Emerging Technologies and Accelerated Commercialization
Energy Performance Validation Project
Final Project Report

Prepared for
Radiator Labs

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1 Executive Summary

This document represents ERS's Final Project Report (FPR) of an Emerging Technologies and Accelerated Commercialization (ETAC) program proposal submitted by Radiator Labs. It represents a submission for an Energy Performance Validation Project as part of NYSERDA's ETAC program under PON 2689. It proposes the installation of the company's new radiator control technology in two dormitories located in Columbia University's Manhattan campus. This Energy Performance Validation Project is performed under NYSERDA ETAC-EPV-001.

Please note that this document is catered for specific building stock for validating a specific effort and that any use of the technology outside that scope is at one's own risk.

Radiator Labs has developed a new technology called the thermostatic radiator enclosure (TRE), also known as the "Cozy," which aims to reduce energy consumption and improve the thermal comfort of spaces heated by steam radiators. The product consists of an insulating sleeve that fits over the existing radiator to control convective heat transfer. A small electrically powered fan in conjunction with an infrared thermostat is used to deliver heat to the room only when needed. The product addresses the overheating problem that faces many older buildings heated by steam radiators.

The system was installed in two dormitory buildings at Columbia University's campus in New York City. The buildings are heated by steam radiator systems, where the steam is provided by boilers located in the basement of each building. Claremont dormitory is six stories, houses 120 students, and is served with a natural gas-fired boiler and single pipe steam system. Watt dormitory is six stories, houses 160 students, and is served with an oil-fired boiler (converted to natural gas in 2015) and two pipe steam system.

ERS gathered baseline data without the Cozy system installed from the end of October 2013 to the middle of January 2014. The Cozy systems were installed during the last 2 weeks of January 2014, but due to Internet network access and boiler control issues, the systems were not fully commissioned until the end of February and early March. ERS collected post-installation data from the end of commissioning through the middle of May 2014. An interim report was released by ERS in the summer of 2014. Additional post-installation data was collected from the middle of October 2014 to the middle of April 2015, and was utilized along with the first winter of post-installation data, to arrive at the results presented in this report.

A mix of boiler controls system trend data, Radiator Labs' network data, and ERS physical data loggers were used to construct three analysis approaches. Room temperatures were analyzed to confirm that each of the buildings had a drop in average ambient temperature with the system installed. The average room temperature declined between 1.8°F and 3.6°F in the two buildings to the desired set point temperature of 73°F. The lower air temperature resulted in a reduced heat load that was reflected in ERS's boiler run-time analysis. Data showed that the average annual boiler run time decreased by 28% and 41%, for Claremont and Watt, respectively. Finally, a billing analysis was conducted to confirm that the reduced run time resulted in actual energy savings "at the meter." Billed energy use savings of 20% to 24% were found for the two buildings. Increased electric energy use from the radiator circulation fans was between 6.8 and 6.9 kWh annually per radiator, about $1.25 per radiator. These impacts are negligible relative to the project savings. Savings are summarized in Table 1-1.

Table 1-1. Results Summary

Analysis Method	Claremont Hall Savings	Watt Hall Savings
Boiler run-time reduction[1]	28%	41%
Billing reduction (total consumption)	23%	26%
Billing reduction (space heating)	34%	N.D.[2]
Room temperature reduction	1.8°F	3.6°F

[1]This is displayed as a percent of total fuel use for Claremont and percent of space heating use only for Watt.

[2]:N.D. = No data. Due to the format of the collected data it was not possible to provide savings relative to both total consumption and space heating use. Space heating savings will be a larger fraction than the total consumption savings, likely similar in magnitude to that observed in Claremont.

The test deployments uncovered a variety of challenges faced during installation and operation of the system. Significant delays were incurred when connecting the IT and boiler controls systems. It took approximately 3 weeks from the time of the Cozy installation in Claremont, and 5 weeks in Watt, for Radiator Labs to successfully control the boiler and collect data. Access to the university Internet network was one issue; the other was properly integrating to the boiler. Specifically, access to the university network required VPN access and security forms to be filled out. Initially, Radiator Labs' contacts were with the facility staff of the housing department, and although eager to help, could do little to help Radiator Labs connect to the network. It was not until Radiator Labs was moved to an IT department contact that the proper requests could be made to secure access to the network. Delays were incurred while waiting for the proper permissions to be granted during the administrative process. Going forward, Radiator Labs will ask for contact information for the IT department from the project outset. In Watt Hall, after the IT hurdles were overcome, delays arose from the subcontractor responsible for the boiler controller. Proper priority was not given to the project given the previous IT delays, and as a result the project was pushed farther behind schedule. For future sites, the early prioritization of the IT connection will facilitate an earlier installation of the boiler controls. While the specific issues faced for this project (proper security clearances to Columbia's network, algorithm integration to the boiler to ensure a fail-safe backup if the Radiator Labs system fails) are likely to vary by building, both the IT and boiler integration could affect any site. However, it is impossible to predict where exactly a snag may arise. Therefore, for future projects, implementing IT and controls would be the first priority, and the Cozy covers should not be installed unless Radiator Labs has been able to secure full network access as required in a timely manner. Additionally, certain durability issues arose with the current design. An infrared temperature sensor integral to the controls sequence was installed separately from the system and could be easily dislodged. Several components, such as the fan and controller, were also not built into the system cover creating the opportunity for damage to occur. The next generation product, the version of the TRE to be installed during the Focused Demonstration (FD) project (currently underway), will correct these design concerns by incorporating the fan, controller, and temperature sensors all directly into the cover. This improvement will result in decreased installation times as well.

At this stage, ERS has found substantial evidence of energy savings through its analyses of the two test buildings. It is important to note that the results presented in this report reflect only the energy savings and conclusions drawn for these two metered buildings. Data has not been collected for a sufficient quantity of buildings to predict the magnitude of savings for other buildings, or to understand the impact of variables such as building or heating system type. The purpose of the study at this phase was to determine the viability of the Radiator Labs product and to determine if energy savings were possible to obtain. ERS recommends that the scope be expanded to additional buildings in an attempt to understand the expected range of energy savings possible and the building criteria that influence the project savings. This expanded study is currently underway through the FD track of the ETAC program. Furthermore, Radiator Labs has developed a path to correct deficiencies moving forward, which they expect will result in more consistent performance and savings in the future. The final sections of the report provide insights on potential opportunities and challenges to future deployments.

2 Technology Description

Radiator Labs has developed a new technology called a thermostatic radiator enclosure (TRE), also known by the product name Cozy, which aims to reduce energy consumption and improve the thermal comfort of spaces heated by steam radiators. The product consists of an insulating sleeve that fits over the existing radiator to control convective heat transfer. A small electrically powered fan in conjunction with a thermostat is used to deliver heat to the room only when needed. The product addresses the overheating problem that faces many older buildings heated by steam radiators.

Conventional radiators are controlled with manual valves that can be either open or closed. A partially opened valve behaves very similarly to a fully open valve due to the gaseous nature of the pressurized steam. Often, occupants do not manually control valves due to the inconvenience or fear of breaking the valve, and therefore they leave them open.

Steam space heating boilers are typically controlled by either one or several thermostats in select apartments: those thought to be the coldest or that have the most difficult-to-maintain space temperatures. Therefore, the boiler is usually governed by those apartments that require the most heat. These are usually the rooms located at the end of the distribution system. Since the radiators cannot readily be controlled individually, the rest of the apartments receive excess heat, resulting in overheating. This often leads to occupants opening windows to provide thermal comfort.

Radiator Labs plans to reduce boiler energy use by controlling overheating. This may also reduce the frequency in which occupants open windows to maintain comfortable room temperatures. The actual savings realized will be dependent on both the baseline and installed radiator and boiler control strategies. The sources of energy savings are the same as those achieved by installing thermostatic radiator valves (TRVs) on the radiators, but without the intrusive installation (requiring physical modification to the heater) and skilled labor of a plumber. An example of an installed TRE product is provided in Photo 2-1.

Photo 2-1. Radiator Labs TRE Product

For the Claremont dormitory, Radiator Labs deployed an additional energy storage product. A phase change material was added to several containers placed on the radiator with the capacity to store several hours' worth of heat. The purpose is to reduce cycling of the boiler by allowing the boiler to run longer while energy is absorbed by the storage material. For this study, the phase change material impact was not isolated from the impact of the Cozy covers. The differences in building, boiler, and steam system type between the two buildings were expected to add too much uncertainty to accurately quantify the impact of the phase change. Photo 2-2 shows the phase-change containers before the radiator is covered with the Cozy.

Photo 2-2. Claremont Hall Phase-Change Material

3 PROJECT DESCRIPTION

Radiator Labs arranged the installation of their product at two Columbia University student dormitories located in Manhattan. The first building, Claremont dormitory (pictured in Photo 3-1), houses 120 students and was constructed near the turn of the twentieth century. The building is served by a natural gas-fired boiler with high-fire, low-fire, and off burner controls and a single-pipe steam distribution system. The second, Watt dormitory (pictured in Photo 3-2) houses 160 students and was constructed in 1908. From the start of the study through February 2015, the building was served by an oil-fired boiler with modulating burner controls and a two-pipe steam distribution system. The primary fuel was #4 oil through the end of the 2014 heating season, with #2 fuel oil used thereafter. In February 2015, the building underwent a complete conversion to natural gas service for heating. The key features of each building are shown in Table 3-1.

Table 3-1. Key Building Features

Parameter	Claremont Dorm	Watt Dorm
Fuel type	Natural gas	Dual fuel – fuel oil or natural gas
Number of boilers	1	1
Boiler size (input)	2.34 MMBtu	3.36 MMBtu
Boiler utilization	Space heating, DHW	Space heating, DHW
Boiler control	Outdoor air temperature lockout, select room thermostats	Outdoor air temperature lockout, select room thermostats
Boiler firing	High/low/off	Modulating (set to manual)
Steam system	Single pipe	Two-pipe, gravity fed condensate return
Year built	Unknown (pre-war)	1908
Floors	6	6
Student population	120	160

Photo 3-1. Claremont Hall Dormitory

Photo 3-2. Watt Hall Dormitory

4 M&V Activity

A variety of data points were collected at Claremont and Watt during both the pre- and post-installation periods. This data was utilized to analyze the pre- and post-installation boiler run time and fuel use. The sections below provide a list of data points collected, including the type of point, measurement method, time increment, quantity, and metering duration.

4.1 Claremont Hall

Table 4-1 provides a summary of the metered points in Claremont.

