Massachusetts Low-Income Multifamily Initiative Impact Evaluation

October 2015

Prepared for

The Electric and Gas Program Administrators of Massachusetts

Part of the Residential Evaluation Program Area

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Acronym Glossary

Acronym	Definition
ABCD	Action for Boston Community Development, Inc.
AC	Air Conditioning
ADC	Average Daily Consumption
AVGCDD	Average Daily Cooling Degree Days
AVGHDD	Average Daily Heating Degree Days
BA	Bathroom Aerator
BCR	Benefit Cost Ratio
Btu	British Thermal Unit
CAC	Central Air Conditioner
CFL	Compact Fluorescent
CLC	Cape Light Compact
DSW	Deemed Savings Workbook
EEAC	Massachusetts Energy Efficiency Advisory Council
EER	Energy Efficiency Ratio
EFLH	Equivalent Full Load Hours
EISA	Energy Independence and Security Act
EMS	Energy Management System
GPM	Gallons per Minute
HAC	Housing Assistance Corporation
HDD	Heating Degree Day
HEATNAC	Heating Normalized Annual Consumption
HOU	Hours of Use
ISR	In Service Rate
KA	Kitchen Aerators
kWh	Kilowatt Hour
LEAN	Low Income Energy Affordability Network
LED	Light Emitting Diode
LIMF	Low Income Multifamily
LRHDD	Annual long-term Heating Degree Days
MOC	Montachusetts Opportunity Council
NAC	Normalized Annual Consumption
NOAA	National Oceanic and Atmospheric Administration
PA	Program Administrator
PRENAC	Pre Period Normalized Annual Consumption
PRISM	Princeton Scorekeeping Method
PY	Program Year
RAC	Room Air Conditioner
TMY	Typical Meteorological Year
TRM	Technical Reference Manual
VFD	Variable Frequency Drive

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Executive Summary

The Massachusetts Low-Income Multifamily (LIMF) Retrofit Initiative provides technical, financial, and project management support to implement electric and natural gas efficiency upgrades at eligible buildings. This report describes the objectives, methods, and results of the first impact evaluation of the LIMF Initiative.

Objectives

Through a series of workshops held in 2014, the LIMF Stakeholders—including Program Administrators (PAs), evaluators, the low-income advocacy agencies, Energy Efficiency Advisory Council consultants, and other initiative contractors—examined initiative activities and determined evaluation objectives. Based on broader objectives of verifying energy impacts, improving transparency and consistency in savings estimation methods, the evaluation team defined five key evaluation tasks:

1. **Engineering analysis and literature review.** Develop a set of statewide savings estimates for non-custom measures to improve transparency and consistency across the state.
2. **Natural gas billing analysis**. Verify the impacts of the natural gas initiative, which is dominated by weatherization, heating, and water heating measures.
3. **Common area lighting analysis.** Verify the impacts of common area lighting measures, which—combined with in-unit lighting measures—dominate the electric initiative.
4. **On-site verification and measure analysis**. Leverage data collection efforts to verify installation and collect data for non-lighting measures.
5. **Assessment of secondary impacts**. Examine secondary energy and water impacts for existing initiative measures.

Methods

Between January 2015 and August 2015, the evaluation team examined tracking and TRM data, collected and analyzed billing data, and performed site visits with lighting time-of-use (TOU) metering to complete the tasks outlined above. Specifically, the team:

1. Developed a Deemed Savings Workbook (DSW) in Microsoft Excel® that presents proposed statewide savings estimate for non-custom measures, including comprehensive information about algorithms, assumptions, and sources with live calculations.
2. Performed a billing analysis to estimate the impacts of program year (PY) 2012 and PY 2013 natural gas projects.
3. Conducted on-site verification and TOU metering for a sample of 56 electric projects from PY 2014 to estimate a realization rate for common area lighting measures.
4. Collected and analyzed information about energy-efficient showerheads, aerators, and building cooling and heating equipment at the projects in the common area lighting analysis sample.

5. Reviewed tracking and secondary data to update water savings values and estimate interactive impacts of weatherization measures on cooling energy.

The evaluation team completed analysis for all tasks and presented results to the LIMF Stakeholder group on August 24, 2015.

Results

This impact evaluation provides the following results for the LIMF electric and natural gas initiatives:

1. The DSW provides a table of statewide deemed savings values for non-custom measures to improve transparency, consistency, and accuracy across the PA initiatives. The workbook is a Microsoft Excel® workbook and outlines all calculations, assumptions, and sources used to quantify the deemed savings values. Appendix A (Summary of Deemed Savings Values) shows the summary tables for electric and natural gas measures.

2. Through billing analysis of 217 facilities, the team estimated an average savings of 126 therms per unit or 21% of pre-retrofit natural gas consumption (Table 1).

Table 1. LIMF Gross Natural Gas Participant Savings by PA and Overall

PA	Facilities (n)	Units (n)	PRENAC*	Model Savings (therm/unit)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
Berkshire	6	137	685	137	20%	±41%
Columbia	25	1,487	561	107	19%	±25%
Eversource	47	2,407	706	143	20%	±17%
National Grid	139	4,584	581	124	21%	±10%
Eversource + Columbia**	72	3,894	651	129	20%	±15%
Overall* **	**217**	**8,615**	**607**	**126**	**21%**	**±9%**

* Pre-period weather-normalized annual consumption (PRENAC)

** Given common approaches to delivery and estimating *ex ante* savings, the team combined Columbia and Eversource samples to increase sample size and provide modeled savings estimates with improved precision for calculating realization rates.

*** Overall state-level results are population-weighted, based on PA-specific participant unit counts

Compared to the initiative *ex ante* estimates, the billing analysis results represent an average statewide realization rate of 80%, indicating that the initiative is achieving 80% of the reported natural gas savings (Table 2).

Table 2. LIMF Gross Realization Rate Summary by PA and Overall

PA*	Model Savings (therm)	Reported *Ex Ante* Savings (therm)	Realization Rate	*Ex Ante* Savings as % of Pre-Usage
Berkshire	137	241	57%	35%
Columbia	107	131	82%	23%
Eversource	143	136	105%	19%
National Grid	124	166	75%	29%
Eversource + Columbia**	129	134	96%	21%
Overall* **	**126**	**158**	**80%**	**26%**

* Due to few participants and lack of available consumption data, this analysis excluded Liberty and Unitil.

** Given common approaches to delivery and estimating *ex ante* savings, the team combined Columbia and Eversource samples to increase sample size and provide modeled savings estimates with improved precision for calculating realization rates.

*** Overall state-level results are population-weighted, based on PA-specific participant unit counts

The majority of projects that received natural gas efficiency measures to reduce heating consumption also received efficient lighting measures. The lighting upgrade increases heating loads because the more efficient lighting contributes less waste heat into occupied spaces. Gas billing analysis, by its nature, does not separate out these two effects and thus underestimates the savings achieved by the gas saving measures. Separating out the lighting interactive effects on the heating load should increase the realization rate to somewhere between 83% and 89%.

3. The team estimated a statewide realization rate of 97% for common area lighting measures, verifying that auditors are accurately estimating annual energy savings. Table 3 lists the statewide realization rate and relative precision at a 90% confidence level.

Table 3. Common Area Lighting Realization Rates

PA	Realization Rate	Relative Precision at 90% Confidence
National Grid	101%	±8%
Eversource	96%	±2%
Statewide	**97%**	**±3%**

4. Through inspection of showerheads and faucets within 20 apartment units, the team confirmed that all showerheads were below the 2.5-gallon-per-minute maximum threshold and most faucet aerators were below the 1.5-gallon-per-minute threshold.
5. Through documentation of the cooling type at all 56 projects in the common area lighting sample, the team estimated that 89% of facilities use window air-conditioning as the primary cooling equipment.

6. Finally, through literature review and examination of the primary data collected in this study, the evaluation team estimated the deemed values in Table 4.

Table 4. Assessment of Secondary Impacts

Savings Parameter	Annual Value
Faucet Aerator Water Savings – Bathroom*	416 gallons
Faucet Aerator Water Savings – Kitchen*	1,133 gallons
Faucet Aerator Water Savings – Average*	708 gallons
Showerhead Water Savings	1,759 gallons
Clothes Washer Water Savings	6,948 gallons
Cooling Savings (Weatherization)	22 kWh

* The average aerator value is a weighted average based on expected allocation of installed aerators between kitchens and bathrooms. PAs should use the average value for faucet aerators only if they do not track location of the installation aerator equipment.

Study Considerations

Based on the research findings, the team has identified several study considerations to improve LIMF Initiative performance and operations.

Improve Initiative Tracking

The following improvements to the LIMF Initiative tracking systems and data will increase statewide consistency and reporting, facilitate future evaluations, and provide valuable data for future TRM updates and implementation strategies:

- Standardize measure descriptions and measure categories across all PA datasets. For deemed measures, adopt the proposed naming convention outlined in Appendix A (Summary of Deemed Savings Values).
- Define a project unit (such as apartment unit vs. common area, building, or facility) and provide unique identifiers that easily allow for associated measure installations and other project details across these various levels.
- Include additional fields using standardized conventions across all PA datasets such as building type (e.g., row house, high rise), presence of common areas, and meter configuration (e.g., master meter plus in-unit meters, master meter only).
- For lighting measures, track the space type for each installed lighting measure using a table of standard space type options.
- For lighting measures, improve documentation of replaced (i.e., baseline) equipment by requiring auditors to photograph at least one example of baseline and installed fixtures.
- For bi-level lighting installations, track the high and low fixture wattage and estimated HOU at the high and low wattage setting for each installed measure.

Review *Ex Ante* Savings Assumptions for Natural Gas Measures

While realization rates overall and by PA are reasonable, some issues remain with *ex ante* savings. The estimated actual savings are consistent, reasonable, and accurate (high levels of precision in most cases). The PAs achieved between a 19% and 21% reduction in usage. Yet, their *ex ante* values ranged from 18% to 35%. Realization rates less than 100% may be driven by persistence or quality of measure installations, or through overestimation of installed savings. One factor that may have a larger impact on planning estimates for multifamily initiatives is how savings account for vacancies and changes in occupancy. Another important factor to consider for initiatives that similarly deliver holistic services is measure interactive effects—including the impact of efficient lighting on achieving gas savings attributed to reduced heating load. In most cases, initiatives that rely on deemed values tend to have lower realization rates, while those that take into account conditions and consumption levels at each site tend to have higher realization rates. The team recommends a review of *ex ante* savings assumptions to understand and account for how issues like vacancies and measure interactions (e.g., lighting) are addressed.

Application of Realization Rates for Prospective Program Planning

Ideally, this analysis would have produced reliable PA-specific realization rates that reflect the uniqueness of the customers and delivery mechanism. Unfortunately, as mentioned above, that was not possible for smaller PAs. As a result, the team suggests prospectively using realization rates as follows:

- Eversource use their own realization rate of 105%
- National Grid should apply their own realization rate of 75%. National Grid was the only PA that used deemed values instead of simulation modeling.
- Other PAs using the same delivery agency and approach to estimating ex ante savings (i.e., Columbia, Liberty, Unitil) should use a realization rate based on combined analysis sample of Columbia and Eversource at 96%.
- Berkshire should use the statewide realization rate of 80%.

This recommendation should be contingent upon implementation agencies, forward looking, providing documentation to help clarify some of the differences in average *ex ante* savings across PA analysis samples, as mentioned above. The provision of full documentation of *ex ante* calculations will be important to ensure steps are taken to review and refine this process, acknowledging improvements to justify application of these prospective realization rates. Furthermore, we suggest additional safeguards included in the process for verifying and reporting claimed savings estimates, including checks against pre-consumption per project, with explanation provided in cases where expected percent savings occurs over a specified threshold (e.g., 30%).

Examine Factors Driving High and Low Savings

The Princeton Scorekeeping Method (PRISM) analysis provides facility-specific changes in usage, allowing identification of a sample of projects that demonstrated extremes in high and low initiative savings. As a next step, the team recommends performing an on-site assessment for a sample of projects identified through this analysis to provide a deeper understanding of factors driving high and low savings. For example, the study might assess projects with similar building sizes and measure mixes, but with realization rates on opposite ends in order to investigate which key factors may have contributed to such differences in savings.

Collect Data to Assess Appropriate Baseline for Heating System Upgrade Measures

A May 2014 memorandum documented key differences in the baseline assumptions used by PAs to estimate *ex ante* savings for gas heating system upgrades.[1] While collection of key data elements to inform baseline is an important first step, there is concurrent research planned in Massachusetts to consider an approach to baseline assessment that will be aimed at broader statewide applicability. Based on nuances surrounding how conditions for early replacement are characterized and verified, there may be future guidance that refines data requirements and/or methodology for defining the appropriate savings baseline. In particular, low income-specific conditions need to be explicitly considered in the data collection effort (e.g., boilers).

1 Memorandum: Baseline Assumptions for Heating Replacements in the Low Income Multifamily Program. May 2014.

Introduction

This report, developed for the Massachusetts Low-Income Multifamily (LIMF) Retrofit Initiative stakeholders, describes the objectives, methods, and results from the first impact evaluation of the LIMF Retrofit Initiative. The team combined engineering analysis and tracking data review, billing analysis, direct measurement, and on-site verification to achieve the objectives agreed upon by the LIMF stakeholders.

Overview

The LIMF Initiative provides technical, financial, and project management support to implement natural gas and electric efficiency upgrades at eligible residential multifamily buildings. Eligible properties contain five or more units of which at least 50% of the occupants earn 60% or less of the area median income.

Through the LIMF implementation contractors, who oversee most of the initiative processes, the Program Administrators (PAs) provide full funding (i.e., 100% of the equipment and installation costs) to identify and implement cost-effective electric and natural gas efficiency measures. As shown in Table 5, six of the Massachusetts PAs offer the initiative to reduce natural gas consumption, and four PAs offer measures to reduce electricity consumption.

Table 5. Program Administrators: Natural Gas and Electric Support

Program Administrator	Natural Gas	Electric
Berkshire Gas (Berkshire)	✓	
Cape Light Compact (CLC)		✓
Columbia Gas of Massachusetts (Columbia Gas)	✓	
Liberty Utilities (Liberty)	✓	
National Grid	✓	✓
Eversource Energy (Eversource; formerly Northeast Utilities)	✓	✓
Unitil	✓	✓

Each PA uses an implementation contractor, or lead agency that is part of the Massachusetts Low-income Energy Affordability Network (LEAN), to administer most aspects of the initiative. The lead agencies perform or oversee site inspections and energy audits, measure screening, measure implementation, and final inspections. One lead agency, Action for Boston Community Development, Inc. (ABCD), manages the statewide intake process including the leanmultifamily.org website for recruiting participants and performing the initial screening for basic site qualification.

