Comprehensive TRM Review MA19R17-B-TRM

Final Report

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Part of the Residential Evaluation Program Area

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EXECUTIVE SUMMARY

This review assesses the quality of assumptions and values in the Massachusetts Technical Reference Manual (TRM) to ensure that the TRM assumptions reflect the results of recent residential studies, such as the RES 1 Baseline Study.

Objectives and Methods

The TRM documents the calculations used by the state's Program Administrators (PAs) to claim savings through their energy efficiency programs. It is critical that the TRM use the best available data and that its deemed savings values are based on credible, standardized assumptions. The primary goal of this review was to ensure that relevant data from the RES 1 Baseline Study and other recent studies are incorporated into the TRM. A secondary goal was to assess the quality of the values in the residential portion of the TRM and to conduct analysis, where relevant, to improve these parameters.

Our review focused on identifying TRM parameters that were out-of-date, that were based on less relevant data sources (i.e., not Massachusetts or New England-specific), or that have a significant effect on the energy efficiency program's energy, demand, or fossil fuel savings. We designed and implemented a scoring methodology that accounted for these factors and flagged select parameters as a high priority to update. Conversely, parameters from recently published, relevant data sources or that have a low savings impact received a low priority score. The resulting priority scores helped determine which parameters are candidates for updating.

The team reviewed data collected in the RES 1 Baseline Study and other available data sources to identify newer or more robust data available for updating parameter values. Other data sources include but are not limited to federal standard updates, ENERGY STAR updates, and recent evaluation studies.

Recommended Updates

Table 1 describes the measure parameters for which the evaluation team recommends the PAs adopt updated TRM values. Table 1 is organized by measure title, with measures presented in the order in which they appear in the *2019-2021 Plan Version of the MA TRM*.

Table 1: Summary of Recommended TRM Parameter Value Updates

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)	Effective Useful Life (EUL)	Years	20	23
	Baseline Efficiency, ER	AFUE	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
	Baseline Efficiency, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual
Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)	Baseline Efficiency, Oil, ROF	AFUE	83.0%	Through 2020: 83.0% 2021 and on: 86.0%
	Baseline Efficiency, Propane, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.6% actual
Central Air Conditioning (RES-HVAC-CAC)	Baseline Efficiency, ER	SEER	10.0	13.5 nameplate 12.0 actual
	Baseline Efficiency, ROF	SEER	13.0	14.0
Central Ducted HP Fully Displacing Existing Furnace (RES-HVAC-FSHP)	Baseline Efficiency, Oil, ER	AFUE	78%	79%
Central Ducted HP Partially Displacing Existing Furnace (RES-HVAC-FSHP-P)	Baseline Efficiency, Oil, ER	AFUE	78%	79%
Clothes Dryer (RES-A-CD)	EUL, Electric	Years	12	16
	EUL, Gas	Years	12	17
Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)	Baseline % Split of Indirect vs Storage Water Heater (WH)	%	80% Indirect, 20% Storage	24% Indirect, 76% Storage
	Baseline Efficiency, Boiler, ER	AFUE	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
	Baseline Efficiency, Boiler, ROF	AFUE	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual
	Baseline Efficiency, WH, ER Blended Medium-, High-Draw	UEF	0.55	0.58
Dehumidifier (RES-PL-DH)	Capacity	Pints/Day	35	*Remove*
	Efficiency	Liters/kWh	Retirement: 1.0 Baseline: 1.5 Measure: 2.0	Retirement: 1.6 Baseline: 2.8 Measure: 3.3
	Hours of Operation	Hours/Year	Undocumented	*Remove*
	Dehumidification Load	Liters/Year	n/a	1,520
	Energy Savings	kWh/Year	New: 167.6 Retirement: 152.7	New: 82.3 Retirement: 407.1
	Demand Savings	kW	New: 0.04 Retirement: 0.04	New: 0.02 Retirement: 0.10
	EUL	Years	12	17
ECM Circulator Pump (RES-HVAC-ECMCP)	CF_{WP}	-	0.16	0.53

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Furnace, Gas (RES-HVAC-FG)	EUL	Years	18	17
	Baseline Efficiency, ER	AFUE	78.0% nameplate 78.9% actual	85.0% nameplate 81.0% actual
	Baseline Efficiency, ROF	AFUE	85.0%	89.0% nameplate 90.1% actual
Furnace, Oil/Propane (RES-HVAC-FOP)	Baseline Efficiency, Propane, ROF	AFUE	85.0%	89.0% nameplate 90.1% actual
Heat Recovery Ventilator (RES-HVAC-HRV)	HRV Gas Savings	MMBtu	7.7	8.6
	HRV Electricity Savings	kWh	-133	-171
	HRV Demand Savings	kW	-0.10	-0.02
	ERV Gas Savings	MMBtu	-	8.8
	ERV Electricity Savings	kWh	-	-127
	ERV Demand Savings	kW	-	-0.014
Insulation (RES-BS-I)	Heating Degree-Days, Cooling Degree-Hours	HDD, CDH	Varies by City, see Table 3-19	
Low-Flow Showerhead (RES-WH-S)	EUL	Years	7	15
Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)	EUL	Years	7	15
	Electric (Single Family)	kWh	372	247
	Electric (Single Family)	kW	0.08	0.06
	Gas (Single Family)	MMBtu	1.84	1.22
	Oil (Single Family)	MMBtu	2.09	1.32
	Other (Single Family)	MMBtu	1.84	1.22
	Electric (Multi-family)	kWh	335	183
	Electric (Multi-family)	kW	0.09	0.04
	Gas (Multi-family)	MMBtu	1.66	1.41
	Oil (Multi-family)	MMBtu	1.88	1.44
	Other (Multi-family)	MMBtu	1.66	1.41
Pool Pump (RES-MAD-PP)	Operating Days per Year	Days/Year	91	122
	Pool Size	Gallons	20,000 to 23,000	22,000
	Flow Rates	gpm	Baseline: 64 2S: 66 high, 33 low VS: 50 high	Baseline: 97 2S: 97 high, 48 low VS: 77 high, 31 low
	Daily Operating Hours	Hours/day	Baseline: 8.5 2S: 2 high, 12.5 low VS: 2 high, 18 low	Baseline: 5.7 2S: 2 high, 9.5 low VS: 2 high, 15.7 low
	Energy Factor	EF	Baseline: 2.1 2S: 2.0 high, 5.2 low VS: 4.0 high, 8.8 low	Baseline: 2.0 2S: 1.9 high, 5.3 low VS: 2.9 high, 10.5 low
	Energy Savings	kWh/year	2S: 842, VS: 1,062	2S: 639, VS: 1,284
	Demand Savings	kW	2S: 0.87, VS: 1.12	2S: 0.67, VS: 1.35
	EUL	Years	10	6

