5% increase might be the change from a seasonal average efficiency of 90% to a seasonal average efficiency of 91.5%. The pre-analysis estimates of outdoor reset potential efficiency improvement for each site varied from 0.6% to 2.0%, below the rough estimate of 3% from the 2014 study.

©2017 Navigant Consulting, Inc.

Figure 2. Expected and Measured Increase in Efficiency Due to Outdoor Reset (OR) Controls[4]



Source: Navigant analysis of metered data

Table 3 provides the range of savings observed within each group, where minimum increase is the lowest individual increase for all sites in the group and maximum savings is the highest individual increase for all sites in the group. Even among the successful group, sites only achieved about a 1% increase in operating efficiency.

Table 3. Summary of Possible Saving Ranges by Group

Group	Minimum Efficiency Increase (AFUE)	Mean Efficiency Increase (AFUE + 90% Confidence Interval)	Maximum Efficiency Increase (AFUE)
Successful (n = 5)	0.36%	0.96% ± 0.47%	2.69%
Comfort limitation (n = 2)	0.08%	0.21% ± 0.36%	0.29%
Unsuccessful (n = 3)	-0.02%	0.09% ± 0.26%	0.36%
All (n = 10)	**-0.02%**	**0.55% ± 0.32%**	**2.69%**

Source: Navigant analysis of metered data

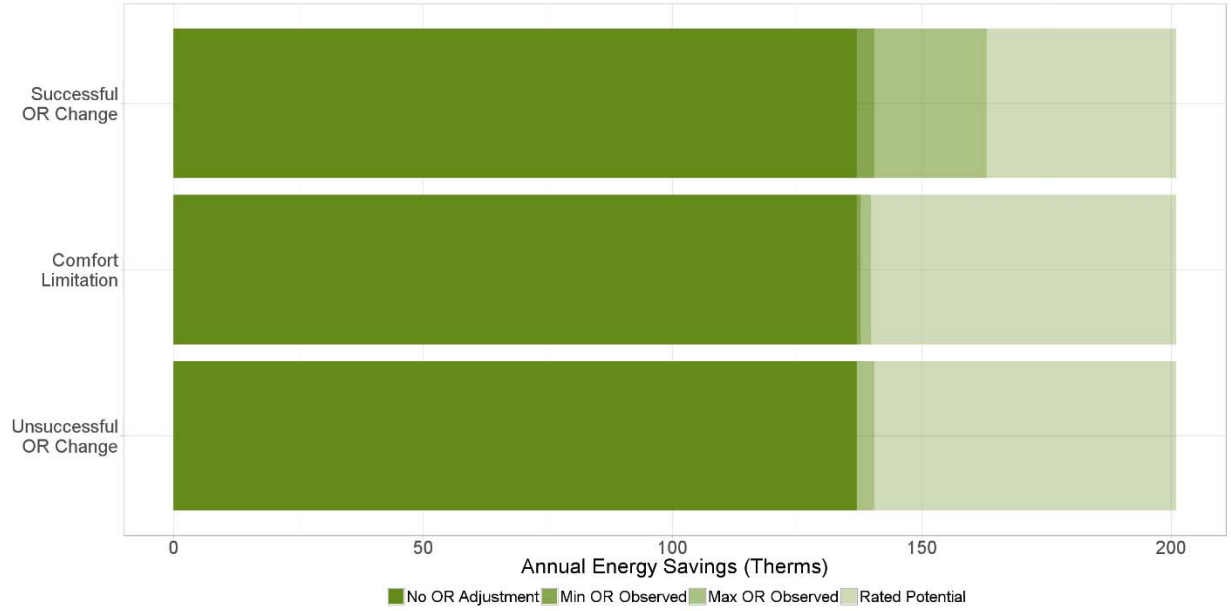
The evaluation team combined these efficiency increase estimates with savings data for 95% Annual Fuel Utilization Efficiency (AFUE) boilers to estimate the range of therm savings possible for each group. Figure 3 summarizes these findings relative to the actual and maximum theoretical therm savings for a new boiler based on a rated efficiency of 95% AFUE. As discussed further in section 4, the evaluation team does not believe that it is realistic to achieve maximum theoretical savings for condensing boiler

[4] Given the uncertainty around the efficiency curves, the evaluation team calculated results for each site using both site-specific and aggregate efficiency curves. Since the site-specific data yielded higher or lower savings than the aggregate efficiency curve depending on the site, Figure 2 presents the minimum and maximum savings for each site.

©2017 Navigant Consulting, Inc.

installations in the vast majority of retrofit installations. While the 2014 study had initially estimated that outdoor reset controls could recoup about half of this difference (33 therms), the mean value for the successful sites accounts for less than one third of this projection (9.3 therms). This demonstrates that the potential for outdoor reset controls alone to address non-condensing behavior and increase savings is limited.

Figure 3. Range of Therm Savings by Group for 95% AFUE Boilers



Source: Navigant analysis of metered data

Table 4 summarizes the possible therm savings by group.

Table 4. Summary of Possible Therm Savings by Group

Group	Minimum Savings (therms)	Mean Savings (therms, with 90% Confidence Interval)	Maximum Savings (therms)
Successful (n = 5)	3.5	9.3 ± 4.6	26.0
Comfort limitation (n = 2)	0.8	2.0 ± 3.5	2.8
Unsuccessful (n = 3)	-0.2	0.9 ± 2.5	3.5
All (n = 10)	**-0.2**	**5.3 ± 3.1**	**26.0**

Source: Navigant analysis of metered data

Customer Behavior and Thermostat Use

The evaluation team's analysis of data from the new smart thermostats installed at each of 17 metered homes revealed several findings:

- **Most customers changed their setpoint schedules.** Some customers reported issues with the smart thermostats and changed their setpoints to override the schedule, or attempted changing the schedule to keep their homes more comfortable. Other customers are just active occupants

that interact with their thermostat regularly—whenever they wake up, return home, or feel uncomfortable. In a few cases, the ramping setpoint schedules programmed during the install visit persisted throughout the study but most customers overrode them within a few days. Due to the small sample size of this study, the evaluation team did not analyze the difference in savings between sites where customers did and did not override their ramping schedules.

- **If customers have setbacks, a ramping schedule should be implemented in order to maintain expected comfort while using optimized outdoor reset controls.** In the two cases where a ramping schedule was programmed and remained in place for the entire study, the setpoints were met quickly. At four sites, the heating system responded too slowly, and the ramping schedule was either too fast or the night setback was too large for the boiler to recover the setpoint in the morning. Six participants noted a slow response time for their heating system, including two participants that dropped from the study due to comfort constraints.
- **Smart thermostats need to be smarter.** A truly smart thermostat would learn how long the system takes to respond; anticipate cold outdoor temperatures and warm setpoints; and start the morning warmup early enough to meet the morning setpoint. The basic ramping schedules and setbacks of the thermostats in this study were not tuned well enough to each individual home or boiler and heating system; thus, some worked but most occupants overrode them.
- **Given the small sample of homes, the evaluation team cannot say if there are any definitive correlations between customer satisfaction, savings, and interaction with thermostats.** Of those who reported being satisfied or happy with their system performance during the study, roughly equal proportions were regular thermostat users and infrequent thermostat users. Of those who had issues, the proportions of regular and infrequent users were also similar. These non-trends were the same when grouping customers by savings and comparing to thermostat use or satisfaction with system performance.

Cost Analysis

Costs and energy savings from outdoor reset controls are highly dependent on site-specific conditions such as existing insulation levels and the size of the home. Therefore, the most cost-effective sites likely meet one of the following requirements:

- Do not require envelope or distribution improvements and have an outdoor reset sensor installed but not programmed
- Only require the installation and programming of an outdoor reset sensor

Contractor estimates for the cost of installing an outdoor reset sensor varied, with 57% of contractors reporting costs between $100 and $500, and 27% noting that the sensor is included with the initial installation of the boiler.

Using the observed natural gas savings from this study[5] as well as the residential gas rate during the study period, the evaluation team found that homeowners with optimized outdoor reset controls might expect average savings of about $5 per year. This analysis does not account for additional energy savings resulting from envelope improvements.

[5] Based on mean observed natural gas savings from all 10 field sites that were candidates for optimized outdoor reset controls.

©2017 Navigant Consulting, Inc.

Energy savings, cost requirements, and overall cost-effectiveness for sites requiring envelope and distribution improvements are very site-specific. The cost ranges from $2,500 to $6,000 reflect the variety of site conditions—from sites requiring small reductions in the heating load to sites requiring substantial improvements and load reductions before it could benefit from outdoor reset controls.

The results of the analysis presented in this report depend on the envelope and emitter characteristics identified during the first site visit. Although the evaluation team spent a considerable amount of time on the zone-level audit for both metering and non-controls sites, it was not feasible to fully inspect insulation levels and emitter capacities without conducting a more detailed audit. The estimated insulation levels and emitter output directly affected the cost analysis, potential for optimized outdoor reset controls at each non-controls site, and the outdoor reset curve programmed at each metering site. This complexity combined with high cost indicates that distribution upgrades are not a realistic approach for programs to improve condensing boiler efficiency.

Contractor Surveys

The contractor surveys yielded the following findings:

- Contractors vary outdoor reset approach depending on home and boiler characteristics; this indicates they understand the technical context for properly programming outdoor reset controls even if metering data indicate many of them ultimately program conservative control settings.
- The top two barriers to installing and programming outdoor reset controls were incompatibility with thermostat setbacks and poorly managed customer expectations. Both of these issues relate to customer behavior in addition to technical limitations.
- Contractors overwhelmingly looked to programs for customer education support rather than further technical training for themselves.

Manufacturer Interviews

The boiler and controls manufacturer interviews led to the following key findings:

- Incorporating indoor temperature data, especially from multiple zones, may be more important than outdoor reset controls—but the evaluation team has not been able to identify any studies documenting energy savings from this strategy.
- Two companies offer optimal start features for boilers in the U.S.—Bosch and Tekmar—and both use proprietary technology to communicate with boilers.
- The emphasis on outdoor reset in the U.S., combined with the small size of the U.S. boiler market, has limited innovation. A combination of installer education and regulatory pressure could improve adoption of indoor temperature feedback and optimal start technology, but manufacturers indicated that they did not have plans to introduce new OpenTherm compatible products in the U.S. in the near future.

Program Implications and Conclusions

The primary finding from this study is that changing the outdoor reset curve does produce savings, but the savings are lower than anticipated**.** The evaluation team observed that sites with significant changes in the outdoor reset curve could produce a 0.5%-1.5% improvement in the efficiency of the condensing

©2017 Navigant Consulting, Inc.

boiler, which results in approximately a 5%-15% improvement in measure savings or 5 to 15 therms. Considering most high-efficiency boilers come with outdoor reset controls, capturing these savings could be relatively low-cost for many homes, but even this may not be cost-effective and it is clear these controls alone are not a silver bullet for recouping savings for high-efficiency boilers

Even capturing the maximum potential savings from outdoor reset controls appears to leave significant therm savings on the table: a 1% improvement in operating efficiency would only account for about 10 therms of the roughly 60 therm difference between rated efficiency and the operating efficiency found in the 2014 metering study. This means 92% of the savings difference between current and rated operating efficiency remain unattained. However, due to the typical operating conditions of condensing boilers in retrofit applications, the evaluation team does not believe it is realistic for these units to operate at rated efficiency for the entire heating season except in rare cases with significant envelope improvements—walls, ceilings and windows—in addition to controls improvements. Most boilers also serve indirect hot water loads, where controls dictate the highest supply temperatures possible to meet hot water demands quickly. Furthermore, the majority of the heating load occurs in cold temperatures when most homes require higher supply temperatures.

There are three strategies the Program Administrators (PAs) could pursue to assess what realistic savings potential remains for high-efficiency boilers. The research team offers the following recommendations based on the relevant findings for each strategy.

- **Consider promoting moderate outdoor reset control improvements across all high-efficiency installations**.
    - **Finding 1**: The evaluation team estimates that a moderate outdoor reset curve with temperatures of 180°F supply at 0°F outdoors and 120°F supply at 50°F outdoors would produce an average efficiency improvement of 0.3% relative to the typical operation observed in the 2014 study. While the savings are small, this could be a simple change for contractors to make in standard installations.
    - **Recommendation 1**: The PAs should run cost-effectiveness calculations based on a conservative savings estimate of 3 therms and incremental cost of $250 for controls programming only.
    - **Recommendation 2**: If screening this measure demonstrates it is cost-effective, the PAs should consider developing program offerings aimed at increasing the prevalence of more efficient outdoor reset control settings and proper installation of outdoor sensors.
- **Consider working with regional partners to research and potentially promote smarter supply temperature modulation technologies**.
    - **Finding 2**: The evaluation team found two manufacturers in the U.S. that currently offer control systems capable of modulating supply temperature based on indoor temperature feedback and outdoor temperature—Tekmar and Bosch.
    - **Finding 3**: The U.S. boiler market is relatively small and these offerings are not likely to take off without regulatory or program pressure.
    - **Finding 4**: The evaluation team did not identify any studies with energy savings estimates for implementing advanced supply temperature modulation technologies.
    - **Recommendation 3**: The PAs should conduct a high-level screening of these technologies assuming an optimistic 3% efficiency increase (30 therms) and cost of $750.

©2017 Navigant Consulting, Inc.

  - **Recommendation 4**: If the screening shows that this could be cost-effective, the evaluation team recommends conducting additional evaluation literature research on the savings potential of these technologies.
  - **Consideration 1**: Even a pilot evaluation of these technologies could be expensive, and the evaluation team also suggests the PAs consider a small evaluation study to gauge interest among potential state or utility partners in the Northeast in studying and promoting these products.

- **Consider a study to assess savings potential for simultaneous envelope and control improvements.**
  - **Finding 5:** The best scenario for improving condensing boiler efficiency is to reduce the load before adjusting controls, whether outdoor reset or other supply temperature modulation technology.
  - **Recommendation 5:** The PAs should consider a research study to evaluate the potential for a pilot program aimed at homes with condensing boilers that would offer detailed audits, completion of all necessary weatherization upgrades and adjustment of outdoor reset control settings once these upgrades are completed. Metering participants' boilers before and after upgrades and control setting adjustments could determine whether improved boiler efficiency provides a boost to envelope savings.

Section 4 describes these options in more detail along with the technical, delivery and customer-side barriers that they face.

©2017 Navigant Consulting, Inc.

1. PROGRAM BACKGROUND AND STUDY OBJECTIVES

The Massachusetts High-Efficiency Heating Equipment (HEHE) Rebate Program offers prescriptive rebates for the installation of new high-efficiency natural gas heating and water heating equipment. The 2014 HEHE Impact Evaluation[6] showed that condensing boilers are not achieving maximum energy savings, in part due to installation practices and controls configuration. In the 2014 study, over 50% of metered boilers showed no evidence of effectively programmed outdoor reset controls. The average operating efficiency of the metering sample (standard and combination systems) was 88.4%, almost six percentage points below the average rated new efficiency of 94%. Metered data showed that over 80% of boilers operated with high return water temperatures for the majority of heating hours, resulting in lower than rated operating efficiency: efficiency ratings for residential condensing boilers are based on tests using 120°F return water, conditions which are unrealistic for large portions of the load met in typical residential operation (cold outdoor temperatures and domestic hot water loads). The 2014 study estimated that this difference in operating efficiency resulted in lost savings of over 60 therms per year for the average high-efficiency boiler relative to rated efficiency. Based on high-level calculations, the evaluation team estimated that improved outdoor reset controls might be able to recapture as much as 33 therms in first year savings by improving operating efficiency by 3%. These results suggested that the use of optimized outdoor reset controls in combination with better thermostat settings and customer education could increase realized savings.[7]

This follow-on study field tested the proposed solutions and included deeper site-specific analysis of existing data from the 2014 HEHE Impact Evaluation, additional field data collection and metering, and contractor surveys. The objectives of this study included the following:

- **Estimate the savings associated with specific controls-only outdoor reset improvements** to condensing boiler installations at a subset of homes from the 2014 evaluation
- **Estimate the costs associated with controls-only improvements** as well as distribution design and/or envelope improvements
- **Estimate the share of homes in which a controls-only solution** or distribution/envelope approach would improve boiler efficiency
- **Explore possible program mechanisms to incent greater adoption** of improved condensing boiler installation practices
- **Understand other barriers to adoption and quality installation** of condensing boilers

The evaluation team chose to focus on outdoor reset controls because they are the most common control strategy for modulating boiler supply temperature in the U.S. Most condensing boilers ship with controls

[6] *High Efficiency Heating Equipment Impact Evaluation*, Final Report, March 2015. http://ma-eeac.org/wordpress/wp-content/uploads/High-Efficiency-Heating-Equipment-Impact-Evaluation-Final-Report.pdf.

[7] With an outdoor reset control, the condensing boiler attempts to deliver a supply temperature that varies according to outdoor temperature and that matches the load. As outdoor temperatures rise, the boiler lowers its supply temperature, resulting in lower return water temperatures, increased condensing, and increased efficiency. However, because condensing boiler systems are more closely matched to the loads, they are less able to respond to large temperature setbacks that customers may be setting on their thermostats (US Department of Energy National Renewable Energy Laboratory, Measure Guideline: Condensing Boilers – Control Strategies for Optimizing Performance and Comfort in Residential Applications, May 2013, available at http://www.nrel.gov/docs/fy13osti/57826.pdf).

©2017 Navigant Consulting, Inc.

and sensors; the lack of effectively programmed controls observed in the previous study suggested that simply installing and adjusting existing controls properly could yield additional savings with relatively low effort. Other control strategies (described in more detail in sections 3.6 and 4.2) would require more expensive and invasive configuration and might not be compatible with all systems.

1.1 Research Questions

This study sought to answer the following research questions:

- What are current best practices around implementing optimized outdoor reset controls, and how often do HEHE contractors currently use these practices? What training and financial support would contractors need to implement these practices more often?
- What are the specific actions contractors need to take in order to apply optimized outdoor reset controls during condensing boiler installations?
- Do customers need to use different thermostats and thermostat settings in order to maintain expected comfort while using optimized outdoor reset controls?
- What are the costs associated with taking these actions?
- What is the range of savings associated with optimized outdoor reset controls?
- How often can optimized outdoor reset controls make a significant impact on savings?
- How often do customer comfort complaints arise from using an optimized outdoor reset control?
- What is the prevalence of non-controls barriers (i.e., not enough baseboard length, undersized piping) that limit the implementation of optimized outdoor reset controls?

1.2 Structure of this Report

The remainder of this report is organized into three sections. Section 2 contains the study methodology and describes the field data collection and analysis approaches. Section 3 presents the results of the savings and cost analyses. And, Section 4 provides considerations for program offerings and the evaluation team's conclusions.

Appendix A provides additional methodological details, and Appendix B contains information related to the Wi-Fi thermostat data collected for a subset of study participants.

©2017 Navigant Consulting, Inc.

