RLPNC 17-14: Massachusetts Residential New Construction Incremental Cost

FINAL REPORT

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SUBMITTED TO:
The Massachusetts Electric and Gas Program Administrators

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Executive Summary

The goal of this study is to document the incremental costs associated with participating in the Massachusetts Residential New Construction (RNC) Low-Rise Path and Multifamily High-Rise (MFHR) programs for the Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants. Specifically, this study identifies the incremental costs associated with moving from baseline new construction practices to common practices identified in program participant housing units. This report addresses incremental costs for single-family detached homes, single-family attached homes, low-rise [1] multifamily housing units, and high-rise [2] multifamily buildings.

This study answers the following research questions:

- What are the incremental costs per square foot to move from baseline construction practices to construction practices commonly found in RNC and MFHR participant projects?
- How do incremental costs vary for different building types?
- How do incremental costs vary by measure and efficiency level?
- How do current incremental costs compare to historical incremental costs for the RNC market?

Methodology

The team used a combination of baseline study results and program records to assess the key differences between projects that participate in the RNC programs (both low-rise and MFHR) and those that do not. The team used these data to develop cost templates that were provided to a variety of contractors with expertise in the RNC market. Contractors provided measure-level cost estimates for both baseline construction practices and RNC participant construction practices. These templates were then aggregated to calculate the average incremental costs associated with participating in the low-rise and MFHR RNC programs. More details on the study methods can be found in sections 1.3 and 2.1 of this report.

Program Samples

Low-Rise Sample

The team leveraged 2016 and 2017 program records (3,268 REM/Rate files) to determine the mix of housing types participating in the low-rise path of the RNC program, the range of savings over the RNC User Defined Reference Home (UDRH), and the most common measures and associated efficiency levels installed in participating projects. Figure 1 presents the proportion of

[1] Buildings with three stories or less.
[2] Buildings with four or more stories.

housing types that were identified in the low-rise sample. As shown, single-family detached homes (68%) represent the majority of program housing units.

Figure 1: Percent of Low-Rise Housing Types

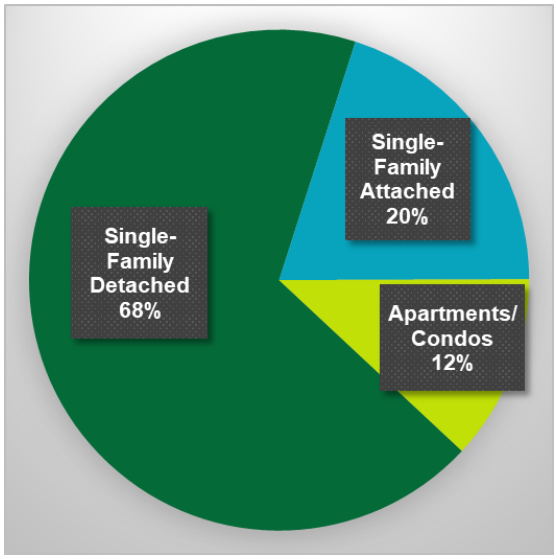
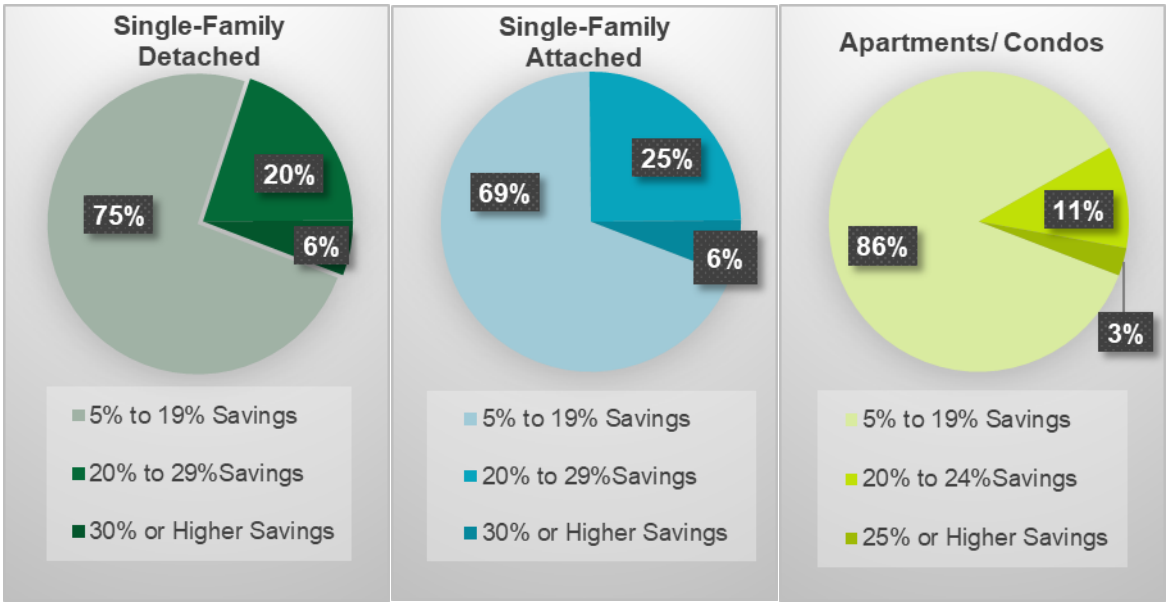


Figure 2 presents the energy efficiency level savings ranges that were used to guide our analyses. The majority of housing units, regardless of housing type, fall into the lowest savings range of 5-19%.

Figure 2: Percent of Low-Rise Housing Types in Efficiency Level Savings Ranges

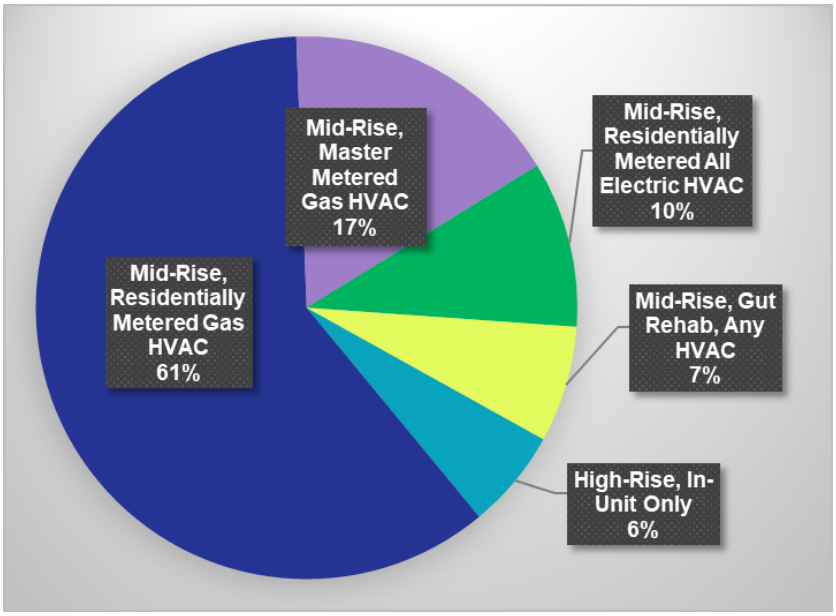


Multifamily High-Rise Sample

The team reviewed program documentation for 72 projects that participated in the 2017 MFHR program. The team used this documentation to identify the measures most frequently incentivized

by the program, as well as the associated efficiencies. Figure 3 presents the distribution of participants' projects by various project types that typically enroll in the MFHR program.

Figure 3: Distribution of Evaluated Projects



FINDINGS

Low-Rise Findings

Figure 4 presents the overall incremental cost per square foot for each housing type and efficiency level. Incremental costs range from a low of $1.42 per square foot for starting efficiency single-family attached homes to a high of $4.12 per square foot for high efficiency apartments and condominiums.

Figure 4: Incremental Cost per Square Foot by Housing Type and Efficiency Level

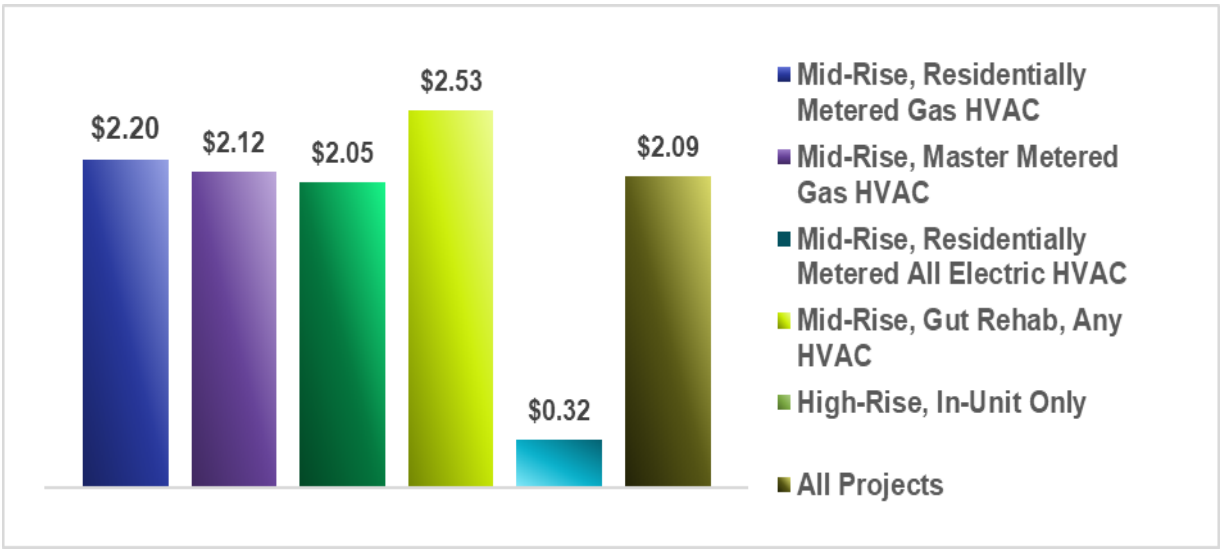
Figure 5 shows average incremental costs per square foot by housing type. In this case, each housing type includes the homes in all three efficiency levels. As shown, the average incremental cost per square foot ranges from $1.66 for single-family attached homes to $2.25 for apartments and condominiums. The average for all homes is $2.00.

Figure 5: Incremental Cost per Square foot by Housing Type and All Homes

MFHR Findings

Figure 6 presents the overall incremental costs associated with program participants when compared to the current program baseline assumptions. As shown, the overall incremental cost is $2.09 per square foot. Projects participating in the "in-unit only" program path have the lowest incremental cost ($0.32 per square foot), while all other project types have incremental costs between $2.05 and $2.53 per square foot. It should be noted that in-unit only projects typically receive building-level incentives through a custom commercial and industrial incentive program.

Figure 6: Overall MFHR Incremental Cost ($/Sq. Ft.)



CONCLUSIONS, RECOMMENDATIONS, AND CONSIDERATIONS

Based on the findings from this study, we offer the following conclusions, recommendations, and considerations.

Conclusion: The incremental cost associated with participating in the low-rise path program is $2.00 per square foot across all housing types. Single-family detached homes, the most common type of participating housing unit (68% of program participants), have incremental costs ranging from $1.90 per square foot for the starting participation efficiency range level to $3.19 per square foot for the highest participating efficiency range level.

Conclusion: The overall incremental cost associated with participating in the MFHR is $2.09 per square foot for all project types. Building participant projects have incremental costs ranging from $2.05 per square foot for mid-rise buildings with all electric mechanical equipment to $2.53 per square foot for mid-rise gut rehab projects. Projects participating in the "in-unit only" path have the lowest incremental cost ($0.32 per square foot).

Conclusion: Recruiting contractors to estimate building costs can be extremely difficult, primarily due to time constraints and sensitivity to releasing price information.

> **Consideration:** Future evaluations should consider the following approach for contractor recruitment efforts, particularly when they involve cost information.
>
> - Call the contractor or business and set up a time to either visit in person or schedule a phone call to review the template.
> - Offer non-disclosure agreements to verify anonymous cost data (this was offered to potential recruits later in the recruitment process).
> - Consider requiring program home builders to provide sub-contractor information. This would aid several types of evaluations in recruiting specific contractor types.
> - Try to avoid recruiting contractors during their busiest seasons (varies by sector).

Conclusion: It came to the attention of the evaluation team that there have been issues regarding the allocation of incremental costs across electric and gas PAs in the past.