Table 4-1. Claremont Hall Metered Points

Parameter/ Point	Unit	Period	Discrete Points[1]	Metering Equipment[2]	Interval	Start Date	End Date
Boiler aquastat	°F	Pre-/ post-	1	Boiler system	15 minutes	10/29/13	5/30/14
	°F	Post	1	Boiler system	15 minutes	9/22/14	4/22/15
Boiler on	State	Pre-/ post-	1	Boiler system	State change	11/22/13	5/30/14
	State	Post	1	Boiler system	State change	10/23/14	4/22/15
Boiler call	State	Pre-/ post-	1	Boiler system	State change	11/20/13	5/30/14
	State	Post	1	Boiler system	State change	10/20/14	4/22/15
Boiler stack temp	°F	Pre-/ post-	1	Boiler system	15 minutes	10/29/14	5/30/14
	°F	Post	1	Boiler system	15 minutes	9/22/14	4/22/15
Domestic hot water/coil temp	°F	Pre-/ post-	2	Boiler system	15 minutes	10/29/13	5/30/14
	°F	Post	2	Boiler system	15 minutes	9/22/14	4/22/15
Outdoor temp	°F	Pre-/ post-	1	Boiler system	15 minutes	10/29/13	5/30/14
	°F	Post	1	Boiler system	15 minutes	9/22/14	4/22/15
Governing apt. temp	°F	Pre-/ post-	6	Boiler system	15 minutes	10/29/13	5/30/14
	°F	Post	6	Boiler system	15 minutes	9/22/14	4/22/15
Gas use	Therms	Pre-/ post-	1	Utility meter (Con Edison)	Monthly	2/24/12	5/10/15
Boiler blower motor	State	Post-	1	ERS motor logger	State change	1/29/14	5/12/14
Boiler stack temp	°F	Post-	1	ERS thermocouple	3 minutes	1/29/14	4/19/14
Room temp	°C	Pre-	37	Radiator Labs system	Approximately 6 minutes	10/27/13	1/29/14
	°C	Post-	66		Approximately 3 minutes	2/3/14	4/18/14
	°C	Post-	66		Approximately 5 minutes	11/14/14	4/26/15
Radiator temp	°C	Pre-	34	Radiator Labs system	Approximately 6 minutes	10/27/13	1/29/14
	°C	Post-	66		Approximately 3 minutes	2/3/14	4/18/14
	°C	Post-	66		Approximately 5 minutes	11/14/14	4/26/15
Fan status	Minutes	Post-	66	Radiator Labs system	Approximately 5 minutes	3/3/14	4/18/14
	Minutes	Post-	66			11/14/14	4/26/15

[1] Discrete points refer to the number of measurement locations e.g., twenty-four rooms had HOBO loggers installed to collect room temperature, resulting in twenty-four data sets.

[2] The "boiler system" metered data was collected with a system installed and operated by TriStar, a boiler controls company. In addition, ERS installed a HOBO motor on/off logger on the boiler blower motor to measure run time. ERS also installed a k-type thermocouple with a HOBO data logger to collect stack temperature. The Radiator Labs System refers to the wireless network and gateway installed by Radiator Labs to monitor system performance and control the firing signal to the boiler. The installed thermocouples and thermocouple logger are accurate to within ±2.2°C (±4°F) ±0.75% of reading. The accuracy of the TriStar and Radiator Labs systems is unknown.

Several changes with the metering strategies and data collection intervals occurred over the course of the metering period, as detailed in the following bullets.

- The boiler stack and aquastat were switched to a 1-minute increment after December 24. This increased the robustness of the analysis.
- The boiler trending system was down for several periods during the pre-installation period. This resulted in fewer available data points for analysis; however, sufficient data to draw conclusions was still collected during the pre-installation phase.
  - December 17, 2013 through December 25, 2013
  - January 6, 2014 through January 16, 2014
  - January 28, 2014 and January 29, 2014
- The boiler trending system was down for several periods during the post-installation period. This resulted in fewer available data points for analysis; however, sufficient data to draw conclusions was still collected during the post-installation phase.
  - November 5, 2014 through November 15, 2014
  - February 6, 2015 through February 13, 2015
- The boiler blower motor logger was tampered with and removed from February 3, 2014 through March 20, 2014 when ERS re-visited the site and corrected the installation. This resulted in a loss of data between February 3, 2014 and March 20, 2014. The Radiator Labs system data was used to supplement this data gap.
- ERS did not receive run time data from the radiator circulation fans for the 2015 heating season. Sufficient fan runtime data from the 2014 post-install season was utilized to estimate the fan energy penalty resulting from the Cozy installations.
- The Radiator Labs room temperature was logged approximately every 15 minutes through December 2013. As the system became more robust, metering was closer to a 3-minute interval. This increased the robustness of the analysis.

Where data was found to be missing, other data sources and measurements were utilized to analyze the system. In addition, ERS performed a utility bill analysis to corroborate the savings calculated using the data shown in Table 4-1 above, which increased the confidence in the data integrity and energy savings.

4.2 Watt Hall

Table 4-2 provides a summary of the metered points in Watt Hall.

Table 4-2. Watt Hall Metered Points

Parameter/Point	Unit	Period	Discrete Points[3]	Metering Equipment[4]	Interval	Start Date	End Date
Boiler run time	State	Pre-/post-	1	Radiator Labs model	Average daily	11/1/13	5/12/14
Boiler run time	State	post-	1	Boiler system	Average daily	3/20/14	5/6/14
	State	Post	1	Boiler system	State change	10/22/14	4/22/15
Boiler blower motor	State	Pre-/post-	1	ERS motor logger	State change	1/3/14	5/12/14
Boiler stack temp	°F	Pre-/post-	1	ERS thermocouple	1 minute	1/3/14	5/12/14
Oil consumption	Gallons	Pre-/post-	1	Customer bills	Delivery (biweekly)	10/9/12	2/9/15
Gas use	Therms	Post	1	Customer bills	Monthly	2/26/15	5/9/15
Room temp	°F	Pre-/post-	24	HOBO logger	5 minutes	10/21/13	5/23/14
Room temp	°C	Post-	111	Radiator Labs system	Approximately 5 minutes	2/19/14	4/4/14
	°C	Post	111	Radiator Labs system	Approximately 5 minutes	10/22/14	4/22/15
Fan status	State	Post-	117	Radiator Labs system	Approximately 5 minutes	3/3/14	4/15/14
Radiator temp	°C	Post-	111	Radiator Labs system	Approximately 5 minutes	2/19/14	4/4/14
	°C	Post	111	Radiator Labs system	Approximately 5 minutes	11/6/14	4/26/15

5 Analysis Methodology

The initial approach put forth by ERS in the Performance Validation Plan relied on three separate analyses to triangulate the results, with each analysis approaching savings from a different point in the system:

- **Boiler run-time analysis** – The first approach was to use data collected about the boiler run time to create a regression to the outdoor weather conditions. With the Radiator Labs system in place, the boiler was expected to run less than before the system installation.
- **Billing analysis** – Next, billing data was used to confirm that a reduction in run time actually led to a reduction in billed natural gas and fuel oil use in each affected building.

[3] Discrete points refer to the number of measurement locations e.g., twenty-four rooms had HOBO loggers installed to collect room temperature, resulting in twenty-four data sets.

[4] The "boiler system" metered data was collected with a system installed and operated by US Energy Group (USEG), a boiler controls company. In addition, ERS installed a HOBO motor on/off logger on the boiler blower motor to measure run time. ERS also installed a k-type thermocouple with a HOBO data logger to collect stack temperature. The Radiator Labs System refers to the wireless network and gateway installed by Radiator Labs to monitor system performance and control the firing signal to the boiler. The installed thermocouples and thermocouple logger are accurate to within ±2.2°C (±4°F) ±0.75% of reading. The accuracy of the USEG and Radiator Labs systems is unknown.

- ❑ **Room temperature analysis** – As a final check, pre- and post-installation room temperature data was used to confirm that the savings viewed were from a drop in temperature of the overheated rooms.

Due to inherent uncertainties in the methods, each had strengths and weaknesses. More emphasis was placed on the first two methods, which were expected to yield the highest confidence in savings. Each approach is discussed in greater detail in the following sections.

The Radiator Labs Cozy system will also result in an increase in electric energy consumption from the circulation fan. The impact of the fans was quantified using trended data. This analysis is discussed later in the report in Section 5.4.