Measure Name	Parameter Name	Unit	Existing Value	Proposed Value
Programmable Thermostat (RES-HVAC-PT)	EUL	Years	15	19
Quality Installation with Duct Modification (RES-HVAC-QIDM)	Energy Savings	kWh/year	513	230
	Demand Savings	kW	0.85	0.18
Room Air Cleaner (RES-PL-RAC)	Energy Savings	kWh	391	Varies; see Table 3-27
Room Air Conditioner (RES-PL-ROOMAC)	EUL	Years	8	12
Stand Alone Water Heater (RES-WH-SASWH)	Baseline Efficiency, ER	UEF	Medium Draw: 0.52 High Draw: 0.58 Blended: 0.55	Medium Draw: 0.56 High Draw: 0.60 Blended: 0.58
	EUL	Years	13	10
Thermostatic Valve (RES-WH-TV)	EUL	Years	7	15
Variable Frequency Drive (RES-MAD-VFD)	Energy Savings	kWh/HP	Varies by type; see Table 3-33	
	Demand Savings, Summer	kW/HP_{SP}	Varies by type; see Table 3-33	
	Demand Savings, Winter	kW/HP_{WP}	Varies by type; see Table 3-33	

Parameters with No Recommended Updates

The team identified several measures and parameters for which updated parameter values are not recommended. Table 2 lists these measures and the reasons why this study does not recommend updated parameter values for them.

Table 2: Measures Not Recommended for Update by this Study

Measure Names and Codes	Reason for Not Updating
• Air Source Central Heat Pumps (RES-HVAC-ASHP) • Central Air Conditioning (RES-HVAC-CAC), efficient level • Ductless Mini-Split Heat Pumps (RES-HVAC-DMHP)	The PAs use program data to update measure parameters.
• Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP) • Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P) • Ductless Mini-Split Heat Pump with Integrated Controls – Fully Displacing Existing Boiler (RES-HVAC-FS-DMSHP) • Ductless Mini-Split Heat Pump with Integrated Controls – Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)	This study recommends revised measure lifetime values. Revised measure savings values will be informed by a new energy optimization study.
• Refrigerator/Freezer Recycling (RES-A-RFR)	Improved data is not available.
• Faucet Aerators (RES-WH-FA) • Pipe Wrap, Water Heating (RES-WH-PW) • Early Retirement Clothes Washers (RES-A-ERCW) • Clothes Dryers (RES-A-CD) • Heat Pump Quality Installation Verification (RES-HVAC-HPQIV) • Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)	Measures represent a small portion of program savings.

1. INTRODUCTION

1.1 Background

The Massachusetts Technical Reference Manual (MA TRM) is foundational to the calculation of savings claimed by residential energy efficiency programs in the state. As a result, mid-plan revision of the TRM is critical to ensure that it uses the best available data and that its deemed savings values are based on credible, standardized assumptions. This revision process improves the accuracy of the savings claimed by energy efficiency programs that rely on the TRM. The primary goal of this review is to ensure that relevant data from the RES 1 Baseline Study and other recent studies are incorporated into the TRM. A secondary goal of this effort is to assess the quality of the values in the residential portion of the TRM and to conduct analysis to improve these parameters.

In early 2020, the evaluation team reviewed the existing data sources and assumptions used for residential market-rate measures in the *2019-2021 Plan Version of the MA TRM* (published October 2018). Specifically, the evaluation team reviewed 47 residential measures (listed in Table 1-1) and documented 759 parameter values or assumptions associated with these measures. These values and assumptions include any inputs that directly contribute to the calculation of energy, demand, or fossil fuel savings. In cases where the TRM specified the deemed kWh, kW, or MMBtu savings, the team also reviewed the source calculations that led to these values, even when not directly published in the TRM. Our review did not examine variables such as net-to-gross, measure costs, or in-service rates.

To select a subset of TRM parameters for detailed review, the team prioritized the collected parameters based on the impact of the parameter value on program savings and based on the data sources cited in the TRM (with older, less relevant sources designated as a high priority for review).

The evaluation team hosted a TRM workshop on March 17, 2020 to review our prioritization of different TRM parameters. During the workshop, the Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants provided feedback on the TRM parameters we proposed to update. The team sought further input from the PAs and consultants in a memo submitted on April 9, 2020, which recommended values for a subset of parameters that could be referenced with minimal effort from in-house data sources such as the RES 1 Baseline Study. Additionally, the team conducted an in-depth analysis of several high priority parameters that could not be directly referenced from prior studies.

This report contains all the recommendations that result from this TRM review study. A databook attached to this report details each individual parameter reviewed in this study with information on the data source cited for each parameter and the updated values that the team recommends.

1.2 Scope of Review

The scope of this TRM review is limited to the market-rate residential efficiency measures described in Section 1 of the *2019-2021 Plan Version of the Massachusetts TRM*. The evaluation team's review focuses on assumptions pertaining to the calculation of deemed kWh, kW, and MMBtu savings. Impact factors in the TRM, such as in-service rates, realization rates, and net-to-gross ratios, are covered by other studies and are not in scope for this review. In addition, this review excludes the following measures for the following reasons:

- **Lighting** measures, **Active Demand Reduction** measures, **New Construction** measures, and **Code Compliance** measures are evaluated under separate evaluation contracts.

- **Wi-Fi Thermostat** and **Temperature Optimization** measures are subjects of ongoing studies and should not be updated until those studies are complete.
- Measures for **Education Kits**, **Advanced Power Strips**, and **Home Energy Reports** were recently evaluated and updated by measure-specific studies.
- **Custom Multi-Family** measures and **Heat Pump High Rise** measures use savings calculated with site-specific parameters that cannot be generalized.

Table 1-1 lists the measures reviewed by the evaluation team and includes the measure category, TRM section number, and measure code for each measure.

