Con Edison EEPS Programs - Impact Evaluation of Multifamily Low Income Program

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energy & resource solutions

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1 Executive Summary

Consolidated Edison Company of New York (CECONY) requisitioned an impact evaluation of its Multifamily Low Income Program (MFLI, or the Program). This document contains the results of that evaluation.

1.1 Program Background and Objectives

MFLI targets existing residential multifamily low income buildings within the New York City and Westchester County Housing Authorities (NYCHA and WCHA, respectively). The Program offers equipment and weatherization assistance through efficiency measures, energy management systems, and building shell improvements and is open to income-eligible multifamily residential buildings with natural gas heating and oil-to-gas conversion customers.

The goals of this impact evaluation were to (1) evaluate the Program's performance by developing gross savings realization rates (RRs) for projects acquired during program years 2009–2011 and (2) provide actionable recommendations for improving the Program's implementation as a result of these assessments.

1.2 Research Approach

During the 2009–2011 evaluation time frame, the Program sponsored projects at two housing authority participants, one of which comprised 99% of program-reported savings. That lone project (Housing Authority 1, or HA-1)[1] is the focus of this evaluation study, and it incurred natural gas savings through the replacement of failed steam traps throughout the heating hot water (HHW) distribution system (78% of savings), boiler replacements (11%), sealing of envelope penetrations (9%), and insulation of steam distribution piping (2%). No statistical sampling of the population was required to assess the gross or net MFLI impacts, as the

[1] The two incented MFLI projects occurred at separate housing authorities. Therefore, projects are referred to by housing authority designation (HA-1 or HA-2) in this report. Each participating housing authority project featured multiple buildings and natural gas accounts impacted by project measures. For example, HA-1 involved measures that affected eleven high-rise multifamily buildings, thirteen distinct natural gas accounts across these eleven buildings and often multiple measures per account. A summary of the distinctions among the terms project, housing authority, building, and account is provided in Appendix A.

assessment of the largest-saving project (HA-1) led to evaluation results with a relative precision of less than 1%.

The evaluators employed a two-pronged analysis approach to evaluate HA-1 project impacts:

1. **Analysis of pre/post monthly utility bills** – The evaluators correlated pre- and post-project monthly natural gas usage with historic heating degree day data to determine the effect of weather on energy consumption at each natural gas account influenced by the project. Each correlation was normalized with typical weather data to eliminate any year-to-year weather anomalies. Utility bills inherently include the interactivities among incented measures.
2. **Supporting boiler performance measurement** – Though utility bill analysis is the most comprehensive method of assessing the project's interactive impacts, it does not provide reasons for any RR discrepancies that might lead to specific areas for Program improvement. Therefore, the evaluators supported the billing analysis findings with supplemental measurement and verification (M&V) of selected measures comprising nine of the thirteen natural gas accounts affected by the HA-1 project.

1.2.1 Attribution

MFLI sponsors natural gas efficiency measures at affordable housing authorities that might not otherwise have the resources to undertake such capital-intensive projects without the assistance of utility incentives. Both MFLI participants in the evaluation population received a majority of project funding through program rebates. Due to program design and inherent customer characteristics, the evaluators did not assess MFLI attribution in this evaluation and assumed a net-to-gross ratio of 1.0 for the two MFLI participants in the 2009–2011 time frame.

1.3 Results

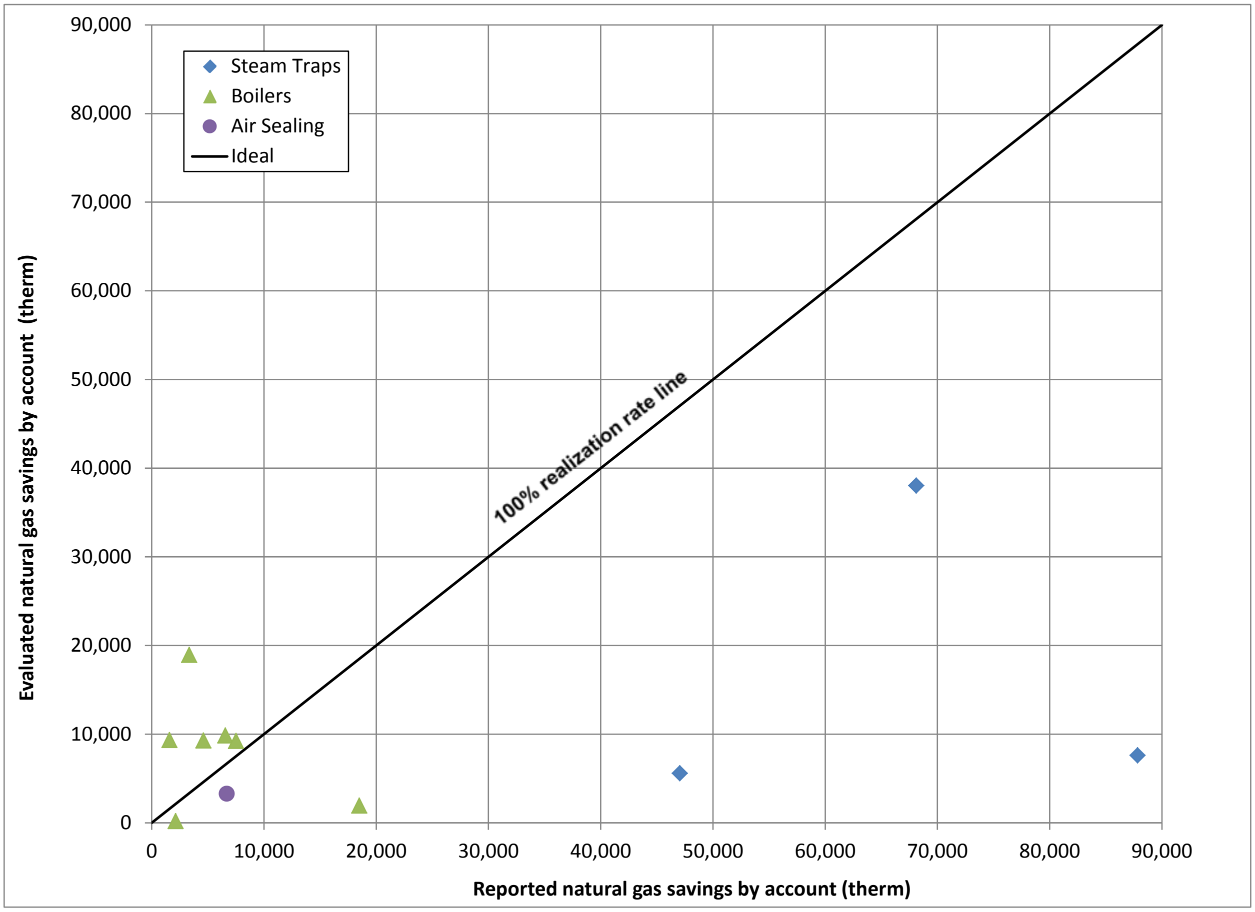
The evaluators determined net impacts for the two housing authorities – Housing Authority 1 (HA-1) and Housing Authority 2 (HA-2) – receiving MFLI funding during program years 2009–2011. The results by project are presented in Table 1-1.

Table 1-1
MFLI Net Gas Impacts, Reported vs. Evaluated

Project	Measures	Total Reported Savings (Therm)	Total Evaluated Savings (Therm)	RR
HA-1	Boiler replacement, steam traps, pipe insulation, air sealing	261,103	116,417	45%
HA-2	Boiler replacement	1,647	2,319	141%
Total		**262,750**	**118,736**	**45%**

To further analyze HA-1's realized savings, the evaluators were able to isolate billing analysis savings by account and by largest-saving measure. HA-1 is comprised of eleven high-rise multifamily buildings spanning thirteen CECONY natural gas accounts. Figure 1-1 compares each analyzed HA-1 account's realized and reported natural gas savings by the largest-saving measure affecting each account.

Figure 1-1
Evaluated Savings vs. Reported Savings by HA-1 Account's Primary Measure



As is evident from the scatter plot, steam traps featured the lowest RRs of the project's three primary measures. Boiler replacement performance varied widely among the seven accounts but featured an RR of 141% on average.

To further investigate the reasons behind the HA-1 billing analysis results, evaluators performed M&V to assess the performance of a selection of condensing boilers incented by the Program. Through the analysis of 3 months of performance data metered during the winter season, the evaluators determined information supporting the better-than-expected condensing boiler performance:

- **Boiler run time** – The installed condensing boilers at HA-1, on average, feature approximately twice as many full-load hours as assumed in the tracking savings calculations.
- **Baseline efficiency** – The preexisting efficiency represents an appropriate baseline for boiler replacement measures. Through M&V analysis, the preexisting boilers at HA-1 were estimated to operate at 81% efficiency, nearly identical to the Program's assumption of 80% recommended by code.
- **As-built efficiency** – The installed HA-1 boilers operate at a lower-than-predicted efficiency, on average, due to a high return water temperature limiting the condensing boilers' heat recovery ability.

Steam traps are less conducive to M&V than condensing boilers. However, the evaluation team's supplemental M&V findings on better-than-expected boiler performance support the initial billing analysis conclusion that steam traps are the primary contributor the Program's 45% RR.

1.4 Conclusions and Recommendations

The MFLI incented comprehensive projects at two housing authorities during the evaluation timeframe. With an evaluation population of only two projects, one of which saved 99% of total program-reported savings, the identification of broad, statistically significant conclusions and recommendations is limited. Therefore, the evaluators request that careful consideration is exercised when applying the results of this evaluation study to predict future performance of this program or other programs with similar measure offerings.

1.4.1 Conclusions

The results of this evaluation study led the evaluation team to three key project-specific conclusions:

1. **The variance in RRs was high among the analyzed natural gas accounts at the Program's larger participant, HA-1** – The evaluators examined RRs by measure type among eleven HA-1 accounts and determined that measure type greatly affected project performance. For example, HA-1 accounts receiving steam trap replacements featured a RR of 25%, while accounts with condensing boiler replacements featured a RR of 141%.
2. **The replacement of failed steam traps did not save as anticipated –** After examination of steam traps in a selection of building spaces and discussion with facility representatives, validating building full-load-hours (FLH) through post-retrofit billing analysis, and validating the absence of leaking by the new steam traps, the evaluators

concluded that the actual percentage of preexisting HA-1 steam traps that were inoperable was smaller than the Program's assumption of 35%.

3. **The replacement of preexisting atmospheric boilers with condensing boilers saved more than anticipated** – Through follow-up M&V of installed condensing boilers, the evaluators determined that HA-1 boilers operated for a greater number of full-load hours than assumed by the Program, leading to greater evaluated savings from the installation of higher-efficiency equipment.

1.4.2 Program Recommendations

Based on the results and conclusions of this study, the evaluation team offers three main recommendations for increasing program effectiveness. The evaluation team notes that the applicability of these recommendations may be limited, should the Program's scope or participation levels change in the future.