> **Recommendation:** The evaluation team recommends that the PAs allocate incremental costs based on the relative proportion of incentives provided for both the low-rise and MFHR programs. For example, if the electric PAs pay 40% of the incentives for all low-rise housing units (overall incremental cost of $2.00 per square foot) and the gas PAs pay 60% of the incentives, then the electric PAs would account for an incremental cost of $0.80 per square foot and the gas PAs would account for $1.20 per square foot.

Section 1 Low-Rise Incremental Cost

This section focuses on the Massachusetts Residential New Construction (RNC) Program Low-Rise Path, which addresses housing in buildings with three stories or less. Specifically, this study identifies the incremental costs associated with moving from baseline new construction practices to common practices identified in program participant housing units.

- Section 1.1 describes the sample of program homes we worked with.
- Section 1.2 describes the measures and upgrade specifications we addressed.
- Section 1.3 describes the approach we used to estimate the incremental cost associated with building a home that participates in the low-rise RNC program versus building a home built to baseline specifications.
- Section 1.4 describes how the team analyzed the data and calculated incremental costs per square foot.
- Section 1.5 presents study results and how they compare to the 2013 RNC incremental cost study findings.[3]
    - There are key differences in the current program requirements and those that were in place during the 2013 study. In addition, the current study handled low-rise multifamily incremental costs differently than the previous study. These differences are explained in detail in Section 1.5.2 and should be considered when reviewing comparisons between the two studies.

1.1 Program Homes – Our Sample

ICF provided REM/Rate® data for 3,268 program homes.[4] This data set included all housing units that enrolled in the program in 2016 or 2017 and were completed by the end of February 2017. We assume the measures incorporated in these housing units are representative of the measures being implemented in housing units participating in 2018.

The Team looked at three housing types: single-family detached, single-family attached, and apartments and condominiums in multifamily buildings with three stories or less. For each housing type, we looked at three energy efficiency level ranges; these ranges are defined based on the percent savings above the UDRH. For each housing type, the energy efficiency level ranges begin at 5% savings above the UDRH, as that is the current program minimum requirement (Table 1).

[3] http://ma-eeac.org/wordpress/wp-content/uploads/Residential-New-Construction-Program-Incremental-Cost-Final-Report-6.11.13.pdf

[4] REM/Rate is energy modeling software that is commonly used to develop Home Energy Rating System (HERS) scores for new housing units.

Table 1: Efficiency Level Savings Ranges

Efficiency Levels	Single-Family Detached Homes Percent Savings above UDRH	Single-Family Attached Homes Percent Savings above UDRH	Apartments and Condominiums 1-3 Story Buildings Percent Savings above UDRH
Starting Efficiency	5% to 19%	5% to 19%	5% to 19%
Medium Efficiency	20% to 29%	20% to 29%	20% to 24%
High Efficiency	30% or Higher	30% or Higher	25% or Higher
All Efficiency Levels	**5% to 53%**	**5% to 42%**	**5% to 39%**

Figure 7 shows the percentage of each housing type in the program sample, and Figure 8 shows the percentage of each home type falling into each efficiency level. As shown, the majority of homes (68%) are single-family detached, and the majority of all home types (69% to 86%) fall in the 5% to 19% savings range. Overall, just over half (51%) of all housing units are single-family detached homes with 5% to 19% savings.

Figure 7: Percent of Housing Types

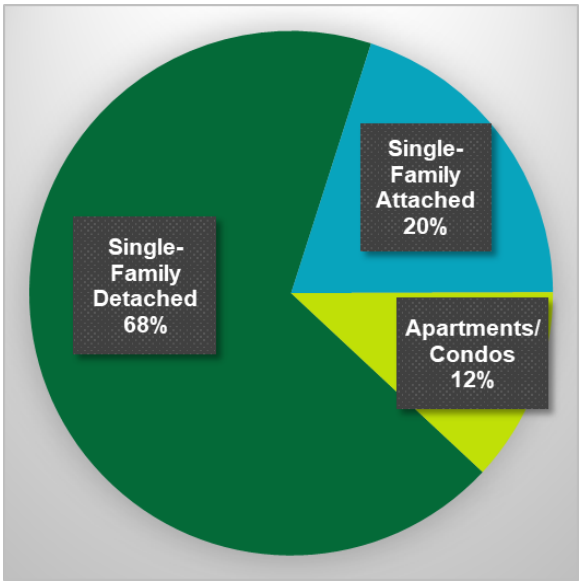
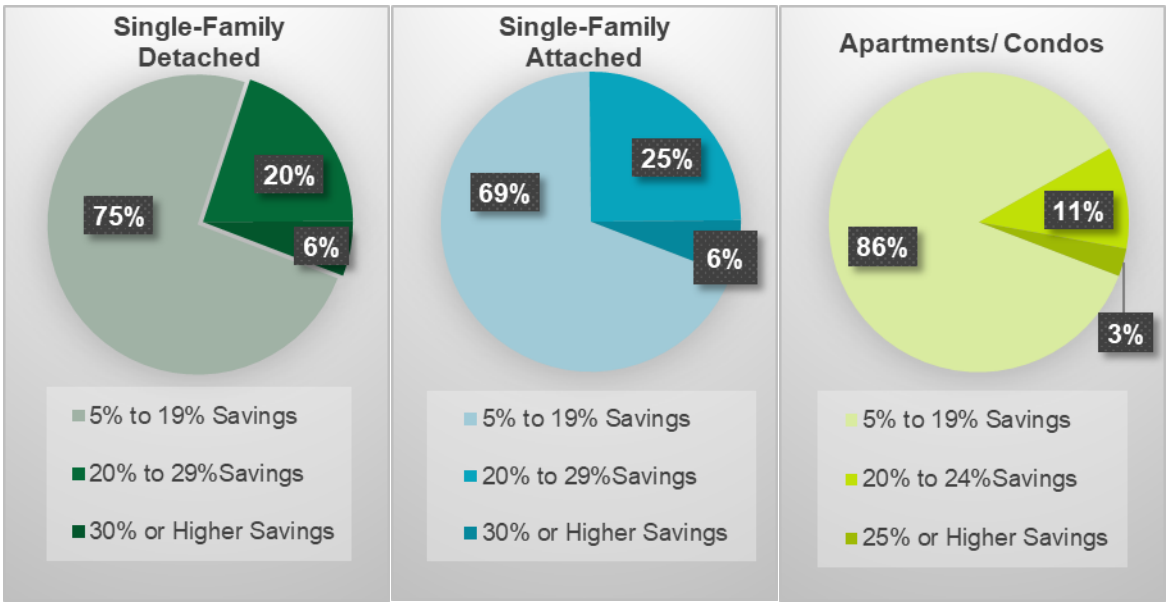


Figure 8: Percent of Housing Types in Efficiency Level Saving Ranges



1.2 MEASURES AND SPECIFICATIONS

Given the high number of building components and practices that affect new construction efficiency, it was important to prioritize identifying those that have the most impact on energy efficiency and are common practice in program homes. The team analyzed the program home sample data to ensure that the measures selected for the incremental cost analysis met these criteria. Table 2 shows the measures addressed in this study and the percentages of program homes with these measures. As shown, the listed measures represent the heating systems, cooling systems, water heaters, and ventilation systems that are installed in at least 92% of all program homes.

Table 2: Measures Addressed

Home Characteristic	Variation	Program Housing Units Signed & Completed in 2016 & 2017	
		Number of Housing Units	Percent of Housing Units
Heating System Types	Gas Furnace	2,611	80%
	Gas Boiler	379	12%
Cooling System Types	Central Air Conditioner or ASHP	2,943	90%
	No Central Air Conditioning	288	9%
Water Heater Types	Instantaneous Gas	1,906	58%
	Conventional Gas	661	20%
	HPWH	486	15%
Shell Measures	Conditioned/Ambient Walls	3,268	100%
	Flat Ceilings	2,274	70%
	Vaulted Ceilings	1,988	61%
	Floors over Unconditioned Basement	1,880	58%
	Windows	3,268	100%
Air Infiltration	ACH50 Air Changes per Hour at 50 Pascals	3,268	100%
Duct Leakage	Duct Leakage to the Outside CFM per 100 Sq. Ft. of CFA at 25 Pascals	3,120	95%
Mechanical Ventilation	Bath Fans Controlled by Timer or Continuous Operation	3,227	92%
	HRV or ERV	217	7%

This study does not include primary research to address the incremental costs of residential lighting measures. Instead, estimates of residential lighting incremental costs are based on the current lighting-specific evaluation – the RLPNC 17-15 Shelf Stocking report.[5] The methods and results of the separate incremental lighting cost analysis are presented in Appendix A.

Once the measures were identified, the team specified the upgrade efficiencies for each measure to reflect common practices in program homes. Tables showing the baseline and upgrade

[5] The RLPNC 17-15 Shelf Stocking report is currently an on-going study that provides recent lighting cost data.

specifications for each measure, along with the incremental cost per square foot for the upgrades, are provided in Appendix C. Table 3 is an example of the information provided in Appendix C, showing the specifications for windows. The following section provides more detailed information on how we developed the upgrade specifications.

Table 3: Window Specifications

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Single-Family Detached Homes			
3,000 Square Feet	U-30 SHGC[6] 30	U-29 SHGC 28	$0.91
3,000 Square Feet	U-30 SHGC 30	U-26 SHGC 29	$1.69
Single-Family Attached Homes			
2,200 Square Feet	U-30 SHGC 30	U-29 SHGC 28	$0.79
2,200 Square Feet	U-30 SHGC 30	U-28 SHGC 28	$0.83
Apartments/Condos			
1,300 Square Feet	U-30 SHGC 30	U-29 SHGC 29	$0.96
1,300 Square Feet	U-30 SHGC 30	U-28 SHGC 28	$1.05
1,300 Square Feet	U-30 SHGC 30	U-26 SHGC 32	$1.78

1.3 METHODOLOGY

This section describes the approach the team used to estimate the incremental cost associated with building a home that participates in the low-rise RNC program versus building a home built to baseline specifications. The baseline specifications are based on the 2017 RNC program UDRH.[7] The team calculated incremental costs using a dollar per square foot metric.

As described earlier, the team developed a list of efficiency measures based on a review of program home sample data. The team worked directly with building contractors to procure information on the cost for each measure. The team asked contractors to provide baseline measure costs (based on UDRH specified efficiencies) and upgrade measure costs (based on the increased efficiencies associated with program housing units). The team aggregated measure-level costs to develop incremental cost values for single-family detached homes, single-family attached homes, and apartments/condominiums.

[6] SHGC is Solar Heat Gain Coefficient. It is a criterion in establishing window ENERGY STAR qualification. The **SHGC** is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. **SHGC** is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits.

[7] http://ma-eeac.org/wordpress/wp-content/uploads/Single-Family-Code-Compliance-Baseline-Study-Volume-5-2.pdf

The processes for developing measure-level efficiency specifications, developing contractor templates, recruiting contractors, and conducting secondary research are described in more detail in the sections below.

1.3.1 Measure Level Specifications

The team reviewed REM/Rate data for the 3,268 program homes that enrolled in the 2016 and 2017 low-rise RNC program and were completed by the end of February 2017. We reviewed the data to identify measures and/or system types and efficiency levels that were most reflective of the sample population. The identified measures are included in the incremental cost analysis (see Table 2). The team divided the sample by home type (i.e., single-family detached homes, single-family attached homes, and apartments/condominiums) and split each of these home types into three efficiency levels (described earlier), defined by the energy savings achieved over the UDRH (see Table 1).

For each measure, the team calculated the average efficiencies and equipment capacities (where relevant) for homes in each home type efficiency level. In addition, the team calculated the average home size (in square feet) for homes in each home type efficiency level. The team compared the average efficiencies for each measure to the UDRH-specific values. We used measures with specifications that were more efficient than the UDRH to develop contractor templates. In general, we considered efficiency levels with average measure-level efficiencies the same or lower than UDRH values to have no incremental cost. However, for heating and cooling systems, the baseline and upgrade specifications included both efficiency and capacity. In these cases, it is possible the increased cost of a higher efficiency unit is less than the decreased cost of a lower capacity unit, resulting in a negative incremental cost. The measure-level specifications and average incremental cost per square foot for all home types and energy savings levels are presented in Appendix C.

