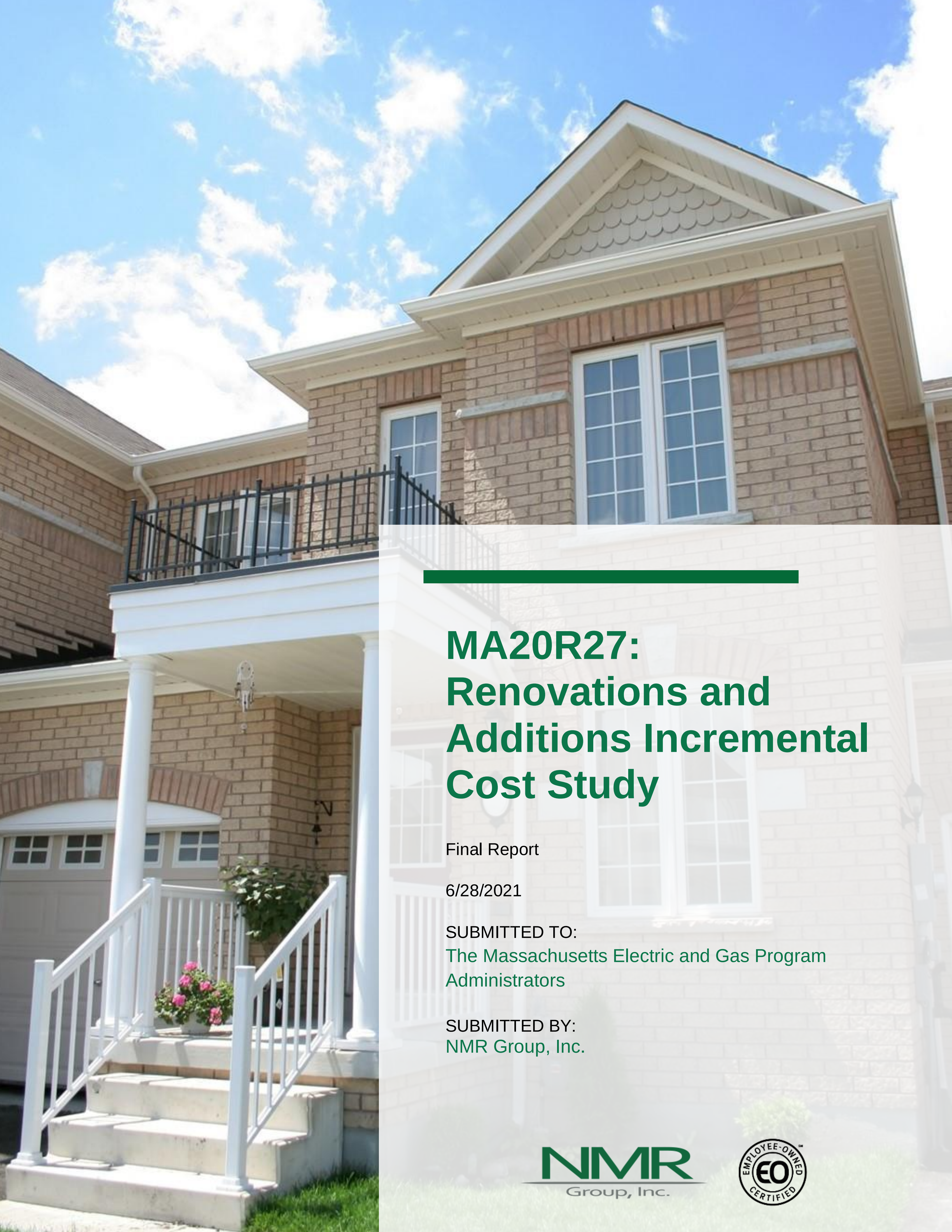

MA20R27: Renovations and Additions Incremental Cost Study

Final Report

6/28/2021

SUBMITTED TO:
The Massachusetts Electric and Gas Program Administrators

SUBMITTED BY:
NMR Group, Inc.

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Executive Summary

The goal of this study is to estimate the incremental costs associated with participating in the Program Administrators' (PAs') Residential Renovations and Additions Program (referred to as the R&A program). The study is designed to estimate both retrospective and prospective incremental costs, reflecting the previous design of the program but also addressing recent program changes as it pertains to baseline assumptions. A secondary goal of the study is to provide a brief summary of program practices.

There are two baseline scenarios for which incremental costs are quantified in this study. The first are those associated with the original program design (i.e., the incremental costs of upgrading renovations from pre-existing baseline conditions and additions from a User Defined Reference Home [UDRH] baseline). For both additions and renovations, the high-efficiency case is based on actual conditions found in program participant housing units.

For the second set of baseline conditions, NMR (the team) estimated the incremental cost of shifting to an industry standard practice (ISP) baseline for renovation projects, rather than pre-existing conditions. The *RLPNC 18-12 Home Renovations and Additions Market Characterization Evaluation*[1] found evidence that the program should expect homeowners to make upgrades in the absence of the program. Adopting an ISP baseline that is more efficient than pre-existing conditions lowers the energy savings associated with the upgrades while also reducing the incremental cost. Given the recommendation in RLPNC 18-12, the program has since updated the renovations baseline to ISP, including retrospectively calculating 2020 savings.

The summary of program practices was based on a program data review of 973 projects that had participated in the R&A program as of October 22, 2020. NMR explored the existing conditions and final conditions for various measures, including heating systems, cooling systems, domestic hot water systems, duct leakage, air infiltration, and building envelope measures.

METHODOLOGY

In the MA19R18 Incremental Cost Update Study,[2] NMR utilized a new approach for developing incremental costs that incorporated the cost values from the National Renewable Energy Laboratory's (NREL) National Residential Efficiency Measures Database (NREMDB). NREL's Building Energy Optimization Tool (BEopt) energy modeling software incorporates NREMDB's national average measure-level costs for both retrofit and residential new construction (RNC) applications.[3] NMR extracted NREMDB RNC installation costs (labor and/or material costs, as appropriate) from the software as part of the MA19R18 study. For the current study, NMR reviewed the NREMDB via the BEopt software to assess if the costs had changed since they

[1] https://ma-eeac.org/wp-content/uploads/MARLPNC_1812_RenoAddMarketPotential_Report_Final_2020.03.30_Clean_v2.pdf
[2] https://ma-eeac.org/wp-content/uploads/MA19R18_RNCIncCostUpdate_Final_2020.03.27_clean.pdf
[3] https://beopt.nrel.gov/downloadBEopt2

were extracted for the MA19R18 study, and also extracted additional costs for equipment with efficiencies below what was assessed in the MA19R18 study, to better reflect the retrofit market. This was important for quantifying costs for the R&A Program, as pre-existing and ISP efficiency values for some measures in the participant data were well below what is found in measures among the RNC sample assessed in the MA19R18 study. NMR then plotted the new measure cost and efficiency combinations to develop cost equations representing lines of best fit for the NREMDB cost data, factoring in any added efficiency values. In instances where cost information was not readily available in the NREMDB (primarily lighting costs), the team applied the methods used in both the MA19R18 study and the original RLPNC 17-14 Residential New Construction Incremental Cost study.[4]

After developing the updated incremental cost equations from the NREMDB line of best fit equations, the team applied them to the participant R&A data to create three distinct values:

- A renovation baseline incremental cost
- An addition baseline incremental cost
- A final incremental cost using the actual efficiency of the upgraded measures

The team developed incremental costs for renovations relative to the program's ISP baseline values, **except** in cases where the pre-existing measure efficiency was better than the ISP value, in which case the pre-existing efficiency was used as the baseline value, yielding a lower incremental cost for that measure.[5] The addition costs used RNC UDRH efficiency values from the *MA19X02-B-RNCBL Residential New Construction Baseline/Compliance Study* for baseline efficiency values.[6] For participants that installed heat pumps, the team calculated the total cost for the equipment and split that between the heating and cooling end-uses to avoid double-counting costs.

