A Focused Demonstration Project: The “Cozy” by Radiator Labs

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A Focused Demonstration Project: The "Cozy" by Radiator Labs

Final Report

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Abstract

Radiator Labs has developed a technology that eliminates overheating in steam-heated buildings, the predominant heating technology found in larger, older cities like NYC.

Beginning in 2013, with NYSERDA ETAC (Emerging Technologies Accelerated Commercialization) support, Radiator Labs engaged in an ETAC focused demonstration to establish the technology's impact in seven full-building deployments. After five years of third-party evaluation, the project team found that the technology saved 25% on average in all buildings evaluated with savings as high as 45%. The smallest efficiency gain (14.5%) was found in a building that, post retrofit, is among the most efficient one-pipe steam buildings in the entire NYC area, demonstrating the impact of the technology even on relatively efficient buildings.

Keywords

Steam Heat, Radiator Labs, TRV, Cozy

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Summary

This final project report (FPR) by Energy & Resource Solutions' (ERS) is an Emerging Technologies and Accelerated Commercialization (ETAC) program proposal submitted by Radiator Labs, Inc. It represents a submission for a focused demonstration project as part of New York State Energy Research and Development Authority's (NYSERDA) ETAC program under Project Opportunity Notice (PON) 2689 and performed under NYSERDA ETAC-FD-001. It involves the installation of the company's radiator control technology in the five locations listed in Table S-1.

Table S-1. Focused Demonstration Project Locations

Address	Building Type
3601 Kings Highway, Brooklyn, NY	Residential
400 West 119th St. (Butler Hall), New York, NY	Dormitory (Columbia University)
The Lunt-Fontanne Theatre, New York, NY	Commercial
295 Clinton Avenue, Brooklyn, NY	Residential
1215 Myrtle Avenue, Brooklyn, NY	Residential

Please note that information in this document is catered to specific building stock to validate a specific effort; any use of the technology outside that scope cannot be expected to produce valid results.

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 is intended to reduce overheating—a common problem that faces many older buildings heated by steam radiators.

The system was previously installed in two dormitory buildings at Columbia University's campus in New York City. As part of the Energy Performance Validation (EPV) project in the 2014–2015 season, ERS utilized three approaches for their analysis (room-temperature reduction, boiler run-time, and billing) to validate the technology at these locations and found substantial evidence of energy savings resulting

from the installations. Through the focused demonstration (FD) track of the ETAC program, the scope was expanded to additional buildings shown in Table S-1 to develop an understanding of the expected range of energy savings possible as well as the building criteria that influence the project savings.

Similar to the EPV project analysis, the ERS team constructed three approaches for their analysis, using boiler controls system trend data, Radiator Labs' network data, utility billing data, and ERS physical data loggers. Initially, a billing analysis was conducted to confirm that the installation of Cozy units at all five buildings in this study resulted in actual measurable energy savings. A boiler run-time analysis was performed for 3601 Kings Highway and Butler Hall to confirm that real quantifiable energy savings resulted in reduced run time of the space heating boilers. Finally, room-temperature analyses were performed for 3601 Kings Highway and Butler Hall to confirm that the reduced heat load reflected in ERS's boiler run-time analysis results in lower room temperatures in the post-installation scenario.

Pre-project data collection was not conducted for 295 Clinton Avenue, and post-project data collection was not conducted for 1215 Myrtle and the Lunt-Fontanne Theatre in this study; therefore, neither a room-temperature analysis nor a boiler run-time analysis was feasible for these buildings. Only the billing analysis results were utilized to calculate the energy-use savings, which are summarized in Table S-2. A billing analysis was performed using two different methodologies:

- Seasonal heating energy use per heating degree day (HDD)[1]
- Linear regression analysis of monthly energy usages per HDD

The billing analysis results for the five buildings included in this study, along with the Claremont and Watt dormitories, which were part of the EPV project in the 2014–2015 season, are provided in Table S-2.

[1] HDD is a measurement designed to quantify the demand for energy needed to heat a building. It is the number of degrees that a day's average temperature is below 65°F (18°C), which is the temperature below which buildings need to be heated.

Table S-2. Results Summary

Analysis Method	3601 Kings Highway Savings	Butler Hall Savings	Lunt-Fontanne Savings	1215 Myrtle Savings	295 Clinton Avenue Savings	Claremont Hall Savings	Watt Hall Savings
Billing reduction (seasonal analysis)a	19%	18%	28%	22%	14%	32%	45%
Billing reduction (linear regression analysis)b	20%	22%	22%	16%	16%	43%	47%

[a] The savings percentages are calculated using a seasonal 'MMBtu/HDD' consumption model and are based on the space heating energy use only. For Claremont and Watt Halls, the post-installation billing data was updated based on the most recent fuel consumption data provided, and the billing analysis results were updated from the EPV report.

[b] A linear regression analysis of the monthly energy usages with historic HDD are not considered to be the preferred analysis methodology because most of the facilities in this study utilized more than one fuel type for heating in the pre- or post-installation case, which increases additional meaningless information within the data sets.

It is evident from the results shown in Table S-2 that ERS has found substantial evidence of energy savings through its analyses of the five additional buildings through the FD project. Space heating energy savings ranging from 14% to 45% were observed in the seasonal billing analysis from installation of this technology for the buildings in the EPV and FD study.

1 Site Description

Following the successful installation at two Columbia University student dormitories located in Manhattan, Radiator Labs arranged the installation of their product at five more locations in the New York Metropolitan Area. The key site features of each building are shown in Table 1.

Table 1. Key Site Features

Building	Fuel Type	Number of Boilers	Project Installation
3601 Kings Highway, Brooklyn	Natural gas, No. 2 oil	1	Jan. 2015
400 West 119th (Butler Hall), Manhattan	Natural gas, No. 4 oil	2	Nov. 2015–Mar. 2016
The Lunt-Fontanne Theatre, Manhattan	District steam	N/A	Nov. 2015
295 Clinton Avenue, Brooklyn	Natural gas	1	Feb. 2016
1215 Myrtle Avenue, Brooklyn	Natural gas, No. 2 oil	1	Nov. 2016

2 Measurement and Verification Data Collection

ERS worked with Radiator Labs to collect measurement and verification (M&V) data in a few different ways. First, utility billing data was collected for all five buildings to analyze the pre- and post-installation fuel use. Boiler controls system trend data, Radiator Labs' network data, and ERS's physical data loggers were utilized to compile a variety of data points at 3601 Kings Highway and Butler Hall during the pre- and post-installation periods to analyze the boiler run time and room-temperature reduction. Data loggers were also installed on the boiler at 295 Clinton Avenue to analyze the post-installation boiler run time, but the loggers were not returned as planned to ERS, and hence a boiler run-time reduction analysis was not feasible. The following sections provide a list of data points collected, including the type of point, measurement method, time increment, quantity, and metering duration for each site.