Table 1-1: List of Measures Covered in This Review, by Measure Category

Measures listings include TRM Section, Measure Name, and Measure Code	
Appliances/Plug Load	**HVAC (continued)**
1.12. Clothes Dryer (RES-A-CD)	1.8. Central AC Quality Installation Verification (QIV) (RES-HVAC-CACQIV)
1.21. Dehumidifier (RES-A-DH)	1.9. Central Air Conditioning (RES-HVAC-CAC)
1.28. Early Retirement Clothes Washers (RES-A-ERCW)	1.10. Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)
1.52. Refrigerator/Freezer Recycling (RES-A-RFR)	1.11. Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)
1.53. Room Air Cleaner (RES-PL-RAC)	1.14. Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)
Building Shell	1.15. Combo Furnace/Water Heater (RES-HVAC-CFWH)
1.3. Air Sealing (RES-BS-AS)	1.19. DMSHP with Integrated Controls Fully Displacing Existing Boiler (RES-HVAC-DMSHP)
1.39. Insulation (RES-BS-I)	1.20. DMSHP with Integrated Controls Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)
Hot Water	1.22. Down-Size 1/2 Ton (RES-HVAC-DSHT)
1.16. Condensing Water Heater (RES-WH-CWH)	1.23. Duct Insulation (RES-HVAC-DI)
1.30. Faucet Aerator (RES-WH-FA)	1.24. Duct Sealing (RES-HVAC-DSAF)
1.35. Heat Pump Water Heater (RES-WH-HPWH)	1.25. Ductless Mini-Split Heat Pump (DMSHP) (RES-HVAC-DMHP)
1.38. Indirect Water Heater (RES-WH-IWH)	1.26. Ductless Mini-Split Heat Pump (DMSHP) Quality Installation Verification (QIV) (RES-HVAC-MSHPQIV)
1.43. Low-Flow Showerhead (RES-WH-S)	1.27. ECM Circulator Pump (RES-HVAC-ECMCP)
1.44. Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)	1.31. Furnace, Gas (RES-HVAC-FG)
1.46. On-Demand/Tankless Water Heater (RES-WH-ODTWH)	1.32. Furnace, Oil/Propane (RES-HVAC-FOP)
1.48. Pipe Wrap (Water Heating) (RES-WH-PW)	1.33. Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)
1.55. Stand Alone Water Heater (RES-WH-SASWH)	1.34. Heat Pump Quality Installation Verification (QIV) (RES-HVAC-HPQIV)
1.57. Thermostatic Valve (RES-WH-TV)	1.36. Heat Recovery Ventilator (RES-HVAC-HRV)
Motors	1.47. Pipe Wrap (Heating) (RES-HVAC-PW)
1.49. Pool Pump (RES-MAD-PP)	1.50. Programmable Thermostat (RES-HVAC-PT)
1.58. Variable Frequency Drive (RES-MAD-VFD)	1.51. Quality Installation (QI) with Duct Modification (RES-HVAC-QIDM)
Refrigeration	1.54. Room Air Conditioner (RES-PL-ROOMAC)
1.59. Vending Miser (RES-R-VM)	
HVAC	
1.4. Air Source Central Heat Pump (RES-HVAC-ASHP)	
1.5. Boiler Reset Control (RES-HVAC-BSC)	
1.6. Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)	
1.7. Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)	

1.3 Report Structure

Section 2 of this report describes the evaluation team's methodology for prioritizing parameters for review. The methodology section also describes certain analytical methods the team used to develop updated parameter values for different measures.

Section 3 describes the individual parameters in the TRM for which the evaluation team recommends updated values. Section 3 is organized by measure, with the text for each measure describing the parameters that we (the evaluation team) considered, the analysis we undertook, and the updated values we recommend.

Section 4 lists the measures and parameters that the evaluation team does not recommend updating at this time and justifies each of these decisions.

Section 5 describes the measures and parameters recommended for future evaluation planning and future Baseline Study iterations.

Appendix A details our review of parameters related to the heat recovery ventilators measure. Appendix B provides additional analysis from our review of heating degree day and cooling degree hour parameters.

2. METHODOLOGY

2.1 Methodology for Documenting and Prioritizing Parameters

Our review focused on identifying TRM parameters that were out-of-date, based on less relevant data sources (i.e., not Massachusetts or New England-specific), or had a significant effect on the measure's energy, demand, or fossil fuel savings. We designed and implemented a scoring methodology that accounted for these factors and flagged select parameters as a high priority to update. Conversely, parameters from recently published, relevant data sources or that have a low savings impact received a low priority score. The resulting priority scores helped determine which parameters are candidates for updating as part of this review.

The first step in the approach involved reviewing documentation of the in-scope TRM measures and the inputs that support each measure. The evaluation team reviewed the 2019-2021 plan version of the TRM (published in October 2018), including all sources and documentation associated with the in-scope measures. To assess the quality of the existing data sources, the team documented the inputs and assumptions of each TRM measure. These inputs included kWh or MMBtu unit savings, demand savings, baseline efficiencies, post-retrofit efficiencies, coincidence factors, measure life, and other factors that impact energy consumption (e.g., operating hours, capacities, and heating and cooling load assumptions). Net-to-gross factors, measure costs, and in-service rates were excluded from the review.

For each parameter, the team documented the variable name, variable value, units, TRM footnote number, source name, page number, source year, source link, and notes specific to each input. To ensure that recommended updates were consistent, we created an index of values used across different measures in the TRM.

After documenting each parameter's sources, the evaluation team scored the quality of the existing data—independent of whether more current data is available—and weighed source quality against the relative portfolio-level impact of each measure. The prioritization exercise helped the team evaluate parameter sources and impacts using the following criteria:

- **Existing source age**. Recently published data sources are preferable.
- **Existing source origin**. The highest preference is given to primary research, publications created by MA-specific PAs and evaluators, and government-provided publications. Undocumented/uncited sources are given the lowest ranking.
- **Impact on program savings**, as quantified in the Benefit Cost Ratio Model. The team ranked the measures by their total reported MMBtu net annual savings (first year savings) and assigned a prioritization score from 1 to 4, with a score of 4 representing measures with the highest savings.

The team overlaid a user-editable weighting for each criterion and then combined all criteria into a single priority score using the following general equation:

$$\begin{aligned}\boldsymbol{Priority\ Score}\ \% \\ &= \boldsymbol{Age\ Weight}\ \% \times \frac{\boldsymbol{Age\ Score}}{\boldsymbol{4}} + \boldsymbol{Origin\ Weight}\ \% \times \frac{\boldsymbol{Origin\ Score}}{\boldsymbol{4}} \\ &+ \boldsymbol{Impact\ Weight}\ \% \times \frac{\boldsymbol{Impact\ Score}}{\boldsymbol{4}}\end{aligned}$$

As a result, each parameter received a final priority score between 0% and 100% to indicate the relative priority for updating. Higher scores indicate parameters that are a higher priority for updating.

Table 2-1 summarizes the criteria we used to prioritize parameters for updating.

Table 2-1: Summary of Parameter Prioritization Criteria

Prioritization Factor	Weight	Scoring Criteria			
		1 (Low Priority)	2	3	4 (High Priority)
Age: Existing source publication date	2	2015-2019	2010-2014	2005-2009	2004 and earlier
Origin: Existing source origin (or equivalent)	3	Primary research sponsored by the PAs and EEAC	Publications covering geographies and climates beyond MA, such as EPA and DOE sources	Publications with a limited or less applicable scope, such as data from a single vendor or other states' TRMs	Data source is not cited or is not available
Impact: Impact on program savings	4	Low impact on portfolio savings	Moderate impact on portfolio savings		High impact on portfolio savings

For most of the reviewed parameters (60%, or 458 out of 759), the team determined that the TRM's current assumptions are up-to-date and that further study would likely not improve the accuracy of the TRM's current assumption.

2.2 Review of RES 1 Baseline Study and Other Sources

Next, the team reviewed the RES 1 Baseline Study and other available data sources to identify newer or more robust data available for updating parameter values. Other data sources include but are not limited to federal standard updates, ENERGY STAR updates, and recent evaluation studies. The RES 1 Baseline Study has collected primary data from over 6,000 surveys and 300 onsite metered homes with subsequent follow-up surveys occurring on an annual basis. In particular, the RES 1 Baseline Study provides data related to the capacity, measure life, baseline efficiencies, and post-retrofit efficiencies of many types of HVAC equipment. The team identified RES 1 datapoints that could directly inform approximately 130 of the MA TRM's algorithms and variable values. These datapoints do not include the demand impact model values that have already been updated in the TRM.