To fully account for incremental costs using the program's previous approach to renovation savings, which assumes that the pre-existing condition would have persisted in the absence of the Program, the team factored in retrofit, removal, and installation labor costs from the NREMDB data for each measure type.[7] If a renovation involved installing a more efficient version of the same equipment type, the team applied the NREMDB cost associated with installing that measure in a retrofit scenario. It should be noted that some mechanical equipment is replaced because it fails, and some mechanical equipment may be replaced while it still functions. The current approach to calculating savings uses replace on failure (ROF) values, unless pre-existing

[4] https://ma-eeac.org/wp-content/uploads/RLPNC_17-14_RNCIncrementalCost_26JUL2018_Final.pdf

[5] The evaluation team discussed the implications of a dual baseline with the PA and EEAC working group. The dual baseline conversation was discussed to determine whether the ISP baseline could be applied to cases where the scope of the project did not expand due to the program incentives, and to use a pre-existing baseline for aspects of the project that were expanded (e.g., a kitchen renovation project was expanded to include air sealing and ceiling insulation). It was noted that this dual baseline concept would increase savings opportunities and programmatic opportunities to obtain additional savings in renovation projects. However, it was noted that logistical challenges to adopting this dual baseline concept exist and to date there are no solutions to overcome challenges to implement this dual baseline concept in the R&A program.

[6] https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf

[7] These costs are not relevant to ISP renovation or Addition cost scenarios because there is equipment being installed in the counterfactual baseline scenario in each case, which would cancel out any labor costs from the final upgrade. BEopt labor costs were uniform across efficiency levels.

efficiencies are better (as noted above). If the mechanical equipment replacement type (e.g., early replacement or ROF) is collected in the future, this may allow for a standard UDRH-type dual-baseline to take place of the pre-existing efficiency of mechanical equipment. While it is not currently known, the early replacement baseline may be a better representation of what the upgrades that are occurring in the R&A program. To understand this to a greater extent the program may try to collect this data as a part of participation or through homeowner/contractor surveys that ask about mechanical equipment replacement scenarios.

If a renovation involved installing a new equipment type altogether, the final cost included the removal cost of the pre-existing equipment type and the installation cost of the new equipment type. For the updated program savings approach – assuming that the participant would have implemented ISP-level upgrades for affected measures in the absence of the program, and thus that there would have been labor costs in the counterfactual – these costs cancel out as BEopt labor costs did not vary by the efficiency of the equipment.

As a final step in developing overall costs, the team leveraged the findings from the on-going *MA20R23 RNC Energy Optimization Cost Study* to apply Massachusetts-specific labor and materials cost adjustments. These adjustments – a materials multiplier of 1.152 and a labor multiplier of 1.214 – reflect data from the MA20R23 study to reflect the added expense of labor and materials in the Massachusetts market relative to national values in the NREMDB.

The team reviewed program tracking data and exported measure-level data from the R&A program energy models. The program uses Ekotrope[8] energy modeling software to calculate savings for the program. The team then cleaned the data for all measures, which entailed a labor-intensive process of matching existing model records to final model records. This process allowed the team to understand, at a measure-level, whether the measure was associated with a renovation or an addition, a critical aspect of assigning incremental costs to the program due to the different baselines associated with renovations vs. additions. Note that while the team was able to identify many measures that were specific to a renovation or to an addition, some records were not clearly identifiable as a renovation or addition. In those cases, the team would apply a proportion of costs to the renovation baseline and a proportion of costs to the addition baseline. This proportion was based on how much of the conditioned floor area (CFA) increased between the existing and final models.

The team also used the cleaned program tracking data to compile summary statistics of current program practices. These include descriptive statistics that detail what improvements have occurred and to what extent, at the measure-level.

It should also be noted that that incremental costs for additions are calculated from the added CFA of the project, while incremental costs for renovations are based on the existing CFA. This is due to lack of data to understand the actual renovated area within the home. This technically understates incremental costs for renovated area, as most renovations do not cover the entire CFA of the existing home. However, unless the program begins specifically tracking renovated

[8] https://ekotrope.com/home-page/

area of the project (in CFA), the incremental costs for renovations will be based on the entire CFA of the existing structure.

Results

Overall incremental cost results. Table 1 provides the incremental cost estimates for the R&A program in units of dollars per square foot of CFA across program homes. It shows the incremental costs from renovations and additions separately. As previously noted, the team calculated renovation costs for two baselines: the incremental costs of the pre-existing conditions baseline and the incremental costs of the ISP baseline.

However, readers should note that **the incremental costs for renovations do not describe the cost per square foot of renovated area. These incremental costs were calculated for program cost-effectiveness testing only and represent the conditioned square footage of the entire home, pre-renovation.** The team presents this caveat because program records did not identify which specific parts of a given home were renovated. Accordingly, the team calculated the incremental costs for renovations relative to the entire pre-existing CFA of a given project, rather than just the renovated portion of the home. **A program participant should expect to experience higher incremental costs *relative to the square footage of the actual area being renovated*.**

The incremental costs for additions are calculated based on the CFA added to a given project, and on average, describe the incremental costs just for the additions themselves.

For renovations using a pre-existing conditions baseline, all measure upgrades had incremental costs calculated. Essentially, this means that the incremental cost for the pre-existing conditions baseline is relative to no renovation occurring, and therefore represents the full cost to upgrade the existing area. When calculated against an ISP baseline, incremental costs are lower because they reflect the difference between program practices and assumed typical renovation practices outside the program. The building shell is the primary driver and mechanical equipment is the secondary driver for the cost increase between the pre-existing and the ISP baseline scenarios (Table 4).

The cumulative incremental costs combine the costs associated with both the renovation and addition aspect of the project and divides the total cost by the finished homes CFA.

Table 1: Incremental Costs per Square Foot of Conditioned Floor Area

	Incremental cost ($/ft^2)				
	R&A baselines			*R&A Cumulative:*	
	Renovations: pre-existing baseline	Renovations: ISP baseline	Additions: UDRH baseline	Pre-existing and additions	ISP and additions
Overall	**$9.11** per ft^2 of whole home CFA, excluding addition CFA	**$3.05** per ft^2 of whole home CFA, excluding addition CFA	**$1.28** per ft^2 of addition CFA	**$7.85** per ft^2 of final CFA	**$2.77** per ft^2 of final CFA

Overall program summary results. NMR's review of current program practices included a review of heating, ventilation, and air conditioning systems (HVAC), water heating systems, duct leakage, air infiltration, and the building envelope. This review assessed the existing conditions, as the home existed before any renovation or addition work took place, and the final conditions, after all renovation and addition work was completed.