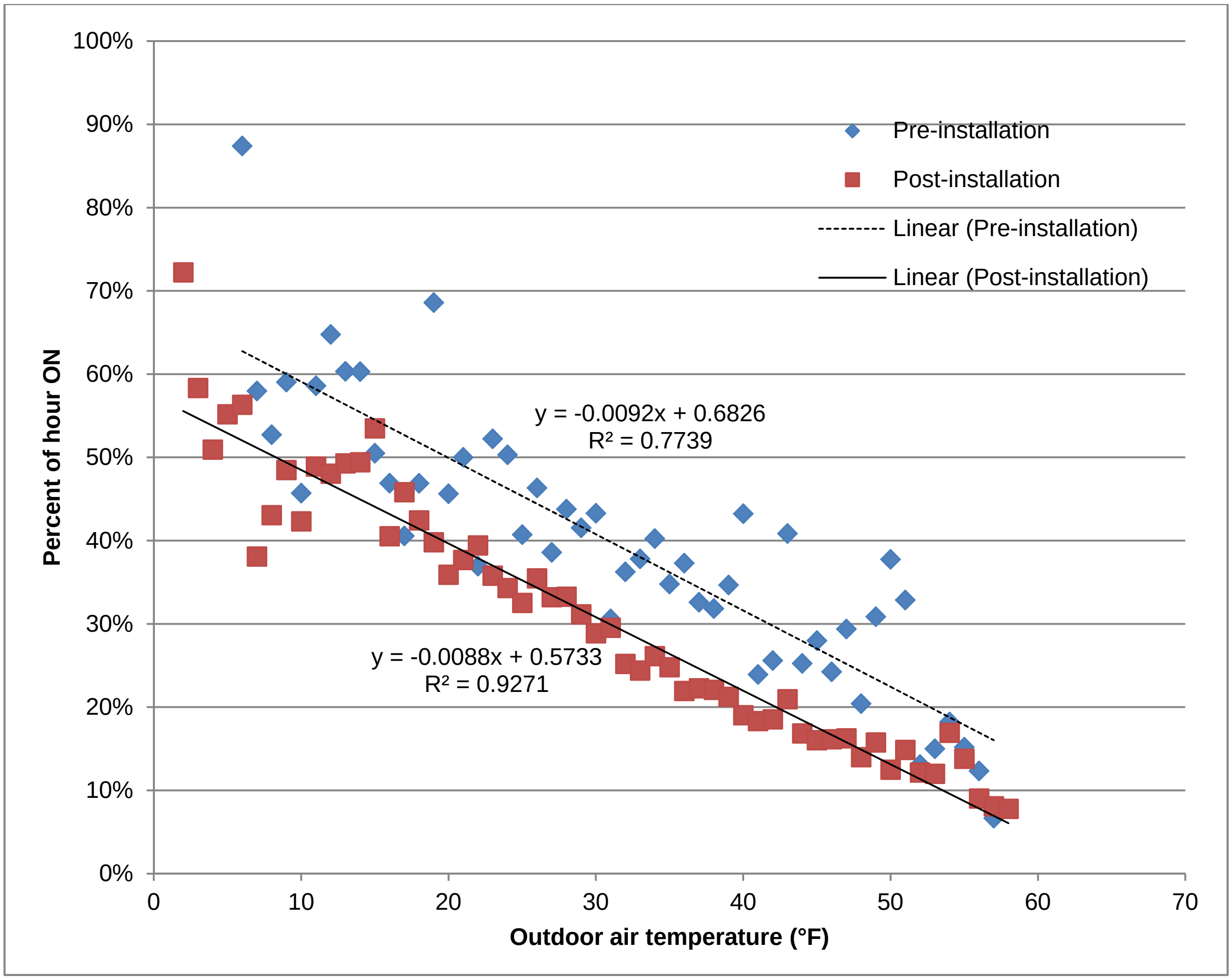
5.1 Boiler Run-Time Analysis

Claremont Hall – For Claremont, the TriStar boiler system remained in place during both the pre- and post-installation periods, providing a continuous source of boiler firing data. The data provided an on/off signal each time the boiler switched operating modes. ERS used this data to calculate the hourly percent-run time for the pre- and post-installation periods, and regressed this hourly data against the outdoor air temperature (OAT). The pre-installation period extended from October 29, 2013 when the data was first made available, through January 25, 2014 when the installation of the Radiator Labs product began. Although installation of the Cozy units took only a few days, it took substantially longer to work out commissioning issues, including programming the Radiator Labs sensors to control the operation of the boiler and to obtain the proper Columbia University internet network connections. Data from the project installation through February 23, 2014 was excluded from ERS's analysis.

By February 24, 2014, Radiator Labs was able to obtain satisfactory control of the boiler system and was collecting sufficient data over their wireless network. The post-installation period continued through May 9, 2014. Since the 2014 post-installation data consisted of very limited peak winter space heating operational hours, Radiator Labs collected the same set of data points for Claremont hall from October 23, 2014 to April 22, 2015 to represent a longer duration of post-installation data, and made it available to ERS for analysis.

Figure 5-1 provides a regression of the hourly pre- and post-installation boiler run-time data binned by OAT. A difference in percent firing time is evident between the pre- and post-installation periods.

Figure 5-1. Claremont Hall Boiler Run-Time Regression



The regressions from Figure 5-1 above were used with typical metrological year weather data (TMY3) to extrapolate savings to a full heating season. The heating season was set from October 1 through May 31 as required by New York City law. Heating was modeled to be off if the OAT was above 58°F, in line with local laws and consistent with the data collected. The system was also modeled as off after May 21 when the students moved out.

Nameplate data indicated that the boiler's max input rate was 2.3 MMBtu. The boiler is capable of operating in one of three modes: high-fire, low-fire, or off. ERS compared the run-time data to the utility bills for the building and estimated that, based on the percent-run time that was observed, the boilers operated at an average of 60% natural gas input. The firing rate does not have an effect on the calculations when determining the percent savings; it will only impact the magnitude (therms) of savings. For the purpose of this study, determining the validity of the product and establishing the magnitude of energy savings, percent savings is the critical metric to understand. Absolute savings will be contingent upon boiler size, building size, and boiler efficiency.

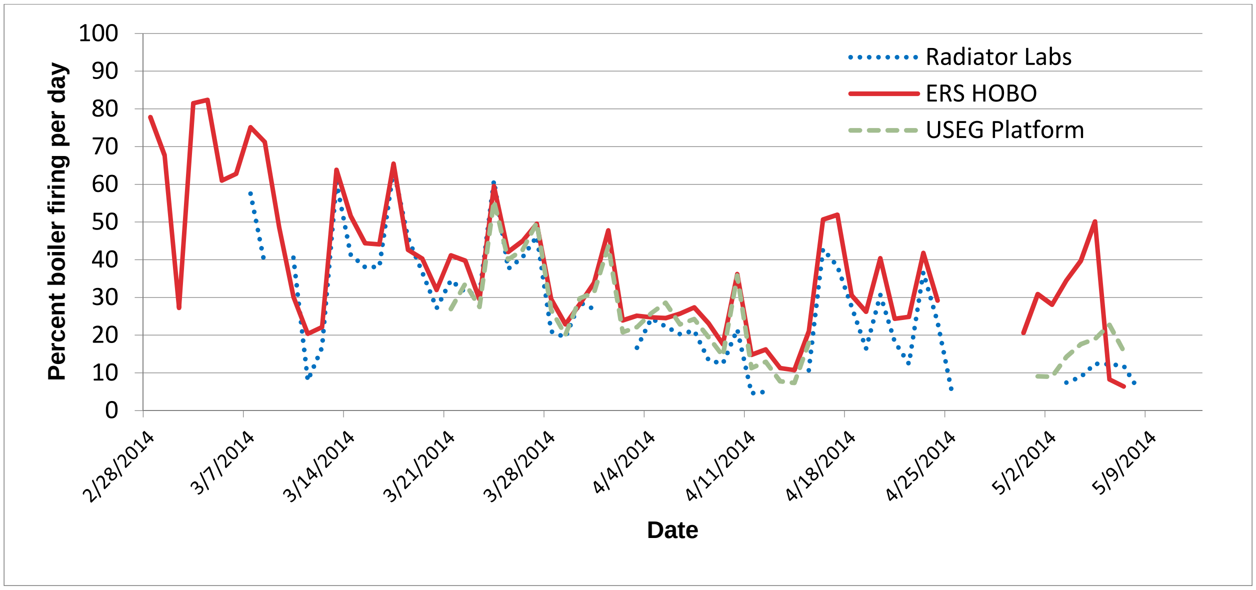
ERS's boiler run-time analysis resulted in an annual energy savings of 28% and an absolute savings of approximately 6,417 therms/yr. ERS's weather-normalized baseline energy use was 22,935 therms/yr with an as-built energy use of 16,518 therms/yr.

Watt Hall – a similar type analysis was conducted for Watt. However, for this building, the baseline boiler monitoring system was not as robust as in Claremont. Three proxies for measuring the run time of the boiler were used during the metering period:

- **Radiator Labs data** – The two datasets provided by the Radiator Labs team included data from October 29, 2013 through May 9, 2014 and from October 22, 2014 through April 22, 2015. Several temperature sensors were attached to radiators in the building. Using the change in temperature of the radiators, it was possible to estimate when steam was in the radiators, and therefore when the boiler was firing.
- **ERS metered data** – ERS was able to install a HOBO motor on/off logger during a visit to the site in January 2014, allowing for the capture of several weeks of baseline data. This was left in place through the end of the study period.
- **USEG boiler data** – Once the new boiler controls system was online and interfaced correctly with the Radiator Labs product, data was collected from the boiler in a similar fashion to Claremont through a boiler control system installed by USEG. However, this data was only available during the post-installation period, beginning March 20, 2014.

For the analysis, the Radiator Labs dataset was used since it offered the longest pre- and post-installation data set. However, the two additional datasets were used to confirm the effectiveness of Radiator Labs' data. Figure 5-2 shows an overlay of the three data sources. The USEG and ERS sources match closely with the Radiator Labs dataset, with the Radiator Labs dataset showing consistently lower run time compared to the other two datasets. This is because the boiler serves both domestic hot water (DHW) and space heat, and both the USEG and ERS meters capture the total boiler run time for both end uses. The Radiator Labs dataset only captures the space heating portion of the run time. Since the Radiator Labs' data was used for the boiler analysis, the percent savings will only be of the space heating energy use, not the building's total energy use. For the billing analyses and Claremont boiler analysis, savings are displayed as a percentage of total building energy use.

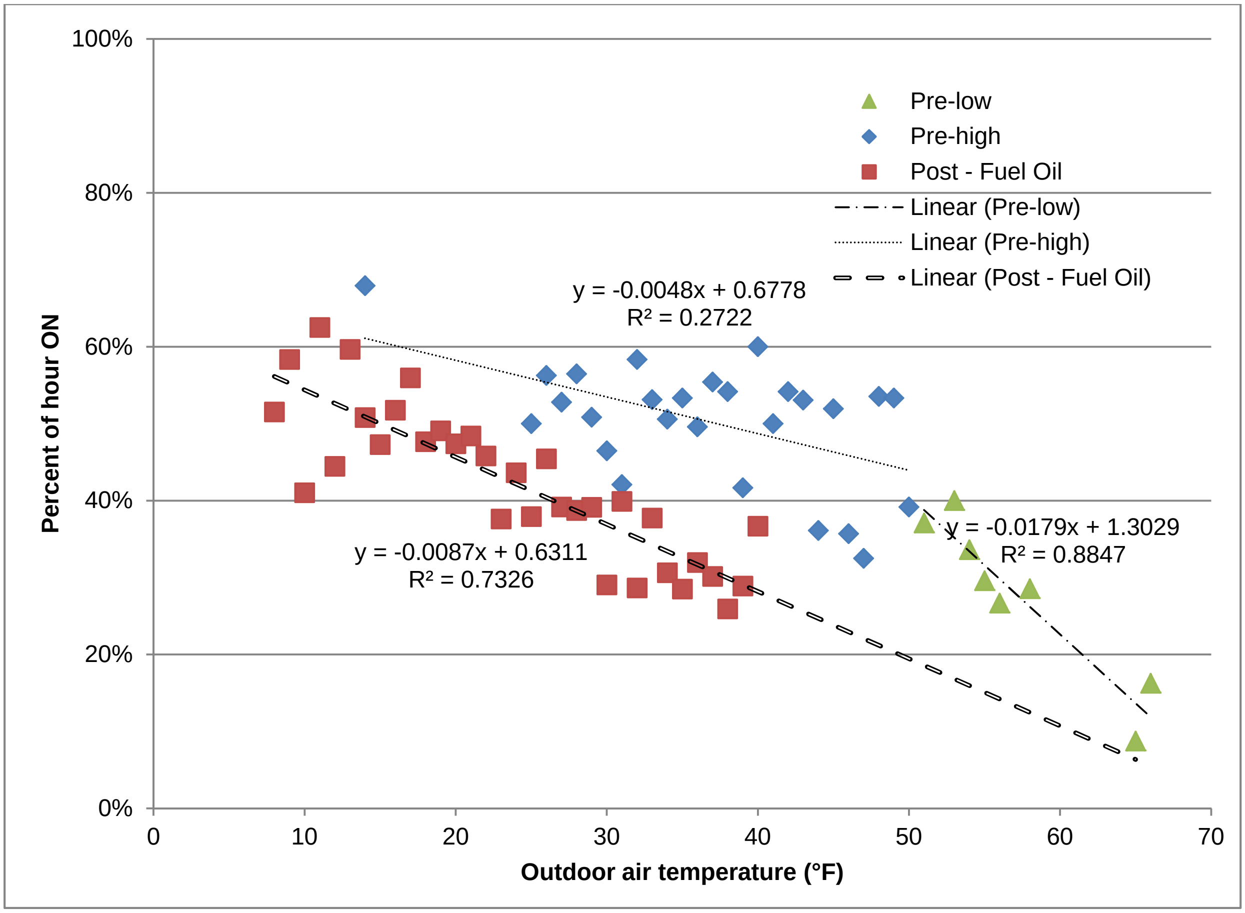
Figure 5-2. Post-Installation Data Run-Time Model Overlay