2. METHODOLOGICAL APPROACH

2.1 Overview

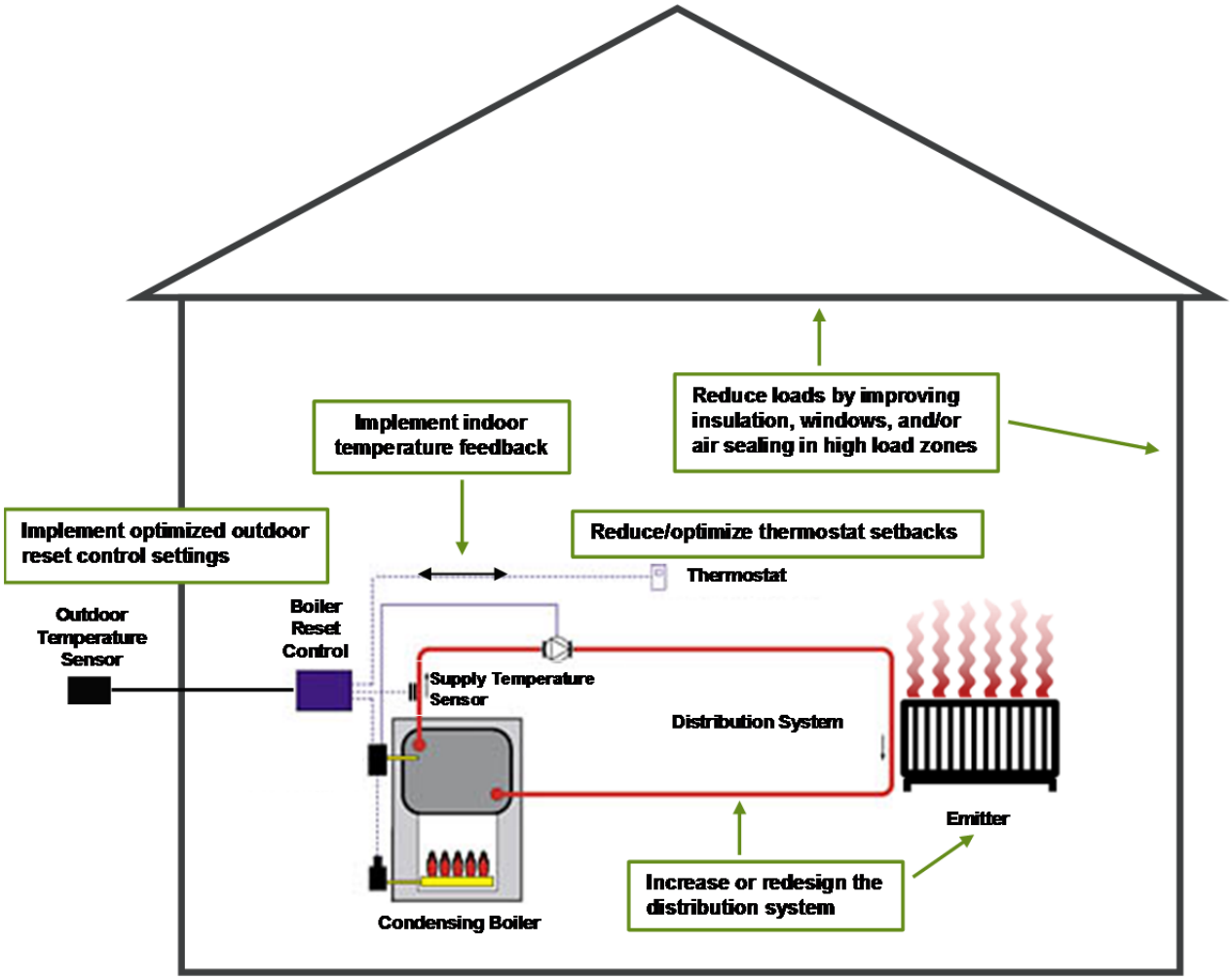
Figure 4 summarizes installation improvement options for homes with condensing boilers. Throughout this report, the evaluation team refers to two types of installation improvements: controls-only solutions and non-controls solutions:

- Controls-only solutions encompass the following:
    - Implementing optimized and aggressive outdoor reset control settings
    - Reducing/optimizing thermostat setbacks
    - Providing homeowners with instructions on how to program their thermostats
    - Educating homeowners on what to expect from their boiler
- Distribution/envelope solutions require more extensive energy efficiency measures, including the following:
    - Increasing or redesigning the distribution system
    - Reducing loads by improving insulation, windows, and/or air sealing in high load zones

The evaluation team also conducted interviews with boiler and controls manufacturers to better understand existing technology available in Europe and the U.S. for one additional strategy to improve boiler efficiency: ***implementing indoor temperature feedback*** to allow the boiler to reduce supply temperatures when space temperatures are close to customers' thermostat set points.

©2017 Navigant Consulting, Inc.

Figure 4. Installation Improvements for Homes with Condensing Boilers[8]



The field work in this study focused on controls-only solutions as the lowest-cost option, while the evaluation team conducted research on costs and other barriers associated with distribution/envelope solutions. The field data collection and analysis included the following components:

1. **Analysis of existing and secondary data (pre-analysis):** The evaluation team analyzed data collected during the 2014 HEHE Impact Evaluation and other literature regarding optimal/best practices associated with outdoor reset controls to prepare for the field study. Prior to the site visits, the evaluation team used site-specific data to inform data collection needs and assign an initial prediction of whether optimized outdoor reset controls would be feasible for each site or if non-controls solutions would be required. For the sites where a controls-only solution was deemed feasible, the evaluation team developed site-specific optimized outdoor reset control settings.

[8] Adapted from: Siegenthaler, John, P.E. PM Engineer Magazine, "Outdoor Reset Control--No Quality Hydronic System Should Be Without It." 2/27/01, Accessed 2/27/17. http://www.pmengineer.com/articles/86699-outdoor-reset-control-no-quality-hydronic-system-should-be-without-it

©2017 Navigant Consulting, Inc.

2. **Installation site visits:** During the first visit to each site, the evaluation team performed zone-level equipment sizing calculations using a tablet-based Manual J tool[9] and used a standard protocol to determine whether or not to adjust the outdoor reset control settings determined through the pre-analysis prior to implementation. For sites where the Manual J audit indicated that the pre-analysis control settings would likely result in comfort issues, the optimized control settings were adjusted to be less aggressive.
    - For controls-only sites, field engineers implemented the controls strategy along with the necessary metering and monitoring equipment to estimate savings from improved supply and return water temperatures. The evaluation team also installed wireless communicating thermostats that allow ramping operation and provided homeowners with simple instructions showing them how to program their thermostats and shift ramping periods, if necessary, to address a comfort issue.
    - For sites that were not candidates for optimized outdoor reset controls, the evaluation team conducted an audit to develop a list of improvements needed before the site could benefit from optimized control settings.
3. **Retrieval site visits:** During the second visit to each site, the evaluation team collected all removable study equipment from the controls-only sites and conducted a brief customer satisfaction/engagement survey.
4. **Analysis of boiler metering data:** For sites with controls-only solutions, the evaluation team analyzed the metered data to estimate the improvement in performance.
5. **Cost estimates:** For sites that were not candidates for optimized outdoor reset controls, the evaluation team conducted research on costs for the improvements, including distribution and envelope solutions.
6. **Contractor surveys and analysis:** In addition to the field study, the evaluation team conducted surveys with contractors to determine typical practices and barriers to improved installation practices.
7. **Manufacturer Interviews:** After reviewing the initial study results, the evaluation team and the PAs decided to conduct additional research on “smarter” boiler control technologies, including the OpenTherm communication protocol. Traditional thermostat communication protocols allow thermostats to communicate basic information to boilers and other heating systems, namely whether there is a call for heat. The OpenTherm communication protocol has gained popularity in Europe and allows any thermostat and boiler with the protocol installed to communicate additional information, such as how to modulate supply water temperature based on outdoor conditions and setpoint schedule.[10] The evaluation team interviewed boiler and controls manufacturers as well as a representative from the OpenTherm Association.

[9] Carmel HVAC ResLoad-J software: used to calculate peak heating loads per ACCA Manual J for each zone in a home

[10] “Why OpenTherm?” OpenTherm Association. https://www.opentherm.eu/why-opentherm/ Accessed October 27, 2016.

©2017 Navigant Consulting, Inc.

Table 5 describes the scope and rationale for each of these activities.

Table 5. Evaluation Activities

Activity	Rationale
Analysis of existing and secondary data (pre-analysis)	Use site-specific data to inform data collection needs and assign initial likelihood of controls-only solution viability for each site. Screen out sites with load constraints due to non-controls barriers (not enough insulation and/or distribution). Review manufacturing installation documents and related literature to confirm optimal outdoor reset control strategies. Develop site-specific optimized outdoor reset controls for controls-only sites.
Installation site visits and solution viability assessment	Determine if the optimized outdoor reset control settings should be adjusted prior to implementation, install metering equipment at controls-only sites, conduct audit, and develop a list of solutions for sites that are not candidates for optimized outdoor reset controls.
Retrieval site visits	Retrieve metering equipment from controls-only solution sites.
Analysis of boiler metering data	Determine the new efficiency curves for each site and estimate the percentage improvement in performance resulting from optimized outdoor reset controls.
Cost estimates	Develop a list of solutions (emitter/envelope improvements) and cost estimates for sites that are not candidates for optimized outdoor reset controls.
Contractor surveys and analysis	Assess current installation practices, barriers to implementing optimized controls, and possible program solutions.
Manufacturer interviews	Better understand advanced control strategies for boilers used in Europe and what barriers these technologies face in the United States.

2.2 Site-Specific Analysis of Data from 2014 HEHE Impact Evaluation

Prior to this field study, the evaluation team re-analyzed data from the 2014 study to determine which sites would be good candidates for inclusion in this study and what the optimal outdoor reset curve was for each of the sites where a controls-only solution was feasible. Metered data showed that over 80% of boilers operated with high return water temperatures for the majority of heating hours, resulting in lower than rated operating efficiency.

The evaluation team screened out sites that did not appear to have reset controls installed (19), appeared to have at least one zone in which the load was not being adequately met on the coldest days (4), or already showed strong condensing behavior at outdoor temperatures of 30°F or below (5).[11] For the remaining 32 sites, the evaluation team used logged supply temperatures from 2014 to develop an estimate of the current outdoor reset curve programmed to each boiler. The evaluation team then used the observed outdoor reset curve to derive a recommended initial optimal and aggressive reset curve that could provide increased efficiency while maintaining customer comfort. These curves assumed that the

[11] The evaluation team concluded that the sites which already showed condensing behavior above 30°F did not have potential for significant improvement due to outdoor reset control changes.

©2017 Navigant Consulting, Inc.

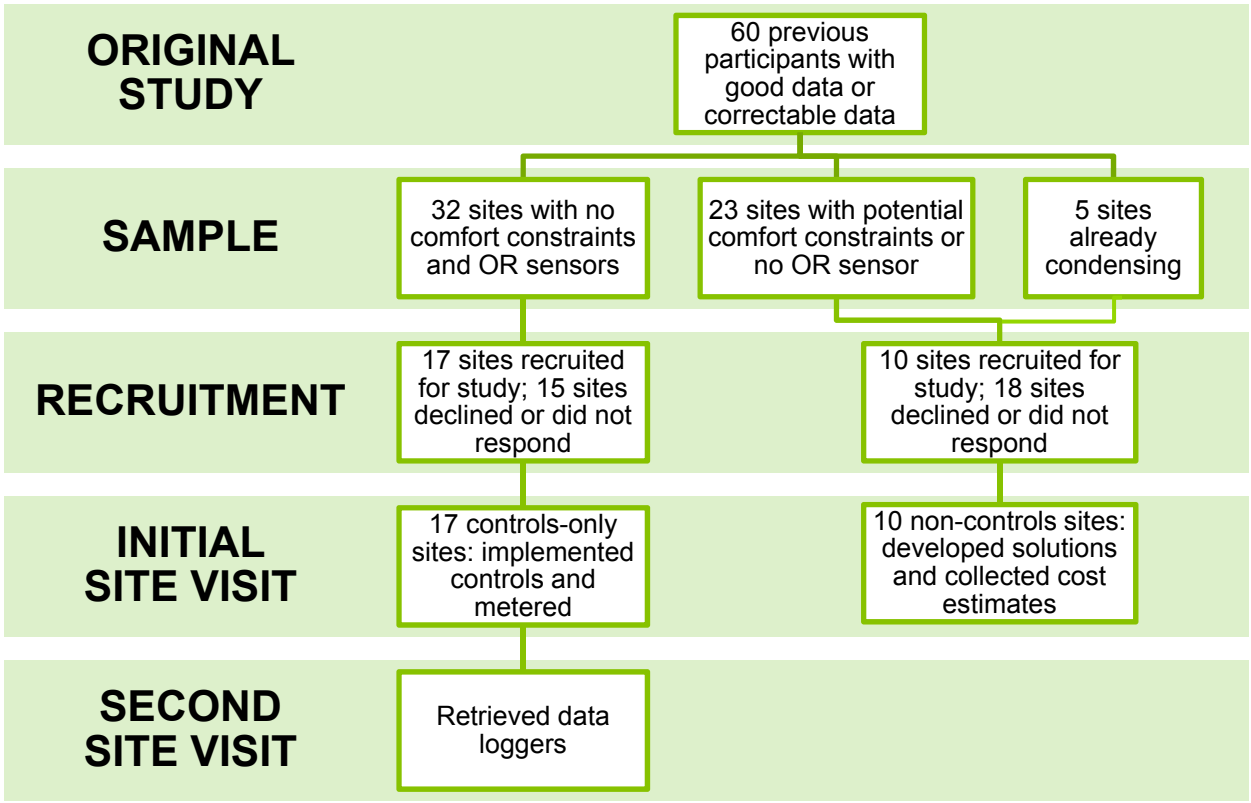
total heating load varies linearly with the temperature difference between indoors and outdoors and translated the load to a required supply water temperature using a standard ASHRAE radiator capacity curve.

The evaluation team used the optimal reset curves to determine a predicted efficiency increase for each site using the model of efficiency as a function of the return water temperature from the 2014 study. The evaluation team then used the predicted seasonal efficiency increase for each site to prioritize sites for the new study and to remove any sites that did not show much potential for improvement from optimized outdoor reset controls.

2.3 Field Data Collection Approach

As illustrated in Figure 5, the evaluation team found 60 residences from the 2014 study that had the data needed to be included in this study. Of those 60 homes, 32 had outdoor reset sensors installed and did not appear to have comfort constraints. Of this sample, the evaluation team implemented controls-only solutions and conducted additional metering at 17 sites. The 10 non-controls sites were selected from the remainder of the 60 site sample, which included sites that either did not have outdoor reset sensors installed or had potential comfort constraints. The non-controls sites received an initial site visit where the evaluation team collected data to support the cost analyses associated with distribution and envelope solutions. All participants received a $50 gift card at each site visit.

Figure 5. Field Data Collection Outline



©2017 Navigant Consulting, Inc.

2.3.1 Initial Site Visit

For all sites, the evaluation team performed an initial site visit audit to collect zone-level envelope and emitter characteristics. For controls-only sites, these characteristics determined if the evaluation team should adjust the optimized outdoor reset control settings prior to implementation. For non-controls sites, the evaluation team used the audit results to identify possible emitter or envelope improvements needed before the site could benefit from outdoor reset controls. The audit included the following on-site activities:

- Collect zone-level housing details: square footage, insulation levels, window types and quantities, wall construction, and distribution equipment type
- Gather emitter (baseboard) characteristics including length, output, etc.
- Perform zone-level equipment sizing calculations
- Record thermostat schedules and homeowner occupancy and usage characteristics

2.3.2 Long-Term Metering for Controls-Only Sites

The evaluation team implemented controls solutions at the 17 participating sites that showed controls-only savings potential in the site-specific 2014 data analysis. As part of the initial site visit, the evaluation team collected emitter characteristics and performed zone-level equipment sizing calculations, which determined if the evaluation team should adjust the optimized outdoor reset control settings prior to implementation.

At four of the 17 controls-only sites, the Manual J audit results indicated that the planned outdoor reset control settings would likely result in comfort issues, so the evaluation team adjusted the settings to be less aggressive. For these sites, energy savings were still expected, although somewhat less than the initial analysis suggested.[12] At all 17 sites, the evaluation team implemented the controls strategy as determined through the site-specific 2014 data analysis and initial on-site audit (i.e., optimized the outdoor reset control settings and programming) and installed metering equipment to:

- Monitor operation of the boiler pump and gas valve status using motor loggers
- Monitor the supply and return hot water temperatures
- Use additional temperature or pump motor loggers to determine when the boiler is serving a hot water load (if the unit has an indirect water heater attached)

The metering approach followed the protocol used in the 2014 evaluation and lasted approximately 2 months between February and April 2016, thus spanning a range of outdoor winter temperatures.[13] The evaluation team also installed wireless communicating thermostats in up to three zones per home. For homes with more than three zones, field staff installed thermostats in the three most utilized zones according to feedback from the homeowners. The evaluation team programmed the wireless thermostats based on the programming of the original thermostats. If the original thermostat did not have a temperature setback, the evaluation team did not implement a setback schedule. For thermostats with

[12] Ultimately, of these four sites, one site still had comfort limitations, one was successful, and two dropped from the study.

[13] The monitoring period was shorter than that for the 2014 study and was also milder, with the exception of the record cold weekend at the beginning of February 2016. In all cases, there was sufficient weather in the 20-50°F range where the bulk of outdoor reset savings occur to accurately assess the impact of changing the control settings. Results were extrapolated to a full typical winter.

©2017 Navigant Consulting, Inc.

setbacks, the evaluation team implemented a ramping schedule that began a warm-up well in advance of a scheduled temperature change in order to deliver expected comfort when returning from setbacks. For setback settings, the evaluation team programmed the temperature setpoints to match those indicated by the homeowner and original thermostat and only changed the timing of the setpoints. The evaluation team provided homeowners with instructions on how to program their thermostats and shift ramping periods. Field staff installed an Ecobee thermostat at one site (the only one with wiring that could provide power to the thermostat) and Building 36 thermostats at the rest of the metering sites.

Throughout the metering period, the evaluation team collected data from these thermostats and monitored how the homeowners were using them. In addition to using the data in the energy savings analysis, the data also served as an important customer engagement tool by providing an indication of which homeowners were experiencing comfort issues due to the temperature reaching the setpoint more slowly than expected. Customers complaining about comfort or heating quality were given the option to either have their controls adjusted or drop from the study.

At the end of the study, the evaluation team collected logging equipment from each site, gave customers the option of keeping or re-setting their new outdoor reset control settings, and conducted a short customer satisfaction interview to learn about participants' experience with both the wireless communicating thermostats and the reset control settings.

2.4 Field Data Analysis

The evaluation team analyzed the field data in three phases:

1. Logger data processing and quality control (QC)
2. Development of efficiency models
3. Calculation of seasonal efficiency improvements

The following sections describe each phase and further detail is provided in Appendix A.

2.4.1 *Logger Data Processing and QC*

To ensure the quality of the final analysis, the evaluation team conducted an extensive data cleaning and QC process. First, the evaluation team plotted data from each individual logger file and visually inspected it for missing and/or bad data. Once the evaluation team checked the individual logger files, they combined data from all of the different loggers for each site and merged it with the data collected in the 2014 study.

Next, the evaluation team adjusted the supply and return water temperatures from the 2014 study to compensate for the differences in temperature sensors and installation characteristics between the two studies. The evaluation team derived this adjustment from the observed temperatures during domestic hot water (DHW) operation, which should be independent of the programmed outdoor reset curve and thus should be the same in the two studies. Where the observed domestic hot water temperatures did not match, the evaluation team adjusted the data from the 2014 study to be comparable to the data from the current study.

©2017 Navigant Consulting, Inc.

Since the analysis was highly dependent on the synchronization of data from different data loggers, the evaluation team also investigated logger time drift[14] and made adjustments where it was found. In particular, the evaluation team found that most of the loggers collecting supply and return temperature data had some degree of time drift. The evaluation team adjusted the data from those loggers by examining the difference between the time of the boiler gas valve opening and the corresponding time that the supply temperature began to increase. Without logger time drift, this time difference would be roughly constant; where it changed significantly over the course of the study period, it indicated time drift which the evaluation team corrected.