Heating systems. The amount of oil-fired heating systems fell from 17% of homes to 6%. Usage of natural gas systems and propane fuels increased the most (53% to 60%, and 6% to 9% of systems). Specifically, natural gas furnaces represent 40% and gas boilers represent 20% of homes in the program, while propane furnaces represent 5% and boilers represent 4% of program homes. The prevalence of electric heating systems increased from 23% to 25%. Electrically heated homes are primarily heat pumps (14% MSHP, 8% CASHP, and 1% GSHP) and the rest is made up of electric resistance (<2%). The overall efficiency for all heating system types increased when compared to the existing equipment. See Section 3.1 for additional details.

Cooling systems. There were 360 homes (37%) that added permanent cooling systems – either central air-conditioners or heat pumps – after work was completed. Central air-conditioners were the most prevalent system type overall (62%), followed by mini- or multi- split heat pumps (MSHPs, 16%). The prevalence of room air conditioners dropped from 45% to 10% after work was completed. The cooling system efficiencies for all system types increased, though the most dramatic increases were with heat pump systems. See Section 3.1 for additional details.

Water heating systems. Gas instantaneous systems were the most popular domestic hot water systems in the finished homes (12% to 37% penetration from start to finish). Heat pump water heaters (HPWHs) only saw a modest increase in penetration the finished homes (6% to 8%).

Air Infiltration. Only 32% of homes conducted air infiltration testing before any work was completed and only 35% of homes conducted air infiltration testing after work was finished. The average air infiltration of homes that conducted initial air infiltration tests fell from 10.6 ACH50 to 4.6 ACH50 after work was complete. The existing and final conditions for the remaining homes applied default air infiltration values in both settings, making it unclear whether air sealing practices occurred during the renovation. See Section 3.2.1 for more details.

Duct leakage. The number of duct systems observed in participant homes increased from 11% before any work was conducted to 24% after work was completed, with 1% of existing duct systems being removed. Testing the duct systems for leakage to the outside (LTO) was more common, on a percent basis, than air infiltration testing, with 92% of duct systems being tested. The team cross checked homes that tested duct leakage with homes that tested air infiltration and found that 96% of this subset of homes also tested for air infiltration. See Section 3.2.2 for more details.

Building envelope. The team reviewed above grade walls, flat ceilings, vaulted ceilings, framed floors, foundation walls, and windows. Overall, the impacts from the renovations and additions impacted at least 50% of the measure area for all building envelope components except windows. See Section 3.3 for more details.

CONCLUSIONS AND RECOMMENDATIONS

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

Conclusion: The incremental cost associated with participating in the R&A program is estimated to be $9.11 per square foot of home CFA (excluding any addition area) for renovations using the pre-existing conditions baseline and $3.05 using the ISP baseline. The incremental costs for the additions portion of the program are estimated to be $1.28 per square foot of addition CFA. Note that incremental costs for renovations are based on the area of the whole home (excluding any additions) and incremental costs for additions are based only on the newly added CFA. The program calculates cost effectiveness based on the total CFA across the final models and does not apportion costs by renovation or addition. This necessitates a single, cumulative incremental cost estimate for the program, weighted across renovation and addition project areas. The cumulative incremental cost for both renovations and additions for the pre-existing conditions baseline is $7.85 and is $2.77 for the ISP baseline, again noting the caveat that these are results for cost-effectiveness purposes, not the costs that participants would experience if compared to the square footage of the area actually being improved.

Recommendation: The savings for the R&A program were recalculated with the ISP baseline; therefore, we recommend using the incremental cost of $2.77 per CFA for the R&A program retrospectively and prospectively.

Conclusion: The team observed that only 32% of homes had tested air infiltration of the home during the initial audit and only 35% of homes had tested air infiltration during the final audit. Of the 32% of projects that conducted initial air infiltration testing, only 49% (n=155) improved the air tightness of the home. For projects that were untested, it appears that generic air leakage values were used; these projects did not indicate that an improvement in air infiltration occurred.

Consideration: The program could benefit from an increased focus on air sealing. This may require more frequent pre- and post-air infiltration testing than recent program project data indicate as standard practice.

Conclusion: The incremental cost for renovations reflects the incremental cost of the project upgrades spread across the existing CFA of the project (i.e., the whole home, excluding any newly added area). As the R&A program savings are derived from whole home savings, the incremental costs described in Table 1 are associated with program cost-effectiveness testing. This incremental cost is not what the participant will experience and should not be marketed as expected costs per square foot of renovated area to participants or contractors.

Consideration: Energy modeling tools used by the program do not natively identify exactly which portions of a program home were renovated, added, or left untouched. Accordingly, the PAs should consider tracking the renovated area of the project to allow energy savings and incremental costs to be interpreted based on the impacted area of the renovation compared to the total area of the home. This would allow for evaluators and PAs to better understand exactly how the program is impacting participant homes. It would also allow incremental costs to be calculated relative to the part of the home being improved, which may help potential program participants better estimate the relative costs of participating for their projects.

Conclusion: The team observed 97 homes with duct systems in both the existing and final home and had tested for duct LTO. Of those 97 homes, only 28 homes (29%) reduced duct LTO.

Consideration: There are opportunities for the program to increase focus on duct LTO. This can effectively be related to duct sealing practices and conducting LTO tests or through bringing the HVAC distribution system inside the thermal envelope to effectively eliminate LTO. The program can encourage participant contractors to include duct sealing in the scope of renovation projects that cannot bring the HVAC distribution system into the thermal envelope, due to issues such as project scope, cost, or technical feasibility. Some existing duct systems may be difficult to access and may make traditional duct sealing practices ineffective (both in terms of cost and energy savings), in these cases the program may consider promoting advanced sealing practices such as Aeroseal. In projects that are adding HVAC distribution systems to additions or as a part of the renovation, the program could provide guidance to participant contractors on strategies to install new ductwork inside the thermal envelope. Guidance to contractors could be in the form of training, case studies of participant projects that applied these strategies, and identification of and solutions for the barriers that prevent these strategies from being incorporated regularly into projects.

Conclusion: The R&A program covers a wide variety of projects and has an opportunity to impact almost all residential energy conservation measures. Some measures may be easier and cheaper to include in the scope of a R&A project, such as air sealing or attic insulation since they do not require extensive expansion of the project scope, while switching from renovating the kitchen wall area to renovating the entire exterior wall area of the home would be extensive.

Consideration: The PAs should consider including some 'core services' in every R&A project. For example, including comprehensive air sealing in every project would increase savings associated with program participants. The same could be true for upgrading flat attic insulation. The PAs might also consider a best practice guide for more extensive efficiency practices, such adding exterior wall or foundation wall insulation.

1

Section 1 Introduction

The following subsections describe the program home population, the measures that are included in this study, and details on the methodology used to calculate the incremental cost of the Residential Renovations and Additions (R&A) Program.

1.1 Renovation and Addition Program Homes

This study includes the population of homes that participated in the R&A program from program inception in 2019 through October 2020. The team obtained measure level data for the program from Ekotrope energy models. General summary statistics of the R&A program are displayed in Table 2.

Table 2: R&A Program Summary Statistics

Summary statistic	All R&A program homes
n-value	*973*
Percent of renovation only projects	59%
Percent of addition only projects	<1%
Percent of projects with renovation and addition	40%
Percent of projects with no area change	60%
Percent of projects with <500 ft^2 of CFA added	14%
Percent of projects with 500+ ft^2 of CFA added	26%
Percent of single-family homes in the program	65%
Percent of multifamily units in the program	35%

1.2 Measures and Specifications

There are several building components, systems, and practices that impact the efficiency of renovations or additions added to existing homes. The team maintained a similar approach to the RLPNC 17-14 and MA19R18 studies, which was to focus and prioritize the measures that have the most impact on energy efficiency and are common practice in program homes. However, this study encompasses more measures than those previous studies as those focused entirely on residential new construction (RNC), while this study encompasses renovations of existing residential units, which have more varied building components and systems that were more common in the past. The team analyzed the program home data to determine what program renovation and building practices are occurring.

