Report on Equipment Upgrade Incentive Project *December 2021*

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ABSTRACT

The National Oilheat Research Alliance (NORA) has in-place a rebate program which aims to increase consumer efficiency and safety by encouraging replacement of existing equipment with modern, efficient systems. This report describes the results of an analysis of the energy savings associated with the upgrade of 6,412 home heating boiler systems under this program. Savings are estimated based on two methods, the first of which is analysis of fuel delivery and degree day data before and after the equipment change out. The second approach involves characterization of the type of equipment before and after the upgrade. Both methods gave similar results.

The average savings was found to be 20%. For the 6,412 boiler upgrades done as of the beginning of 2021, the total savings after one year was 1,090,040 gallons, $3,488,128, and 15,833 tons of greenhouse gas emissions. These savings were extended to 5, 10, and 25 years. Simple payback on the NORA upgrade incentive was found to be about 1 year.

Contents

1.Introduction

The National Oilheat Research Alliance (NORA) has in-place a rebate program which aims to increase consumer efficiency and safety by encouraging replacement of existing equipment with modern, efficient systems. The current program offers rebates on boiler and furnace replacements, storage tanks, and/or burner controls but rebates may also extend to water heaters, smart thermostats, and other energy efficient equipment.

The NORA rebate program is administered through state organizations, which are part of NORA, operating within the basic NORA requirements. Details of the program, including rebate amount, are different in each state. All participating organizations, however, as part of the rebate application process, are required to provide information with details of the equipment replaced and new equipment installed.

In the NORA rebate program, boiler replacements have been the most significant actions. As of the start of 2021, 6,412 boilers and 2,101 warm air furnaces have been upgraded. The work presented in this report focused on the boiler upgrades and was planned to develop estimates of the annual fuel energy savings achieved by the implemented upgrades.

2. Approach to Analysis of Savings

Data on all equipment upgrades are provided to NORA by participating states in a spreadsheet format. Data provided include the make, model, age, and estimated Annual Fuel Utilization Efficiency (AFUE) of the replaced unit. Unfortunately, not all this information has been reported for all sites. The same information, except age, is to be provided for the new, upgrade unit. Previous year oil consumption is also typically reported.

The age of the replaced units was typically between 25 and 35 years. Many were reported to be 50 years old and some reported to be 70-80 years old. Ages of the replaced units are as reported by the installation contractors and it is expected that, in many cases, these are just estimates. In a significant number of cases the age, make, and model were all reported as simply “unknown”.

In estimating the annual reduction in fuel consumption, use of the AFUE information alone was rejected for two important reasons:

1. In reviewing the data it is clear that the installer doing the work and applying for the rebate simply estimated the AFUE to meet the application requirements. To illustrate, in some cases AFUE values of 50 were input for boilers 13 years old. For boilers in this category, the minimum required AFUE during the time of installation was much higher. In another example, for boilers 50 years old, an AFUE of 50 was also estimated. During the time of installation, the AFUE metric was not yet in use.

2. The AFUE metric relates to heating only and does not include domestic hot water load. It is very common for oil-fired hydronic heating equipment to also be used for domestic hot water. This includes tankless coil boilers or other newer designs using external heat exchangers to produce domestic hot water from the heating circuit or boilers which have indirect domestic hot water storage tanks which are heated from the space heating boiler.

In this study, two alternative approaches were used to estimate annual energy savings associated with the equipment upgrades. Approach 1 involves correlations between heating degree days and heating fuel energy input based on delivery data. Approach 2 involves use of boiler system estimated steady state thermal efficiency and idle loss. Both of these are discussed further below.

In Approach 1, a regression analysis for energy used and degree days is developed. The general approach to this is commonly used in energy studies [1-6]. [1] Energy input can be expressed as kWh/day, Btu/day, gallons of fuel used per day, or other similar terms. In this work gallons of fuel per day has been used. For analyses of this type kWh/day is also commonly used and the conversion between these is: 1 gallon/day = 40.73 kWh/day.

In the method deployed here, correlations between gallons of fuel used per day ("gal/day") and degree days per day ("DD/day") were developed before and after the new equipment was installed. One example correlation is shown in Figure 1. Each point on this plot represents a fuel delivery which could range from 75 to 225 gallons.