The final QC step involved making site-level QC plots of the logged data for each site, to check for overall alignment between the different loggers and any suspect operation. Based on these QC checks and customer dropouts, the evaluation team dropped seven sites from the study:

- Two sites were cancelled due to customer complaints.
- Three sites experienced failures of one of the key loggers needed for the analysis. The analysis for this study hinged on the data from certain loggers (in particular, those on the gas valve and boiler supply and return water pipes); thus, the failure of a single logger could result in the data for an entire site being unusable. Logger failures are an unfortunate yet unavoidable part of end-use metering, and this failure rate is similar to the 2014 study and other comparable studies performed by the evaluation team.
- Two sites had suspect data that the evaluation team could not explain: one site had many periods where the boiler was on (gas valve was open) but supply/return temperatures were decreasing (when they were expected to increase), and the other had return water temperatures that were almost identical to the corresponding supply water temperatures.

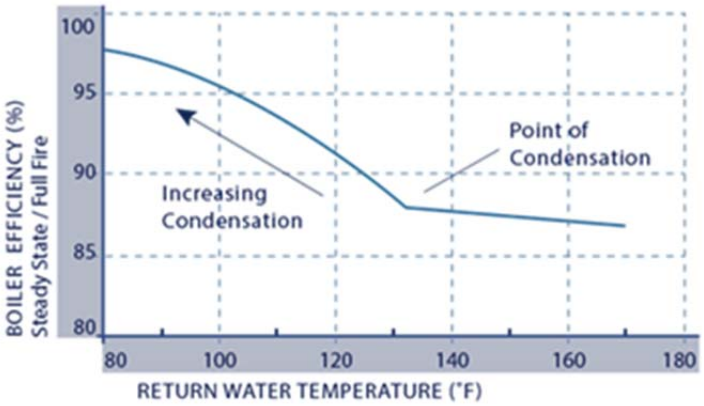
2.4.2 *Development of Efficiency Models*

Once the data cleaning and QC work was completed, the evaluation team developed updated efficiency models relating return water temperature to overall boiler efficiency using both the logged data and data from spot measurements of efficiency and gas consumption performed during the site visits. For context, Figure 6 shows a generic condensing boiler efficiency curve.

[14] In certain instances, the internal clock of the data logger was slightly faster or slower than actual clock time. This resulted in the data timestamps being offset from clock time, with that offset growing steadily larger over the logged period.

©2017 Navigant Consulting, Inc.

Figure 6. Condensing Boiler Efficiency Curve[15]



The purpose of adjusting the boiler outdoor reset curve is to reduce the supply water temperature such that the corresponding return water temperature is low enough to result in condensation; thus, the boiler operates in the higher efficiency portion of the curve more of the time. However, the efficiency curve varies with the design of the boiler. As such, the evaluation team gathered spot measurement data at each site to model the custom efficiency curves for each boiler.

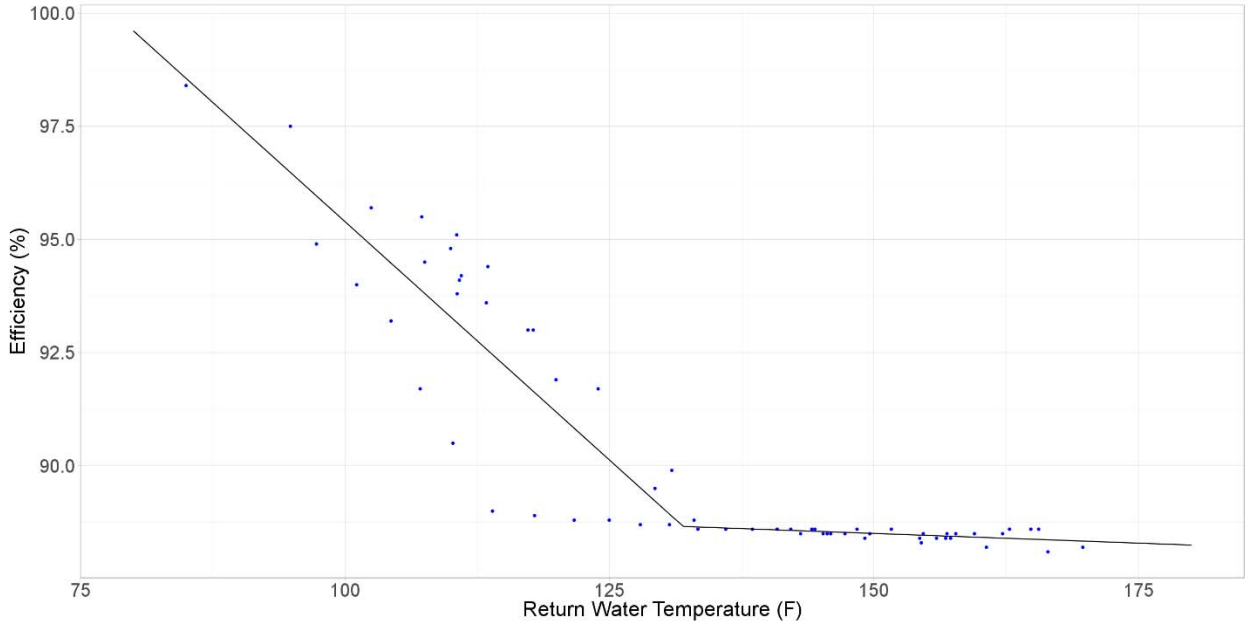
The evaluation team took several sets of spot measurements at each site: one during the installation visit and two during the retrieval visit (standard and DHW operation). The evaluation team combined the data from all spot measurements and adjusted the efficiency data based on visual QC to ensure that it lined up with the temperature data and the efficiency measurements were consistent across the different sets of spot measurements. The evaluation team discarded a small subset of data that appeared unreliable.

Finally, the evaluation team determined which sites had sufficient data for a site-specific efficiency model by looking for the segmented linear shape that is characteristic of a condensing boiler efficiency curve. The evaluation team then created segmented linear models (SLMs) of efficiency as a function of return water temperature for each site with sufficient data, as well as an aggregate model using the data from all sites and data from the 2014 study. An example of spot measurements and the resulting efficiency model for one site is shown in Figure 7.

[15] Image source: Shen, Lester. Home Energy Pros, "High Efficiency Should Be a Drain: A Closer Look at Condensing Boilers." Blog post 10/29/13, Accessed 10/20/14. http://homeenergypros.lbl.gov/profiles/blogs/high-efficiency-should-be-a-drain-a-closer-look-at-condensing

©2017 Navigant Consulting, Inc.

Figure 7. Efficiency Model for Site 364



Source: Navigant analysis of metered data

2.4.3 *Calculation of Seasonal Efficiency Improvements*

After developing the updated efficiency models, the final step was to combine them with the logged data to calculate seasonal efficiency improvements. The steps completed by the evaluation team are as follows:

1. Combine logged data with outdoor temperature data from the National Oceanic and Atmospheric Administration (NOAA)
2. Use efficiency models (both site-specific and aggregate) to assign efficiency to all logged data by return water temperature
3. Calculate the average efficiency by outdoor temperature, weighting by the temperature difference between the supply and return temperature (used as a proxy for load on the system)
4. Calculate the seasonal efficiency for the existing and implemented outdoor reset curves by taking the average efficiency across all outdoor temperatures, weighting by total heating load

This resulted in a range of seasonal efficiency improvement values for most sites, which represented the different outcomes of using the site-specific model versus the aggregate efficiency model.

2.4.4 Smart Thermostat Analysis

The evaluation team collected thermostat data from several sources:

- **Field data collection forms:** Field techs recorded heating and cooling setpoints as reported by the customer and programmed these setpoints into the customer's new thermostats.

©2017 Navigant Consulting, Inc.

- **Loggers:** Field techs placed a temperature logger next to every installed smart thermostat. These loggers recorded dry bulb temperature and relative humidity every 10 minutes for the duration of the metering period.
- **Smart thermostats:** Ecobee and Building 36 supplied data at 5-minute and as-recorded intervals, respectively. This data included indicators for system state (heating, cooling, or idle), heating and cooling setpoint, and current actual temperature at the thermostat, among other variables. The key data point collected was the actual heating setpoint.

2.4.5 Moderate Outdoor Reset Curve Analysis

The results from the primary analysis indicated that the aggressive outdoor reset curves implemented in this study may not be appropriate for all sites. Based on this, the evaluation team performed a secondary analysis to determine an estimate of the efficiency improvement from a more moderate curve, which would be appropriate to implement in the majority of homes.

First, the evaluation team estimated the change in programmed supply water temperature (SWT) that would result from implementing the recommended OR curve in all sites from the 2014 study, as follows:

- Calculated the observed relationship between programmed SWT and actual SWT for all sites in the 2016 study
- Used this relationship to derive programmed SWT curves from actual metered SWT data for all sites in the 2014 study
- Calculated the difference between the programmed SWT and the recommended SWT, for all outdoor temperatures

Next, the evaluation team used the resulting change in programmed SWT to calculate efficiency improvement for each site in the following steps:

- Calculated the relationship between the change in programmed SWT and the resulting change in RWT for the sites in the current study
- Used the aggregate efficiency model to translate RWT into efficiency
- Took the weighted average efficiency for each site across all outdoor temperatures, weighting by the total heating load

2.5 Cost Analysis

The evaluation team's cost analysis focused on estimating costs for both controls-only and non-controls solutions for condensing boiler installations. The evaluation team drew on findings from the field study, including the solutions identified during the first site visit. For sites that were not candidates for optimized outdoor reset controls (non-controls sites), the evaluation team conducted research on costs for potential improvements, including distribution and envelope solutions.

The evaluation team categorized the sites' heating zones into two conditions to determine which zones would require distribution and envelope solutions:

©2017 Navigant Consulting, Inc.

- **Constrained:** This condition describes zones and homes for which the emitter output at the desired supply temperature is less than the design day heating load.[16] Homes with this condition are not candidates for optimized outdoor reset controls.
- **Unconstrained:** This condition describes zones and homes for which the emitter output is equal to or greater than the design day heating load. For this analysis, the evaluation team assumed that homes must meet this condition before the site could benefit from optimized outdoor reset controls (controls-only solutions).

For each non-controls site, the evaluation team compared the emitter output with the design day heating load calculated with the Manual J tool to determine which zones were constrained. Next, the evaluation team characterized envelope and emitter characteristics for each zone to identify the improvements needed for the home to be unconstrained. To estimate the total cost of the improvements, the evaluation team used a variety of cost studies and databases,[17] as well as the contractor surveys, which also informed cost estimates for outdoor reset sensors.

2.6 Contractor Surveys

In addition to the field study, the evaluation team developed a contractor survey to determine typical practices and barriers to improved installation practices. The participants included heating equipment contractors and plumbers who install hydronic heating and water heating equipment. Through the contractor survey, the evaluation team sought to assess the following:

- Condensing boiler installation practices, particularly controls
- Whether/how often contractors adjust control settings or use manufacturer defaults in relation to customer actions or complaints that arise from levels of comfort or heating quality that are less than desirable
- Barriers to quality installation and controls commissioning for condensing equipment (e.g., lack of training and financial support)
- Possible solutions and associated costs for improving the installation and controls commissioning for condensing equipment as well as non-controls improvements (e.g., to the distribution system or envelope)

2.7 Manufacturer Interviews

After reviewing the initial study results, the evaluation team and the PAs decided to conduct additional research on “smarter” boiler control technologies, including the OpenTherm communication protocol. Traditional thermostat communication protocols allow thermostats to communicate basic information to boilers and other heating systems, namely whether there is a call for heat. The OpenTherm communication protocol has gained popularity in Europe and allows any thermostat and boiler with the

[16] The design day heating load is the maximum heating load the HVAC system is designed to accommodate.

[17] The evaluation team used the following sources to develop cost estimates: *Northeast Energy Efficiency Partnership Incremental Cost Study Report*, Navigant Consulting, 2011; *Ex Ante Measure Cost Study*, Itron, 2014; National Residential Efficiency Measures Database, NREL, 2013; Michigan Efficiency Measures Database, 2016.

©2017 Navigant Consulting, Inc.

protocol installed to communicate additional information, such as how to modulate supply water temperature based on outdoor conditions and setpoint schedule.[18]

The evaluation team completed interviews with an OpenTherm representative, a boiler manufacturer, and three thermostat/controls manufacturers, representing a variety of perspectives on the boiler controls market in North America and Europe. These interviews sought to answer the following researchable questions:

- How mature are the OpenTherm protocol and smart thermostat technology for manipulating supply temperature settings in Europe? Are there any existing studies demonstrating savings from this technology?
- What are the barriers to selling this technology in the United States?
- Could a Massachusetts incentive program reduce barriers to bringing this technology to the US?

[18] "Why OpenTherm?" OpenTherm Association. https://www.opentherm.eu/why-opentherm/ Accessed October 27, 2016.

3. RESULTS

The following sections summarize the findings from the metering sites, non-controls sites, and contractor surveys. Given the small sample size, the evaluation team has presented ranges and examples of site-specific results as well as averages.

3.1 Savings from Optimized Outdoor Reset (OR) Controls

After the data cleaning process, the evaluation team had 10 sites with sufficient clean data to estimate savings. Table 6 summarizes the final disposition of the 17 metering sites.

Table 6. Summary of Metering Site Dispositions

Final Disposition	Number of Sites
Clean, usable data	10
Metering equipment failure	3
Customer altered OR control settings	1
Dropped out of study	2
Inexplicable data trends	1
Total metering sites	**17**

The evaluation team grouped the 10 sites with clean, usable data into three results categories:

- **Successful:** At five sites, the evaluation team implemented the reset curves as planned in the pre-analysis and boiler operation changed as predicted. These sites showed energy savings comparable to the pre-analysis estimates, although some were higher and some were lower.
- **Comfort Limitations:** At two sites, the evaluation team could not implement the planned reset curve due to comfort limitations. One site's audit showed enough capacity constraint to warrant a less aggressive curve. At the second site, the customer requested that the evaluation team adjust the settings shortly after the installation. These sites yielded lower savings.
- **Unsuccessful:** Although the evaluation team implemented the optimal reset curve at the remaining three sites, it did not work as intended. At one site, the data suggested that the outdoor air sensor may have been broken. At another site, the control changes did not stay programmed.[19] At the third site, the boiler's minimum default boiler temperature setting of 130°F limited the reset curve effectiveness.[20]

Figure 8 illustrates the range of efficiency increase across controls-only sites with useable data as compared to the expected savings estimated in the pre-analysis (see section 2.2). The efficiency increase is the number of percentage points the seasonal efficiency changed due to the outdoor reset controls

[19] The cause of this is not known for certain, but the evaluation team suspects it was due to a hardware issue.

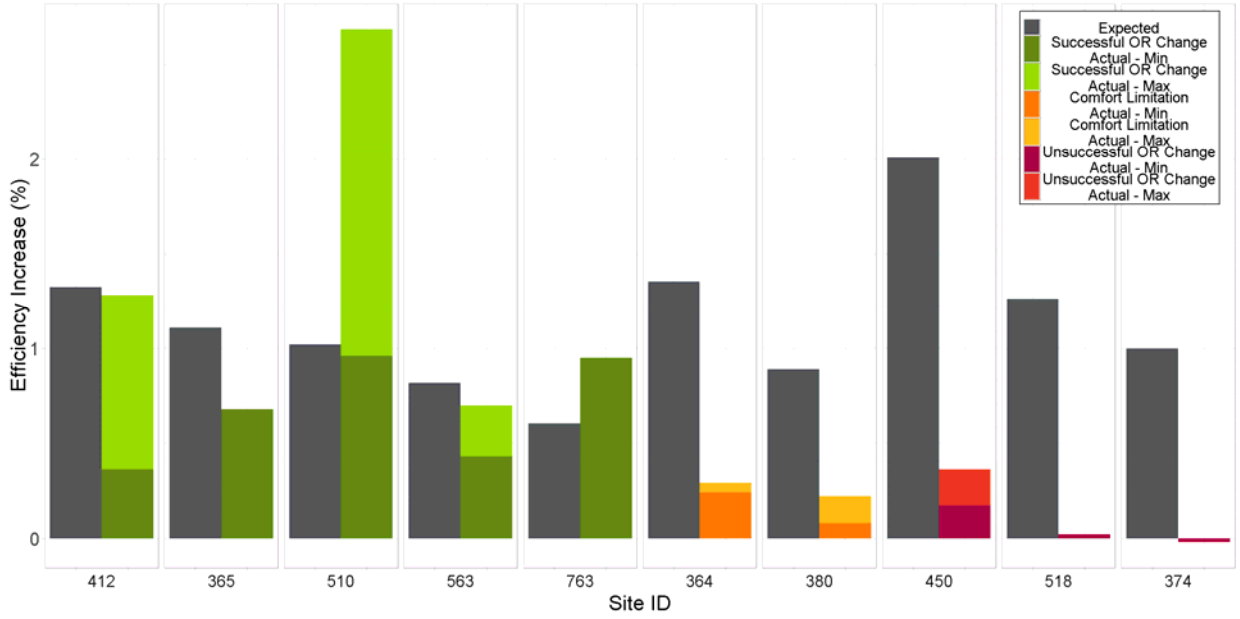
[20] This boiler has two minimum temperature settings: minimum boiler temperature and low boiler water temperature. The minimum boiler temperature default setting is 130°F. If the low boiler water temperature setting is set below 130°F, it appears that the minimum boiler temperature setting limits the effectiveness of the programmed outdoor reset curve.

©2017 Navigant Consulting, Inc.

adjustments. For example, a 1.5% increase might be the change from a seasonal average efficiency of 88.5% to a seasonal average efficiency of 90%. The pre-analysis estimates of outdoor reset potential efficiency improvement for each site varied from 0.6% to 2.0%, below the rough estimate of 3% from the 2014 study.

Given the uncertainty around the site-specific efficiency curves, the evaluation team presented the minimum and maximum savings for all sites with a site-specific curve. The site-specific data may yield higher or lower savings than the average efficiency curve depending on the site. Two of the five successful sites achieved a measured efficiency increase that exceeded the expected increase estimated in the pre-analysis, and two others' measured increases were close to the evaluation team's projections. This demonstrates that when implemented as planned, outdoor reset control changes did generate savings as expected. However, the fact that the outdoor reset control changes could not be implemented as planned at half of the sites indicates that outdoor reset control changes may not always be a quick fix to recoup energy savings.

Figure 8. Expected and Measured Increase in Efficiency Due to Outdoor Reset (OR) Controls



Source: Navigant analysis of metered data

Table 7 provides the range of savings observed within each group, where minimum increase is the lowest individual increase for all sites in the group and maximum savings are the highest individual increase for all sites in the group. The mean value for the successful sites accounts for 8% of the gap between the observed and maximum potential savings based on rated efficiency in the 2014 study.

©2017 Navigant Consulting, Inc.