The measure list expands upon the measures included in the MA19R18 update and the original RLPNC 17-14 measure list, as the participant homes of the R&A program encompass a broader set of systems, fuel types, and components than seen in typical RNC. Note that the baseline efficiencies for traditional ducted central air-source heat pumps (CASHPs) and mini- or multi- split heat pump systems (MSHPs) are separated.[9]

Table 3 describes the following:

- The measures addressed in this study and the percentage of program homes with these measures
- The efficiency units for the baseline efficiency values
- The baseline efficiency values for renovations using the pre-existing conditions baseline
- The baseline efficiency values for the renovations using the Industry Standard Practice (ISP) baseline
- The baseline efficiency values for additions, derived from on-site measurements, during the recent MA19X02-B-RNCBL Residential New Construction Compliance/Baseline Study

Baseline efficiency values for additions are derived from both the User-defined Reference Home (UDRH) inputs, when applicable, and directly from the baseline study report.[10]

The baseline efficiency values indicate the cutoff point to which incremental costs are applied to program homes. Homes with efficiency values below the baseline are attributed no incremental cost, and homes that outperform the baseline are assigned a calculated incremental cost.

[9] MSHPs are heat pump systems with an inverter-driven compressor, which traditionally condition space through one or more distribution points (single-zone or multi-zone), such as a wall-mounted cassette or a ceiling cassette. Ductless mini-split system configurations have evolved over time and can now be either ductless, ducted, or a mixed configuration. For the purposes of this report, MSHP systems include inverter-driven heat pump systems, regardless of configurations, while ASHPs denote traditional heat pump systems, which condition space through a central distribution system.

[10] In some instances, the UDRH provides values that are combined between systems or fuels, such as HVAC, or provides U-values for entire building shell components rather than the average nominal R-value.

Table 3: Measure List and Baseline Efficiency Values Summary

Measure	Efficiency unit	Percent of homes with measure (n=973)	Baseline efficiency value		
			Pre-existing conditions	ISP baseline	Additions - UDRH baseline
Building shell measures					
Above grade walls	R-value	100%	Pre-existing conditions	13*	21.8
Flat attics	R-value	67%	Pre-existing conditions	37*	43.8
Vaulted ceilings	R-value	46%	Pre-existing conditions	37*	41.6
Framed floors	R-value	83%	Pre-existing conditions	5*	30.1
Foundation walls	R-value	30%	Pre-existing conditions	Pre-existing conditions	14.3
Windows	U-value	89%	Pre-existing conditions	0.29	0.29
Heating systems					
Gas furnace	AFUE	43%	Pre-existing conditions	85*	93.9
Propane furnace	AFUE	5%	Pre-existing conditions	85*	93.9
Oil furnace	AFUE	2%	Pre-existing conditions	83*	N/A
Gas boiler	AFUE	24%	Pre-existing conditions	79.3*	94.9
Propane boiler	AFUE	4%	Pre-existing conditions	79.3*	94.9
Oil boiler	AFUE	6%	Pre-existing conditions	84*	N/A
CASHP - Heating	HSPF	9%	Pre-existing conditions	8.2*	9.3
MSHP - Heating	HSPF	15%	Pre-existing conditions	8.2*	9.3
GSHP - Heating	HSPF	1%	Pre-existing conditions	CASHP baseline	16
Cooling systems					
Central AC	SEER	51%	Pre-existing conditions	13*	14.1
CASHP - Cooling	SEER	10%	Pre-existing conditions	14*	16.6
MSHP - Cooling	SEER	14%	Pre-existing conditions	15*	19.7
GSHP - Cooling	EER	1%	Pre-existing conditions	CASHP baseline	9.8
Hot water systems					
Storage (fossil fuel)	EF	44%	Pre-existing conditions	0.604*	0.69
Instantaneous	EF	45%	Pre-existing conditions	0.63*	0.95
HPWH	EF	8%	Pre-existing conditions	0.92*	3.39

Additional measures					
Air infiltration	ACH50	100%	Pre-existing conditions	Pre-existing conditions	3.04
Duct leakage to outside	CFM25/100 ft2	61%	Pre-existing conditions	Pre-existing conditions	3.8
Duct insulation	R-value	25%	Pre-existing conditions	Pre-existing conditions	6
Bath fans	Watts	28%	Pre-existing conditions	Pre-existing conditions	60
ERV	SRE	4%	Pre-existing conditions	Pre-existing conditions	72
HRV	SRE	0%	Pre-existing conditions	Pre-existing conditions	72
Lighting**	% of efficient hard-wired fixtures	100%	Pre-existing conditions	Pre-existing conditions	92.1

*Denotes measures that use the baseline ISP efficiency value or the pre-existing efficiency value, whichever is more efficient.
**Lighting is excluded from the total incremental cost calculations. However, the costs associated with lighting upgrades are shown for reference.

Section 2 Measure-level Incremental Cost Updates

This section provides the measure-level incremental costs associated with building to program performance levels.

Table 4 describes the following:

- The percentage of program homes with a given measure
- The percentage of program homes that had a given measure renovated. Note that this percentage includes measures that were upgraded beyond their pre-existing conditions.
- The percentage of program homes that had a given measure included in an addition
- Homes that are above the baseline efficiency value have an incremental cost associated with that given measure. Homes that do not outperform the baseline have no incremental cost. Note that pre-existing baseline conditions do not have a baseline to assess costs against, resulting in an estimate that reflects the total cost of the upgrade against no renovation or addition.
- The average measure-level incremental cost for program performance, calculated in dollars per square foot of conditioned floor area (CFA). Incremental cost values are shown as calculated using the pre-existing renovation baseline (i.e., this equates to the cost of the project as there is no baseline measure to compare against), the ISP renovation baseline, and additions.
    - Incremental cost is equal to the total upgrade cost for each measure divided by the total CFA of the program.
    - Note that incremental costs associated with renovations are compared to the existing CFA and that incremental costs associated with additions are compared to the added CFA. This ensures that CFA is not being factored into the calculations multiple times. Adding renovation and addition incremental costs provides the total incremental cost for the R&A program, which varies based on the renovation baseline that is used.

The following describes the different incremental cost columns presented in Table 4:

A. Renovations: pre-existing baseline (A): these are the incremental costs associated with the pre-existing conditions baseline. The incremental costs were summed for each measure and are divided by the existing CFA of the program.

B. Renovations: ISP baseline (B): these are the incremental costs associated with the ISP conditions baseline. The incremental costs were summed for each measure and are divided by the existing CFA of the program.

C. Additions: UDRH baseline (C): these are the incremental costs associated with the UDRH conditions baseline. The incremental costs were summed for each measure and are divided by the additional CFA of the program.

D. Renovations and additions: ISP and UDRH baseline (D): these are the incremental costs associated with renovations that apply the ISP baseline and additions to the UDRH baseline. The incremental costs for both renovations and additions were summed for each measure and divided by the final CFA of the program.

