BEMS on a Budget: Energy Savings with Low-Cost Monitoring Systems in Affordable Housing

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ABSTRACT

Like recent evolutions in automobiles, high efficiency heating and hot water equipment is driven as much by software as hardware. The equipment has become so complex that it is leading to inappropriate installations and poor operation by untrained maintenance staff charged with keeping the facility going. This results in lost operational savings from wasted energy, reactive, disruptive and costly maintenance emergencies and potentially premature equipment replacement.

To provide continuous commissioning to the owner, New Ecology developed a low-cost, real-time monitoring system to leverage new equipment's on-board sensors, combine it with carefully located analog sensors, and bring this data to the cloud. The same approach, slightly simplified, can also produce benefit in systems with older equipment. These data, combined with technical expertise, enables optimized performance to be pursued and sustained, and provides critical operational feedback to both short- and long-term maintenance functions.

This paper draws on site assessments and data from installed monitoring equipment in 113 multifamily buildings in Massachusetts and Rhode Island to assess hydronic heating and domestic hot water equipment operations, performance, and energy efficiency. In buildings monitored in the last year, 80% are overheating the building, 58% are using inaccurate outdoor temperature readings to modulate load, and over 60% of hot water heaters are cycling excessively. We expose a number of commonly found problems behind the inefficiencies, both expected and not, and deliver energy savings calculated to date.

Introduction

Large buildings, like office towers, hospitals and university buildings, commonly have building energy management systems (BEMS) that control the operation of heating, ventilation and air conditioning and domestic hot water (DHW) systems and can be effectively used to monitor and optimize performance. Almost no mid-sized buildings, like multifamily apartments, have such systems. Wide scale deployment of BEMS in affordable multifamily buildings has been limited because of high initial costs and the degree of expertise needed to understand and operate these systems.

In New Ecology's many years of work in greening affordable multifamily properties, we have observed a wide variance in energy performance between buildings that should be performing similarly and inconsistent savings from the installation of high efficiency equipment. We used our expertise in building operations, engineering and data analysis to figure out why and concluded that the complexity of high efficiency systems has outpaced the ability to operate them effectively. The lack of BEMS means there is no data that can be used to identify problems, fine tune operations or test the conventional wisdom. What's more, the staff typically assigned the task of operating the heating and water systems are inexperienced, under-trained, and over-extended. Most owners believe that savings that might be achieved is not worth the cost of bringing in optimization experts. They also know that bringing in an expert for a one-time fix is not equivalent to creating the capacity to keep watch.

Ratepayer funded energy efficiency programs (EE programs), most often administered by utilities, have played an important role in providing consistent opportunity for implementing energy efficiency upgrades in these buildings. In recent years, these resources have become increasingly available to multi-family housing, which historically fell through the crack between commercial and residential programs. Few, if any of these programs have addressed the issue of optimizing the performance of the retrofits they have incentivized. In fact, most energy efficiency programs have focused heavily on lighting retrofits and other low hanging fruit.

As the supply of low hanging fruit is exhausted it is becoming necessary to find new measures to dramatically reduce energy consumption and greenhouse gas (GHG) emissions. (Grueneich 2015) Electrification is one new area of focus in EE programs, transitioning consumers from gas and oil to a power grid that is getting progressively cleaner as renewables are brought into the mix. Unfortunately, the time frame over which this will occur is long, the expense is high, and effective programs to do this at scale in older buildings, especially in cold climates, have yet to emerge. The world needs dramatic and *rapid* reductions in GHG emissions to mitigate climate change in the *short* term while the political will, funding and systematic change needed to increase electrification and transition more fully to renewable energy spreads. Energy efficiency programs across the country, in their unique role to make accessible and accelerate the adoption of measures with significant energy savings potential in the short term, must do better.

New Ecology has developed an approach that has the potential to be a new energy efficiency program measure that will produce short term impact - a low-cost, remote monitoring system for gas-fired heating and hot water systems. This system, coupled with analytics and implementation, has been demonstrated in the Northeast, and delivered notable energy savings and GHG reductions. The system is scalable and cost-effective for a large number of buildings, not just the affordable multifamily projects that comprised the demonstration.