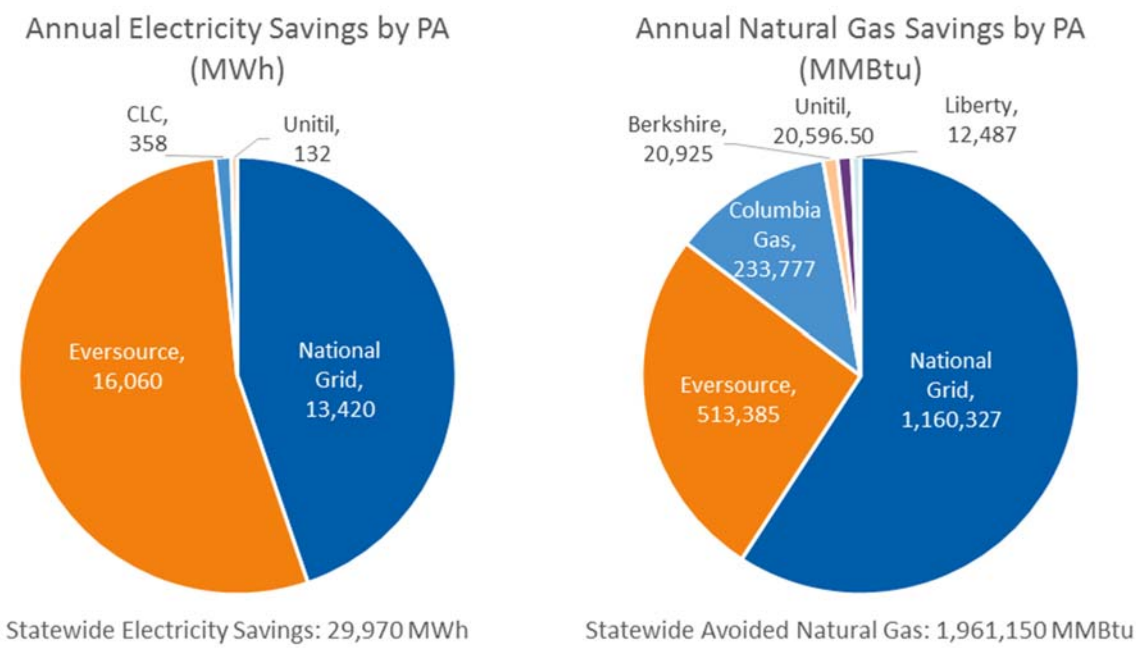
ABCD manages the implementation of measures for Columbia Gas and Eversource. Additional lead agencies support the efforts of the other PAs, who may recruit participants or obtain them from through ABCD. The lead agencies include Action, Inc., (Action) for National Grid; the Housing Assistance Corporation (HAC) for CLC; Community Action Inc. (CAI) for Berkshire Gas; Citizens for Citizens, Inc., for

Liberty Gas; and the Montachusett Opportunity Council (MOC) for Unitil. Third-party vendors participate in a regular and competitive bidding process to earn contracts for installing the approved measures.

For each installed measure, the PAs claim energy and demand savings based on a deemed number, standard algorithm, or custom calculation (including simulation modeling). A deemed number is a single predetermined savings value based on assumptions supported by previous evaluations or engineering analysis. A standard algorithm is a calculation that involves fixed assumptions with one or more project-specific input. Custom calculations are typically performed using computer simulations based on site-specific information and engineering assumptions.

The evaluation team analyzed reported savings data for the Program Year 2014 LIMF Initiative to assess savings by PA. Figure 1 shows the annual electric and gas energy savings claimed by each PA for program year (PY) 2014.

Figure 1. Annual LIMF Electric and Gas Energy Savings by PA (PY 2014)*



*Source: Mass Save. *Performance Details: 2014 Summary Report.* Available online: http://masssavedata.com/Public/PerformanceDetails.aspx .

National Grid and Eversource contributed the majority of the statewide gas and electric energy savings, respectively.

Evaluation Objectives

To determine the study objectives, the residential evaluation team (evaluation team or team) engaged LIMF Initiative stakeholders from the PAs, LEAN, lead agencies, EEAC, and implementation contractors.

The team held multiple workshops to discuss evaluation needs and determine areas of focus for this evaluation.

The first stakeholder workshop, held on July 17, 2014, was principally for fact-finding purposes. It yielded essential information about the operation of the initiative as a whole and enabled the team to identify key areas of interest. Following the meeting, the team held interviews with representatives from the two largest lead agencies—ABCD and Action—and with each PA to discuss their specific evaluation goals, understand their methods for data tacking and savings estimation, and to learn how they operate within the statewide initiative.

The evaluation team also reviewed tracking data obtained directly from the PAs including benefit/cost ratio (BCR) model worksheets and detailed per-site, per-measure tracking data. The team compared the per-measure data to various editions of the Massachusetts Technical Reference Manual (TRM) and to the savings values reported for the PY 2013 LIMF Initiative.

The team compiled its findings from the stakeholder interviews and tracking data review into a technical review memo and presented the results in the second stakeholder workshop held on October 23, 2014. In the memo, the evaluation team proposed research activities that address the stakeholders' evaluation goals. The memo focused on measures that represented the most savings and that had the greatest uncertainty in savings estimation.

During the final stakeholder workshop, held on December 1, 2014, the stakeholders and evaluation team agreed upon a defined set of research objectives. Table 6 shows the final list of evaluation objectives and the approach to achieve each objective.

Table 6. LIMF Impact Evaluation Research Objectives

Research Objective	Approach
1. Verify energy impacts achieved by the LIMF Initiative*	Ensure savings methods and assumption are clearly documented
2. Improve Transparency of Savings Estimation Methods	Ensure savings methods and assumption are clearly documented
3. Improve Consistency in Savings Estimation, Tracking, and Reporting	Provide recommendations to improve consistency in estimated savings values, data tracking methods, and reported savings.
4. Highlight Initiative Achievements	Document verified energy and cost savings for LIMF customers
	Estimate non-energy benefits

* The impact evaluation focused on energy impacts only; it did not include demand impacts.

Following the final stakeholder workshop, the evaluation team developed a detailed evaluation plan based on the objectives in the table above and specific evaluation tasks outlined to achieve each objective.

Report Organization

This report is organized into the five research tasks determined through stakeholder meetings:

1. **Engineering analysis and literature review.** For measures not requiring primary data collection, the evaluation team used existing literature and engineering analysis to determine the best method for estimating savings. This effort included these activities:
   - Defining a common set of naming conventions to standardize the granularity of data and to improve transparency;
   - Recommending the best approach to estimate savings; and
   - When applicable, selecting the most appropriate deemed values to maximize consistency.
2. **Billing analysis**. The team estimated savings using a combination of regression models. The team used the participants' billing and tracking data to model monthly facility-level gas consumption.
3. **Metering study**. The team metered lighting hours of use (HOU) for a variety of common area space types to determine realization rates relative to *ex ante* energy savings.
4. **On-site verification and measure analysis**. The team conducted on-site visits to verify installed equipment and operating parameters.
5. **Assessment of secondary savings**. The team explored project benefits beyond primary fuel conservation. Specifically, the team reviewed the estimation of water savings and the impact of weatherization measures on cooling season energy consumption.

Task 1. Engineering Analysis and Literature Review

Through the initial technical review process, the evaluation team analyzed savings data for the PY 2013 LIMF Initiative.[2] This activity highlighted three opportunities for increased transparency and consistency:

- **Measure naming convention**. In many cases, PAs used different names and level of detail to track measures, making it difficult to make measure-level comparisons across PA initiatives. For example, some PAs separate common area lighting from in-unit lighting, while others combine them into a single category.
- **Savings calculation methods**. In some cases, PAs use different methods to estimate savings. For example, one PA may use a deemed value while another uses a calculation.[3]
- **Deemed values and assumptions**. PAs may use different deemed values to estimate savings for the same measure. These values may or may not be applicable to the LIMF Initiative.

To improve transparency and consistency in tracking, estimating, and reporting *ex ante* savings estimates for non-custom[4] measures, the evaluation team developed the LIMF Deemed Savings Workbook (DSW). The DSW presents a set of statewide deemed savings values and provides comprehensive documentation of the methods and assumptions used to estimate those values.

The team also reviewed inconsistent baseline assumptions used by PAs to estimate savings from heating system upgrades and recommended data collection to support a dual baseline approach in the future. This discussion is summarized at the end of this chapter and documented in a May 2014 memorandum.[5]

Methods

The PAs provided a new statewide measure list (developed by the PA common assumptions working group) noting that all PAs would use the same list of measure names for future LIMF activities. This statewide measure list solved the inconsistency in measure naming conventions.

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2 Cadmus. *MA LIMF Technical Review Summary of Findings Memo*. Prepared for the Electric and Gas Program Administrators of Massachusetts. 2014.

3 Certain PAs use deemed values to estimate savings from every measure. The evaluation team does not propose that they change their approach, but it has identified opportunities for greater standardization among the PAs that do use the algorithm approach to estimate savings.

4 Non-custom measures use standard algorithms and assumptions to estimate savings. Savings estimates may be deemed (e.g., a single savings value per measure) or deemed-calculated (e.g., a deemed algorithm with one or more project-specific inputs).

5 Memorandum: Baseline Assumptions for Heating Replacements in the Low Income Multifamily Program. May 2014.

To address differences in savings estimation methods and values, the team:

- Reviewed the Massachusetts TRM and PA tracking data and conducted stakeholder interviews to document existing savings estimation methods and values used by each PA for each measure.
- Examined all source material cited in the TRM to assess the validity of each assumption.
    - In most cases, the data were not specific to LIMF buildings. Values were often based on studies focused on either low-income single-family or standard-income multifamily buildings.
- Compared calculation methods and assumptions across measures to identify opportunities to improve consistency among savings assumptions for the overall initiative.
- Selected appropriate savings estimation methods and assumptions for each measure taking into account recent evaluation results, existing consistency among PA estimates, consistency across measures, and relative importance of the measure to overall initiative savings. Many of the assumptions came from the sources cited in the TRM, but the team also considered additional data sources, such as initiative tracking data and ENERGY STAR® calculators.
- Developed comprehensive documentation—the LIMF DSW—of the proposed approach and assumptions for each measure including live calculations in a Microsoft Excel® workbook. The workbook demonstrates how the team calculated the deemed savings values and documents the sources of all assumptions and inputs. For measures using a standard algorithm approach, the workbook allows users to input certain variables based on project-specific information.

Results

The LIMF DSW describes the proposed deemed savings value—including backup algorithms, input assumptions, and sources—for measures that use the deemed or standard algorithm savings approach. PAs may reference this workbook to examine the estimation methods or to collect information to update the statewide TRM. The DSW includes the following sections:

- The summary tab presents the recommended deemed savings value for each measure and compares that value to the existing TRM and PA values used in 2013.
- The measure tabs—named for the measure represented on the tab—indicates the algorithm type (deemed or deemed calculated), presents the proposed deemed savings value, and describes the savings estimation algorithm with sources for all input parameters.
- The revisions tab describes the reasons why the values estimated in the DSW vary from previous TRM or PA tracking estimates.
- The weather tab describes the TMY weather data used in the calculation of air sealing and insulation savings.

The team recommends the Massachusetts PAs adopt these statewide savings values or methods for non-custom measures, with the following exceptions:

- If a PA has the capacity to track data that enables a more accurate savings estimate–for example, tracking pre- and post-installation bulb wattages for LED or CFL replacements–the team recommends that PA continue to use those additional data in their savings calculation. The values proposed in this sections should be used whenever deemed values are necessary or likely to yield better accuracy and consistency.
- If a PA is unable to use the deemed-calculated approach when recommended (e.g., measures such as air sealing and insulation), then it should use the default value calculated using the default assumptions outlined in the deemed savings workbook.

The LIMF DSW does not include values for the following measure categories:

- Natural Gas Measures
  - Heating and water heating equipment
  - Weatherization
- Electric Measures
  - Common Area Lighting

The evaluated savings results and recommendations for these measures are presented with the results for Task 2. Natural Gas Billing Analysis and Task 3. Common Area Lighting.

Electric Measures

Table 7 presents the proposed statewide deemed savings values for non-custom electric measures. The table lists values for annual electricity, annual natural gas, and annual water savings. The last column indicates whether the proposed value represents a significant change from the PY 2013 savings values, and if so, provides a number corresponding to a paragraph below the table that explains the change.

Table 7. Deemed Savings—Electric Measures

#	End-Use	Measure	Type	Annual Savings Value			TRM kWh	Notes **
				kWh*	therms	water		
1	Lighting	Torchiere (2016)***	Deemed	**55.1**	n/a	n/a	211	[1]
2	Lighting	CFL Bulb (2016)***	Deemed	**40.8**	n/a	n/a	47.9	[1]
3	Lighting	LED Bulb (2016)***	Deemed	**55.1**	n/a	n/a	51.5	[1]
4	Lighting	Common Area Fixture (Exterior)	Deemed	**571**	n/a	n/a	100.5	[2]
5	Lighting	Common Area Fixture (Interior)	Deemed	**280**	n/a	n/a	140	[2]
6	Appliances	Window AC Replacement	Deemed	**113**	n/a	n/a	204	[3]
7	Appliances	Refrigerator	Deemed	**330**	n/a	n/a	645	[4]
8	Appliances	2nd Refrigerator Removal	Deemed	**874**	n/a	n/a	1,180	[4]
9	Appliances	Freezer Replacement	Deemed	**158**	n/a	n/a	239	[4]
10	Appliances	Clothes Washer	Deemed	**318**	**13**	**6,948**	1,218	[5]
11	Appliances	Smart Strip	Deemed	**79**	n/a	n/a	79	****
12	Appliances	Waterbed	Deemed	**872**	n/a	n/a	872	****
13	Wx	Air Sealing, Electric	User Input	397	n/a	n/a	n/a	[6]
14	Wx	Insulation, Electric	User Input	1,377	n/a	n/a	n/a	[6]
15	HVAC	Heating System Retrofit–Furnace (Gas)	Deemed	**172**	n/a	n/a	172	****
16	HVAC	Heating System Retrofit–Furnace (Oil)	Deemed	**132**	n/a	n/a	132	****
17	HVAC	Thermostat, Electric	Deemed	**257**	n/a	n/a	257	****
18	HVAC	Demand Circulator, Electric	User Input	560	n/a	n/a	n/a	[7]
19	HVAC	Pipe Wrap, Electric	Deemed	**129**	n/a	n/a	129	****
20	DHW	Heat Pump Water Heaters (50 Gallon)	Deemed	**1,687**	n/a	n/a	1,775	[8]
21	DHW	DHW Tank Wrap, Electric	Deemed	**73**	n/a	n/a	73	[9]
22	DHW	Showerhead, Electric	Deemed	**217**	n/a	**1,759**	129	[10]
23	DHW	Faucet Aerator, Electric–Average*****	Deemed	**62**	n/a	**708**	97	[10]
24	DHW	Faucet Aerator, Electric–Kitchen	Deemed	**106**	n/a	**1,133**	97	[10]
25	DHW	Faucet Aerator Electric–Bathroom	Deemed	**31**	n/a	**416**	97	[10]
26	Misc	TLC Kit (Eversource 0941)	Deemed	**69**	n/a	n/a	18	[11]
27	Misc	TLC Kit (Eversource 0971)	Deemed	**69**	n/a	n/a	18	[11]
28	Misc	TLC Kit (CLC)	Deemed	**152**	n/a	**836**	126	[11]

* Values in grey text are the default deemed assumptions for measures that use a deemed calculated approach.
** Numbers correspond to the descriptions following the table.
*** Indicates that deemed savings value is dependent on the selected program year.
**** Proposed deemed savings values are the same or similar to the values used in 2013.
***** PAs should use the average value for faucet aerators unless they track kitchen and bathroom installations separately.