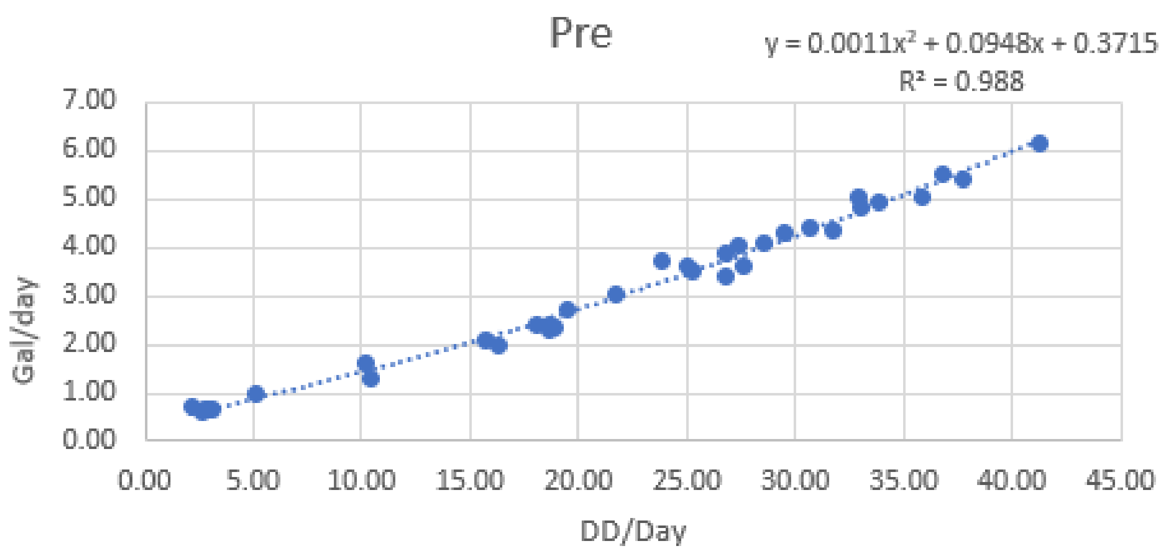

Figure 1 Example fuel use / degree day correlation for a site before implementation of the boiler system upgrade

In some studies of this type, a linear relationship has been used but, for this study a second order polynomial regression was used as this generally fit the data better. In all cases the curves do not depart significantly from linear. The y-axis intercept in this regression would be the summer (non-heating) fuel consumption in gallons per day.

For each site, correlations of this type were developed for the before and after cases. The daily distribution of degree days, based on historical degree day data, for one year – 2018 – was

[1] The Energy Research Center (ERC) has an active patent (7,127,361 issued in 2004) which uses a similar methodology in products and inventions. Anyone using this method should review that patent.

combined with these correlations to determine annual fuel use before and after for this specific year and then annual fuel savings.

The degree day data for these correlations were obtained from www.degreedays.net/pro [7] , and is recorded by airports that are close to the location of each target home site. These data provide daily degree days from the present time back to 2010 or earlier. The installations of upgraded heating systems were typically done in the 2016 – 2018-time frame, providing 10 years of degree day data, at least, before the installation and 3-5 years of data after installation.

The normal reporting data for the NORA rebate program do not include detailed fuel delivery data (gallons delivered and date) before and after the installation. These data are, however, available in the service company operating databases. In this project, several service companies were asked to make these data available for specific sites where installations were done of boilers within the target timeframe. All companies agreed to support this effort and, in some cases, NORA staff spent time at the companies to download these data. Detailed fuel delivery data from hundreds of candidate sites were obtained.

Automated processing of the delivery and degree day data was done to generate the correlations. Some of the sites were rejected or required special handling of the data for several reasons and this is discussed in some detail in Section 4.

In Approach 2, boiler systems before and after upgrade were assigned values of steady state thermal efficiency and idle loss. Here idle loss is expressed as a percentage of the full load steady state energy input rate and represents energy usage during times when there is no heating or domestic hot water load. In the common example of a tankless coil cast iron boiler, this would represent the energy input rate required to keep the boiler hot in the summer when there is no domestic hot water demand. This is commonly done to ensure a sudden hot water demand can be met rapidly at all times.

Approach 2 is largely based on prior studies of the performance of integrated hydronic heating systems [8, 9]. A key aspect of the model used is a linear relationship between fuel energy input and thermal energy output in hydronic heating systems. Only two parameters, steady state efficiency and idle loss, are needed to develop this relationship for a specific system. This linear relationship approach has also been used in the development of test methods and in-field performance modeling for larger, commercial-size boilers [10].

With this, the linear model can be expressed as $y = a*x + b$, where x is the required output of the boiler, and y is the required input. The b coefficient, or the y-intercept of the model, is calculated by multiplying the max input required of the boiler by the idle loss percentage.

To enable analysis of annual energy use for a specific boiler, this linear relationship must be combined with a building heat demand. For this, annual, hourly heat demand was calculated for a 2,500-ft^2 typical ranch-style house whose energy and temperature parameters were generated using *Energy-10* software. This theoretical house was assumed to have standard code construction, including 2x4 stud wall construction with basement and roof. The roof has an R30 insulation level. The daily temperature setpoint was 70°F with nighttime setback of 63°F. For this study the house was located in central New York. To obtain total load on the hydronic heating system a typical domestic hot water load was added to the space heating load.

To implement this approach, old boilers (before installation) and the new boilers (after installation) were sorted into one of three categories using this classification method. For the old boiler, these categories are denoted as a, b, and c, with c being the worst-performing old boiler, and a being the best-performing. For the new boiler, these categories are denoted as A, B, and C, using the same approach as that used for the old boiler. The steady state and idle loss figures that define each of these categories are provided below in Table 1.

It was found necessary to add an additional classification for the old boilers, named class “d”. This refers to sites for which there is no information about the replaced boiler. This could be because the system is old and the label is no longer available. The performance of boiler systems in Class d was assumed to be the same as for those in Class c.