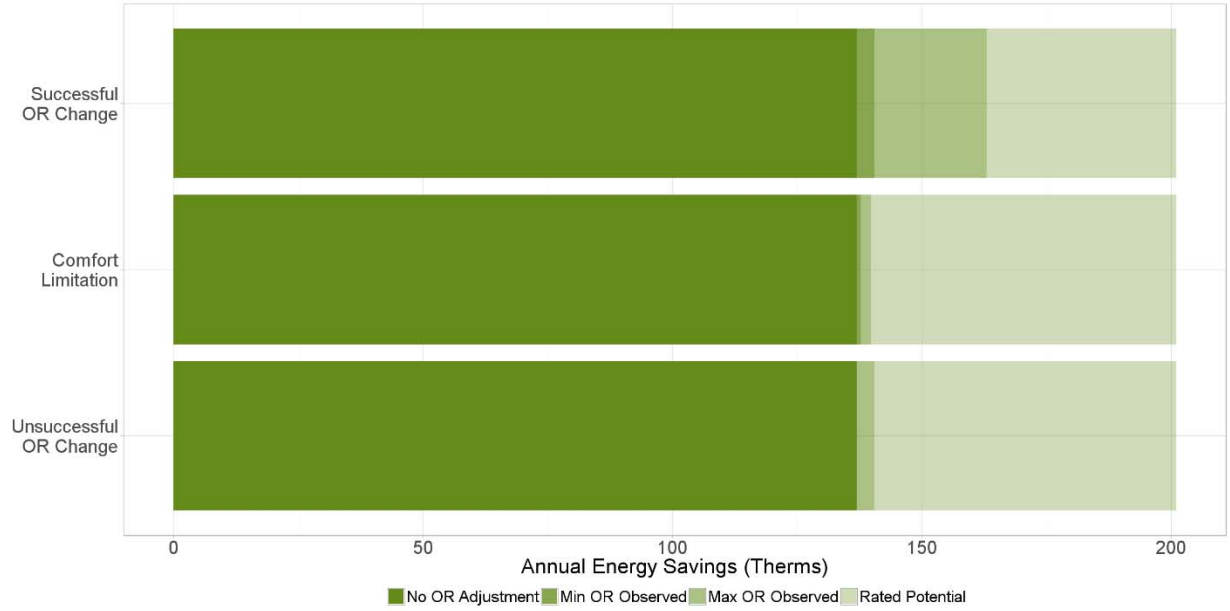
Table 7. Summary of Possible Savings by Group

Group	Minimum Efficiency Increase (AFUE)	Mean Efficiency Increase (AFUE + 90% Confidence Interval)	Maximum Efficiency Increase (AFUE)
Successful (n = 5)	0.36%	0.96% ± 0.47%	2.69%
Comfort limitation (n = 2)	0.08%	0.21% ± 0.36%	0.29%
Unsuccessful (n = 3)	-0.02%	0.09% ± 0.26%	0.36%
All (n = 10)	**-0.02%**	**0.55% ± 0.32%**	**2.69%**

Source: Navigant analysis of metered data

The evaluation team combined the efficiency increase estimates with savings data for 95% Annual Fuel Utilization Efficiency (AFUE) boilers[21] to estimate the range of therm savings possible for each group. Figure 9 summarizes these findings relative to the actual and maximum theoretical therm savings for a new boiler. As discussed further in section 4, the evaluation team does not believe that it is realistic to achieve maximum theoretical savings for condensing boiler installations in the vast majority of retrofit installations.

Figure 9. Range of Therm Savings by Group for 95% AFUE Boilers



Source: Navigant analysis of metered data

Table 8 summarizes the possible therm savings by group.

[21] The boilers included in this study were all in the 95% AFUE tier, and savings cannot be easily extrapolated to other tiers. However, the evaluation team expects that the savings would be similar for boilers in other tiers.

©2017 Navigant Consulting, Inc.

Table 8. Summary of Possible Therm Savings by Group

Group	Minimum Savings (therms per site)	Mean Savings (therms per site, with 90% Confidence Interval)	Maximum Savings (therms per site)
Successful (n = 5)	3.5	9.3 ± 4.6	26.0
Comfort limitation (n = 2)	0.8	2.0 ± 3.5	2.8
Unsuccessful (n = 3)	-0.2	0.9 ± 2.5	3.5
All (n = 10)	**-0.2**	**5.3 ± 3.1**	**26.0**

Source: Navigant analysis of metered data

The comfort issues encountered in this study indicated that the aggressive outdoor reset curves implemented in this study may not be appropriate for all sites. Based on this, the evaluation team performed a secondary analysis to determine an estimate of the efficiency improvement from a more moderate curve, which would be appropriate to implement in the majority of homes. The evaluation team estimates that a moderate outdoor reset curve with temperatures of 180°F supply at 0°F outdoors and 120°F supply at 50°F outdoors would produce an average efficiency improvement of 0.3% (~3 therms per year).

3.2 Site Results Case Studies

The following section presents two site case studies to illustrate the drivers of the overall savings associated with each site. There are three main factors that influenced the achieved savings for each site:

- The magnitude of the change in outdoor reset curve that the evaluation team attempted to implement at each site
- How much the return water temperature was affected by the change in outdoor reset curve
- The efficiency model that translated changes in return water temperature into efficiency improvements

The following are examples of two sites representing the range of savings, and discussion of what drove the differences.

©2017 Navigant Consulting, Inc.

SITE 510: EFFECTIVE IMPLEMENTATION EXAMPLE

- **Overview:** Implemented reset curve that differed significantly from existing curve; resulted in return temperatures being substantially lower at all outdoor temperatures
- **Result:** Upper end of the study's savings; overall efficiency improvement was 1% total AFUE using the aggregate efficiency model and 2.7% using the site-specific model

Figure 10 shows the change between the implemented outdoor reset curve and what was originally found on-site, as well as the resulting change in average supply temperatures.

Figure 10. Outdoor Reset Curves and Average Supply Temps, Site 510

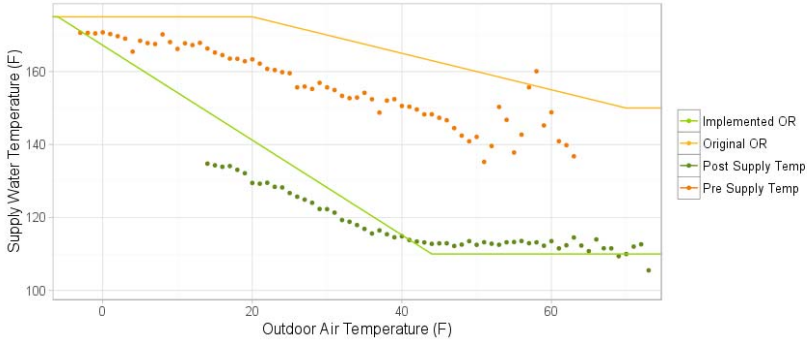


Figure 11 shows the resulting change in boiler temperatures. Note the reduction in return temperature (which drives efficiency) for all outdoor temperatures.

Figure 11. Boiler Temps, Site 510

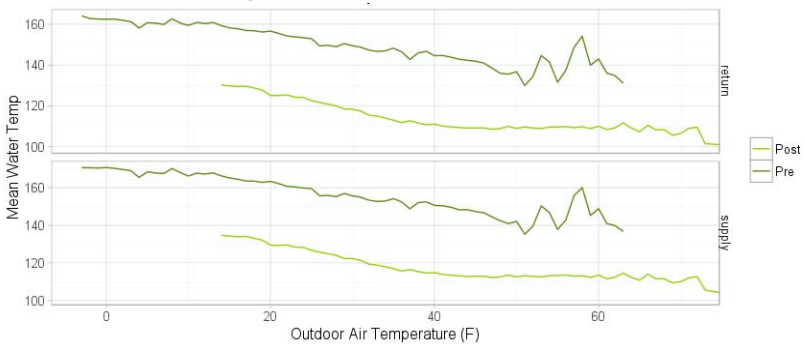


Figure 12 shows the efficiency models used to translate the reduction in return temperature to efficiency improvements. The site-specific model resulted in higher savings due to greater efficiency at lower return water temperatures, which was where the unit operated the most.

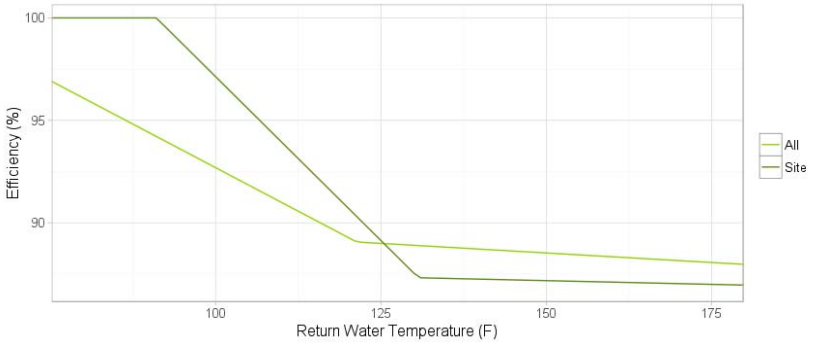
Figure 12. Efficiency Models, Site 510

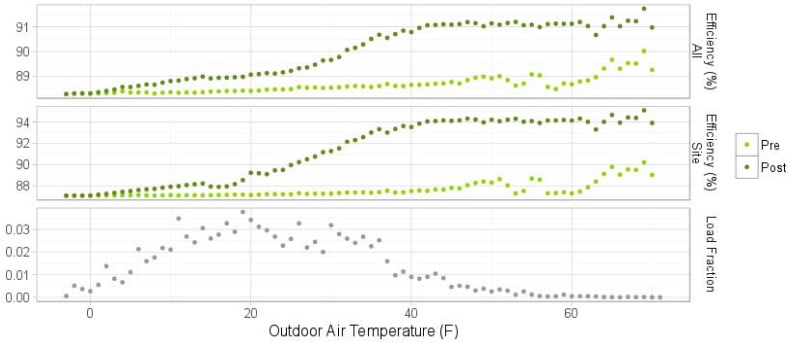
Figure 13 shows the overall efficiency using the different models, as well as the load fraction used to create a seasonal weighted average efficiency improvement.[22] The site-specific model resulted in greater efficiency gains for the bulk of outdoor temperatures, resulting in higher overall savings.

Figure 13. Weighted Average Efficiencies, Site 510

[22] Includes a combination of measured and modeled efficiencies. See Section 2 for more details.

©2016 Navigant Consulting, Inc.





SITE 380: LIMITED IMPLEMENTATION EXAMPLE

- **Overview:** Savings limited by occupant comfort concerns; initially implemented reset curve that differed significantly from existing curve, but customer was not satisfied so the curve changed to one much less aggressive; resulted in minimal changes to the return temperatures
- **Result:** Small overall efficiency improvement; total season efficiency was 0.2% using the aggregate efficiency model, and 0.1% using the site-specific model

Figure 14 shows the small change between the final implemented outdoor reset curve and what was originally found on-site, as well as the minimal resulting change in average supply temperatures.

Figure 14. Outdoor Reset Curves and Average Supply Temps, Site 380

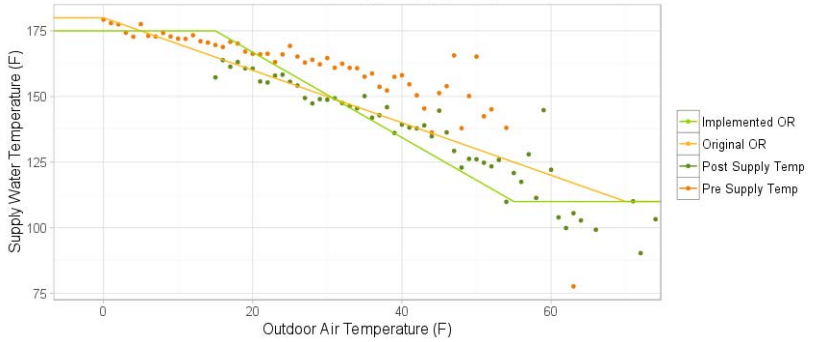
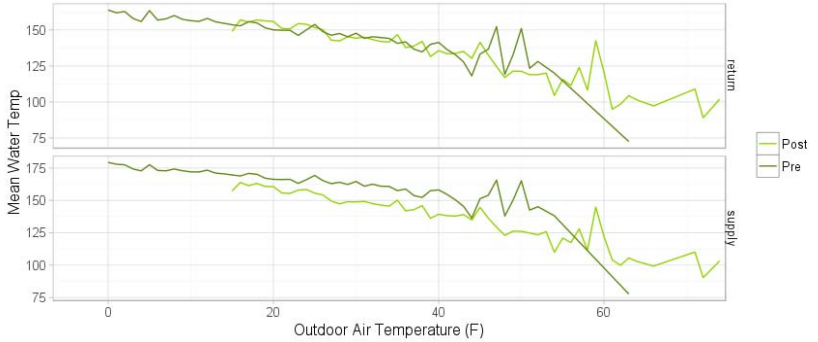


Figure 15 shows the resulting change in boiler temperatures. Note the reduction in return temperature is much smaller than that of Site 510.

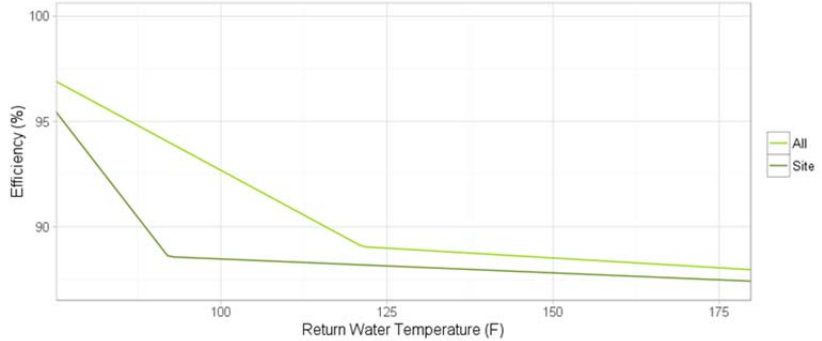
Figure 15. Boiler Temps, Site 380



©2016 Navigant Consulting, Inc.

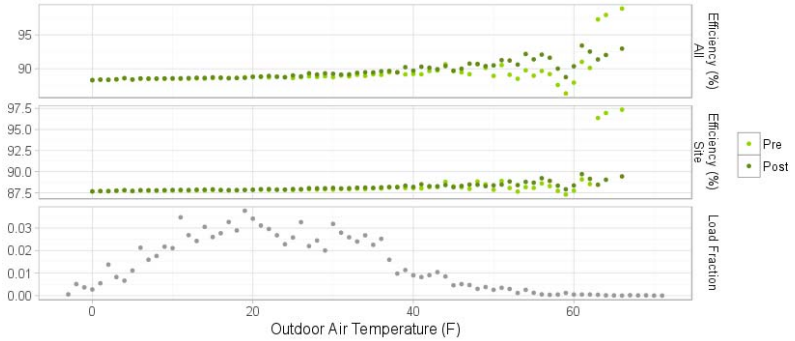
For this site, the site-specific efficiency model resulted in smaller savings due to the hinge point of the curve occurring at a much lower return water temperature, where the unit seldom operated (Figure 16).

Figure 16. Efficiency Models, Site 380



The overall efficiency graph for this site (Figure 17) shows small savings at all outdoor temperatures, though the aggregate model resulted in slightly higher savings in this case.

Figure 17. Weighted Average Efficiencies, Site 380



©2016 Navigant Consulting, Inc.

3.3 Customer Behavior and Thermostat Use

The evaluation team used thermostat data to augment customer survey responses and to inform the boiler efficiency analysis. More specifically, in instances where customers use large setbacks, the smart thermostat data was used to discern whether the boiler did or did not meet the setpoint and whether customer setpoints changed over time. Thermostat data was also used to verify customer-reported setpoints, schedules, and assessments of system performance (whether the setpoint was met or not). Appendix B provides examples of the visual QC tools used to inspect the thermostat data.

The evaluation team's analysis of the thermostat data revealed several findings:

- **Most customers changed their setpoint schedules.** Some customers reported issues with the smart thermostats and changed their setpoints to override the schedule, or attempted changing the schedule to keep their homes more comfortable. Other customers are just active occupants that interact with their thermostat regularly—whenever they wake up, return home, or feel uncomfortable. In a few cases, the ramping setpoint schedules programmed during the install visit persisted throughout the study but most customers overrode them within a few days.
- **If customers have setbacks, a ramping schedule should be implemented in order to maintain expected comfort while using optimized outdoor reset controls.** In some isolated cases where a ramping schedule was programmed and remained in place for the entire study, it was clear that setpoints were met quickly. In other cases, it was clear that the heating system responded too slowly, and the ramping schedule was either too fast or the night setback was too large for the boiler to recover the setpoint in the morning. Six participants noted a slow response time for their heating system, including two participants that dropped from the study due to comfort constraints.
- **Smart thermostats need to be smarter.** A truly smart thermostat would learn how long the system takes to respond, anticipate cold temperatures and warm setpoints, and start the morning warmup early enough to meet the morning setpoint. The basic ramping schedules and setbacks of the thermostats in this study were not tuned well enough to each individual home; thus, some worked but most occupants overrode them.
- **Given the small sample of homes, the evaluation team cannot say if there are any definitive correlations between customer satisfaction, savings, and interaction with thermostats.** Of those who reported being satisfied or happy with their system performance during the study, roughly equal proportions were regular thermostat users and infrequent thermostat users. Of those who had issues, the proportions of regular and infrequent users were also similar. These non-trends were the same when grouping customers by savings and comparing to thermostat use or satisfaction with system performance.

The following tables include data from the 15 metered sites who participated for the entire duration of the study; however, only 10 have estimates of positive savings, 14 have survey responses indicating how often the occupants adjusted thermostats, and only 9 have both. Where data is missing in any category, it is omitted in the following tables.

Table 9 shows a slight trend indicating that occupants who use their thermostat frequently are generally happier with the performance of their boiler. Two out of the three sites that were not happy with boiler performance were part of the "successful" group that achieved a fair amount of energy savings. For these

©2017 Navigant Consulting, Inc.

two sites, the evaluation team returned the outdoor reset curve to the original settings during the second site visit.

Table 9. Occupant Thermostat Adjusments and Customer Satisfaction with Boiler Performance

Was customer happy with boiler performance?	How often did occupant adjust thermostat?				Total
	1 - No changes	2 - Rare changes	3 - Occasional changes	4 - Frequent changes	
Yes	1	**3**	1	**5**	**10**
Neutral	0	0	0	1	**1**
No	0	2	0	1	**3**
Grand Total	**1**	**5**	**1**	**7**	**14**

Source: Navigant analysis of metered data, thermostat data, and customer interviews

In Table 10, it is unclear whether there is any consistent relationship between savings and how frequently occupants adjusted their thermostats. The majority of sites showed small or no savings with frequent thermostat changes, but at least one site with an active occupant had energy savings.

Table 10. Occupant Thermostat Adjusments and Energy Savings

Did the study achieve savings at this site?	How often did occupant adjust thermostat?				Total
	1 -No changes	2 - Rare changes	3 - Occasional changes	4 - Frequent changes	
1 = No/low savings	0	1	0	4	5
2 = Some savings	0	2	0	2	4
Grand Total	**0**	**3**	**0**	**6**	**9**

Source: Navigant analysis of metered data, thermostat data, and customer interviews

The data in Table 11 may indicate that savings come at the cost of occupant satisfaction with boiler performance, as two of the four sites with some savings were also sites where customers complained of comfort limitations. Without a larger sample of sites, it is impossible to say if there might be more neutral or generally happy occupants where the new boiler settings also lead to savings.

Table 11. Energy Savings and Customer Satisfaction with Boiler Performance

Did the study achieve savings at this site?	Was customer happy with boiler performance?			Total
	Yes	Neutral	No	
1 = No/low savings	**4**	1	0	**5**
2 = Some savings	2	1	2	**5**
Grand Total	**6**	**2**	**2**	**10**

Source: Navigant analysis of metered data, thermostat data, and customer interviews

©2017 Navigant Consulting, Inc.

3.4 Cost Analysis

Costs and energy savings from outdoor reset controls are highly dependent on site-specific conditions such as existing insulation levels, distribution, and the size of the home. Due to these factors, the most cost-effective option is likely unconstrained sites that have an outdoor reset sensor installed but not programmed, or unconstrained sites only requiring the installation and programming of an outdoor reset sensor. Contractor estimates for the cost of installing an outdoor reset sensor varied, with 57% of contractors reporting costs between $100 and $500, and 27% noting that the sensor is included with the initial installation of the boiler.

For sites that were not candidates for optimized outdoor reset controls, the evaluation team conducted research on the improvements identified through the site visit and audit analysis, including the costs associated with distribution and envelope solutions. The audit site conditions ranged from sites requiring small reductions in the heating load to sites requiring substantial improvements and load reductions in order to reach an unconstrained condition. The following two examples present the range of site conditions, as well as the range of costs required before the sites could benefit from optimized outdoor reset controls.