2.1 3601 Kings Highway

Table 2 provides a summary of the metered points in 3601 Kings Highway.

Table 2. 3601 Kings Highway Metered Points

Parameter/Point	Period	Discrete Points[1]	Unit	Metering Equipment[2]	Interval	Start Date	End Date
Boiler aquastat	Pre-	1	°F	Boiler system	Daily	10/1/14	4/29/15
Boiler run time	Pre-	1	Hours	Boiler system	Daily	10/1/14	4/29/15
Boiler stack temp	Pre-	1	°F	Boiler system	Daily	10/1/14	4/29/15
Domestic hot water/coil temp	Pre-	2	°F	Boiler system	Daily	10/1/14	4/29/15
Domestic hot water/condensate return temp	Pre-	2	°F	Boiler system	Daily	10/1/14	4/29/15
Outdoor temp	Pre-	2	°F	Boiler system	Daily	10/1/14	4/29/15
Governing apt. temp	Pre-	1	°F	Boiler system	Daily	10/1/14	4/29/15
Boiler combustion fan current	Pre-	1	Amps	ERS current transformer	2 minutes	11/16/14	3/23/15
Gas use	Pre-/ post-	1	Therms	Utility meter	Monthly	12/26/12	5/25/17
Oil consumption	Pre- /post-	1	Gallons	Customer bills	Delivery	1/24/13	5/30/15

Table 2 continued

Parameter/Point	Period	Discrete Points[1]	Unit	Metering Equipment[2]	Interval	Start Date	End Date
Boiler blower motor	Pre-	1	State	ERS motor logger	State change	11/16/14	5/15/15
	Post-	1	State	ERS motor logger	State change	1/19/16	5/31/16
Room temp	Pre-	7	°F	ERS temperature logger	Approximately 10 minutes	11/16/14	5/15/15
	Post-	9	°F	ERS temperature logger	Approximately 10 minutes	1/19/16	5/31/16

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

[2] The "boiler system" metered data was collected with a system installed and operated by Entech, a boiler controls company. In addition, ERS installed a HOBO motor on/off logger on the boiler blower motor to measure run time.

2.2 Butler Hall

Table 3 provides a summary of the metered points in Butler Hall.

Table 3. Butler Hall Metered Points

Parameter/ Point	Unit	Period	Discrete Points	Metering Equipment1	Interval	Start Date	End Date
Boiler aquastat	°F	Pre-	1	Boiler system	1 minute	11/10/14	5/15/14
Boiler on	State	Pre-	1	Boiler system	State change	12/28/14	6/2/15
Boiler call	State	Pre-	1	Boiler system	State change	12/23/14	5/30/15
Boiler stack temp	°F	Pre-	1	Boiler system	1 minute	12/23/14	6/2/15
Domestic hot water/coil temp	°F	Pre-	2	Boiler system	15 minutes	12/23/14	6/2/15
Outdoor temp	°F	Pre-	1	Boiler system	15 minutes	12/23/14	6/2/15
Governing apt. temp	°F	Pre-	10	Boiler system	15 minutes	12/23/14	6/2/15
Oil consumption	Gallons	Pre-	1	Customer bills	Delivery	4/11/14	3/11/15
Gas use	Therms	Post-	1	Utility meter	Monthly	4/8/16	6/7/17
Boiler blower motor	State	Pre-	1	ERS motor logger	State change	11/16/14	3/25/15

Table 3 continued

Parameter/ Point	Unit	Period	Discrete Points	Metering Equipment[1]	Interval	Start Date	End Date
Boiler blower motor	State	Post-	1	ERS motor logger	State change	1/20/16	5/31/16
Boiler combustion fan current	Amps	Pre-	1	ERS current transformer	2 minutes	11/10/14	3/15/15
Room temp	°F	Pre-	8	ERS temperature logger	Approx. 10 minutes	11/10/14	5/15/15
	°F	Post-	6	ERS temperature logger	Approx. 10 minutes	1/20/16	5/17/16

[1] 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.

2.3 The Lunt-Fontanne Theatre

Table 4 provides a summary of the metered points in the Lunt-Fontanne Theatre. Only the facility district steam usage was collected for both pre- and post-project scenarios.

Table 4. Lunt-Fontanne Theatre Metered Points

Parameter/ Point	Unit	Period	Discrete Points	Metering Equipment	Interval	Start Date	End Date
Boiler call	State	Pre-	1	Tristar boiler system	State change	2/16/15	5/14/15
Outdoor temp	°F	Pre-	1	Tristar boiler system	15 minutes	2/16/15	5/14/15
District steam use	Mlb	Pre-/ post-	1	Financial records	Monthly	8/13/13	11/16/16
Steam and condensate temperatures	°F	Pre-	4	ERS thermistor	State change	11/12/14	2/16/15

2.4 1215 Myrtle Avenue

Table 5 provides a summary of the metered points at 1215 Myrtle Avenue. Only the facility natural gas usage was collected for both pre- and post-project scenarios.

Table 5. 1215 Myrtle Avenue Metered Points

Parameter/ Point	Unit	Period	Discrete Points	Metering Equipment	Interval	Start Date	End Date
Boiler on	State	Pre-	1	Tristar boiler system	State change	11/12/14	6/5/15
Boiler call	State	Pre-	1	Tristar boiler system	State change	11/12/14	6/5/15
Boiler stack temp	°F	Pre-	1	Tristar boiler system	1 minute	11/12/14	6/5/15
Outdoor temp	°F	Pre-	1	Tristar boiler system	15 minutes	11/12/14	6/5/15
Gas use	Therms	Pre-/post-	1	Utility meter	Monthly	7/14/14	8/17/17
Room temp	°F	Pre-	10	ERS temperature logger	Approximately 10 minutes	11/12/14	6/5/15

2.5 295 Clinton Avenue

Table 6 provides a summary of the metered points at 295 Clinton Avenue. Only the facility heating fuel usage was collected for both pre- and post-project scenarios.

Table 6. 295 Clinton Avenue Metered Points

Parameter/ Point	Unit	Period	Discrete Points	Metering Equipment1	Interval	Start Date	End Date
Oil consumption	Gallons	Pre-/post-	1	Customer bills	Delivery	4/11/14	3/11/15
Gas use	Therms	Pre-/post-	1	Utility meter	Monthly	4/8/16	6/7/17
Boiler blower motor	State	Post-	1	ERS motor logger	State change	11/16/14	3/25/15
Room temp	°F	Post-	8	ERS temperature logger	Approximately 10 minutes	11/10/14	5/15/15

[1] 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.

3 Analysis Methodology

ERS utilized utility billing analysis methodology to calculate energy savings from the installation of Cozy units at each of the buildings. A higher degree of confidence is achieved by substantiating the results of the billing analysis methodology with boiler run-time analysis and room-temperature analysis.