Table 1 Classification of Old and New Boiler Systems for Analysis

Boiler System Class	c	b	a	C	B	A
Steady State Efficiency (%)	78	80	84	84	86	87
Idle Loss (%)	2.5	1.5	1	1	0.8	0.1

Using these classifications and the linear input/output approach, the expected annual reduction in fuel consumption can be calculated for each combination of old and new systems for the model house used. Also needed for this analysis is an assumption of the oversize factor – i.e., the maximum output capacity relative to the maximum load. Based on the AFUE Test Procedure the average value for this was assumed to be 1.7 [11]. This was implemented using a MATLAB code and results are presented in Table 2.

Table 2. Calculated Annual Energy Savings for All Combinations of Upgrades

Upgrade Case	a to C	a to B	a to A	b to C	b to B	b to A	c to C	c to B	c to A
Annual Reduction in Fuel Consumption	0.0	3.81	10.04	8.24	11.74	17.46	16.64	19.81	25.01

To implement Approach 2, it is necessary to judge the class that a boiler system should be put into and this is, to some degree, subjective. The following guidelines were developed in an effort to improve the repeatability of the classification process.

Old (Original Boiler)

Class a – AFUE 84 or greater. Indirect tank with thermal purge to tank.

Class b AFUE 80 or greater. Can be tankless coil or indirect. Boiler has insulation 1 ½ inch or greater. Boiler does not have large metal burner mount.

Class c AFUE < 80% or unknown. All units over 40 years old. Tankless coil. Poorly insulated. All units which have large metal burner mounts.

Class d – No information available.

New (Replacement Boilers)

Class A – AFUE 87 or greater. Indirect tank with boiler thermal purge to tank. Boiler insulation 1 ½ inch or greater. Control of heating season idle losses through outdoor reset, other weather responsive control, or thermal purge. Boiler does not remain hot under no-load state.

Class B – AFUE 86 or greater. Can be tankless coil or indirect. Boiler has insulation 1 ½ inch or greater. Boiler does not have large metal burner mount.

Class C – AFUE 84 or greater. Tankless coil without outdoor reset control. Minimal insulation. No controls to reduce boiler temperature under low load conditions.

3. Results

For the sites selected as appropriate for use, a class category was assigned to both the old and new boilers. Historical degree day data was then downloaded from the relevant local airport. The gallons per day / degree days per day regression curves were then developed and annual gallons used for the 2018 model year Pre- and Post- were then calculated.

Service Company #1 Dataset

Service Company #1, in the Long Island area had a variety of new and old boilers and fuel delivery data for 112 sites were submitted. The final results from the analysis of these sites is displayed below, in Figure 2:

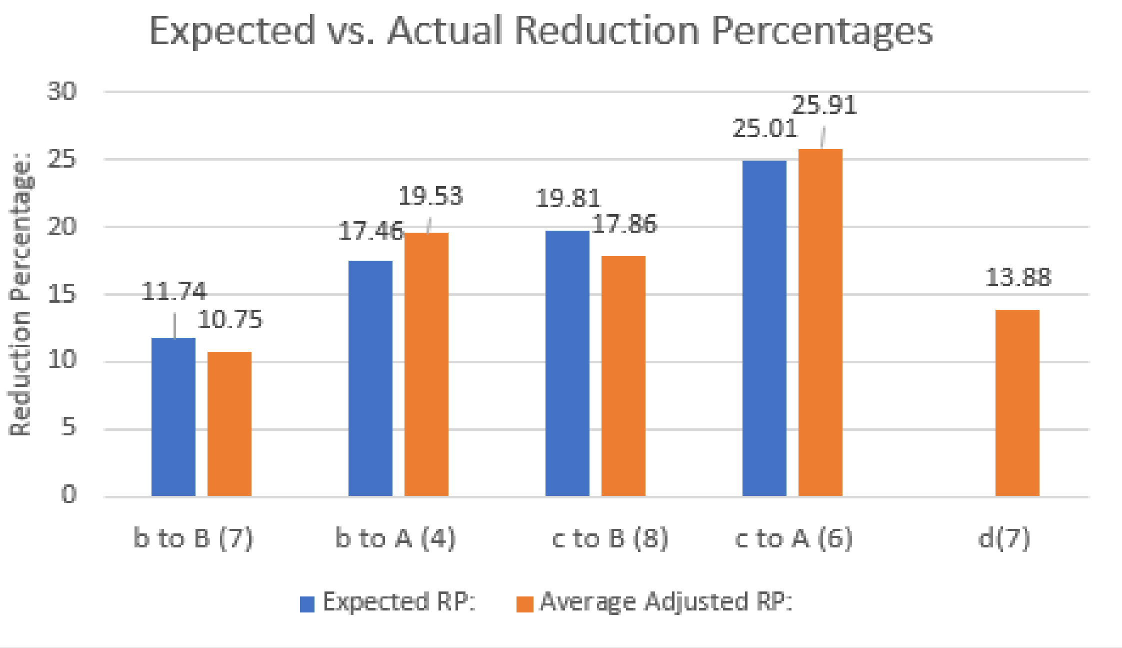

Figure 2 Service Company #1 reduction percentages for each upgrade case[1]

[1.] Note "Expected RP" is the expected reduction in fuel use based only on the classification of the old and new boilers – see Table 2. "Average Adjusted RP" is the annual fuel use reduction based on the regression analysis of the fuel delivery data.