Deemed Savings Values by Measure

The following sections describe the key assumptions for measures with proposed changes to the deemed savings. Each section is labeled with the note number corresponding to the last column in Table 7. Unless otherwise stated, references to the TRM imply the Massachusetts statewide TRM.

[1] CFL/LED Bulbs and Torchieres

The proposed deemed savings values for CFLs, LEDs, and torchieres are different from the PY 2013 estimates due to changes in baseline lighting and new evaluation results. The Energy Independence and Security Act of 2007 (EISA) mandated that all general service lamps should be more efficient than the existing technologies of 2007. To allow manufacturers time to adapt, EISA shifted the permissible wattage in stages between 2012 and 2014. This caused the baseline wattage of installed lighting to decrease gradually, reducing the potential for energy savings.

The results in this evaluation are based on the recorded pre- and post-installation wattages of CFL and LED bulbs installed as part of the LIMF Initiative by National Grid in PY 2013 and a shifting pre-installation wattage based on NMR's market adoption model.[6]

[2] Common Area Fixtures

The deemed value for interior and exterior common area fixtures are based on PY 2014 PA tracking data and the RR calculated in Task 3 (Common Area Lighting) of this evaluation. See Table 22 on page 45 of this report for more details.

The previous common area fixture values are specific to the replacement of a screw-based incandescent bulb with a pin-based CFL. LIMF common areas often use brighter, higher power lighting that yield greater savings when replaced than screw-based incandescent bulbs. Additionally, the previous exterior fixture value assumes the light is only on for 2.9 hours per day, while most LIMF exterior lighting operates an average of 12 hours per day.

[3] Window AC Replacement

The proposed deemed savings value is based on an update to the equivalent full load hours (EFLH) parameter in the deemed savings calculation. The previous EFLH value was 360 hours per year, but represented central air conditioning equipment across the Northeast. The new EFLH value is the average EFLH result for room air conditioners in Massachusetts, as reported in Table i-2 of the 2008 Coincidence Factor Study by RLW Analytics.[7]

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6 NMR Group, forthcoming 2016-2018 Market Adoption Model. Values provided by NMR to Cadmus on 9/16/2015 in the following file: *MA-Task 3c Lighting Market Assessment 2016-2018 Market Adoption Model_REVISED_8 28 15 V2.xlsx.* The DSW includes all of the assumptions used to estimate savings.

7 RLW Analytics. *Coincidence Factor Study: Residential Room Air Conditioners*. Prepared for Northeast Energy Efficiency Partnerships' New England Evaluation and State Program Working Group. 2008.

[4] Refrigerators and Freezers

The proposed deemed savings values for the refrigerator replacement and freezer replacement measures are based on a dual baseline approach. The approach assumes that the existing equipment has an average remaining useful life of six years, after which multifamily customers would replace the existing equipment with an even mix of new (code-compliant) and used units. The assumed average energy consumption of pre- and post-installation is based on National Grid tracking data from PY 2013.

[5] Clothes Washer

The proposed deemed savings value reflects the 2012 updates to both Federal and ENERGY STAR® minimum efficiency requirements for clothes washers. The previous values were based on minimum efficiency requirements that expired in 2015.

The proposed value includes both electric and natural gas impacts and is a blended average of savings expected from systems that use electricity or natural gas as the water heating fuel. The average is weighted based on the distribution of water heating fuel in Massachusetts' residential sector.[8]

[6] Air Sealing and Insulation

Eversource estimates savings for weatherization measures with custom building simulation models, which is a robust approach for estimating shell measure savings and cited as best practice.[9] Where building simulation methods are not used, the evaluation team recommends a standard algorithm approach that uses project-specific estimates of insulation type/thickness, square footage, location, and efficiency of heating equipment to estimate savings for air-sealing and insulation measures. The proposed algorithms and inputs match those described in the 2014 TRM.

The workbook provides deemed values—338 kWh for air-sealing and 1,377 kWh for insulation—based on default parameters applied to the proposed engineering algorithm. PAs that cannot use the algorithm approach can use these default deemed values.

[7] Demand Circulators

The current MA TRM does not include a savings value for demand circulator upgrades. Some PAs used 5,320 kWh as the annual savings value for planning purposes only. This value represented the estimated savings from a single site at which ten demand circulators were installed in 2012.

The team suggests adopting a calculation to estimate savings using site-specific information. The DSW outlines an algorithm based on the rated horsepower and efficiencies of the baseline and installed

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8 Opinion Dynamics Corporation. *Massachusetts Residential Appliance Saturation Survey (RASS) Volume 1: Summary of Results and Final Analysis*. 2009. Available online: http://ma-eeac.org/wordpress/wp-content/uploads/11_MA-Residential-Appliance-Saturation-Survey_Vol_1.pdf

9 Internal Performance Measurement & Verification (IPMVP) Committee. *Concepts and Options for Determining Energy and Water Savings: Volume 1*. IPMVP Option C. 2002. Available online: http://www.nrel.gov/docs/fy02osti/31505.pdf

equipment. It only includes savings due to improved pump efficiency because the extent to which partial load operation impacts savings is unconfirmed. Thus, the estimate in this report is conservative. The team used engineering assumptions to calculate the default deemed savings value.

[8] Heat Pump Water Heaters

The proposed deemed savings values for 50-gallon HPWHs are based on the results of a 2012 metering study of HPWH units by Steven Winter Associates, Inc.[10] The study compared the measured energy consumption of baseline electric resistance and new HPWH units operating in single-family residential homes in Massachusetts and Rhode Island.

[9] DHW Tank Wrap

The proposed deemed savings value for DHW tank wrap matched the value described in the 2014 TRM. In the technical review memo, the evaluation team found that some PAs were not using this deemed savings value.[11]

[10] Showerheads and Aerators

The proposed deemed savings value is based on an engineering calculation and the following input assumptions: estimates of flow rate reduction, typical annual hot water consumption, water temperatures, and water heating efficiency. These calculated estimates are similar to recent evaluation results and TRM assumptions from other regions. The average savings value assumes that the ratio of installed kitchen aerators to bathroom aerators is 1.03 to 1.50, based on the 2012 Home Energy Services Impact Evaluation.[12]

The previous savings values were based on rule-of-thumb estimates and key assumptions showerheads with electric water heating did not align with the assumptions for showerheads with natural gas water heating. The proposed values use the same algorithm and assumptions to estimate energy and water savings for both electricity and natural gas water heating systems, so all proposed savings values are consistent.

[11] TLC Kit

This measure represents a bundle of direct-installation measures including aerators, LED night lights, and hot water thermometers. Since PAs may include different combinations of measures in their TLC Kits, the evaluation estimated deemed savings values for each unique kit.[13] Table 8 shows the measures that makeup of each TLC kit currently offered in the LIMF Initiative and their respective savings.

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10 Steven Winter Associates, Inc. *Heat Pump Water Heaters Evaluation of Field Installed Performance*. Sponsored by National Grid and NSTAR. 2012

11 Cadmus, *MA LIMF Technical*, 2014

12 Cadmus. *Home Energy Services Impact Evaluation*. Prepared for Massachusetts Program Administrators. 2012.

13 Only Eversource and CLC provided TLC Kits at the time this study was completed.

Table 8. TLC Kit Measures Currently Offered in the LIMF Initiative

Measure	Annual Per Unit kWh Savings[14]	Installation/ Adoption Rate[14]	Eversource Kit #1* (0941)		Eversource Kit # 2* (0971)		CLC	
			Qty	Annual kWh Savings	Qty	Annual kWh Savings	Qty	Annual kWh Savings
Faucet Aerator	62**	0.61	0	0	0	0	2	75
LED Night Light	19	0.56	2	21	2	21	1	11
Drip Gauge	0	n/a	0	0	0	0	1	0
Hot Water Thermometer	67	0.27	0	0	0	0	1	18
Refrigerator/Freezer Thermometer	0	n/a	1	0	1	0	0	0
Refrigerator Coil Brush	0	n/a	1	0	0	0	0	0
Wall Plate Stopper***	8	0.50	12	48	12	48	12	48
Annual Energy Savings				**69**		**69**		**152**

* The only difference between Eversource Kit #1 and Kit #2 is that Kit #1 contains a refrigerator coil brush, and Kit #2 does not.
** DSW savings value for *Faucet Aerator, Electric-Average,* see note [8]
*** Also referred to as outlet or switch gasket.

Natural Gas Measures

Table 9 presents the proposed statewide deemed savings estimates for non-custom natural gas measures. The table provides deemed savings estimates for annual electricity, annual natural gas, and annual water savings. The last column indicates whether the proposed value represents a change from the savings values used by the PAs in PY 2013.

Table 9. Deemed Savings – Natural Gas Measures

#	End-Use	Measure	Type	Annual Savings Value			TRM therms	Notes
				kWh	therms	water		
1	HVAC	Thermostat, Gas	Deemed	**25**	**22.6**	n/a	23	*
2	HVAC	Pipe Wrap, Gas	Deemed	n/a	**11.4**	n/a	11.4	*
3	DHW	Showerhead, Gas	Deemed	n/a	**10.7**	**1,759**	11.4	[11]
4	DHW	Faucet Aerator, Gas–Average**	Deemed	n/a	**3.0**	**708**	8.6	[11]
5	DHW	Faucet Aerator, Gas–Kitchen	Deemed	n/a	**5.2**	**1,133**	8.6	[11]
6	DHW	Faucet Aerator, Gas–Bathroom	Deemed	n/a	**1.6**	**416**	8.6	[11]

* Proposed deemed savings values are the same or similar to the values used in PY 2013.
** PAs should use the average value for faucet aerators unless they track kitchen and bathroom installations separately.

[14] Cadmus. *Low Income Single Family Program Impact Evaluation*. Prepared for the Electric and Gas Program Administrators of Massachusetts. 2012.

[11] Showerheads and Aerators

The evaluation team updated the deemed savings values using similar methods and parameter assumptions as the showerheads and aerators offered through the electricity initiative—see note [9].

Heating System Replacement Baseline

In spring 2014, the evaluation team discussed a discrepancy between National Grid and the other PAs regarding the baseline assumptions used to estimate *ex ante* savings from heating system upgrades. National Grid treats this measure as a time-of-replacement, using standard practice for new equipment as the baseline for the full life of the measure. The other PAs treat the replacement as a retrofit measure, using the existing conditions as the baseline for the full life of the measure. This discrepancy results in inconsistent savings assumptions and eligibility for comparable heating system measures across the state.

The evaluation team presented the merits and drawbacks of the two baseline assumptions and researched methods used for similar measures in other programs and states. Details of this discussion, findings, and recommendations are available in the May 2014 memorandum titled "Baseline Assumptions for Heating Replacements in the Low Income Multifamily Program".

Task 2. Natural Gas Billing Analysis

The majority of *ex ante* savings in the LIMF Retrofit natural gas initiative come from weatherization, heating system, and water heating system equipment upgrades. The team performed a billing analysis to verify the actual impacts of measures on participants' natural gas consumption and to estimate a realization rate for initiative *ex ante* estimates.

Methods

To estimate actual changes in energy consumption within participating projects, the evaluation team used several modeling approaches, including Princeton Scorekeeping Method (PRISM) and fixed-effects regression models to perform a statistical billing analysis.[15] Using historical billing data from up to a year before and after participation, the team estimated initiative-level natural gas savings associated with measure installations. These models incorporated weather data to normalize consumption and control for weather effects. The analysis also attempted to include a comparison group, selected from participants occurring in 2014, to control for impacts of non-programmatic factors (e.g., change in economic conditions). Unfortunately, for reasons described below, this portion of the billing analysis was not successful.

For the model specifications, see Appendix B (Billing Analysis Model Specification).

Data Sources

The team used the following data sources to perform the billing analysis:

1. **Program tracking data** provided by each of the Massachusetts PAs, for all gas participants from January 2012 to December 2014. These data included participant names, contact information (e.g., address), unique customer identifiers (e.g., utility account numbers), participation dates, and total participant *ex ante* savings estimates. The PAs also provided detailed measure data, which included measure name or description, *ex ante* per-unit measure savings, and in some cases measure-specific details such as quantities and efficiency levels.
2. **Billing data** provided by the PAs, for all gas participants. These data included meter-read dates and all therms consumption, by participant account, between January 2011 and December 2014.
3. **Massachusetts weather data**, including daily average temperatures from January 2010 through December 2014 for 12 weather stations, corresponding to the nearest monitoring station locations associated with LIMF participants. The team used zip codes to match daily heating degree days (HDDs) to respective monthly billing data read dates and obtained TMY3 (typical

15 Performing fixed-effects regression models with panel data is consistent with UMP protocols for evaluating whole-building retrofit. Source: National Renewable Energy Laboratory. *UMP Whole-Building Retrofit with Consumption Data Analysis Evaluation Protocol*. 2013. Available online: https://www1.eere.energy.gov/wip/pdfs/53827-8.pdf.

meteorological year) 15-year normal weather averages from 1991–2005 from the National Oceanic and Atmospheric Administration (NOAA) to assess energy usage under normal weather conditions.