Demonstration Projects in Massachusetts and Rhode Island

In August of 2016, New Ecology received a competitive grant award from the Massachusetts Clean Energy Center to demonstrate that targeted, remote monitoring of central boiler system operations can identify fuel/cost saving opportunities without sacrificing tenant comfort or domestic hot water availability. New Ecology's proposal included a match from a multi-year grant awarded us from the JPB Foundation. In January 2017, National Grid, the sole gas and electric public utility in Rhode Island, awarded New Ecology funds for a project of the same type. In all, remote monitoring systems were installed 103 buildings in Massachusetts and 10 in Rhode Island.

Methodology

New Ecology devised a multi-step approach appropriate for methodically working through and documenting a large-scale demonstration project. This included development of a process to identify and assess boiler rooms, determining what data points to collect and how to collect them, what off-the-shelf products to purchase to assemble a low-cost data collection system, how to build and test the assembly before and after installation, and how to combine and interpret the data collected for the purpose of saving energy.

Remote Monitoring System Design. The design of the remote monitoring system considered the data points being collected, the boiler room environment, the need to transmit data out of the boiler room to our cloud-based database, and the need to conduct quality control testing of each system before deployment. A NEMA enclosure was selected to protect and serve as a way to mount our equipment – a cellular modem, input modules and power supply.[1] Modbus cards were installed in "smart" boilers,[2] and less sophisticated boilers had relays installed to note on/off events. Multiple analog temperature sensors were located on pipes throughout the boiler room to measure conditions like heating water supply and return and DHW storage tank temperatures. The data collected was sent to a control center in the NEMA enclosure and transmitted to the cloud by cell modem. On average, 62 data points were collected at one-minute increments for each installation.

Outreach & Assessment. New Ecology enjoys a large and diverse client base of owners, developers and managers of affordable multifamily properties, greatly simplifying outreach efforts. We sought to work in properties that met the following criteria:

- Gas or oil heating fuel;
- Central heating boiler;
- One to one relationship between gas meter and building;
- Boiler age between 2 and 10 years old; and
- Baseboard or fan coil emitters.

Participants signed a no-cost agreement that stipulated they would maintain a WegoWise subscription and provide New Ecology access to their account,[3] and that we could implement our recommendations at their buildings. Between the New Ecology staff knowledge of our client's buildings, and information gleaned from WegoWise, the site selection was narrowed and ultimately one of our engineers conducted 133 boiler room assessments. Having the same engineer do all of the assessment work ensured a level of consistency in the study approach than what the assessment form alone could guarantee. The assessment collected valuable information that was later utilized in system fabrication, installation and analysis.

Fabrication & Installation. Each monitoring system was built to match the assessment, and 100% of the fully assembled systems, including wired temperature sensors, were tested before being installed in a participant's building. During installation, all sensors were carefully mounted, after cutting into the pipe insulation, labeled and the pipes were re-insulated. The installations were neat and intentionally unobtrusive. Prior to the installation crew leaving a site, connectivity via cell modem back to our office was tested to ensure data could flow to our cloud-based database. All of the monitoring systems in Massachusetts, except one, were installed by

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[1] NEMA stands for National Electrical Manufacturers Association, an organization that, among many other things, has set standards for weather-proof enclosures.

[2] Modbus is a communications protocol and hardware specification in widespread use in the electronics and computing industries that allows intelligent devices to share information.

[3] WegoWise is an on-line database of, primarily, multifamily properties across the country. It automatically imports data from many utilities and provides a platform to benchmark building energy and water performance.

the end of 2016. In Rhode Island, where the project did not commence until late January 2017, the installations were completed in March 2017.