ERS regressed the pre- and post-installation average daily boiler run time from Radiator Labs' data against OAT. The pre-installation period included data from October 31, 2013 through January 3, 2014. The Cozy system was installed during the middle of January 2014; however, significant boiler controls and network access setbacks prevented proper operation until mid-March 2014. The 2014 post-installation period included data from March 13, 2014 through May 8, 2014. Since the 2014 post-installation data consisted of very limited peak winter space heating operational hours, Radiator Labs collected the same set of data points for Watt hall from October 23, 2014 to April 22, 2015 to represent a longer duration of post-installation data. ERS utilized the most recent post-installation data to regress average boiler run time vs. OAT. These regressions are plotted in Figure 5-3.

It should be noted that the Watt hall boiler was fired with fuel oil until February 2015, at which point natural gas service was connected allowing it to dual fire. Following this upgrade, the boiler was fired with natural gas. It was not clear whether additional changes to the boiler control or operation were made concurrent with the upgrade, such as tuning for the new fuel; therefore, ERS excluded all data after the fuel switch to natural gas from our post-installation analysis to keep the results comparable to the baseline data. This resulted in the exclusion of data from February 9, 2015 through April 22, 2015 in ERS's analysis.

Figure 5-3. Watt Hall Boiler Run-Time Regression



The baseline case had a relatively weak R-squared value for a single regression, possibly indicating controls issues with the boiler system, or different operation at lower temperatures. For OATs in the range of 25°F to 50°F, the boiler run time remains relatively consistent between 50% and 60%. This could indicate either overheating at warmer temperatures, or underheating at colder temperatures. In either case, there was likely a comfort issue in the building during the pre-installation period, since heating load normally correlates to the outdoor weather conditions in a well-tuned system, as shown in the post-case regression. The pre-installation data set appeared to be broken into two sections, and so two regressions were used, one for temperatures below 50°F and the other for temperatures above 50°F.

The regressions from the plot above were used with TMY3 data to extrapolate savings to a full heating season. The heating season was set from October 1 through May 31 as required by New York City law. Students' occupancy was from September 2 through May 21 from the university's academic calendar. Heating was modeled as off above 68°F from the intercepts of the regressions in Figure 5-3 above. This is higher than NYC's 58°F requirement, and it may be due to the location of the building's outdoor thermostat or desire to keep the rooms at a certain temperature. Nameplate data indicated that the maximum input of the boiler was 3.4 MMBtu.

During the site visits it was noted that the boiler's firing rate had been manually set to the 3/8 position, which equates to 37.5%.

ERS's boiler run-time analysis resulted in an annual energy savings of 41% and an absolute savings of approximately 11,957 therms/yr. ERS's weather-normalized baseline energy use was 29,186 therms/yr with an as-built energy use of 17,229 therms/yr. Using a typical energy content of 145,600 Btu/gallon for #4 fuel oil, this equates to 20,045 and 11,833 gallons/yr of #4 fuel oil before and after the Cozy installation, respectively. This would result in a #4 fuel oil savings of 8,212 gallons/yr. Although the building predominantly used #4 fuel oil in the periods analyzed in ERS's analysis, it is likely that natural gas will be the predominant fuel for the building moving forward. The observed fuel oil savings equates to 16,540 therms/yr of natural gas savings and a projected post-installation annual natural gas usage of 23,802 therms/yr in a typical weather year.

An analysis of billing data from the pre-installation period normalized to TMY3 conditions yielded 33,477 gallons of annual oil use.

ERS's interim report compared datasets with similar fuel types in the pre- and post-installation periods, and presented annual energy savings of 24% resulting from the boiler run-time analysis, but this analysis included limited post-installation data and was therefore revised to include additional post-installation data from the 2014-2015 heating season in this final report. However, the boiler fuel type varied between the interim report data collection (#4 fuel oil during the 2013-2014 heating season) and final post-installation (#2 fuel oil during 2015 heating season). As a result, there is uncertainty around the absolute annual energy savings for the cozy installation in Watt, although ERS is confident that the savings are likely to be between 24% and 41%, as calculated in our interim and final percent runtime analysis results.

5.2 Billing Analysis

A billing analysis using natural gas or fuel oil deliveries during the pre- and post-installation periods was used to determine if the drop in boiler run time resulted in an actual decrease in energy consumption. During the heating season both boilers also provided DHW in addition to space heating for the buildings. Smaller auxiliary DHW systems are used when the dorms are not occupied in the summer.

Claremont Hall – Data for the 2013–14 heating season gas use was obtained through Con Edison billing data and used to define the pre-installation boiler natural gas use. Data from the 2012–13 season was not used since a previous Radiator Labs test had been conducted on the building during that period. Data from the late winter in 2014 and the 2014-2015 heating season were used to define the post-installation boiler natural gas usage. Table 5-1 provides the total gas use, as well as adjustments for the students' DHW use. Columbia University's academic calendar was used to adjust for months in which there was partial student occupancy in the dormitories, as shown in Table 5-1 for 'Student Occupancy'. For the months of May, August, and September, the natural gas usage along with partial student occupancy information were utilized to estimate the monthly DHW usage of the building. Heating degree days (HDD) were based on weather data from New York City's Central Park station and a base temperature of 65°F.

Table 5-1. Claremont Hall Billing Data

Start	End	Period	HDD	Use (Therms)	Student Occupancy	Space Heating Use (Therms)
6/10/2013	7/10/2013	Pre	10	0	None	0
7/10/2013	8/8/2013	Pre	0	0	None	0
8/8/2013	9/9/2013	Pre	6	228	10 days	0
9/9/2013	10/8/2013	Pre	72	924	Full	0
10/8/2013	11/6/2013	Pre	265	1,879	Full	854
11/6/2013	12/10/2013	Pre	730	3,486	Full	2,461
12/10/2013	1/10/2014	N/A	986	3,234	10 days	2,209
1/10/2014	2/10/2014	N/A	1,054	4,746	20 days	3,721
2/10/2014	3/12/2014	N/A	969	3,599	Full	2,574
3/12/2014	4/10/2014	Post	662	2,632	Full	1,607
4/10/2014	5/9/2014	Post	310	1,814	Full	789
5/9/2014	6/10/2014	Post	82	672	15 days	0
6/10/2014	7/10/2014	Post	0	9	None	0
7/10/2014	8/8/2014	Post	0	0	None	0
8/8/2014	9/9/2014	Post	0	28	10 days	0
9/9/2014	10/8/2014	Post	0	718	Full	0
10/8/2014	11/6/2014	Post	233	1,665	Full	640
11/6/2014	11/30/2014	Post	521	1,378	Full	353
11/30/2014	12/10/2014	Post	234	574	10 days	243
12/10/2014	1/9/2015	Post	823	2,627	20 days	1,602
1/9/2015	2/10/2015	Post	1,142	4,065	Full	3,040
2/10/2015	3/12/2015	Post	1,128	3,880	Full	2,855
3/12/2015	4/10/2015	Post	658	2,481	Full	1,456
4/10/2015	5/11/2015	Post	250	1,472	15 days	447

The pre- and post-installation period space heating gas use was regressed to HDD. The regressions are provided in Figure 5-4. These regressions were then applied to monthly TMY3 HDD (also base 65°F) to estimate baseline and installed gas use and annual savings.

Figure 5-4. Claremont Hall Monthly Gas Use Regression

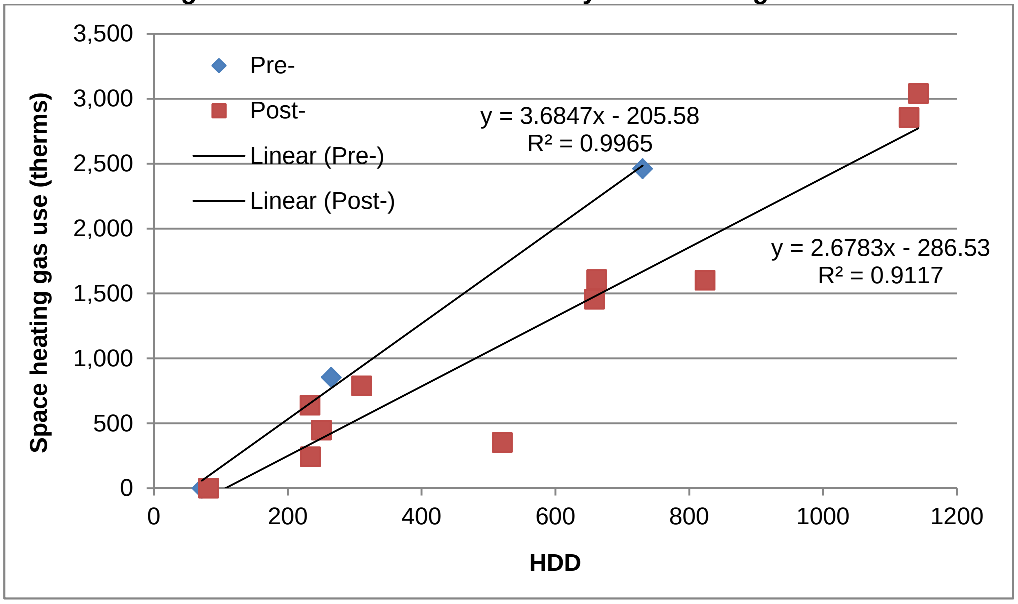


Table 5-2 provides the monthly gas use under TMY3 weather conditions. The billing data indicates a savings of 34% of total annual space heating natural gas use, and 23% of total annual natural gas use (space heating and DHW).