E. Renovations and additions: pre-existing and UDRH baseline (E): these are the incremental costs associated with renovations that apply the pre-existing conditions baseline and additions to the UDRH baseline. The incremental costs for both renovations and additions were summed for each measure and divided by the final CFA of the program.

Table 4: Incremental Cost Summary Table (All Program Homes)

Measure	Percent of homes with measure (n=973)	Percent of homes with renovation present (n=973)	Percent of homes with addition present (n=973)	Incremental Cost ($/ft^2): Renovations: pre-existing baseline (A)	Renovations: ISP baseline (B)	Additions: UDRH baseline (C)	Renovations and additions: ISP and UDRH baseline (D)	Renovations and additions: pre-existing and UDRH baseline (E)
Building Shell Measures								
Above Grade Walls	100%	90%	21%	$2.17	$0.93	$0.21	$0.81	$1.85
Flat Attics	67%	54%	10%	$0.84	$0.19	$0.09	$0.18	$0.72
Vaulted Ceilings	46%	37%	12%	$0.56	$0.27	$0.21	$0.26	$0.51
Framed Floors	83%	45%	15%	$0.43	$0.26	$0.09	$0.23	$0.38
Foundation Walls	30%	16%	11%	$0.20	$0.13	$0.10	$0.13	$0.18
Windows	89%	44%	1%	$1.11	$0.08	$0.02	$0.07	$0.93
Heating Systems								
Gas Furnace	43%	30%	12%	$0.50	$0.13	$0.03	$0.11	$0.43
Propane Furnace	5%	4%	2%	$0.09	$0.03	$0.01	$0.03	$0.08
Oil Furnace	2%	0%	0%	$0.00	$0.00	$0.00	$0.00	$0.00
Gas Boiler	24%	9%	4%	$0.40	$0.13	<$0.01	$0.11	$0.34
Propane Boiler	4%	3%	2%	$0.09	$0.03	<$0.01	$0.02	$0.08
Oil Boiler	6%	1%	0%	$0.02	<$0.01	<$0.01	<$0.01	$0.02
CASHP - Heating	9%	7%	3%	$0.12	$0.02	$0.02	$0.02	$0.11
MSHP - Heating	15%	9%	6%	$0.29	$0.02	$0.04	$0.03	$0.25
GSHP - Heating	1%	1%	0%	$0.02	<$0.01	<$0.01	<$0.01	$0.02
Cooling Systems								
Central AC	51%	35%	10%	$0.76	$0.02	$0.02	$0.02	$0.64
CASHP - Cooling	10%	8%	2%	$0.17	$0.03	$0.01	$0.02	$0.15
MSHP - Cooling	14%	11%	2%	$0.20	$0.11	$0.05	$0.10	$0.18
GSHP - Cooling	1%	1%	0%	$0.02	<$0.01	<$0.01	<$0.01	$0.02
Hot Water Systems								
Storage	44%	10%	4%	$0.15	$0.02	$0.03	$0.02	$0.13
Instantaneous	45%	31%	13%	$0.43	$0.16	$0.01	$0.14	$0.36
HPWH	8%	5%	2%	$0.08	$0.03	$0.01	$0.03	$0.07
Additional Measures								

Air Infiltration	100%**	21%**	40%*	$0.40	$0.40	$0.01	$0.34	$0.34
Duct Leakage to Outside	61%	3%	40%*	$0.01	$0.01	$0.20	$0.04	$0.04
Duct Insulation	25%	9%	8%	$0.01	$0.01	$0.02	$0.01	$0.01
Bath Fans	28%	13%	8%	<$0.01	<$0.01	$0.03	$0.01	$0.01
ERV	4%	3%	2%	$0.02	$0.02	$0.06	$0.03	$0.03
HRV	0%	0%	0%	$0.00	$0.00	$0.01	<$0.01	<$0.01
Lighting†	100%	29%	40%*	$0.02	$0.01	<$0.01	$0.01	$0.02
Total Incremental Cost				**$9.11**	**$3.05**	**$1.28**	**$2.77**	**$7.85**

*The team was unable to determine what percentage of homes had an addition and an upgrade due to the whole-home nature of these measures. These values represent all homes with an addition.

**Note that only 35% of the final energy models included tested infiltration values. The remainder of the projects used what appeared to be default values for air infiltration.

†Lighting is excluded from the total incremental cost calculations. However, costs associated with lighting upgrades are shown for reference.

Section 3 Program Summary Statistics

The team compiled some additional summary statistics on the R&A program. Statistics are included for heating, ventilation, and air-conditioning (HVAC) equipment, domestic hot water systems, air infiltration, duct leakage, and building shell components (i.e., walls, ceilings, floors).

3.1 Mechanical Equipment Summary Statistics

Table 5 provides a comparison of heating systems and fuel types. Oil heating systems fell in prevalence by almost two-thirds (17% to 6%), replaced by various equipment types.

Table 5: Heating System Comparisons

Fuel type	Existing systems	ISP baseline	Final systems
n (Equipment)	*1,182*	*N/A*	*1,216*
Electric	23%	N/A	25%
Natural gas	53%	N/A	60%
Oil	17%	N/A	6%
Propane	6%	N/A	9%
Wood	<1%	N/A	<1%
Existing and final system type comparison			
Gas furnace	24%	N/A	40%
Propane furnace	3%	N/A	5%
Oil furnace	5%	N/A	2%
Gas boiler	29%	N/A	20%
Propane boiler	3%	N/A	4%
Oil boiler	12%	N/A	5%
CASHP	9%	N/A	8%
MSHP	4%	N/A	14%
GSHP	1%	N/A	1%
Other*	11%	N/A	2%
Existing and final system efficiency comparison			
Gas furnace (AFUE)	85.6	85	93.5
Propane furnace (AFUE)	86.6	85	93.6
Oil furnace (AFUE)	77.1	83	78.1
Gas boiler (AFUE)	82.8	79.3	90.4
Propane boiler (AFUE)	76.4	79.3	87.7
Oil boiler (AFUE)	77.3	84	83.1
CASHP (HSPF)	8.3	8.2	9.9
MSHP (HSPF)	9.7	8.2	10.9
GSHP (HSPF)	9.3	8.2 (CASHP baseline)	13.1

*The “Other” category includes wood systems, electric resistance, and other natural gas, propane, or electric systems described in the data as “Custom” or hydronic radiant floor systems.

Table 6 provides a breakdown of home cooling systems pre- and post-program participation. Almost half (45%) of sites with cooling prior to participating in the program were using room air conditioners; that number falls to 10% among finished homes. About 360 homes added permanent cooling in the form of central ACs or heat pumps that were absent during a renovation or combination renovation and addition.

Table 6: Cooling System Comparisons

Equipment type	Existing systems	ISP baseline	Final systems
Existing and final system type comparison			
n (equipment)	*603*		*968*
Central AC	43%	N/A	62%
CASHP	6%	N/A	11%
MSHP	6%	N/A	16%
GSHP	1%	N/A	1%
Room AC	45%	N/A	10%
Existing and final system efficiency comparison			
Central AC (SEER)	13.2	13	13.7
CASHP (SEER)	13.8	14	17.8
MSHP (SEER)	16.8	15	20.6
GSHP (EER)	12.0	14 (uses CASHP baseline)	18.9
Room AC (EER)	9.3	N/A	9.7

*Room ACs do not have an ISP baseline value. Room ACs were not included in the incremental cost calculations above, they are just here for reference as many homes in the program at least initially begin with Room AC for cooling.