- **Site 506:** This site needs a relatively small load reduction to one zone in order to benefit from optimized outdoor reset controls. Solutions for this site to achieve an unconstrained condition include insulating the walls and ceiling and/or adding distribution. Upgrading wall and ceiling insulation would likely cost between $2,500 and $3,000 for this site.
- **Site 684:** This site consisted of two zones that would require a substantial load reduction to benefit from optimized outdoor reset controls. Unlike Site 506, this site would likely require a combination of wall insulation, ceiling insulation, window replacements, and additional distribution to achieve an unconstrained condition. Upgrading wall insulation, ceiling insulation, and windows would likely cost between $3,500 and $4,000 or more for this site. Additionally, distribution upgrades would likely be required for one of the two zones, adding an additional $1,500 to $2,000 to the overall cost for this site.

Using the observed natural gas savings from this study[23] as well as the residential gas rate during the study period, the evaluation team found that homeowners with optimized outdoor reset controls might expect savings of about $10 per year, on average, or up to $30 per year for sites with greater potential. This analysis does not account for additional energy savings resulting from envelope improvements.

Energy savings, cost requirements, and overall cost-effectiveness for sites requiring envelope and distribution improvements are very site-specific. The cost range for the examples presented above is similar, even though one site would require a small heating load reduction and the other would require a much larger reduction to reach an unconstrained condition. Contractor estimates for the addition of 5,000 Btu of distribution ranged from about $500 to $5,000, with 58% of contractors (15 out of 26) reporting costs between $500 and $1,500. Several contractors noted that distribution costs depend on several site-specific factors including zoning, insulation, system configuration, and home size.

The results of the analysis presented in this report depend on the envelope and emitter characteristics identified during the first site visit. Although the evaluation team spent a considerable amount of time on

[23] Observed natural gas savings from sites that were candidates for optimized outdoor reset controls and had “successful” implementation of outdoor reset control settings (n=5).

the zone-level audit for both metering and non-controls sites, it was not feasible to fully inspect insulation levels and emitter capacities without conducting an even more detailed audit. The estimated insulation levels and emitter output directly affected the potential for optimized outdoor reset controls at each non-controls site, as well as the outdoor reset curve programmed at each metering site. As a result, an outdoor reset control program would require a balance between data requirements, outdoor reset curve optimization based on site-specific characteristics, and the type/duration of work contractors would be willing to complete for each site.

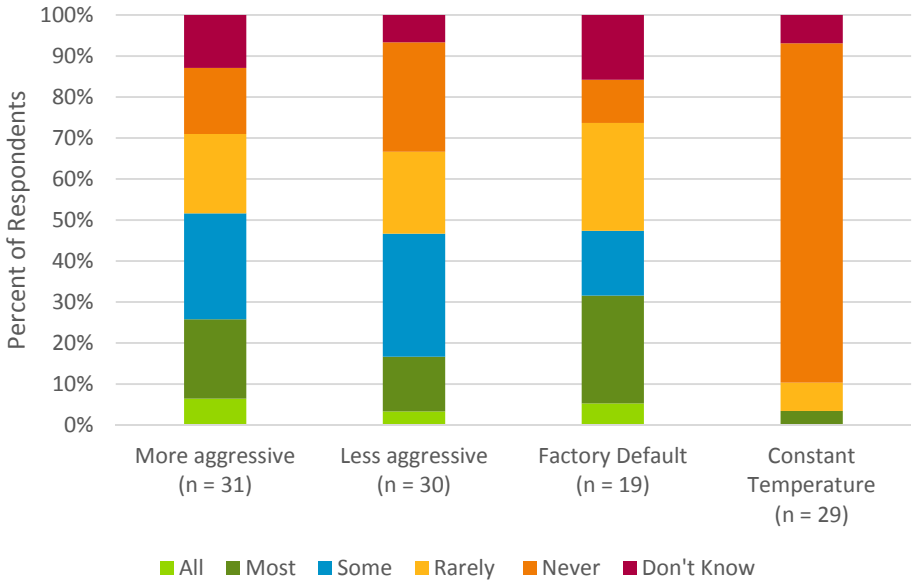
3.5 Contractor Surveys

The evaluation team surveyed a total of 41 contractors and plumbers who install and service condensing boilers. The survey included contractors who installed one to 100 boilers in 2016, with the majority of respondents (27 of 41) reporting that they installed up to 20 condensing boilers in 2016. A larger number of contractors reported using aggressive (more efficient) reset curves the majority of the time

3.5.1 Installation Practices

The survey found that contractors typically install outdoor air reset controls with new condensing boilers: 30 out of 37 respondents reported that they install outdoor air reset sensors in at least 90% of condensing boiler installations. Contractors' approaches to programming outdoor reset curves were more variable: only one contractor reported always using the factory default reset curve and an equal number of respondents reported using the default "rarely" and for "most" installations (five respondents each). Figure 18 illustrates this variability; the survey asked contractors in what portion of homes they use each of the four approaches below.

Figure 18. Frequency of Outdoor Reset Curve Approaches

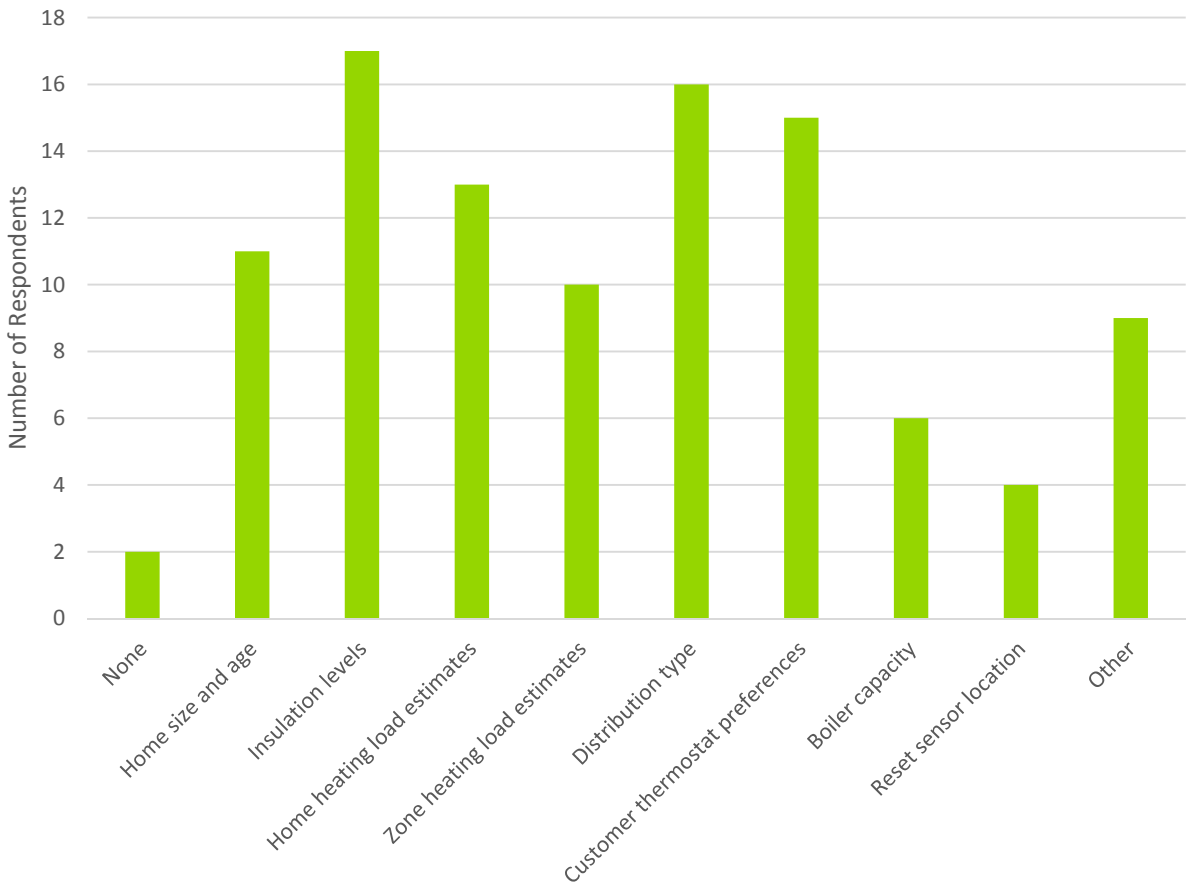


Source: Navigant analysis of survey data

The data suggests that contractors will adjust settings on a home-by-home basis. Most contractors said that they consider multiple home-specific factors when deciding how to program outdoor reset controls—

at least three factors on average. As shown in Figure 19, the most common factors were home insulation levels, type of distribution, and customers' preferred thermostat settings. Only two contractors reported not considering any home or boiler characteristics when setting a curve. However, the 2014 metering study found that 30% of homes with condensing boilers did not have a working outdoor reset sensor installed, indicating that survey respondents could be more attuned to outdoor reset controls than the broader contractor population who are installing condensing boilers.

Figure 19: Home and Boiler Characteristics Considered in Outdoor Reset Programming



Source: Navigant analysis of survey data

When asked about what home and boiler characteristics contractors considered in outdoor reset programming, other responses included occupancy patterns by zone, special considerations for hydro air systems,[24] the amount of distribution, importance of comfort to the customer and customer age. One contractor said that he teaches customers how to adjust the reset curves themselves. The majority of contractors (31 out of 32) use some kind of load calculations when deciding how to program reset curves; 17 reported using Manual J and another five reported using load calculation software that complies with Manual J such as Wrightsoft®. Five contractors reported using professional judgment, but four of these respondents said they also use some kind of load calculation process.

[24] Hydro air systems use a boiler to create hot water which is piped through small diameter tubing into fan coils that produce hot air.

©2017 Navigant Consulting, Inc.

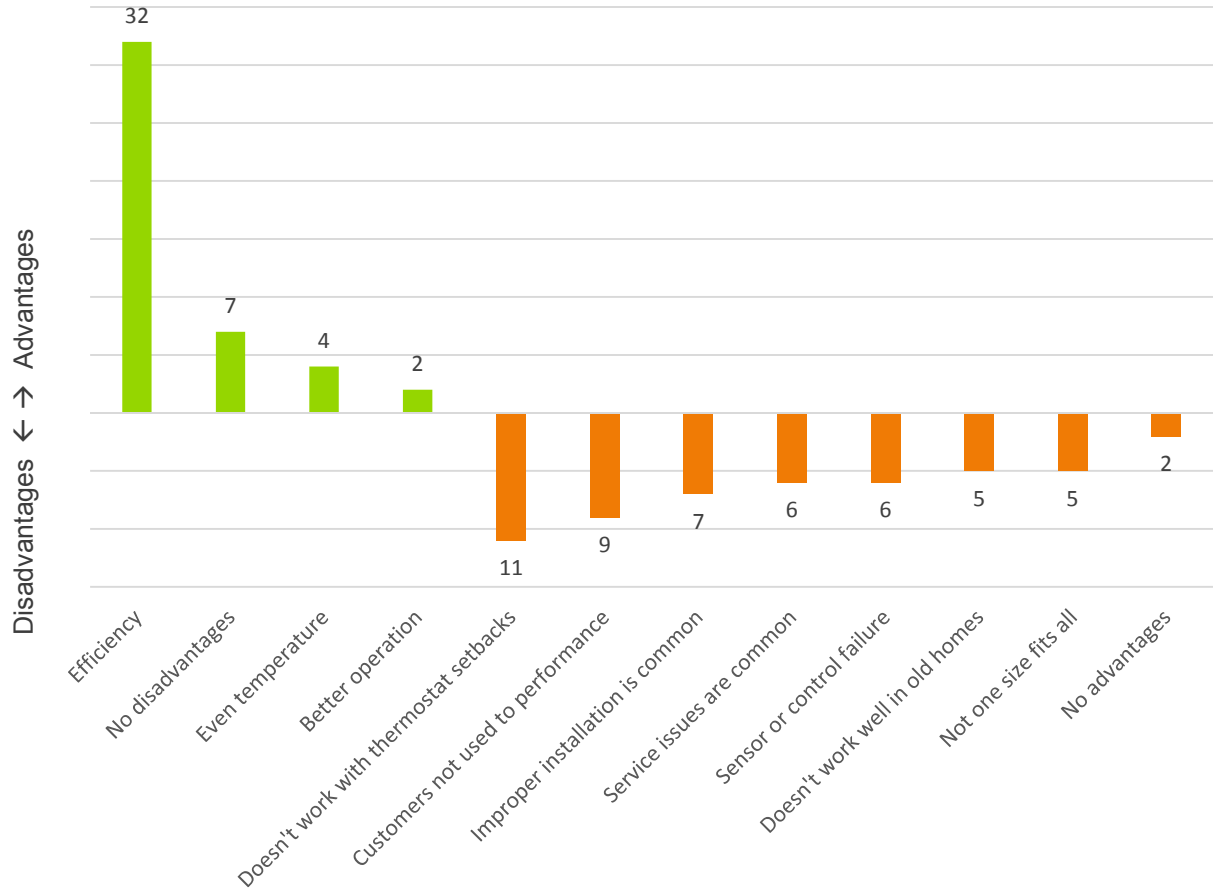
3.5.2 Barriers to efficient controls configuration

The survey responses indicated that the largest barriers to efficient programming of outdoor reset controls are home characteristics and customer expectations. As described in the previous section, most contractors appear to understand the technical limitations of installing outdoor reset controls. When asked what home and boiler characteristics must be present in order to program an aggressive reset curve, 14 of 33 contractors mentioned good weatherization (e.g. tight windows, good insulation, or newer homes). Other factors included distribution factors such as sufficient distribution or the right type of distribution, boiler capacity, thermostat habits, and age of the customer.

While most contractors did not identify specify customer preferences that would keep them from installing outdoor reset controls, five contractors noted that they did not install these controls for elderly customers. Two contractors mentioned customers who want a “quick response” and general customer preference. As shown in Figure 20, the top two disadvantages contractors reported to installing and programming outdoor reset controls centered on customer preferences: thermostat setback habits can be problematic (e.g. it takes longer for the home to heat up after a setback) and customers may not expect or be satisfied with the change in performance from their boilers. Contractors often specified more than one advantage or disadvantage.

©2017 Navigant Consulting, Inc.

Figure 20. Advantages and Disadvantages of Installing and Programming Outdoor Reset Controls



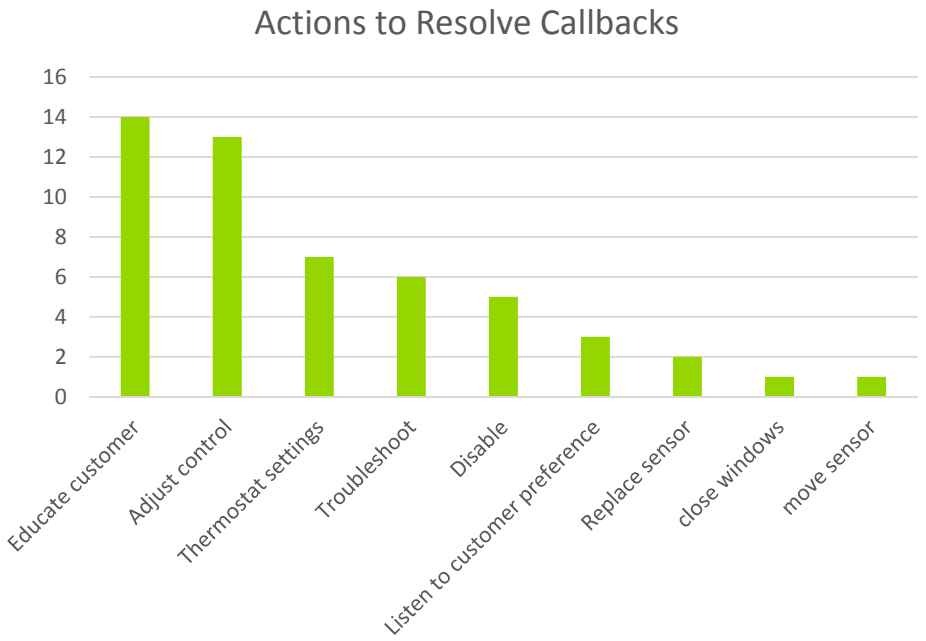
n= 36

While several contractors noted that improper installation and service issues were common, only two thought that contractor education could help mitigate these risks. A plurality of respondents (7 of 18) thought educating customers was the best strategy for mitigating risk associated with installing and programming outdoor reset controls. Other suggestions included ensuring the installation is an appropriate application (three respondents), improving sensor quality (two respondents), and educating contractors (two respondents).

Despite the noted risk of service issues, 24 of 37 contractors reported very few callbacks (5% or fewer) from installations with outdoor reset. Twenty of 35 respondents indicated the callback rate was the same as for other installations, though 12 reported a higher rate of callbacks for outdoor air reset installations and only three said their installations with reset controls had fewer callbacks than other homes. The most common reasons for callbacks were “slow” heat and comfort complaints. As shown in Figure 21, when responding to callbacks from homes with outdoor air reset controls, many contractors educate their customers and/or adjust the control settings. Some also adjust thermostat settings or disable the control.

©2017 Navigant Consulting, Inc.

Figure 21. Contractor Actions to Resolve Callbacks



n=37

3.5.3 Possible solutions to improve outdoor reset control implementation

The most common recommendation from the contractors for how programs could improve customer awareness and adoption of outdoor reset controls was to provide customer education on the benefits and performance characteristics of systems with these controls (22 of 37 respondents). Specific comments included providing literature for customers, increasing customer awareness of outdoor reset, and managing customer expectations. Only four contractors felt that additional contractor training would help; other suggestions including focusing on other measures and having a customer hotline for outdoor reset-related calls.

23 of 38 contractors said that there was nothing programs could do to increase their likelihood of programming more aggressive outdoor reset curves and an additional five reported that they already do program aggressive curves.

It appears that most contractors understand the technical limitations of programming outdoor reset controls in homes with lower insulation, high infiltration and/or limited distribution: these barriers and managing customer expectations are the largest hurdles to overcome. Thus, programs may want to provide contractors with materials to educate customers on what to expect from outdoor reset controls.

3.6 Manufacturer Interviews

The team completed interviews with an OpenTherm representative, a boiler manufacturer, and three thermostat/controls manufacturers, representing a variety of perspectives on the boiler controls market in North America and Europe. The manufacturer interviews led to the following key findings, described in more detail in the section below:

- Incorporating indoor temperature data, especially from multiple zones, may be more important than outdoor reset controls—but the evaluation team has not been able to identify any studies documenting energy savings from this strategy.
- Two companies offer optimal start features for boilers in the U.S.—Bosch and Tekmar—and both use proprietary technology to communicate with boilers.
- The emphasis on outdoor reset in the U.S., combined with the small size of the U.S. boiler market, has limited innovation in this area in this country. A combination of installer education and regulatory pressure could improve adoption of indoor temperature feedback and optimal start technology.

3.6.1 Importance of indoor temperature feedback

Interviewees universally emphasized the importance of indoor temperature feedback in optimizing comfort and efficiency, in addition to or instead of outdoor reset sensors. The main application of OpenTherm is to communicate between indoor thermostats (sometimes referred to as "room controls") and the boiler. Outdoor reset is uncommon in Europe outside of Germany. In Europe, the efficiency standards are based on the system efficiency (boiler plus controls), not only the boiler. Systems using outdoor reset alone cannot achieve the highest efficiency rating, which is reserved for systems with multiple indoor thermostats and an algorithm integrating the measurements from those thermostats. [25,26]

Several interviewees offered explanations as to why outdoor reset alone is insufficient; one stated that in well-insulated homes, the outdoor temperature is a poor control parameter, while another noted that an outdoor sensor would provide all the necessary data only in a controlled environment in which there was no solar gain or wind load. Some smart controls and thermostats do incorporate outdoor temperature via the internet, but the outdoor temperature is just one input into the algorithms and the indoor temperature readings are considered more important.