Analysis. After early data reporting, it became clear that the installations should be grouped to ease analysis. In all, six analysis groups were created, half of which were Modbus enabled boilers, meaning that the signals being sent to the boiler could be read and the boilers response measured. The other three groups had less sophisticated, analog control systems, but some boiler commands were inferred through combinations of other data points collected. The six groups are:

- 1: Lochinvar boilers, separate heating and DHW systems, Modbus enabled
- 2: Lochinvar boilers, combined heating and DHW systems, Modbus enabled
- 3: Burnham boilers, analog, on-board controls
- 4: Mixed manufacturers, analog, Tekmar controls
- 5: Mixed manufacturers, analog, basic controls
- 6: Mixed manufacturers (not Lochinvar), Modbus enabled

Lochinvar boilers were singled out for the sole reason that many were installed, and continue to be installed, through the Massachusetts Low-Income Multifamily Energy Efficiency program. Burnham boilers were singled out because their controllers had greater functionality than the other analog boilers.

The analysis protocol for each group was guided by the potential for making improvements given the existing equipment and controls. The basic approach was to look for opportunities to lower water temperatures while still satisfying load, to address settings that cause frequent equipment cycling and to maintain a channel of communication with the building maintenance staff for reporting of complaints.

Before the initial analysis, data was collected from each site for a period of time that allowed for recording system behavior under existing conditions over a wide range of outdoor air temperatures. Depending on when the remote monitoring system was installed, it could take months to experience the wide range of winter temperatures contained in a normal season. It was important to allow enough time to fully grasp the interaction between the equipment, the building's distribution system and the building itself before analyzing the data and recommending changes. When enough data had been collected, it went through a quality control process and was then analyzed manually by an engineer and checked.

Optimization. Once the initial optimization strategy was determined, a notice was prepared for the participant describing the recommended set-point changes and identifying other observations that were affecting performance but were outside of the project's scope and budget to resolve. Examples of this include broken system sensors and DHW mixing valves in need of service. Shortly after the participant agreed to the recommended changes, they were implemented by New Ecology staff to ensure they were completed as intended and had the desired result. Data collection continued, with periodic check-in for complaints, for a period of time long enough to enable comparison of system behavior before and after implementation and calculate the resulting impact.

Results

Data collection continues today at 85% of the original 113 sites. Sites were eliminated if the participant disconnected our monitoring equipment, replaced any of the equipment being monitored or if consistent data connectivity was problematic. In all, we began with monitoring 312 boilers and water heaters, 184 of which are Modbus enabled.

Fifty-five sites have been *excluded* from the results being reported at present. In addition to the reasons noted above, they are excluded at this time because there were fewer than three months of post-optimization data, there was a disruption in data collected that interfered with savings calculations, we are waiting for action by the site on needed repair or maintenance, and, in a small number of sites, there were complications beyond the project scope and budget. Also, in six instances, we determined that settings had been changed after our optimization efforts, thus negating our work. Most of the 55 now excluded will be able to be included in the coming year.

The results reported in this paper are for 56 sites that were optimized and where we have at least three months of gas data since the changes were made. Table 1 provides a summary of metrics for all 56 buildings based on normalized utility bill savings data as of April 2018. All data analysis is done in accordance with the International Performance Measurement and Verification Protocol (IPMVP),[4] by an IPMVP certified staff member. We anticipated energy savings of between five and twenty percent. The current average across all 56 buildings is 10.1 percent.

Table 1 – Overall program results, to date

Metric	**Value**
# sites with 3+months post implementation data and positive savings	56
Average savings from this group, %	10.1
Running total of energy saved from this group, therms	84,328
Reduction in GHG emissions to date, lbs CO_2e	18,591

Table 2 provides similar metrics by analysis group as well as the number in each analysis group at the start of the project versus the number included in the results presented. Please note that the data presented in both Tables 1 and 2 do not represent a complete year for all locations. The following figures explain how improved performance was achieved.

Table 2 – Overall program results by analysis group, to date

Analysis group	# at start	# in results	Average savings (%)	Running total of energy saved (therms)
1	36	22	11.0	50,969
2	22	15	9.8	14,008
3	14	8	11.9	7,883
4	14	4	7.7	6,085
5	16	1	8.3	1,969

[4] The IPMVP was originally developed in 1997 to help increase investment in energy and water efficiency, demand management and renewable energy projects around the world. IPMVP presents common principles and terms that are widely accepted as basic to any good measurement and verification process.