1. **Consider a more thorough, interactive savings calculation approach for large or complex projects –** The larger MFLI project in the evaluation time frame featured a high degree of interactivity among incented measures. To better estimate this interactivity, the evaluators recommend that the Program employ advanced analysis techniques, including: pre/post M&V when possible, building energy modeling, separation of savings analyses at the individual building level, and more comprehensive pre-project data collection and assessment.

2. **Pre-retrofit performance sampling** – For projects with large savings that depend on equipment characteristics of a large number of units' operating conditions such as poorly functioning steam traps or radiator thermostats, conduct performance measurements on a statistically valid sample of units prior to the retrofit to more accurately estimate the percentage of units that have failed and the percentage partially failed.

3. **Consider a savings correction after one year** – Two of the Program's most prevalent measures – steam trap replacements and envelope air sealing – cannot be sufficiently assessed using traditional performance measurement techniques. MFLI savings estimates often feature a high degree of uncertainty and therefore are good candidates for savings correction based on a year's worth of post-project utility bills, normalized for weather effects. This self-evaluation step would inform the Program of measure performance as quickly as possible and would greatly improve final Program savings reports and future impact evaluation results.

4. **More accurate classification of participating buildings** - The Program's tracking savings incorporated a boiler FLH estimate that contradicted the New York Technical

Manual[2] (NYTM) recommendation. The evaluators recommend that the Program more accurately classify each participating building to align with the most appropriate recommendations provided in the NYTM.

[2] "New York Standard Approach for Estimating Energy Savings," New York Department of Public Service, October 2010. http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/06f2fee55575bd8a852576e4006f9af7/$FILE/TechManualNYRevised10-15-10.pdf

2 INTRODUCTION

Consolidated Edison Company of New York (CECONY) and Orange & Rockland Utilities (O&R), collectively "the Companies," have completed the delivery of the first cycle (2009–2011) of a portfolio of Energy Efficiency Portfolio Standard (EEPS) Utility Administered programs, as ordered by the New York Public Service Commission. This document presents a detailed impact evaluation of the CECONY Multifamily Low Income Program (MFLI, or the Program).

2.1 Program Background and Objectives

MFLI targets natural gas savings at existing multifamily affordable housing buildings within the New York City and Westchester County Housing Authorities (NYCHA and WCHA, respectively). The Program offers equipment and weatherization assistance through efficiency measures, energy management systems, and building shell improvements and is open to income-eligible multifamily housing authorities with natural gas heating. The Multifamily Electric and Gas Program (MFEG), included in the evaluation work plan with the MFLI but addressed in a separate report, is an electric and gas program targeting multifamily energy savings through a number of common-area and in-unit measures. Together, the programs account for about 54% of the total CECONY gas portfolio savings goal in the 2009–2011 program implementation period.

During the 2009–2011 evaluation time frame, the MFLI sponsored projects at two housing authority participants, one of which comprised 99% of program-reported savings. Table 2-1 summarizes the two projects – Housing Authority 1 and Housing Authority 2 – incented by MFLI during the evaluation time frame.

Table 2-1
MFLI Projects during Evaluation Time Frame

Project	Measures	Total Reported Savings (Therm)	Share of Savings
Housing Authority 1	Boiler replacements, steam traps, pipe insulation, air sealing	261,103	99.4%
Housing Authority 2	Boiler replacements	1,647	0.6%
Total		**262,750**	**100.0%**

Due to its large savings share, the Housing Authority 1 project (HA-1) is the focus of this evaluation study. In the following sections, the evaluators assess the natural gas savings incurred through the installation of steam traps throughout the heating hot water (HHW) distribution system (78% of HA-1 savings), boiler replacements (11%), sealing of envelope penetrations (9%), and insulation of steam distribution piping (2%). The HA-1 project encompassed eleven high-rise multifamily buildings spanning thirteen CECONY natural gas accounts.

2.2 Evaluation Objectives

The intent of the impact evaluation of MFLI was twofold. First, the evaluation team provided a general assessment of the Program's performance in total during the 2009–2011 period. Second, the evaluation team provided actionable recommendations for improving the Program's implementation as a result of these assessments.

To assess program performance, the evaluation team applied a combination of two data collection and analysis methods by which program savings were calculated. First, since the Program achieves only natural gas savings, the evaluation team requested monthly gas consumption data, pre- and post-project, for all natural gas accounts affected by the HA-1 project. Utility bill analysis is a cost-effective first step to assessing the performance of program measures, which are often interactive. Next, the evaluation team enhanced the initial billing analysis with targeted measurement and verification (M&V) at a selection of the eleven affordable housing buildings affected by the HA-1 project.

The overall evaluation scope and objectives are identified in Table 2-2, as represented in the evaluation plan submitted for this program. These objectives were reviewed and approved by New York Department of Public Service (DPS) staff.

Table 2-2
Evaluation Scope and Objectives

Objective	Definition
Evaluation scope	Primary data collection activities focused on steam trap, boiler, and air sealing measures at the Program's largest-saving participant (HA-1).
Gross energy impacts	Report annual first-year gross natural gas savings at the customer meter based on utility bill analysis coupled with equipment-specific M&V. Results will be weather normalized to a typical year using typical meteorological year (TMY3) weather data.
Gross demand impacts	The Program achieves only natural gas savings; therefore, peak demand savings are not applicable.
Program attribution	The Program sponsored two affordable housing participants during the evaluation time frame. Due to the affordable housing characteristics of program participants, the evaluation team has not assessed attribution in this study and has assumed the net-to-gross ratio to be unity.
Precision	Due to the low number of program participants, statistical sampling was not necessary. The evaluation team assessed the performance of the HA-1 project only, which comprised over 99% of all program-reported natural gas savings, leading to an evaluation relative precision of less than 1%.

3 Evaluation Methodology

The methodology used to evaluate program natural gas savings is presented in the following sections. The general steps of the evaluation methodology include a review of project files, on-site data collection, and billing analysis and targeted measurement and verification (M&V) analysis approaches.

3.1 Project Files Overview

The Multifamily Low Income Program (MFLI, or the Program) incents natural gas-saving measures that can be highly interactive and complex to measure. For example, it is difficult to distinguish gas savings between a boiler replacement and simultaneous sealing of envelope penetrations. For this primary reason, the evaluation team initially assessed whole-building savings using analysis of weather-normalized pre- and post-project utility bills.

CECONY provided extensive monthly natural gas bills for each master-meter account affected by MFLI projects that occurred in December 2010 and December 2011 at the larger-saving participant of the two, Housing Authority 1 (HA-1). Utility billing data spanned 2008–2009 (pre-project) and 2012–2013 (post project).

Additional files relevant to the evaluated MFLI project included:

- Tracking data outlining savings by measure at each of HA-1's eleven affected buildings
- Savings assumptions and algorithms used to determine tracking savings
- Pre-/post-inspection documentation
- Various correspondence confirming the timing of project completion and incentive delivery

3.2 On-Site Data Collection

The evaluation team next supplemented information from project files with site-specific data collected through on-site visits at a selection of the eleven multifamily buildings impacted by the HA-1 project. Table 3-1 lists each of the major data collection categories addressed during the evaluators' on-site visits and discussions with facility staff. The Site-Specific Data Collection Form has been included in Appendix B for reference.

Table 3-1
Data Collected by Evaluators during Site Visits

Category	Explanation
Building characteristics	The evaluators collected data to verify each selected HA-1 building's characteristics, including age, envelope, number of floors, number of units and bedrooms, and approximate square footage. This information was used to verify information in project files and to "sanity check" the utility consumption data provided by CECONY.
Utility account information	The evaluators confirmed the end uses covered by each of the natural gas accounts for which monthly consumption data was supplied by CECONY. Additionally, evaluators confirmed that each of the master-metered accounts is paid for by the housing authority management, not tenants. This information allowed the evaluators to accurately interpret natural gas consumption patterns.
Occupancy	The evaluation team quantified tenant occupancy levels, pre- and post-project, to determine if changes in gas consumption were partially attributable to fluctuations in occupancy.
Equipment data and operating characteristics	Field engineers collected nameplate data and operating characteristics for equipment relevant to project measures, including boilers, heat exchangers, control systems, and building envelope. Additionally, the evaluators noted each building's heating setpoints and seasonal cutoffs used when extrapolating metered data.
Baseline information	The evaluators collected information on the preexisting systems at each facility in order to confirm that an early replacement baseline is appropriate for all measures. Such information included equipment age, operability, maintenance schedule, and history of repairs.

3.3 Billing Analysis

This section outlines the analysis of pre- and post-project consumption data from natural gas accounts at buildings affected by the evaluated project.

3.3.1 Baseline

Inherent in a billing analysis approach is the assumption that the evaluation baseline reflects the preexisting systems at the facility. As is evident in Table 3-2, the Program assumed the preexisting system represented the project baseline for steam trap, air sealing, and pipe insulation measures. However, the Program assumed a code-compliant (normal replacement) baseline for boiler replacement measures.

Table 3-2
Comparison of Program and Evaluation Baselines by Measure

Measure Type	Program Baseline	Evaluation Baseline
Boiler replacement	Atmospheric boiler operating at efficiency defined by ASHRAE 90.1 2007 code (80%)	Preexisting boiler (if evidence of patch and repair to keep systems operating past effective useful life)
Steam traps	Preexisting steam traps – Program assumed that 35% had failed	Preexisting steam traps – Unknown quantity failed
Pipe insulation	Preexisting uninsulated pipe	Preexisting uninsulated pipe
Air sealing	Preexisting envelope penetrations	Preexisting envelope penetrations

To assess whether the preexisting boiler systems might represent an appropriate project baseline, the evaluators referenced documentation from the New York DPS[3] citing a special circumstance exception for multifamily central systems that exceed effective useful life (EUL). This exception allows for the designation of an early replacement baseline (reflecting the preexisting system) for multifamily central systems (including boilers) that exceed EUL but have been actively maintained by the facility through patch-and-repair practices as needed. Further information on this special circumstance exception can be found in Appendix C.

3.3.2 Facility Accounts by Measure Type and Share of Savings

After receiving pre/post utility bills from CECONY, the evaluation team associated accounts with HA-1 buildings and processed the data into consistent monthly intervals. During telephone interviews with facility representatives and subsequent on-site data verification, the evaluators first grouped each impacted HA-1 natural gas utility account by measure type to ensure that seasonal effects were appropriately addressed in the analysis approach. Additionally, the evaluators examined the relative share of program-reported savings at each account to prioritize the HA-1 buildings receiving follow-up site visits from the evaluation team.

Table 3-3 illustrates the HA-1 project measures, building-account relationships, relative savings share, and analysis approach for each of the thirteen natural gas accounts comprising HA-1.