Table 5-2. Claremont Hall Billing Analysis Summary

Month	TMY3 HDD	Pre Use - Overall (therms)	Pre Use - Space Heating (therms)	Post Use - Space Heating (therms)	Savings (therms)
January	1,119	4,174	3,918	2,711	1,207
February	846	3,938	2,913	1,980	933
March	661	3,256	2,231	1,484	746
April	401	2,295	1,270	786	484
May	161	900	387	144	243
June	3	0	0	0	0
July	0	0	0	0	0
August	3	0	0	0	0
September	28	1,025	0	0	0
October	304	1,940	915	528	387
November	512	2,704	1,679	1,084	596
December	918	3,690	3,178	2,173	1,005
Total	**4,957**	**23,922**	**16,492**	**10,891**	**5,601**

Watt Hall – Oil delivery data was provided by Columbia University for the 2012–13 and 2013–14 heating seasons. Deliveries occur approximately twice per month. For the 2014-2015 heating season, the Watt hall boiler utilized #2 fuel oil until February 9, 2015. According to the heating fuel bills provided to ERS, the last delivery of #2 fuel oil took place on February

9, 2015 and the first natural gas was billed on February 26, 2015. A summary of the deliveries is provided in Table 5-3. HDD were based on weather data from New York City's Central Park station and a base temperature of 65°F.

Table 5-3. Watt Hall Billing Data

Start	End	Period	HDD	#4 Fuel Oil Gallons	#2 Fuel Oil Gallons	Natural Gas (Therms)	Equivalent Input (Therms)
N/A	10/8/2012	N/A	N/A	1,730	N/A	N/A	2,562
10/9/2012	11/2/2012	Pre-	233	1,000	N/A	N/A	1,481
11/3/2012	11/5/2012	Pre-	68.2	1,545	N/A	N/A	2,288
11/6/2012	11/19/2012	Pre-	290.8	2,438	N/A	N/A	3,611
11/20/2012	12/3/2012	Pre-	310.7	2,270	N/A	N/A	3,362
12/4/2012	12/17/2012	Pre-	290.4	2,291	N/A	N/A	3,393
12/18/2012	12/31/2012	Pre-	389.3	2,306	N/A	N/A	3,415
1/1/2013	1/12/2013	Pre-	322.9	1,958	N/A	N/A	2,900
1/13/2013	1/27/2013	Pre-	511	2,701	N/A	N/A	4,000
1/28/2013	2/6/2013	Pre-	313	2,686	N/A	N/A	3,978
2/7/2013	2/15/2013	Pre-	267.3	2,142	N/A	N/A	3,172
2/16/2013	2/25/2013	Pre-	314.6	2,436	N/A	N/A	3,608
2/26/2013	3/6/2013	Pre-	240	2,108	N/A	N/A	3,122
3/7/2013	3/16/2013	Pre-	245	2,078	N/A	N/A	3,078
3/17/2013	3/27/2013	Pre-	302.1	2,227	N/A	N/A	3,298
3/28/2013	4/10/2013	Pre-	236.7	1,615	N/A	N/A	2,392
4/11/2013	5/2/2013	Pre-	246.8	1,903	N/A	N/A	2,818
5/2/2013	11/11/2013	Pre-	617	1,683	N/A	N/A	2,493
11/12/2013	11/25/2013	Pre-	298.9	2,365	N/A	N/A	3,503
11/26/2013	12/9/2013	Pre-	339.9	2,220	N/A	N/A	3,288
12/10/2013	12/23/2013	Pre-	377.6	2,355	N/A	N/A	3,488
12/24/2013	1/6/2014	Pre-	464.3	2,943	N/A	N/A	4,359
1/7/2014	1/17/2014	Pre-	324	2,091	N/A	N/A	3,097
1/18/2014	1/30/2014	N/A	541.6	3,210	N/A	N/A	4,754
1/31/2014	2/8/2014	N/A	293.4	2,064	N/A	N/A	3,057
2/9/2014	2/19/2014	N/A	399	2,469	N/A	N/A	3,657
2/20/2014	3/2/2014	N/A	340.1	2,309	N/A	N/A	3,420
3/3/2014	3/17/2014	N/A	436.7	2,021	N/A	N/A	2,993
3/18/2014	3/31/2014	Post-	345	1,660	N/A	N/A	2,458
4/1/2014	4/21/2014	Post-	296.4	1,704	N/A	N/A	2,524
4/22/2014	10/6/2014	Post-	318.7	N/A	2,000	N/A	2,760
10/7/2014	10/27/2014	Post-	130.7	N/A	801	N/A	1,105
10/28/2014	12/22/2014	Post-	1205.7	N/A	6,341	N/A	8,751
12/23/2014	2/9/2015	Post-	1616.7	N/A	9,209	N/A	12,708
2/26/2015	3/11/2015	Post-	447.5	N/A	N/A	2,677	2,677
3/12/2015	4/9/2015	Post-	658.1	N/A	N/A	2,971	2,971
4/10/2015	5/8/2015	Post-	246	N/A	N/A	2,971	2,971

Note: The utility billing data from 10/28/14 to 12/22/14 combines 4 different oil deliveries and 12/23/14 to 2/9/15 combines 5 different oil deliveries respectively. The billing data was combined for the purpose of obtaining a reasonable regression with the HDD.

Since the Watt hall boiler heating fuel types changed during the pre- and post-installation periods, the pre- and post-installation period space heating fuel use (in therms of energy input) was regressed against HDDs to provide a comparison based of the amount of energy supplied by each fuel type. For #2 and #4 fuel oil, energy content values of 138,000 Btu/gallon and

148,100 Btu/gallon were assumed by ERS to estimate the overall energy input to the boiler. While the combustion behavior of liquid fuels was expected to be similar between the grades of fuel oil such that a heat content adjustment could be used, the switch to natural gas cannot be as easily quantified. Switching fuel introduces the potential for additional variation into the analysis via a change in boiler combustion efficiency. Therefore the natural gas data points at the end of the heater season were not used. The regressions are provided in Figure 5-5. These regressions were then applied to monthly TMY3 HDD to estimate baseline and installed gas use and annual savings.

Figure 5-5. Watt Hall Oil Use Regression

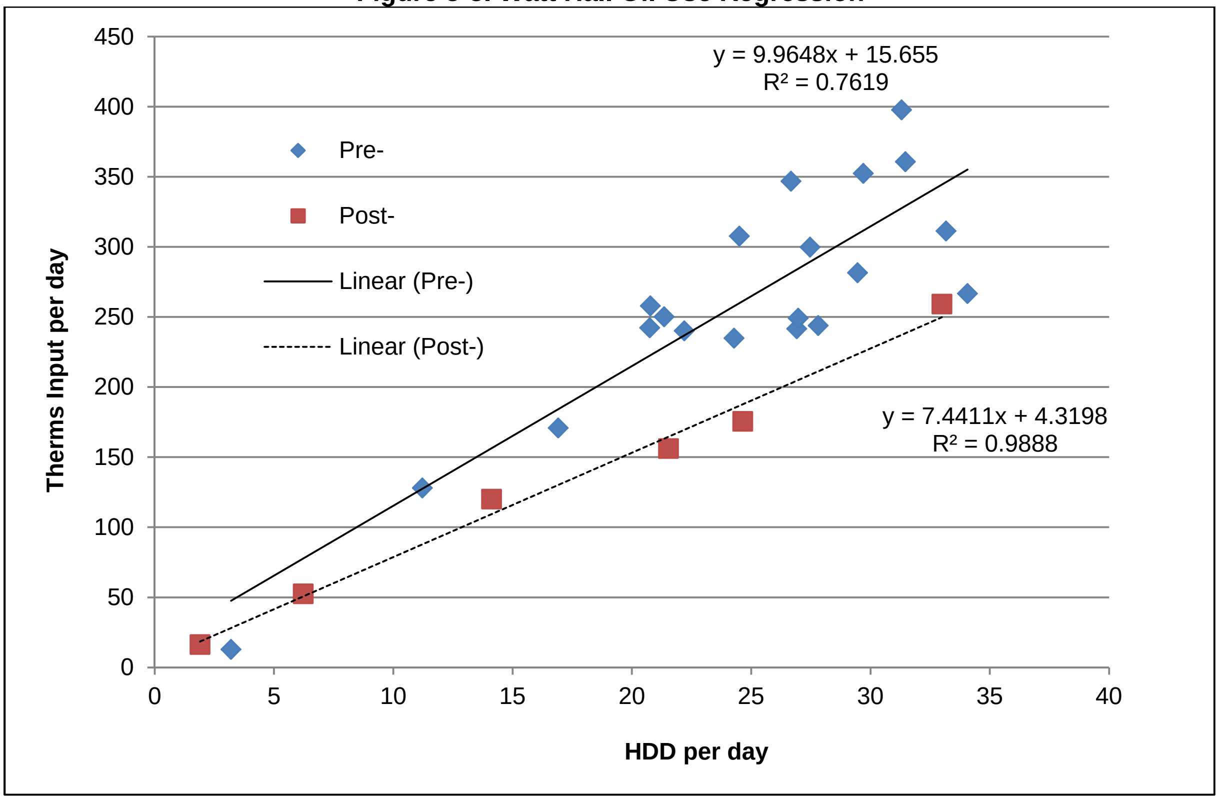


Table 5-4 provides the monthly oil use under TMY3 weather conditions. The billing data indicates a savings of 26% of total annual billed use, which includes the boiler usage for both space heating and DHW.