- **Billing analysis**. The first approach uses utility billing data to confirm that the installation of TRE units actually led to a reduction in billed natural gas and fuel oil use in each affected building. The pre-installation and post-installation space heating fuel usage at each of the facilities per HDD data for a base temperature of 65°F are calculated and then normalized to typical meteorological year weather (TMY3) data on an annual basis to estimate the savings from the project.
- **Boiler run-time analysis**. Next, data collected about the boiler run time is used to create a regression to the outdoor weather conditions to confirm that the energy savings from the billing analysis results in reduced run time of the space heating boilers with the Radiator Labs system in place. Since pre- and post- project boiler run-time data was collected only for 3601 Kings Highway and Butler Hall, the boiler run-time analysis was completed only for these two buildings in this study.
- **Room-temperature analysis**. As a final check, the pre- and post-installation room-temperature data was used to confirm that the savings were from a drop-in temperature of the overheated rooms. Since pre- and post-project average room-temperature data was collected only for 3601 Kings Highway and Butler Hall, the room-temperature analysis was completed only for these two buildings in this study.

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.

3.1 Billing Analysis

A billing analysis using natural gas or fuel oil deliveries during the pre- and post-installation periods was used to determine whether the installation of Cozy units at all five buildings in this study resulted in an actual decrease in energy consumption.

3.1.1 3601 Kings Highway

Data for fuel use during heating seasons from 2013 through 2017 for the 3601 Kings Highway facility was obtained through billing data. Table 9 provides the billing data for gas use and fuel oil deliveries. The facility has a dual-fired boiler, and billing data shows that both oil and natural gas were utilized by the boiler for space heating during the analysis.

Table 7. 3601 Kings Highway Billing Data

Start	End	Fuel	Unit	Use	Equivalent MMBtu	Period
2/25/2013	12/26/2014	Natural gas	Therms	67,032	6,703	Pre-
2/25/2013	12/26/2014	No. 2 fuel oil	Gallons	3,960	546	Pre-
12/26/2014	1/27/2015	Natural gas	Therms	6,093	609	Commissioning
1/27/2015	5/25/2017	Natural gas	Therms	83,992	8,399	Post-

ERS utilized the billing data from Table 7 to estimate the fuel usage for space heating in the pre- and post-installation scenarios by adjusting for domestic hot water (DHW) use as shown in Tables 8 and 9. HDDs were based on weather data from New York City's John F. Kennedy International Airport weather station and a base temperature of 65°F.

Table 8. Pre-Installation Space Heating Energy Usage–3601 Kings Highway

Start	End	Space Heating Use (MMBtu)	HDD
2/25/2013	12/26/2014	5,183	8,223

Table 9. Post-Installation Space Heating Energy Usage–3601 Kings Highway

Start	End	Space Heating Use (MMBtu)	HDD
1/27/2015	5/25/2017	5,809	11,343

The pre- and post-installation period energy usages for space heating were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space heating fuel use, and annual savings. A linear regression analysis of the monthly energy usages with historic HDDs were not performed because the facility utilized more than one fuel type for heating in the pre-installation case, which increases additional meaningless information within the data sets and contributes to erroneous calculations. Table 10 provides the monthly space-heating fuel usage under TMY3 weather conditions. The billing data indicates a savings of 19% of total annual natural gas use.

Table 10. 3601 Kings Highway Billing Analysis Summary

Month	TMY3 HDD	Post-Use (MMBtu)	Pre-Use (MMBtu)	Savings (MMBtu)
January	958	490	604	113
February	933	478	588	110
March	712	365	449	84
April	412	211	260	49
May	174	89	110	21
June	15	8	10	2
July	0	0	0	0
August	3	2	2	0
September	53	27	33	6
October	264	135	166	31
November	595	305	375	70
December	838	429	528	99
Total	4,957	2,539	3,124	586

3.1.2 Butler Hall

Data for fuel use during heating seasons from 2014 through 2017 for Butler Hall was obtained through billing data. Table 11 provides billing data for gas use and fuel oil deliveries. It appears that the facility predominantly used fuel oil in the pre-installation scenario and switched over to natural gas in the post-installation scenario.

Table 11. Butler Hall Billing Data

Start	End	Fuel	Unit	Use	Equivalent MMBtu	Period
8/9/2013	12/9/2015	Natural gas	Therms	28,184	2,818	Pre-
8/9/2013	12/9/2015	No. 2 fuel oil	Gallons	203,529	29,715	Pre-
12/9/2015	1/8/2016	Natural gas	Therms	6,093	609	Commissioning
1/8/2016	6/7/2017	Natural gas	Therms	187,240	18,724	Post-

ERS utilized the billing data from Table 11 to estimate the space-heating fuel usage in the pre- and post-installation scenarios by adjusting for student DHW use as shown in Tables 12 and 13. The HDDs were based on weather data from New York City's Central Park weather station and a base temperature of 65°F.

Table 12. Pre-Installation Space Heating Energy Usage–Butler Hall

Start	End	Space Heating Use (MMBtu)	HDD
8/9/2013	12/9/2015	24,673	11,088

Table 13. Post-Installation Space Heating Energy Usage–Butler Hall

Start	End	Space Heating Use (MMBtu)	HDD
1/8/2016	6/7/2017	6,906	4,007

The pre- and post-installation period energy usages for space heating were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space heating fuel use, and annual savings. A linear regression analysis of the monthly energy usages with historic HDDs were not performed because the facility utilized more than one fuel type for heating in the pre-installation case, which increases additional meaningless information within the data sets and contributes to erroneous calculations. Table 14 provides the monthly space-heating fuel usage under TMY3 weather conditions. The billing data indicates a savings of 18% of the total annual natural gas use.

Table 14. Butler Hall Billing Analysis Summary

Month	TMY3 HDD	Post-Use (MMBtu)	Pre-Use (MMBtu)	Savings (MMBtu)
January	1,119	2,038	2,490	452
February	846	1,542	1,883	342
March	670	1,221	1,492	271
April	410	746	911	165
May	185	337	411	75
June	15	27	33	6
July	0	1	1	0
August	10	18	22	4
September	45	81	99	18
October	310	565	690	125
November	512	932	1,139	207
December	918	1,672	2,043	371
Total	**5,040**	**9,179**	**11,215**	**2,036**

3.1.3 1215 Myrtle Avenue

Data for natural gas use during heating seasons from 2014 through 2017 for the 1215 Myrtle Avenue facility was obtained through billing data. The facility boiler uses only natural gas as heating fuel. ERS estimated the space-heating fuel usage in the pre- and post-installation scenarios by adjusting for DHW use. The HDDs were based on weather data from New York City's John F. Kennedy International Airport weather station and a base temperature of 65°F. Table 15 provides the billing data for gas use and space-heating gas usage in the pre- and post-installation scenarios.