6	11	6	5.9	3,415
Total	113	56	10.1	84,328

The problem of a poorly located outdoor air sensor existed in almost 60% of the buildings in the project. Figure 1 illustrates the effect this condition can have on boiler operation. The y-axis is system supply temperature and the x-axis is outdoor air temperature. The graph contains three lines – the green line is the local weather data, the blue is the outdoor air sensor temperature data provided to the boiler controls, and the red line is the system supply temperature in response to the temperature data received from the outdoor air sensor.

The blue line shows clearly that the sun begins to affect the outdoor air sensor temperature reading consistently each day. This rising value eventually informs the boiler that it is warm outside, and the boiler goes into warm weather shutdown. The actual outdoor temperatures are actually around 20°F colder that that being reported to the boiler. Once the sun effect is lessened, the boilers turns back on and must work very hard to catch up to supply what the building needs. This scenario is an inefficient way to operate and also creates a condition ripe for tenant complaints. Tenant complaints may in turn result in an inappropriate response from a building operator, i.e., the operator may increase set-points to quell the complaint, but the core cause is never understood and the newly implemented set-points keep the system in an inefficient state.

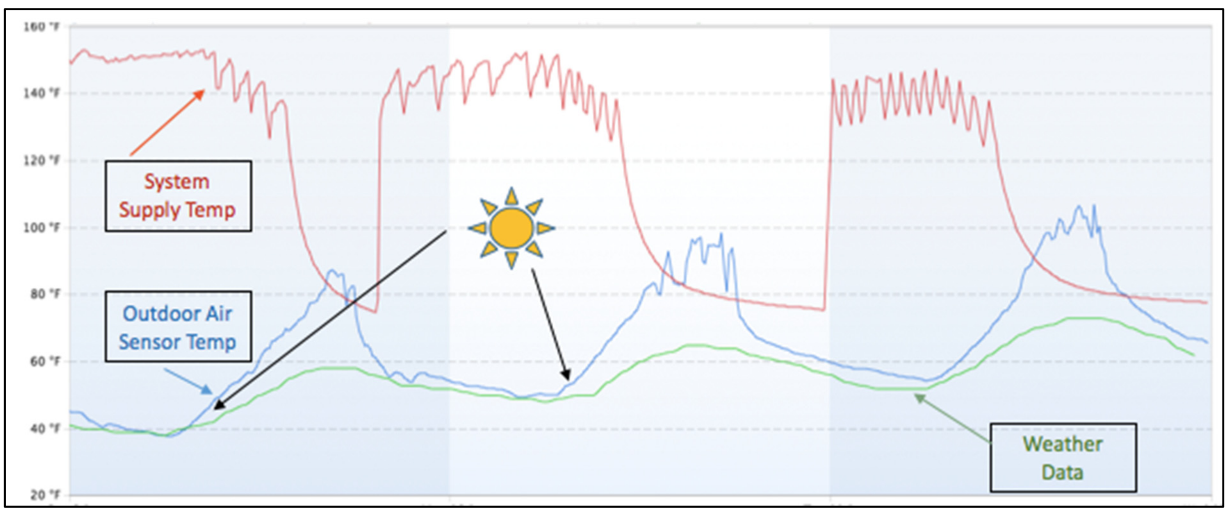

Figure 1: Outdoor air sensor affected by the sun

Figure 2 shows the performance of a heating system prior to implementing any recommendations. This site is part of Analysis Group 1, but results are fairly typical across Analysis Groups.

The y-axis represents the system heating supply temperature to the building in response to input from the outdoor air sensor and the x-axis represents local weather station data. Since over half of the sites in the demonstration, this one included, had poorly located outdoor air sensors, weather station data was used as a better measure of actual, local conditions when evaluating performance. The dark blue lines in Figure 2 represent the upper and lower limits of the existing outdoor reset curve that was programmed into the boiler controls at the time of assessment. Each blue x represents a data point recorded every 15 minutes. For example, the graph depicts that at an outdoor temperature of 30°F that the system supply temperature ranged between 135°F and 165°F. This wide range creates the 'cloudy' nature of the data and serves as an indicator of a poorly located outdoor air sensor.