3.6.2 Optimal start features

Controls manufacturers (in both the U.S. and Europe) also rely on optimal start algorithms, with various degrees of learning capabilities, to deal with the issue of temperature lag with lower supply temperatures. Optimal start algorithms generally look at the time the boiler took to reach the desired setpoint over the previous several weeks and adjust the time that the boiler starts accordingly. The European version of the Nest thermostat (with OpenTherm) uses both optimal start and modulation, but the U.S. version only has the optimal start feature. Tekmar and Bosch both offer boiler controls that use proprietary two-way communicating protocols similar to OpenTherm and incorporate an optimal start algorithm. Bosch's controls are compatible only with Bosch boilers. However, Tekmar's controls work with a wide variety of boilers. In a multi-zoned system with multiple indoor thermostats, Tekmar's algorithm aggregates the measurements and sends a signal to the boiler control, which modulates the boiler temperature. The

[25] Plumb Center UK, "What is ErP? Energy Related Products and Energy Labelling." http://www.plumbcenter.co.uk/info/erp-what-is-erp/

[26] European Commission. "Guidelines accompanying Regulations (EU) No 811 & 812/2013 with regard to energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and of water heaters, hot water storage tanks and packages of water heater and solar device." September 2015, pp. 11-12 https://ec.europa.eu/energy/sites/ener/files/documents/GuidelinesSpaceWaterHeaters_FINAL.pdf

boiler temperature is set based on the zone with the highest heat loss, and then the other zones, which require less heat, will cycle on and off as necessary.

3.6.3 Barriers to advanced controls

One interviewee noted that some U.S. jurisdictions requiring outdoor reset may give consumers the perception that it is the most efficient option, while nearly all interviewees felt strongly that two-way communication between the indoor thermostats and the boiler was a more efficient system. This perception may be leading to a lower consumer demand for more advanced controls.
Interviewees believe that the main barrier to better use of this type of control system in the United States is installation contractors' preference for simpler, on-off switches, and the fact that the HVAC industry is slow to change and adopt new innovations.[27] Some also noted that the relatively small size of the residential boiler market in the United States leads manufacturers to spend relatively little effort on improving boiler performance and also makes it a smaller area of focus for energy efficiency programs.

3.6.4 Strategies for increasing US adoption

Most of the interviewees thought that installers could benefit from additional education regarding more advanced controls. One interviewee noted that a benefit of adopting OpenTherm in the U.S. would be to enable a wider variety of control options for installers to choose from regardless of the boiler manufacturer, thereby increasing the likelihood of an installer setting up a two-way communication system rather than outdoor reset. Some interviewees thought that a regulatory push—for example, an efficiency standard requiring a feature that relies on two-way communication—could spur the U.S. market to adopt a communication protocol such as OpenTherm. However, one interviewee thought that the OpenTherm protocol may be less useful in the United States because there are typically multiple systems (heating *and* cooling) connected to a single thermostat, while OpenTherm is a point-to-point system connecting only to a boiler. The general view is that OpenTherm is simple and cheap to implement, and it (or a similar communications protocol – perhaps one that can accommodate multiple HVAC systems) could be beneficial in the U.S. boiler market.

[27] One manufacturer offered an opposing viewpoint, that many condensing boilers are actually installed with a more advanced control on the boiler itself (i.e. a signal input to change the boiler temperature). However, that does not necessarily mean that the controls are configured to optimize efficiency.

©2017 Navigant Consulting, Inc.

4. PROGRAM CONSIDERATIONS AND CONCLUSIONS

The primary finding from this study is that changing the outdoor reset curve does produce savings, but savings are lower than anticipated**.** The evaluation team observed that sites with significant changes in the outdoor reset curve could produce a 0.5%-1.5% improvement in the efficiency of the condensing boiler, which results in approximately a 5%-15% improvement in measure savings or 5 to 15 therms. Considering most high-efficiency boilers come with outdoor reset controls, capturing these savings could be relatively low-cost for many homes, but even this may not be cost-effective and it is clear these controls alone are not a silver bullet for recouping savings for high-efficiency boilers.

Even capturing the maximum potential savings from outdoor reset controls appears to leave significant therm savings on the table: a 1% improvement in operating efficiency would only account for about 10 therms of the roughly 60 therm difference between rated efficiency and the operating efficiency found in the 2014 metering study. This means for the average successful site, 83% of the savings difference between current and rated operating efficiency are unattained, and for a more typical site with only 5 therms of savings, this lost savings estimate climbs to 92%. However, due to the typical operating conditions of condensing boilers in retrofit applications, the evaluation team does not believe it is realistic for these units to operate at rated efficiency for the entire heating season except in rare cases with significant envelope improvements—walls, ceilings and windows—in addition to controls improvements. Most boilers also serve indirect hot water loads, where controls dictate the highest supply temperatures possible to meet hot water demands quickly. Furthermore, the majority of heating load occurs in cold temperatures when most homes require higher supply temperatures.

There are three strategies the Program Administrators (PAs) could pursue to assess what realistic savings potential remains for high-efficiency boilers. The research team offers the following recommendations based on the relevant findings for each strategy.

- **Consider promoting moderate outdoor reset control improvements across all high-efficiency installations**.
    - **Finding 1**: The evaluation team estimates that a moderate outdoor reset curve with temperatures of 180°F supply at 0°F outdoors and 120°F supply at 50°F outdoors would produce an average efficiency improvement of 0.3% relative to the typical operation observed in the 2014 study. While the savings are small, this could be a simple change for contractors to make in standard installations.
    - **Recommendation 1**: The PAs should run cost-effectiveness calculations based on a conservative savings estimate of 3 therms and incremental cost of $250 for controls programming only.
    - **Recommendation 2**: If screening this measure demonstrates it is cost-effective, the PAs should consider developing program offerings aimed at increasing the prevalence of more efficient outdoor reset control settings and proper installation of outdoor sensors.
- **Consider working with regional partners to research and potentially promote smarter supply temperature modulation technologies**.
    - **Finding 2**: The evaluation team found two manufacturers in the U.S. that currently offer control systems capable of modulating supply temperature based on indoor temperature feedback and outdoor temperature—Tekmar and Bosch.

©2017 Navigant Consulting, Inc.

  - **Finding 3**: The U.S. boiler market is relatively small and these offerings are not likely to take off without regulatory or program pressure.
  - **Finding 4**: The evaluation team did not identify any studies with energy savings estimates for implementing advanced supply temperature modulation technologies.
  - **Recommendation 3**: The PAs should conduct a high-level screening of these technologies assuming an optimistic 3% efficiency increase (30 therms) and cost of $750.
  - **Recommendation 4**: If the screening shows that this could be cost-effective, the evaluation team recommends conducting additional evaluation literature research on the savings potential of these technologies.
  - **Consideration 1**: Even a pilot evaluation of these technologies could be expensive, and the evaluation team also suggests the PAs consider a small evaluation study to gauge interest among potential state or utility partners in the Northeast in studying and promoting these products.

- **Consider a study to assess savings potential for simultaneous envelope and control improvements.**
  - **Finding 5:** The best scenario for improving condensing boiler efficiency is to reduce the load before adjusting controls, whether outdoor reset or other supply temperature modulation technology.
  - **Recommendation 5:** The PAs should consider a research study to evaluate the potential for a pilot program aimed at homes with condensing boilers that would offer detailed audits, completion of all necessary weatherization upgrades and adjustment of outdoor reset control settings once these upgrades are completed. Metering participants' boilers before and after upgrades and control setting adjustments could determine whether improved boiler efficiency provides a boost to envelope savings.

The following sections describe these options in more detail along with the technical, delivery and customer-side barriers that they face.

4.1 Moderate outdoor reset control improvements

This study demonstrated that there are modest but achievable savings that could be captured through more efficient outdoor reset curve settings. If cost-effective, the PAs could consider offering a small bonus incentive for implementing a standard reset curve or more efficient settings along with high-efficiency installations, or offer a standalone incentive for existing high-efficiency. This approach faces the following barriers:

- **Technical: Outdoor reset is not "one size fits all."** The evaluation team estimates that a curve with temperatures of 180°F supply at 0°F outdoors and 120°F supply at 50°F outdoors would produce an average efficiency improvement of 0.3% (~3 therms per year) relative to the typical operation observed in the 2014 study. While the savings are small, this would be a simple change for contractors to make in standard installations and the evaluation team does not see a way to cost-effectively and accurately determine site-specific, more aggressive curve settings without running a much higher risk of customer callbacks.
- **Delivery: Contractors may be skeptical.** In the contractor survey, respondents indicated that their outdoor reset approach varies depending on home and boiler characteristics; this indicates they understand the technical context for properly programming outdoor reset controls. A

©2017 Navigant Consulting, Inc.

program offering incentives for a standard outdoor reset curve would need technical documentation to assure contractors the curve is appropriate for the majority of homes and tools to discern when callbacks are likely.

- **Customer: Customers need to understand how outdoor reset controls will affect their system operation.** Homeowners frequently use their thermostats as switches instead of thermostats. They need education on how to use a thermostat as a thermostat—set it and forget it—and to be informed of the benefits to using ramping thermostat schedules with their new condensing boiler. The PAs could develop educational material to address this barrier.

4.2 Smarter supply temperature modulation technologies

In the manufacturer interviews, the evaluation team found that many European and some American market actors offer products designed to make condensing boilers operate more efficiently. These products typically use one or more of the following strategies:

- Boiler supply temperature modulation based on outdoor temperature (i.e. outdoor reset controls)
- Boiler supply temperature modulation based on indoor temperatures and thermostat setpoints
- Optimal start algorithms (with various levels of learning capabilities) that optimize boiler supply temperature modulation based on one or both of the above plus thermostat schedule

These features often come with smart thermostats capable of many other energy saving features such as automated “away” settings. These technologies broaden the opportunities to reduce supply temperature and thereby return temperatures, theoretically increasing the amount of time boilers operate in condensing mode. Promoting adoption of these technologies faces the following barriers:

- **Technical: Savings are uncertain.** The European Energy-Related Products (ErP) directive increases system efficiency ratings by 2% to 3% over outdoor reset control settings alone for incorporating one or more indoor temperature sensors with modulating boilers, but the evaluation team did not discover any documentation supporting these estimates of efficiency improvements.
- **Delivery: Few products with these capabilities are available in the U.S. market and most contractors are unfamiliar with them.** Bosch and Tekmar have products available, although Bosch controls and boilers can only be installed together. The small size of the U.S. boiler market—approximately six million homes nationwide—makes it unlikely that more manufacturers will develop similar products absent regulation or that manufacturers with products in Europe will begin marketing them in the U.S. Contractors are familiar with outdoor reset but manufacturers reported that contractors have less experience with control configuration for modulating supply temperature based on indoor data and combining these with newer thermostats. The Tekmar system requires installation of a new controller and contractors would likely need additional training to install and program this system effectively.
- **Customer: There is little awareness of—and therefore little demand for—smart supply temperature modulation products.** A program offering would need to help contractors educate customers on the energy and comfort benefits of these technologies and spurring adoption could require generous incentives and/or require coupling this technology with each rebated boiler.

Given the savings uncertainty and limited availability of products designed to modulate supply temperatures to make condensing boilers operate more efficiently, the evaluation team recommends conducting additional literature research to better understand the mechanisms of the Tekmar products in

©2017 Navigant Consulting, Inc.

particular. If initial estimates indicate these controls could be cost-effective, the evaluation team recommends the PAs consider surveying other program administrators in the Northeast region to gauge interest in further research to refine savings estimates.

4.3 Simultaneous envelope and control upgrades

The results of the load reduction/capacity improvement opportunities study for non-controls sites did not show low-cost load reductions or capacity additions at typical HEHE condensing boiler sites. However, there could be greater opportunities in homes where homeowners are also exploring weatherization upgrades. The PAs should consider completing a follow up evaluation study that targets dramatically reducing envelope losses at homes with high-efficiency boilers. This study would evaluate the effects of implementing much more aggressive outdoor reset controls in conjunction with envelope upgrades. This approach faces the following barriers:

- **Technical: Contractors need expertise and good data on home characteristics to effectively program more aggressive curves successfully.** Determining the actual load and emitter capacity for each zone is time-consuming and prone to error, primarily due to unmarked convectors with unknown capacity. If the load/capacity balance is uncertain, it increases the risk of customer complaints when an aggressive outdoor reset curve is used. This is the primary reason that contractors will reject using more aggressive resets. Audit data on envelope upgrade details would give contractors more confidence implementing more efficient settings.
- **Delivery: This would require contractors with both audit and HVAC expertise.** Home Energy Services (HES) vendors could need additional training if they are not HVAC contractors or familiar with condensing boilers, and providing data to heating contractors would likely add burden to HES vendors or the PAs.
- **Customer: Sufficient load reductions will be expensive.** To truly maximize boiler efficiency while maintaining comfort, home heating loads in all zones must be as low as possible. Even with program incentives and HEAT Loans, not all customers will be able to afford full insulation, air sealing and potentially even window upgrades at one time.

©2017 Navigant Consulting, Inc.

APPENDIX A. DETAILED METHODOLOGY

A.1 Site-Specific Analysis of Data from the 2014 High-Efficiency Heating Equipment (HEHE) Impact Evaluation

Prior to beginning this field study, the evaluation team re-analyzed data from the 2014 HEHE study to determine which sites would be good candidates for inclusion and what the optimal outdoor reset curve was for each of those sites. First, the evaluation team screened out sites for one of the following reasons:

- The site did not appear to have reset controls installed.
- The site appeared to have at least one zone in which the load was not being adequately met on the coldest days.

To determine the zones that were not meeting the load, the evaluation team plotted data for each site during the coldest days of the winter and visually inspected the data to determine how long it took to reach the temperature setpoint for each zone.

Next, the evaluation team determined an estimate of the current outdoor reset curve that was programmed to each boiler (using logged supply temperatures) by:

- Limiting the logged data to the times when the boiler was on (gas valve state logger was open)
- Removing data when the system was providing domestic hot water (DHW)—DHW state logger was open—since the system overrides the supply temperature setpoint for DHW operation
- Finding the median supply water temperature for each 1°F bin of outdoor dry bulb temperature

Then, the evaluation team used the observed outdoor reset curve to derive a recommended optimal reset curve that the customer could implement, which would provide increased efficiency while maintaining the same level of comfort of the existing curve. The evaluation team based this on the assumption that the existing curve was providing adequate performance at the coldest temperatures since units that did not appear to be meeting the load had been previously screened out. The steps were as follows:

1. Determine a theoretical relationship between supply water temperature (SWT) and delivered capacity for a typical distribution system. The evaluation team based this relationship on radiator curves taken from the 2008 ASHRAE Handbook of HVAC Systems and Equipment (Section 35.4, Table 2), assuming an indoor temperature setpoint of 65°F.
2. For each site, determine the maximum SWT from the logged data as well as the corresponding maximum capacity delivered by the system. The evaluation team assumed this to also be the maximum heating load for that site since the system appeared to be meeting the load.
3. Determine the load at each outdoor temperature from the max load, assuming that the heating load varies linearly with the temperature difference between the conditioned space and the outside.
4. Using the radiator curve from step no. 1 and the loads derived in step no. 3, calculate the required SWT at each outdoor temperature.
5. Determine a linear approximation of the required SWT curve to program it into the boiler. Limit the maximum SWT to 175 and the minimum to 110.

©2017 Navigant Consulting, Inc.

Finally, the evaluation team used the optimal reset curves to determine a predicted efficiency increase for each site, as follows:

1. Use an assumed delta T between the SWT and return water temperature (RWT)—varying linearly between 20°F at 170 SWT and 10°F at 110—to determine resulting return water temperatures.
2. Using the efficiency model as a function of RWT from the 2014 study, determine the efficiency for both the old and new outdoor reset curves at each outdoor temperature.
3. Using the aggregate loads at each outdoor temperature from the 2014 study, derive a weighted average seasonal efficiency (weighting by the load) for the old and new outdoor reset curves and take the difference between new and old.

The evaluation team then used the predicted seasonal efficiency increase for each site to prioritize sites for the new study and to remove any sites that did not show much potential for improvement from optimized outdoor reset controls.

A.2 Field Data Analysis

The field data analysis for this study was broken into three main parts:

1. Logger data processing and quality control (QC)
2. Development of efficiency models
3. Calculation of seasonal efficiency improvements

Logger Data Processing and QC

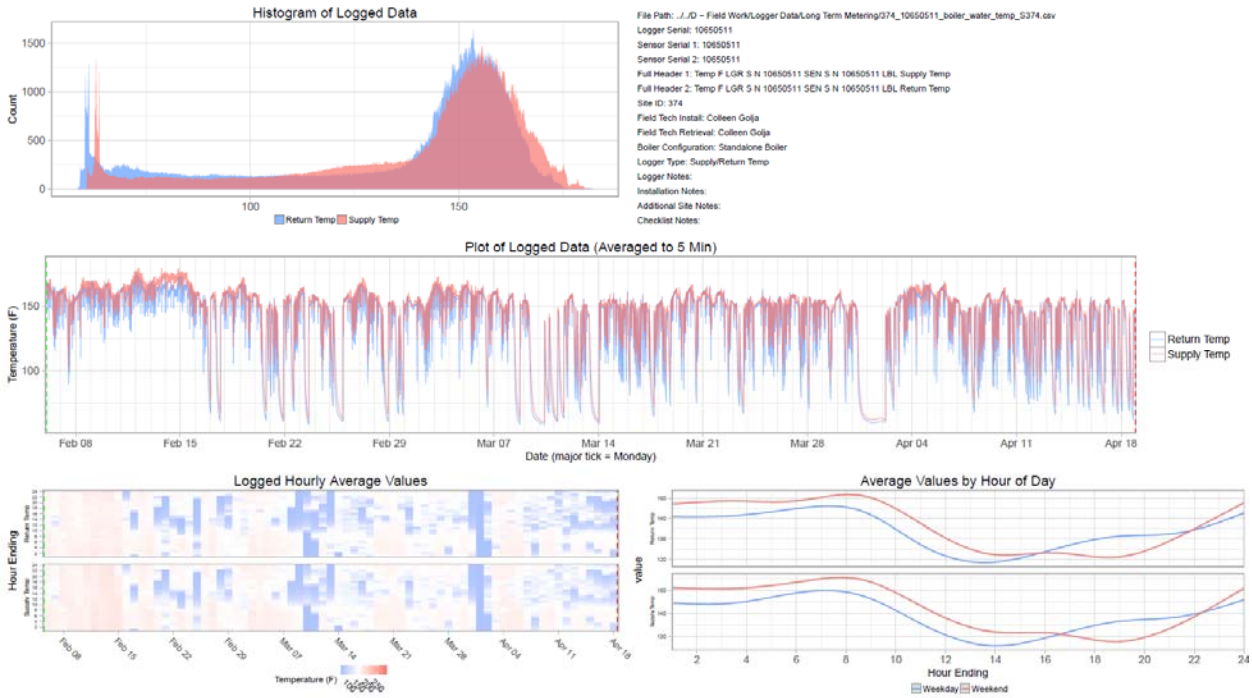
To ensure the quality of the final analysis, the evaluation team underwent an extensive data cleaning and QC process. First, the evaluation team plotted and visually inspected the data from each individual data logger file for the following:

1. Bad data: Data that was clearly out of a reasonable range for the application (e.g. water temperatures above the boiling point)
2. Missing data/loggers that filled up before the logging period was complete
3. Flickering: Repeated quick on/off changes in a state logger, which can be due to a bad connection to a probe or some other interference

The evaluation team adjusted the data from each logger as appropriate—flickering was filtered out of the data, sites with incomplete/missing data had their analysis limited to the dates that had good data, and loggers with suspect/bad data were removed from the analysis entirely. Figure 22 shows an example of a QC chart for one of the loggers.