Table 5-4. Watt Hall Billing Analysis Summary

Month	TMY3 HDD	Pre Use (Therms)	Post Use (Therms)	Savings (Therms)
January	1,119	11,166	8,331	2,835
February	846	8,450	6,302	2,147
March	661	6,604	4,924	1,680
April	401	4,007	2,985	1,022
May	161	1,619	1,202	417
June	3	47	28	19
July	0	16	4	11
August	3	50	30	20
September	28	295	213	82
October	304	3,047	2,268	779
November	512	5,113	3,811	1,302
December	918	9,166	6,837	2,329
Total	**4,957**	**49,580**	**36,935**	**12,645**

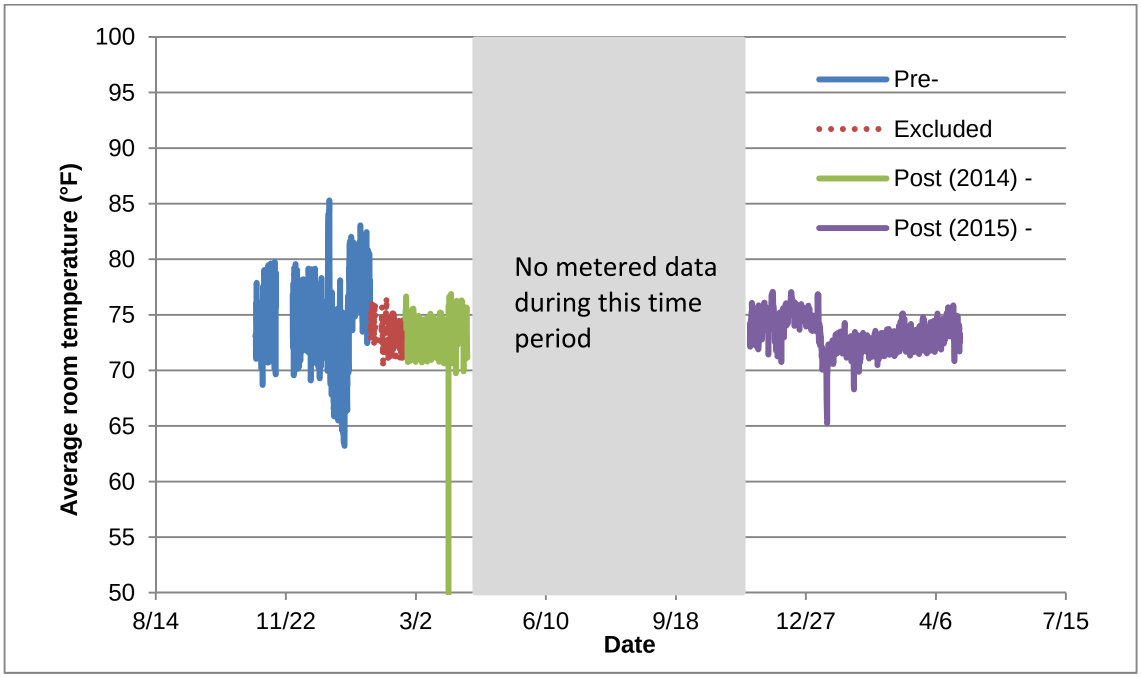
5.3 Room Temperature Analysis

Although the boiler run time and billing analysis clearly show a drop in energy usage for both buildings, conducting a room temperature analysis traces the energy savings back to the source. ERS's understanding is that the installation of a Cozy on each radiator is the only change that has been made to the radiator and room temperature controls. Therefore, if the average temperature of the building is lower, it indicates that the visible drop in energy use was a result of the installed Cozy units' impact on room temperature control.

Comparing the three analysis methods, estimating energy savings using the room temperature data is the least certain analysis method. Energy loss from the building is highly dependent on the insulating value of the building shell (walls and roof) and also infiltration rates. Both of these parameters are difficult to measure precisely. Adding further uncertainty to the analysis is occupancy behavior. Student surveys conducted by Radiator Labs indicate that many students used to open their windows to alleviate overheating. Open windows would greatly increase the ventilation rate of the building and would impact the observed room temperatures. Therefore, although this method was indicated as an approach in the Performance Validation Plan, given the quality of the data collected and consistency of the results of the billing analysis and boiler run-time analysis, the room temperature analysis was used only to qualitatively demonstrate the reduction the improved space temperature control and reduced heating load.

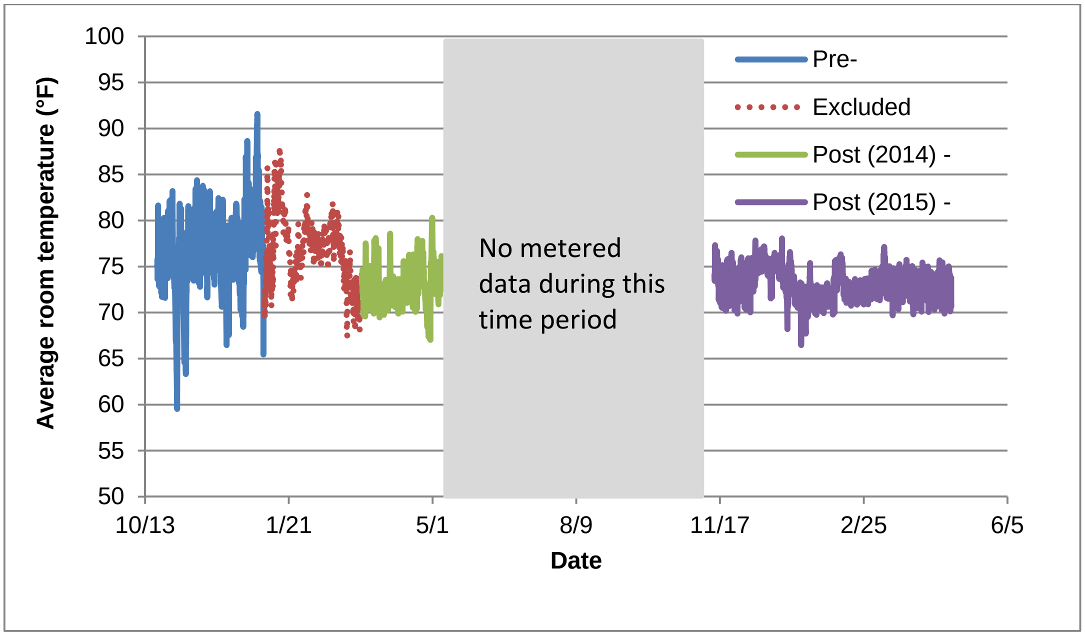
Claremont Hall – In Claremont, room temperature data was collected through the Radiator Labs system. Since the Cozy system had been tested the season before (2012-13), many of the rooms still had wireless infrared temperature sensors installed. For thirty-one rooms, baseline temperature data was collected for a period of 10 weeks. Data was collected for approximately 6 weeks in the 2013-2014 heating season and approximately 22 weeks in the 2014-2015 heating season in the post-installation case. Without the Cozy system in place, the average room temperature was 75°F. With the system installed, the average temperature dropped 1.8°F, to 73.2°F. Figure 5-6 shows the average room temperature for the building during both the pre- and post- periods. Baseline temperatures ranged from 65°F to almost 85°F. With the Cozy system installed, temperatures consistently ranged between 70°F and 77°F.

Figure 5-6. Average Claremont Hall Room Temperature



Watt Hall – In Watt Hall, no Radiator Labs infrastructure was in place prior to the testing. ERS installed HOBO temperature loggers in twenty-four rooms to collect baseline and post-case data. Baseline data was collected for 10 weeks, while post-installation case data was collected for 7 weeks in the 2013-2014 heating season and approximately 24 weeks in the 2014-2015 heating season. The average temperature without the Cozy system was 76.9°F, while with the Cozy system installed the average room temperatures dropped to 73.3°F, a drop of 3.6°F. Figure 5-7 shows the average room temperature for the building during both the pre- and post- periods. Baseline temperatures ranged from 70°F to 85°F. With the Cozy system installed, temperatures consistently ranged between 70°F and 78°F, with most temperatures below 75°F.

Figure 5-7. Average Watt Hall Room Temperature



5.4 Circulation Fan Energy Use

Each Cozy has a circulation fan that cycles on each time that the infrared thermostat indicates that heating is required. The installation of this fan results in a marginal increase in electric energy use, which will offset some of the heating fuel savings realized with the Cozy. ERS took spot measurements of fan kW demand and reviewed fan run-time data to quantify these electric impacts.

Spot power measurements taken with a Kill-A-Watt plug-in power meter showed that the fan consumed 4 watts when running. There is only one speed for the on/off fan used. The Radiator Labs system also collects fan on/off status as a data point. Daily run time (minutes) was totaled for each day for fifty-five rooms in Claremont and ninety rooms in Watt. Run-time data over the course of the season was collected and regressed to the OAT. Colder days resulted in an increased call for heat in the rooms and therefore increased fan run time. The results of the daily fan run-time regressions vs. OAT are provided for both Claremont and Watt in Figure 5-8 and Figure 5-9, respectively.

Although the boiler run-time regression for Claremont showed that the boiler was off above 58°F, the radiator fans are called to run based on room temperature. Therefore, it is possible that the fans could run even if OATs are above the NYC legal heating minimum temperature.