[3] Case 07-M-0548, Energy Efficiency Portfolio Standard (EEPS), Order Approving Consolidation and Revision of Technical Manuals (issued October 18,2010). http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B90EF3CB5-16EC-4141-B25F-C19937351402%7D

Table 3-3
Analyzed MFLI HA-1 Accounts by Measure Type and Share of Savings

Account (Last Five Digits)	HA-1 Building ID(s)	Measure Type: Replace HHW Boiler	Measure Type: Replace DHW Boiler	Measure Type: Steam Traps	Measure Type: Pipe Insulation	Measure Type: Air Sealing	% Total HA-1 Therm Savings	Selected for Billing Analysis?	Selected for On-Site M&V?
00001	1	■			■		0.6%	Yes	No
60007	2	■	■		■	■	2.5%	Yes	Yes
01004	3	■				■	1.3%	Yes	No
10000	4			■			18.0%	Yes	Yes
14000	5	■				■	7.1%	Yes	Yes
00003	6	■	■			■	2.9%	Yes	Yes
00008	7	■					0.8%	Yes	No
95008	7	■					1.8%	Yes	Yes
90009	7					■	2.6%	Yes	Yes
11000	8			■			26.1%	Yes	Yes
75000	9			■			33.6%	Yes	Yes
20004	10					■	1.8%	No[1]	Yes
00009	11					■	1.0%	No[1]	No

[1] Accounts ending in 20004 and 00009 did not feature sufficient pre-project utility data to allow for accurate analysis of whole building savings.

Billing analysis was conducted separately for each account. Even though two of the thirteen HA-1 accounts were not included in the billing analysis, evaluators were able to assess over 97% of HA-1 savings through billing analysis. Evaluators selected the nine largest-saving HA-1 accounts, comprising 96% of total HA-1 project savings, for targeted M&V, as discussed in Section 3.4.

3.3.3 Natural Gas Utility Bills and Dependence on Weather

As illustrated in Table 3-3, each of the facility's accounts received at least one measure that saved natural gas during the heating months. Therefore, the evaluation team initially assessed each account's variation with heating degree days (HDD) during pre- and post-project periods. The evaluators examined the monthly pre- and post-project natural gas usage against monthly HDDs to establish the relationship between the two. Historic HDDs were referenced from the nearby White Plains, New York weather station. Figures 3-1 and 3-2 illustrate examples of the dependence of natural gas usage on HDDs for an example account at HA-1.

Figure 3-1
Pre- and Post-Project Gas Consumption Bills vs. Actual HDD for HA-1 Example Account

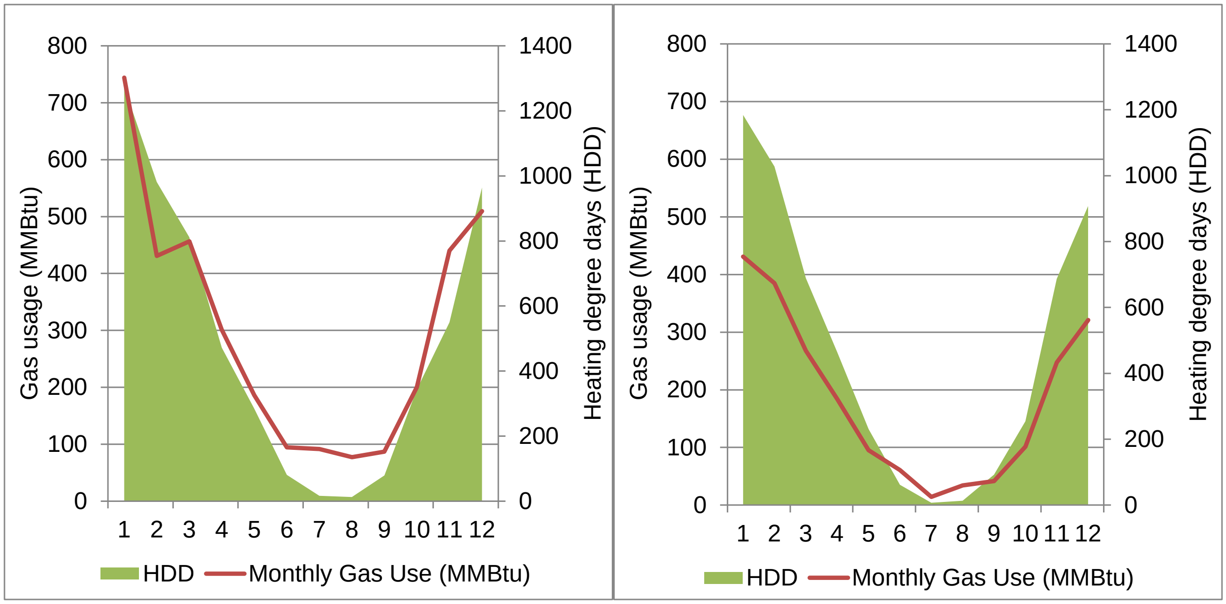
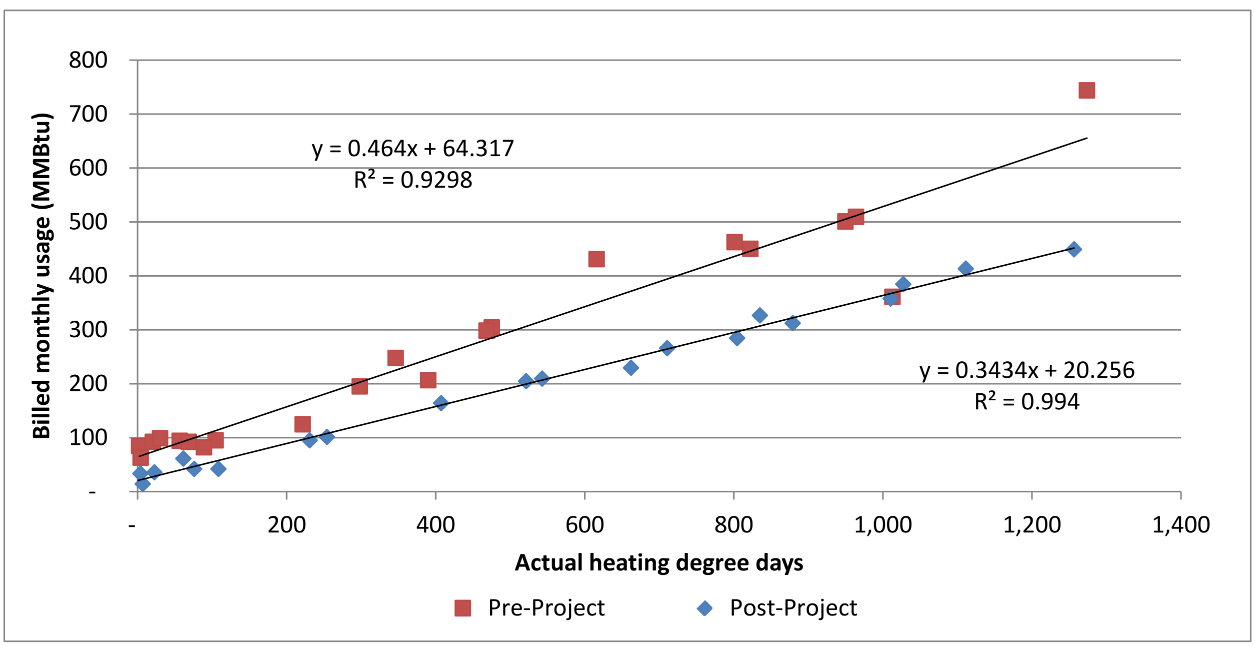


Figure 3-2
Correlations of Pre/Post Gas Usage with HDDs for HA-1 Example Account



3.3.4 Weather Normalization

Given the observed relationship between natural gas consumption and HDD, the evaluators next removed any weather anomalies in pre- or post-project billing periods by normalizing monthly natural gas usage with TMY3 weather. The evaluators applied MMBtu-to-HDD correlations, such as those illustrated in Figure 3-2, to monthly TMY3 HDDs at the White Plains weather station to determine typical monthly natural gas usage. This normalization step is illustrated using the following equation:

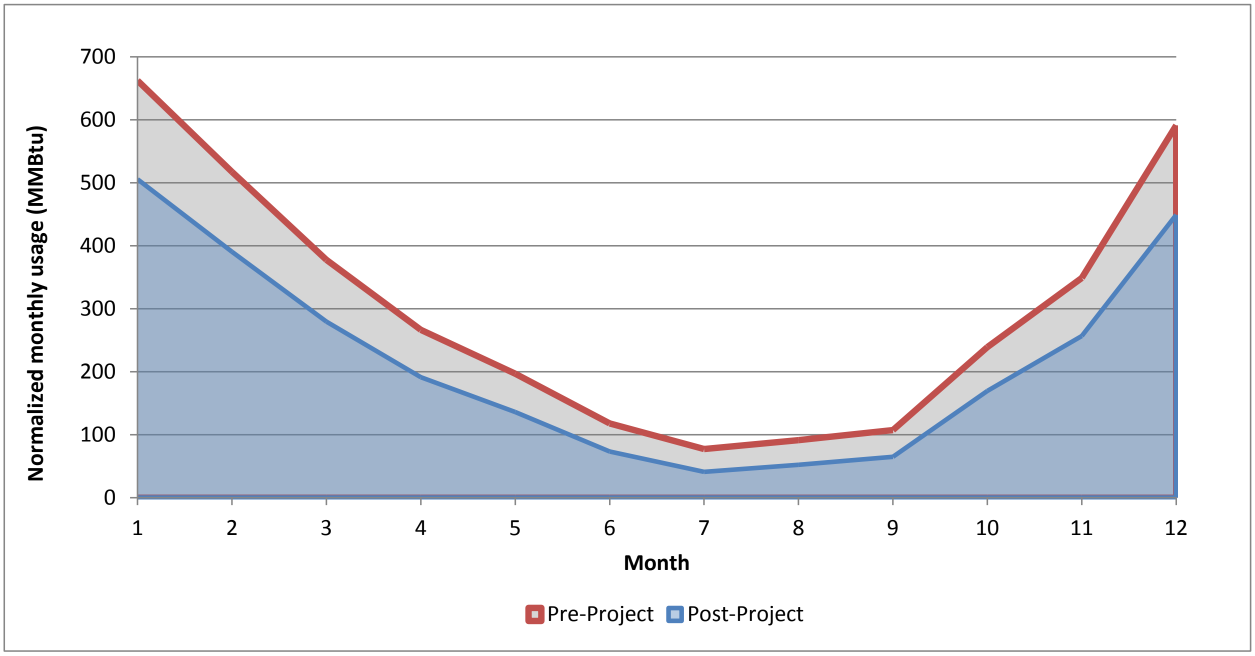
$$G = \sum_{j=1}^{12} m \times HDD_j + b$$

where,

G	= Annual typical gas usage (MMBtu)
j	= Month of year
m	= Slope of linear regression line, in MMBtu/HDD
HDD_j	= Total heating degree days per month
b	= Intercept of linear regression line, in MMBtu

Figure 3-3 compares the weather-normalized pre-project and post-project natural gas usage for the same example account examined Figures 3-1 and 3-2.

Figure 3-3
Comparison of Weather-Normalized Pre- and Post-Project Usage for Example Account



The evaluators followed the methodology outlined in Sections 3.3.1, 3.3.2, and 3.3.3 for eleven of the HA-1's thirteen natural gas accounts with sufficient monthly billing data.