Participant Group

For the impact analysis, the team gathered data from a participant (treatment) group composed of LIMF participants from the 2012 and 2013 calendar years. This allowed for a complete 12 month period of available consumption data both before (2011) and after (2014) initiative participation. The team used a rolling specification for assigning pre- and post-periods, identifying a range of months around the installation period for each participant.

Starting with a census of participants from this period (i.e., 373 facilities), the evaluation team identified a final participant group for the analysis after screening for several criteria. The team conducted billing analysis using participants who had at least 10 months of pre-period and post-period billing data. The analysis included account-level reviews of pre- and post-period consumption for all individual participants to identify anomalies (e.g., periods of unoccupied units) that could bias the results. The team also applied additional screening criteria, which are described in detail in the Data Processing and Screening section.

Comparison Group

The analysis attempted to use a comparison group of “nonparticipants” to account for exogenous factors that may have occurred simultaneously to initiative activity. These factors can include macroeconomic effects, increases or decreases in energy rates, or other interactions that may have affected energy consumption outside of the initiative influence. For each PA initiative, the evaluation team identified comparison groups using samples of customers who participated after the analysis period. For this analysis, the team selected the comparison group from customers who participated in the initiative between approximately January 2014 and December 2014, comprised of 95 facilities.

Data Challenges and Study Considerations

While the process of transforming disparate datasets into an integrated analysis has its challenges, the team encountered several issues in working with the LIMF data that posed particular difficulty.

- Program tracking data varied across and within PA files in terms of how measures and projects had been characterized or aggregated. These issues required standardization on several levels, including: (1) creating unique and common measure names and categories across and within each dataset – datasets varied in these designations, from detailed measure descriptions (e.g., attic hatch insulation) to definitions that more closely approximated end use categories (e.g., HVAC, weatherization), and (2) aggregating project information tracked at the apartment unit and building levels to the facility or complex level.
- Consumption datasets did not include fields in all cases that easily linked meters to the project information in program tracking systems. Multifamily projects could contain a mix of residential and commercial meters, per-unit or master meters, or meters that spanned several buildings

across a complex. Even if individual per-unit meters exist for a project, the team may not be able to identify whether or not these units are contained within the same building (e.g., row houses).

- Along with standardized measure naming conventions and protocols for defining the level of aggregation in the tracking system, other information that would help this and similar research include: (1) multifamily building type (e.g., row house, X unit complex with exterior courtyard), (2) presence of common areas, and whether this is conditioned or unconditioned space, (3) meter configuration indicator (e.g., master meter plus individual meters, only master meter), (4) associated rate class by meter type, and (5) whether heating, cooling, and water heating occur centrally, or within individual units.
- Occupancy. This poses a challenge to all billing analyses. However, it is particularly problematic in multifamily analysis. Occupancy issues (i.e., vacancies) occur more frequently in multifamily structures and are often harder to detect, especially in master metered buildings. Additionally, it is often the case that there is high correlation between vacancies and remodels (including participation in utility initiatives), making the changes in consumption harder to explain.

Data Processing and Screening

The process of matching projects from PA program tracking data to associated usage data is extremely important in billing analyses, in particular for multifamily studies. The team's approach included several key steps:

1. ***Identified unit of analysis.*** Program tracking data differed across and within PA datasets in terms of how project data were aggregated, including installations at the unit, building, or facility/complex levels.
2. ***Aggregated data to facility level.*** Due to this organization, the team aggregated all project information to the facility level to ensure it accounted for all measure installation information occurring within a project. Additionally, a unique ID was fairly consistent across PAs at the facility level, which lent itself to the process of matching with consumption data. The team applied the same aggregation process to the consumption data, rolling up usage across all potential meters within a facility (including both residential and commercial, in some cases) to create an aggregate monthly consumption stream per project.
3. ***Matched program tracking to billing data.*** Once the team aggregated both to the facility level, usage data were matched to program tracking data, carrying along project information such as measure detail, *ex ante* savings, and number of units per building.
4. ***Performed matching checks and* diagnostics.** The team ran several different diagnostics to ensure that these data correctly matched, including assessing per-unit usage (i.e., dividing total annual usage by unit count per facility) to ensure realistic consumption. Additionally, the team produced graphs of pre- and post-usage for every project and reviewed these profiles to check for anomalies, such as spikes or missing data. Finally, the team checked the count of meters with usage for a given project and whether this changed across or within the pre- and post-periods (potentially indicating missing data or cases of extreme vacancies).

Ultimately, the team used the following criteria to remove anomalies, incomplete records, and outlier accounts that could have biased savings estimations:

- Inability to merge the participant and measure data with the billing data, including instances of customers for which different addresses are listed between the participant data, measure data, and billing data files;
- Accounts with fewer than 10 months of billing data in the pre- or post-period;
- Accounts with changes in gas usage from the pre- or post- period of more than 70%;[16]
- Accounts with low annual usage in the pre- or post-period (e.g., less than 150 therms per unit); and
- Other extreme values, including data gaps or vacancies in the billing analysis (i.e., anomalies).

Model Attrition

Application of the data screens described above resulted in final analytic samples consisting of 217 participant facilities. This represents 58% of the original number of participating facilities during the study period.

For two PAs, Unitil and Liberty, low numbers of participants and a lack of available consumption data resulted in their exclusion from this analysis. Table 10 shows overall participant attrition per PA, and Table 11 lists detail around specific screens.

Table 10. Final Participant Group Attrition Per PA and Overall

PAs	Pre-Screen Count		Post-Screen Count		Percentage Kept	
	Facility	Units	Facility	Units	Facility	Units
Berkshire	15	677	6	137	40%	20%
Columbia	42	2,355	25	1,487	60%	63%
Eversource	56	3,317	47	2,407	84%	73%
Liberty*	n/a	181	n/a	0	n/a	0%
National Grid	260	10,180	139	4,584	53%	45%
Unitil*	n/a	505	n/a	0	n/a	0%
Overall	**373**	**16,529**	**217**	**6,615**	**58%**	**52%**

*Due to few participants and lack of available consumption data, this analysis excluded Liberty and Unitil.

16 Changes in usage of this magnitude are probably due to missing meter data, vacancies, home remodeling or addition, seasonal occupation, or fuel switching. Changes of usage over a certain threshold are not anticipated to be attributed to initiative effects and can confound the analysis of consumption for this purpose.

Table 11. Overall State-Level Participant Group Attrition Detail*

Screen	Facilities		Units	
	Count	Percentage	Count	Percentage
Participant Population	**373**	**100%**	**16,529**	**100%**
No match between tracking to billing data	17	5%	664	4%
Missing or inconsistent unit counts	3	1%	83	1%
Insufficient pre/post billing data (<10 months)	69	18%	4,082	25%
Missing meters at facility	44	12%	1,727	10%
Pre/post usage per unit less than 150 therms	2	1%	127	1%
Project-level inspection of pre/post usage	21	6%	1,231	7%
Final Participant Group	**217**	**58%**	**8,615**	**52%**

* Totals exclude Liberty and Unitil as a lack of consumption data prohibited further processing and screening.

Participant Data Summary

To provide context for initiative activity and drivers of energy savings, Table 12 shows a comparison of measure frequencies, by PA, between the analysis sample and initiative population. The measure distributions indicate the frequency of installations for participants in the analysis sample closely resembles that of the initiative participant population. Thus, even after screening the data for sufficient billing months and outliers, the analysis sample closely resembles the initiative population as a whole.

Table 12. Comparison of Measure Distribution Between Sample and Population, per PA

Category	Measure	Berkshire		Columbia		Eversource		National Grid	
		Sample	Population	Sample	Population	Sample	Population	Sample	Population
Shell	Air sealing	33%	64%	84%	80%	81%	75%	73%	72%
	Insulation	33%	21%	72%	68%	79%	76%	58%	61%
	Shell other	n/a	n/a	n/a	n/a	n/a	n/a	47%	48%
	Windows	n/a	n/a	4%	2%	n/a	n/a	n/a	n/a
HVAC	Duct sealing and insulation	n/a	n/a	32%	23%	19%	18%	7%	8%
	Thermostats	n/a	n/a	n/a	n/a	4%	2%	2%	3%
	Heating system replacement	50%	43%	48%	41%	21%	25%	60%	55%
Water heating	Aerators	n/a	n/a	16%	16%	n/a	n/a	57%	55%
	Showerheads	n/a	n/a	n/a	n/a	n/a	n/a	47%	48%
	DHW other	n/a	n/a	n/a	n/a	32%	27%	39%	40%
	Water heater replacement	n/a	n/a	40%	30%	n/a	n/a	63%	58%
Other**	Other	n/a	n/a	8%	9%	11%	9%	40%	49%
Facility Count		**6**	**14**	**25**	**44**	**47**	**55**	**139**	**260**

* Variation in measure naming conventions across program tracking data resulted in differences in the level of detail measures were summarized by PA.
** This category includes custom projects, HVAC tune-up/repair, and other miscellaneous measures (e.g., ventilation, moisture controls).

Results

This section presents evaluated gas savings estimates for the statewide and PA-specific initiatives.

Weather-normalized annual consumption in the pre-initiative period (PRENAC) is included in these results to characterize the average per unit energy consumption prior to any initiative treatment. Additionally, consideration of initiative impacts in terms of savings as a percentage of pre-period usage (i.e., PRENAC) is a helpful metric for comparison purposes and for assessing the magnitude of initiative impacts, since this ratio normalizes these savings relative to consumption levels.

Model Results[17]

Table 13 lists the changes in energy consumption from the pre- to post-initiative periods for the participant group for each PA and at the statewide level.

Table 13. LIMF Gross Natural Gas Participant Savings Per PA and Overall

PA Group	Facilities (n)	Units (n)	PRENAC	Model Savings (therm/unit)	Savings as Percentage of Pre-Usage	Relative Precision at 90%
Berkshire	6	137	685	137	20%	±41%
Columbia	25	1,487	561	107	19%	±25%
Eversource	47	2,407	706	143	20%	±17%
National Grid	139	4,584	581	124	21%	±10%
Eversource + Columbia*	72	3,894	651	129	20%	±15%
Overall**	**217**	**8,615**	**607**	**126**	**21%**	**±9%**

* Given common approaches to delivery and estimating *ex ante* savings, the team combined Columbia and Eversource samples to increase sample size and provide modeled savings estimates with improved precision for calculating realization rates.

**Overall state-level results are population-weighted, based on PA-specific participant unit counts

Participants achieved estimated gross energy savings of 126 therms overall, while PA-specific therm savings estimates vary slightly with percentage savings relative to pre-period usage consistently between 19% and 21%.

Table 14 lists realization rates for each PA and overall, based on the per-unit evaluated savings compared to per-unit *ex ante* savings. The table also shows savings percentages relative to PRENAC for both modeled and *ex ante* savings.

[17] The Model Results section presents billing analysis results from the PRISM modeling approach, in which regressions are run on individual facilities. The team also ran combined fixed-effects regression models for each group and found extremely comparable evaluated gross savings estimates. See Appendix D.

Table 14. LIMF Gross Realization Rate Summary Per PA and Overall

Utility	Model Savings (therm)	Reported *Ex Ante* Savings (therm)	Realization Rate	Model Savings as Percentage of Pre-Usage	*Ex Ante* Savings as Percentage of Pre-Usage
Berkshire	137	241	57%	20%	35%
Columbia	107	131	82%	19%	23%
Eversource	143	136	105%	20%	19%
National Grid	124	166	75%	21%	29%
Eversource + Columbia*	129	134	96%	20%	21%
Overall**	**126**	**158**	**80%**	**21%**	**26%**

* Given common approaches to delivery and estimating *ex ante* savings, the team combined Columbia and Eversource samples to increase sample size and provide modeled savings estimates with improved precision for calculating realization rates.

**Overall state-level results are population-weighted, based on PA-specific participant unit counts

While some variation in realization rates exist across PAs, model savings as a percentage of pre-usage is relatively constant. By comparison, *ex ante* savings percentages range from 19% to 35%, highlighting that planning estimates may be contributing to this variation in realization rates across PAs.

Comparison Group Results

Upon running comparison groups through the different regression approaches, the team found decreasing consumption (i.e., savings) ranging from 1% to 8% of pre-period usage. As the intent of a comparison group in this analysis is to control for exogenous effects, affecting both participant and comparison group usage in the absence of the initiative, the team did not anticipate observing savings of this magnitude from these nonparticipants. Due to extreme weather during the winter of 2013 - 2014, it is possible that some nonparticipant facilities reached heating capacity, or even reduced heating load to manage costs, while participant facilities experienced more comfortable indoor temperatures and did not exhibit similar behavior. In discussion with PAs, EEAC consultant, and other LIMF stakeholders, it was decided that these levels of and variation in nonparticipant savings were likely driven in part by other influencing factors beyond those intended for measurement. While the gross savings presented in this report still contain some level of influence attributed to exogenous effects, LIMF stakeholders decided not to include this comparison group for calculating adjusted gross savings.

Lighting Interactive Effects

As the LIMF Initiative typically treats buildings holistically, the majority of projects receiving gas-savings measures that reduce heating consumption are also receiving efficient lighting which increases heating loads because the more efficient lighting is contributing less waste heat to help heat the building. Gas billing analysis, by its nature, does not separate out these two effects and thus underestimates the savings achieved by the gas saving measures.

By assuming approximately one therm reduction for each efficient light replacing an incandescent bulb, this may result in approximately 1 to 15 therms per unit, depending on the average number of bulbs replaced per unit.[18] While the modeled savings reflects the true change in consumption (*i.e.*, the actual reduction in therms for the participant group), it may be appropriate to consider adjustments to the realization rates to back out the lighting interaction, treating this consistently across modeled and *ex ante* estimates. In this case, assuming replacement of five to 10 bulbs, the gross statewide realization rate of 80% would increase to somewhere between 83% and 89%.