It is important to note that these wide-ranging supply temperatures did not result in tenant complaints. Since the building was satisfied at a large range of supply temperatures, an opportunity exists to change set-points in a manner that captures most of the data points, i.e., to lower and narrow the range of supply temperatures delivered at each outdoor air temperature. Addressing the outdoor air sensor is an important part of the solution so that the settings changes don't cause complaints that did not previously exist.

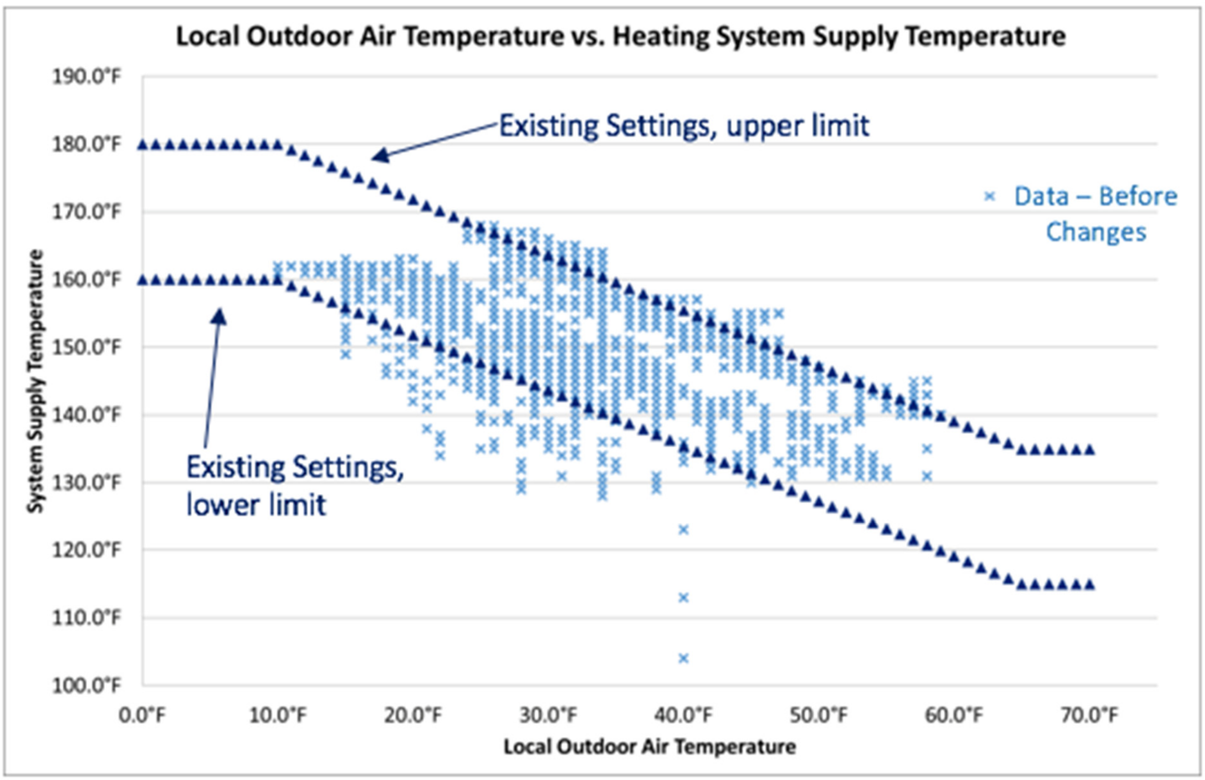

Figure 2: Heating performance before initial optimization

Figure 3 shows the performance for the same building as Figure 2 after the initial effort at optimization. As the owner was not willing to pay the cost of relocating the outdoor air sensor to the extreme opposite end of the building, we instead installed a 'solar shield'. These are commercially available devices that are intended to mitigate the impact of direct sun on the sensor.[5] A new outdoor reset curve was implemented so that most of the data previously recorded, the blue x's in Figure 2, would be captured between the new upper and lower limits. These two changes were expected to keep supply temperatures to the building in the range of

[5] There are multiple solar shields available, so several were tested to identify one that would be most effective. New Ecology is currently, and more formally, repeating that test to include additional solar shield products and to document the results.

those historically delivered, and improve the outdoor temperature input to the boilers to minimize the ‘cloud’ of data.