Table 15. 1215 Myrtle Avenue Billing Data

Start	End	Billed Gas Usage (Therms)	Space Heating Gas Usage (MMBtu)	HDD	Period
7/14/2014	8/12/2014	51	0	0	Pre-
8/12/2014	9/10/2014	51	0	1	Pre-
9/10/2014	10/16/2014	143	9	95	Pre-
10/16/2014	11/10/2014	165	11	257	Pre-
11/10/2014	12/11/2014	686	63	697	Pre-
12/11/2014	1/20/2015	1044	99	1,148	Pre-
1/20/2015	2/11/2015	810	75	774	Pre-
2/11/2015	3/12/2015	1056	100	1,091	Pre-
3/12/2015	4/14/2015	735	68	725	Pre-
4/14/2015	5/18/2015	208	15	262	Pre-
5/18/2015	6/18/2015	99	4	80	Pre-
6/18/2015	7/13/2015	58	0	0	Pre-
7/13/2015	8/11/2015	59	0	0	Pre-
8/11/2015	9/11/2015	57	0	0	Pre-
9/11/2015	10/12/2015	61	1	80	Pre-
10/12/2015	11/9/2015	134	8	223	Pre-
11/9/2015	12/10/2015	414	36	480	Pre-
12/10/2015	1/19/2016	746	69	814	Pre-
1/19/2016	2/10/2016	610	56	631	Commissioning
2/10/2016	3/11/2016	706	65	792	Commissioning
3/11/2016	4/13/2016	487	43	582	Post-
4/13/2016	5/11/2016	209	15	326	Post-
5/11/2016	6/13/2016	90	3	98	Post-
6/13/2016	7/13/2016	56	0	4	Post-
7/13/2016	8/12/2016	45	0	0	Post-
8/12/2016	9/12/2016	45	0	0	Post-
9/12/2016	10/18/2016	144	9	126	Post-

Table 15 continued

Start	End	Billed Gas Usage (Therms)	Space Heating Gas Usage (MMBtu)	HDD	Period
10/18/2016	11/9/2016	55	0	210	Post-
11/9/2016	12/12/2016	483	43	605	Post-
12/12/2016	1/11/2017	785	73	841	Post-
1/11/2017	2/15/2017	807	75	914	Post-
2/15/2017	3/13/2017	519	46	606	Post-
3/13/2017	4/11/2017	389	33	641	Post-
4/11/2017	5/12/2017	98	4	273	Post-
5/12/2017	6/13/2017	78	2	127	Post-
6/13/2017	7/19/2017	63	1	1	Post-
7/19/2017	8/11/2017	51	0	582	Post-

ERS utilized the billing data from Table 15 to estimate the space-heating fuel usage in the pre- and post-installation scenarios by adjusting for DHW use as shown in Tables 16 and 17. The HDDs were based on weather data from New York City's John F. Kennedy International Airport weather station and a base temperature of 65°F.

Table 16. Pre-Installation Space-Heating Energy Usage–1215 Myrtle Avenue

Start	End	Space Heating Use (MMBtu)	HDD
7/14/1014	1/19/2016	559	6,728

Table 17. Post-Installation Space Heating Energy Usage–1215 Myrtle Avenue

Start	End	Space Heating Use (MMBtu)	HDD
3/11/2016	8/11/2017	349	5,354

The pre- and post-installation period energy uses for space heating were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space heating fuel use, and annual savings. Table 18 provides the monthly space-heating fuel usage under TMY3 weather conditions. The billing data indicates a savings of 22% of total annual natural gas use.

Table 18. 1215 Myrtle Avenue Billing Analysis Summary

Month	TMY3 HDD	Pre-Use (MMBtu)	Post-Use (MMBtu)	Savings (MMBtu)
January	1,119	80	62	17
February	846	78	61	17
March	670	59	46	13
April	410	34	27	7
May	185	14	11	3
June	15	1	1	0
July	0	0	0	0
August	10	0	0	0
September	45	4	3	1
October	310	22	17	5
November	512	49	39	11
December	918	70	55	15
Total	**5,040**	**412**	**323**	**89**

Since the facility utilizes only natural gas for its heating needs, the pre- and post-installation period gas usage for space-heating was also regressed to HDD. The regressions are provided in Figure 1. These regressions were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space-heating fuel use, and annual savings.

Figure 1. Heating Gas Use Regression–1215 Myrtle Avenue

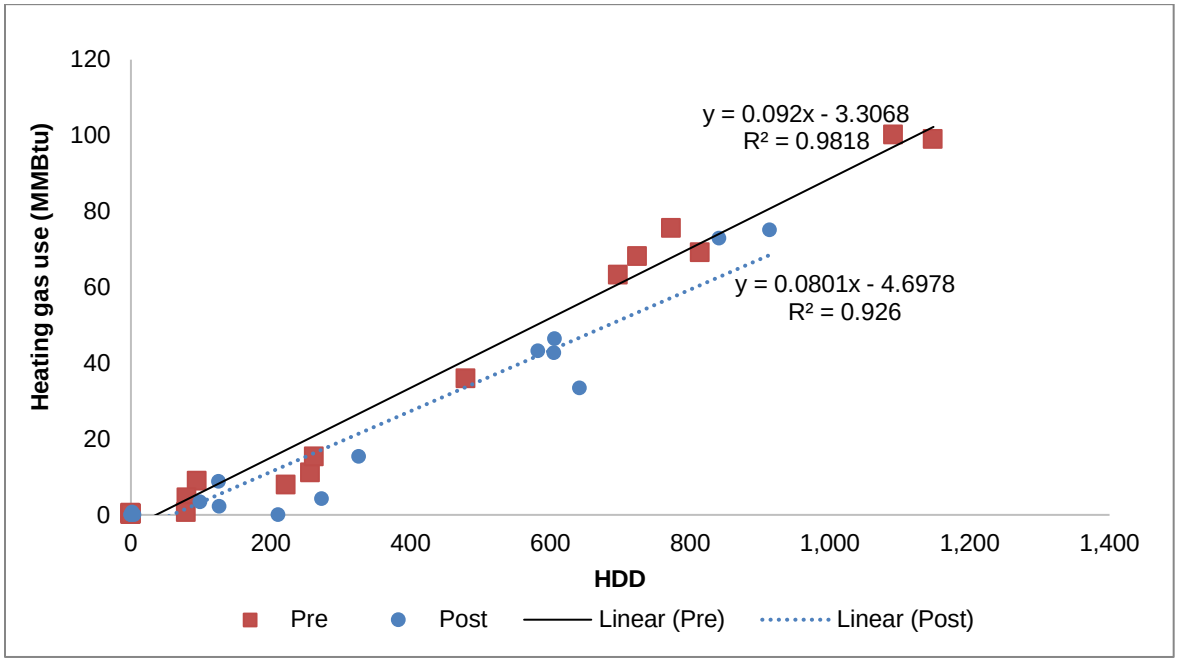


Table 19 provides the monthly space-heating gas usage under TMY3 weather conditions, estimated using the linear regression models. The billing data indicates a savings of 16% of the total annual natural gas use.