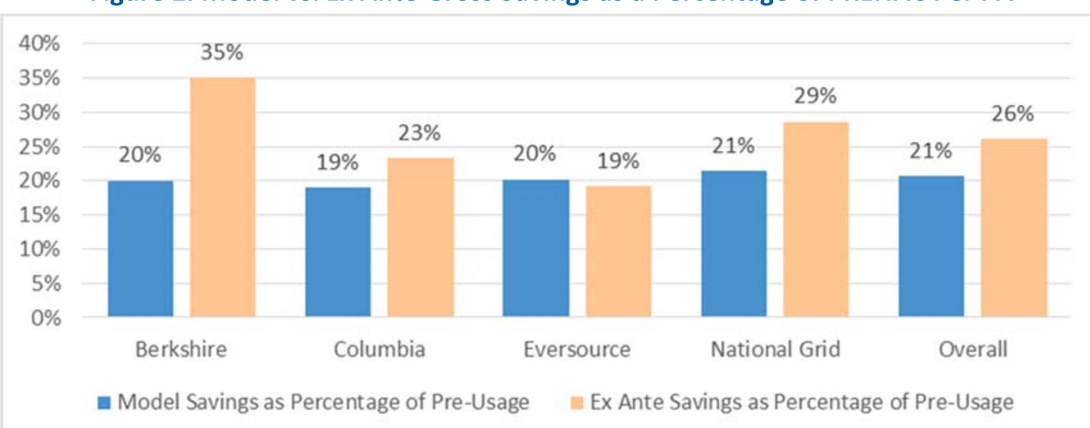
Model Diagnostics

To provide context around the impact results, the team examined several different diagnostics and summaries of initiative data. The following figures present a comparison of modeled and *ex ante* savings as percentages of PRENAC, with Figure 2 showing differences per PA. It is apparent that realized savings are consistent across the PAs with *ex ante* values varying considerably.

Figure 3 shows a comparison of overall modeled and *ex ante* savings percentages by usage quartile. While percentage savings are comparable between *ex ante* and modeled savings in higher usage quartiles, Q1 and Q2 demonstrate substantially higher percentage *ex ante* savings. In fact, *ex ante* percentage savings in Q1 and Q2 are higher than those claimed on average for projects in higher usage quartiles. This seems to indicate planning estimates for lower usage quartiles may be overestimating the savings potential.

Figure 4 shows a comparison of modeled and *ex ante* percentage savings by projects that received or did not receive heating system replacements.

Figure 2. Model vs. *Ex Ante* Gross Savings as a Percentage of PRENAC Per PA



18 Cadmus, NMR. *Impact Evaluation: Home Energy Services – Income Eligible and Home Energy Services Programs (R16)*. Presented to the Energy Conservation and Management Board, the Connecticut Light and Power Company, the United Illuminating Company, the Southern Connecticut Gas Company, Yankee Gas Services, and the Connecticut Natural Gas Company. 2014. Available Online: Final Report.

Figure 3. Model vs. *Ex Ante* Gross Savings as a Percentage of PRENAC Per Usage Quartile

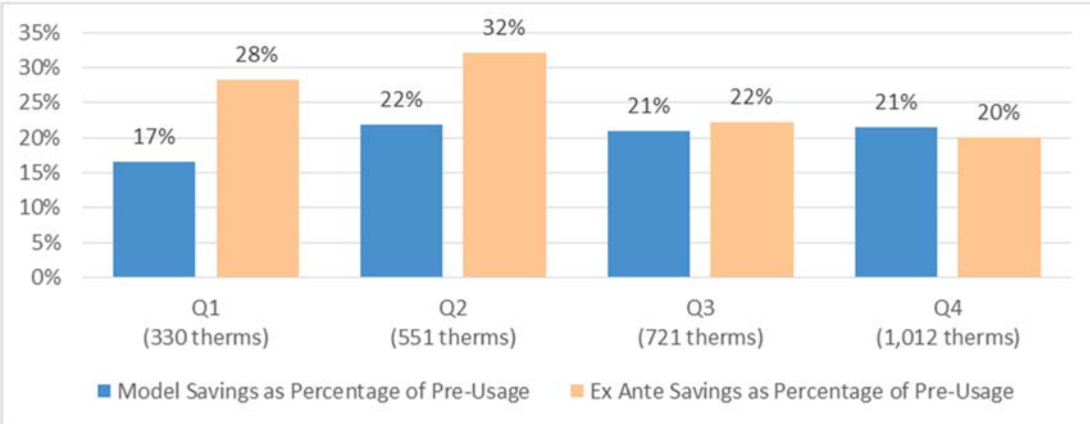
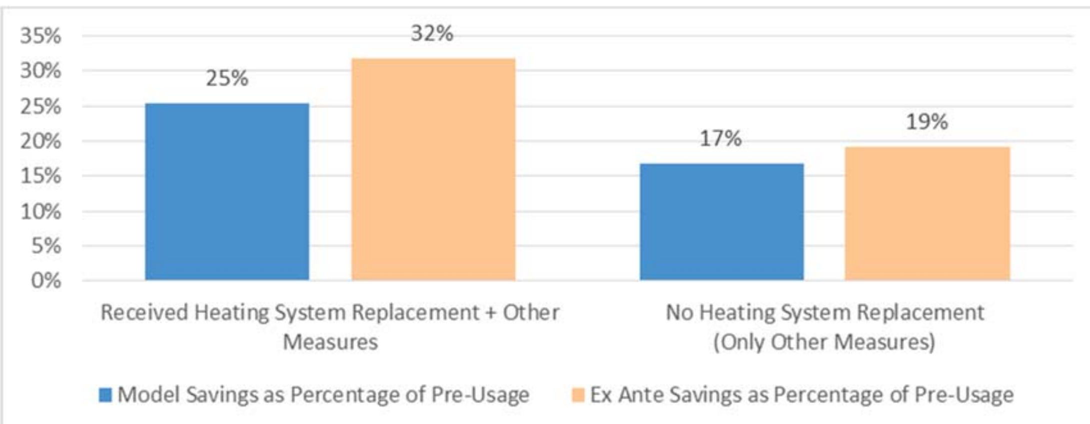


Figure 4. Model vs. *Ex Ante* Gross Savings as a Percentage of PRENAC



While projects without heating system replacements have lower average percentage savings, this is relatively consistent between modeled and *ex ante* estimates. Projects within heating system replacements demonstrate a larger difference between planning and evaluated results.

Comparison of Realization Rate by Claimed Savings Type

The evaluation team calculated *ex ante* savings estimates using two approaches: project-specific simulation modeling and deemed calculated savings. For simulated savings, the team used actual usage to calibrate facility-specific models, which then calculated a benefit/cost ratio to optimize measure installation for a given project. Table 15 provide a comparison of savings and realization rates for each type of claimed savings.

While evaluated savings are similar in terms of absolute therm savings and percentage of PRENAC, the realization rate for projects claiming deemed *ex ante* savings show lower realization rates than for projects using simulation modeling. This is not surprising since simulation modeling should provide for a more accurate estimate of savings as it accounts for some level of measure interaction and is calibrated using actual usage data.

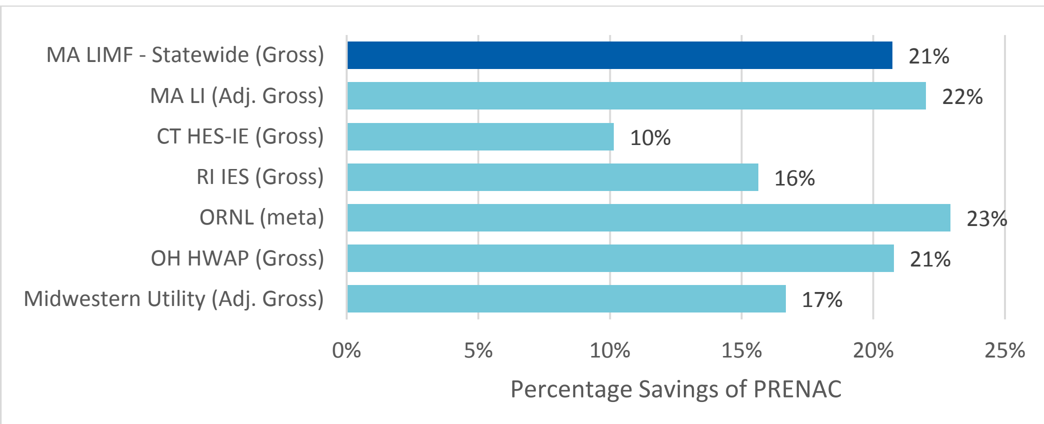
Table 15. LIMF Gross Natural Gas Participant Savings Per Claimed Savings Type

Claimed Savings Type	Facilities	PRENAC	Model Savings (therms)	Realization Rate	Model Savings as Percentage of Pre-Usage	*Ex Ante* Savings as Percentage of Pre-Usage	Relative Precision at 90%
Standard Algorithm	139	581	124	75%	21%	29%	±10%
Sim Modeled	78	650	129	89%	20%	22%	±14%

Benchmarking

Benchmarking is always an important component of evaluation, to provide context around the results and how performance compares to other initiatives. The team was unable to identify many multifamily low-income initiatives evaluated using billing analysis that delivered a similar mix of measures to benchmark against. Despite this limitation, the team compared these results against a range of recent evaluations of single family low-income programs that evaluated whole-building natural gas savings and whose programs deliver a similar combination of shell, water heating, and HVAC measures.[19,20,21,22,23] Figure 5 shows a comparison of the LIMF Initiative gross evaluated savings.

Figure 5. Comparison of Evaluated Savings as a Percentage of PRENAC by Program



19 Cadmus, *Low Income Single*, 2012.

20 Cadmus. *Impact Evaluation: Rhode Island Income Eligible Services*. Prepared for National Grid. 2014.

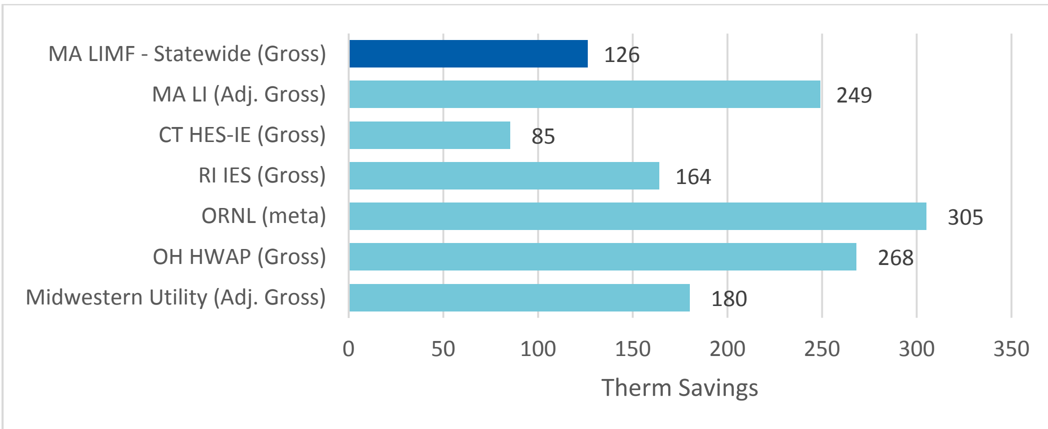
21 Quantec, LLC. *Ohio Home Weatherization Assistance Program Impact Evaluation*. Prepared for Ohio Office of Energy Efficiency. 2006.

22 Schweitzer, Martin. *Estimating the National Effects of the U.S. Department of Energy's Weatherization Assistance Program with State-Level Data: A Metaevaluation Using Studies from 1993 to 2005*. 2005.

23 Cadmus, *Impact Evaluation: Home Energy Services-Income Eligible and Home Energy Services Programs.* Prepared for the Connecticut Energy Conservation and Management Board. 2014.

Figure 6 shows a comparison of the average per-participant therm savings from the comparable studies. Absolute therm savings are lower for LIMF participants than the other comparable single-family studies due to lower average pre-period usage. As shown in Figure 5, in terms of savings percentage, the LIMF Initiative savings are consistent, if not higher, than other single-family low-income weatherization initiatives.

Figure 6. Comparison of Evaluated Absolute Savings by Program



Task 3. Common Area Lighting

The review of tracking data for the electric LIMF Retrofit Initiative indicated that almost three-quarters of electric LIMF Initiative savings resulted from lighting upgrades. Since the PAs had recently conducted research on in-unit lighting measures and had not previously studied common area lighting in multifamily buildings, this task focused on lighting upgrades in common areas.

Methods

Common area lighting includes all lighting measures that occur outside an individual tenant unit. Therefore, this category included exterior lighting, parking garage lighting, and interior lighting in stairwells, hallways, common spaces, offices, and other non-tenant spaces.

For a sample of PY 2014 projects that included common area lighting measures, the team performed site visits to verify installed lighting equipment and install light loggers. The team used the collected data to estimate energy savings and compared the results to tracking data to determine realization rates of common area lighting measures implemented through the initiative.

Sample Design

The evaluation team reviewed the tracking documentation for lighting projects installed in PY 2014 and developed the evaluation sample. The team selected a sample by dividing the population into three strata based on the total common area lighting savings claimed for each project.

Population

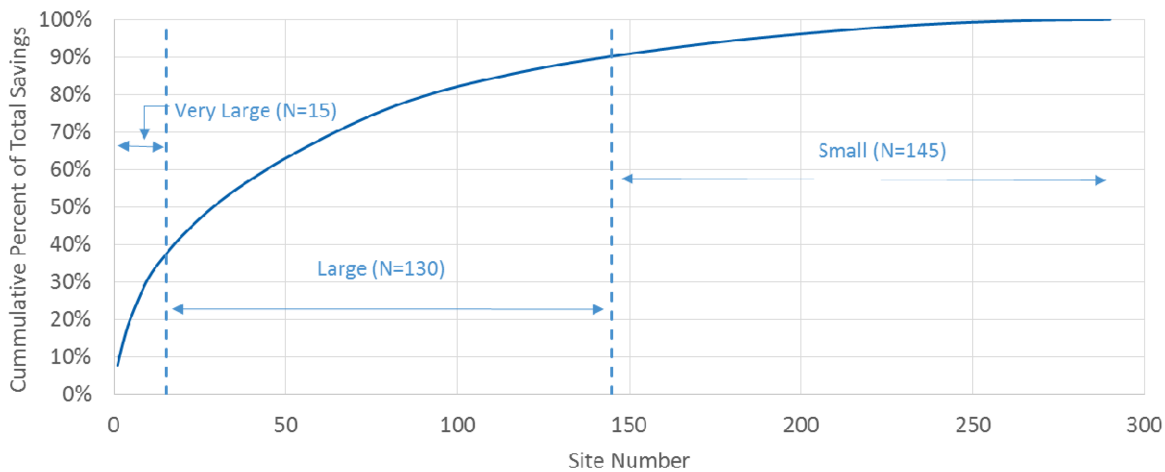
Table 16 shows the number of tracked projects and annual savings (kWh) by PA for common area lighting projects implemented in PY 2014.