The green lines on Figure 3 show the new outdoor reset curve. The red + signs indicate the results of implementing this curve and adding the solar shield on the outdoor air sensor. The red data shows a tighter band of performance almost entirely within the new reset curve, and a high degree of overlap with the lower, previous data points shown in Figure 2. These changes did not result in any new complaints, and after 10 months of recording post-implementation data, and normalizing for weather, the overall gas saved for space heating, as measured at the boilers is 10%. Further optimization may be possible.

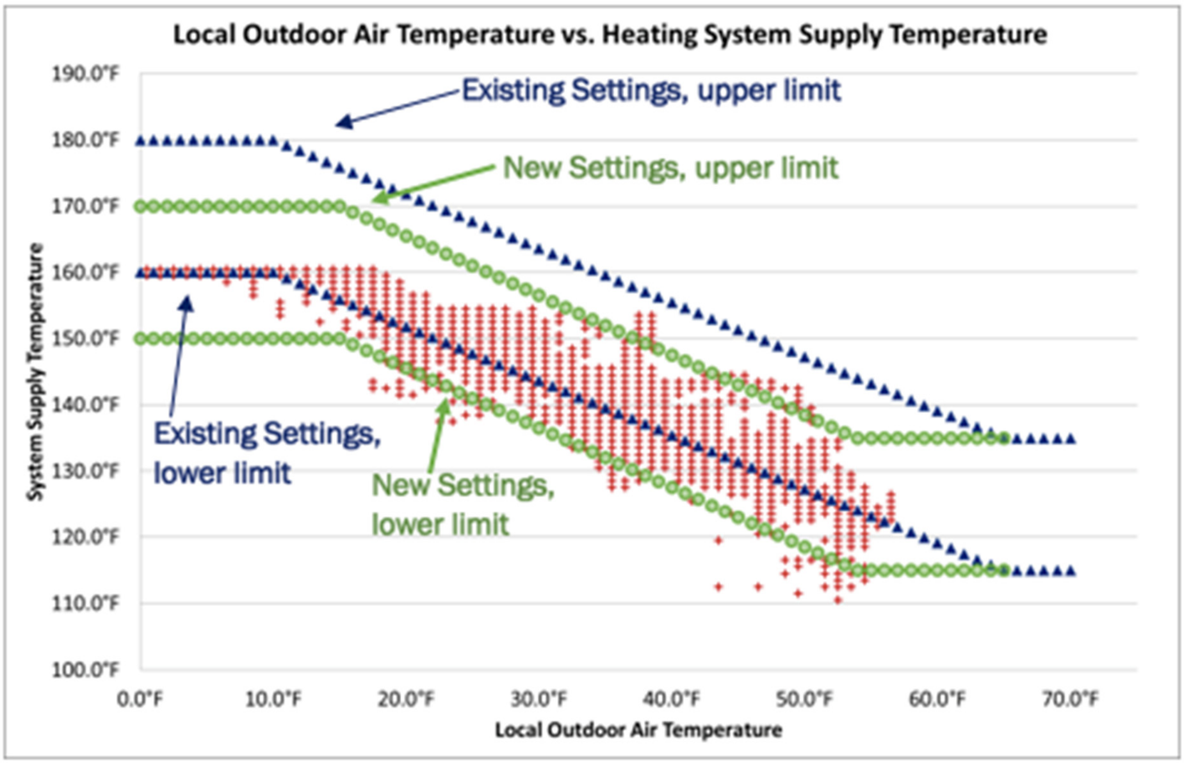

Figure 3: Heating Performance After Initial Optimization

Figure 4 illustrates the results of addressing excessive boiler cycling, which was most prevalent in hot water heaters and is a behavior that has long been believed to reduce equipment life due to excessive wear. (McKeegan 2005, p. 1 and Arena 2013, p. 64) The y-axis on this graph represents the percent of modulation while the x-axis is time, specifically three 24-hour periods. The operation of two water heaters, red and blue, are shown.