The RES 1 survey data that could inform estimates of replace-on-failure baseline efficiency levels for HVAC equipment has a small sample size. For example, the team identified only 17 survey records that could inform the ROF baseline efficiency levels for natural gas boilers and natural gas furnaces, and just 14 records that could inform the ROF baseline efficiency levels for central ACs. For these equipment types, the team reviewed additional data sources to inform the ROF baseline efficiency levels. A 2019 study[1], "Analysis of Residential HVAC Sales Data from HARDI Distributors (TXC65)," provides data describing distributor sales of HVAC equipment to the Massachusetts market in 2014-2017. Based on this distributor data, the team calculated an industry standard practice (ISP) efficiency level as a shipment-

[1] Available online at: https://ma-eeac.org/wp-content/uploads/TXC65_HARDI_Data_Memo_Final_2019.11.15.pdf

weighted average efficiency, excluding program-supported shipments and half of shipments that appear to be program-eligible but were not program-supported. The team then used RES 1 data (with low sample size) and estimated ISP levels to select an appropriate baseline level for HVAC replace-on-failure scenarios.

2.3 Recurrent Methodologies for Updating Parameters

Section 3 of this report describes the sources and methods our team used to update parameters for individual measures. To keep the Section 3 discussion of individual parameters concise, the subsections that follow describe recurrent methodologies that the team applied across multiple measures.

2.3.1 Early Retirement Baseline Efficiencies

For early retirement measures, the baseline efficiency should reflect existing, operable equipment replaced by the customer. The evaluation team used recent survey data from the RES 1 Baseline Study to characterize the stock of installed equipment in Massachusetts and to examine the baseline efficiencies of products eligible for early retirement measures.

To evaluate plausible early retirement units, existing equipment should still be within its defined expected useful life (EUL). Because of age-related degradation and less stringent code requirements in the past, the early retirement efficiency values may be lower than current code-mandated values. In most cases, EUL considerations resulted in the team considering datasets for equipment installed prior to 2010 (i.e., equipment that is at least 10 years old), as well as the subset that had installed equipment between 2000 and 2010 (between 10 and 20 years old). The team compiled a list of existing nameplate efficiency values (e.g., Annual Fuel Utilization Efficiency [AFUE] or Energy Factor [EF] values) for RES 1 households within each dataset and considered the sample size to evaluate its reliability before calculating the mean efficiency value.

To estimate age-related performance degradation, we referenced a National Renewable Energy Laboratory (NREL) study[2] that quantified *in situ* efficiency based on the type of equipment, its age, and its maintenance frequency:

$$\boldsymbol{Actual\ Efficiency} = (\boldsymbol{Nameplate\ Efficiency}) \times (\mathbf{1} - \boldsymbol{Maintenance\ Factor})^{\boldsymbol{Age}}$$

Using this equation, the team estimated the *in situ* performance of each recorded unit using an assumed maintenance factor representing professional annual maintenance, as this provides the smallest and most conservative level of degradation.[3] The team then calculated the mean degraded efficiency of type of product. The team used the mean degraded values for the age bins most representative of early retirement units, given the EUL of each measure.

2.3.2 Measure Life

In the initial measure review, we found that nearly two-thirds of the EUL assumptions for residential TRM measures cited older sources (circa 1998-2011) or cited the Massachusetts Common Assumptions.

[2] Building America Performance Analysis Procedures for Existing Homes. Technical Report, NREL/TP-550-38238, May 2006. https://www.nrel.gov/docs/fy06osti/38238.pdf

[3] The alternative maintenance factors listed in the NREL technical report represent “no annual maintenance”, which would have resulted in higher overall degradation.

When accounting for lifetime electricity or fossil fuel savings, an inaccurate measure life assumption can make a substantial difference in total portfolio savings estimates.

Surveys conducted during the RES 1 Baseline Study gathered information on the annual turnover of various residential appliances and HVAC equipment. Our team leveraged this information for the TRM update by estimating the EUL for end-uses with high saturations as the reciprocal of the percentage of units that were replaced in a given year.

The team considered that a minimum number of conclusive data points is required to reliably inform a change to the existing EUL values. Measures with low market penetration and low replacement rates provide fewer datapoints to analyze and, consequently, higher uncertainty around the results. In practice, all but two measures had market penetration values above 20%, and all of the changes recommended in this report were based on data from a minimum of 80 product replacement records.

The team also considered exogenous factors that influence a customer's decision to replace a product.[4] For example, utility incentive programs can encourage customers to replace equipment earlier than they would in the absence of incentive programs. This could skew an analysis based on customer activity, leading to a finding of shorter EUL values. We ignored this potential effect, since our analysis found longer EUL values than what is currently used in the TRM. It is possible that these EUL values could be even longer in the absence of program incentives but quantifying this effect would require a more extensive study of product lifetimes than was possible in the scope of this review.

Additional factors affecting measure life include longer-term market trends toward increasing or decreasing penetration. For example, oil boilers are broadly being phased out of the Massachusetts service territory as newer and more efficient technologies take over. In this case, survey results would show a bias toward a shorter calculated EUL than the real oil boiler life expectancy. Conversely, increased market-wide adoption of central air conditioners (A/Cs) would yield a longer calculated EUL, as the current equipment stock is likely to skew younger and incur lower failure rates. Where such factors are identifiable, the team has commented on potentially sources of bias and their likely impacts.

Furthermore, the RES 1 survey data only interviews customers who have inhabited their residence for the entire year. This means that replacements made upon a change of occupancy—a common time for equipment to be upgraded or changed-out—are not captured in the survey data. This has the effect of biasing survey results toward a longer EUL value than actual.

Despite the introduction of potential biases within the EUL analysis, the results are still based on real, Massachusetts-specific customer data, and are likely more appropriate than previously cited values.

2.3.3 Replace on Failure, Time of Sale, or New Installation Baseline Efficiencies

For non-early-retirement measures (referred to in this report as Replace on Failure or ROF measures), the baseline efficiency represents the typical efficiency of products installed by customers in the absence of program incentives. The team analyzed the efficiencies of all equipment installed by RES 1 survey respondents who were program nonparticipants and who installed equipment after 2010. We assumed that the mean efficiency value of products installed by nonparticipants since 2010 represents a good approximation of the equipment that customers select in the absence of program incentives. These baseline efficiency values are higher than the minimum product efficiency standards when nonparticipant customers select high efficiency products. Our analysis of survey respondents' participation status is ongoing and results depending on this participation analysis will be provided in a forthcoming addendum to this report.

[4] Note that EUL is defined by customer replacement for any reason, not just equipment failure.

2.3.4 Updates Based on Federal Standards, Codes, or Other Sources

In the absence of RES 1 survey data to directly characterize equipment parameters, our recommended updates were informed by a literature review of codes, federal standards, baseline studies, or other sources. In addition, even when RES 1 survey data was available, the evaluation team used these external sources to corroborate the values obtained from our analysis of survey data.