1.3.2 Contractor Templates

The team developed building contractor templates using the measure-level specifications identified for all home types and efficiency levels. Each template had the average program home size (for homes with a given measure) or the average square feet of insulated area for insulation shell measures, the UDRH efficiency value (base specification), and the program efficiency value (upgrade specification) for each efficiency level. The team provided additional information beyond efficiency specifications that may affect costs, such as equipment capacity, within the template on a measure by measure basis. The additional information was based on program data or leveraged from the 2015-16 Massachusetts Single-Family Code Compliance/Baseline Study[8] if program data were not available. The template allowed contractors to input additional information (e.g., manufacturer, model number, project scope notes, etc.), as appropriate, and costs for both the base efficiency case and the upgrade case. The measure-level incremental cost per square foot was calculated automatically within each of the templates. The low-rise contractor templates were provided to the PAs and EEAC consultants on December 21, 2017 (see Appendix E).

[8] http://ma-eeac.org/wordpress/wp-content/uploads/Single-Family-Code-Compliance-Baseline-Study-Volume-2.pdf

1.3.3 Contractor Recruitment

To populate the contractor templates, the team recruited a variety of contractors from across the state who were actively involved in the RNC market. The team targeted a total sample size of five unaffiliated contractor responses per measure. We bundled the templates together based on contractor specialty. For example, HVAC contractors received the heating, cooling, water heating, ventilation, and duct leakage templates.

The team utilized a multi-method recruiting approach to obtain the targeted sample sizes. When we were unable to procure the targeted number of contractor responses, we had to supplement those we received with secondary research. The team offered HVAC and insulation contractors a $500 honorarium[9] for completing contractor templates. As part of the recruitment process, the team identified contractors who were actively engaged in new construction projects and who installed the specific measures included in the templates. The team initially targeted program participant contractors, but we generated additional samples as needed.[10] The team primarily used phone and email recruitment tactics; however, in-person visits[11] were conducted as a final recruiting strategy.

Contractor recruitment proved to be challenging for a variety of reasons. The first challenge of the recruitment process was finding responsive contractors. Once contact was made, the contractor had to meet the screening requirements (mentioned above). We informed contractors that any data they provided would be anonymous and aggregated with other responses. However, contractors were generally unwilling to participate. Contractors typically gave the following reasons when explaining their unwillingness to participate:

- Resistance to giving out cost data (proprietary information)
- Insufficient time to complete the templates due to high workloads
- Flat refusals
- An agreement to participate, but never completing the templates

Over 120 contractors were contacted multiple times by phone, email, and personal visits. On at least six separate occasions, the team procured agreement from the contractor to participate only to have the contractor later drop out of the study. The team added the in-person visits in the final phase of our recruiting effort, which resulted in achieving our target sample size for all insulation measures. The total recruitment period lasted over two months. The team gave contractors up to two weeks to complete the template, but contractor attrition extended the recruitment period. The team used secondary research to supplement contractor estimates for measures that did not have five contractor responses. Table 4 provides the contractor response count per measure.

[9] The team offered an alternative honorarium of $100 per completed template to contractors who were only able to complete one or two individual templates.
[10] After available program participant contact information was exhausted, the team opened the recruitment to all types of building contractors that met the screening requirements.
[11] The team conducted in-person visits at plumbing supply houses, lumber yards, building supply stores, and insulation contractor offices.

Table 4: Contractor and Secondary Research Responses

Contractor Responses		Program Measures	Number of Contractor Templates	Secondary Research Templates
Contractor Types	Secondary Research Description			
Shell Measures				
Five unaffiliated insulation contractors and building suppliers (windows) completed the incremental cost template.	**Windows: internet research and one-off quotes from building supply companies.**	Conditioned Walls	5	NA
		Flat Ceiling	5	NA
		Cathedral Ceiling	5	NA
		Framed Floor	5	NA
		Higher Efficiency Windows	3	2
HVAC Measures				
Five unaffiliated HVAC contractors completed HVAC measure templates. Two contractors only installed heating and cooling measures.	**Internet research on equipment cost data was gathered for base and upgrade efficiency values. Secondary templates considered the same manufacturer for all efficiency options when data were available.[1]**	Gas Furnace	5	NA
		Gas Boiler	4	1
		Central AC	5	NA
		ASHP - Cooling	5	NA
		Instantaneous Gas WH	3	2
		Conventional Gas WH	3	2
		Heat Pump Water Heater	3	2
Additional Measures				
Insulation Contractors estimated ACH50, while HVAC contractors estimated ventilation and LTO costs.	**Multiple methods were used for secondary research for the additional measures category. Additional details will be provided in the full report.**	Duct Leakage CFM25/100 ft^2	2	3
		Air Infiltration ACH50	3	2
		Ventilation – Bath Fans	1	3
		Ventilation - HRVs	1	4
		Lighting[2]	NA	NA

[1] When no cost data were available from a manufacturer for a certain specification, the team used a similar manufacturer's cost data.

[2] Incremental lighting costs leveraged bulb cost data from the RLPNC 17-15 Shelf Stocking evaluation.

1.3.4 Secondary Research

The team conducted secondary research when we did not receive five completed contractor templates for a measure. Secondary research consisted of completing a contractor template using internet research for cost data. The secondary research templates attempted to use the same

manufacturer for any given template, but this was not always possible for a variety of reasons (e.g., no cost data available for a given specification, no model that met the template specifications). In these cases, we used data from a similar priced manufacturer to build a complete template. The team used this method to supplement contractor responses for water heating equipment, ventilation, boilers, and windows.

The team used a different approach for air infiltration and duct leakage. For these measures, we assumed a labor rate per hour and estimated the hours of work required to achieve the specified air or duct leakage levels. The team based the assumed labor estimates on conversations with participating HVAC contractors and HERS raters

1.4 INCREMENTAL COST ANALYSIS

This section describes how we calculated overall incremental costs per square foot for each of the three efficiency savings level ranges for each of the three low-rise sector housing types – single-family detached, single-family attached, and apartments and condos in one to three story multifamily buildings. Data from the contractors provided the incremental cost per square foot for each measure, home type, and efficiency level. For measures that all homes have (windows and air leakage), the final incremental costs per square foot come directly from the completed contractor templates.

However, not all homes have all the measures that were considered as part of this study. For example, not all homes have ducts. For duct leakage upgrades, we multiplied the average incremental cost per square foot from the completed contractor templates by the square footage of homes with ducts to calculate the total cost of the upgrades for the group of homes being analyzed. We then divided that by the total square footage of all homes in the group to calculate an average cost per square foot for all homes in the group. The equation below presents an example of how the overall duct leakage upgrade incremental cost would be calculated for a specific group of homes, for example high efficiency single-family detached homes.

$$Overall\ Inc.Cost\ per\ Sq.Ft. = \frac{Duct\ Leakage\ Inc.Cost\ per\ Sq.Ft.\ x\ Sq.Ft.of\ Homes\ with\ Ducts}{Sq.Ft.of\ All\ Homes\ in\ Group\ Being\ Analyzed}$$

This approach is consistent with what was done in the last incremental cost study[12] that showed incremental cost per square foot spread over all homes, not just the homes that had a given measure. Using the same approach enables us to make reasonable comparisons between the results of the two studies.

Not all homes have flat ceilings, vaulted ceilings, or floors over unconditioned basements. Almost one-third (30%) of program homes in our sample do not have flat ceilings, 39% do not have vaulted ceilings, and 42% do not have floors over an unconditioned basement. For all insulation

[12] http://ma-eeac.org/wordpress/wp-content/uploads/Residential-New-Construction-Program-Incremental-Cost-Final-Report-6.11.13.pdf

measures, including conditioned/ambient walls, which all homes have, contractors provided estimates of the incremental cost of upgrades per square foot of insulated area. We multiplied these estimates by the square footage of insulated area to calculate the total incremental cost for each group being analyzed and divided that by the total square footage of the homes in the group to calculate an average cost per square foot for all homes.

Heating, cooling, water heating, and ventilation measures vary among the program homes in terms of what components and mechanical system types (e.g., gas furnace vs. gas boiler) are present. To address this issue, we assessed incremental costs for the most prevalent individual building components and technologies and weighted the results to represent program distributions.

- For heating systems, we looked at natural gas and propane furnaces and boilers. These heating systems provided all heating in 92% of program homes in our sample.
- For water heating systems, we looked at instantaneous gas, conventional gas, and electric heat pump water heaters. These water heating systems provided all water heating in 93% of program homes in our sample.
- For ventilation, we looked at bathroom fans and heat recovery ventilation (HRV) systems.[13] These types of ventilation provided all ventilation in 94% of program homes in our sample.

1.5 Low-Rise Results

This section presents the final incremental costs per square foot for the low-rise sector. We present results at two levels. The first level, shown in Figure 9, is the overall incremental cost per square foot for each housing type and efficiency level. Incremental costs range from a low of $1.42 per square foot for starting efficiency single-family attached homes to a high of $4.12 per square foot for high efficiency apartments and condominiums.

[13] ERV ventilation systems were considered to have no incremental cost, due to higher average efficiencies in baseline homes compared to program homes.

Figure 9: Incremental Cost per Square Foot by Housing Type and Efficiency Level

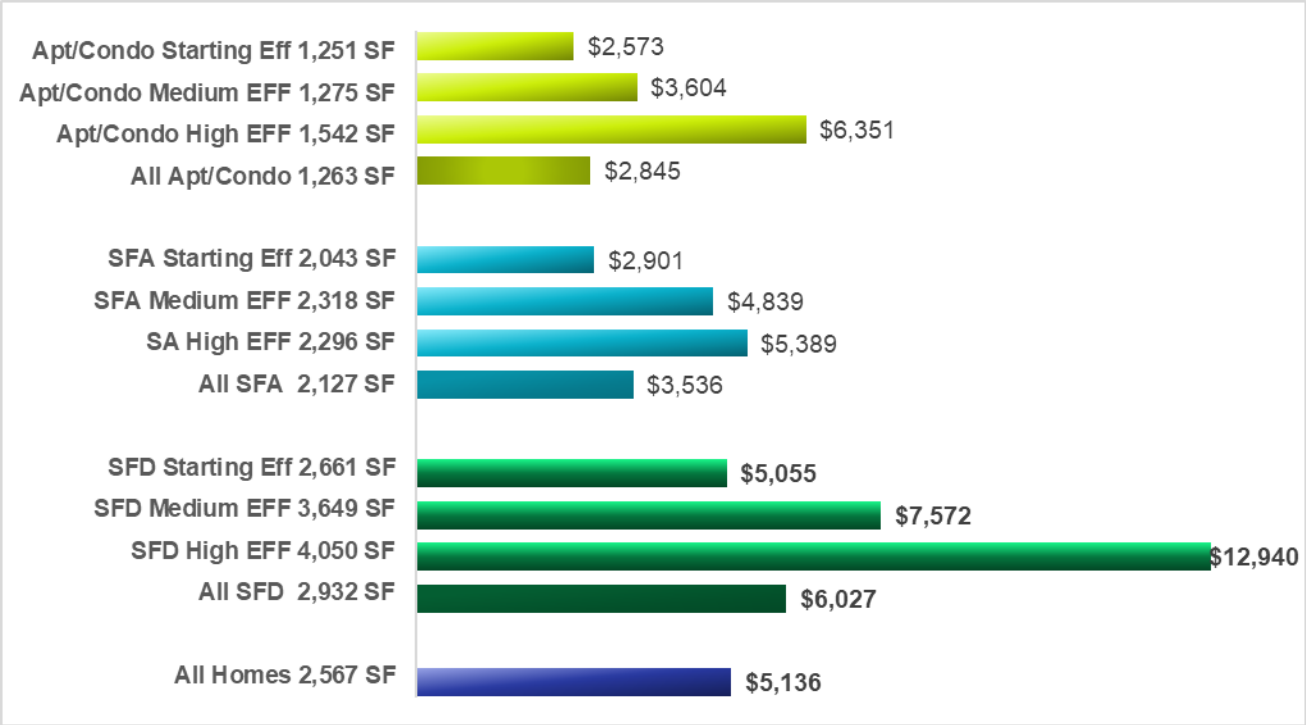
Figure 10 shows average incremental costs per square foot by housing type. In this case, each housing type includes the homes in all three efficiency levels. As shown, the average incremental cost per square foot ranges from $1.66 for single-family attached homes to $2.25 for apartments and condominiums. The average for all homes is $2.00.

Figure 10: Incremental Cost per Square Foot by Housing Type and All Homes

Detailed tables of incremental costs per square foot, by measure, for each home type and efficiency level are presented in Appendix D.

To determine how much it will cost a builder to move from building a baseline level home to a program level home, we multiplied the average incremental cost per square foot for each housing type/efficiency level group of homes by the average square footage of those homes. Figure 11 shows, logically, that the average cost per home increases for each housing type as the efficiency level climbs. The largest incremental cost is for the large (over 4,000 Sq. Ft.), high efficiency, single-family detached homes. The average incremental cost for all homes is just over $5,000.