Table 7 shows domestic hot water system characteristics for homes before and after participating in the program. The share of heat pump water heaters in homes only increased 2% during upgrades, while gas and electric storage heaters were largely replaced with gas instantaneous systems.

Table 7: Domestic Hot Water System Comparisons

Fuel type	Existing systems	ISP baseline	Final systems
n (equipment)	*1000*	*N/A*	*1000*
Electric	22%	N/A	19%
Natural gas	59%	N/A	66%
Oil	11%	N/A	6%
Propane	9%	N/A	10%
Existing and final system type comparison			
Gas storage	39%	N/A	23%
Propane storage	6%	N/A	2%
Oil storage	1%	N/A	1%
Electric storage	12%	N/A	9%
HPWH	6%	N/A	8%
Gas instantaneous†	12%	N/A	37%
Propane instantaneous†	2%	N/A	7%
Oil instantaneous†	1%	N/A	1%
Gas boiler*	8%	N/A	7%
Propane boiler*	1%	N/A	1%
Oil boiler*	9%	N/A	4%
**Includes homes where there is not additional DHW system and boilers provide hot water via indirect tanks and tankless coils. †Includes combi appliances with no indirect tank.*			
Existing and final system efficiency comparison			
Gas storage (EF)	0.62	0.604	0.68
Propane storage (EF)	0.52	0.604	0.76
Oil storage (EF)	0.62	0.604	0.64
Electric storage (EF)	0.90	0.92	0.92
HPWH (EF)	2.29	0.92	3.17
Gas instantaneous† (EF)	0.87	0.63	0.93
Propane instantaneous† (EF)	0.84	0.63	0.93
Oil instantaneous† (EF)	0.68	0.63	0.77
†Includes combi appliances with no indirect tank.			

3.2 Air Infiltration and Duct Leakage Summary Statistics

3.2.1 Air Infiltration

The team observed that only 32% of homes had tested the air tightness of the home during the initial audit and only 35% of homes had tested for air infiltration during the final audit. These observations are based on Ekotrope modeling data that indicates whether the air infiltration value was tested and confirmed with a blower door test. **For projects that were untested, it appears that generic air infiltration (expressed in units of ACH50) values were used; these projects did not indicate that an improvement in air infiltration occurred.** Note that the incremental costs developed above only considered projects that were both tested and had improved air infiltration.[11]

These observations do not suggest that air sealing practices are not occurring in the untested projects, but it also does not confirm that air sealing was conducted.

Table 8 provides average air infiltration results. Due to the different results seen when considering the air infiltration values of sites that had completed blower door tests compared to all projects, the team has provided results for all homes, all homes that received initial testing, and all homes that received initial testing and were upgraded. As shown in the table, the projects that conducted initial air infiltration tests measured drastic improvement, on average, in the tightness of the building envelope upon completion of the project. However, of the projects that conducted initial air infiltration testing, only 49% (n-155) of homes improved the air tightness of the home.

Table 8: Average Air Infiltration (ACH50)

Category	Existing conditions ACH50	Final conditions ACH50	Average percent improvement	Average improvement (ACH50)
Percent of homes with air infiltration tests (n=973)	32%	35%		
All projects (n=973)[a]	5.86	3.91	33%	1.95
All initially tested projects (n=314)	10.32	4.59	56%	5.73
Initially tested projects with improvement, excludes projects with additions (n=86)	19.62	5.98	70%	13.64
Initially tested projects with improvement, includes projects with additions (n=155)	16.72	5.06	70%	11.66

[a] Air infiltration values for non-tested projects typically fell into the range of 3.02-3.70 ACH50. The air infiltration values used by non-tested projects are default values which is why the final condition ACH50 is lower than it is for homes that actually had improvements. There were 659 projects (68%) that had default ACH50 values that indicate the home was relatively tight, the default values that were used are closer to what is seen in new construction compared to existing home stock.

3.2.2 Duct Systems

The number of duct systems observed in participant homes increased from 11% (n-107) before any work was conducted to 24% (n-234) after work was completed, with 1% (n-10) of existing duct systems being removed. The energy model data indicated that 92% of duct systems in existing homes were tested for LTO before the project began and upon final inspection. Generally, in cases where testing did not occur, a duct system was added or removed from the project. The team cross referenced the projects that conducted LTO tests with projects that completed air infiltration tests, as both tests require a blower door to measure, and found that 96% of projects that conducted duct LTO tests also measured air infiltration. This indicates projects that focus on duct sealing may also have a focus on air sealing for the entire envelope.

[11] There were nine projects identified did not have air infiltration tested in the initial audit but appeared to have non-generic values (generic ACH50 values fell in the range of 3.57-3.70). Due to uncertainty, the team assumed these projects were not tested.

Table 9 describes duct leakage to the outside per 100 square feet of CFA (LTO per 100ft^2) for all homes with duct systems,[12] homes with the same duct systems in both the initial and final inspections, and homes with the same duct systems in both the initial and final inspections that had measured improvements in duct leakage.

Table 9: Duct Leakage to the Outside (LTO per 100 ft^2)

Category	Existing duct leakage (LTO/100 ft^2)	Final duct leakage (LTO/100 ft^2)	Average percent improvement	Average improvement (LTO/100 ft^2)
All homes with duct leakage values in energy model (n=242)	5.8	2.5	57%	3.3
Homes with duct system in existing and final (n=97)	6.1	3.4	44%	2.7
Homes with improved duct system in existing and final (n=28)	11.0	1.8	83%	9.2

3.3 Building Envelope Summary Statistics

The following subsections describe the summary statistics for building envelope measures. The data is presented as a full summary of the home, the existing area, and the final area. To help visualize this process, see the figure below.

[12] This includes LTO values for all homes that had a duct system in either the existing, final, or both energy models.

Figure 1: Example of the existing home area, addition area, and total area of the final home

3.3.1 Above Grade Walls

Table 10 describes summary statistics for all above grade walls abutting unconditioned space and the outdoors. The team estimates that 64% of existing wall area was improved over ISP baseline conditions (see Table 3 to reference baseline efficiency values by measure). The team estimates that 41% of the wall area in additions was better than the UDRH baseline.

Table 10: Summary Statistics for Walls to Unconditioned Space and Outdoors

Category	Average R-value, existing conditions	Average R-value, final conditions	Wall area (ft^2), existing conditions	Wall area (ft^2), final conditions
All homes wall area (n=972)	7.4	18.1	1,818,048	1,838,159
Renovations only*				
Total wall area, excluding addition walls (n=972)	7.4	17.7	1,817,473	1,694,050*
Wall area exceeding pre-existing conditions (n=873)**	5.8	19.8	1,303,332	1,247,049
Wall area exceeding ISP baseline (n=794)**	6.2	20.9	1,140,430	1,085,474
Additions only				
Addition wall area (n=199)	N/A	23.0	N/A	144,109
Addition wall area exceeding UDRH (n=84)	N/A	28.4	N/A	58,760

*Some renovations removed wall area as a part of the project, for example a wall area is removed to join the addition to the existing home.

**The values represented for these categories reflect the wall area that was upgraded beyond the pre-existing conditions and the wall area that was upgraded beyond ISP baseline conditions. These are values derived from two separate baselines for renovations.

Table 11 shows a breakdown of the proportion of wall area abutting unconditioned space and the outdoors by R-value ranges. The existing conditions statistics are relative to the existing wall area and existing R-values, while the final conditions statistics are relative to the final wall area and final R-values.