Figure 5-8. Claremont Hall Fan Run Time

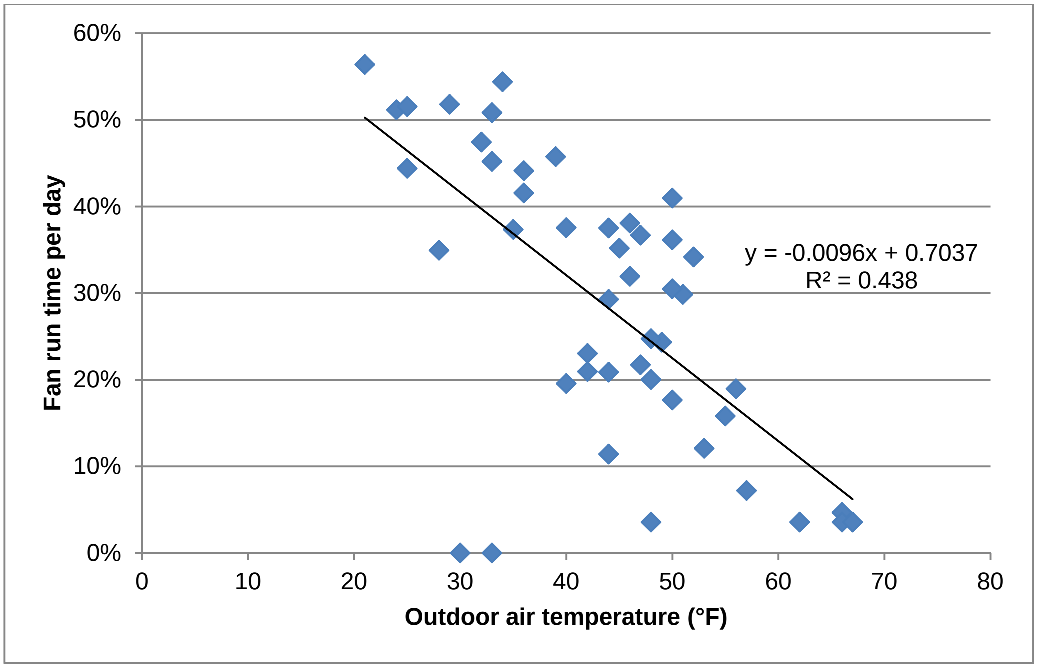
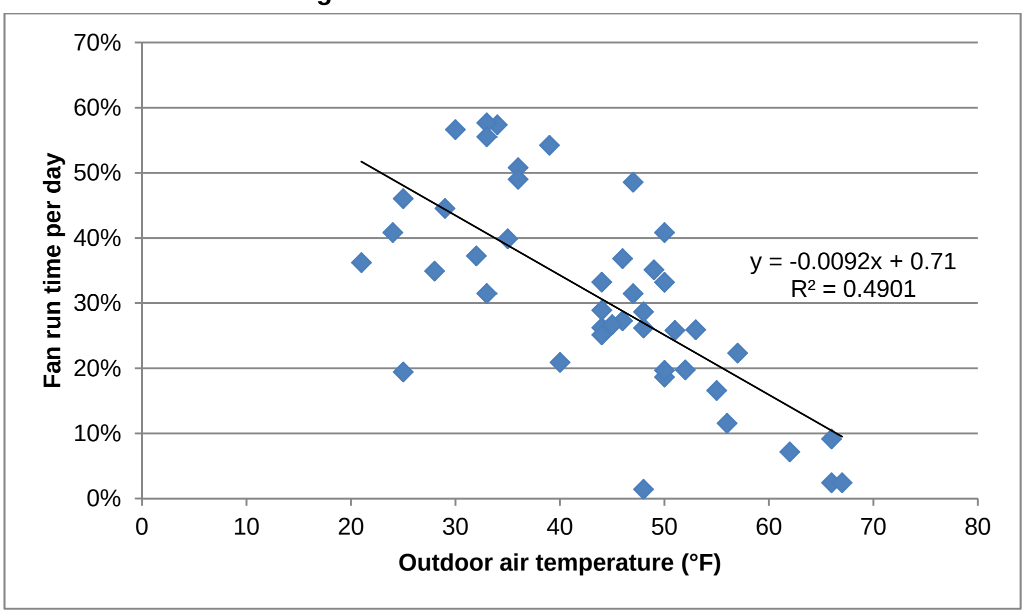


Figure 5-9. Watt Hall Fan Run Time



This regression was applied to TMY3 data to extrapolate fan energy use to a full heating season. For Claremont and Watt, the annual use would be 1,691 and 1,725 hours, respectively, or between 6.8 and 6.9 kWh annually per radiator. At typical New York City electric rates of $0.18 per kWh this would amount to $1.25 in additional cost per radiator per year. Table 5-5 provides a summary of the penalty from increased electric use. The total project cost savings are provided in Section 6.

Table 5-5. Energy Penalty Impacts (Total per building)

Building	Number of Cozy's	Cost Penalty Due to Fans	Energy Penalty (kWh)
Claremont	71	$89	480
Watt	117	$146	807
Total	**188**	**$235**	**1,287**

6 Results Summary

A summary of the analysis results is provided in Table 6-1.

Table 6-1. Summary of Results

Method	Metric	Claremont	Watt
Boiler run time	Run-time reduction	28%	41%*
	Savings (therms)	6,417	11,957
	Savings (gallons)	N/A	8,212
Billing	Reduction of total	23%	24%
	Savings (therms)	4,860	11,957
	Savings (gallons)	N/A	8,212
Room temperatures	Average pre- temperature (°F)	75.0	76.9
	Average post- temperature (°F)	73.2	73.3
	Temperature reduction (°F)	1.8	3.6
Annual energy use	TMY3 (therms)	23,922	49,580
	TMY3 (gallons)	N/A	33,477

Note: *= For the Watt Hall boiler run-time analysis, the percent savings is of only the space heating component. For all others, the percent savings is of the total billed energy (oil/gas) use.

Table 6-2 provides a summary of the cost savings. The oil and natural gas rates used were $3.15 per gallon and $1.12 per therm, respectively, per the facility's utility bills. Savings are the net of the increased electric costs from the fans discussed in Section 5.

Table 6-2. Annual Cost Savings

Building	Total Cost Savings
Claremont	$7,100
Watt	$24,670
Total	**$31,770**

Both buildings saw similar reductions in boiler run time, although the magnitude of the calculated savings was larger for Watt Hall, which houses more students and has a correspondingly larger heating energy use. From the metered data, Watt also appeared to be more overheated in the base case, further increasing the baseline energy use. Average temperatures in Watt Hall dropped 3.6°F, while temperatures dropped 1.8°F in Claremont. The baseline temperatures in Watt Hall were 2°F warmer than Claremont. The increased magnitude of overheating allowed for a larger temperature reduction compared to Claremont when the building achieved its setpoint of 73°F.

There were uncertainties introduced in to the boiler run-time analysis for the Watt Hall due to a change in boiler fuel type for the pre- and post-installation periods, as explained in section 5.1. As a result, there is uncertainty around the absolute annual energy savings for the cozy installation in Watt, although ERS is confident that the savings are likely to be between 24% and 41%, as calculated in our interim and final percent runtime analysis results.

Both buildings showed a reduction in the weather-normalized billed fuel use, and an additional season of post-installation metering re-affirms the results provided by the previous analysis calculations shown in ERS' interim project report.

7 Future System Improvements and Iterations

Several difficulties hampered installation and operation of the Cozy system during testing. In response to these challenges, and to add additional functionality to the Radiator Labs product, Radiator Labs has released several upgrades to their system to be incorporated with their next generation of the technology. Any future Radiator Labs deployments will incorporate these new features. Many of these challenges were specific to this EPV project and will be adequately addressed for the new installations currently under review through the FD track.

- **Internet connectivity** – Radiator Labs experienced difficulty successfully connecting their gateway and equipment to Columbia University's wireless system. In addition to hampering data collection, this also impacted the system's ability to successfully control the boiler, resulting in a prolonged commissioning period, which limited the amount of post-installation data that could be collected. This was mitigated in part through the second season of post-case data collection.

  With the expectation that problems may arise when attempting to connect to existing network infrastructure, especially within large institutional clients, Radiator Labs should prioritize Internet connectivity. Going forward, the physical radiator covers will not be installed until a building is successfully connected. For future ETAC-related testing, this means that IT installation will occur during the baseline period, allowing up to 3 months for problems to be resolved, rather than a 1- to 2-week period. If a building is not successfully connected, installation of the covers should not go forward.

  Similarly, connectivity issues emerged with a real-time utility-grade gas meter. Claremont had recently been fitted with a Con Edison interval gas meter which could provide much higher resolution gas use data (on the order of daily or even hourly use). This additional data would have allowed for a more refined calibration of the boiler run-time model; run time on a daily basis could be compared to actual gas use. Additionally, DHW use could be more accurately estimated by looking at gas use on only the days when space heating was not required. While this level of data quality is not expected at every site due to high installation costs, for those sites where the data is available every effort should be made to acquire that data. In this case, confusion among Con Edison, Columbia University, and Radiator Labs arose over the proper contacts and protocol required to enable the meter. Ultimately, the other data collected allowed for an analysis to be completed, albeit at less confidence and accuracy than if this additional data had been collected. Given the short period of post-case metering, any additional data point would have been valuable. Additional data collected the following season added additional confidence to the analysis.

- **Boiler controller** – The Radiator Labs system does not have its own boiler controller system, but rather it sends an electronic on/off signal to the existing boiler firing system. The Radiator Labs algorithm is based on room temperature data from all of the rooms, rather than a select few as in the baseline case. Once a certain threshold of rooms fall below the minimum temperature, the system will send the firing signal to the boiler controller. Therefore the boiler must have an internet enabled boiler controller. Although many boilers have these controllers already, for those that do not upgrades are estimated to cost around $6,500. Less expensive new options may make the Radiator Labs system more attractive to smaller buildings or buildings with less sophisticated existing boiler controls.
- **User experience** – a QR code system will be implemented with new installations. This will allow the Cozy system installers with QR code scanning technology, to quickly scan each system and track which room and radiator it is installed on. Additionally, this will give occupants the ability to scan their radiator and program their desired temperature, within a certain predetermined temperature threshold limit set up by Radiator Labs during the installation process. Since the system is Internet based, Radiator Labs could update or modify the limits as needed to optimize system performance and comfort.
- **Design improvements** – A survey was conducted at the end of the heating season in Claremont to determine how well the Cozy units were still functioning. The largest deficiency observed, in seven of forty-nine rooms, was the incorrect operation of the infrared temperature sensor. In these cases the device had either been unplugged, placed in the wrong direction, or had fallen down. Incorrectly functioning sensors have the potential to reduce occupant comfort and energy savings. A design change was made to correct this in future product releases. The temperature sensor will now be built into the cover system as an integral part of the Cozy, and therefore it will no longer be separately installed. This should greatly reduce instances where the sensor is dislodged. The close proximity to the radiator is not expected to cause inaccurate room temperature readings. The thermostat uses an infrared sensor that will be pointed away from the Cozy and the radiator into the center of the room.
- **Aesthetic improvements** – A design change will also incorporate the fan and controller into the radiator cover. These components will be on the inside, rather than sticking out into the room. This should prevent accidental contact with these components, as well as be more visually appealing. While this would not have an impact on energy savings

directly, it may make occupants and building managers more willing to deploy the technology.

- **Additional benefits** – The Radiator Labs Cozy system collects a vast amount of data that can be used to diagnose other energy inefficiencies in the building. For example, in two pipe steam systems, Radiator Labs collects temperature data downstream of the steam trap. By reviewing the temperature difference between the radiator and condensate line, failed steam traps can be identified in real time and replaced as needed. Without the system, staff would be required to physically inspect each room and take temperature measurements, a time-consuming process usually done seasonally, at best. Radiator Labs was able to identify eight steam traps in need of replacement in Watt Hall. Since Radiator Labs also collects temperature data in each room, the temperature decay rate of each room can be observed. This rate quantifies how quickly the room drops in temperature after the heat is shut off. Rooms can be compared to each other, and those which lose heat the fastest may be candidates for weatherization upgrades. A quick decay constant indicates that there are high shell or infiltration losses, likely caused by lack of insulation or air gaps around windows or doors. Monitoring this data could also alert facility staff to opened windows since these rooms may fail to warm up, or will drop in temperature extremely quickly. These "poor performers" will govern the rate of boiler firing; and reducing these losses can result in further reduction in heating energy use. These features use a combination of automatic screening algorithms and human review. Steam trap data review is conducted on a daily basis during the system diagnostic report. Failed traps are flagged for human review of the data.