Table 19. 1215 Myrtle Avenue Billing Analysis Summary (Linear Regression Model)

Month	TMY3 HDD	Pre-Use (MMBtu)	Post-Use (MMBtu)	Savings (MMBtu)
January	958	85	72	13
February	933	82	70	12
March	712	62	53	9
April	412	35	28	6
May	174	13	9	3
June	15	0	0	0
July	0	0	0	0
August	3	0	0	0
September	53	0	0	0
October	264	21	16	5
November	595	51	43	8
December	838	74	63	10
Total	**4,957**	**423**	**353**	**68**

3.1.4 The Lunt-Fontanne Theatre

Data for district steam use during heating seasons from 2014 through 2016 for the theatre was obtained through billing data. The facility uses district steam for the purposes of space heating only. The HDDs were based on weather data from New York City's John F. Kennedy International Airport weather station and a base temperature of 65°F. Table 20 provides the billing data for gas use and space-heating gas usage in the pre- and post-installation scenarios.

Table 20. The Lunt-Fontanne Theatre Billing Data

Start	End	Billed District Steam Usage (Mlb)	HDD	Period
8/18/2013	9/17/2013	0	16	Pre-
9/17/2013	10/16/2013	0	100	Pre-
10/16/2013	11/14/2013	24	373	Pre-
11/14/2013	12/17/2013	134	822	Pre-
12/17/2013	1/17/2014	253	920	Pre-
1/17/2014	2/18/2014	462	1193	Pre-
2/18/2014	3/19/2014	265	878	Pre-

Table 20 continued

Start	End	Billed District Steam Usage (Mlb)	HDD	Period
3/19/2014	4/17/2014	48	567	Pre-
4/17/2014	5/19/2014	0	302	Pre-
5/19/2014	6/17/2014	0	56	Pre-
6/17/2014	7/18/2014	24	1	Pre-
7/18/2014	8/18/2014	134	0	Pre-
8/18/2014	9/17/2014	253	11	Pre-
9/17/2014	10/17/2014	462	85	Pre-
10/17/2014	11/14/2014	265	310	Pre-
11/14/2014	12/17/2014	48	799	Pre-
12/17/2014	1/20/2015	0	994	Pre-
1/20/2015	2/18/2015	0	1,074	Pre-
2/18/2015	3/19/2015	0	956	Pre-
3/19/2015	4/20/2015	0	609	Pre-
4/20/2015	5/19/2015	0	217	Pre-
5/19/2015	6/28/2015	0	77	Pre-
6/28/2015	7/20/2015	14	0	Pre-
7/20/2015	8/18/2015	132	0	Post-
8/18/2015	9/17/2015	238	2	Post-
9/17/2015	10/19/2015	521	132	Post-
10/19/2015	11/17/2015	313	262	Post-
11/17/2015	12/17/2015	43	458	Post-
12/17/2015	1/19/2016	0	743	Post-
1/19/2016	2/18/2016	0	929	Post-
2/18/2016	3/21/2016	0	651	Post-
3/21/2016	4/19/2016	0	511	Post-
4/19/2016	5/19/2016	0	297	Post-
5/19/2016	6/17/2016	0	44	Post-
6/17/2016	7/19/2016	0	2	Post-
7/19/2016	8/17/2016	10	0	Post-
8/17/2016	9/16/2016	112	1	Post-
9/16/2016	10/18/2016	259	124	Post-
10/18/2016	11/16/2016	2.43	310	Post-
11/16/2016	12/19/2016	194	703	Post-
12/19/2016	1/19/2017	276	835	Post-
1/19/2017	2/16/2017	241	749	Post-
2/16/2017	3/21/2017	164	824	Post-
3/21/2017	4/18/2017	6	448	Post-
4/18/2017	5/17/2017	0	260	Post-
5/18/2017	6/16/2017	0	86	Post-
6/17/2017	7/18/2017	0	0	Post-

The pre- and post-installation period energy uses for space heating were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space heating fuel use, and annual savings. Table 21 provides the monthly fuel usage for space-heating under TMY3 weather conditions. The billing data indicates a savings of 28% of total annual steam use.

Table 21. The Lunt-Fontanne Theatre Billing Analysis Summary

Month	TMY3 HDD	Post-Use (MMBtu)	Pre-Use (MMBtu)	Savings (MMBtu)
January	958	189	136	53
February	933	184	132	52
March	712	141	101	40
April	412	81	58	23
May	174	34	25	10
June	15	3	2	1
July	0	0	0	0
August	3	1	0	0
September	53	10	7	3
October	264	52	37	15
November	595	118	85	33
December	838	166	119	47
Total	**4,957**	**980**	**704**	**277**

Since the facility utilizes only district steam for its heating needs, the pre- and post-installation period district steam uses were also regressed to HDD. The regressions are provided in Figure 2. These regressions were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space-heating steam use, and annual savings.

Figure 2. District Steam Use Regression–Lunt-Fontanne Theatre

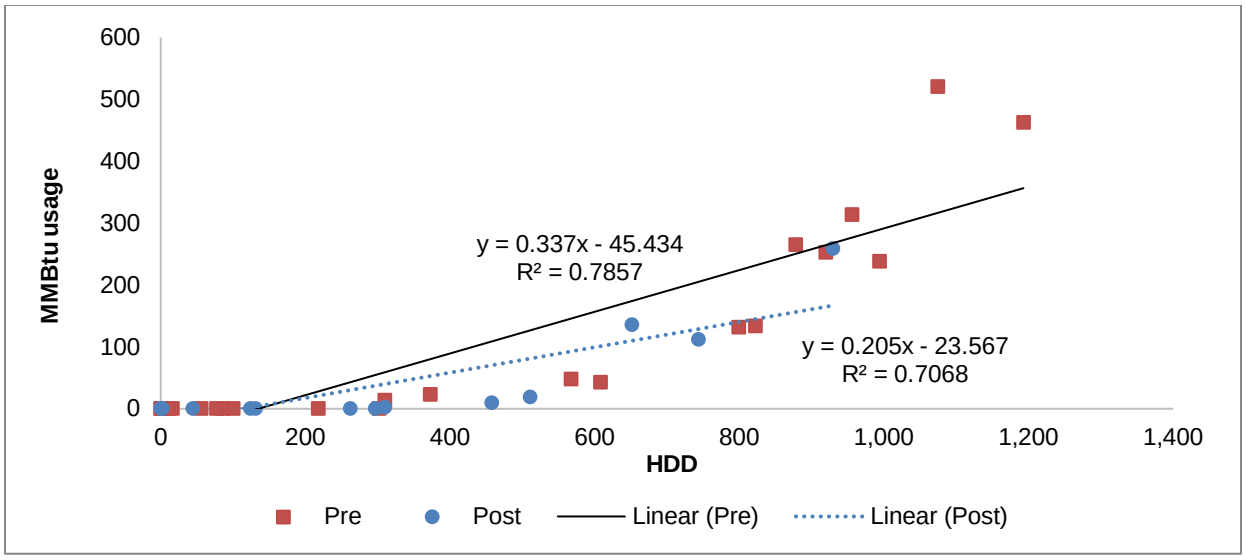


Table 22 provides the district steam usage under TMY3 weather conditions, estimated using the linear regression models. The billing data indicates a savings of 22% of total annual district steam usage.