This figure displays the reduction percentages seen in the analysis of the Service Company #1 sites, with each pair of columns representing a different boiler upgrade case. The first thing that is worth noting is that, out of the nine possible boiler upgrade cases, only four were seen in the Service Company #1 dataset. This is an occurrence that will carry over to other datasets as well as it is unlikely, for example, in the field to see either a “C” class new boiler, or an “a” class old boiler. The exclusion in site data of these two classes of boiler narrows down the boiler upgrade cases from nine to just four: b to B, b to A, c to B, and c to A. One additional case, case “d” occurs when information about the old boiler is unknown, preventing it from being classified and also preventing it from having an expected reduction percentage value at all. As discussed above, these units were assumed to have the same performance as “c” units although this might overestimate the performance of the old system and underestimate the savings. This brings the total number of boiler upgrade cases up to five, which are all displayed in Figure 2. The small number in parentheses next to each case on the horizontal axis of Figure 2 represents the number of sites contained in each orange column. Something else to note about this dataset is that, despite the fact that 112 sites were present in the first large dataset at the beginning, only 32 appear in Figure 2. This occurs because the site data is put through a decision structure which gradually reduces the number of sites that are accepted as valid for the analysis. This decision structure is explained further in Section 4.

The results that Figure 2 displays are significant for two reasons. First and foremost, the adjusted reduction percentage (ARP) agrees quite closely with the expected reduction percentage for each of the four cases where an expectation exists. Secondly, these results represent significant energy savings at these installation sites.

Service Company #2 Dataset

The next set of sites that was analyzed was a set of 101 sites that were all handled by Service Company #2, also in the Long Island, N.Y. area. The final results from the analysis of these sites is displayed below, in Figure 3:

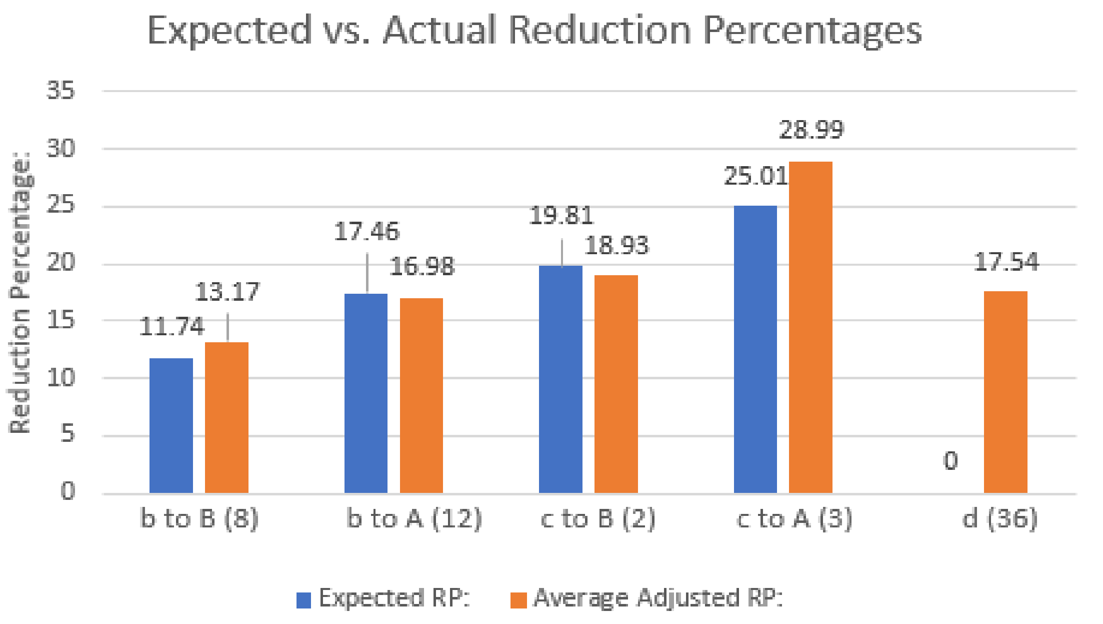

Figure 3 Service Company #2 reduction percentages for each upgrade case

It is again worth noting that, despite starting with 101 sites, only 61 sites are displayed in this figure. Additionally of interest is that there are more "d" cases (36) than there are all four of the other cases combined (25). As stated above, the "d" case occurs when information about the old boiler is not known.

Similar to the first dataset, this second dataset also shows that the ARP for each of the four different boiler upgrade cases agrees quite closely with expectation. This means that the classification of boilers used in this research, as well as their associated Steady State and Idle Loss numbers, are relatively accurate. It is also worth noting that, for four out of the five different cases, this dataset had higher ARP's than Service Company #1's dataset, which represents even further savings for the customer.