3. RECOMMENDED MEASURE PARAMETER UPDATES

This section describes the measure parameters for which the evaluation team recommends updated values. This section is organized by measure title, with measures presented in the order in which they appear in the *2019-2021 Plan Version of the MA TRM*.

3.1 Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team found a 34% saturation for gas boilers. The proposed EUL value is informed by approximately 95 replacements per year (out of nearly 2,200 respondents with natural gas boilers) over a 2-year period. All replacements are considered to be standard replacements, and any early retirement considerations should be derived separately. Details are shown in Table 3-1.

Table 3-1: Natural Gas Boiler Effective Useful Life

Parameter Name	Existing EUL (Years)		Proposed EUL (Years)
	EUL	Rolled Up Measure	
EUL – Gas Boiler	20 years	19 years	23 years (not averaged with ER replacements)

Parameter: Natural Gas Hot Water Boiler Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of boilers aged 10-20 years old.
Existing Source: Negotiated between PAs and EEAC.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 85.5% AFUE for a sample size of 32 respondents with boiler systems aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 80.0% AFUE using the method described in section 2.3.1.[5] Then, we applied a factor of 0. 96738 to estimate actual in situ performance of 77.4%.[6] Details are shown in Table 3-2.

Table 3-2: Gas Boiler Early Retirement Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Boiler, ER	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual

[5] The team assumed a typical replacement age of 13.3 years and applied a degradation factor of 0.005, which represents "professional annual maintenance".

[6] This *in situ* performance factor is based on Table 16 of the 2015 HEHE Impact Study, which found that baseline boilers typically underperform compared to their nameplate rating.

Parameter: Natural Gas Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new boilers.
Existing Source: Federal minimum standard for gas boilers.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 88.5% AFUE for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=17. Distributor data compiled from HARDI showed a shipment-weighted average of 86.6% AFUE for shipments that represent the ISP level, as described in section 2.2. However, this HARDI data represents sales across the Northeast including regions outside Massachusetts. Distributor survey data from TXC52 data showed a weighted average of 84.3% AFUE for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 86.5% AFUE is appropriate. We applied a factor of 0.96738 to estimate actual *in situ* performance of 83.7% AFUE.[7] Details are shown in Table 3-3.

Table 3-3: Gas Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual

3.2 Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW)

Parameter: Oil Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: Federal minimum standards for oil boilers increased on January 15, 2021.
Existing Source: Outdated federal minimum standard for oil boilers.
New Source: New federal minimum standard for oil boilers.
Methodology: Per 10 CFR 430.32 (e)(2)(iii)(A), the federal minimum standards for oil boilers increased to 86% AFUE, taking effect January 15, 2021. The new federal baseline level should not be applied prior to when it took effect in January 2021. Details are shown in Table 3-4.

Table 3-4: Oil Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Oil Boiler, ROF	83.0%	Through 2020: 83.0% 2021 and on: 86.0%

Parameter: Propane Hot Water Boiler Baseline Efficiency, Replace on Failure.
Explanation: Aligned with natural gas furnace efficiency values.
Existing Source: Federal minimum standard for natural gas boilers.
New Source: HARDI, TXC52 and RES 1 data for natural gas boilers.
Methodology: Due to similarities in boiler construction and overlaps in natural gas and propane boiler product lines, the team aligned assumptions of propane boiler efficiency with assumptions of natural gas boiler efficiency, described in section 3.1. Details are shown in Table 3-5.

[7] This *in situ* performance factor is based on Table 16 of the 2015 HEHE Impact Study, which found that baseline boilers typically underperform compared to their nameplate rating.

Table 3-5: Propane Boiler Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Propane Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.6% actual

3.3 Central Air Conditioning (RES-HVAC-CAC)

Parameter: Central Air Conditioning Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of central air conditioners aged 10-20 years old.
Existing Source: Uncited source.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 13.5 SEER for a sample size of 31 respondents with central A/C systems aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 12.0 SEER using the method described in section 2.3.1.[8] Details are shown in Table 3-5.

Table 3-6: Central Air Conditioner Early Retirement Baseline Efficiency

Parameter Name	Existing SEER	Proposed SEER
Baseline SEER – Central Air Conditioner, ER	10 SEER	13.5 SEER nameplate 12.0 SEER actual

Parameter: Central Air Conditioner Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new central A/Cs.
Existing Source: Federal minimum standard for split system central A/Cs.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 14.8 SEER for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=14. Distributor data compiled from HARDI showed a shipment-weighted average of 13.6 SEER for shipments that represent the ISP level, as described in section 2.2. Distributor survey data from TXC52 data also showed a weighted average of 13.6 SEER for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 14.0 SEER is appropriate. Details are shown in Table 3-6.

Table 3-7: Central Air Conditioner Replace on Failure Baseline Efficiency

Parameter Name	Existing SEER	Proposed SEER
Baseline SEER – Central Air Conditioner, ROF	13.0 SEER	14.0 SEER

[8] The team assumed a typical replacement age of 12 years and applied a degradation factor of 0.01, which represents "professional annual maintenance".

3.4 Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)

Parameter: Oil Furnace Baseline Efficiency, Early Retirement.
Explanation: Baseline values should be internally consistent between the early retirement oil furnace measure and the ducted heat pump measure.
Existing Source: Uncited source.
New Source: 2018 Home Energy Services Impact Evaluation (RES 34).[9]
Methodology: The team reviewed RES 34 survey data to estimate the average efficiency of oil furnaces in existing Massachusetts homes. The data represents more than 20,000 oil furnaces surveyed between 2014 and 2016 including participants and nonparticipants. The team found an average efficiency of 79% AFUE for homes with oil furnaces.

Table 3-8: Oil Furnace Early Retirement Baseline Efficiency

Parameter Name	Existing	Proposed
Baseline AFUE – Oil Furnace, ER	78%	79%

Parameter: Switchover Temperature.
Explanation: The switchover temperature could be rephrased to better state that the switchover point is to electric resistance, not to fossil fuel heating.
Existing Source: 2018 Energy Optimization study.
New Source: For ease of use, the team recommends providing further clarification in the MA TRM around the switchover for measures where the newly installed system fully displaces the existing system and only one system remains. The switchover for these measures describes the switch between the heat pump's vapor compression operation and its electric resistance backup heating.

3.5 Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)

See the parameter updates and explanations from Section 3.4, "Central Ducted Heat Pump Fully Displacing Existing Furnace."

3.6 Clothes Dryer (RES-A-CD)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 59% saturation of electric clothes dryers and a 23% saturation of gas clothes dryers. The proposed EUL values are informed by approximately 240 electric dryer replacements and approximately 88 gas dryer replacements (out of nearly 1,500 respondents with gas dryers) over a 2-year period. Details are shown in Table 3-8.