8 RECOMMENDATIONS

Based on the data collected for the two-building pilot study, ERS finds that the Radiator Labs system has demonstrated achievable energy savings, but further study is needed to understand the appropriate market segments and applications for this product. ERS has the following recommendation for the study.

- **Future locations** – ERS recommends that the Cozy units be deployed and monitored in additional buildings with various construction types, ages, steam system configurations, and end users. Collecting data from a variety of facility types will not only add confidence to the energy savings, but also provide information about the magnitude and range of savings, as well as insights to the best facility types for the system. The building stock that uses steam heating systems is diverse, and therefore presents many variables that can impact savings. Due to the challenges of finding and enrolling suitable host sites, ERS recommends engaging as many diverse sites as possible. Rather than design a specific sample set and limit host sites based on building characteristics, it may be beneficial to instead collect metered data from the sites and analyze for trends in savings after the study is complete. This study is currently underway through the FD track of the ETAC program.

8.1 Building Checklist

To expedite the survey of buildings and to quickly screen potential facilities for fit, ERS has developed set of questions for potential sites. The questions are designed to find buildings with the greatest potential for energy savings, as a percentage of baseline energy use and magnitude of savings, as well as ease of installation and likelihood of adoption by the occupants and buildings' staff.

This subsection provides the list of the questions. The following subsection (8.2) provides explanation to why the question was asked and further information that may be of interest to readers who would like to gain a deeper understanding of the question development thought process. Subsection 8.2 was not intended to be distributed to building operators (or other survey respondents. Questions 1 through 3 require a "yes" answer. For the remaining questions, yes answers are not required, but buildings ranking with a higher number are expected to be better candidates.

At this time the building data set is not sufficiently large to draw conclusions about the relative impact of questions four through eleven. Proposed additional study could provide information to draw qualitative conclusions about the relative impacts of these variables.

Consider the following eleven questions for a potential building:

1. Is the building heated by steam (generated by an oil or natural gas boiler) and does it use cast-iron radiators?
2. Are the radiators clear of obstructions (decorative covers/casings, set back from the wall by a few inches) and are most within 10 feet of an electric outlet? (At least 90% of the stock)
3. Is the building free of thermostatic radiator valves (TRVs)?
4. Does the building staff receive complaints during the heating season (either too hot or too cold)?
5. Are tenants/occupants opening windows during the winter to maintain a comfortable temperature?
6. Is the heating system greater than 30 years old? If unknown, is the building greater than 30 years old.
7. Do fewer than 10% of the rooms in the building have control points (e.g., a building with fifty units would have five or fewer thermostats governing the steam system)?
8. Is the DHW heating system separate from the space heating boiler system? If not, is the building use something other than a dormitory, hotel, or facility where tenants/guests reside?
9. Is the building temperature maintained 24/7 during the winter (i.e., no setbacks on nights or weekends), and is this required (as in residential buildings)?

10. Does the building operator have control over the tenant spaces to complete the upgrades (i.e., a dormitory or rental apartments) and ensure that the Radiator Lab Cozy products will remain installed?
11. Has an Internet-enabled boiler controller already been installed?

8.2 Question Categories

1. **Heat source** –Based on the testing conducted during this study, savings have only been validated for heating systems where steam is generated with a local boiler (natural gas or oil fired). While it is logical to extend these savings to other fuel sources, it is not known what the energy savings from a district steam or cogeneration plant may be. For these systems, the distribution controls are likely different, since there is no boiler to cycle on and off. One to two of these heating sources may be selected for future testing to understand how the steam source impacts savings and to develop and test measurement tools and data collection methods. However, widespread deployment would not be encouraged at this time. The system is only designed for use with radiators.
2. **Unobstructed radiators** – It is critical that the radiators be clear of any obstructions or covers. Some radiators may have metal covers for aesthetic reasons, hiding the cast iron radiator. In most cases, this will not be compatible with the Radiator Labs system. The existing cover would likely interfere with the Cozy, preventing the fans from successfully circulating the air and inhibiting the installation of the temperature sensors. Likewise, clearance (a few inches) is also required between the wall and radiator to slide the Cozy into place. The Cozy fan needs to be plugged in, and the built-in cord is approximately 10 feet long. Although extension cords can be used, their use should be the exception rather than the rule.
3. **Existing TRVs –** Buildings that already have TRVs installed would require additional study to determine if they are good candidates for the Cozy. These are competing technologies that deliver savings using the same method, reducing the transfer of heat to spaces within the building that are already sufficiently heated.
4. **Occupant complaints** – If occupants are complaining, especially that the building is too hot, this is a very good indication that the building is overheated and wasting energy and substantial savings are possible. Alternatively, if some occupants are complaining that the building is too cold, this indicates that the system could be improperly balanced, and the Cozy system could help to increase distribution to the underheated rooms.
5. **Open windows** – Occupants may not file complaints with the building mangers, especially if the spaces are overheated. It is far more common that a tenant would opt to open a window instead to cool the space to a comfortable temperature, rather than alerting building management to a problem. If windows are opened during the winter while the heating system is on, this is a very good indication that the building is overheated and wasting significant energy.
6. **Building age** – In general, the older the building stock, the more potential there may be for savings due to poorly performing steam systems that drive up the steam use per

square foot in the building. Old buildings have less sophisticated control and distribution systems, resulting in opportunity for improvements via precise temperature control, and the steam system balancing effects of being able limit heat to rooms that have met their set point.

7. **Building size** – Larger buildings are ideal for the Radiator Labs upgrade, on an economic basis. Although energy savings on a percentage basis may be the same, the Radiator Labs system incurs fixed start-up costs including recruitment, legal fees, site visit travel time, boiler controllers and connections, and software/hardware costs for the gateway. In a large building these costs can be spread over a larger number of units.
8. **Heating system control** – The fewer room temperature sensors used to control the boiler firing, the more likely a building is to be overheated. Location of these thermostats in the distribution system will likely have an effect on savings potential, however the limited scope of the study thus far prevents quantitative conclusions from being drawn. In a system with few temperature sensors, these thermostats are likely placed in the coldest rooms of the system. Therefore, the boiler is run to satisfy the worst-performing rooms and in the process it overheats the other rooms. The Cozy can deliver savings by monitoring the temperature in each room, ensuring that as the worst-performing rooms are heated, the other rooms are only heated until their setpoints are met. A small number of temperature sensors also means that if failure occurs the building may be governed by only a couple of rooms, or if occupants of these rooms open windows, then the rest of the building becomes increasingly overheated.
9. **DHW system** – Buildings with only space heating loads are good candidates to evaluate the Cozy's performance, as it is more straightforward to isolate the impact of the Cozy on the building's boiler energy use than it is in buildings where the space heating boilers heat DHW; however, this does not exclude buildings where DHW is heated by the boiler, as these can still be candidates for testing when sufficient metered data is available to isolate the building's space heating energy usage. Similarly, buildings such as a commercial office will have small DHW loads and would be good candidates even if space and water heating are on the same heating system.
10. **Heating setpoints** – The best buildings for the Radiator Labs retrofit are those that would be required to maintain minimum temperatures throughout the heating season. This would include residential buildings or hotels as opposed to commercial office spaces, which could program nighttime setbacks, reducing baseline energy use and providing less potential for savings.
11. **Occupant acceptance** – In order for the Cozy system to operate effectively, a high penetration rate for installation is required. Much as a chain is only as strong as its weakest link, the Radiator Labs system loses effectiveness for each radiator that is not outfitted with the Cozy. Building owners must have suitable control over the occupants to ensure that access can be granted to each room and that the systems will stay installed. In the case of student dormitories or rental apartments, these systems would be owned

by the building and protected under the same methods as other damage (fees, security deposits, etc.).

12. **Boiler control system** – The Radiator Labs system requires at a minimum an Internet-enabled boiler control so that the communication can be established to direct the on/off call and collect data. These controls can be installed as a retrofit by Radiator Labs, but the projected $6,500 cost will reduce the payback of the project. The exact effect is dependent on the number of radiators, fuel cost, and baseline energy use.

8.3 Other Metrics and Considerations

- **Steam use energy use intensity** – Ideal candidates for the Cozy system will have poorly functioning steam systems that drastically overheat buildings. By metering such buildings, along with newer buildings with better performing steam systems, a better picture can be developed of the characteristics that make a building a good candidate for the Cozy system. To quantify these "poor performers" heating use per square foot or similar metrics could be used to identify buildings with higher than typical heating loads.
- **Schools** – K through 12 and university classroom buildings may also be good candidates for the Cozy system, provided the buildings are heated with a steam system. When compared to dormitories, these types of buildings typically have a much smaller DHW load relative to the space heating load, enabling the energy savings associated with the Cozy to be more easily identified in utility bills.
- **Commercial facilities** – Commercial office space may offer an additional market area to explore. However, the challenges in this sector may be greater, as these clients typically have more demanding aesthetic and economic criteria when selecting a product due to tenant preferences. These facilities may be less willing to work with a newly commercialized product and may prefer more robustly tested "off the shelf" solutions. The changes to the next generation Cozy include, aesthetic improvements, reduced installation time, and more robust data analysis features (steam trap monitoring etc), and may help to overcome these hurdles and entice commercial clients. If utility costs are passed along to the tenants, Radiator Labs may face issues with split incentives, and find that building owners are not interested in the product. The best opportunities may lie outside of the class-A office space with smaller real estate owners/properties. Due to occupancy patterns, existing controls will play a large part in potential energy savings.
- **Space temperature setpoints and system controls –** ERS expects that space temperature setpoints and heating system controls may have a significant impact on the energy savings potential of the Cozy system. Building setpoints may be lowered substantially during unoccupied periods reducing the potential for savings. Conversely, if no setbacks are in place, the Radiator Labs system may be able to add additional savings by programing nighttime, weekend, and holiday setback temperatures. Buildings with less sophisticated boiler and space temperature controls are expected to offer more opportunity for savings.