Service Company #3 Dataset

A set of 18 sites, all handled by Service Company #3, was analyzed as well. The results of this analysis are displayed below, in Figure 4:

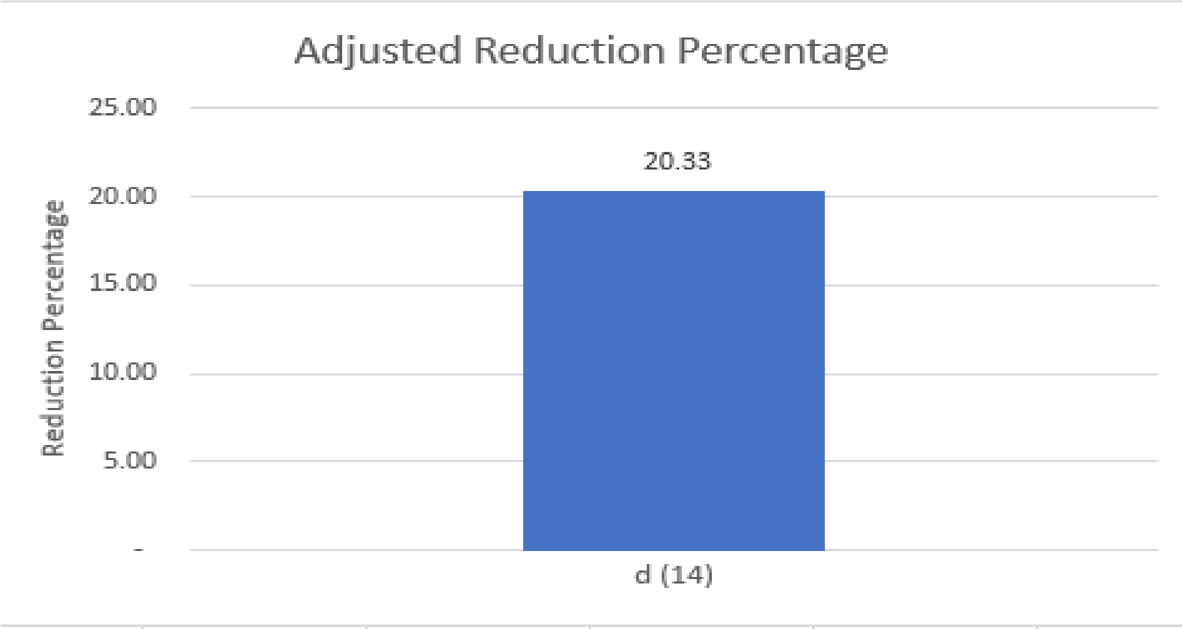

Figure 4 Service Company #3 reduction percentages for each upgrade case

The first thing that is important to note with this dataset is that there is only one column displayed in Figure 4. This is because, for this dataset, information about the pre-existing boiler, before installation of a new, upgraded boiler, was unknown. This meant that all the sites in this dataset were of the "d" class. Something else that is worth noting with this dataset is that only 14 sites are represented in the above figure, out of the 18 that analysis began with. Similar to the other datasets, four of the sites in this dataset had to be discarded, as their correlation coefficients for either pre-installation or post-installation fuel delivery data were not at or above a value of 0.8. Lastly, this dataset once again represents significant savings for the customer, as the Adjusted Reduction Percentage for this dataset had a value of 20.33%.

Service Company #4 Dataset

This fourth set of data encompassed 99 sites, all of which had "A" class boilers installed as the new heating system. The results of this analysis are displayed below, in Figure 5:

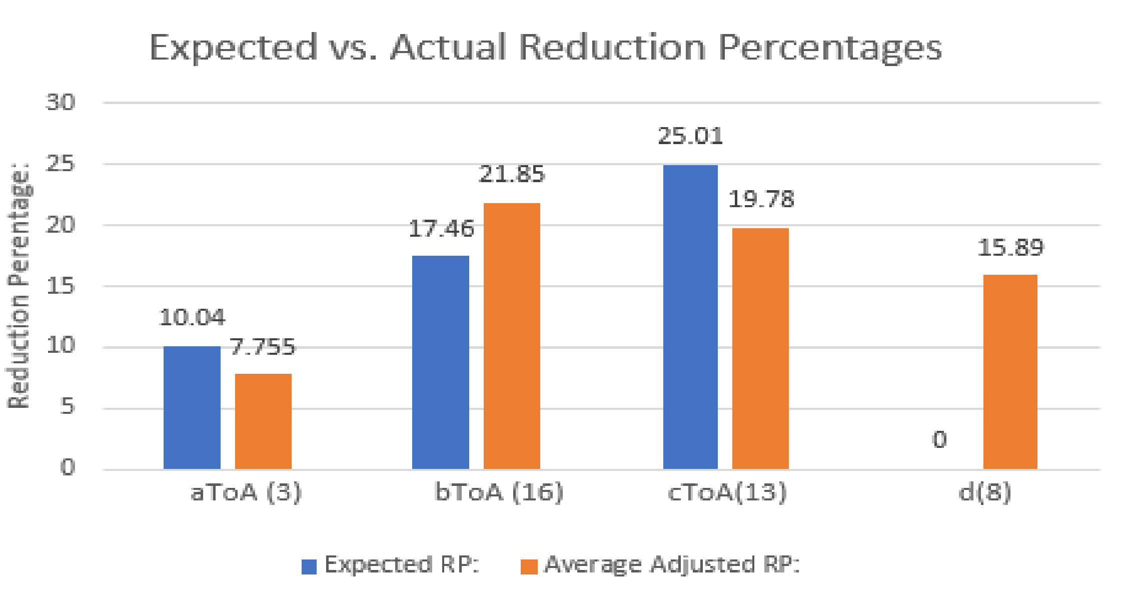

Figure 5 Service Company #4 reduction percentages for each upgrade case

This dataset had 8 unknown old boilers with the “d” classification, 13 sites undergoing a “c” to “A” transition, 16 sites undergoing a “b” to “A” transition, and 3 sites undergoing an “a” to “A” transition. The “a” to “A” results are important because they are the first sites in this analysis to represent this specific boiler upgrade case. Naturally, this “a” to “A” transition is uncommon as most customers prefer to upgrade to a new boiler only after their old boiler has depreciated a significant amount, and thus better belongs in the “b” or even “c” classifications due to its waning performance. As can be seen in Figure 5, the expected reduction percentage for the “a” to “A” case agrees somewhat closely with the expectation, once again confirming the validity of this bin analysis method. With the number of sites for each of these cases at 16 and 13 respectively, this difference can be greatly affected by an outlier or two within each set of results. For example, if the lowest reduction percentage displayed in the “b to A” category (5.95%), and the highest reduction percentage in the “c to A” category (41.87%) are removed from the adjusted reduction percentage calculations, then the “c to A” reduction percentage changes to 20.93, and the “b to A” reduction percentage changes to 20.52. Therefore, it is fair to state that, given the smaller sample size that this data represents, the difference made by a few outliers can cause some irregularities in the data, such as what is seen here. One last detail that is worth mentioning with this dataset is that, despite beginning with 99 sites, all of which had enough data to be considered for analysis, only 40 are displayed above in Figure 5. Less than half of the sites out of the original population were considered valid because 51 sites had correlation coefficients less than 0.8, and 8 sites displayed either an increase in usage or a decrease of less than 1%. For 51 of these sites to have correlation coefficients below 0.8 is quite significant, and suggests that there was a systemic issue with the regularity of fuel deliveries in this dataset.

Another way to consider the upgrade data is the age of the units which are replaced. This data is not reported for all sites but it has been reported for all sites in Service Company #1. Figure 6 shows the distribution of replaced system age for 112 sites. The average age is 36 years and the median age is 30 years (over half of the replaced units are over 30 years old).