Table 16. LIMF Lighting Projects and Savings by PA (PY 2014)

PA	Number of Projects	% of Population Projects	Annual kWh Savings	% of Population Savings
National Grid	168	58%	5,342,356	33%
Eversource East	107	37%	9,462,307	59%
Eversource West	14	5%	1,307,665	8%
Unitil	1	0%	44,853	0%
Total	**290**	**100%**	**16,157,180**	**100%**

Figure 7 shows the cumulative savings (across all PAs) based on the number of projects. The curve demonstrates a range in project sizes, with a small number of large projects that make up a majority of the savings, as well as a large number of small projects.

Figure 7. Cumulative Savings by Number of Projects



The evaluation team divided the population into three strata:

- **Very Large Stratum.** The very large stratum included all projects that were above the 95th percentile based on total energy savings (>179,193 kWh). This stratum, made up of 15 projects, accounted for 37% of the population annual energy savings. The team decided to pursue a census of these projects. By including as many of these projects in the evaluation sample as possible, the team eliminated sampling uncertainty for a large portion of the total savings, and, therefore, reduced sampling uncertainty in the overall estimate of total annual energy savings.
- **Large stratum.** The large stratum included the 130 projects with annual energy savings greater than the median value (21,791 kWh) that were not included in the very large stratum. These projects made up 53% of the population savings.
- **Small stratum.** The small stratum included the 145 projects with annual energy savings less than the median value (21,791 kWh). These projects made up 10% of the population savings.

Table 17 summarizes how the team defined the three strata and shows each stratum's share of the common area lighting population by number of projects and estimated annual kWh savings.

Table 17. Definition of Common Area Lighting Population

Strata	Minimum Annual kWh	Maximum Annual kWh	Projects in Population	Total Annual kWh Savings	% of Population Savings
Very Large	179,193	n/a	15	6,024,347	37%
Large Sample	21,792	179,192	130	8,554,016	53%
Small Sample	0	21,791	145	1,578,817	10%
Total	**n/a**	**n/a**	**290**	**16,157,180**	**100%**

Sample

Table 18 shows the sample of projects visited by strata and PA.

Table 18. Number of Common Area Lighting Sample of Projects Visited and PA Per Strata

Strata	Population	# Projects Visits	PA	
			National Grid	Eversource
Very Large	15	10	1	9
Large	130	40	18	22
Small	145	6	2	4
Total	**290**	**56**	**21**	**35**

The evaluation team attempted to visit all of the very large projects; however, due to site availability and scheduling constraints, the team was only able to visit 10 of the 15 projects. Table 19 shows the percentage of annual savings (kWh) within the population and the percentage of savings attributable to the projects we visited by each stratum.

Table 19. Percentage of Annual kWh Savings by Population and Projects Visited Per Strata

Strata	% of Population (Annual kWh Savings)	% of Stratum Visited (Annual kWh Savings)
Very Large	37%	74%
Large	53%	28%
Small	10%	7%
Total	100%	43%

The very large stratum makes up 37% of annual kWh savings from the entire population. The team visited 10 out of the 15 census sites, which account for 74% of the total savings from that stratum.

Verification and Metering

The evaluation team recruited customers through a two-stage process. First, the team sent a recruitment letter to all applicable sites that explained the purpose of the evaluation and the activities that would take place on-site; the letter also offered two $50 incentives to encourage participation. The letter gave recipients the option, if interested in participating, of contacting the evaluation team directly to arrange a visit. Second, the team called facility/building managers and explained the same material outlined in the letter. If the contact agreed to have the field technicians audit the site and install metering equipment, the team scheduled a visit.

While on site, the evaluation team's field technicians verified the installed lighting fixtures and compared their observations to the installed measures listed in the PA's tracking data. They recorded number of fixtures installed, fixture type, location, and wattage whenever available. At each project, the technician also installed up to 10 meters to record the HOU of each fixture. As shown in Table 20, the field technicians installed two types of meters.

Table 20. Common Area Lighting Metering Equipment

Parameter	Instrument	Units	Interval	Duration
Common Area Lighting HOU	Light Logger (UX90-002M)	State or ON/OFF	Continuous	4–6 Weeks
Common Area Bi-Level Lighting HOU	Light Level Meter (U12-012)	Light Intensity	1.5 Minutes	4-6 Weeks

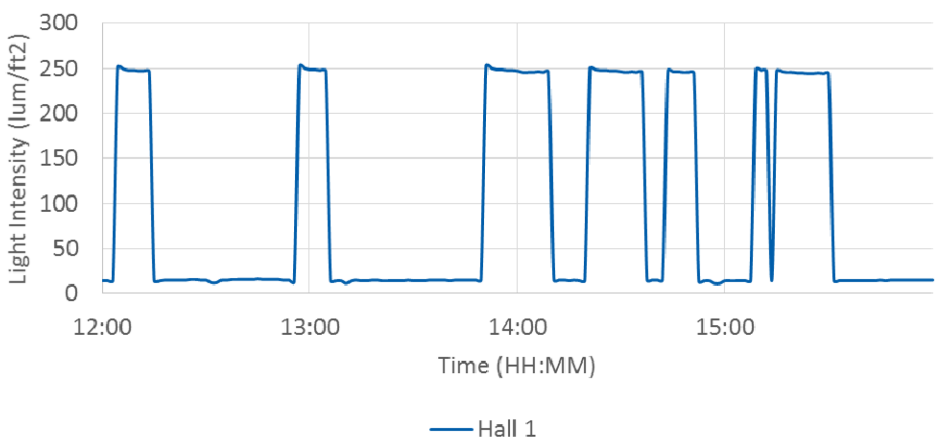
The light logger (UX90-002M) detects only whether the fixture is on or off; it was used for fixtures that only operate in the on or off state. The light level meter (U12-012) records the intensity (lumens per square feet) of light; it was used on dimmable lights typical in hallways and stairways.

The meters collected data over a three to six week period between June 9, 2015, and August 11, 2015.

Meter Data Analysis

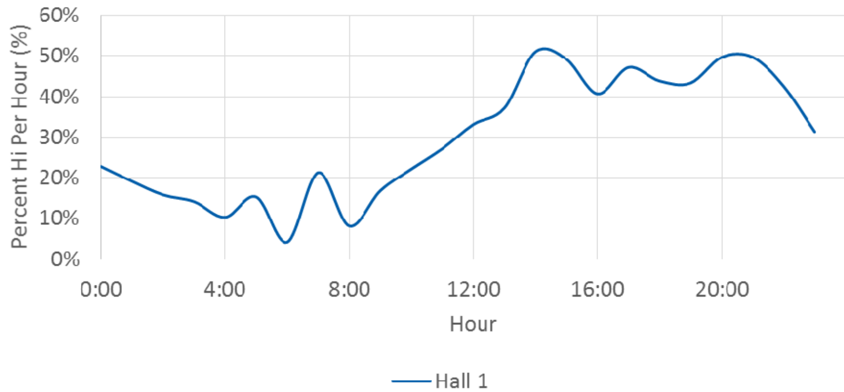
Figure 8 shows a four-hour sample of raw data from a single (U12-012) light level meter installed in a hallway bi-level light fixture.

Figure 8. Common Area light Metering Raw Data Sample (Bi-Level)



There was a clear and consistent step change in light intensity that corresponded to the fixture switching between the high and low brightness/wattage setting. The output from a (UX90-002M) light logger was similar, but the step function proceeded from zero to one to indicate on and off. The team used this information to create daily runtime profiles that indicated what percentage of the time the light was in the on or high setting for a weekday, Saturday, Sunday, and holiday. Figure 9 shows the average weekday runtime profile from the same meter data shown in Figure 8.

Figure 9. Sample Weekday Common Area Light Runtime Profile (Bi-Level)



Since the bi-level lighting was occupancy controlled, it was not surprising that the light was at the high setting most frequently from 12:00 p.m. to 9:00 p.m. and on the low setting most frequently from 12:00 a.m. to 8:00 a.m.

Figure 10 and Figure 11 show the distribution of the metered HOU for the bi-level hallway and stair space types.

Figure 10. Stairway HOU Distribution High Level (Bi-Level)

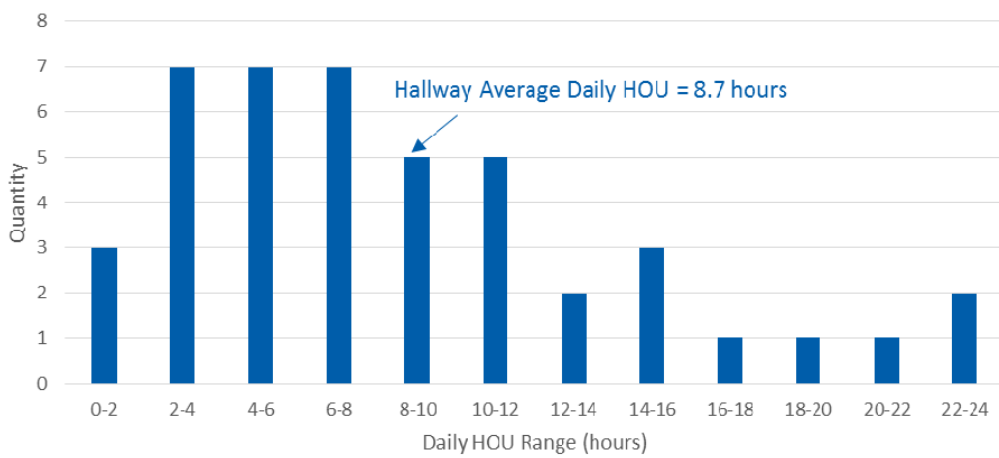
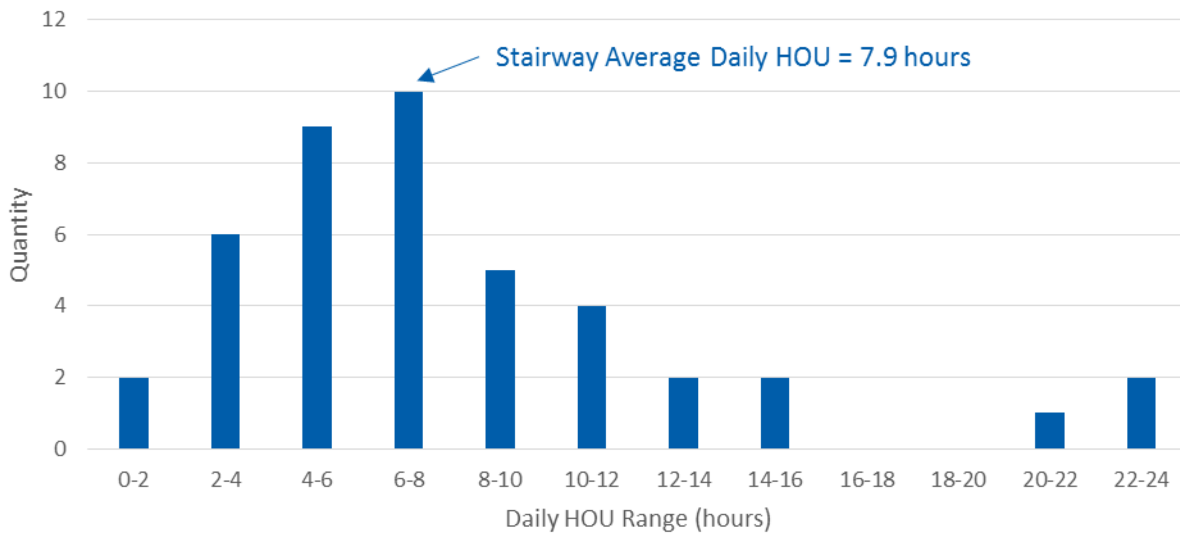


Figure 11. Hallway HOU Distribution at High Level (Bi-Level)



Interior common area lighting in LIMF buildings typically operate 24 hours per day, seven days per week or are controlled by a timer/occupancy sensor. As such, it is likely that the interior lighting had negligible seasonal dependence. The evaluation team estimated annual hours of use by extrapolating the computed daily runtime profiles over the entire year.

The team confirmed that exterior lighting operated through a timer or occupancy control. The current estimate of 12 hours per day for exterior was reasonable when compared to secondary research, which confirmed average daily hours of darkness for Massachusetts as 11 hours and 47 minutes.[24] Where exterior metering did occur, the team normalized data for photocell-controlled lighting using the hours of darkness.

Action and ABCD both acknowledged that bi-level exterior lighting is generally not cost-effective, but both are open to looking for opportunities to implement this measure.

Sample Analysis

The evaluation team calculated the realization rate for each stratum using the following equation:

$$RR = \frac{\sum ex\ post\ savings}{\sum ex\ ante\ savings}$$

The team then extrapolated the realization rate for each stratum to the stratum population and summed the stratum population *ex post* savings to estimate *ex post* savings for the total LIMF total population of common area lighting projects.

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24 U.S. Naval Observatory. *Duration of Daylight/Darkness Table for One Year*. 2015. Available online: http://aa.usno.navy.mil/data/docs/Dur_OneYear.php.

Results

Table 21 lists the realization rate and relative precision for National Grid, Eversource, and statewide. These results are based on installed fixture verification and time-of-use metering for 56 common area lighting projects in the PY 2014 LIMF Initiative.

Table 21. Common Area Metering Equipment

PA	Realization Rate	Relative Precision at 90% Confidence
National Grid	101%	±8%
Eversource	96%	±2%
Statewide	**97%**	**±3%**

All realization rates are close to 100% indicating the actual energy savings are similar to the *ex ante* estimates from the implementation contractors.

Deemed Savings Value

Given the highly varied nature of common area lighting, the team suggests estimating savings using an algorithm that incorporates site-specific information whenever possible. However, Table 22 provides deemed savings values for PAs that do not calculate savings using site-specific inputs.

Table 22. Common Area Lighting Deemed Savings Values

Space Type	Qty New Fixtures	*Ex Ante* Savings (kWh/yr)	Per Fixture *Ex Ante* Savings (kWh/yr)	Realization Rate	Per Fixture *Ex Post* Savings (kWh/yr)
Exterior	11,639	6,851,891	589	97%	571
Interior	32,225	9,305,289	289	97%	280

The team separated interior and exterior lighting because exterior lighting tends to use higher wattage fixtures and consistently operates for 4,380 hours per year resulting in significantly higher savings than interior fixtures. The team calculated a deemed value using the quantity of interior and exterior fixtures installed, the *ex ante* savings, and the statewide realization rate.