Table 11: Proportion of Wall Area to Unconditioned Space and Outdoors by R-value Category

Category	Existing conditions	Final conditions
n (wall to unconditioned or outside area)	*1,818,048*	*1,838,159*
R5 or less	45%	3%
R6-R13	45%	24%
R14-R20	8%	32%
R21-R24	1%	28%
R25-R30	<1%	7%
R30+	0%	5%

Table 12 presents the percent of wall (to unconditioned space or the outside) area covered by insulation material type. As with the table above, the existing conditions reflects the proportion of insulation materials that were there before renovations occurred. The final conditions show which insulation materials were more commonly used to insulate walls that abut unconditioned space or the outdoors.

Table 12: Proportion of Insulation Materials by Wall Area to Unconditioned Space and Outdoors

Insulation category	Existing conditions	Final conditions
n (wall to unconditioned or outside area)	*1,818,048*	*1,838,159*
Cellulose	12%	13%
Fiberglass batts	52%	37%
Fiberglass, blown-in	4%	1%
High density spray foam	<1%	29%
Low density spray foam	1%	15%
Mineral wool	2%	2%
Vermiculite	<1%	N/A
XPS/EPS/Polyisocyanurate	<1%	<1%
Uninsulated	29%	2%

3.3.2 Flat Attics

Table 13 describes summary statistics for all flat ceilings. The team estimates that 57% of existing flat ceiling area was improved beyond ISP baseline conditions (see Table 3 to reference baseline efficiency values by measure). The team estimates that 51% of the flat ceiling area in additions was better than the UDRH baseline.

Table 13: Summary Statistics for Flat Ceilings

Category	Average R-value, existing conditions	Average R-value, final conditions	Flat ceiling area (ft^2), existing conditions	Flat ceiling area (ft^2), final conditions
All homes with flat attic area (n=653)	19.1	42.9	702,254	639,995
Renovations only*				
Total flat ceiling area, excluding addition flat ceiling (n=620)	19.2	42.7	671,277	563,901
Flat ceiling area exceeding pre-existing conditions (n=379)**	12.3	45.9	366,054	389,404
Flat ceiling area exceeding ISP baseline (n=317)**	12.8	49.0	296,445	322,064
Additions only				
Addition flat ceiling area (n=95)	N/A	43.8	N/A	76,094
Addition flat ceiling area exceeding UDRH (n=47)	N/A	50.7	N/A	38,655

*Some renovations removed flat ceiling area as a part of the project, for example some renovations may add insulation along the rafters and extend the thermal boundary to the roof deck.

**The values represented in these categories reflect the flat ceiling area that was upgraded beyond the pre-existing conditions and was upgraded beyond ISP baseline conditions. These are values derived from two separate baselines for renovations and have different associated areas.

Table 14 shows a breakdown of the proportion of flat ceiling area by R-value ranges. The existing conditions statistics are relative to the existing flat ceiling area and existing R-values, while the final conditions statistics are relative to the final flat ceiling area and final R-values.

Table 14: Proportion of Flat Ceiling Area by R-value Category

Insulation category	Existing conditions	Final conditions
n (flat ceiling area)	*702,254*	*639,995*
R13 or less	36%	3%
R13-R24	37%	8%
R25-R31	8%	5%
R32-R40	10%	29%
R41-R48	2%	11%
R49-R56	2%	28%
R57-R63	5%	13%
R64+	0%	4%

Table 15 presents the proportion of flat ceiling area covered by insulation material type. As with the table above, the existing conditions reflects the proportion of insulation materials that were there before renovations occurred. The final conditions show which insulation materials were more commonly used to insulate flat ceilings.

Table 15: Proportion of Insulation Materials by Flat Ceiling Area

Insulation category	Existing conditions	Final conditions
n (flat ceiling area)	*702,254*	*639,995*
Cellulose	28%	37%
Fiberglass batts	52%	23%
Fiberglass, blown-in	0%	0%
High density spray foam	0%	30%
Low density spray foam	0%	7%
Mineral wool	6%	1%
Vermiculite	0%	N/A
XPS	0%	0%
Uninsulated	14%	2%

3.3.3 Vaulted Ceilings

Table 16 describes summary statistics for all vaulted ceilings. The team estimates that 58% of existing vaulted ceiling area was improved beyond ISP baseline conditions (see Table 3 to reference baseline efficiency values by measure). The team estimates that 53% of the vaulted ceiling area in additions was better than the UDRH baseline.

Table 16: Summary Statistics for Vaulted Ceilings

Category	Average R-value, existing conditions	Average R-value, final conditions	Vaulted ceiling area (ft^2), existing conditions	Vaulted ceiling area (ft^2), final conditions
All homes with vaulted ceiling area (n=443)	12.7	39.2	284,589	467,833
Renovations only				
Total vaulted ceiling area, excluding addition vaulted ceiling (n=354)	12.7	37.7	284,589	332,434
Vaulted ceiling area exceeding pre-existing conditions (n=294)**	10.7	40.1	232,882	287,857
Vaulted ceiling area exceeding ISP baseline (n=190)**	11.1	44.1	148,136	192,414
Additions only				
Addition vaulted ceiling area (n=119)	N/A	42.9	N/A	135,399
Addition vaulted ceiling area exceeding UDRH (n=74)	N/A	48.7	N/A	71,301

**The values represented for these categories reflect the vaulted ceiling area that was upgraded beyond the pre-existing conditions and the vaulted ceiling area that was upgraded beyond ISP baseline conditions. These are values derived from two separate baselines for renovations and have different associated areas.

Table 17 shows a breakdown of the proportion of vaulted ceiling area by R-value ranges. The existing conditions statistics are relative to the existing vaulted ceiling area and existing R-values, while the final conditions statistics are relative to the final vaulted ceiling area and final R-values.

Table 17: Proportion of Vaulted Ceiling Area by R-value Category

Insulation category	Existing conditions	Final conditions
n (vaulted ceiling area)	*284,589*	*467,833*
R7 or less	40%	1%
R8-R14	14%	1%
R15-R21	32%	6%
R22-R29	7%	4%
R30-R37	6%	23%
R38-R45	1%	37%
R46-R53	1%	23%
R54+	0%	4%

Table 18 details the percent of vaulted ceiling area covered by insulation material type. As with the table above, the existing conditions reflects the proportion of insulation materials that were there before renovations occurred. The final conditions show which insulation materials were more commonly used to insulate vaulted ceilings.

Table 18: Proportion of Insulation Materials by Vaulted Ceiling Area

Insulation Category	Existing conditions	Final conditions
n (vaulted ceiling area)	*284,589*	*467,833*
Cellulose	12%	8%
Fiberglass batts	56%	11%
Fiberglass, blown-in	<1%	0%
High density spray foam	1%	46%
Low density spray foam	1%	33%
Mineral wool	1%	1%
Polyisocyanurate	1%	0%
Vermiculite	<1%	N/A
XPS	1%	<1%
Uninsulated	29%	1%

3.3.4 Framed Floors

Table 19 describes summary statistics for all framed floors abutting unconditioned space and the outdoors. The team estimates that 61% of existing framed floor area was improved over ISP baseline conditions (see Table 3 to reference baseline efficiency values by measure). The team estimates that 50% of the framed floor area in additions was better than the UDRH baseline.