In Figure 4, prior to implementing settings changes, there are over 30 cycles of 90%+ modulation rates in the first 14 hours of Tuesday, the 9th. This is similar to racing between red stoplights in your car. Once the changes were made, the graph instantly shows a new profile, to longer fire times at lower modulation rates. By comparison, the first 14 hours of Wednesday, the 10th saw only two cycles of the same magnitude as those during the same time period the previous day, and an overall reduction in the number of cycles of any magnitude. There is reason to intuit that this gentler operation pattern will result in reduced wear on the water heaters.

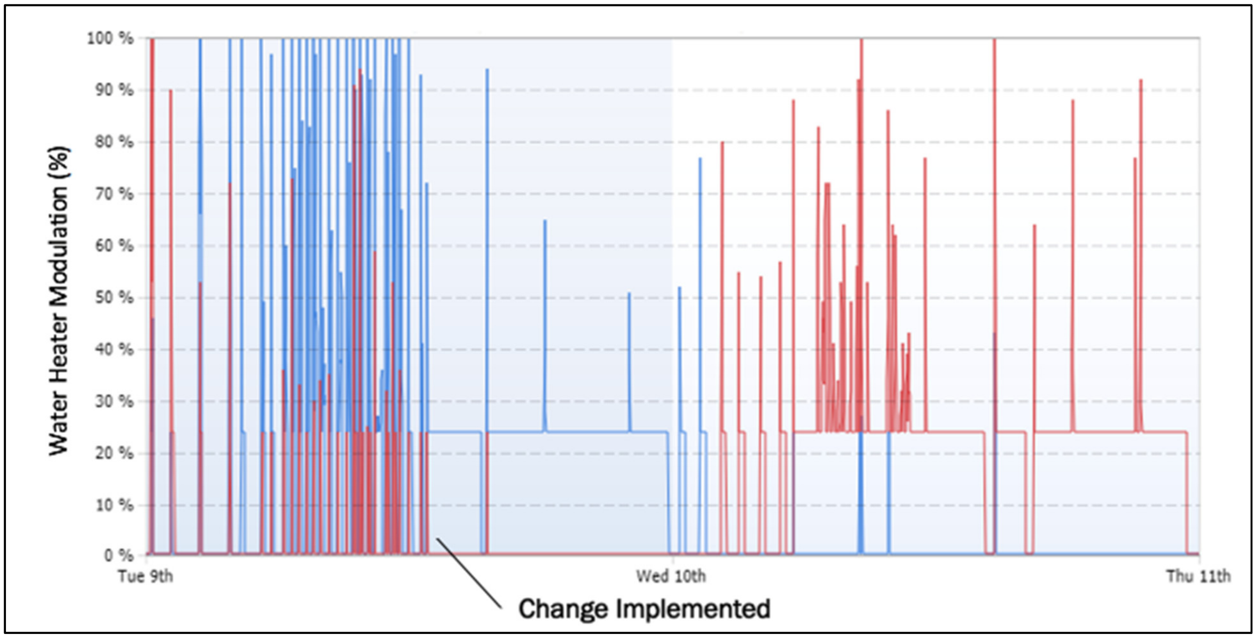

Figure 4: Settings changed to reduce equipment cycling

Conclusions

As illustrated in the Results section, this project demonstrated that remotely monitoring equipment can generate the data that, when coupled with analysis, will lead to improved performance without risk of generating tenant complaints. Lowering water temperatures, in combination with appropriately locating the outdoor air sensor or otherwise improving system functionality, can result in significant energy savings in many buildings. Also illustrated is how drastically the number of boiler and water heater cycles and modulation rates can be reduced. Although the study has not measured savings associated specifically with that change, it is believed that such changes reduce wear and will have a positive effect on the equipment life.