Table 22. The Lunt-Fontanne Theatre Billing Analysis Summary

Month	TMY3 HDD	Pre-Use (Mlb)	Post-Use (Mlb)	Savings (Mlb)
January	958	277	217	61
February	933	269	210	59
March	712	195	153	41
April	412	0	0	0
May	174	0	0	0
June	15	0	0	0
July	0	0	0	0
August	3	0	0	0
September	53	0	0	0
October	264	0	0	0
November	595	155	123	32
December	838	237	186	51
Total	**4,957**	**1,133**	**888**	**245**

3.1.5 295 Clinton Avenue

Data for fuel use during heating seasons from 2014 through 2017 for the 295 Clinton Avenue facility was obtained through billing data. Table 23 provides the billing data for gas use and fuel oil deliveries. The facility has a dual-fired boiler, and the billing data shows that both oil and natural gas were utilized by the boiler for space heating during the analysis.

Table 23. 295 Clinton Avenue Billing Data

Start	End	Fuel	Unit	Use	Equivalent MMBtu	Period
10/25/2014	6/27/2016	Natural gas	Therms	88,189	8,819	Pre-
10/25/2014	6/27/2016	No. 2 fuel oil	Gallons	11,200	1,546	Pre-
6/27/2016	9/27/2016	Natural gas	Therms	5,218	522	Commissioning
9/27/2016	5/23/2017	Natural gas	Therms	11,149	1,115	Post-
9/27/2016	5/23/2017	No. 2 fuel oil	Gallons	22,100	3,050	Post-

ERS utilized the billing data from Table 23 to estimate the fuel usage for space heating in the pre- and post-installation scenarios by adjusting for DHW use, as shown in Tables 24 and 25. The HDDs were based on weather data from New York City's John F. Kennedy International Airport weather station and a base temperature of 65°F.

Table 24. Pre-Installation Space-Heating Energy Usage–295 Clinton Avenue

Start	End	Space Heating Use (MMBtu)	HDD
10/25/2014	6/27/2016	6,760	8,999

Table 25. Post-Installation Space-Heating Energy Usage–295 Clinton Avenue

Start	End	Space Heating Use (MMBtu)	HDD
9/27/2016	5/23/2017	2,761	4,262

The pre- and post-installation period energy uses for space heating were then applied to monthly TMY3 HDD (also base 65°F) to estimate the baseline, installed space heating fuel use, and annual savings. A linear regression analysis of the monthly energy usages with historic HDDs were not performed because the facility utilized more than one fuel type for heating in the pre-installation

case, which increases additional meaningless information within the data sets and contributes to erroneous calculations. Table 26 provides the monthly fuel usage for space heating under TMY3 weather conditions. The billing data indicates a savings of 14% of total annual natural gas use.

Table 26. 295 Clinton Avenue Billing Analysis Summary

Month	TMY3 HDD	Pre- Use (MMBtu)	Post- Use (MMBtu)	Savings (MMBtu)
January	958	620	719	99
February	933	604	701	96
March	712	461	535	74
April	412	267	309	43
May	174	113	131	18
June	15	10	12	2
July	0	0	0	0
August	3	2	3	0
September	53	34	39	5
October	264	171	198	27
November	595	386	447	62
December	838	542	629	87
Total	**4,957**	**3,211**	**3,723**	**513**

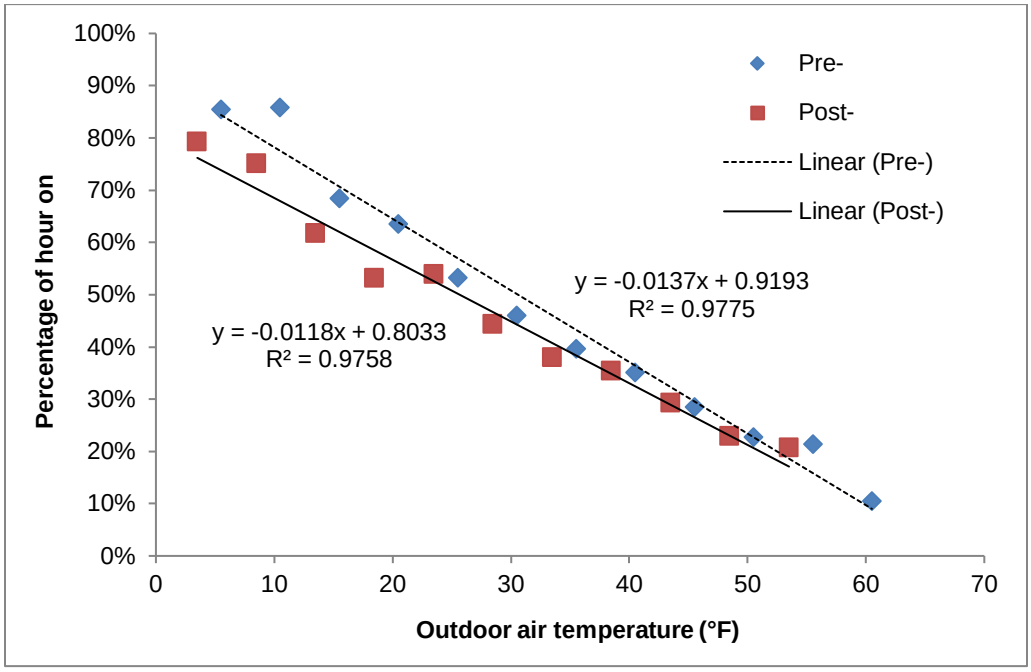
3.2 Boiler Run-Time Analysis

3601 Kings Highway. For 3601 Kings Highway, ERS installed a HOBO[2] motor on/off logger on the boiler combustion blower motor to measure the run time during both the pre-installation 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 run-time percentage for the pre- and post-installation periods and regressed this hourly data against the outdoor air temperature (OAT). The pre-installation period extended from November 16, 2014, when the data was first made available through January 15, 2015, when the installation of the Radiator Labs product began. The post-installation data was collected by ERS from January 19, 2016 through May 31, 2016.