3.4 Supporting Measurement and Verification

The goal of supplementary, measure-specific analysis was to develop supporting site-level evidence of the account-level performance observed in the utility bill analysis. This information ultimately did not define the evaluated program savings, but rather allowed the evaluators to further investigate potential areas for program improvement, as discussed later in Sections 4 and 5.

The measures incented by MFLI at HA-1 include boiler replacements, installation of steam traps, pipe insulation, and envelope air sealing. Natural gas systems are often challenging to measure without directly tapping the gas line—vaporous flow is less consistent than liquid flow and cannot accurately be measured from outside the distribution line, such as with electric current. Nonetheless, the evaluators applied proxy measurement techniques to meter boiler performance and verified equipment that could not be metered. Each is described in this section.

3.4.1 On-Site Verification

The evaluators verified the installation and operability of a selection of incented equipment. Table 3-4 lists the verification details of each of the four measures implemented at HA-1.

Table 3-4
Verification Details by Measure

Measure	Verification Details
Boiler replacement	Verify installation and operability of all boilers Note quantity, size, age, make/model of installed systems Verify end uses covered by boiler systems Discuss operability of preexisting boilers
Steam traps	Verify installation and operability of a selection of steam traps Inspect a selection of steam traps in common areas and accessible tenant units Note overall quantity of installed steam traps Discuss operability of preexisting steam traps
Pipe insulation	Verify length and thickness of accessible pipe insulation
Envelope air sealing	Discuss and inspect the envelope penetrations sealed as a result of the project

3.4.2 Boiler Performance Measurement

The evaluators applied proxy performance measurement techniques to estimate the performance of a selection of boilers installed during the HA-1 project. The evaluation team selected boilers for performance measurement based on the share of savings among the thirteen natural gas accounts of HA-1. As illustrated in Table 3-3 above, the four HA-1 accounts with boiler replacement measures selected for on-site M&V end in digits 60007, 14000, 00003, and 95008.

At each of the boiler rooms corresponding to those four accounts, evaluators deployed a variety of metering equipment to estimate boiler performance. Table 3-5 outlines the measurement details and objectives for each selected boiler.

Table 3-5
Boiler Performance Measurement Details

Equipment Monitored	Parameter Measured	Measurement Equipment	Observation Frequency	Metering Duration	Objectives
Boiler exhaust stack	Combustion efficiency, stack temperature, excess air	TPI 712 combustion analyzer	Spot	Spot	Determine boiler combustion efficiency at various firing rates. Develop combustion efficiency versus load level curve.
Boiler combustion fan	Current draw	HOBO four-channel logger, Onset 20-A CT[4]	5 minute	13 weeks	Determine boiler firing frequency and duration (purge excluded). Correlate with outside air conditions and/or time of day. Extrapolate metered data to annual loading profile.
Boiler supply and return piping	Water temperature	HOBO thermocouple loggers and thermocouples	1 minute	4 weeks	Assess boiler's condensing capability as a function of inlet temperature. Outlet temperature serves as a proxy for loading profile.

The evaluators deployed the above meters in mid-November 2013 and retrieved them in February 2014. The extended metering period allowed for boiler performance data to be collected over a wide range of outside air temperatures, resulting in more robust data than monthly utility bills.

[4] Average-root-mean-square (RMS) CTs were deployed upstream of the VFD (on the line side) on all metered boiler combustion air fans. The evaluators acknowledge that added uncertainty is introduced when average- instead of true-RMS CTs are used to meter amperage of motors with VFDs, due to potential waveform distortion introduced by the VFD. This uncertainty does not directly affect the evaluated savings result of this study, as the project's evaluated savings were driven by billing analysis, and the boiler fan amperage was used simply to disaggregate savings and savings discrepancy by measure. However, moving forward, the evaluators recommend that CTs or amp-clamp readers with true-RMS capability are preferable to measure current on motors with non-linear loads, such as those controlled by VFDs.

3.4.3 Boiler Performance Analysis

The evaluators processed 3 months of interval combustion fan amperage and inlet/outlet temperature data into hourly averages. They chose hourly averages to match up metered data with hourly White Plains weather conditions during the metering period, as provided by the National Oceanic and Atmospheric Administration (NOAA).

The evaluators next analyzed the hourly amperage data to determine each boiler's loading profile. Using the following affinity law relationships, the evaluators converted combustion fan motor amperage data into a boiler loading level at each hour:

$$\left(\frac{I}{FLA}\right) = \left(\frac{MBH_{input}}{MBH_{max}}\right)^{a}$$

$$\left(\frac{I}{FLA}\right)^{\frac{1}{a}} \times 100 = \left(\frac{MBH_{input}}{MBH_{max}}\right) \times 100 = \ Percentage\ of\ \ MBH_{max}$$

where,

I	= Amperage reading at interval as recorded by data loggers
FLA	= Nameplate full-load amperage of boiler combustion fan
MBH_{input}	= Hourly input, in MBtu per hour (MBH), that corresponds with combustion fan amperage reading, I
MBH_{max}	= Nameplate boiler input in MBH
a	= The exponent that characterizes the relationship between the fan amperage reading and the boiler input. The ideal value from the affinity law is 3; however, the evaluators assumed a value of 2.2 based on previous boiler research[5] on static pressure losses and other distribution system inefficiencies.

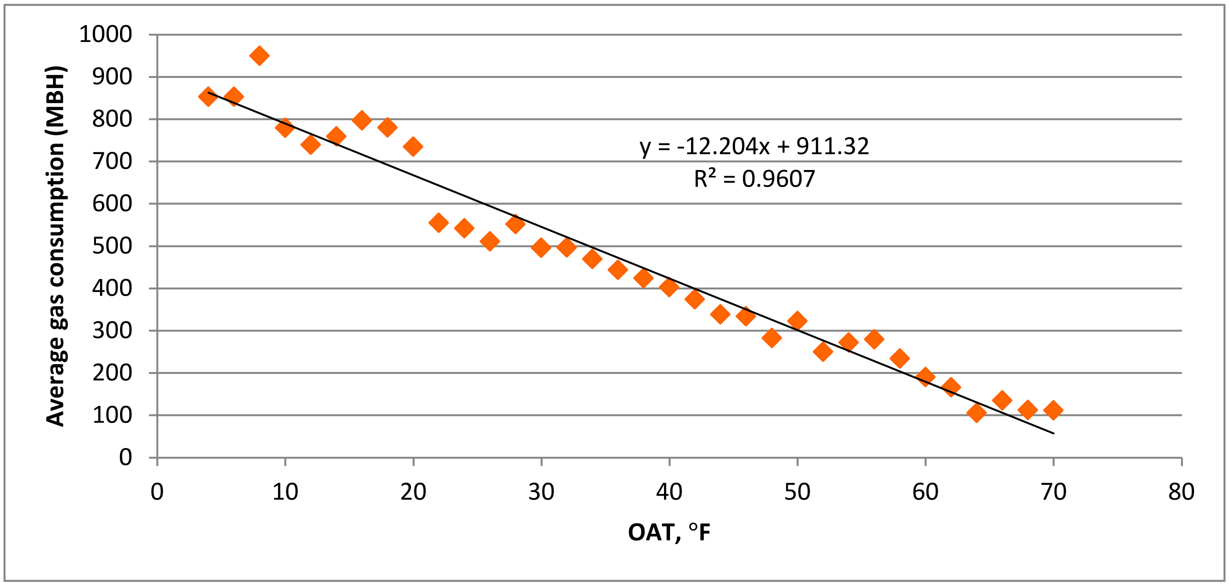
The above calculation was performed for all metered boilers, including both heating hot water (HHW) and domestic hot water (DHW) boilers. The next calculation steps depend on the type of boiler and have therefore been separated between HHW and DHW.

Heating Hot Water Boilers

[5] "2013 California Building Energy Efficiency Standards: Process Boilers," California Utilities Statewide Standards and Codes Team, October 2011. http://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/current/Reports/Nonresidential/Covered_Processes/2013_CASE_Process_Boilers%2010.28.2011.pdf

For boilers supplying space heating, the evaluators examined the boiler input as a function of weather during the metering period. The evaluators correlated the gas input (in MBH) with hourly NOAA outside air temperatures (OATs) at the White Plains weather station. Please note that Figure 3-4 shows the average gas consumption at each OAT experienced over the metering period and is presented for illustrative purposes only.

Figure 3-4
Average Boiler Input vs. White Plains OAT during Metering Period



As expected, the boiler's highest average consumption occurs at the coldest temperatures, decreasing linearly to about 10% of the maximum at the metering period's warmest temperatures. The full gas consumption-OAT correlation, comprising all hourly data over the three-month metering period, was then used to model the boiler's consumption over a typical year of White Plains weather. Based on information collected during the site visit, the evaluated facility activates the boiler plant on October 1 and deactivates it on May 31 of each year. This period equates to 5,832 hours of heating season. Summing the boiler's modeled consumption during each hour of the heating season yields an estimate of the as-built system's annual gas consumption in MBtu, as illustrated by the formula below:

$$G = \sum_{j=1}^{5832} (f \times OAT_j + b)$$

where,

G	= Annual space heating gas consumption for TMY3 (MBtu)
j	= Hour during heating period (Oct 1–May 31) of TMY3 year

f	= Slope of Figure 3-4 regression line, in MBH/°F
OAT_j	= Outdoor air temperature at hour, j, from TMY3 weather file (°F)
b	= Intercept of Figure 3-4 regression line, in MBH