Finding and implementing changes that save energy was in line with project expectations, and the average savings of 10.1 percent to date are within the expected five to 20 percent predicted. It is a wide-spread and long held belief that high-efficiency equipment is very often operating out of condensing mode, therefore inefficiently. (Jones 2017) Lesser known and discussed was the potential for saving energy in buildings with non-condensing boilers and water heaters. The result presented, though a relatively small sample, provide insight that savings can also be achieved in this equipment. At this juncture, 58 buildings received an initial optimization and reported savings that were included. It is interesting that the magnitude of savings across Analysis Groups is a relatively consistent percentage. Data still being collected on these and other sites that will help refine these numbers, but the current data does imply that the magnitude of savings is something of which the EE programs should take notice.

The existence of boiler short-cycling was also expected and is a well-known occurrence that largely goes unnoticed and uncounted. The high number of boilers and water heaters that were short cycling, roughly 60 percent of each, was somewhat surprising. Identifying short-cycling requires observation over time, and most operators are not in the boiler room long enough to notice or count. The full data set shows that during this demonstration project, thousands of boiler cycles were eliminated each month across all buildings as a result of settings changes. A single building showed a reduction of over 1,500 cycles/month.

More surprising were issues that were discovered that optimization alone will not solve, for example:

- Over 50 percent of the combined heat and hot water systems are mixing water resulting in unnecessary heat being sent out to the building and causing the call for DHW to be prolonged;
- Over 20 percent of the sites had boiler/controls mix-matches, such as:
  - Third party controls that were added to boilers that had onboard controls, over-complicating the control scheme and adding unnecessary cost;
  - Settings that resulted in non-condensing boilers operating at condensing temperatures, potentially damaging the equipment;
  - Boilers in buildings with fancoil emitters that were supplying temperatures in excess of the fancoil's design parameters;
- 40 percent of the buildings were supplying unsafe DHW temperatures – too hot is a scalding hazard and too low may create breeding grounds for Legionella bacteria - being delivered to the tenants; and
- 40 percent of the DHW mixing valves were clearly not receiving regular maintenance and were essentially tracking the hot water temperature being supplied to the valve.

These unexpected findings will inform future development of this remote monitoring system and service as, not only a way to save energy through optimization but, a way to provide valuable input to a building's maintenance activities. This is a service that has the capability to aid the staff responsible for maintenance in affordable multifamily housing and other buildings.[6]

New Ecology's Next Steps

New Ecology has been working on this issue for five years, and is gratified to have detailed data that supports our experiences. There is still more work to do and other opportunities to explore, such as;

- Determine the cause of negative savings at each location where they occurred, and rectify to the extent possible;
- Automate the analysis further to achieve greater cost savings;
- Re-analyze data for all buildings to search for additional optimization steps;
- Continue to develop data-driven maintenance alerts;
- Incorporate the ability to read other 'connected' devices, such as water meters, into our platform for more comprehensive, robust analyses and service;
- Seek other parties interested in demonstration pilots in other climates, other utility territories, or even for other equipment; and
  - Continue work in Massachusetts and Rhode Island towards the adoption of a remote monitoring and optimization service as a new energy efficiency measure, expected in both states by 2019.

[6] New Ecology is developing maintenance related alerts for operators. We are also looking at the broader learnings from this project, for design and installation, and are looking for the best way to share these learnings with others in the industry.

References

Grueneich, D. 2015. *The Next Level of Energy Efficiency: The Five Challenges Ahead*. The Electricity Journal. https://www.sciencedirect.com/science/article/pii/S104061901500144X

Jones, D. 2017. *Principals of Condensing Boiler System Design*. https://www.group14eng.com/wp-content/uploads/2017/01/Condensing-Boiler-System-Design-Tool.pdf

McKeegan, J. 2005. *Short-system Prevention for Double-Digit Savings, Part I: Fundamentals and Hydronics.* ASHRAE. http://ashraephilly.org/images/downloads/CTTC_Articles/1603_cttc.pdf

Arena L and Faakye, O. 2013. *Optimizing Hydronic System Performance in Residential Applications*. US Department of Energy Building Technologies Office. https://www.nrel.gov/docs/fy14osti/60200.pdf