Figure 11: Average Home Incremental Cost



1.5.1 Insulation Upgrade Cost

The PAs and EEAC consultants requested information on the cost per square foot of specific increases in the R-value of insulation in conditioned/ambient walls, flat ceilings, vaulted ceilings, and floors over unconditioned basements. The per square foot cost for an upgrade doesn't vary by the size of the area being insulated (see Appendix C). For each of these insulation categories, insulation contractors reported the same upgrade cost per square foot regardless of the size of the insulated area. Figure 12 shows the incremental cost per square foot for each insulation category and R-value upgrade. Table 5 shows the same information as Figure 12, along with the range of the sizes of insulated area we asked about for each upgrade.

Figure 12: Insulation Upgrade Cost per Square Foot

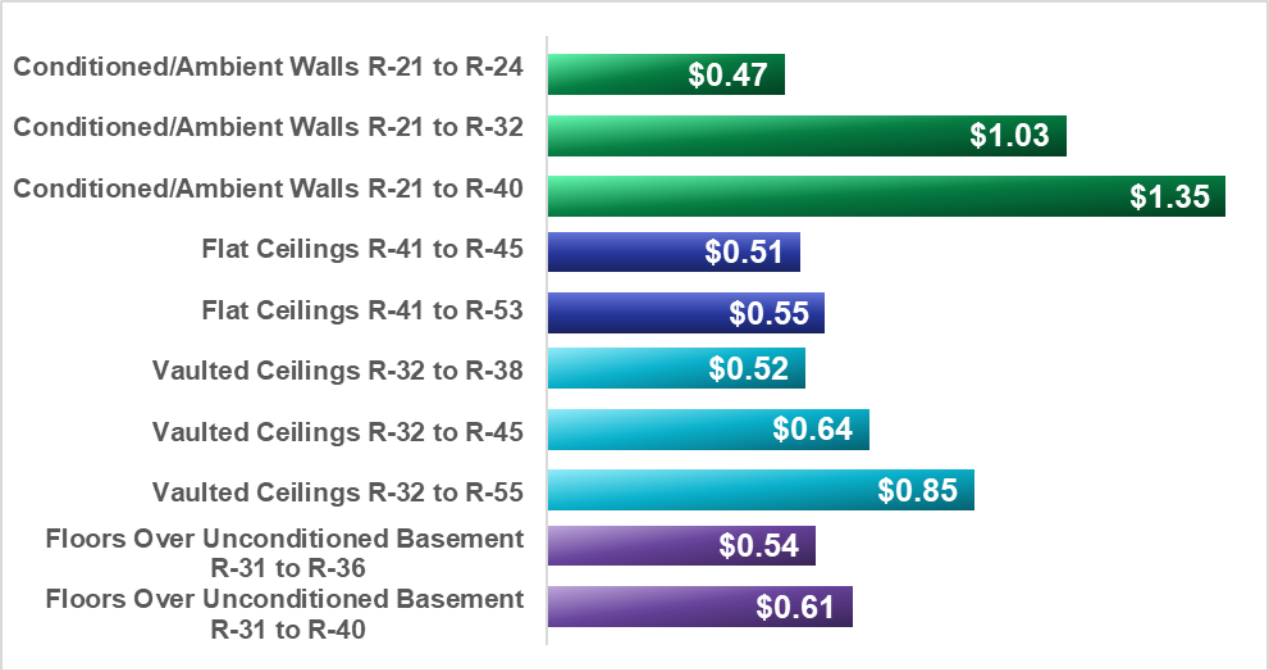


Table 5: Insulation R-Value Upgrades and Costs

Conditioned/Ambient Walls			
Upgrade	R-21 to R-24	R-21 to R-32	R-21 to R-40
Insulated Area Sq. Ft.	1,000 to 2,500	1,000 to 2,500	2,700
Upgrade Cost per Sq. Ft.	$0.47	$1.03	$1.35
Flat Ceilings			
Upgrade	R-41 to R-45	R-41 to R-53	
Insulated Area Sq. Ft.	1,000 to 1,500	1,000 to 1,500	
Upgrade Cost per Sq. Ft.	$0.51	$0.55	
Vaulted Ceilings			
Upgrade	R-32 to R-38	R-32 to R-45	R-32 to R-55
Insulated Area Sq. Ft.	1,000 to 1,500	1,000 to 1,500	1,000 to 1,500
Upgrade Cost per Sq. Ft.	$0.52	$0.64	$0.85
Floors over Unconditioned Basement			
Upgrade	R-31 to R-36	R-31 to R-40	
Insulated Area Sq. Ft.	1,000 to 1,500	1,000 to 1,500	
Upgrade Cost per Sq. Ft.	$0.54	$0.61	

1.5.2 Comparison to Previous Study

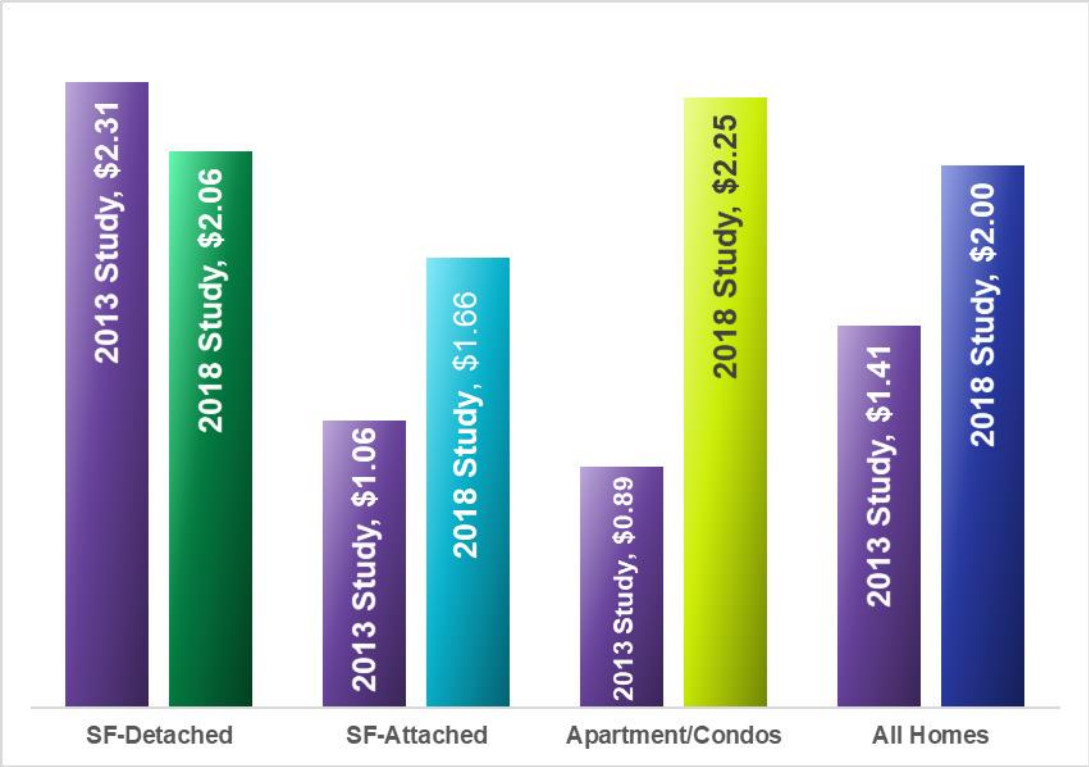
Before comparing the results of the current incremental cost study to the previous (2013) study, it is important to point out key differences between the two studies.

- The program home sample in the current study is 3,268 homes, almost two and a half times the number of homes in the 2013 study sample (1,316 homes).

- The 2013 study looked at one to three story multifamily **building** square footage, while the current study looked at only in-unit square footage.
- The three 2018 efficiency range savings levels are not the same as the three 2013 tier level savings ranges.

Figure 13 shows the average incremental costs per square foot for the three housing types and all homes for both studies. Compared to the previous study, current study incremental cost per square foot is slightly lower for single-family detached homes, notably higher for attached homes, and much higher for apartment/condominium housing. Overall, for all homes, the average incremental cost per square foot of $2.00 is 42% higher than the previous study average incremental cost of $1.41.

Figure 13: Comparison of Previous and Current Study Incremental Cost per Square Foot by Housing Type



The average incremental cost per square foot for all single family detached homes is down 13% from $2.31 in the 2013 study to $2.06 in the 2018 study. Readers familiar with the results of the 2013 study may find this confusing because the incremental cost per square foot of $1.90 for single family detached homes in the 2018 starting efficiency range (see Figure 9) is higher than the $1.19 incremental cost per square foot in the lowest savings range (Tier I) of the 2013 study. However, the Tier savings levels in the 2013 study and the saving levels in the 2018 study are so different that it is impossible to make useful comparisons between 2013 study tier and 2018 study efficiency level incremental cost per square foot. Using single-family detached (SFD) homes as an example:

- Of the 2018 study 1,658 SFD starting efficiency homes (5% to 19% savings):
  - Only 34% would have been 2013 study Tier I homes (15% to 29% savings).
  - Almost two-thirds (66%) would not have been included in the 2013 study because they had savings of less than 15%.
- All of the 2018 study 436 SFD medium efficiency homes (20% to 29% savings) would have been Tier I homes in the 2013 study,
- Of the 2018 study 122 SFD high efficiency homes (30% + savings):
  - Almost all (95%)) would have been 2013 study Tier II homes.
  - Only 5% would have been 2013 study Tier III homes.

The biggest factor behind the increased cost per square foot for apartment and condominium housing in one to three story buildings is likely the difference in how the 2013 study looked at this type of housing. The 2013 study calculated incremental cost per **building** square footage and the current study included only in-unit square footage. Other factors driving the higher overall incremental cost for this housing type are higher window, duct leakage, and air infiltration incremental costs. Incremental cost per square foot for window upgrades in starting level efficiency apartments and condos is almost five times the incremental cost per square foot for Tier I homes in the 2013 study. The incremental cost per square foot for both duct leakage and air infiltration in the current study are more than double the incremental cost per square foot in the 2013 study.

The notably higher incremental cost per square foot for attached homes in the current study reflects higher window upgrade costs, more air source heat pumps being installed, and slightly higher HVAC measure costs.

Section 2 Multifamily High-Rise Incremental Cost

This section focuses on the Multifamily High-Rise (MFHR) New Construction Program, which addresses RNC housing units in buildings with four or more stories. MFHR projects cover both mid-rise and high-rise multifamily buildings. Mid-rise is typically considered projects with four to ten stories while high-rise is considered projects with 11 or more stories. Specifically, this study identifies the incremental costs associated with moving from baseline new construction practices to common practices identified in MFHR program participant projects.

- Section 2.1 details the methodology for the incremental cost assessment.
  - Section 2.1.1 explains the program sample that was leveraged for this analysis.
  - Section 2.1.2 details the processes that the team used to develop contractor templates.
  - Section 2.1.3 discusses the contractor recruitment methods and results.
  - Section 2.1.4 documents the steps that were taken to assess the incremental costs associated with participating in the MFHR program.
- Section 2.2 documents the results of our incremental cost assessment.
  - Section 2.2.1 presents incremental cost results for MFHR participants by project type.
  - Section 2.2.2 offers a comparison to the 2013 MFHR program incremental cost assessment.
    - The MFHR program has evolved and the options available for participants have changed over time. While the program still offers an in-unit option, the measures available for incentives are now different (e.g., no appliance incentives are available). Similarly, the program no longer offers a prescriptive path for whole building participants – they all follow a performance-based pathway with modeled energy savings. These changes should be considered when comparing the incremental costs from these two studies.

2.1 Multifamily High-Rise Methods

The team calculated the incremental costs associated with participating in the MFHR program based on contractor estimates that identified the costs associated with building projects to baseline efficiency levels and to program efficiency levels. The team calculated incremental costs for 18 energy conservation measures (ECMs) that were found in program participant buildings. After we procured the contractor estimates, the team applied incremental costs to a sample of 72 participant buildings to calculate a unique incremental cost for each project that was considered as part of this evaluation. These steps are discussed in more detail in the following sections.

2.1.1 Program Sample

The evaluation team worked with ICF, the MFHR program implementation contractor, to procure program data for a sample of 2017 program participants. ICF provided the team with documentation for 72 projects that participated in the 2017 program. The sampled projects represent the distribution of project types that were completed through the program as of October 2017. The implementation team was interested in seeing how costs varied across five different project types that are typically seen in the program. The distribution of the projects reviewed for this evaluation are presented in Figure 14.