©2017 Navigant Consulting, Inc.

Figure 22. Logger QC Chart Example



Source: Navigant analysis of metered data

Once the evaluation team checked the individual logger files, it combined the data from all of the different loggers for each site and then combined that data with the data from the 2014 study.

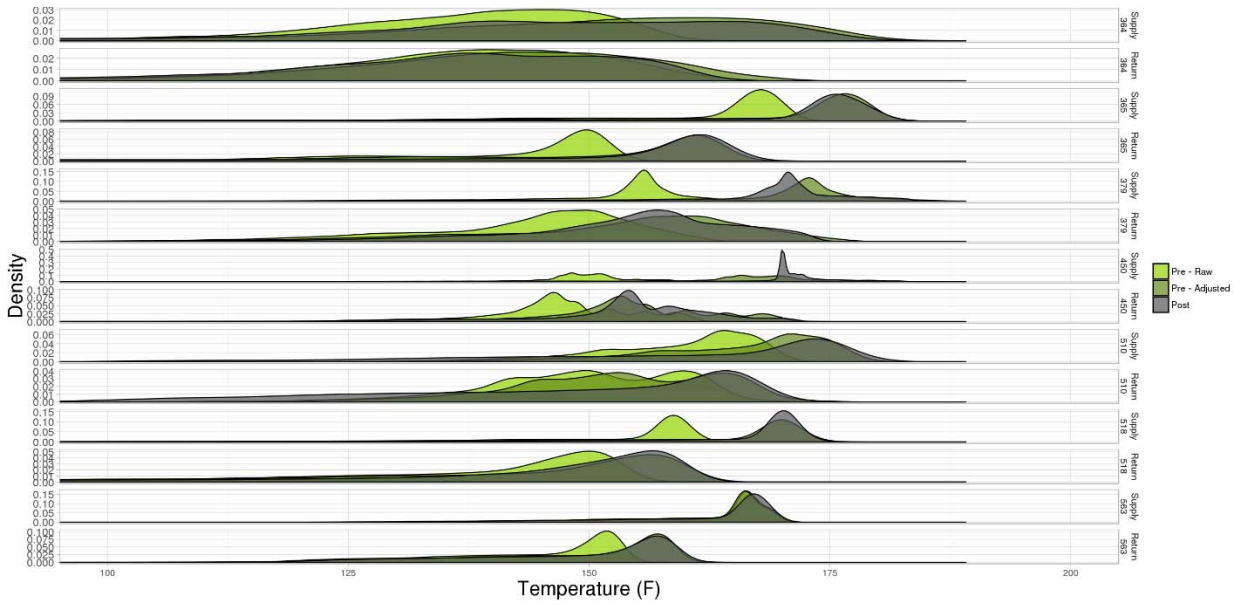
Next, the evaluation team made an adjustment to the SWTs and RWTs from the 2014 study to compensate for the differences in temperature sensors and installation characteristics between the two studies. The steps for each site that had integrated DHW were as follows:

1. Limit the data to the times when the system was calling for DHW. In theory, the SWT for DHW operation should be independent of the outdoor reset curve; thus, these temperatures should be consistent between the two studies.
2. Calculate the 90th percentile of SWT and RWT observed during DHW operation in both studies and the percent difference between the values in the two studies.
3. Scale the temperature values (for all data, not just DHW operation) from the 2014 study to match the ones in the current study.
    a. Assume that the temperature offset varies linearly by the difference between the water temperature and an assumed air temperature (80°F) in the enclosure in which the sensor was installed
    b. Add a temperature offset to the 2014 SWT and RWT data scaled from 0 at <80°F to the full DHW temperature difference at the DHW temperature
4. Visually QC the resulting adjusted SWT and RWT data and make changes to the temperature adjustment until the final distributions of the 2014 and current data line up.
5. For sites without integrated DHW (and thus a site-specific temperature adjustment could not be calculated), apply the average of the site-specific temperature adjustments.

©2017 Navigant Consulting, Inc.

The final distributions of SWT and RWT are shown in Figure 23 (with 2014 data labeled as “Pre” and current data labeled as “Post”).

Figure 23. Logged Supply and Return Temperatures During DHW Use



Source: Navigant analysis of metered data

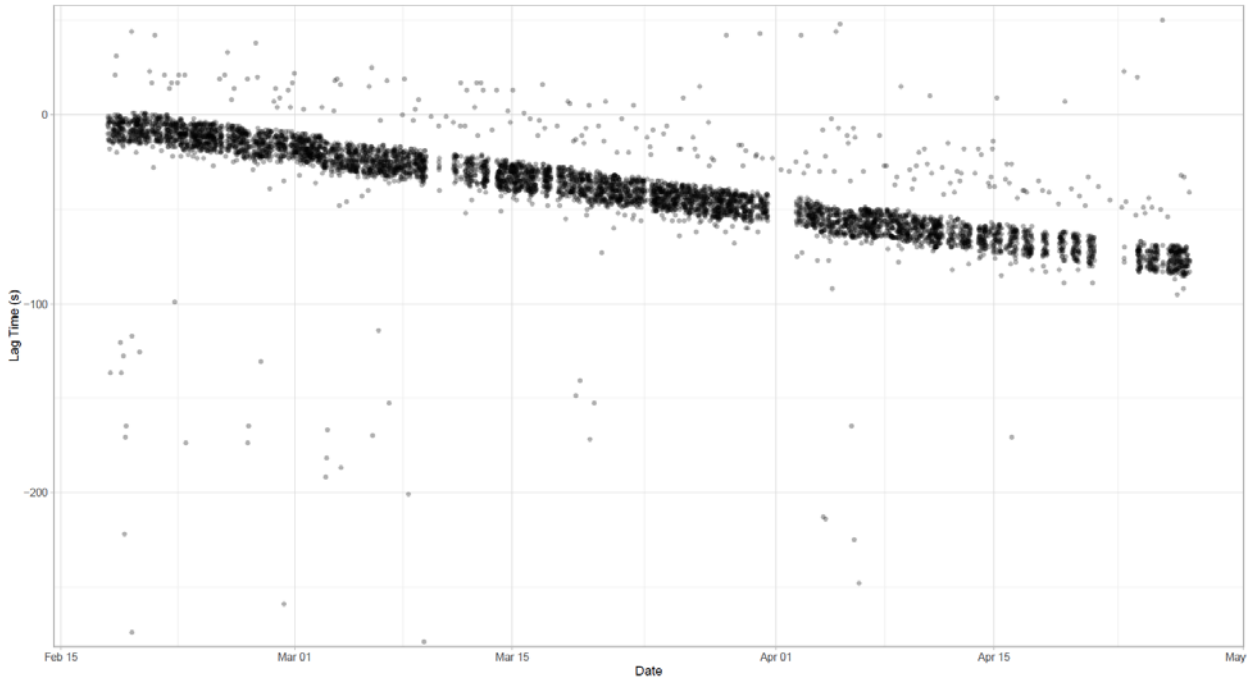
The analysis was highly dependent on the synchronization of the data from different data loggers, so the evaluation team also investigated logger time drift and made adjustments where it was found. In particular, the evaluation team found that most of the loggers that were collecting SWT and RWT data had some degree of time drift. The evaluation team adjusted the data from those loggers as follows:

1. Determine each time that the SWT began to increase—defined as greater than 0.02°F per second.
2. For each time that the boiler turned on (gas valve state logger switched to “open”), calculate the time difference between the boiler turning on and the nearest temperature increase. Assume that this time difference should be fairly constant for a given boiler.
3. Plot these time differences over the logged period; where there is a trend (increasing or decreasing), visually determine the average difference, which represents the total time drift over the logged period.
4. Adjust the timestamps of the logged data, scaling linearly from 0 at the beginning of the data to the full time drift at the end.
5. Iterate steps 1-4 until the adjusted time differences show no trend from the beginning to the end of the logged period.

An example of the plots before and after the adjustment is shown in Figure 24 and Figure 25:

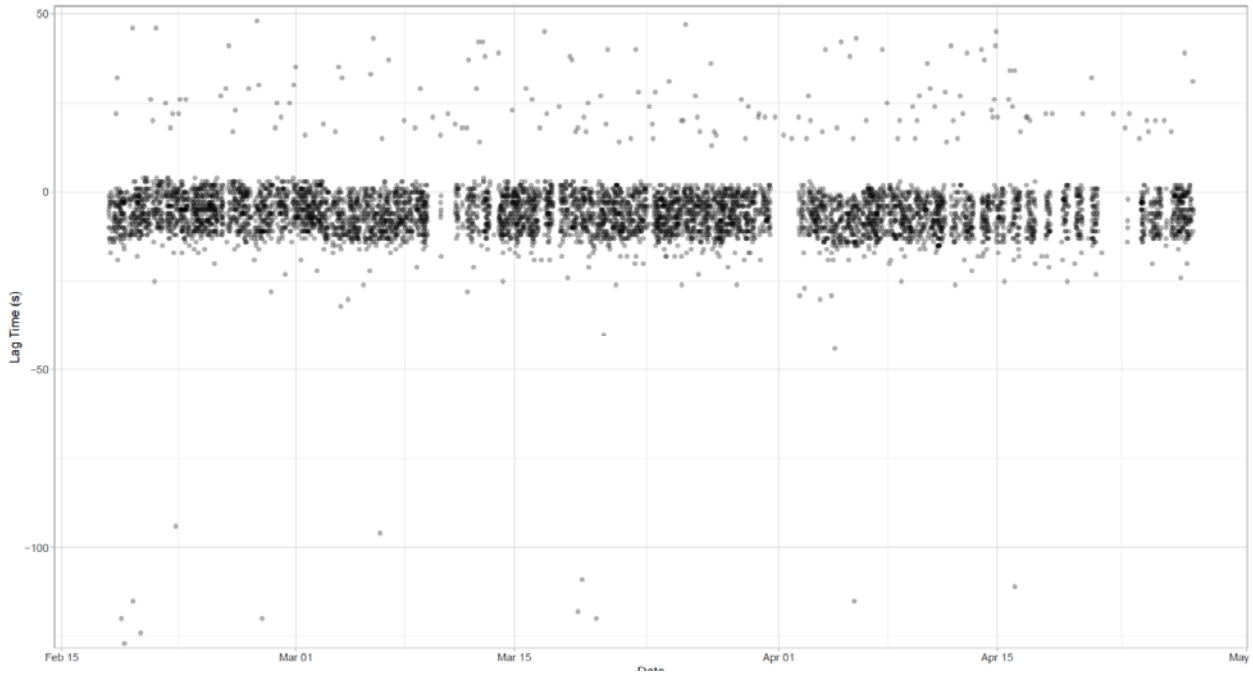
©2017 Navigant Consulting, Inc.

Figure 24. Lag Time Between Gas Valve and Temp Increase for Site 365: Before Adjustment



Source: Navigant analysis of metered data

Figure 25. Lag Time Between Gas Valve and Temp Increase for Site 365: After Adjustment



Source: Navigant analysis of metered data

Once the evaluation team quality controlled the individual loggers and adjusted the temperature loggers for temperature offset and time drift, the final QC step involved making site-level QC plots of all of the logged data for the site. The evaluation team made plots for a sampling of the dates/times that the data

©2017 Navigant Consulting, Inc.

was collected to check for overall alignment between the different loggers and any suspect operation (e.g., SWT and RWT increasing when the boiler gas valve was closed). An example of a site-level QC plot is shown in Figure 26.

Figure 26. Logged Data for Site 364 2016-03-07

Source: Navigant analysis of metered data

Based on these QC checks, the evaluation team dropped seven sites from the study:

1. Two sites were cancelled due to customer complaints
2. Three sites had failures of one of the key loggers needed for the analysis (gas valve or boiler water temperatures)
3. Two sites had suspect data that the evaluation team was unable to explain: one had many periods where the boiler was on (gas valve was open) and SWTs/RWTs were decreasing (when they would be expected to increase), and the other had RWTs that were almost identical to the corresponding SWTs.

Development of Efficiency Models

After cleaning and doing QC work on the logger data, the evaluation team developed updated efficiency models relating RWT to overall unit efficiency using both the logged data and data from spot measurements of efficiency and gas consumption performed during the site visits. Recognizing that these efficiency models would be important drivers of the overall results, the evaluation team took several sets of spot measurements at each site: one during the install visit and two during the retrieval visit (standard and DHW operation). First, the evaluation team combined and transferred the data, and then performed further QC checks using the following steps:

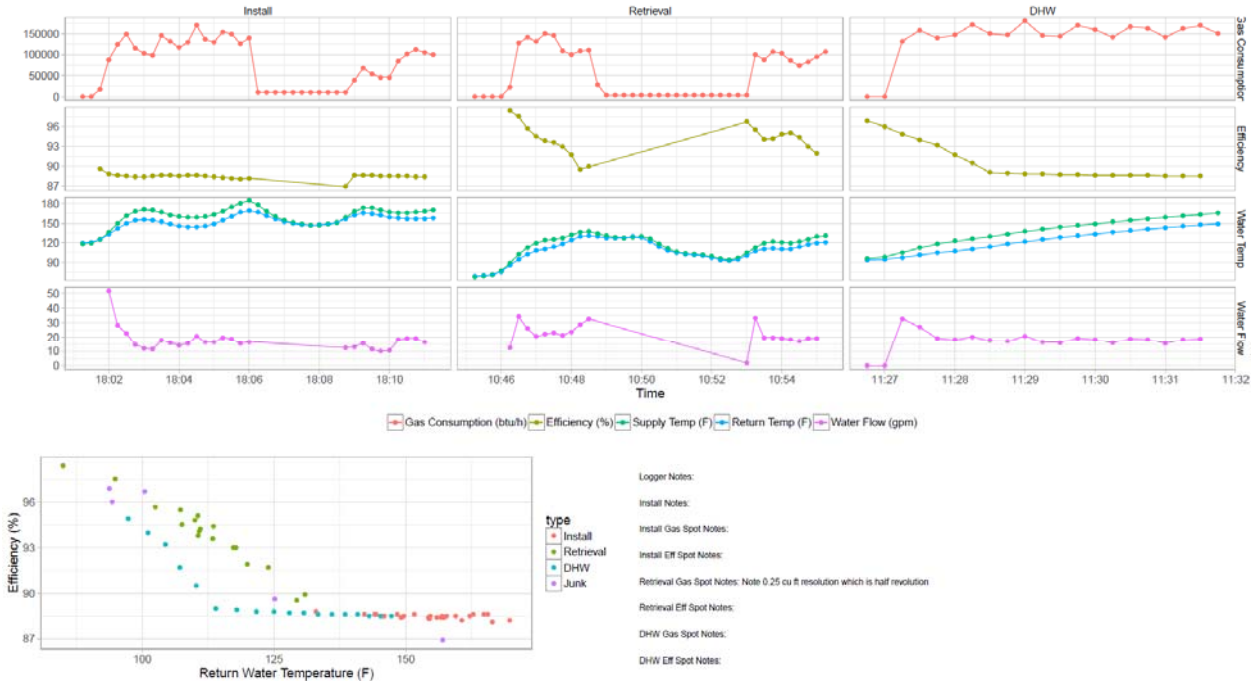
1. Convert spot measurement data (gas consumption/efficiency at intervals) into time-series data.
2. Combine spot measurement data with logged temperature data; plot all data.

©2017 Navigant Consulting, Inc.

3. Adjust timestamps from spot measurements to line up with boiler temperatures based on visual QC. Since there may have been discrepancies between the clocks used to do the spot measurements and the loggers' internal clocks, the evaluation team made adjustments based on visual inspection to align the start of the increase in SWT and RWT temperatures with the start of the gas consumption.
4. Adjust efficiency for some sets of spot measurements so that the base efficiencies of all sets of measurements line up. There are two roughly linear parts to the efficiency model for each site: the relatively flat portion at higher RWTs and the steeper portion at lower RWTs (when the unit is condensing). In some cases, the evaluation team adjusted different sets of spot measurements so that all measurements at a given site had the same efficiency in the non-condensing portion of the curve. This compensated for variations in the efficiency measurements due to changes in outdoor temperature and calibration of the efficiency probe.
5. Throw out any data that looks unreasonable (e.g. efficiency values of 100%, which is impossible to achieve in practice).

An example of the QC plot used to adjust the spot measurement data is shown in Figure 27.

Figure 27. Spot Measurements for Site 364

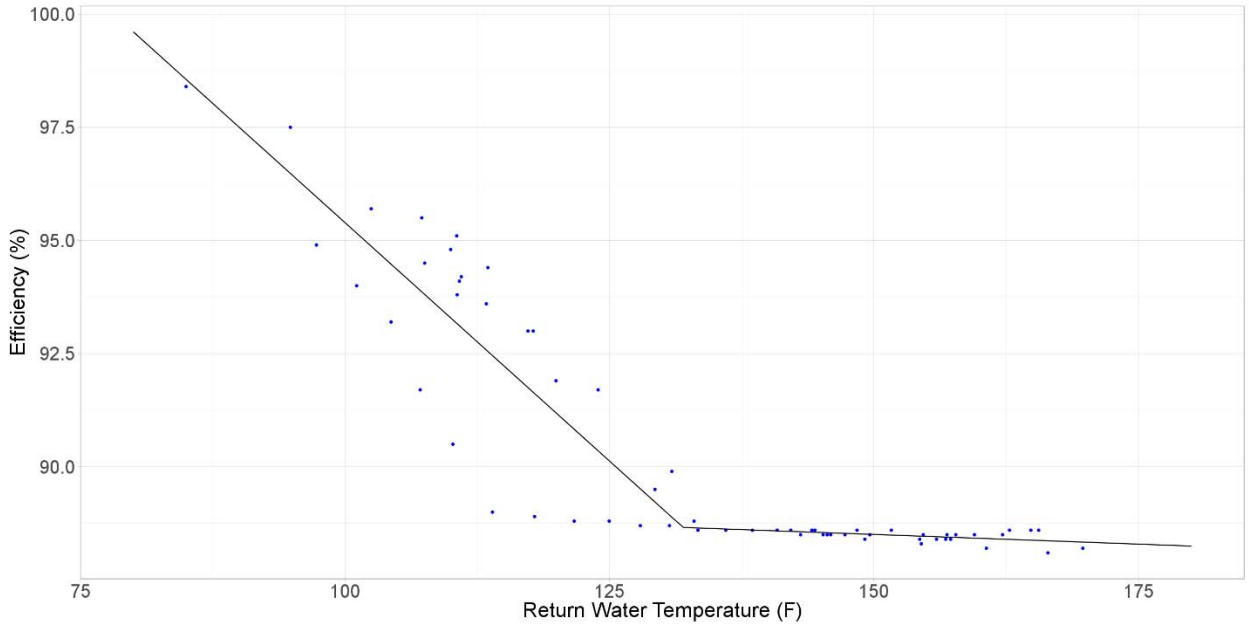


Source: Navigant analysis of metered data

Once the evaluation team had cleaned and checked the data for quality, it determined which sites had sufficient data for a site-specific efficiency model by looking for the segmented linear shape that is characteristic of a condensing boiler efficiency curve. The evaluation team then created segmented linear models (SLMs) of efficiency as a function of RWT for each site that had sufficient data, as well as an aggregate model using the data from all sites and data from the 2014 study. An example plot of the spot measurement data and the resulting SLM for one site is shown in Figure 28.

©2017 Navigant Consulting, Inc.