Findings Related to Pre-Installation Fixture Wattage

For one National Grid project, the team found a discrepancy between the tracking data and on-site observations regarding the pre-installation fixture information. For this project, the tracking data listed the pre-fixture wattage as 190 watts. During the on-site verification activities, the team found an existing pre-installation fixture (which had been repurposed) with a nameplate of a 70-watt high pressure sodium lamp. The facility contact confirmed the 70-watt lamp represented pre-installation fixtures for the project. For this observed fixture, the actual pre-installation fixture wattage would be 95 watts including the ballast, much lower than the 190-watts-per-fixture estimate in the tracking data.

Due to the large quantity of these fixtures in the project, this discrepancy in the pre-installation fixture wattage could have a large impact on the evaluated results for the project. Including the pre-installation fixture adjustment in the evaluated savings calculation resulted in a realization rate of 55% for the site. Without the pre-installation fixture adjustment the adjustment, the project realization rate is 102% (due to higher metered hours of use).

Through stakeholder discussions about these evaluation findings, the team determined not to include the pre-installation adjustment in the final results. The evaluation results only include adjustments to post-installation fixture counts and wattage and to annual hours of use estimates (based on metered data). To minimize potential for future errors in the documentation of pre-installation fixture wattage and to support future evaluation efforts, the PAs should, if they have not already, develop protocols for collecting and verifying pre-installation wattages that include taking photographs of each type of replaced fixture.

Task 4. On-Site Verification and Measure Analysis

While installing light meters on-site for Task 3, the evaluation team investigated several specific measures identified as of particular interest during the stakeholder workshops. This activity provided third-party verification of measure installations and allowed for additional data collection at the customer facility. The field technicians set out to investigate the following measures:

- Showerheads and aerators
- Condensing boilers
- Water heating systems
- Air conditioning (AC) units
- Energy management systems (EMS)/controls
- Variable frequency drives (VFD)

The team completed the following for this task:

1. Examined the persistence of measures at risk of removal (e.g., showerheads and aerators);
2. Collected detailed system information to supplement the billing analysis;
3. Discussed building operation and performance with facility managers to collect anecdotal feedback.

The field technicians did not encounter any instances of EMS/controls or VFDs at the sample of projects they visited. The remaining measures were assessed.

Showerheads and Aerators

Showerheads and faucet aerators reduce water consumption and water heating fuel (electrical energy or natural gas consumption). However, users do not always embrace these devices, so there is the risk that over time, they may be removed or replaced with less efficient models.

Methods

At each project where the team determined faucet aerators or showerheads had been installed, field technicians asked the building manager to let them into five units to inspect the installed equipment. The field technicians provided $10 incentives to each resident that allowed them into their homes. When inside, the technicians recorded the rated flow rate of all faucet aerators and showerheads within the unit. Typically, the field technicians observed one kitchen faucet aerator, one bathroom faucet aerator, and one showerhead.

Results

In the sample, the evaluation team found five projects with faucet aerators and/or showerheads installed as part of the initiative. For one of these projects, the building manager declined to allow the field technicians into the tenant units. At each of the four remaining projects, the field technicians entered five units.

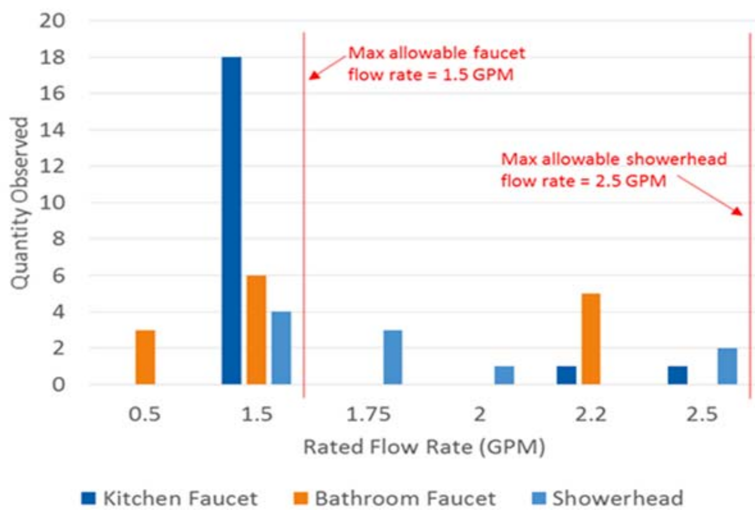
Among the projects that the technicians inspected, the implementers always installed kitchen faucet aerators, but bathroom faucet aerators and showerheads were installed only in some of the units. Table 23 lists which measures were installed in the project units the field technicians inspected.

Table 23. Faucet Aerator and Showerhead Installations Per Project Site

Project #	Kitchen Faucet Aerators	Bathroom Faucet Aerators	Showerheads
1	✓	✓	
2	✓		✓
3	✓	✓	
4	✓	✓	✓

To calculate savings for faucet aerators and showerheads, the TRM suggests using deemed values. The TRM specifies the flow rate of faucet aerators should not exceed 1.5 gallons per minute (GPM) and showerheads should not exceed 2.5 GPM. Figure 12 shows the distribution of flow rates observed among the units inspected.

Figure 12. Distribution of Observed Faucet Aerators and Showerheads by Rated Flow Rate



To calculate the in-service rate (ISR) of each measure, the evaluation team divided the number of observed faucet aerators and showerheads that were below the maximum allowable flow rate threshold and divided by the total number found during the project audit. Table 24 shows the quantity of faucet aerators and showerheads observed below the allowable threshold, total inspected, and computed ISR.

Table 24. ISR Calculation for Faucet Aerators and Showerheads

Parameter	Value
Faucet Aerators	
Quantity Below 1.5 GPL	27
Total Faucets	34
Faucet ISR	**79%**
Showerheads	
Quantity Below 2.5 GPL	10
Total Showerheads	10
Showerhead ISR	**100%**

Due to the low number of these measures observed, the team does not recommend adopting these ISR values. However, the data suggest faucet aerators do not persist; therefore, the total achievable savings are often not realized. A more extensive study is required to obtain statistically significant results. However, since these measures account for a small percentage of total LIMF Initiative savings, the expense of such a study may outweigh its benefit.[25]

Air Conditioning Equipment

The purpose of this task was to determine what, if any, air conditioning systems LIMF buildings use and quantify the prevalence of room air conditioners (RAC) and central air conditioning systems (CAC).

Methods

At each of the 56 projects the field technicians visited, they discussed the air conditioning systems with site personnel. If the building used CACs, they inspected the units and recorded nameplate information. If the building used RACs, they determined whether they were supplied by the building or owned by the tenant.

Results

The evaluation team divided the air conditioning systems observed at the projects sites into eight categories. Table 25 lists the defined categories and shows the prevalence of each system in terms of quantity observed and percentage of the total.

25 Aerators and showerheads accounted for 0.2% of LIMF kWh savings and 2.1% of LIMF therm savings in PY 2013. (Cadmus, *MA LIMF Technical*, 2014)

Table 25. Type of Air Conditioning Equipment Observed On site

AC System Uniform	Percentage
Tenant Owned RAC	63%
CAC - Common/Office + Tenant Owned RAC	17%
Building Owned RAC	4%
Heat Pumps	4%
CAC - Common/Office	4%
CAC - Common/Office + Building Owned RAC	2%
Mix of CAC, Tenant owned RAC, and Building Owned RAC	2%
CAC	2%

Eighty-nine percent of the projects sampled used RAC to cool the tenant units, 93% of which were supplied by the tenant, not building management. Twenty-eight percent of the projects used CAC to cool common areas and/or office space, and only one site (2%) used CAC to cool the entire building.

Task 5. Assessment of Secondary Impacts

Several measures installed as part of the LIMF Initiative result in secondary benefits. During the technical review phase, the evaluation team found that the PAs did not uniformly claim savings for all of these measures. The purpose of this task was to improve consistency in measuring and estimating savings among the PAs by clearly outlining acceptable secondary savings.

The team focused on two areas: water savings and cooling energy savings resulting from weatherization. Similar to Task 1, the team evaluated the approaches for calculating these savings outlined in the TRM and determined a recommended approach.

Water Savings

Three measures currently implemented as part of the LIMF Initiative result in water savings: faucet aerators, showerheads, and clothes washers. The evaluation team recommends the PAs track savings for each of these measures since water savings is a quantifiable benefit.

Methods

Similar to the methods employed in Task 1. Engineering Analysis and Literature Review, the team reviewed the savings calculations outlined in the TRM, the cited sources, and other secondary resources (e.g., ENERGY STAR calculator) to determine the best approach to calculating savings.

Faucet Aerator Savings

To estimate water savings from faucet aerators, the team used the following equation:

$$\Delta GAL = (GPM_{BASE} - GPM_{EFF}) \times N_{OCC} \times MIN_{PPD} \times 365$$

Where:

ΔGAL	=	Annual water savings (gallons/year)
GPM_{BASE}	=	Baseline flow rate (gallons/minute)
GPM_{EFF}	=	Installed flow rate (gallons/minute)
N_{OCC}	=	Average number of people per household
MIN_{PPD}	=	Daily minutes of water use per person
365	=	Days per year

The evaluation team calculated the water savings from kitchen and bathroom faucet aerators individually and then computed a weighted average based on the number of kitchen aerators and bathroom aerators typically installed in a unit.

Table 26 lists the input assumes used to estimate annual water savings from low-flow bathroom and kitchen aerators.

Table 26. Faucet Aerator Water Saving Calculation Inputs

Input	Values		Units	Source
	Bathroom Aerator	Kitchen Aerator		
Low-Flow Equipment				
Baseline flow rate - rated	1.30	1.30	gallons/min	Federal standard
Installed flow rate - rated	1.00	1.00	gallons/min	Average installed (for this study)
Reduction in flow rate	0.30	0.30	gallons/min	(calculated)
Water Consumption				
Household members	2.30	2.30	people	Low-income audit data (Cadmus, *Low Income*, 2012)*
Daily use per person	1.65	4.51	minutes/person/day	Cadmus, *Showerhead and Faucet*, 2013*
Minutes of use per day	3.8	10.4	minutes/day	(calculated)
Water Savings				
Water savings per day	1.14	3.105	gallons/day	(calculated)
Water savings per year	**416**	**1,133**	**gallons/year**	**(calculated)**

* See Appendix C for full citations.

Table 27 shows assumptions used to estimate the weighted average water savings for bathroom and kitchen aerators.

Table 27. Average Faucet Aerator Water Saving

Input	Values	Units	Source
Average kitchen aerators installed	1.03	aerators/apartment	Cadmus, *Home Energy*, 2012*
Average bathroom aerators installed	1.50	aerators/apartment	Cadmus, *Home Energy*, 2012*
Weighted average water savings	**708**	**gallons/year/aerator**	**(calculated)**

* See Appendix C for full citations.

The Massachusetts TRM currently assigns water savings of 332 gallons per year, but does not distinguish between kitchen and bathroom aerators.[26] The inputs listed in Table 26 and Table 27 are more relevant to the Massachusetts LIMF Initiative.

Showerhead Savings

The team estimated water savings from showerheads using the following equation:

[26] KEMA. *Evaluation of the Weatherization Residential Assistance Partnership (WRAP) and Helps Programs.* 2010. Presented to the Energy Conservation and Management Board, the Connecticut Light and Power Company, the United Illuminating Company, the Southern Connecticut Gas Company, Yankee Gas Services, and the Connecticut Natural Gas Company.

$$\Delta GAL = (GPM_{BASE} - GPM_{EFF}) \times N_{OCC} \times N_{SHOWERS} \times MIN_{SHOWER} \times \%Impact \times 365$$

Where:

ΔGAL	=	Annual water savings (gallons/year)
GPM_{BASE}	=	Baseline flow rate (gallons/minute)
GPM_{EFF}	=	Installed flow rate (gallons/minute)
N_{OCC}	=	Average number of people per household
$N_{SHOWERS}$	=	Showers per person per day
MIN_{SHOWER}	=	Shower length
%Impact	=	Proportion of showering activity affected by replacement
365	=	Days per year

The evaluation team set the as-used water flow rate equal to the maximum rated flow after scaling it back linearly to account for water pressure at the residence that is less than 80 psi rating pressure. Table 28 shows the values and sources of all the inputs the team used to estimate showerhead savings.

Table 28. Showerhead Savings Calculation Inputs

Input	Values	Units	Source
Low-Flow Equipment			
Baseline flow rate - rated	2.50	gallons/min	Federal standard
Baseline flow rate - as used	2.05	gallons/min	Calculated (Cook, 2008)*
Installed flow rate - rated	2.00	gallons/min	Average Installed [this study]
Installed flow rate - as used	1.78	gallons/min	Calculated (Cook, 2008)*
Reduction in flow rate	0.50	gallons/min	(calculated)
Water Consumption			
Household Members	2.30	people	Low-income audit data (Cadmus, *Low Income*, 2012)*
Showers (pcpd)	0.70	showers/person/day	(Cadmus, *Low Income*, 2012), (Cook, 2008), (Mayer, 2006)*
Shower Length (min)	8.20	minutes/shower	(Cadmus, *Low Income*, 2012), (Biermayer, 2006), (Mayer, 2006)*
Proportion Affected	0.73	%	HES audit data
Minutes of use per day	9.6	minutes/day	(calculated)
Water Savings			
Water savings per day	4.82	gallons/day	(calculated)
Water savings per year	**1,759**	**gallons/year**	**(calculated)**

* See Appendix C for full citations.

The value currently proposed in the TRM (3,696 gallons per year) is higher than the value calculated in Table 28. The team calculated this value using the rated flow as opposed to the as-used flow rate and assumed an average shower lasts 12.2 minutes instead of 8.2 minutes. In the report providing the value in the TRM, they explain, "[we] suspect that the reported usage of 12.2 minutes per shower per day may be overstated, because of a tendency of respondents to overstate the frequency with which they actually take showers, but there are no data on this specific population to refute this claim."(KEMA, 2010). Based on additional secondary data sources, the team considers 8.2 minutes per shower a more accurate value.[27]

Clothes Washer Savings

The team estimated savings for clothes washers using the ENERGY STAR calculator. For clothes washers installed in shared laundry rooms in multifamily residences, the calculator assumes a capacity of 2.8 cubic feet, a modified energy factor of 2.2, a water factor of 4.5, and that the machine washes 24 loads per week. Using these inputs, the calculator estimated each washer will save 6,948 gallons per year. This value is smaller than the value in the 2014 TRM (15,813 gallons per year) which is based on an outdated baseline.