Figure 14: Distribution of Evaluated Projects

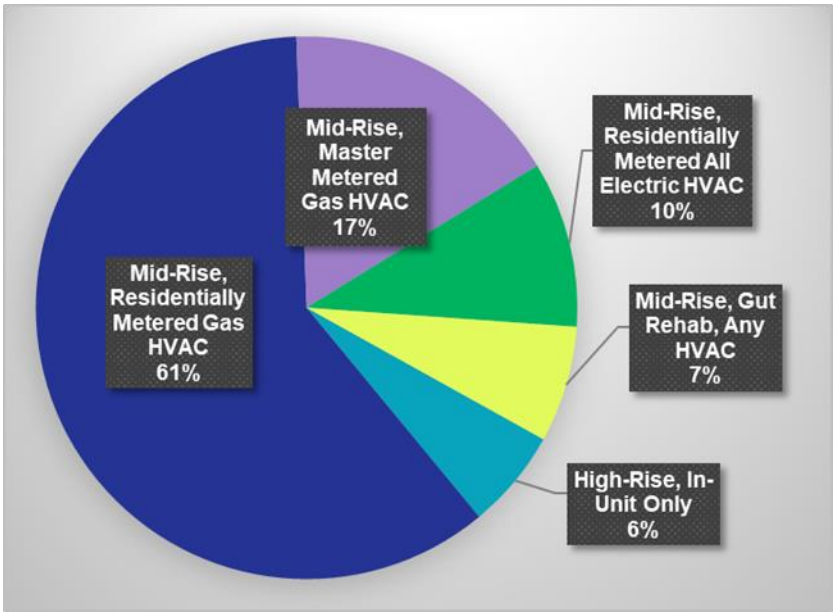


Table 6 presents the ECMs that were considered as part of our analysis and the penetration rates of those measures within the sampled buildings. The ECMs and their associated efficiency levels were documented through program modeling reports that were provided by ICF for each of the sampled projects.

Table 6: MFHR Measure List and ECM Penetration

Measure Category	Measure Details	# of Projects with Incentivized ECMs	ECM Penetration
Heating and Heat Pump Systems	Ductless Mini-Split Heat Pumps	3	4%
	Furnace	17	24%
	Water Source Heat Pumps	2	3%
	Variable Refrigerant Flow	6	8%
	Commercial Gas Boilers	14	19%
Cooling Systems	Central Air Conditioning Systems	46	64%
Water Heating Systems	Gas Stand-Alone DHW Tanks	4	6%
	Instantaneous DHW Systems	38	53%
Building Shell	Wall Insulation	12	17%
	Roof Deck/Attic Insulation	26	36%
	Fenestration	55	76%
Lighting	Residential In-Unit	61	85%
	Commercial Common Area	31	43%
Water Fixtures	Kitchen Faucet Aerators	68	94%
	Lavatory Faucet Aerators	68	94%
	Low-Flow Showerheads	68	94%
Motors and Drives	Variable Frequency Drives	8	11%
Ventilation	ERV/HRV	17	24%

2.1.2 Contractor Templates

The team developed contractor templates for the MFHR incremental cost assessment by leveraging a combination of the 2017 baseline inputs[14] and program records for the sampled projects. Specifically, the team used the 2017 baseline inputs for the MFHR program to provide baseline specifications for the templates. The team developed the upgrade efficiencies in the templates after reviewing the ECMs found in program projects and their associated efficiency levels. The MFHR templates were provided to the PAs and EEAC consultants on January 19, 2018 (see Appendix E).

2.1.3 MFHR Contractor Recruitment

After the team developed the MFHR contractor templates, we recruited a variety of contractors[15] to provide the actual cost estimates for the measures and efficiency levels listed in the templates. The team targeted a sample size of three unaffiliated contractor responses per measure.

Our MFHR contractor recruitment effort leveraged email and phone recruiting tactics to obtain the target sample size. The team offered contractors a $300 honorarium for each completed

[14] http://ma-eeac.org/wordpress/wp-content/uploads/Addendum-to-MA-Multifamily-High-Rise-Baseline-Study.pdf
[15] For the purposes of this report, *contractors* refer to general contractors, engineers, architects, plumbers, and insulation contractors.

contractor template.[16] During the recruitment process, the evaluation team screened for contractors who were actively engaged in new construction projects and had experience installing the ECMs listed in the contractor templates. The team asked the contractors to return completed templates within two weeks, or provide an estimated return date that would work for them.

The team utilized the contact information for each of the MFHR program participants that were included in the evaluation. This included contact information for the primary building contact, general contractor, mechanical engineer, architect firm, electrical engineer, HVAC contractor, plumber, insulation contractor, and energy consultant. It should be noted that not every project provided information for all of these contact fields. The team identified a total of 102 unique contacts in the dataset. The team began the recruitment effort by targeting primary contacts and general contractors. After we exhausted those contacts, the team worked through the remaining available contacts.

The team initially used emails as the primary recruitment strategy. The team sent emails to potential study participants on three separate occasions. The intent of the email recruitment strategy was to provide contacts with an introduction to the study and solicit participation or leads for contractors that would be able to provide estimates for the measures of interest. This tactic worked well initially; however, contractor attrition was an issue and there were a few instances where contractors agreed to participate and never completed the contractor template. Similar to the low-rise portion of the study, each time a contractor agreed to participate and failed to complete the template, it extended the timeline to achieve the desired sample size of three contractor estimates per ECM.

The team used direct phone contact to follow up with potential recruits after our initial emails. Direct conversations with contractors were essential in understanding why response rates were so low. As was the case with our low-rise recruitment effort, some companies were skeptical to release cost data. This is viewed as proprietary data by most companies. However, the most common reason to decline participation was due to high-demand workloads that designers and estimators were experiencing. Despite the potential to earn up to $4,200 by providing estimates on all included measures, contacts frequently dismissed the idea of participation out of hand. Others expressed interest but ultimately declined due to constraints on their time, while some suggested they could complete the templates at a date well beyond the end of the study timeline. Although the recruitment effort took longer than anticipated, the team eventually achieved the targeted sample size of three contractors for each ECM.[17] The recruitment period for MFHR contractors began in late January and lasted until the end of May.

2.1.4 Analysis

The team received incremental cost estimates from five contractors, resulting in three estimates for all measures except those where secondary research was deemed to be more appropriate. The team used secondary research to calculate the incremental costs associated with lighting, faucet aerators, and low-flow showerheads. The team applied the incremental cost results

[16] A total of 14 MFHR templates were designed.
[17] All MFHR contractor responses came from cities or towns east of Worcester, MA. This is not surprising given that most MFHR construction in the state takes place in the greater Boston area.

provided by the contractors to each of the sampled projects to calculate a specific incremental cost estimate for each of the 72 projects considered in this analysis.

The contractor templates did not cover all the possible upgrade efficiencies that were identified in the program modeling reports. As a result, the team interpolated and extrapolated results from the contractor estimates to develop unique incremental costs specific to each project and the individual incentivized measures within each project.

Throughout this report, incremental costs are presented on a dollar per square foot basis. For MFHR projects, this required assessing what proportion of the project square footage an ECM was serving for any given project. For example, some ECM upgrades were only applied to residential square footage and did not affect the common areas of the project. In cases such as these, the team calculated overall total cost for the upgrade, based on the square footage the ECM served. The team then divided the total cost by the overall project square footage to calculate an overall dollar per square foot metric that reflected the full square footage of the project. The algorithm below presents an example of a project that installed an ECM that only served the residential square footage and not the common areas. The team used this process for most ECMs as they typically serve only a portion of a buildings square footage.

$$Overall\ Inc.Cost\ per\ Sq.Ft. = \frac{Residential\ Inc.Cost\ per\ Sq.Ft.\ x\ Sq.Ft.of\ Residential\ Area}{Sq.Ft.of\ Whole\ Building}$$

2.2 MULTIFAMILY HIGH-RISE RESULTS

This section details the results of the MFHR incremental cost assessment. Figure 15 presents the incremental costs associated with program participants when compared to the current program baseline assumptions. As shown, the overall incremental cost is $2.09 per square foot. Projects participating in the “in-unit only” program path have the lowest incremental cost ($0.32 per square foot), while all other projects types have incremental costs between $2.05 and $2.53 per square foot. It should be noted that in-unit only projects typically receive building-level incentives through a custom commercial and industrial incentive program.

Figure 15: Overall MFHR Incremental Cost ($/Sq. Ft.)

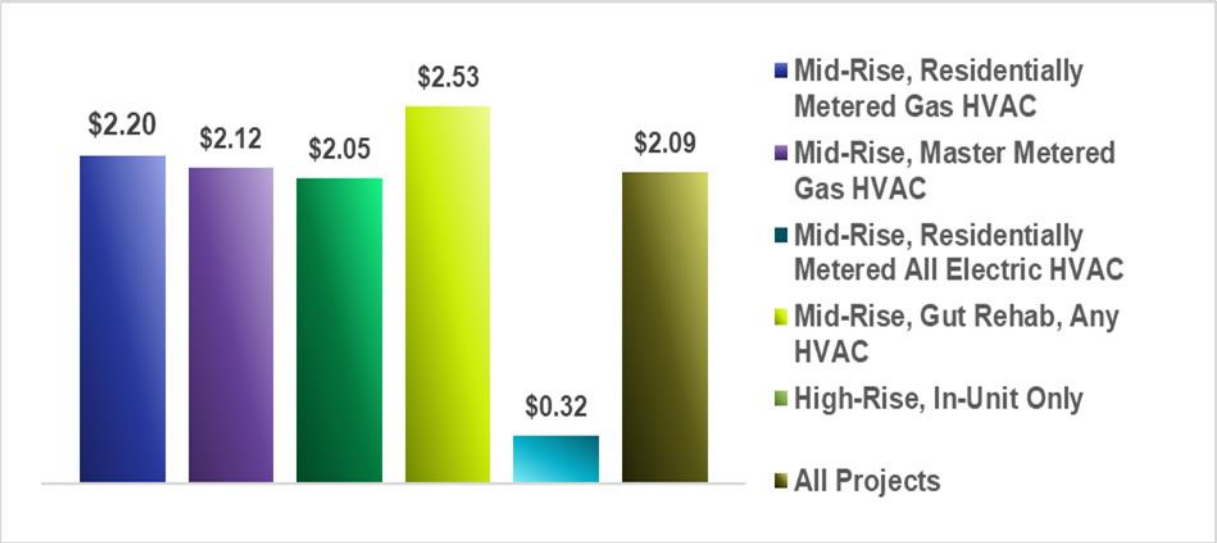


Table 7 presents the overall incremental cost, by measure, for all project types. As shown, gas stand-alone water heaters have the highest incremental cost ($1.48 per square foot) followed by central air conditioning systems ($0.95 per square foot) and instantaneous water heaters ($0.70 per square foot). The three measures with the lowest incremental costs are roof deck insulation ($0.19 per square foot), VFDs ($0.04 per square foot), and all low-flow water fixtures combined ($0.01 per square foot).

Table 7: Measure-Level Incremental Cost ($/Sq. Ft.)

Measure Details	# of Projects w/ECM	$/Sq. Ft.
Gas Stand-Alone DHW Tanks	4	$1.48
Central Air Conditioning Systems	46	$0.95
Instantaneous DHW Systems	38	$0.70
ERV/HRV	17	$0.47
Fenestration	55	$0.46
Variable Refrigerant Flow	6	$0.42
Water Source Heat Pumps	2	$0.41
Furnace	17	$0.38
Wall Insulation	12	$0.37
Ductless Mini-Split Heat Pumps	3	$0.36
Commercial Gas Boilers	14	$0.29
All Lighting*	65	$0.25
Roof Deck/Attic Insulation	26	$0.19
Variable Frequency Drives	8	$0.04
All Low-Flow Fixtures**	68	$0.01
All Measures	**72**	**$2.09**

*Includes common area lighting ($0.14/sq. ft. served) and residential lighting ($0.30/sq. ft. served).
**Includes showerheads, kitchen aerators, and lavatory aerators.

2.2.1 MFHR Results by Project Type

Table 8 presents incremental costs for mid-rise projects that are residentially metered and have gas HVAC equipment. As shown, the average overall incremental cost for these projects is $2.20 per square foot across 44 separate projects. Measure-level incremental costs range from $0.01 for all low-flow fixtures to $1.48 for gas stand-alone hot water heaters. More than 80% of these projects received incentives for instantaneous water heaters, fenestration, lighting, and low-flow water fixtures.