DHW Boilers

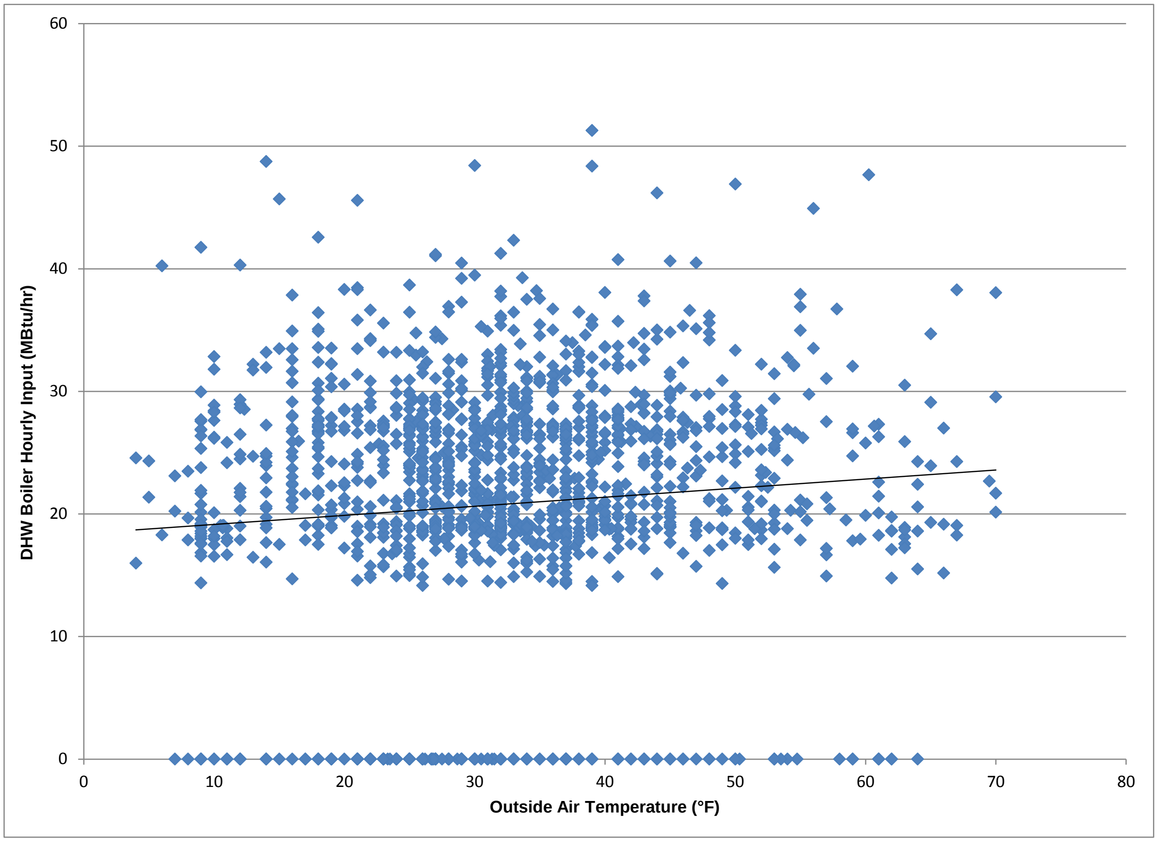
For boilers supplying DHW, boiler operation is dependent on the demand for DHW throughout the building. Therefore, the evaluators examined DHW metered data, gathered from impacted HA-1 DHW boilers over the evaluation metering period, as a function of a daily/hourly schedule, reflecting the fluctuations in occupancy throughout a typical day. Table 3-6 illustrates an example loading profile (percentage of full-load consumption) by hour of day and day of week.

Table 3-6
Average DHW Boiler Loading Level by Hour of Day and Day of Week

Weekday ▼ Hour of Day ▶	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Sunday	23%	15%	9%	14%	15%	14%	23%	43%	61%	52%	73%	73%	74%	53%	62%	45%	63%	58%	46%	43%	50%	33%	28%	23%
Monday	19%	16%	13%	8%	16%	24%	28%	38%	63%	73%	68%	66%	72%	53%	53%	54%	53%	56%	63%	50%	51%	40%	44%	28%
Tuesday	24%	22%	15%	10%	10%	30%	19%	42%	59%	81%	74%	56%	57%	60%	49%	44%	62%	72%	71%	42%	45%	38%	41%	34%
Wednesday	19%	18%	14%	12%	25%	23%	19%	31%	47%	81%	77%	62%	72%	60%	63%	49%	51%	52%	60%	50%	40%	34%	37%	24%
Thursday	19%	19%	16%	15%	10%	19%	27%	43%	69%	63%	68%	59%	50%	51%	41%	40%	56%	65%	62%	54%	40%	43%	33%	24%
Friday	23%	18%	19%	9%	10%	27%	23%	40%	71%	78%	70%	61%	54%	55%	44%	42%	33%	48%	63%	46%	43%	32%	30%	28%
Saturday	27%	20%	18%	11%	13%	8%	20%	35%	46%	61%	78%	61%	68%	49%	64%	43%	45%	50%	58%	53%	49%	39%	23%	31%

The evaluators also examined DHW boiler loading as a function of OAT, but no correlation was evident, as illustrated in Figure 3-5.

Figure 3-5
DHW Boiler Loading vs. Outside Air Temperature



The daily/hourly schedule was used to model the total DHW boiler gas consumption over a full year, as illustrated by the formula below:

$$G = \sum_{h=1}^{52} \sum_{i=1}^{7} \sum_{j=1}^{24} L_{hij} \times MBH_{input}$$

where,

G	= Annual DHW gas consumption (MBtu)
h	= Week of year
i	= Day of week
j	= Hour of day
L_{hij}	= DHW boiler loading level by hour j, week h, and day i
MBH_{input}	= Rated boiler input (MBH)

4 RESULTS

The results of the Multifamily Low Income Program (MFLI, or the Program) impact evaluation's on-site data collection, billing analysis, and measurement and verification (M&V) analysis are presented in the following sections.

4.1 Data Collection Findings

The results of the evaluators' data collection activities, first introduced in Section 3.2, are presented in Table 4-1. Pertinent findings were determined through on-site inspection and interviews with facility staff.

Table 4-1
Results of On-Site Data Collection

Category	Findings
Building characteristics	The evaluators examined each Housing Authority 1 (HA-1) account's annual natural gas usage and corresponding building square footage and compared each building's heating density with a benchmark value. Each of the accounts was within the expected range for New York multifamily buildings of this size.
Utility account information	Nearly every HA-1 account included meters that covered both space heating and domestic hot water uses.
Occupancy	The evaluators determined no significant differences in occupancy between pre- and post-project billing periods. HA-1 buildings were nearly fully occupied during both periods, and any vacancy was quickly filled. The affordable housing status of MFLI-eligible customers often results in a waiting list of potential tenants.
Equipment data and operating characteristics	The evaluators determined that each HA-1 building's space heating boilers were activated on October 1 and deactivated on May 31 of each year. This finding is consistent with New York municipal law for multifamily buildings with central heating. The evaluators spot-measured an average common area space temperature of 75°F in the post-project case. Only the HA-1 project's domestic hot water boiler retrofits saved throughout the year; all other project measures saved only during the heating season.
Baseline information	The evaluators noted that HA-1's preexisting boiler systems had been repaired as necessary to sufficiently heat each building. Though some boilers had aged past effective useful life (EUL), the evaluators referenced the New York DPS's special circumstance exception for multifamily central systems, as outlined in Appendix C. Therefore, due to the operability and patch/repair history of the replaced equipment, the baseline for all HA-1 measures was the preexisting system. This baseline was reflected in the pre-project facility bills and therefore required no adjustment.

Category	Findings
Steam trap inspection	Project documents indicate the replacement of 1,248 failed steam traps among three HA-1 accounts. This quantity could not be confirmed from review of project invoices or discussion with facility staff. The evaluators were not able to inspect each of the replaced steam traps and therefore inspected a selection of steam traps in each affected building. This inspection involved a walkthrough with facility staff, who identified steam traps that were replaced as a result of the project. The evaluators inspected approximately 25 newly-installed steam traps and observed that none of them had failed open or were otherwise leaking. Though the inspected steam traps do not represent a statistically representative selection of the total replaced, the evaluators confirmed operability of uninspected traps through discussion with facility staff on maintenance history since the project.

4.2 Billing Analysis Results

Using the billing analysis methodology outlined in Section 3.3, the evaluators determined the impacts of eleven of the thirteen HA-1 natural gas accounts. These results are presented in Table 4-2.

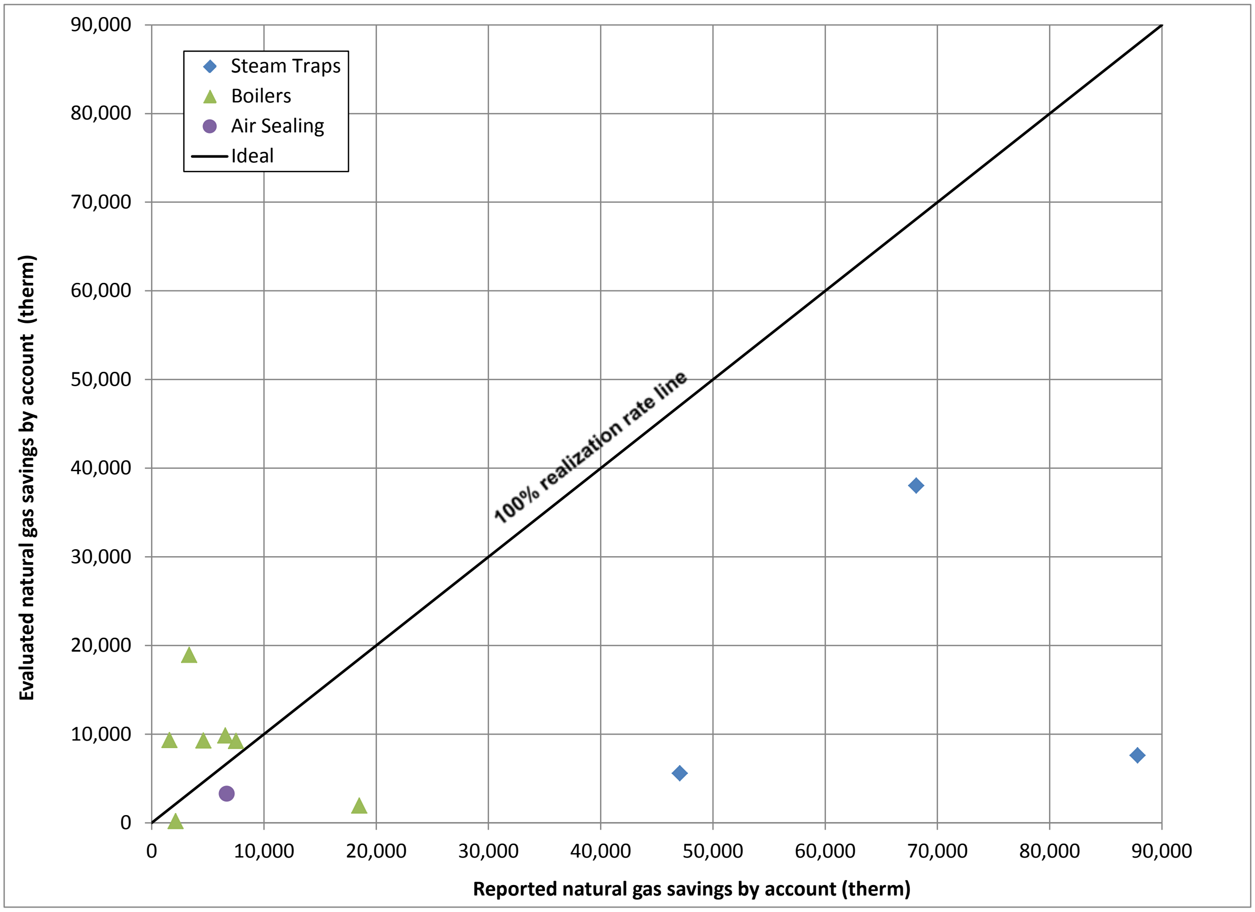
Table 4-2
Billing Analysis Results by HA-1 Account

HA-1 Account (Last Five Digits)	% Total HA-1 Reported Gas Savings	Selected for Billing Analysis?	Selected for On-Site M&V?	Reported Savings (Therm)	Evaluated Savings (Therm)	Realization Rate
00001	0.6%	Yes	No	1,572	9,316	593%
60007	2.5%	Yes	Yes	6,550	9,842	150%
01004	1.3%	Yes	No	3,340	18,928	567%
10000	18.0%	Yes	Yes	47,056	5,575	12%
14000	7.1%	Yes	Yes	18,485	1,927	10%
00003	2.9%	Yes	Yes	7,503	9,226	123%
00008	0.8%	Yes	No	2,120	188	9%
95008	1.8%	Yes	Yes	4,599	9,272	202%
90009	2.6%	Yes	Yes	6,682	3,295	49%
11000	26.1%	Yes	Yes	68,111	38,015	56%
75000	33.6%	Yes	Yes	87,842	7,603	9%
20004	1.8%	No	Yes	4,732[a]		
00009	1.0%	No	No	2,511[a]		
Totals	**100%**			**253,860**	**113,188**	**45%**

[a] These accounts with anomalous pre-project bills are not included in the summation of total reported or evaluated savings or the realization rate calculation.