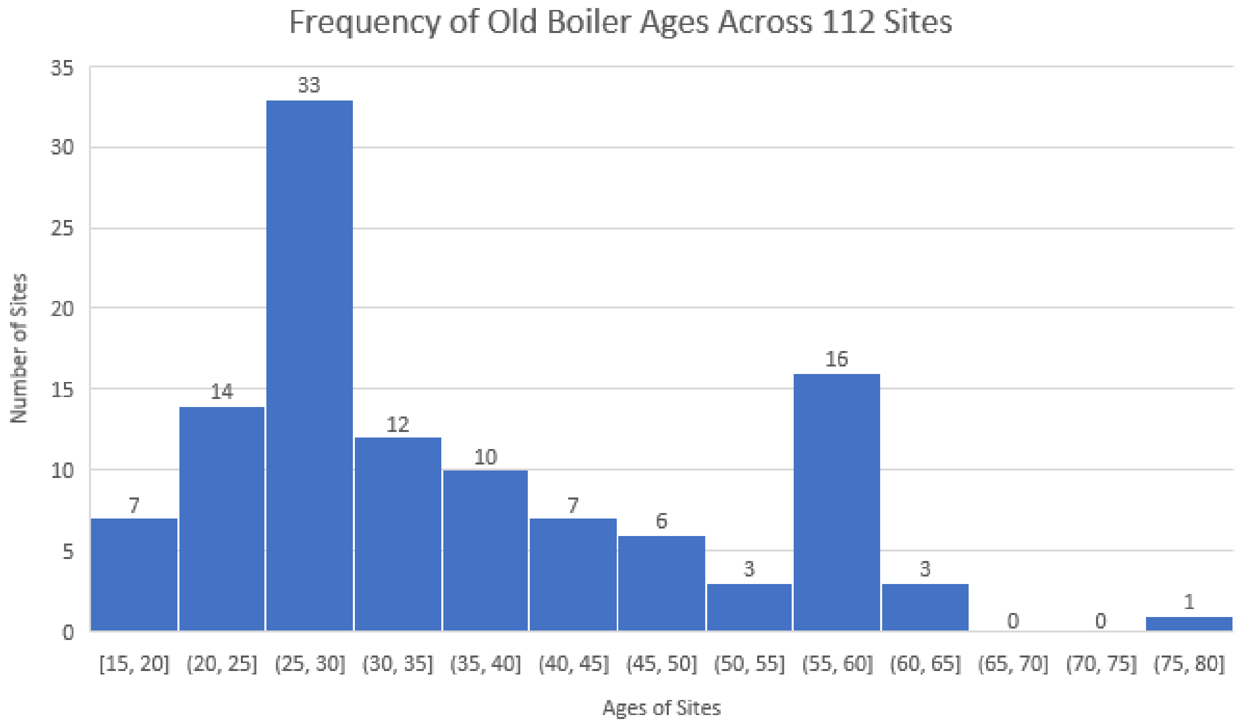

Figure 6 Age distribution of replaced units for Service Company #1

4. Note on Data Filtering and Inconsistencies

The percentage of valid sites that were considered for this research out of all possible sites for which data was available was small. For the service company #1 dataset, out of the 112 sites for which data, only 32 sites were considered in the analysis. For Service Company #2's dataset, out of the 101 sites where data existed, only 61 were included in the analysis. The filtering of these sites occurs due to mainly four reasons: lack of ample delivery data, custom fuel delivery amounts, back-to-back fuel deliveries, and behavioral changes on the part of the customer. Lack of ample delivery data is a problem in the data that occurs when, either before or after installation of a new boiler, there are less than five fuel deliveries. Often this is due to the customer joining the fuel marketer shortly before or leaving shortly after the upgrade. This creates a problem for the analysis because, when there are too few data points, an unreasonable model forms easily, as the smallest of inconsistencies among few data points ruins the otherwise statistically solid foundation of the model. Another problem that comes up during this research is custom fuel delivery amounts. As discussed above in the analysis it is generally assumed that there is a strong correlation between fuel consumption and degree days. When a customer orders a custom amount of fuel delivered, such as 100 gallons, rather than a "fill-up" it ruins this correlation. When this issue is found to have occured, analysis on that site can no longer continue, and the site is dropped. A third issue that affects this study is the problem of back-to-back fuel deliveries. This occurs when a customer has fuel deliveries twice in a very short period of time, most often with two deliveries taking place on the same day. This could occur when the truck runs out of fuel before completing the delivery and returns later. In most cases this can be resolved by combining the deliveries in the analysis. The fourth and final issue to be accounted for in the data is that of behavioral changes on the part of the customer. This issue helps explain the more peculiar results that occur in the data, such as *increases* in fuel consumption after a boiler upgrade is done. This could occur if the customer begins heating their house more. This can be caused by a variety of factors, such as lowering fuel prices, or having more people spend more time in the home. In order to account for the issue of customers using more fuel *after* a boiler upgrade was made, a decision structure was used to filter the data. Any site that had an increase in fuel use, or a decrease in fuel use that was less than 1% (a meager improvement at best), was neglected from the averages displayed in the figures above. The reasoning for neglecting the results of a site that had an increase in fuel use is that, if a customer had a better boiler installed, then it is impossible that their temperature setpoints might change and consumption would increase purely due to this better system being put in place. Instead, other factors such as those mentioned above must have played a role in causing this odd result. A similar reasoning is applied for sites with a decrease in fuel ranging between 0-1%. It is reasonable to expect that a boiler upgrade would cause at least a 1% decrease in fuel consumption.

In some of the cases where fuel use increased or the correlation coefficient was poor, service companies often explained that conditions changed such as increased use of vacation homes or changing and erratic use of wood stoves. Sites, for example, in the Catskill Region of New York include many vacation-type homes and these situations were common. Sites from all service companies, at which the correlation coefficients were less than 0.80, were rejected from use in this study.

Another point raised during the development of this analysis is the impact that the COVID-19 restrictions may have had on the post-installation fuel use. During this time there was a clear increase in the number of people staying at and working from home which could lead to changes in thermostat settings and increased heating fuel use. In this study fuel use was captured only from delivery to delivery and generally there were not enough fuel deliveries during the strongest part of the COVID period to enable consistent conclusions to be drawn. There are, in the literature, several studies which seek to examine this question. Most of these focus on electric power use but some address direct residential fuel use as well. While it can be generally concluded that there was an increase in residential electric power use, the available data does not consistently lead to the conclusion that there was an increase in direct residential heating fuel use [12-14]. For this reason, this was not further considered in this study. Some but not all of the post-install period used for the analysis here had an overlap with the COVID shutdown period. Weather impacts during this time period were reported to be at least as significant as the COVID shutdowns.

5. Overall Impact of the NORA Rebate Program

To evaluate the average savings achieved by the boiler system upgrades under the NORA Rebate Program, beyond the limited number of sites for which fuel delivery data could be obtained, the distribution of upgrades cases over the broader data set was evaluated. Service Companies 1, 2 and 4 were used for this. As noted above, data on the old systems was not available for Service Company 3. Figure 7 presents the results of this analysis.