Table 8: Mid-Rise, Residentially Metered Gas HVAC ($/Sq. Ft.)

Measure	# of Projects w/ECM	% of Projects w/ECM	$/Sq. Ft.
Gas Stand-Alone DHW Tanks	4	9%	$1.48
ERV/HRV	2	5%	$0.91
Central Air Conditioning Systems	32	73%	$0.88
Instantaneous DHW Systems	35	80%	$0.70
Ductless Mini-Split Heat Pumps	2	5%	$0.46
Fenestration	37	84%	$0.45
Commercial Gas Boilers	1	2%	$0.28
Water Source Heat Pumps	1	2%	$0.26
Furnace	14	32%	$0.25
Roof Deck/Attic Insulation	17	39%	$0.24
All Lighting*	39	89%	$0.23
Wall Insulation	6	14%	$0.18
Variable Frequency Drives	2	2%	$0.02
All Low-Flow Fixtures**	44	100%	$0.01
Variable Refrigerant Flow	0	0%	--
All Measures	**44**	**100%**	**$2.20**

*Includes common area lighting ($0.13/sq. ft. served) and residential lighting ($0.28/sq. ft. served).
**Includes showerheads, kitchen aerators, and lavatory aerators.

Table 9 presents the incremental costs for mid-rise, commercially metered projects, with gas HVAC equipment. The overall average incremental cost for these projects is $2.12 per square foot across 12 separate projects. Measure-level incremental costs range from less than $0.01 per square foot for roof deck insulation to $0.95 per square foot for central air conditioning systems. These projects most frequently received incentives for low-flow water fixtures (83%), lighting (83%), fenestration (75%), and central air conditioning systems (67%).

Table 9: Mid-Rise, Commercially Metered Gas HVAC ($/Sq. Ft.)

Measure	# of Projects w/ECM	% of Projects w/ECM	$/Sq.Ft.
Central Air Conditioning Systems	8	67%	$0.95
Wall Insulation	2	17%	$0.75
Furnace	2	17%	$0.73
Fenestration	9	75%	$0.57
Water Source Heat Pumps	1	8%	$0.57
Instantaneous DHW Systems	2	17%	$0.56
ERV/HRV	7	58%	$0.32
Commercial Gas Boilers	9	75%	$0.27
All Lighting*	10	83%	$0.26
Variable Refrigerant Flow	3	25%	$0.12
Variable Frequency Drives	4	33%	$0.06
All Low-Flow Fixtures**	10	83%	$0.01
Roof Deck/Attic Insulation	5	42%	<$0.01
Gas Stand-Alone DHW Tanks	0	0%	--
Ductless Mini-Split Heat Pumps	0	0%	--
All Measures	**12**	**100%**	**$2.12**

*Includes common area lighting ($0.11/sq. ft. served) and residential lighting ($0.32/sq. ft. served).
**Includes showerheads, kitchen aerators, and lavatory aerators.

Table 10 presents incremental costs for mid-rise, residentially metered projects, with all electric HVAC equipment. As shown, the overall average incremental cost for these projects is $2.05 per square foot across seven projects. Central air conditioning systems ($1.28 per square foot) had the highest incremental cost, and low-flow water fixtures had the lowest again. Lighting (100%), fenestration (100%), and low-flow water fixtures (86%) were the most frequently incentivized measures.

Table 10: Mid-Rise, Residentially Metered All Electric HVAC ($/Sq. Ft.)

Measure	# of Projects w/ECM	% of Projects w/ECM	$/Sq. Ft.
Central Air Conditioning Systems	3	43%	$1.28
Variable Refrigerant Flow	3	43%	$0.73
Wall Insulation	3	43%	$0.56
Fenestration	7	100%	$0.47
ERV/HRV	4	57%	$0.42
Ductless Mini-Split Heat Pumps	1	14%	$0.18
All Lighting*	7	100%	$0.18
Roof Deck/Attic Insulation	2	29%	$0.10
All Low-Flow Fixtures**	6	86%	$0.01
Commercial Gas Boilers	0	0%	--
Gas Stand-Alone DHW Tanks	0	0%	--
Instantaneous DHW Systems	0	0%	--
Variable Frequency Drives	0	0%	--
Furnace	0	0%	--
Water Source Heat Pumps	0	0%	--
All Measures	**7**	**100%**	**$2.05**

*Includes common area lighting ($0.18/sq. ft. served) and residential lighting ($0.26/sq. ft. served).
**Includes showerheads, kitchen aerators, and lavatory aerators.

Table 11 presents the incremental costs for mid-rise, gut rehab projects with any primary fuel for HVAC equipment. Only five projects fell into this category, and the average overall incremental cost is $2.53 per square foot. Measure-level incremental costs were highest for furnaces ($1.54 per square foot) and lowest for fenestration. All projects received incentives for lighting and low-flow water fixtures, while 60% of projects received incentives for central air conditioning systems, ERVs or HRVs, and commercial gas boilers.

Table 11: Mid-Rise, Gut Rehab, Any HVAC ($/Sq. Ft.)

Measure	# of Projects w/ECM	% of Projects w/ECM	$/Sq. Ft.
Furnace	1	20%	$1.54
Central Air Conditioning Systems	3	60%	$1.40
Instantaneous DHW Systems	1	20%	$0.87
ERV/HRV	3	60%	$0.67
All Lighting*	5	100%	$0.46
Roof Deck/Attic Insulation	2	40%	$0.33
Commercial Gas Boilers	3	60%	$0.31
Wall Insulation	1	20%	$0.08
Variable Frequency Drives	2	40%	$0.03
All Low-Flow Fixtures**	5	100%	<$0.01
Fenestration	2	40%	<$0.01
Gas Stand-Alone DHW Tanks	0	0%	--
Ductless Mini-Split Heat Pumps	0	0%	--
Variable Refrigerant Flow	0	0%	--
Water Source Heat Pumps	0	0%	--
All Measures	**5**	**100%**	**$2.53**

*Includes common area lighting ($0.27/sq. ft. served) and residential lighting ($0.56/sq. ft. served).
**Includes showerheads, kitchen aerators, and lavatory aerators.

Table 12 presents the incremental costs for the four high-rise projects that participated in the in-unit only participation pathway. As shown, the average overall incremental cost for these projects is $0.32 per square foot. All of these projects received incentives for lighting, while three of four (75%) received incentives for low-flow water fixtures.

Table 12: High-Rise, In-Unit Only ($/Sq. Ft.)

Measure	# of Projects w/ECM	% of Projects w/ECM	$/Sq. Ft.
Commercial Gas Boilers*	1	25%	$0.42
ERV/HRV	1	25%	$0.20
All Lighting**	4	100%	$0.16
All Low Flow Fixtures***	3	75%	<$0.01
Gas Stand-Alone DHW Tanks	0	0%	--
Instantaneous DHW Systems	0	0%	--
Wall Insulation	0	0%	--
Roof Deck/Attic Insulation	0	0%	--
Fenestration	0	0%	--
Variable Frequency Drives	0	0%	--
Central Air Conditioning Systems	0	0%	--
Ductless Mini-Split Heat Pumps	0	0%	--
Variable Refrigerant Flow	0	0%	--
Furnace	0	0%	--
Water Source Heat Pumps	0	0%	--
All Measures	**4**	**100%**	**$0.32**

*One in-unit only project received incentives for a whole building boiler.
**No common area lighting for the in-unit only projects. These results represent in-unit lighting incremental costs for the entire square footage of the project.
***Includes showerheads, kitchen aerators, and lavatory aerators.

2.2.2 Comparison to Previous Study

This section provides a brief comparison to the incremental costs that were developed for MFHR buildings in the 2013 incremental cost study.[18] The previous RNC incremental cost study presented results for MFHR buildings (four stories or more) under the following three scenarios:

- Residential In-Unit
  - This path included incentives for lighting, appliances, and infiltration.
- Whole Building Simple Prescriptive
  - This path included wall and ceiling insulation, windows, HVAC equipment, water heating equipment, VFDs, and common area lighting.
- Whole Building Interactive Prescriptive
  - This path included all the measures identified in the whole building simple prescriptive path, but with higher efficiency standards for implementation.
- Based on the information provided above, it is clear that the program has evolved and the options available for participants have changed. While the program still offers an in-unit option, the measures available for incentives are now different (e.g., no appliance

[18] http://ma-eeac.org/wordpress/wp-content/uploads/Residential-New-Construction-Program-Incremental-Cost-Final-Report-6.11.13.pdf

incentives are available). Similarly, the program no longer offers a prescriptive path for whole building participants – they all follow a performance-based pathway with modeled energy savings. These changes should be considered when comparing the incremental costs from these two studies.

Table 13 presents a comparison of the incremental costs between the 2013 study and the current study. As shown, in-unit only projects had the lowest incremental cost per square foot in both studies ($0.14 in 2013 and $0.32 in 2018). The whole building incremental costs have increased relative to the 2013 study. The 2013 study had incremental costs of $1.21 or $1.65 per square foot depending on the participation pathway, while the current study results show an incremental cost of $2.19 per square foot for all whole building participants.

Table 13: Comparison of Incremental Cost Results – 2013 and 2018 Studies

Program Path	$/Sq. Ft.
2013 Study	
In-Unit Prescriptive	$0.14
Whole Building Simple Prescriptive	$1.21
Whole Building Interactive Prescriptive	$1.65
2018 Study	
In-Unit Only	$0.32
All Whole Building Projects	$2.19

Appendix A Lighting Incremental Cost

A.1 Low-Rise Lighting

This section describes the approach used to estimate the incremental cost of the efficient lighting in homes that participate in the low-rise RNC program versus a home built to baseline specifications. The baseline lighting specifications are based on the most recent RNC baseline conducted in Massachusetts, the 2017 Mini-Baseline study. [19] The team leveraged light bulb cost data from the ongoing RLPNC 17-15 Shelf Stocking report.[20]

The program provides participant builders with LED light bulbs at no cost. Therefore, there is no incremental cost for efficient lighting in the low-rise RNC program due to the program incentive. The analysis described in this section looks at what the incremental cost would be to builders without direct program support for light bulbs.

The team leveraged data from the shelf stocking report to identify the cost associated with average efficient and inefficient light bulbs. The analysis treated halogen bulbs as inefficient and LED bulbs as efficient. The average efficient (LED) and inefficient (halogen) costs were weighted by the proportion of bulb-shapes (A-line, reflector, and other) in the mini-baseline study.[21]

REM/Rate energy models provide the saturation of efficient lighting at the fixture level for program homes. However, to determine the incremental cost, the team needed efficient and inefficient bulb counts. The team constructed the bulb counts using the 2017 mini-baseline data. We calculated two factors: the average number of fixtures per square foot and the average number of bulbs per fixture. The team applied these two factors to the average square footage for each program home type and energy savings level. The team multiplied these bulb counts by the REM/Rate efficient fixture saturation to determine the average number of efficient and inefficient lightbulbs in program and non-program homes. The results from this process are shown in Table 14, which shows the increased number of efficient lightbulbs installed in program homes compared to non-program homes. The lighting incremental cost per square foot for each building type and energy savings level is presented in Table 15. As shown, the incremental lighting cost ($0.02 per square foot) is the same across all housing types and savings levels.

[19] http://ma-eeac.org/wordpress/wp-content/uploads/RLPNC-17-2-Single-Family-New-Construction-Mini-Baseline-Study.pdf

[20] The RNCPL 17-15 Shelf Stocking study is currently on-going.

[21] The team weighted the average cost for each bulb-shape by lighting technology by the baseline proportions. We did this to account for the different costs associated with different types of bulbs. The team excluded WIFI-connected bulbs from this analysis.

Table 14: Estimated Increased Efficient Bulb Counts

Low-Rise Program Sector	Starting Efficiency Range	Medium Efficiency Range	High Efficiency Range
Single-Family Detached	18.3	24.0	27.0
Single-Family Attached	13.1	13.9	16.4
Multifamily 1-3 Story Apartments and Condos	7.4	8.2	7.9

[1] Bulb counts are calculated based on the average fixtures per square foot and the average bulbs per fixture. The calculations resulted in bulbs that are not whole numbers.