Figure 4-1's scatter plot illustrates the significant variance among the eleven billing analysis results, which have been color-coded by each account's largest-saving measure. Ideally, the evaluated savings would always match the program-reported savings. This ideal is shown as a solid black line on the chart. Actual findings are plotted as points on the scatter graph, with program-reported savings on the x-axis and evaluated gross savings on the y-axis. If all the points were to fall directly on the line, it would mean that the evaluated savings were exactly the same as the program-reported savings, and the realization rate (RR) was 100%. A pattern of points below the ideal line suggests an RR of less than 100%; points above the line suggest an RR greater than 100%.

Figure 4-1
Evaluated Savings vs. Reported Savings by Account's Primary Measure



To further investigate the variance among the eleven analyzed gas accounts, the evaluators next explored whether the savings significantly varied by primary measure type. The HA-1 project included four distinct measures: installation of steam traps, replacement of boilers, insulation of heating pipes, and sealing of envelope penetrations. These measures often overlapped; therefore, it was not always possible to isolate a specific measure's performance among the eleven analyzed gas accounts. Nonetheless, the billing analysis RRs varied significantly by measure, as shown in Table 4-3.

Table 4-3
HA-1 Billing Analysis Results by Measure Type

Primary Measure Type	HA-1 Accounts Receiving This Measure		HA-1 Accounts Exclusively Receiving This Measure	
	Number of Accounts	Total RR	Number of Accounts	Total RR
Boilers	7	133%	2	141%
Steam traps	3	25%	3	25%
Pipe insulation	2	236%	0	N/A
Air sealing	5	102%	1	49%

Accounts receiving boiler replacements generally performed well, with evaluated savings exceeding tracking savings in most cases. However, the accounts receiving steam trap installations, which accounted for 78% of the total reported gas savings at HA-1, only realized a quarter of the reported savings in pre/post bills. The evaluators could not draw clear conclusions on air sealing and pipe insulation measures due to relatively low savings claims.

4.3 Boiler Measurement and Verification Results

In order to further investigate the program's evaluated savings, the evaluators analyzed the performance of the HA-1 project's largest-saving measure conducive to measurement and verification (M&V): the installation of condensing boilers. This investigation, though not directly influencing the total evaluated savings for the project, provides information on why the boiler measures performed better than expected.

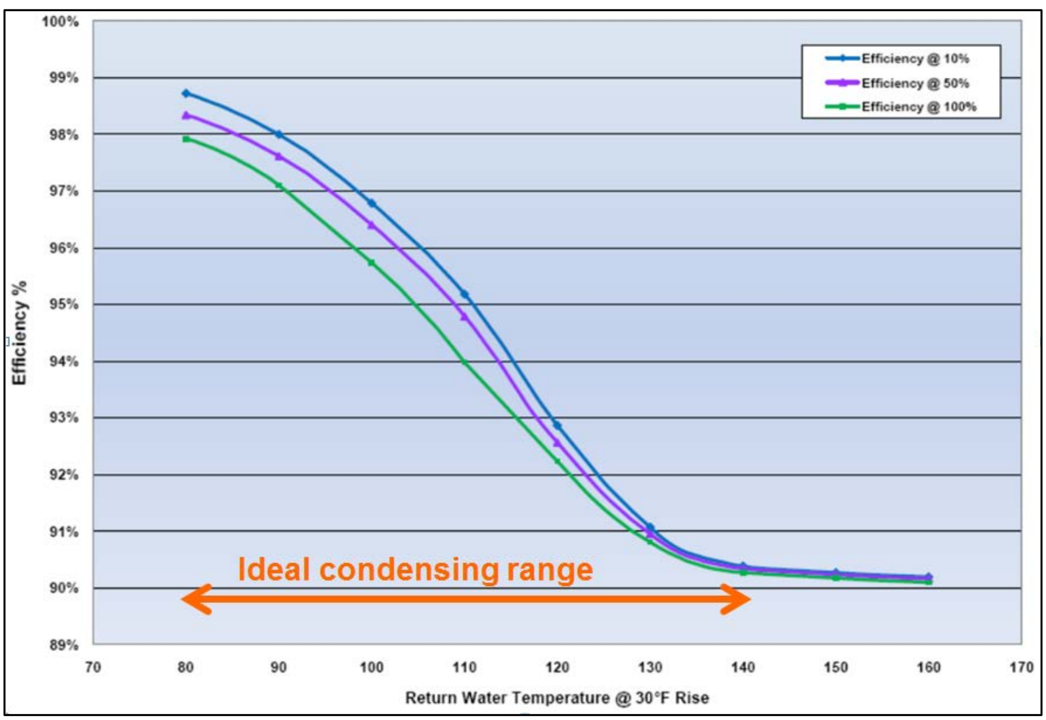
Through analysis of metered data from installed condensing boilers at HA-1 buildings, the evaluators determined three key results that impacted the evaluated savings for this measure.

1. **Boiler annual hours of operation** – The extrapolated metered data indicated that the installed condensing boilers operated significantly longer than assumed in tracking savings calculations. The Program referenced the New York Technical Manual's (NYTM's) annual full-load-hours (FLH) value of 757 for low-rise multifamily buildings[6] in New York City, while the evaluators calculated 1,939 full-load heating hours and 5,378 total heating hours per year for the metered boiler plants on average. The evaluators primarily attribute this difference to the higher-than-usual space heating setpoint observed during the meter deployment and retrieval site visits, as well as the high daytime occupancy rates evident from the domestic hot water (DHW) load profile in Table 3-6. Higher annual FLH led to significantly higher savings from improving the boiler plant efficiency.

[6] The NYTM classifies "low-rise multifamily buildings" as featuring 2 conditioned floors.

2. **Preexisting boiler efficiency** – The Program assumed a New York State Energy Conservation Code (NYSECC) baseline boiler efficiency of 80% in tracking savings calculations, whereas the evaluators determined that the preexisting atmospheric boilers represented a more appropriate evaluation baseline. The evaluators used natural gas meter readings from the logger deployment and retrieval site visits to calibrate the hourly boiler spreadsheet analysis with the actual gas consumption during the 3-month evaluation time frame. The evaluators next compared the normalized natural gas savings from the November – February metering period's pre- and post-project utility bills with the normalized savings calculated from metered data on boiler loading. Knowledge of the average post-project combustion efficiency from spot measurements allowed the evaluators to calculate a pre-project combustion efficiency of 81%, only slightly higher than the Program's code assumption. This slight difference had a negligible effect on boiler measure performance.
3. **Installed boiler efficiency** – Condensing boilers achieve their highest efficiency when the return water temperature is relatively low, allowing the boiler to recover latent heat from its exhaust stack. Figure 4-2 illustrates the condensing range for the most prevalent condensing boiler model (manufactured by Lochinvar) installed in this project.

Figure 4-2
Lochinvar Performance Curves – Combustion Efficiency at Various Firing Rates as a Function of Return Water Temperature



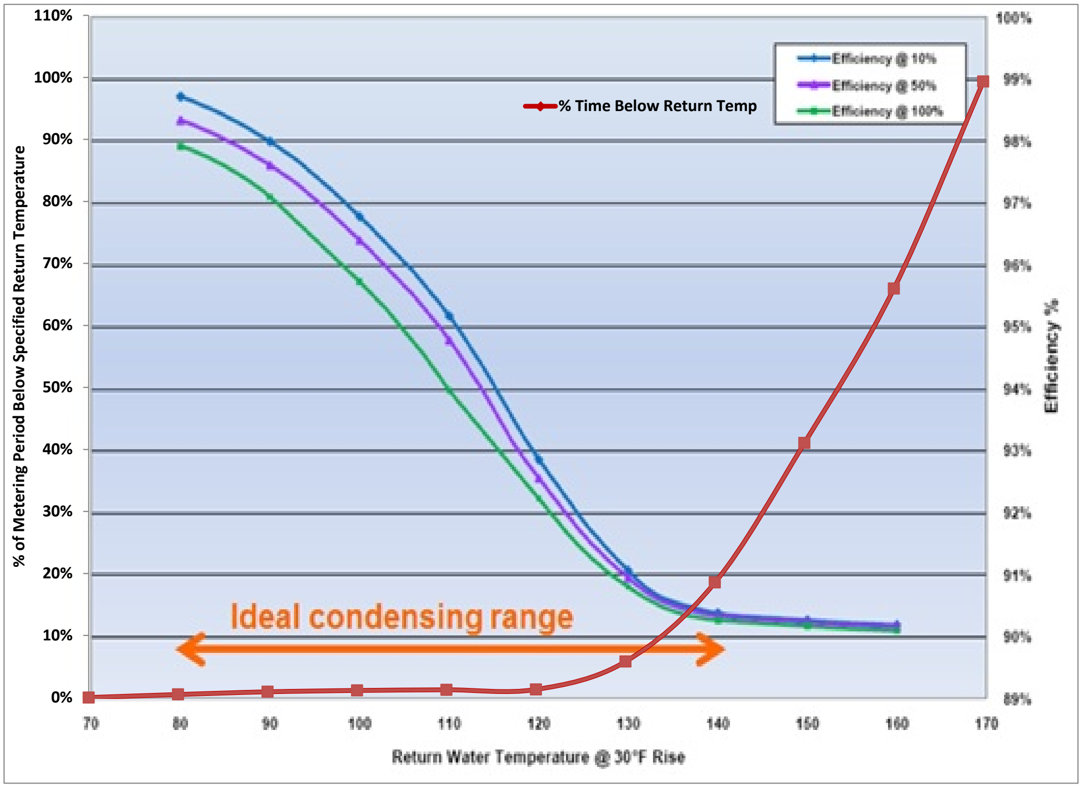
The evaluators metered the boilers' return temperature over the November 2013 to February 2014 metering period to examine its effect on boiler efficiency. Table 4-4 compares spot-measured return temperatures and spot-measured combustion efficiencies for a variety of boiler firing rates among the plants selected for M&V.

Table 4-4
Measured Combustion Efficiency and Return Water Temperature at Various Firing Rates

Boiler Firing Rate (%)	Assumed Boiler Efficiency (%)[a]	Actual Combustion Efficiency (%)	Boiler Return Temperature (°F)
20%	96.2%	88.7%	162
20%	96.2%	88.8%	142
49%	96.2%	88.5%	174
50%	96.2%	88.7%	142
53%	94.1%	88.0%	167
50%	96.2%	88.6%	162
65%	96.2%	88.4%	174
75%	96.2%	88.4%	162
100%	96.2%	87.6%	162
100%	96.2%	87.7%	174

[a] Boiler efficiency and combustion efficiency are not identical terms. Boiler efficiency includes all losses from boiler input to boiler output, such as conduction and radiation losses through the boiler shell, whereas combustion efficiency reflects only those losses occurring during the combustion phase at the burner and through the stack. However, the two are predictably comparable, with boiler losses exceeding combustion losses by 1%–2% depending on load.