[2] HOBO is a trademark for an electronic device that records measurements, such as temperature or relative humidity at set intervals over time.

Figure 3 provides a regression of the hourly pre- and post-installation boiler run-time data binned by OAT. A difference in firing time percentage is evident between the pre- and post-installation periods.

Figure 3. Boiler Run-Time Regression–3601 Kings Highway



The regressions from Figure 3 were used with TMY3 to extrapolate savings to an entire 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.

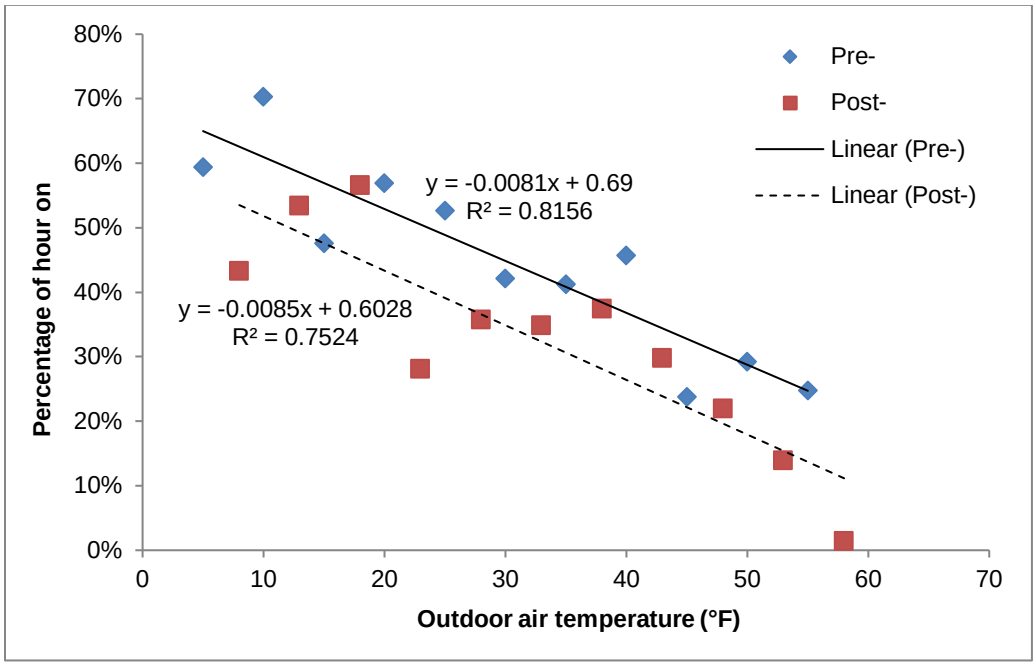
Nameplate data indicated that the boiler's maximum input rate was 2.678 million British thermal units (MMBtu). ERS compared the run-time data to the utility bills for the building and estimated that, based on the observed run-time percentage, the boiler operated at an average of 50% natural gas input. The firing rate does not have an effect on the calculations in determining the savings percentage; 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—the savings percentage 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 9% and an absolute savings of approximately 2,440 therms/yr. ERS's weather-normalized baseline energy use was 28,209 therms/yr with an as-built energy use of 25,769 therms/yr.

Butler Hall. A similar analysis was conducted for the Butler Hall dormitory building. The Butler Hall building utilizes two steam boilers with a maximum input rate of 6.4 MMBtu. The TriStar boiler system remained in place during the pre-installation period, providing a continuous source of boiler firing data from the primary boiler. The data provided an on/off signal each time the boiler switched operating modes. ERS used this data to calculate the hourly run-time percentage of the primary boiler for the pre-installation period and regressed this hourly data against the OAT. ERS installed HOBO motor on/off loggers on the primary boiler blower motor to measure the run time during the post-installation period, providing an on/off signal each time the boiler switched operating modes. ERS used this data to calculate the hourly run-time percentage for the post-installation period and regressed this hourly data against the OAT. The pre-installation period extended from December 28, 2014, when the data was first made available through June 2, 2015, when the installation of the Radiator Labs product began. The post-installation data was collected by ERS from January 20, 2016 through May 31, 2016.

Figure 4 provides a regression of the hourly pre- and post-installation boiler run-time data binned by OAT for the primary boiler. A difference in percentage of firing time is evident between the pre- and post-installation periods.

Figure 4. Boiler 1 Run-Time Regression–Butler Hall



The regressions from Figure 4 above were used with TMY3 data to extrapolate savings to an entire 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 to be off after May 16 when the students moved out. The savings resulting from the run-time reduction of boiler 1 was extrapolated to boiler 2 as well, to estimate the energy savings for space heating resulting from project installation.

ERS compared the run-time data to the utility bills for the building and estimated that, based on the observed run-time percentage, the boilers operated at an average of 45% natural gas input. ERS's boiler run-time analysis resulted in an annual energy savings of 27% and an absolute savings of approximately 28,725 therms/yr. ERS's weather-normalized baseline energy use was 106,061 therms/yr with an as-built energy use of 77,336 therms/yr.

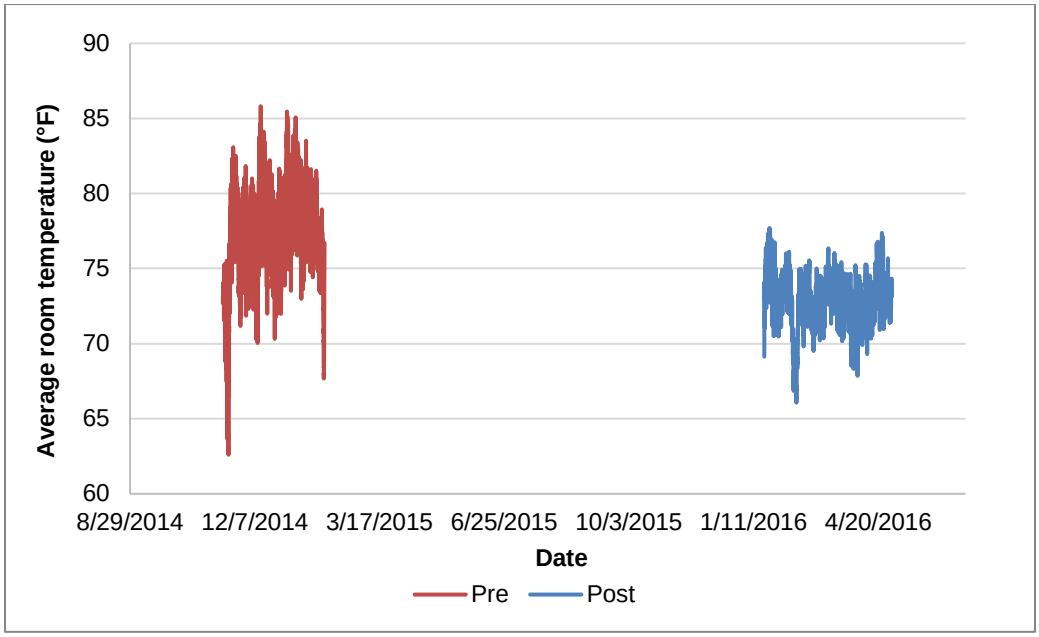
3.3 Room-Temperature Analysis

Although the boiler run time and billing analysis clearly show a decrease in energy usage, 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.