Table 15: Lighting Incremental Cost Results

Low-Rise Program Sector	Starting Efficiency Range		Medium Efficiency Range		High Efficiency Range	
	$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.
Single-Family Detached	$0.02	100%	$0.02	100%	$0.02	100%
Single-Family Attached	$0.02	100%	$0.02	100%	$0.02	100%
Multifamily 1-3 Story Apartments and Condos	$0.02	100%	$0.02	100%	$0.02	100%

A.2 MULTIFAMILY HIGH-RISE LIGHTING

As with the low-rise incremental cost assessment, the team leveraged cost data from the RLPNC 17-15 Shelf Stocking study to calculate the incremental cost associated with lighting upgrades in the MFHR program. The MFHR program provides incentives for projects that have lower lighting power densities (LPD) than the current baseline specifications. The current baseline values can be found in the MFHR Baseline Study UDRH Addendum.[22] The baseline LPD specifications vary based on the space being served. Common areas have numerous baseline specifications while residential spaces all have the same baseline LPD requirements.

Program records indicated what the upgrade LPD was for all common areas and for in-unit residential spaces. The team compared these upgrade values to the baseline specifications and used them to calculate the incremental costs associated with lighting upgrades. The team assumed that the difference between the base case and the upgrade case was solely due to LED light bulbs and/or fixtures. The team used the cost data from the shelf stocking study to develop a dollar per watt figure for LED bulbs and fixtures. The team multiplied this value by the difference between the base case LPD and the upgrade case LPD to calculate the incremental cost for lighting on a dollar per square foot basis. The algorithm below is an example of how the team

[22] http://ma-eeac.org/wordpress/wp-content/uploads/Addendum-to-MA-Multifamily-High-Rise-Baseline-Study.pdf

developed these calculations for residential lighting. The same calculations apply to common areas.

$$Res.Inc.Cost\ per\ Sq.Ft. = \left(\frac{Base\ Case\ Watt}{Sq.Ft.} - \frac{Upgrade\ Case\ Watt}{Sq.Ft.}\right) \times \left(\frac{LED\ Price\ (\$)}{Watt}\right)$$

The team calculated the overall incremental cost for the building by multiplying the residential and common area incremental cost per square foot by their respective building areas. The team then divided the total incremental cost by the overall building square footage to develop one incremental cost per square foot value for the building. The incremental costs associated with MFHR lighting are presented throughout Section 2.2.

Appendix B Low-Rise Efficiency Levels

The tables below detail the efficiency level ranges, by housing type, that were used as the basis for the low-rise incremental cost assessment.

Table 16: Efficiency Level Ranges for Single-Family Detached Housing Units

Efficiency range	Percent Savings above UDRH	% of Single-Family Detached Program Homes (n=2,216 Homes)	% of Total Program Units (SF and MF) (n=3,268 Units)
Starting Efficiency Range	5% to 19%	75%	51%
Medium Efficiency Range	20% to 29%	20%	13%
High Efficiency Range	30% or Higher	6%	4%
All Efficiency Levels	**5% to 53%**	**100%**	**68%**

Table 17: Efficiency Level Ranges for Single-Family Attached Housing Units

Efficiency range	Percent Savings Above UDRH	% of Single-Family Attached Program Units (n=652 Units)	% of Total Program Units (SF and MF) (n=3,268 Units)
Starting Efficiency Range	5% to 19%	69%	14%
Medium Efficiency Range	20% to 29%	25%	5%
High Efficiency Range	30% or Higher	6%	1%
All Efficiency Levels	**5% to 42%**	**100%**	**20%**

Table 18: Efficiency Level Ranges for Low-Rise Multifamily Units

Efficiency range	Percent Savings Above UDRH	% of Low-Rise Multifamily Program Units (n=400 Units)	% of Total Program Units (SF and MF) (n=3,268 Units)
Starting Efficiency Range	5% to 19%	86%	10%
Medium Efficiency Range	20% to 24%	11%	1.3%
High Efficiency Range	25% or Higher	3%	0.4%
All Efficiency Levels	**5% to 39%**	**100%**	**12%**

Appendix C Low-Rise Specifications and Cost

The tables below detail the base case and upgrade case efficiency specifications, along with the average incremental cost estimate from contractors, for each of the measures and scenarios provided in the low-rise templates.

Table 19: Insulation Shell Measures and Upgrades

Insulated Area	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft. Insulated Area
Conditioned/ Ambient Wall Insulation			
1,000 Square Feet	R-21	R-24	$0.48
1,500 Square Feet	R-21	R-24	$0.47
2,500 Square Feet	R-21	R-24	$0.47
1,000 Square Feet	R-21	R-32	$1.05
1,500 Square Feet	R-21	R-32	$1.03
2,500 Square Feet	R-21	R-32	$1.03
2,700 Square Feet	R-21	R-40	$1.35
Flat Ceiling Insulation			
1,000 Square Feet	R-41	R-45	$0.51
1,500 Square Feet	R-41	R-45	$0.50
1,000 Square Feet	R-41	R-53	$0.56
1,500 Square Feet	R-41	R-53	$0.55
Vaulted Ceiling Insulation			
1,000 Square Feet	R-32	R-38	$0.52
1,500 Square Feet	R-32	R-38	$0.51
1,000 Square Feet	R-32	R-45	$0.64
1,500 Square Feet	R-32	R-45	$0.64
1,000 Square Feet	R-32	R-55	$0.85
1,500 Square Feet	R-32	R-55	$0.85
Floor Over Unconditioned Basement Insulation			
1,000 Square Feet	R-31	R-36	$0.54
1,500 Square Feet	R-31	R-36	$0.53
1,000 Square Feet	R-31	R-40	$0.61
1,500 Square Feet	R-31	R-40	$0.61

Table 20: Window Upgrades

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Single-Family Detached Homes			
3,000 Square Feet	U-30 SHGC 30	U-29 SHGC 28	$0.91
3,000 Square Feet	U-30 SHGC 30	U-26 SHGC 29	$1.69
Single-Family Attached Homes			
2,200 Square Feet	U-30 SHGC 30	U-29 SHGC 28	$0.79
2,200 Square Feet	U-30 SHGC 30	U-28 SHGC 28	$0.83
Apartments/Condos			
1,300 Square Feet	U-30 SHGC 30	U-29 SHGC 29	$0.96
1,300 Square Feet	U-30 SHGC 30	U-28 SHGC 28	$1.05
1,300 Square Feet	U-30 SHGC 30	U-26 SHGC 32	$1.78

Table 21: Heating System Upgrades

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Gas Furnaces Single-Family Detached Homes			
3,000 Square Feet	94 AFUE 100,000 Btu/hr No ECM	95 AFUE 100,000 Btu/hr With ECM	$0.13
3,000 Square Feet	94 AFUE 100,000 Btu/hr No ECM	95 AFUE 77,000 Btu/hr with ECM	$0.09
3,000 Square Feet	94 AFUE 100,000 Btu/hr No ECM	96 AFUE 70,000 Btu/hr With ECM	$0.13
Gas Furnaces Single-Family Attached Homes			
2,100 Square Feet	94 AFUE 69,000 Btu/hr No ECM	95 AFUE 69,000 Btu/hr With ECM	$0.13
2,100 Square Feet	94 AFUE 69,000 Btu/hr No ECM	95 AFUE 56,000 Btu/hr With ECM	$0.14
2,100 Square Feet	94 AFUE 69,000 Btu/hr No ECM	95 AFUE 51,000 Btu/hr With ECM	$0.21
Gas Furnaces Apartments/Condos			
1,500 Square Feet	94 AFUE 50,000 Btu/hr No ECM	95 AFUE 50,000 Btu/hr With ECM	$0.18
1,500 Square Feet	94 AFUE 50,000 Btu/hr No ECM	96 AFUE 50,000 Btu/hr with ECM	$0.26
Gas Boilers Single-Family Detached Homes			
4,000 Square Feet	94 AFUE 140,000 Btu/hr	95 AFUE 140,000 Btu/hr	$0.00
4,000 Square Feet	94 AFUE 140,000 Btu/hr	95 AFUE 125,000 Btu/hr	-$0.10
4,000 Square Feet	94 AFUE 140,000 Btu/hr	95 AFUE 110,000 Btu/hr	-$0.19
Gas Boilers Single-Family Attached Homes			
2,300 Square Feet	94 AFUE 80.000 Btu/hr	95 AFUE 80,000 Btu/hr	$0.00
Gas Boilers Apartments/Condos			
1,100 Square Feet	94 AFUE 46.000 Btu/hr	95 AFUE 46.000 Btu/hr	$0.00

Table 22: Cooling System Upgrades

Home Size Square Feet	Base Case		Upgrade		Contractor Incremental Cost per Sq. Ft.
Central Air Conditioning System Single-Family Detached Homes					
4,000 Square Feet	13.4 SEER	5.5 Ton Unit	13.9 SEER	4 Ton Unit	$0.00
Central Air Conditioning System Single-Family Attached Homes					
2,400 Square Feet	13.4 SEER	3.5 Ton Unit	13.9 SEER	3 Ton Unit	$0.08
2,400 Square Feet	13.4 SEER	3.5 Ton Unit	14.7 SEER	2.5 Ton Unit	$0.08
Central Air Conditioning System Apartments/Condos					
1,400 Square Feet	13.4 SEER	2 Ton Unit	13.8 SEER	2 Ton Unit	$0.23
1,400 Square Feet	13.4 SEER	2 Ton Unit	14.5 SEER	2 Ton Unit	$0.32
Ducted ASHP Cooling System Single-Family Detached Homes					
2,700 Square Feet	14.7 SEER	4 Ton Unit	17.4 SEER	4 Ton Unit	$0.41
2,700 Square Feet	14.7 SEER	4 Ton Unit	16.5 SEER	3 Ton Unit	$0.13
2,700 Square Feet	14.7 SEER	4 Ton Unit	16.9 SEER	3 Ton Unit	$0.13
Ducted ASHP Cooling System Single-Family Attached Homes					
2,900 Square Feet	14.7 SEER	4 Ton Unit	16.8 SEER	3 Ton Unit	$0.12
Ducted ASHP Cooling System Apartments/Condos					
1,100 Square Feet	14.7 SEER	1.5 Ton Unit	17.0 SEER	1.5 Ton Unit	$0.44
1,100 Square Feet	14.7 SEER	1.5 Ton Unit	16.0 SEER	1.5 Ton Unit	$0.20
1,100 Square Feet	14.7 SEER	1.5 Ton Unit	16.2 SEER	1.5 Ton Unit	$0.20

Table 23: Water Heating Upgrades

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Instantaneous Gas Water Heater Single-Family Detached Homes			
3,000 Square Feet	.91 Energy Factor - 9 GPM	.95 Energy Factor - 9 GPM	$0.08
Instantaneous Gas Water Heater Single-Family Attached Homes			
2,200 Square Feet	.91 Energy Factor - 9 GPM	.95 Energy Factor - 9 GPM	$0.10
Instantaneous Gas Water Heater Apartments/Condos			
1,300 Square Feet	.91 Energy Factor - 9 GPM	.96 Energy Factor - 9 GPM	$0.13
Conventional Gas Water Heater Single-Family Detached Homes			
3,300 Square Feet	.65 Energy Factor - 50 Gal	.72 Energy Factor - 50 Gal	$0.25
3,300 Square Feet	.65 Energy Factor - 50 Gal	.75 Energy Factor - 50 Gal	$0.25
Conventional Gas Water Heater Single-Family Attached Homes			
2,200 Square Feet	.65 Energy Factor - 50 Gal	.76 Energy Factor - 50 Gal	$0.25
Conventional Gas Water Heater Apartments/Condos			
1,300 Square Feet	.65 Energy Factor - 50 Gal	.82 Energy Factor - 50 Gal	$0.42
1,300 Square Feet	.65 Energy Factor - 50 Gal	.85 Energy Factor - 50 Gal	$0.42
Heat Pump Water Heater Single-Family Detached Homes			
2,500 Square Feet	2.72 Energy Factor - 50 Gal	3.13 Energy Factor - 50 Gal.	$0.01
2,500 Square Feet	2.72 Energy Factor - 50 Gal	3.17 Energy Factor - 50 Gal.	$0.01
2,500 Square Feet	2.72 Energy Factor - 50 Gal	3.06 Energy Factor - 50 Gal.	$0.01
Heat Pump Water Heater Single-Family Attached Homes			
2,000 Square Feet	2.72 Energy Factor - 50 Gal	3.21 Energy Factor - 50 Gal.	$0.00
2,000 Square Feet	2.72 Energy Factor - 50 Gal	3.17 Energy Factor - 50 Gal.	$0.00
2,000 Square Feet	2.72 Energy Factor - 50 Gal	3.24 Energy Factor - 50 Gal.	$0.00
Heat Pump Water Heater Apartments/Condos			
1,100 Square Feet	2.72 Energy Factor - 50 Gal	2.99 Energy Factor - 50 Gal.	$0.00
1,100 Square Feet	2.72 Energy Factor - 50 Gal	2.91 Energy Factor - 50 Gal.	$0.00
1,100 Square Feet	2.72 Energy Factor - 50 Gal	3.08 Energy Factor - 50 Gal.	$0.00