Figure 4-3
Lochinvar Efficiency Curves with HA-1 Boiler Return Water Temperature Profile



As is evident from Table 4-4, the installed HA-1 boilers, on average, operated at a return temperature significantly higher than the ideal condensing range. This led to spot-measured combustion efficiencies considerably lower than the design boiler efficiencies assumed in tracking savings calculations. Figure 4-3 illustrates the return water temperature profile of an installed HA-1 condensing boiler, which indicates that the boiler spent fewer than 20% of its operating hours within the ideal condensing range during the November-February metering period. Higher-than-expected return water temperatures negatively impacted the evaluated savings, though not significantly enough to overcome the positive impact of the FLH difference. All other incented HA-1 boilers metered by the evaluators indicated similar operating profiles.

This type of discrepancy is not uncommon for condensing boilers and is perhaps indicative of a control system issue. The average temperature delta between supply and return is significantly lower than usual, indicating that the boilers are not correctly adjusting the supply heating hot water (HHW) temperature based on building heating load.

Condensing boilers are more efficient than standard boilers even when operating in noncondensing mode. Their larger stainless steel heat exchangers can extract more heat from the combustion gas before it goes to the stack than a conventional standard efficiency boiler's heat exchanger can extract. Roughly speaking, a condensing boiler can save up to 20%

compared to a standard boiler when condensing and can save about 10% when not condensing, so the penalty for operating in noncondensing mode may halve the potential savings.

The 52% realization rate penalty due to the boilers operating in noncondensing mode was more than offset by the boilers' FLH operation that was 256% of the predicted level.

The higher-than-anticipated condensing boiler savings further reinforce that the steam traps are the primary contributor to the program's lower evaluated savings. The boiler M&V findings also provided insight to program recommendations, as discussed in Section 5.

4.4 Attribution

MFLI sponsors natural gas efficiency measures at affordable housing authorities that might not otherwise have the resources to undertake such capital-intensive projects without the assistance of utility incentives. Both MFLI participants in the evaluation population received the majority of project funding through program rebates. Low-income multifamily and residential programs with similar design have claimed a 1.0 net-to-gross ratio due to the characteristics of their customer bases. Therefore, the evaluators did not research program attribution during this evaluation cycle and assumed a net-to-gross ratio of 1.0 for the two MFLI participants in the 2009–2011 time frame.

4.5 Program Level Savings Results

The MFLI evaluation focused on the HA-1 project, which accounted for over 99% of program-reported total natural gas savings during the evaluation time frame. While Housing Authority #2 (HA-2) was not examined due to low savings share, the evaluators believe specific findings from HA-1 are applicable to HA-2. Specifically, since the HA-2 project involved only one measure, boiler replacements, the evaluators applied the 141% RR for the two HA-1 accounts that exclusively received boiler replacement measures to the reported savings for HA-2. This RR determined from billing analysis was corroborated with metered performance data among a sample of incented boilers, as outlined in Section 4.3.

Table 4-5 summarizes the impact evaluation results for each of the Program's two projects completed between 2009 and 2011.

Table 4-5
Reported vs. Evaluated MFLI Savings, 2009–2011

Project	Measure Types	Total Reported Savings (Therm)	Total Evaluated Savings (Therm)	RR
HA-1	Boiler replacement, steam traps, pipe insulation, air sealing	261,103	116,417	45%
HA-2	Boiler replacement	1,647	2,319	141%
Total		**262,750**	**118,736**	**45%**

5 Conclusions and Recommendations

As a result of the MFLI impact evaluation, the evaluation team identified several conclusions that led to two recommendations for improving program effectiveness, all of which are presented in the following sections.

5.1 Conclusions

The MFLI incented comprehensive projects at two housing authorities during the evaluation timeframe. With an evaluation population of only two projects, one of which saved 99% of total program-reported savings, the identification of broad, statistically significant program-level conclusions is difficult. Further, as each of the two projects featured no more than four interactive measure types that are mostly not conducive to traditional measurement and verification approaches, the identification of measure-level conclusions is limited. Therefore, the evaluators request that careful consideration is exercised when applying the results of this evaluation study to predict future performance of this program or other programs with similar measure offerings.

The evaluators have identified three key project-specific conclusions based on the results of this evaluation study:

1. The variance in realization rates (RRs) was high among the analyzed natural gas accounts at the Program's larger participant, Housing Authority #1 (HA-1). The evaluators examined RRs by measure type among the eleven examined HA-1 accounts and determined that measure type greatly affected project performance.
2. The replacement of failed steam traps at HA-1 did not save as anticipated. After examination of steam traps in a selection of building spaces and discussions with facility representatives, the evaluators speculate that the main contributor to the low RR was a higher-than-actual installation rate assumed by the Program. The tracking savings reflect a 35% replacement of all 3,594 steam traps in the three affected accounts.
3. The replacement of preexisting HA-1 atmospheric boilers with condensing boilers saved more than anticipated. Through follow-up measurement and verification (M&V) at HA-1 buildings that received condensing boilers, the evaluators determined three major findings that led to better-than-anticipated overall performance of the HA-1 boiler replacement measure:
    a. The Program referenced a full-load heating hours value of 757 for New York City low-rise multifamily buildings, but the evaluators calculated 1,939 hours of full-load heating on average. This difference was the primary contributor to higher boiler savings than anticipated.

b. The Program assumed a boiler baseline defined by New York State Energy Conservation Code (NYSECC) 2007, whereas the preexisting boiler is a more appropriate baseline, per the DPS documentation outlined in Appendix C. Through billing analysis and M&V results, the evaluators estimate that pre-project HA-1 boilers operated at an efficiency of 81%.

c. The evaluators determined that the installed condensing boilers at HA-1 do not reach the highest efficiency levels due to high boiler return temperatures outside of the ideal condensing range. The project application's proposed combustion efficiency was 96%, whereas the evaluated combustion efficiency was 88%, which reduced savings by 52%. However, this difference was more than offset by the additional FLH described in item a.

5.2 Recommendations

The evaluation team's recommendations for the Program are given in the following section. The evaluation team again notes the limited applicability of these recommendations should the Program's scope or participation levels change in the future.

5.2.1 Program Recommendations

Based on the results and conclusions of this study, the evaluation team offers three main recommendations for increasing program effectiveness:

1. **Consider a more thorough, interactive savings calculation approach for large or complex projects –** The larger MFLI project in the evaluation time frame featured a high degree of interactivity among incented measures. To better estimate this interactivity, the evaluators recommend the Program employs advanced analysis techniques, which include:

   a. **Pre/post M&V when possible** – Some program measures, such as boiler replacements and EMS installations, would benefit from a comparison of pre- and post-project performance measurement.

   b. **Building energy modeling** – Measure interactivities cannot be accurately predicted using spreadsheet analysis. Building energy modeling, grounded with pre-project performance measurement, would improve accuracy.

   c. **Separate building-level analyses** – The HA-1 project was analyzed and incented at the housing authority level, but the evaluators believe that more accurate savings estimation is possible if the Program considers incentive applications and subsequent analysis at the individual building level.

2. **Pre-retrofit performance sampling** – For projects with large savings that depend on equipment characteristics of a large number of units' operating conditions such as poorly functioning steam traps or radiator thermostats, conduct performance measurements on a statistically valid sample of units prior to the retrofit to more accurately estimate the percentage of units that have failed and the percentage partially failed.
3. **Consider a savings correction after one year** – Two of the Program's most prevalent measures – steam trap replacements and envelope air sealing – cannot be assessed using traditional performance measurement techniques. MFLI savings estimates often feature a high degree of uncertainty and therefore are good candidates for a savings correction based on a year's worth of post-project utility bills, normalized for weather effects. This self-evaluation step would greatly improve final program savings reports and future impact evaluation results.
4. **More accurate classification of participating buildings –** The Program's tracking savings incorporated a boiler FLH estimate that reflected the NYTM's recommendation for low-rise multifamily buildings. The NYTM defines "low-rise" as having two or fewer conditioned floors; however, all but one of HA-1's eleven buildings exceeded two floors. The evaluators recommend that the Program more accurately classify each participating building to align with the most appropriate recommendations provided in the NYTM.

Appendix A: Glossary of Terms

Prior to addressing specific terms that appear in the report's body, the evaluators have added a table that summarizes the distinctions among the identifying terms project, housing authority, building, account, and measure.

Term	Definition
Project	The Program incented two projects during the 2009-2011 evaluation timeframe.
Housing authority	The two incented projects occurred at separate housing authorities. Therefore, projects are referred to by housing authority designations HA-1 or HA-2.
Building	The participating housing authority projects each featured multiple impacted multifamily buildings. For example, HA-1 involved measures that affected eleven high-rise multifamily buildings.
Account	Each project impacted multiple natural gas accounts as well. For example, HA-1 affected thirteen distinct natural gas accounts across the eleven buildings.
Measure	Impacted natural gas accounts featured at least one measure incented by the Program, but oftentimes featured multiple, interactive measures per account.

boiler efficiency – An efficiency term that accounts for all losses that occur between boiler input and output, including firing losses, incomplete combustion, heat exchanger inefficiency, stack losses, and shell losses.

CECONY – Consolidated Edison Company of New York.

combustion efficiency – An efficiency term that accounts for firing losses, incomplete combustion, and heat exchanger inefficiency during boiler operation.

condensing boilers – Boilers that achieve high efficiency by recovering waste heat from the exhaust stack to preheat the entering cold water.

DPS – New York Department of Public Service.

Energy Efficiency Portfolio Standard (EEPS) – The state-mandated utility-administered programs.

energy management system (EMS) – A system used by building operators to monitor, measure, control, and schedule their building loads.

ex ante savings estimate – Forecasted savings used for program and portfolio planning purposes.

ex post savings estimate – Savings estimate reported by an evaluator after the energy impact evaluation has been completed.

free rider, free ridership (FR) – A program participant who would have implemented the program measure or practice in the absence of the program.

full-load heating hours – The number of annual hours that a boiler must operate at full load in order to meet the heating requirement of a building.

heating degree days – A summation of the daily difference between the average outside air temperature and an assumed base temperature (usually between 55°F and 65°F). Heating degree days typically correlate with the space heating requirement for a building.

HVAC – Heating, ventilation, and air conditioning.

measurement and verification (M&V) – A subset of program impact evaluation that is associated with the documentation of energy savings at individual sites or projects using one or more methods that can involve measurements, engineering calculations, statistical analyses, and/or computer simulation modeling.

New York Technical Manual (NYTM) – The DPS-mandated reference document for calculating EEPS program savings.

net to gross, net-to-gross ratio (NTG, NTGR) – The relationship between net energy or net demand savings, where net is measured as what would have occurred without the program, what would have occurred naturally, and gross savings (often evaluated savings). The NTGR is the ratio of net savings to gross savings.