Interactive Cooling Impacts

The implementation of measures such as insulation and air sealing improves a home's building envelope and typically results in reduced heating and cooling loads. The purpose of this activity was to quantify the cooling energy savings attributable to weatherization measures.

Methods

Based on data collected from on-site visits, the team determined that RAC units comprised the majority of AC equipment installed at LIMF sites. The team estimated savings due to weatherization improvements for RAC units using the following equations:

$$kWh\ RAC\ \left[\frac{kWh}{year}\right] = \frac{RAC\ BTU/hr}{RAC\ EER} \times EFLH_{Cool} \times \frac{1}{1000}$$

$$\Delta kWh\ RAC\ \left[\frac{kWh}{year}\right] = kWh\ RAC\ \times \%\ Cooling\ from\ Weatherization \times \%\ Savings$$

Results

Table 29 shows the inputs the evaluation team used to calculate cooling savings due to weatherization.

[27] Cadmus, *Low Income*, 2012; Biermayer 2006; and Mayer 2006. See Appendix D for full citations.

Table 29. Inputs to Calculate Weatherization Cooling Savings of RAC Units

Parameter	Definition	Value	Source
$EFLH_{Cool}$	Equivalent full load hours (cooling)	200	RLW Analytics, 2008*
RAC BTU/hr	Capacity	10,000	ENERGY STAR calculator
RAC EER	Baseline energy efficiency ratio	6.7	Laboratory testing of older, but operable window air conditioners (Cadmus, *OPA Keep*, 2008)*
% Cooling from Weatherization	Percentage of home cooling load impacted by weatherization characteristics	40%	Cadmus, *New Hampshire*, 2013*
% Savings	Percentage of reduction in cooling energy due to installed weatherization measures	18.3%	Cadmus, *New Hampshire*, 2013*
Savings per Unit	**Annual kWh savings per RAC unit**	**22**	**Calculated**

* See Appendix C for full citations.

Table 30 compares estimated from air sealing and insulation during the heating and cooling seasons. The team calculated these savings using the Deemed Savings Workbook (Tasl 1) for a typical multifamily unit.

Table 30. Typical Weatherization Savings

Measure	Annual Savings (kWh)
Air Sealing (Heating)	397
Insulation (Heating)	1,377
Weatherization (Cooling)	22

Based on the values in Table 30, savings during the cooling season account for only 1.2% of the total energy savings from weatherization. Since many of the tenants are responsible for installing the RACs in the LIMF buildings (93% according to the data collected on site), some building units do not contain any AC equipment. Thus, on a building or initiative level, the actual savings per tenant unit will be less than estimated above. Since it is would require additional effort to track, the evaluation team does not recommend adding energy savings due to weatherization upgrades from the cooling period.

Appendix A. Summary of Deemed Savings Values

Figure 13. Deemed Savings Summary - Electric

Deemed Savings Summary for LIMF Program (Electric)

Program year: 2016

				Proposed Values for PY2016+				Existing Values for Comparison					
#	End-Use	Measure	Type	Annual Savings Value			NOTES	MA TRM (kWh/year)		2013 Savings Estimates by PA (kWh/year)			
				kWh**	therms	water		2014	2013	NGRID	Eversource	CLC	Unitil
1	Misc	TLC Kit	User Input	70	n/a	432	[1]	n/a	n/a	unk	unk	unk	unk
1a	Misc	TLC Kit (Eversource 0941)	Deemed	69	n/a	n/a	[1]	18	18	unk	25	unk	unk
1b	Misc	TLC Kit (Eversource 0971)	Deemed	69	n/a	n/a	[1]	18	18	unk	25	unnk	unk
1c	Misc	TLC Kit (CLC)	Deemed	152	n/a	863	[1]	126	128	unk	unk	126	unk
2	Lighting	Torchiere (2016)*	Deemed	55.1	n/a	n/a	[2]	211	211	unk	211	unk	unk
3	Lighting	CFL Bulb (2016)*	Deemed	40.8	n/a	n/a	[2]	47.9	48.5	unk	41	48.5	41
4	Lighting	LED Bulb (2016)*	Deemed	55.1	n/a	n/a	[2]	51.5	54.7	unk	41	54.7	54.7
5	Lighting	Common Area Fixture (Exterior)	Deemed	571	n/a	n/a	[10]	100.5	100.5	unk	unk	unk	unk
6	Lighting	Common Area Fixture (Interior)	Deemed	280	n/a	n/a	[10]	140	140	unk	unk	unk	unk
7	Wx	Air Sealing, Electric	User Input	338	n/a	n/a	[9]	n/a	n/a	unk	unk	unk	309
8	Wx	Insulation, Electric	User Input	1,377	n/a	n/a	[9]	n/a	n/a	unk	unk	unk	unk
9	HVAC	Heating System Retrofit	Deemed	133	n/a	n/a	***	132	133	unk	unk	unk	unk
10	HVAC	Thermostat, Electric	Deemed	257	n/a	n/a	***	257	257	unk	257	unk	257
11	HVAC	Demand Circulator, Electric	User Input	560	n/a	n/a	[11]	n/a	n/a	unk	5,320	unk	5,320
12	HVAC	Pipe Wrap, Electric	Deemed	129	n/a	n/a	***	129	129	unk	unk	129	unk
13	DHW	Heat Pump Water Heaters (50 Gallon)	Deemed	1,687	n/a	n/a	[3]	1,775	1,775	unk	1,775	unk	unk
14	DHW	DHW Tank Wrap, Electric	Deemed	73	n/a	n/a	[4]	73	73	55	134	unk	unk
15	DHW	Showerhead, Electric	Deemed	217	n/a	1,759	[5]	129	129	129	unk	unk	129
16	DHW	Faucet Aerator (All), Electric	Deemed	62	n/a	708	[5]	97	97	97	unk	unk	97
17	DHW	Faucet Aerator (Kitchen), Electric	Deemed	106	n/a	1,133	[5]	97	97	97	unk	unk	97
18	DHW	Faucet Aerator (Bathroom), Electric	Deemed	31	n/a	416	[5]	97	97	97	unk	unk	97
19	Appliances	Window AC Replacement	Deemed	113	n/a	n/a	[6]	204	204	unk	204	unk	204
20	Appliances	Refrigerator	Deemed	330	n/a	n/a	[7]	645	645	unk	645	762	unk
21	Appliances	2nd Refrigerator Removal	Deemed	874	n/a	n/a	[7]	1,180	1,180	unk	645	1,180	unk
22	Appliances	Freezer Replacement	Deemed	158	n/a	n/a	[7]	239	239	unk	637	unk	637
23	Appliances	Clothes Washer	Deemed	318	13	6,948	[8]	1,218	1,218	unk	unk	unk	1,218
24	Appliances	Smart Strip	Deemed	79	n/a	n/a	***	79	79	79	79	79	79
25	Appliances	Waterbed	Deemed	872	n/a	n/a	***	872	872	unk	872	unk	unk

NOTES:

*	Indicates that deemed savings value is dependent on the selected program year
***	Proposed deemed savings values are the same or similar to the values used in 2013.

Figure 14. Deemed Savings Summary - Gas

Deemed Savings Summary for LIMF Program (Gas)																
Program year:		2016														
				Proposed Values for PY2016+				Existing Values for Comparison								
#	End-Use	Measure	Type	Annual Savings Value			NOTES	MA TRM (therm/year)		2013 Savings Estimates by PA (therm/year)						
				kWh	therms	water		2014	2013	NGRID	Eversource	CMA	Unitil	Berkshire	Liberty
1	HVAC	Thermostat, Gas	Deemed	25	22.6	n/a	***	23	23	unk	unk	unk	23	unk	unk
2	HVAC	Pipe Wrap, Gas	Deemed	n/a	11.4	n/a	***	11.4	11.4	1.6*	unk	unk	unk	unk	unk
3	DHW	Showerhead, Gas	Deemed	n/a	10.7	1,759	[5]	11.4	11.4	8.6	unk	unk	5.0	unk	unk
4	DHW	Faucet Aerator (All), Gas	Deemed	n/a	3.0	708	[5]	8.6	8.6	5.0	unk	unk	5.0	unk	unk
4a	DHW	Faucet Aerator (Kitchen), Gas	Deemed	n/a	5.2	1,133	[5]	8.6	8.6	5.0	unk	unk	5.0	unk	unk
4b	DHW	Faucet Aerator (Bathroom), Gas	Deemed	n/a	1.6	416	[5]	8.6	8.6	5.0	unk	unk	5.0	unk	unk

*** Proposed deemed savings values are the same or similar to the values used in 2013.

Appendix B. Billing Analysis Model Specification

PRISM Model

The evaluation team used the heating PRISM model to estimate savings in both the pre- and post-period for each customer (i.e., facility) using the following specification:

$$ADC_{it} = \alpha_i + \beta_1 AVGHDD_{it} + \varepsilon_{it}$$

Where, for each facility "i", calendar month "t", and HDD base:

ADC_{it}	=	average daily therm consumption in the pre- or post-initiative period.
α_i	=	the participant intercept, representing the average daily therm base load.
β_1	=	the model space heating slope.
$AVGHDD_{it}$	=	the variable base 50 to 65 average daily HDDs for the specific location.
ε_{it}	=	the error term.

Using the above models, the team calculated weather-NAC using the following equation:

$$NAC_i = \alpha_i * 365 + \beta_1 LRHDD_{it} + \varepsilon_{it}$$

Where, for each facility "i":

NAC_i	=	normalized annual therm consumption.
α_I	=	the intercept equaling the average daily or base load for each participant, representing the average daily base load from the model.
$\alpha_i * 365$	=	annual base-load therm usage (non-weather sensitive).
β_1	=	the heating slope (in effect, usage per heating degree from the model above).
$LRHDD_i$	=	the annual, long-term HDDs (base 50 to 65) of a TMY3 in the 1991–2005 series from NOAA, based on home location
$\beta_1 * LRHDD_i$	=	weather-normalized, annual weather-sensitive (heating) usage (i.e., HEATNAC)
ε_I	=	the error term

After running through all models across variable HDD base temperatures, the best model for each facility "i" is the model with highest R-squared.

Combined Fixed-Effects Model

To estimate gas energy savings, the team used a pre- and post-installation savings analysis fixed-effects modeling method, which used pooled monthly time-series (panel) billing data. The fixed-effects modeling approach corrected for the following:

1. Differences between pre- and post-installation weather conditions; and

2. Differences in usage consumption between participants, through inclusion of a separate intercept for each participant.

This modeling approach ensured that model savings estimates would not be skewed by unusually high-usage or low-usage participants. The following model specification determined overall savings:

$$ADC_{it} = \alpha_i + \Phi_i AVGHDD_{it} + \beta_1 POST_i + \beta_2 POST_i * AVGHDD_{it} + \varepsilon_{it}$$

Where for each facility "i" and monthly billing period "t":

ADC_{it}	=	the average daily therm consumption during the pre- or post-installation initiative period.
α_i	=	the average daily therm base-load intercept for each customer. (This is part of the fixed-effects specification.)
Φ_i	=	the baseline usage per HDD for each customer.
$AVGHDD_{it}$	=	the average daily PRISM base HDDs, based on home location.
β_1	=	the average daily whole-house base-load therm savings.
$POST_i$	=	an indicator variable that is 1 in the post-period (after the latest measure installation) and 0 in the pre-period (prior to participation).
β_2	=	the whole-house heating therm savings per heating degree-day.
$POST_i * AVGHDD_{it}$	=	an interaction between the *POST* indicator variable and the average daily PRISM base heating degree-days (*AVGHDD*).
ε_{it}	=	the modeling estimation error.

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Appendix D. Billing Analysis – Supplemental Results

Measure-Level Modeling

The team estimated measure-level combined fixed-effects regression models in an effort to estimate gross impacts for key measure categories. These models relied on the state-level participant group to provide a higher frequency of measures and utilize the largest available sample. The measure-level analysis uses measure-specific indicators as model parameters and considered their interactions with heating degree days.

Due to the holistic natural of the LIMF initiative, projects often received comprehensive measure bundles, including combinations of shell measures and equipment replacement. This substantial overlap proved challenging to isolate the effects of unique measure categories through this analytical approach, which relies on observing sufficient variation across categories. Table 31 provides

Table 31. Measure Installation Overlap (Percent of Units)

Measure	Air Sealing	Insulation	Heating System Replacement	Water Heating Replacement	Water Heating All
Air Sealing	100%	87%	32%	30%	67%
Insulation	98%	100%	27%	24%	64%
Heating System Replacement	46%	35%	100%	81%	85%
Water Heating Replacement	46%	32%	85%	100%	100%
Water Heating All	62%	53%	56%	62%	100%

For example, participants showed installation of air sealing and insulation together in high frequency. Due to this overlap, the models cannot disentangle the impacts of the two separately. As a results, the team ran a series of diagnostics considering these combinations and whether category-specific results were feasible.

After reviewing frequency of measure installation and overlap across the analysis sample, the team determined three key measure category combinations resulting in the best overall models.

Table 32 provides model results for these measure categories.

Table 32. Measure-Level Gas Savings Impacts

Measure Category	% units	PRENAC	Model Savings (Therms)	Savings % of PRENAC	Relative Precision	*Ex Ante* Savings (Therms)	Realization Rate
Shell + Other*	72%	644	76	12%	±24%	103	74%
Heating system replacement	44%	631	88	14%	±33%	92	96%
Water heating measures	67%	627	48	8%	±57%	57	85%
Overall Fixed Effects CSA		**615**	**125**	**20%**	**±12%**	**158**	**79%**
Overall PRISM		**609**	**126**	**21%**	**±8%**	**158**	**80%**

*The category "Other" could not be split from other shell measures due to collinearity between the groups. This category includes insulation, air sealing, and other (including custom projects, HVAC tune-up/repair, duct insulation/sealing, thermostats, windows, and other shell measures [e.g., attic hatch, doors]).

Despite varying precisions around the measure category-level outputs, the overall combined CSA model demonstrated model estimates nearly identical to the PRISM results. Measure model outputs showed high realization rates for heating system replacement and water heating measures (including equipment replacement and instant savings measures, such as aerators, showerheads, and pipe insulation).