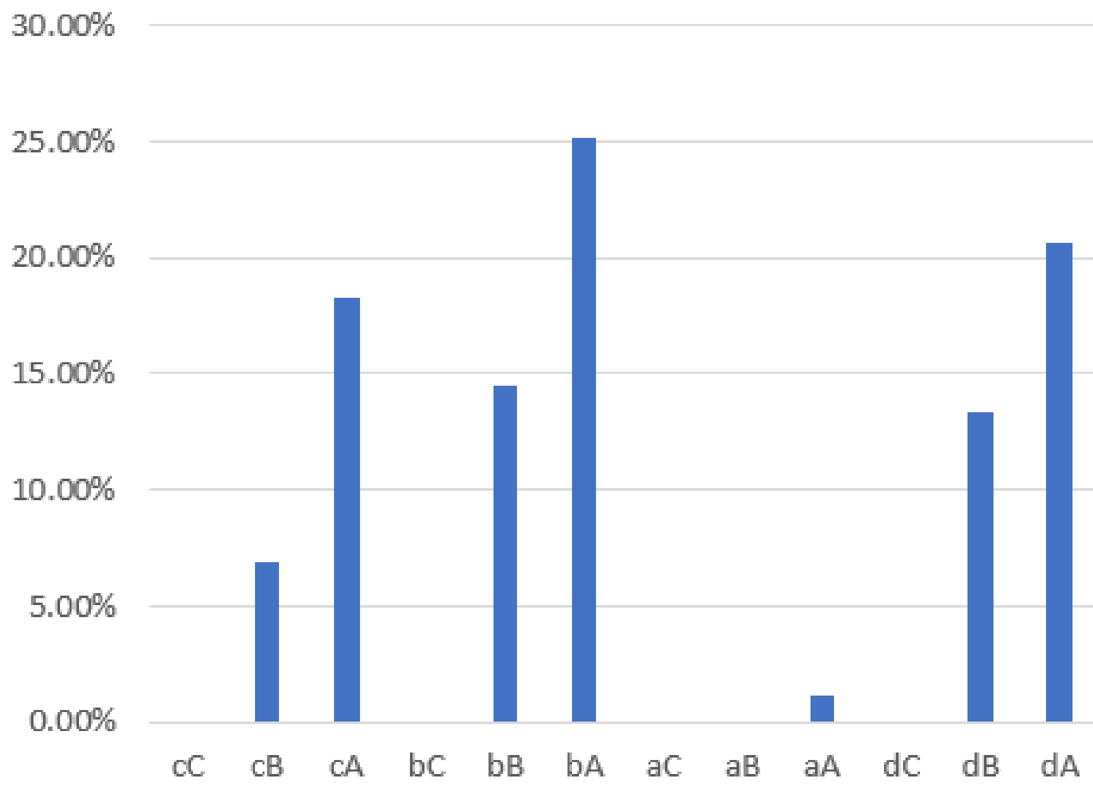

Figure 7 Distribution of upgraded cases for 421 sites in Companies 1, 2, and 4.

As is shown in this figure, the upgrades to Class A and B are the most common for this population set. None of the new systems are in the lower efficiency Class C.

Using the results in Figure 6, and the determined savings with each upgrade combination, a weighted average savings of 20% was calculated. Using an average per-home annual fuel use of 850 gallons, this yields an average annual fuel use reduction of 170 gallons. Using the current average price of heating oil in New York of $3.20/gallon (9/20/2021) [15], the annual average savings is $544. The amount provided to the homeowner in the NORA rebate program varies by state but the most common value is $500. For many of these sites, it is likely that the homeowner would change the boiler system even without the NORA rebate over the next 5-10 years. If the NORA rebate encourages the acceleration of the upgrade by only 12 months, the $500 incentive level is paid-back with fuel savings.

These results can be extrapolated to the total number of boiler replacements done to date under the NORA rebate program, 6,412. Using a GHG score for petroleum No. 2 heating oil of 209 Lb CO_{2e}/MMBtu HHV (20-year lifetime) leads to a reduction of 12,525 tons of CO_{2e} per year from this number of conversions. Using the average fuel and cost savings, Table 3 provides a summary of total fuel and cost savings and CO_{2e} reductions over 1, 5, 10, and 25 years.

Table 3. Projects Reductions in Fuel Use, Cost, and CO_{2e} Emissions of 6,412 Boiler Conversions.

Time Since Conversion	Reduction in Fuel Use	Reduction in Fuel Cost	Reduction in CO_{2e} Emissions
years	gallons	$ (based on current prices)	Tons
1	1,090,040	3,488,128	15,833
5	5,450,200	13,946,100	62,625
10	10,900,400	34,881,280	158,330
25	27,251,000	87,203,200	395,825

The results in this study can also be compared with a published NREL procedure for estimating energy savings with equipment upgrades [16]. This work provides performance degradation factors for a wide variety of equipment types. The general form for boilers is:

$$AFUE = (Base\ AFUE) \times (1-M)^{age}$$

Where:

The Base AFUE recommended for oil-fired boilers is 80%

Age is the boiler age in years

M = a Maintenance Factor - .01 for professionally maintained, oil-fired boilers and .025 for boilers not professionally maintained.

The "Base" AFUE for a conventional oil-fired boiler in this study is 80%. Using this and a replacement age of 30 years and assuming professional maintenance, gives an AFUE of the replaced boiler of 59.2%. Again, the use of AFUE here neglects the domestic hot water load that is commonly applied to these systems in addition to the heating load. If the new boiler were only as efficient as the original value for the base case (80% AFUE), the savings would be 26%. This is higher than the results of the present analysis suggesting the savings projection in the current work may be conservative.

The NREL study was published in the 2006 timeframe. At this time oil-fired heating systems used fuel with much higher sulfur content than is currently used (roughly 2000 ppm vs 15 ppm S). Sulfur is known to be a major cause of boiler corrosion and the accumulation of scale which reduces heat transfer and efficiency. This same report includes Maintenance Factors also for natural gas, which has a sulfur content close to home heating oil and so it might be expected that the efficiency degradation rate of current systems is closer to that of gas. The NREL report lists a Maintenance Factor for gas of 0.005. Using this, the efficiency of an 80% AFUE boiler over 30 years would degrade to 68.8%, a reduction of 14%. This is lower than the results found in the current report based on delivery data. Again, AFUE and the NREL study consider heating only and not domestic hot water loads and so a very close agreement with the current study might not be expected. It should also be noted that this analysis is based on the assumption that the AFUE of the new boiler is the same as that of the old boiler while, as shown above, the replacement boiler should one with higher efficiency. The results of the analysis here also serve to show the very significant benefit of the lower sulfur content in current heating oil.

6. References

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