Table 19: Summary Statistics for Framed Floors to Unconditioned Space and Outdoors

Category	Average R-value, existing conditions	Average R-value, final conditions	Framed Floor area (ft^2), existing conditions	Framed Floor area (ft^2), final conditions
All homes with framed floor area (n=649)	6.8	24.7	575,759	538,742
Renovations only*				
Total framed floor area, excluding addition framed floor (n=616)	6.8	23.7	575,141	484,686
Framed floor area exceeding pre-existing conditions (n=372)**	3.0	30.5	299,525	295,004
Framed floor area exceeding ISP baseline (n=371)**	3.0	30.5	299,221	294,820
Additions only				
Addition framed floor area (n=139)	N/A	34.1	N/A	54,056
Addition framed floor area exceeding UDRH (n=66)	N/A	39.5	N/A	26,941

*Some renovations removed framed floor area as a part of the project, for example some renovations may insulate the foundation wall and extend the thermal boundary beyond the framed floor.
**The values represented for these categories reflect the framed floor area that was upgraded beyond the pre-existing conditions and the framed floor area that was upgraded beyond ISP baseline conditions. These are values derived from two separate baselines for renovations and have different associated areas.

Table 20 shows a breakdown of the proportion of framed floor area to unconditioned space and outdoors by R-value ranges. The existing conditions statistics are relative to the existing framed floor area and existing R-values, while the final conditions statistics are relative to the final framed floor area and final R-values.

Table 20: Proportion of Framed Floor Area to Unconditioned Space and Outdoors by R-value Category

Insulation category	Existing conditions	Final conditions
R5 or less	72%	20%
R6-R20	16%	8%
R21-R30	6%	48%
R31-R40	2%	16%
R40+	3%	8%

Table 21 details the percent of framed floor area covered by insulation material type. As with the table above, the existing conditions reflect the proportion of insulation materials that were there before renovations occurred. The final conditions show which insulation materials were more commonly used to insulate framed floors.

Table 21: Proportion of Insulation Materials by Framed Floor Area

Insulation category	Existing conditions	Final conditions
n (framed floor area)	*575,759*	*538,742*
Cellulose	0%	1%
Fiberglass batts	29%	58%
Fiberglass, blown-in	<1%	1%
High density spray foam	<1%	3%
Low density spray foam	<1%	10%
Mineral wool	1%	8%
XPS/EPS/Polyisocyanurate	<1%	<1%
Uninsulated	69%	19%

3.3.5 Foundation Walls

Table 22 describes summary statistics for all foundation walls abutting unconditioned space and the outdoors. The team estimates that 77% of existing foundation wall area was improved over ISP baseline conditions (see Table 3 to reference baseline efficiency values by measure). The team estimates that 56% of the foundation wall area in additions was better than the UDRH baseline.

Table 22: Summary Statistics for Foundation Walls to Unconditioned Space and Outdoors

	Average R-value, existing conditions	Average R-value, final conditions	Existing conditions foundation wall area	Final conditions foundation wall area
All homes with foundation walls (n=295)	4.1	15.6	143,600	255,337
Renovations only				
Total foundation wall area, excluding addition foundation walls (n=152)	4.1	15.2	142,265	161,029
Foundation wall area exceeding pre-existing/ISP conditions (n=152)*	2.9	17.7	101,622	123,814
Additions only				
Addition foundation wall area (n=139)	N/A	16.2	N/A	94,307
Addition Foundation wall area exceeding UDRH (n=66)	N/A	19.3	N/A	52,569

*Foundation walls have an ISP baseline of pre-existing conditions.

Table 23 shows a breakdown of the proportion of foundation wall area to unconditioned space and outdoors by R-value ranges. The existing conditions statistics are relative to the existing foundation wall area and existing R-values, while the final conditions statistics are relative to the final foundation wall area and final R-values.

Table 23: Proportion of Foundation Wall to Unconditioned Space and Outdoors by R-value Category

Insulation category	Existing conditions	Final conditions
R4 or less	70%	7%
R5-R9	9%	3%
R10-R14	17%	38%
R15-R19	1%	20%
R20+	2%	32%

Table 24 details the percent of foundation wall area covered by insulation material type. As with the table above, the existing conditions reflects the proportion of insulation materials that were there before renovations occurred. The final conditions show which insulation materials were more commonly used to insulate foundation walls.

Table 24: : Proportion of Insulation Materials by Foundation Wall Area

Insulation category	Existing conditions	Final conditions
n (foundation wall area)	*143,600*	*255,337*
Cellulose	N/A	0%
Fiberglass batts	24%	21%
High density spray foam	1%	48%
Low density spray foam	0%	1%
Mineral wool	N/A	2%
XPS/EPS/Polyisocyanurate	4%	19%
Uninsulated	70%	7%

3.3.6 Windows

Table 25 presents summary statistics for participant home windows. Note that only data for 890 of the 973 (89%) participant homes was available, but not all of those 870 projects had window u-values that were verified on-site.[13] The following summary statistics only include participant projects where window u-values were verified in both the existing and final inspection, as indicated in the energy model data.

Table 25: Average Area Weighted U-Values for Verified Windows

Category	Average U-value, Existing Conditions	Average U-value, Final Conditions
All verified windows, n=452	0.47	0.34
All verified windows with upgrade, n=238	0.61	0.28
All verified windows with upgrade over ISP, n=107	0.58	0.25

[13] Verified values are based on window specifications, typically seen by a sticker on the window or from manufacturer specifications. Window u-values that do not have this information available use default value inputs into the energy model, which is based on the window-type (such as a double-paned window with a vinyl frame).

Appendix A Lighting Incremental Cost

Please note that the incremental costs associated with lighting are not included in the summary results presented in the body of the report. These savings are not captured as part of the energy modeling process and are therefore split out. The estimated incremental cost associated with efficient lighting follows the same approach as outlined in the RLPNC 17-14 incremental cost study and in the MA19R18 incremental cost update study (detailed in Appendix A of both reports). The baseline lighting specifications are based on the 2019 baseline study results, and cost data was obtained from the MA19R06 Massachusetts Lighting Sales Data Analysis report.[14]

The R&A program provided participants with LED light bulbs at no cost until January 1, 2021. Therefore, there is no cost for efficient lighting in the low-rise program due to the program incentive. Below, we summarize the methodological process to estimate the theoretical incremental cost for builders to upgrade to efficient light bulbs without direct program support. Moving forward in 2021, the R&A program will not provide LED light bulbs at no-cost. To date, there has not been a replacement methodology to claim savings from lighting on projects.

Ekotrope energy models, used in the R&A program, only include the saturation of efficient lighting at the hard-wired fixture level, and do not include bulb-level details. The team applied a bulb per square foot ratio for hard-wired fixtures, obtained from the 2019 baseline data, to estimate the participant light bulb counts for each program participant. The team multiplied the estimated bulb count by the saturation of efficient fixtures present in each home to determine the number of bulbs to be upgraded.

The technology mix for efficient (LED and CFL) and inefficient (incandescent and halogen) was determined from the 2019 baseline study. The lightbulb cost assigned to inefficient and efficient lightbulbs were weighted by the proportion of lighting technology. Note that the lighting mix for the renovated aspect of the home may differ from the values used; however, due to lack of lighting data, the team applied this method holistically to the R&A program. Program participants that improved over the baseline received an incremental cost per square foot.

[14] http://ma-eeac.org/wordpress/wp-content/uploads/MA19R06-E-LtgSalesDataAnalysisReport_FINAL_2019.10.29.pdf