[9] http://ma-eeac.org/wordpress/wp-content/uploads/RES34_HES-Impact-Evaluation-Report-with-ES_FINAL_29AUG2018.pdf

Table 3-9: Clothes Dryer Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Electric Clothes Dryer	12	16
EUL – Gas Clothes Dryer	12	17

3.7 Combo Condensing Boiler/Water Heater (RES-HVAC-CCBWH)

Parameter: Baseline percentage split of indirect versus storage water heaters.
Explanation: The baseline proportion of indirect versus storage water heaters is used as a weighting factor to calculate weighted average consumption for a theoretical, portfolio average baseline water heater. More up-to-date values can be sourced from RES 1 for the mix of baseline water heater equipment.
Existing Source: The existing source for the proportion of indirect versus storage water heaters is the 2015 *High Efficiency Heating Equipment Impact Evaluation* report.[10] This study cited 2013 program tracking data.
New Source: RES 1 baseline survey.
Methodology: The team compiled a list of households from the RES 1 survey that had natural gas or natural gas plus electric as their heating type, because a new combo condensing unit was unlikely to be a viable option for customers that did not already use natural gas for heating. Out of all the natural gas households surveyed, 35 households (24%) had an indirect water heater, 103 households (71%) had a storage water heater, and seven households (5%) had a tankless water heater. For a point of comparison, the evaluation team referenced NYSERDA's 2015 Residential Baseline Study for New York and found that New York shows a similar baseline split between indirect and storage water heaters.[11] See Table 3-9 for recommended updates.

Table 3-10: Water Heater Baseline Equipment Proportions

Parameter Name	Existing	Proposed
% Split of Indirect vs. Storage WH	80% Indirect 20% Storage	24% Indirect 76% Storage

Parameter: Boiler Baseline Efficiencies, Early Retirement and Replace on Failure.
Explanation: The baseline boiler efficiencies cited in the combo condensing boiler/water heater measure should be consistent with the recommendations defined for the gas boilers measure.
Existing Source: Federal minimum standard and negotiated baseline for gas boilers.
New Source HARDI, TXC52 and RES 1.
Methodology: See Section 3.1, "Boiler, Gas Forced Hot Water."

[10] The Cadmus Group, Inc. (2015). High Efficiency Heating Equipment Impact Evaluation

[11] The overall proportion of water heater types in New York state was: 22.7% indirect water heaters, 73.2% storage water heaters, and 3.7% tankless water heaters. https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/residential-baseline-study/Vol-1-Single-Family-Res-Baseline.pdf

Table 3-11: Boiler Baseline Efficiencies

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Boiler, ER	80.0% nameplate 77.4% actual	85.5% nameplate 77.4% actual
Baseline AFUE – Boiler, ROF	82.0% nameplate 79.3% actual	86.5% nameplate 83.7% actual

Parameter: Water Heater Baseline Efficiency, Early Retirement
Explanation: The baseline water heater efficiencies cited in the combo condensing boiler/water heater measure should be consistent with the recommendations defined for the standalone water heater measure.
Existing Source: Undocumented source.
New Source: RES 1 baseline survey.
Methodology: See Section 3.21, "Standalone Water Heater."

Table 3-12: Water Heater Baseline Efficiency, Early Retirement

Parameter Name	Existing ($EF_{exist,ER}$)	Proposed ($UEF_{exist,ER}$)
Baseline UEF_{exist} – Water Heater, ER	Blend of Medium- and High-Draw Products: 0.55	Blend of Medium- and High-Draw Products: 0.58

3.8 Dehumidifier (RES-PL-DH)

The dehumidifier measure in the 2019-2021 MA TRM uses a standard calculation to estimate energy savings by calculating the difference in energy consumption of the baseline and measure cases. This calculation depends on the dehumidifier capacity, the baseline and ENERGY STAR efficiency levels, and the assumed operating hours for dehumidifiers. For each of these parameters, the values in the TRM are either out-of-date or not well sourced. The dehumidifier capacity value is based on a limited set of units observed at an event in 2010; the baseline and ENERGY STAR efficiency levels are based on older standards that have been updated; and the TRM does not cite a source for the assumed operating hours.

The evaluation team considered updating each of these parameter values and maintaining the calculation approach that the TRM currently uses. However, a review of data from the RES 1 baseline study indicated that typical dehumidifier capacity has increased over time. The average capacity for units purchased between 2009 and 2014 was 52.1 pints/day, while the average capacity of units purchased between 2015 and 2019 was 67.8 pints/day.[12] Thus, a calculation-based method should not assume the same capacity for baseline and replacement dehumidifiers.

Assumptions regarding operating hours present another complication. The TRM calculation currently assumes that the same operating hours apply to baseline and high-efficiency dehumidifiers. However, the EEAC consultants pointed out that low- and high-efficiency units would likely remove a similar amount of moisture from the air, but low-efficiency units would require more operating hours to do so. Thus, a calculation-based method should not assume the same operating hours for baseline and replacement dehumidifiers.

[12] Based on 327 dehumidifiers identified in RES 1 belonging to both participants and nonparticipants.

These complications indicate that the current TRM calculation may not accurately represent the available energy savings from the dehumidifier measure. The evaluation team proposes a new calculation approach that uses baseline and ENERGY STAR efficiency levels, plus a new parameter for "dehumidification load" that represents the amount of moisture removed from the air each year by a typical dehumidifier user.

Parameter: Capacity.
Explanation: Capacity is the average pints of water the dehumidifier can remove per day and is a rated performance metric. The RES 1 Baseline Study has shown that dehumidifier size has grown significantly over time and the retirement case should reflect this.
Existing Source: Cape Light Compact's May 2010 event.
Recommendation: The evaluation team recommends this parameter be removed since the revised calculation method for energy savings does not require it.

Parameter: Baseline and ENERGY STAR Efficiencies.
Explanation: The measure includes three efficiency values: an early retirement baseline efficiency, a replace on failure baseline efficiency, and an ENERGY STAR efficiency for the measure's high efficiency unit.
Existing Source: The current early retirement baseline efficiency assumption comes from the 2005 federal standard.[13] The current replace on failure baseline efficiency assumption comes from the 2007 federal standard, which became effective in 2012. The current ENERGY STAR efficiency value comes from ENERGY STAR version 4.0.[14]
New Source: Each of the three existing sources has an updated version.
Methodology: Beginning with the early retirement case, the TRM states the assumption that "the baseline efficiency for recycling is a unit that is approximately eight years old, meeting the standard that was in place at the time." We propose to update the early retirement case efficiency to a level that complies with the federal standard that took effect on October 1, 2012. In the replace on failure case, the baseline efficiency is described in the TRM as a unit that meets the current federal standard. The current federal standard has an effective date of June 13, 2019 and the team proposes to update the baseline efficiency level to reflect the current federal standard. In the high efficiency measure case, we propose to update the efficiency level to align with ENERGY STAR version 5.0, the newest ENERGY STAR specification.

Parameter: Hours of Operation.
Explanation: The annual hours of operation of the unit was used as an input to the dehumidifier savings calculation in the 2019-2021 plan version of the TRM.
Existing Source: Undocumented source.
Recommendation: The evaluation team recommends this parameter be removed since the revised calculation method for energy savings does not require it.