Figure 28. Efficiency Model for Site 364



Source: Navigant analysis of metered data

Calculation of Seasonal Efficiency Improvements

After developing the updated efficiency models, the final step was to combine them with the logged data to calculate seasonal efficiency improvements. The steps for doing so were as follows:

1. Combine logged data with outdoor temperature data from the National Oceanic and Atmospheric Administration (NOAA) using the Worcester station for all sites
2. Use efficiency models (both site-specific and aggregate for sites with a site-specific model, resulting in two sets of numbers) to assign efficiency to all logged data by RWT for all data points when the boiler was on
3. Calculate the weighted average efficiency for each 1°F bin of outdoor temperature, weighting by the temperature difference between the SWT and RWT (used as a proxy for load on the system)
4. Calculate the seasonal efficiency for the existing (2014 data, or “pre” case) and implemented (“post” case) outdoor reset curves by taking the weighted average efficiency across all outdoor temperature bins; the total load observed in each outdoor temperature bin from the 2014 study was used as the weighting factor

This resulted in a range of seasonal efficiency improvement values for most sites, which represented the different outcomes of using the site-specific versus the aggregate efficiency model.

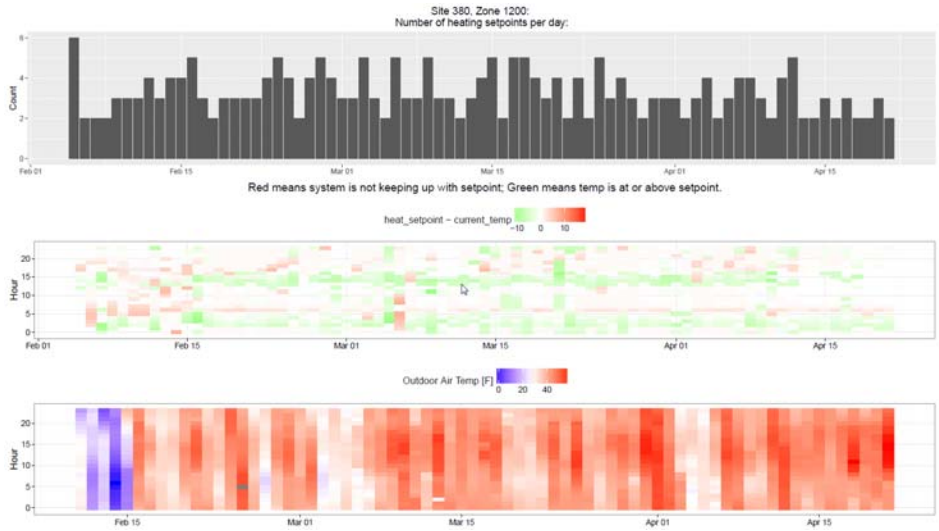
©2017 Navigant Consulting, Inc.

APPENDIX B. THERMOSTAT DATA VISUAL QC

B.1 Daily Setpoints and System Performance

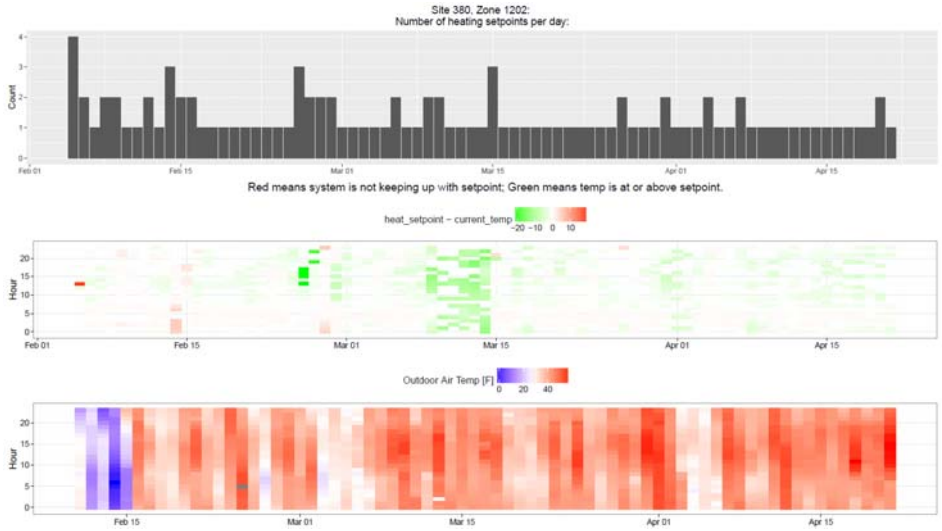
For each zone in each site, the evaluation team used the following data visualization (depicted in Figure 29 and Figure 30) to identify which occupants adjusted thermostats in which zones. The top pane shows a count of unique setpoints per day; the middle shows the difference between the heating setpoint and actual temperature; and the bottom shows outdoor temperature. The x-axis shows time moving left to right, and the y-axes of the two bottom panes shows the hour of each day from 1-24.

Figure 29. Main Zone at Site 380: Daily Interaction from Occupants



Source: Navigant analysis of smart thermostat data

Figure 30. Secondary Zone at Site 380: Occasional Interaction from Occupants



Source: Navigant analysis of smart thermostat data

©2017 Navigant Consulting, Inc.

B.2 Setpoint Schedules

For each zone and each site, the evaluation team plotted the schedules programmed in the original thermostats and in the new smart thermostats to compare them with setpoints as they were recorded throughout the study.

Figure 31. Site 380 Zone Setpoints

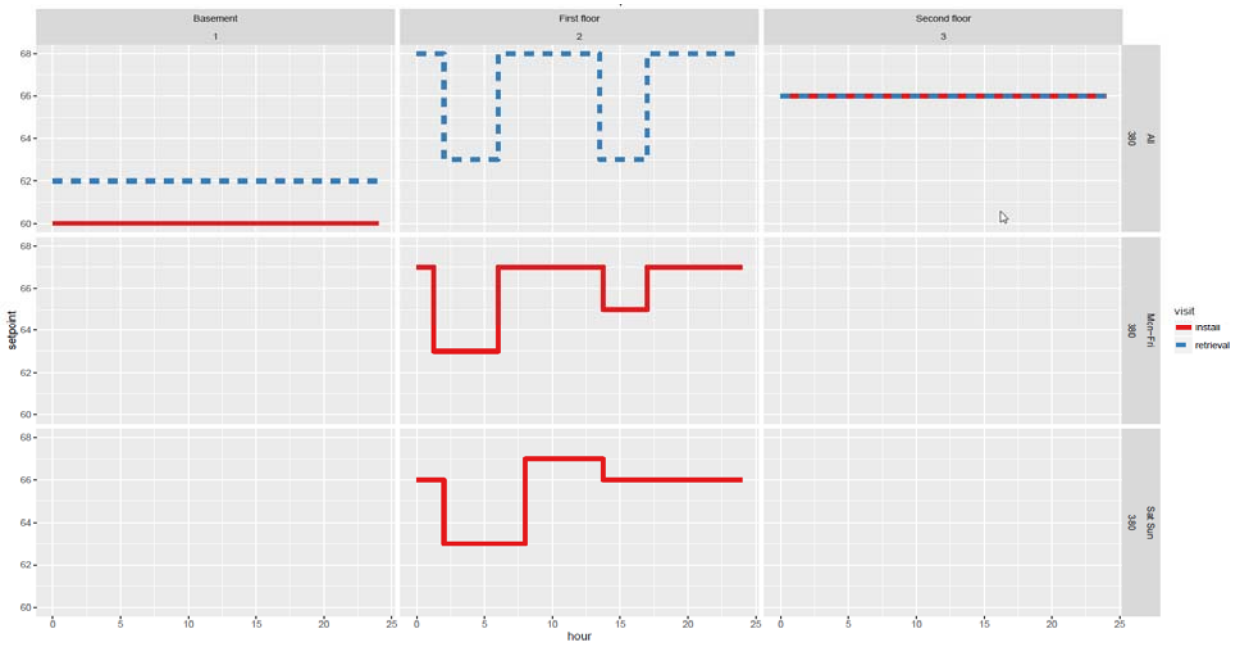
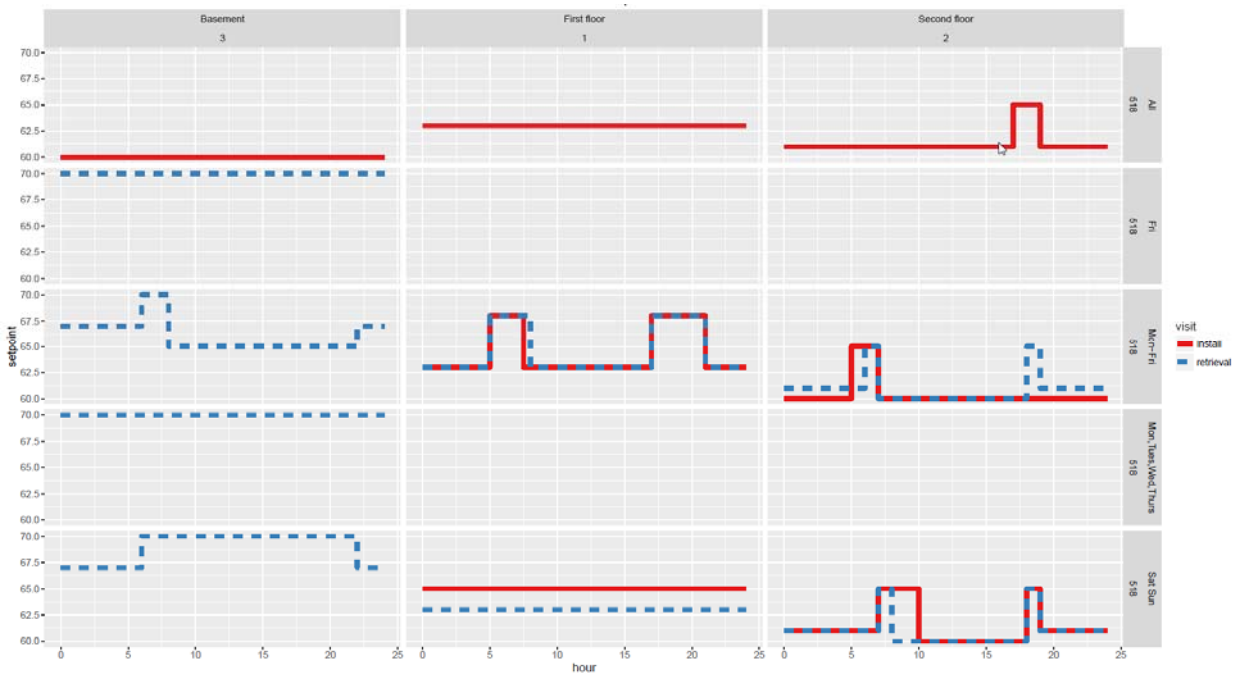


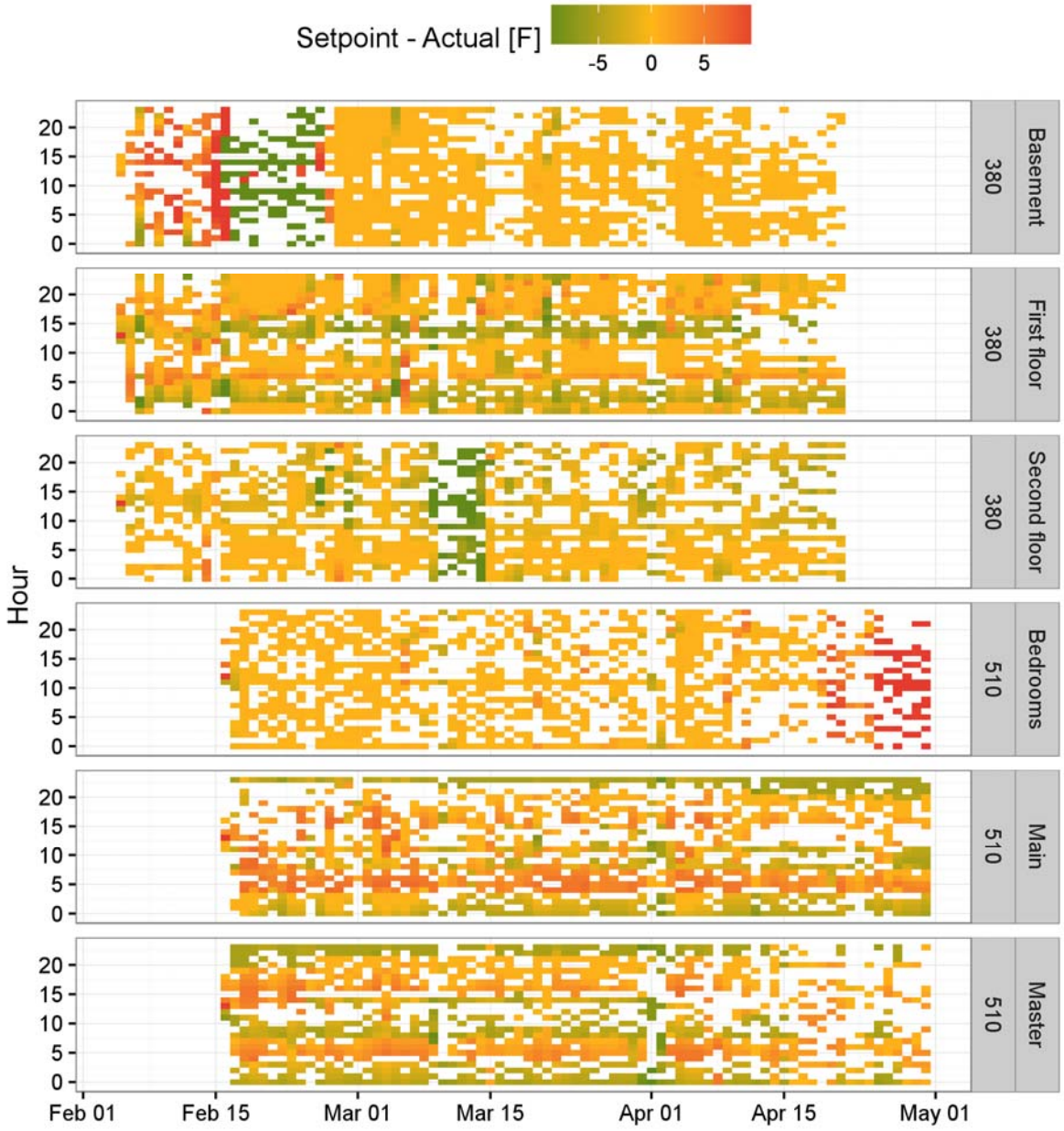
Figure 32. Site 518 Zone Setpoints



B.3 Actual vs. Setpoint

Inspecting the hourly average difference between the heating setpoint and actual temperature makes it easy to identify long and short periods of the day when the setpoint is not met, periods of vacation, or other anomalies. In Figure 33, the first floor at Site 380 shows a single hour every day at 6 a.m. when the setpoint is not met, while the Main zone at Site 510 shows a 4-hour period from 4 a.m. to 8 a.m. when the setpoint is not met.

Figure 33. Sites 380 and 510: Difference Between Heating Setpoint and Indoor Temperature

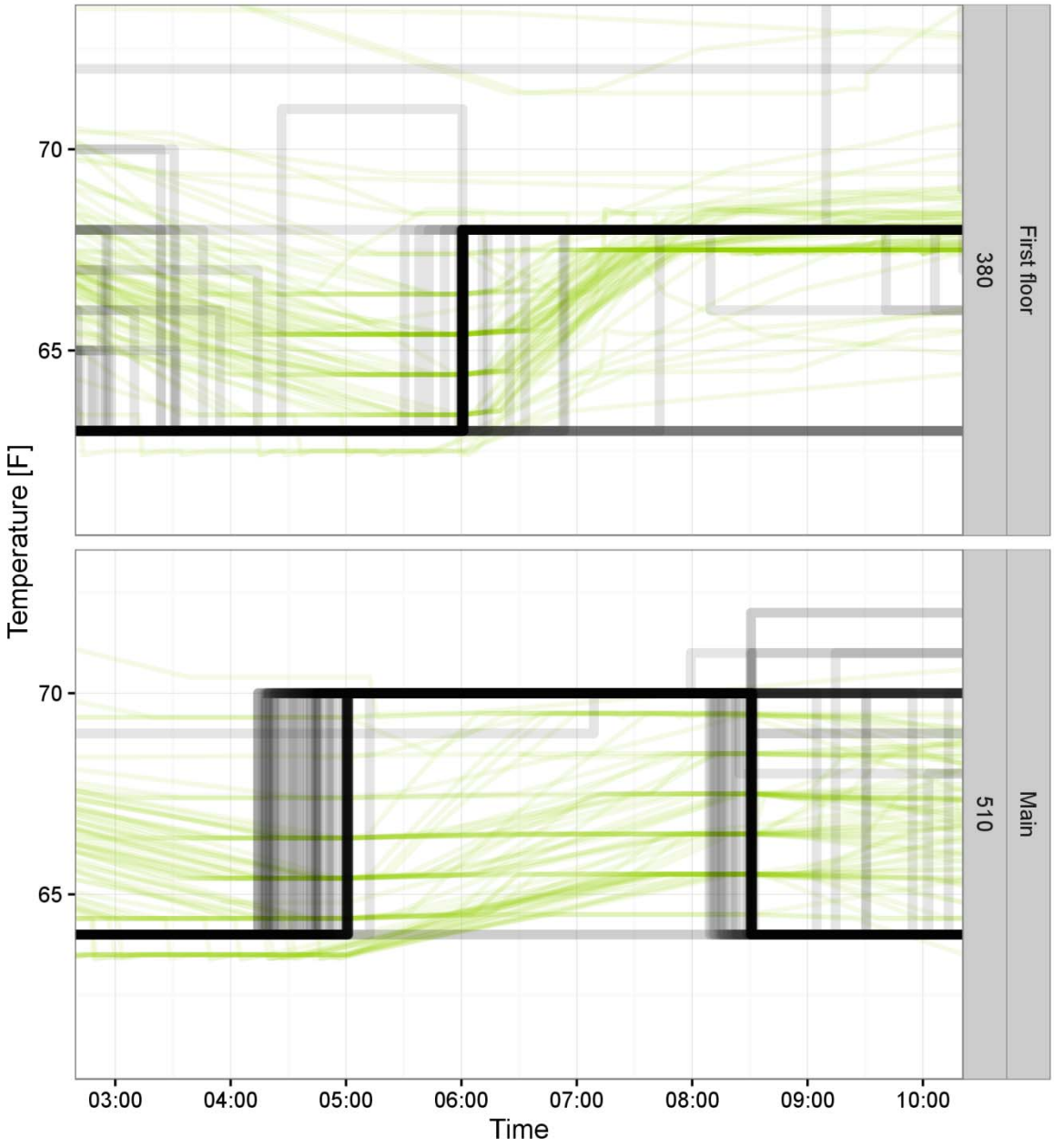


Source: Navigant analysis of smart thermostat data

B.4 Morning Setup

Sites with setbacks typically stress their system the most in the early morning hours when the nighttime setback is removed and the boiler is attempting to heat the home during the coldest part of the day. Figure 34 is an example of a chart that the evaluation team used to identify sites with fast or slow responding systems and to validate whether occupant temperature complaints were due to actual issues with performance.

Figure 34. Setpoint (Black) and Actual Temperature (Green) for All Days in Study: Sites 380 and 510, Primary Zones



Source: Navigant analysis of smart thermostat data

In Figure 34, it is clear that the system at Site 380 is able to respond quickly, meeting the setpoint in roughly 1 hour after the morning setup, while the system at Site 510 takes hours to raise the temperature even a few degrees. The occupants at Site 510 complained of temperature issues, which was partly due to a large setback and partly due to the system responding slowly.

©2017 Navigant Consulting, Inc.