O&R – Orange & Rockland Utilities.

relative precision – Measures the expected error bound of an estimate on a normalized basis. It must be expressed for a specified confidence level. The relative precision (*RP*) of an estimate at 90% confidence is:

$$RP = 1.645 \frac{CV}{\sqrt{n}} \sqrt{1 - \frac{n}{N}}$$

where n is the sample size, N is the population size, and the coefficient of variance is CV = standard deviation / estimate mean value. The square root expression at the end of the equation is the finite population correction factor, which becomes inconsequential and unnecessary for large populations.

realization rate (RR) – The term is used in several contexts in the development of reported program savings. The primary applications include the ratio of project tracking system savings data (e.g., initial estimates of project savings) to savings that (1) are adjusted for data errors and (2) incorporate evaluated or verified results of the tracked savings. In the Updated Guidelines, the realization rate does not include program attribution.

steam traps – A valve-like device used to discharge liquid condensate from steam distribution piping.

TMY3 – Typical meteorological year weather data.

APPENDIX B: DATA COLLECTION FORM

Please record the following information during the verification site visit. Data collection will involve inspection of incentivized or affected equipment, recording of nameplate data, and conversations with site management.

1.1 Site Characteristics

1.1.1 Building/Complex

Number of buildings in complex: ____________

Estimated year of building construction: ____________

Often there are 2-3 basic building types per housing complex. This inventory is useful in planning building samples.

This table can also be used to organize the facility into various unit types for when we extrapolate the in-unit bills over the whole facility.

Building Type	# Buildings	# Floors	# Units	# Bedrooms	Notes / Approx Sq Ft

Has the building undergone major gut rehabilitation during which building was inhabitable over the *[total billing period]*? ______ (Y/N)

If yes, explain:

____

____

1.1.2 Utility Bills

Gas

Are the tenant units individually metered for gas? ______ (Y/N)

If yes: Do tenants pay for space heating costs? _______ (Y/N)

Do tenants pay for domestic hot water costs? _______ (Y/N)

Are the tenant units individually metered for electric? _______ (Y/N)

If yes: Do tenants pay for individual unit electric costs? _______ (Y/N)

How many central gas meters are present per building? _____________

Does the facility feature a dedicated meter for space heating gas usage? _______ (Y/N)

Does the facility feature a dedicated meter for hot water gas usage? _______ (Y/N)

Item #	Meter #	Common Area	In Unit	DHW	Space Heat	Cooking	Clothes Dryers
1							
2							
3							
4							
5							
6							
7							
8							

Can copies of central gas bills be obtained for [*total billing period*]? _______ (Y/N)

1.1.3 Occupancy

Can you estimate the total number of tenants currently residing at the building? ____________

Can you estimate the building occupancy during the [*pre-installation billing period*]? ________%

Can you estimate the building occupancy during the [*post-installation billing period*]? ________%

Can copies of actual occupancy records over these periods be acquired for this evaluation?

_______ (Y/N)

If the occupancy records and/or management's estimates indicate a variation in occupancy:

Can you provide specific reasons for the decline/increase in occupancy over this period?

____

____

____

1.1.4 Central HVAC Characteristics

Primary heating equipment (boiler, unit heaters, heat pumps, etc.): ____________

Primary heating fuel (natural gas, fuel oil, propane, etc.): ____________

Does the building feature an energy management system that monitors HVAC equipment or temperature setpoints from a central computer? _______ (Y/N)

Is the energy management system capable of trending and storing this information? _______ (Y/N)

Can you provide the contact information for the HVAC contractor that monitors this information?

____

At what time of year (or outside air temperature) is the building's central heating system activated?

__________________ (Month or °F)

At what time of year (or outside air temperature) is the building's central cooling system activated?

__________________ (Month or °F)

At what temperature are the common areas maintained during the winter? ________ (°F)

At what temperature are the common areas maintained during the summer? ________ (°F)

1.1.5 Tenant HVAC Characteristics

At what time of year (or outside air temperature) are tenant heating systems typically activated?

__________________ (Month or °F)

At what time of year (or outside air temperature) are tenant cooling systems typically activated?

__________________ (Month or °F)

At what temperature would you estimate the tenant units are maintained in winter?

________ (°F)

At what temperature would you estimate the tenant units are maintained in summer?

________ (°F)

1.2 Equipment Information

Please record information on the equipment affected by the project measures.

1.2.1 Boilers

Boiler ID	Use (Heating, DHW)	Steam/ HW	Make	Model	Year	Fuel	HP	Input Btu/h	Output Btu/h	Metered Combustion Eff.

Notes:

1.2.2 Programmable Thermostat

Location	Make	Model #	Occupied Cooling Setpoint	Occupied Heating Setpoint	Unoccupied Cooling Setpoint	Unoccupied Heating Setpoint	Age of Previous

Notes:

1.3 Baseline Considerations

For those measures for which we anticipate an unclear baseline (boilers, chillers, motors, fans, etc.), this section serves as a data collection template on preexisting equipment. Please ask the following questions verbatim of the site contact or the individual who has knowledge of the equipment in question.

B1. How old was the preexisting equipment? Provide estimate/range if unknown.

____

B2. Was the preexisting equipment operable at the time of equipment replacement?

____________________ *If yes, proceed to **B3**.*

*If no, proceed to **B8**.*

B3. Were any equipment components replaced in the past 10 years (e.g. boiler burner)?

____

B4. Were any major patches required to keep the equipment operable over the past 10 years?

____

B5. How often was the equipment inspected or recommissioned in the preexisting configuration?

____

B6. Please describe the maintenance procedure for the preexisting equipment.

____

____

____

B7. Please estimate how long the preexisting equipment would have operated had it not been replaced as a result of the project?

____

End.

B8. Please describe the performance issues with the preexisting equipment.

____

____

B9. If the equipment had not been replaced as a result of the project, would you have repaired the preexisting equipment to prolong its life?

____

____

End.

APPENDIX C: MFLI EVALUATION BASELINE FRAMEWORK

To develop an evaluation baseline framework for the Multifamily Low Income Program (MFLI, or the Program) impact evaluation, the evaluators first examined the Program's baseline assumptions by measure, along with several New York Department of Public Service (DPS) documents regarding baseline, early replacement, normal replacement, and the applicability of multifamily equipment. Table C-1 illustrates the Program-assumed baselines for the four measures included in 2009–2011 participating projects.

Table C-1
Program Baseline Assumptions by Measure

Measure Type	Program Baseline
Boiler replacement	Atmospheric boiler operating at efficiency defined by ASHRAE 90.1 2007 code (80%)
Steam traps	Preexisting steam traps – all assumed to have failed
Pipe insulation	Preexisting uninsulated pipe
Air sealing	Preexisting envelope penetrations

The evaluators next examined DPS documentation on multifamily central systems to determine if a code baseline was appropriate for the boiler replacement measure. The New York Technical Manual's (NYTM's) Appendix M[1] outlines a process for determining the appropriate dual baseline weighting for savings calculations over the life of the early replacement measure. However, this evaluation focuses on first-year savings only. A follow-up order to the NYTM, issued October 18, 2010,[2] addresses the "special circumstances" for which an early replacement baseline might be considered even for replacement of multifamily equipment that has exceeded EUL. According to the order (emphasis is the evaluators'),

> *"Special circumstance replacements relate only to commercial and industrial machinery and* ***multifamily central systems****, but not to lighting equipment. . . . Special circumstance replacements would typically address equipment operated by customers which are influenced by initial costs more than by life cycle economics, customers lacking capital, customers with split incentives (such as landlord cost for tenant benefit), customers with short time horizons, and other factors which tend to prevent long range economic decision-making with regard to*

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[1] Appendix M: Guidelines for Early Replacement Conditions, effective January 1, 2011. http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/06f2fee55575bd8a852576e4006f9af7/$FILE/Appendix%20M%20final%205-05-2011.pdf

[2] Case 07-M-0548, Energy Efficiency Portfolio Standard (EEPS), Order Approving Consolidation and Revision of Technical Manuals (issued October 18, 2010). http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B90EF3CB5-16EC-4141-B25F-C19937351402%7D

the installation of high efficiency equipment. . . . The general outline of criteria regarding the equipment in place to be determined onsite will be:

- *Equipment age significantly exceeds its effective-useful-life;*
- *Energy consumption significantly exceeds that of current high efficiency models;*
- *There is a history of significant repair or replacement with used equipment; and*
- *The prospective next repair or replacement is likely to initially be much less expensive than replacement with new higher efficiency machinery.*

Equipment fitting these criteria would be subject to a form of dual baseline TRC screening which will reflect the concept that the equipment, while past its effective-useful-life, would likely operate for several additional years, and will allow energy savings for that period to be calculated against the in-place equipment. Under this approach, first year savings would be reported as the difference between the existing equipment's electric usage and that of the high efficiency equipment which replaces it."

Follow-up orders to the NYTM and Appendix M were released in 2010 and 2011, respectively. Therefore, these documents might not directly apply to the two projects included in this evaluation's population, defined by program years 2009–2011. However, the evaluators referenced these documents' valuable baseline guidance on multifamily central equipment that allowed evaluators to define preexisting equipment as the evaluation baseline when appropriate.

Evaluation engineers asked a series of questions while on-site to determine whether or not the replaced equipment had reached the end of its life. The question battery included the following questions:

B1. How old was the preexisting equipment? Provide estimate/range if unknown.

B2. Was the preexisting equipment operable at the time of equipment replacement?
If no, proceed to ***B8****.*

B3. Were any equipment components replaced in the past 10 years (e.g., boiler burner)?

B4. Were any major patches required to keep the equipment operable over the past 10 years?

B5. How often was the equipment inspected or recommissioned in the preexisting configuration?

B6. Please describe the maintenance procedure for the preexisting equipment.

B7. Please estimate how long the preexisting equipment would have operated had it not been replaced as a result of the project?
End.

B8. Please describe the performance issues with the preexisting equipment.

B9. If the equipment had not been replaced as a result of the project, would you have repaired the preexisting equipment to prolong its life?
End.

After considering responses to the questions, reviewing the application materials,[3] and accounting for the Appendix M special circumstances applicability and overall framework, the engineer judged whether the replaced equipment was replaced early or at the end of its life. For all equipment incented by MFLI during the evaluation time frame, the evaluators determined an early replacement baseline. The evaluation baseline by measure is compared with program assumptions in Table C-2.

Table C-2
Comparison of Program and Evaluation Baselines by Measure

Measure Type	Program Baseline	Evaluation Baseline
Boiler replacement	Atmospheric boiler operating at efficiency defined by ASHRAE 90.1 2007 code (80%)	Preexisting boiler
Steam traps	Preexisting steam traps – all assumed to have failed	Preexisting steam traps – all assumed to have failed
Pipe insulation	Preexisting uninsulated pipe	Preexisting uninsulated pipe
Air sealing	Preexisting envelope penetrations	Preexisting envelope penetrations

3 The MPP application materials contain unusually good data on the age of removed equipment.