Of the three methods of analysis, estimating the 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 infiltration rates. Both parameters are difficult to measure precisely. Adding further uncertainty to the analysis is occupancy behavior. Resident surveys conducted by Radiator Labs indicate that many residents prior to the survey opened their windows to alleviate overheating. Open windows would greatly increase the ventilation rate of the building and would impact the observed room temperatures. Therefore, given the quality of the data collected and consistent results of the billing analysis and boiler run-time analysis, the room-temperature analysis was used only to qualitatively demonstrate the reduction in space temperature control and the reduced heating load.

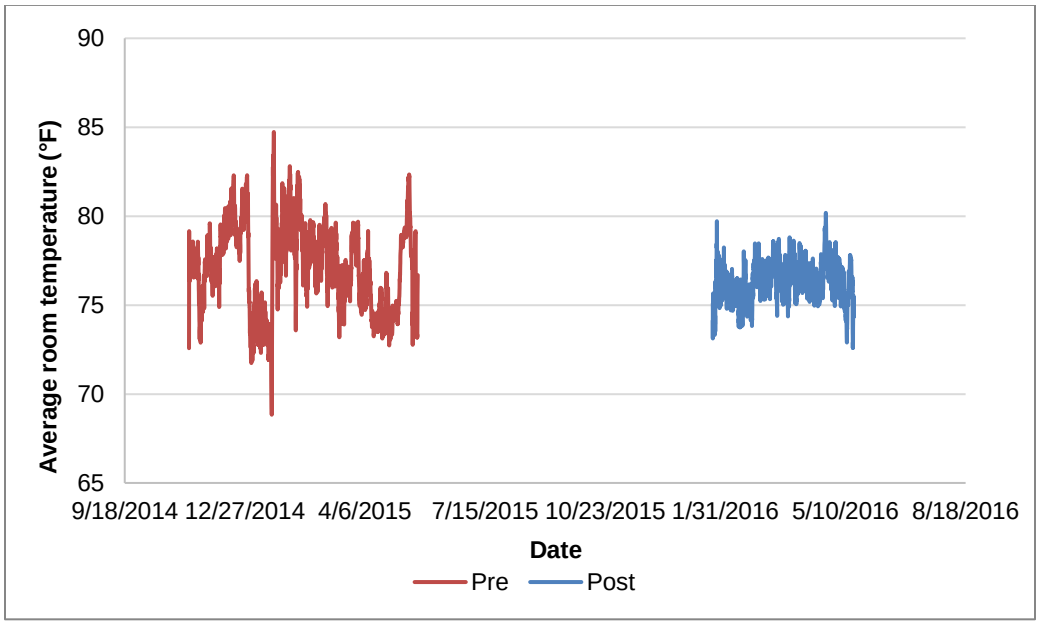
3601 Kings Highway. ERS installed HOBO temperature loggers in seven rooms to collect baseline and post-case data. Baseline data was collected for three months, while post-installation case data was collected for four months. The average temperature without the Cozy system was 77.0°F, while with the Cozy system installed the average room temperatures dropped to 73.0°F, a drop of 4°F. Figure 5 shows the average room temperature for the building during both the pre- and post-installation periods. Baseline temperatures ranged from 62°F to 86°F. With the Cozy system installed, temperatures consistently ranged between 66°F and 77°F, with most temperatures below 75°F.

Figure 5. Average Room Temperature–3601 Kings Highway



Butler Hall. ERS installed HOBO temperature loggers in eight rooms to collect baseline and post-case data. Baseline data was collected for five months, while post-installation case data was collected for four months. The average temperature without the Cozy system was 77.7°F, while with the Cozy system installed the average room temperatures dropped to 76.4°F, a drop of 1.3°F. Figure 6 shows the average room temperature for the building during both the pre- and post-installation periods. Baseline temperatures ranged from 68°F to 85°F. With the Cozy system installed, temperatures consistently ranged between 72°F and 82°F, with most temperatures below 77°F.

Figure 6. Average Room Temperature–Butler Hall



4 Results Summary

A summary of the analysis results is provided in Table27.

Table 27. Summary of Results

Method	Metric	3601 Kings Highway	Butler Hall	Lunt-Fontanne Theatre	1215 Myrtle Avenue	295 Clinton Avenue	Claremont Hall*	Watt Hall*
Billing	Reduction of total	19%	18%	28%	16%	14%	32%	45%
	Savings (therms)	5,856	20,357	N/A	888	5,127	5,687	26,203
	Savings (Mlb steam)	N/A	N/A	277	N/A	N/A	N/A	N/A
Boiler run time	Run-time reduction	9%	27%	N/A	N/A	N/A	28%	41%
	Savings (therms)	2,440	28,725	N/A	N/A	N/A	6,698	23,874
	Savings (Mlb steam)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Room temperatures	Average pre-temperature (°F)	77.0	77.7	N/A	N/A	N/A	75.0	76.9
	Average post-temperature (°F)	73.0	76.4	N/A	N/A	N/A	73.2	73.3
	Temperature reduction (°F)	4.0	1.3	N/A	N/A	N/A	1.8	3.6
Annual energy use	TMY3 (therms)	31,243	112,150	N/A	4,120	37,234	23,922	58,230
	TMY3 (Mlb steam)	N/A	N/A	981	N/A	N/A	N/A	N/A

* Boiler run-time and room-temperatures analyses methodologies and results for Claremont and Watt Halls are provided in the EPV report. Additionally, for Watt and Claremont Halls, the post-installation billing data was updated based on the most recent fuel consumption data provided, and the billing analysis results were updated from the EPV report.

All seven buildings showed a reduction in the weather-normalized billed fuel use, in the range of 14% to 45% of annual fuel energy usage for space heating. Room temperatures were analyzed to confirm that 3601 Kings Highway and Butler Hall had a drop in average ambient temperature with the system installed. The average room temperature decreased between 4.0°F and 1.3°F in 3601 Kings Highway and Butler Hall, respectively. The lower air temperature resulted in a reduced heat load that was reflected in ERS's boiler run-time analysis for the buildings. Data showed that the average annual boiler run time decreased for both 3601 Kings Highway and Butler Hall, although the magnitude of the calculated savings was larger for Butler Hall, which is a university dormitory and has a correspondingly larger heating energy use.

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