Parameter: Dehumidification Load.
Explanation: The dehumidification load represents the amount of moisture removed from the air annually by a typical dehumidifier in Massachusetts.
Existing Source: Not applicable.
New Source: RES 1 Baseline Study meter data.
Methodology: The evaluation team estimated the annual dehumidification load using nameplate efficiency data and annual energy use measurements gathered in the RES 1 Baseline Study for 68 metered dehumidifiers. The average dehumidification load is 1,520 Liters/year.

Parameter: Energy Savings.

[13] https://www.ecfr.gov/cgi-bin/text-idx?rgn=div8&node=10:3.0.1.4.18.3.9.2.

[14] ENERGY STAR® Program Requirements Product Specification for Dehumidifiers, Version 4.0. Accessed at https://www.energystar.gov/sites/default/files/ENERGY%20STAR_Dehumidifiers_V4%200_Specification_Final.pdf

Explanation: The energy savings represent the difference in energy consumption between the baseline and the efficient cases. In the dehumidifier recycling case, this refers to the difference between a federally compliant unit from 8 years ago and the current federal specifications. The new dehumidifier case refers to the difference between a currently federally compliant unit and the current ENERGY STAR specifications.

Existing Source: Industry standard calculation to estimate energy savings by calculating the difference in energy consumption of the baseline and measure cases. The original unit energy savings equations are as follows.

$$\Delta kWh_{New} = \left[Capacity * \left(\frac{0.473}{24}\right) * \left(\frac{1}{Eff_{Base}} - \frac{1}{Eff_{EE}}\right) * Hours\right]$$

$$\Delta kWh_{Recycling} = \left[Capacity * \left(\frac{0.473}{24}\right) * \left(\frac{1}{Eff_{Retire}} - \frac{1}{Eff_{Base}}\right) * Hours\right]$$

Where:
Capacity = Average capacity of dehumidifier in Pints/24 Hours
Eff_{Retire} = Average efficiency of model being recycled, in Liters/kWh
Eff_{Base} = Average efficiency of model meeting the federal standard, in Liters/kWh
Eff_{EE} = Efficiency of ENERGY STAR model, in Liters/kWh
Hours = Dehumidifier annual operating hours
0.473 = Conversion factor: 0.473 Liters/Pint
24 = Conversion factor: 24 Hours/Day

New Source: Revised calculation method based on typical dehumidification loads observed for dehumidifiers in the RES 1 Baseline Study.

Methodology: The evaluation team proposes a new calculation that replaces the capacity and operating hours parameters with a single parameter for dehumidification load, as described above. The revised unit energy savings equations are as follows.

$$\Delta kWh_{New} = Dehumidification_Load * \left(\frac{1}{Eff_{Baseline}} - \frac{1}{Eff_{EE}}\right)$$

$$\Delta kWh_{Recycling} = Dehumidification_Load * \left(\frac{1}{Eff_{Retire}} - \frac{1}{Eff_{Base}}\right)$$

Where:
Dehumidification_Load = Typical annual moisture removal, in Liters/year
Eff_{Retire} = Average efficiency of model being recycled, in Liters/kWh
Eff_{Base} = Average efficiency of model meeting the federal standard, in Liters/kWh
Eff_{EE} = Efficiency of ENERGY STAR model, in Liters/kWh

Parameter: Demand Savings.

Explanation: The demand savings represents the difference in peak demand between the baseline dehumidifier and the measure dehumidifier. In the retirement case, this represents the difference between the retiring unit and the baseline unit. In the replace on failure case, this represents the difference between the baseline unit and an ENERGY STAR unit.

Existing Source: The TRM calculates demand savings by multiplying annual energy savings by the demand factor for dehumidifiers reported in the Navigant Demand Impact Model.

New Source: Navigant Demand Impact Model.

Methodology: The evaluation team recommends continuing to use the impact factors in the Navigant Demand Impact Model, but updating the calculation with the revised energy savings values reported in Table 3-12.

Parameter: EUL.

Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.

New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 40% saturation of dehumidifiers. The proposed EUL value is informed by approximately 150 replacements per year (out of more than 2,500 respondents with dehumidifiers) over a 2-year period.

Table 3-13: Dehumidifiers Updates

Parameter Name	Existing Value	Proposed Value
Dehumidification Load (Liters/year)	n/a	1,520 Liters/year
Efficiency (Liters/kWh)	Retirement: 1.0 liters/kWh* Baseline: 1.5 liters/kWh* Measure: 2.0 liters/kWh	Retirement: 1.6 liters/kWh Baseline: 2.8 liters/kWh Measure: 3.3 liters/kWh
Energy Savings (kWh/year)	New Dehumidifier: 167.6 kWh Retirement: 152.7 kWh	New Dehumidifier: 82.3 kWh Retirement: 407.1 kWh
Demand Savings	New Dehumidifier: 0.04 kW Retirement: 0.04 kW	New Dehumidifier: 0.02 kW Retirement: 0.10 kW
EUL – Dehumidifier (years)	12	17

**Existing efficiency assumptions are not documented in the TRM. The team includes these values based on federal efficiency requirements included in DOE standards effective in 2007 and 2012. (For a specified 35 pints/day capacity dehumidifier)*

3.9 ECM Circulator Pump (RES-HVAC-ECMCP)

Parameter: Summer and Winter Coincidence Factors.
Explanation: The coincidence factors should rely on the most current data available, specific to the Massachusetts PAs.
Existing Source: Energy Resources Solutions 2005 Measure Life Study (cited in the hard copy TRM) and evaluation results (cited in the eTRM, presumably referring to the 2012 Cadmus ECM Circulator Pump Impact Evaluation). The team was unable to verify the existing coincidence factors in either source.
New Source: Demand Impact Model.
Methodology: The team recommends using the Demand Impact Model On-Peak Coincidence values for boiler distribution. While the summer coincidence factor value does not change, the source should be updated in the TRM to the Demand Impact Model (2018). See Table 3-13.

Table 3-14: Recommended ECM Circulator Pump CF Update

Parameter Name	Existing Value	Proposed Value
ECM Circulator Pump CF_{SP}	0.0	0.0
ECM Circulator Pump CF_{WP}	0.16	0.53

3.10 Furnace, Gas (RES-HVAC-FG)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found a 24% saturation for natural gas furnaces. The proposed EUL value is informed by approximately 92 replacements per year (out of over 1,500 respondents with natural gas furnaces) over a 2-year period. Details are shown in Table 3-14.

Table 3-15: Gas Furnace Effective Useful Life

Parameter Name	Existing EUL (years)		Proposed EUL (years), not Weighted with Early Replacement RUL
	EUL	Rolled Up Measure	
EUL – Gas Furnace	18 years	15 years	17 years (not averaged with ER replacements)

Parameter: Natural Gas Furnace Baseline Efficiency, Early Retirement.
Explanation: The team analyzed RES 1 data and applied degradation factors to estimate typical performance of gas furnaces aged 10-20 years old.
Existing Source: Negotiated between PAs and EEAC.
New Source: RES 1 baseline survey.
Methodology: The Baseline Study data showed an average nameplate efficiency of 85.0% AFUE for a sample size of 22 respondents with furnaces aged 10-20 years. We estimated that age-related degradation would reduce the nameplate efficiency to 80.0% AFUE using the method described in section 2.3.1.[15] Then, we applied a factor of 1.012 to estimate actual in situ performance of 81.0% AFUE.[16] Details are shown in Table 3-15.