Table 24: Ventilation Measures

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Bathroom Fans Single-Family Detached Homes			
3,000 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 70 CFM; 17 Watts	$0.02
3,000 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 80 CFM; 17 Watts	$0.02
3,000 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 90 CFM; 30 Watts	$0.02
Bathroom Fans Single-Family Attached Homes			
2,200 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 60 CFM; 13 Watts	$0.02
2,200 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 60 CFM; 13 Watts	$0.02
2,200 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 55 CFM; 13 Watts	$0.02
Bathroom Fans Apartments/Condos			
1,300 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 50 CFM; 13 Watts	$0.03
1,300 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 60 CFM; 13 Watts	$0.03
1,300 Square Feet	Local Switch Fan with 52 CFM; 60 watts	Timer controlled Fan with 55 CFM; 13 Watts	$0.03
Energy Recovery Ventilation (HRV) System Single-Family Detached Homes			
4,300 Square Feet	ERV - 77% Sensible Recovery Efficiency; 60% Total Recovery Efficiency; 135 CFM	ERV - 70% Sensible Recovery Efficiency; 60% Total Recovery Efficiency; 115 CFM	$0.00
Energy Recovery Ventilation (HRV) System Single-Family Attached Homes			
1,900 Square Feet	ERV - 77% Sensible Recovery Efficiency; 60% Total Recovery Efficiency; 135 CFM	ERV - 63% Sensible Recovery Efficiency; 50% Total Recovery Efficiency; 57 CFM	-$0.32
Energy4 Recovery Ventilation (HRV) System Apartments/Condos			
1,800 Square Feet	ERV - 77% Sensible Recovery Efficiency; 60% Total Recovery Efficiency; 135 CFM	ERV - 69% Sensible Recovery Efficiency; 58% Total Recovery Efficiency; 68 CFM	-$0.29

Table 25: Air Infiltration and Duct Leakage Measures

Home Size Square Feet	Base Case	Upgrade	Contractor Incremental Cost per Sq. Ft.
Air Infiltration (ACH50) Single-Family Detached Homes			
3,000 Square Feet	3.6 ACH50	2.8 ACH50	$0.34
3,000 Square Feet	3.6 ACH50	2.0 ACH50	$0.36
3,000 Square Feet	3.6 ACH50	1.2 ACH50	$0.33
Air Infiltration (ACH50) Single-Family Attached Homes			
2,100 Square Feet	3.6 ACH50	2.7 ACH50	$0.38
2,100 Square Feet	3.6 ACH50	2.1 ACH50	$0.39
Air Infiltration (ACH50) Apartments/Condos			
1,300 Square Feet	3.6 ACH50	1.9 ACH50	$0.41
1,300 Square Feet	3.6 ACH50	1.7 ACH50	$0.41
Duct Leakage to the Outside (LTO) Single-Family Detached Homes			
3,000 Square Feet	3.8 CFM25/100SF or 117 CFM25	2.5 CFM25/100SF or 75 CFM25	$0.23
3,000 Square Feet	3.8 CFM25/100SF or 117 CFM25	1 CFM25/100SF or 30 CFM25	$0.32
3,000 Square Feet	3.8 CFM25/100SF or 117 CFM25	0.5 CFM25/100SF or 15 CFM25	$0.38
Duct Leakage to the Outside (LTO) Single-Family Attached Homes			
2,200 Square Feet	3.8 CFM25/100SF or 86 CFM25	3 CFM25/100SF or 66 CFM25	$0.25
2,200 Square Feet	3.8 CFM25/100SF or 86 CFM25	1 CFM25/100SF or 22 CFM25	$0.33
2,200 Square Feet	3.8 CFM25/100SF or 86 CFM25	0.5 CFM25/100SF or 11 CFM25	$0.41
Duct Leakage to the Outside (LTO) Apartments/Condos			
1,300 Square Feet	3.8 CFM25/100SF or 51 CFM25	2.5 CFM25/100SF or 33 CFM25	$0.55
1,300 Square Feet	3.8 CFM25/100SF or 51 CFM25	2 CFM25/100SF or 26 CFM25	$0.64
1,300 Square Feet	3.8 CFM25/100SF or 51 CFM25	1 CFM25/100SF or 13 CFM25	$0.79

Appendix D Low-Rise Detailed Results

The tables on the next pages present detailed low-rise sector incremental costs per square foot results for all measures by housing type and efficiency level.

Table 26: Incremental Cost Summary Table – Detached homes

Detached Single-Family Homes		Measure Description	Starting Efficiency: 5%-19% Savings		Medium Efficiency: 20%-29% Savings		High Efficiency: 30% or Higher Savings	
Upgrade Description	Calculation Details		$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.
Shell Measures								
Insulation R-values and Window U-values	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Conditioned Walls	**$0.03**	100%	**$0.06**	100%	**$0.28**	100%
		Flat Ceiling	**$0.10**	100%	**$0.07**	100%	**$0.09**	100%
		Cathedral Ceiling	**$0.10**	100%	**$0.19**	100%	**$0.24**	100%
		Framed Floor	**$0.02**	100%	**$0.01**	100%	**$0.00**	100%
		Higher Efficiency Windows	**$0.91**	100%	**$0.91**	100%	**$1.69**	100%
HVAC Measures								
Heating Equipment AFUE, Cooling Equipment SEER, and Domestic Hot Water EF	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Gas Furnace	**$0.13**	94%	**$0.09**	81%	**$0.13**	78%
		Gas Boiler	**$0.00**	6%	**-$0.10**	19%	**-$0.19**	22%
		Central AC	**$0.00**	97%	**$0.00**	95%	**$0.00**	89%
		ASHP - Cooling	**$0.41**	3%	**$0.13**	5%	**$0.13**	11%
		Instantaneous Gas WH	**$0.08**	60%	**$0.08**	65%	**$0.08**	35%
		Conventional Gas WH	**$0.00**	25%	**$0.25**	19%	**$0.25**	17%
		Heat Pump Water Heater	**$0.01**	15%	**$0.01**	16%	**$0.01**	48%
Additional Measures								
Additional Measures Include ACH50, Duct LTO, Ventilation and Lighting	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Duct Leakage CFM25/100 ft^2	**$0.23**	100%	**$0.31**	100%	**$0.34**	100%
		Air Infiltration ACH50	**$0.33**	100%	**$0.34**	100%	**$0.36**	100%
		Ventilation – Bath Fans	**$0.02**	99%	**$0.02**	94%	**$0.02**	65%
		Ventilation - HRVs	**$0.06**	1%	**$0.06**	6%	**$0.06**	35%
		Lighting[1]	**$0.00**	100%	**$0.00**	100%	**$0.00**	100%
Total Incremental Cost (weighted by percent of square feet))			**$1.90**		**$2.08**		**$3.19**	

[1] LED light bulbs are provided by the Massachusetts RNC Program at no cost to builders.

Table 27: Incremental Cost Summary Table – Attached homes

Attached Single-Family Homes		Measure Description	Starting Efficiency: 5%-19% Savings		Medium Efficiency: 20%-29% Savings		High Efficiency: 30% or Higher Savings	
Upgrade Description	Calculation Details		$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.
Shell Measures								
Insulation R-values and Window U-values	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Conditioned Walls	**$0.01**	100%	**$0.05**	100%	**$0.11**	100%
		Flat Ceiling	**$0.08**	100%	**$0.06**	100%	**$0.08**	100%
		Cathedral Ceiling	**$0.08**	100%	**$0.18**	100%	**$0.21**	100%
		Framed Floor	**$0.01**	100%	**$0.02**	100%	**$0.01**	100%
		Higher Efficiency Windows	**$0.79**	100%	**$0.79**	100%	**$0.83**	100%
HVAC Measures								
Heating Equipment AFUE, Cooling Equipment SEER, and Domestic Hot Water EF	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Gas Furnace	**$0.13**	97%	**$0.14**	87%	**$0.21**	56%
		Gas Boiler	**$0.00**	3%	**$0.00**	13%	**$0.00**	44%
		Central AC	**$0.00**	99%	**$0.08**	100%	**$0.08**	100%
		ASHP - Cooling	**$0.12**	1%	**$0.00**	0%[1]	**$0.00**	0%[1]
		Instantaneous Gas WH	**$0.10**	59%	**$0.10**	70%	**$0.10**	64%
		Conventional Gas WH	**$0.00**	25%	**$0.00**	12%	**$0.25**	11%
		Heat Pump Water Heater	**$0.002**	16%	**$0.002**	18%	**$0.002**	25%
Additional Measures								
Additional Measures Include ACH50, Duct LTO, Ventilation and Lighting	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Duct Leakage CFM25/100 ft^2	**$0.24**	100%	**$0.32**	100%	**$0.40**	100%
		Air Infiltration ACH50	**$0.00**	100%	**$0.38**	100%	**$0.39**	100%
		Ventilation – Bath Fans	**$0.02**	100%	**$0.02**	98%	**$0.02**	96%
		Ventilation - HRVs	**$0.00**	0%[1]	**$0.08**	2%	**$0.08**	4%
		Lighting[2]	**$0.00**	100%	**$0.00**	100%	**$0.00**	100%
Total Incremental Cost (weighted)			**$1.42**		**$2.09**		**$2.35**	

[1] No homes in savings category with measure.

[2] LED light bulbs are provided by the Massachusetts RNC Program at no cost to builders.

Table 28: Incremental Cost Summary Table – Apartments and Condominiums

Attached Single-Family Homes		Measure Description	Starting Efficiency: 5%-19% Savings		Medium Efficiency: 20%-24% Savings		High Efficiency: 25% or Higher Savings	
Upgrade Description	Calculation Details		$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.	$/Sq. Ft.	% of Sq. Ft.
Shell Measures								
Insulation R-values and Window U-values	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Conditioned Walls	**$0.06**	100%	**$0.12**	100%	**$0.33**	100%
		Flat Ceiling	**$0.03**	100%	**$0.03**	100%	**$0.00**	100%
		Cathedral Ceiling	**$0.15**	100%	**$0.13**	100%	**$0.24**	100%
		Framed Floor	**$0.002**	100%	**$0.00**	100%	**$0.04**	100%
		Higher Efficiency Windows	**$0.96**	100%	**$1.05**	100%	**$1.78**	100%
HVAC Measures								
Heating Equipment AFUE, Cooling Equipment SEER, and Domestic Hot Water EF	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Gas Furnace	**$0.18**	63%	**$0.26**	37%	**$0.26**	56%
		Gas Boiler	**$0.00**	37%	**$0.00**	63%	**$0.00**	44%
		Central AC	**$0.00**	93%	**$0.23**	95%	**$0.32**	67%
		ASHP - Cooling	**$0.44**	7%	**$0.20**	5%	**$0.20**	33%
		Instantaneous Gas WH	**$0.13**	81%	**$0.13**	80%	**$0.13**	64%
		Conventional Gas WH	**$0.42**	14%	**$0.42**	9%	**$0.00**	0%[1]
		Heat Pump Water Heater	**$0.003**	6%	**$0.003**	11%	**$0.003**	36%
Additional Measures								
Additional Measures Include ACH50, Duct LTO, Ventilation and Lighting	**Incremental Costs are the Total Upgrade Cost for Each Measure Divided by Total Square Feet**	Duct Leakage CFM25/100 ft^2	**$0.53**	100%	**$0.60**	100%	**$0.74**	100%
		Air Infiltration ACH50	**$0.00**	100%	**$0.41**	100%	**$0.41**	100%
		Ventilation – Bath Fans	**$0.03**	100%	**$0.03**	98%	**$0.03**	55%
		Ventilation - HRVs	**$0.00**	0%[1]	**$0.12**	2.5%	**$0.12**	45%
		Lighting[2]	**$0.00**	100%	**$0.00**	100%	**$0.00**	100%
Total Incremental Cost (weighted)			**$2.06**		**$2.83**		**$4.12**	

[1] No homes in savings category with measure.
[2] LED light bulbs are provided by the Massachusetts RNC Program at no cost to builders.

Appendix E Contractor Templates

RLPNC_1714_MFHRI
nsulationTemplate_

RLPNC_1714_MFHR
HVACTemplate_19JA

RLPNC_1714_LowRi
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