Table 3-16: Gas Furnace Early Retirement Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Furnace, ER	78.0% nameplate 78.9% actual	85.0% nameplate 81.0% actual

Parameter: Natural Gas Furnace Baseline Efficiency, Replace on Failure.
Explanation: The team analyzed distributor data from HARDI and customer survey data from TXC52 and RES 1 to estimate typical performance of new furnaces.
Existing Source: Negotiated between PAs and EEAC.
New Source: HARDI, TXC52 and RES 1.
Methodology: Customer survey data from the RES 1 Baseline Study showed an average of 90.4% AFUE for systems aged under ten years for customers that self-reported as program non-participants. However, the RES 1 data had a small sample size of n=17. Distributor data compiled from HARDI showed a shipment-weighted average of 89.4% AFUE for shipments that represent the ISP level, as described in section 2.2. Distributor survey data from TXC52 data showed a weighted average of 87.7% AFUE for ISP-level shipments. Based on these three data sources, the team determined that an ROF baseline nameplate efficiency of 89.0% AFUE is appropriate. We applied a factor of 1.012 to estimate actual *in situ* performance of 90.1% AFUE.[17] Details are shown in Table 3-16.

[15] The team assumed a typical replacement age of 12 years and applied a degradation factor of 0.005, which represents "professional annual maintenance".
[16] This *in situ* performance factor is based on Table 18 of the 2015 HEHE Impact Study, which found that baseline furnaces typically outperform their nameplate rating.
[17] This *in situ* performance factor is based on Table 18 of the 2015 HEHE Impact Study, which found that baseline furnaces typically outperform their nameplate rating.

Table 3-17: Gas Furnace Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Gas Furnace, ROF	85.0%	89.0% nameplate 90.1% actual

3.11 Furnace, Oil/Propane (RES-HVAC-FOP)

Parameter: Propane Furnace Baseline Efficiency, Replace on Failure.
Explanation: Aligned with natural gas furnace efficiency values.
Existing Source: Negotiated between PAs and EEAC.
New Source: HARDI, TXC52 and RES 1.
Methodology: Due to similarities in furnace construction and overlaps in natural gas and propane furnace product lines, the team aligned assumptions of propane furnace efficiency with assumptions of natural gas furnace efficiency, described in section 3.10. Details are shown in Table 3-17.

Table 3-18: Propane Furnace Replace on Failure Baseline Efficiency

Parameter Name	Existing AFUE	Proposed AFUE
Baseline AFUE – Propane Furnace, ROF	85.0%	89.0% nameplate 90.1% actual

3.12 Heat Recovery Ventilator (RES-HVAC-HRV)

Parameter: Unit MMBtu and Demand Savings.
Explanation: Heat Recovery Ventilators (HRVs) can help make mechanical ventilation more cost-effective by reclaiming energy from exhaust airflows.
Existing Source: Natural Gas Energy Efficiency Potential in Massachusetts, GDS Associates, 2009.
New Source: New engineering calculation.
Methodology: The existing source is based on older research. The specific calculation, inputs, baseline details, and assumptions were not included in the report and were not available for review. The team conducted a literature review of other state TRMs, state and national energy code analysis, and other publicly available published studies to determine if more recent energy savings values were available. The literature review did not identify a newer or more robust source for HRV energy savings, so the team created an engineering calculation to estimate savings, provided in conjunction with this report, based on available information. Future work to improve the savings estimation could include energy modeling or a metered study. Appendix A includes the literature review summary and a methodology supporting the recommended updates in Table 3-18.

Table 3-19: Heat Recovery Ventilator Updates

Parameter Name	Existing Value	Proposed Value
HRV Gas Savings (MMBtu)	7.7	8.6
HRV Electricity Savings (kWh)	-133	-171
HRV Demand Savings (kW)	-0.10	-0.02
ERV Gas Savings (MMBtu)	No existing value	8.8
ERV Electricity Savings (kWh)	No existing value	-127
ERV Demand Savings (kW)	No existing value	-0.014

3.13 Insulation (RES-BS-I)

Parameter: Heating Degree-Days and Cooling Degree-Hours.
Explanation: Heating degree-days and cooling degree-hours (HDD and CDH, respectively) are used across most residential envelope measures in the TRM. These values are not inherent to the individual measures but rather to the climate of a geographic region. Weather patterns are trending warmer, with the potential to impact heating and cooling loads, particularly when those loads were previously marginal or took place during shoulder seasons. Updating these could improve the accuracy of multiple measures, including air sealing and insulation.
Existing Source: Typical meteorological year (TMY3) data from the period 1991-2005.[18]
New Source: National Oceanic and Atmospheric Administration (NOAA) climate data.
Methodology: The MA TRM lists HDD and CDH values for 15 different locations, and the team has updated the HDD and CDH values for each location using Local Climatological Data from NOAA from 2005-2019.[19] This data differs from TMY3 data in that it calculates the median HDD and CDH values for the most recent 15 consecutive years of weather data. Conversely, TMY3 data builds up a typical weather year out of the months of different calendar years. With impacts of climate change increasing in severity each year, the team determined that the median of the most recent 15 years would most accurately reflect the impact of climate change within the dataset. The team calculated HDD and CDH using a 60°F base temperature for heating and a 75°F base temperature for cooling—values consistent with the TRM's current assumptions. See Appendix B for a detailed discussion of the data analysis.

As Table 3-19 shows, the proposed HDD values are generally lower than the existing HDD values (an average of 1% decrease in HDD) and the proposed CDH values are higher than the existing CDH values (an average of 31% increase in CDH).

Table 3-20: Recommended Heating Degree Day (HDD) and Cooling Degree Hour (CDH) Updates

Weather Station	Existing HDD	Proposed HDD	Difference (%)	Existing CDH	Proposed CDH	Difference (%)
Barnstable Muni Boa	4,379	4,299	–2%	1,349	2,278	+69%
Beverly Muni	5,329	4,856	–9%	3,432	4,205	+23%
Boston Logan Int'l Arpt	4,550	4,299	–6%	4,329	5,382	+24%
Chicopee Falls Westo	5,016	4,940	-2%	4,116	5,577	+35%
Lawrence Muni	4,640	4,815	+4%	3,978	6,041	+52%
Martha's Vineyard	4,312	4,385	+2%	1,345	2,080	+55%
Nantucket Memorial AP	3,988	4,250	+7%	362	518	+43%
New Bedford Rgnl.	4,434	4,604	+4%	4,232	3,938	-7%

[18] TMY3 data was extracted and processed by a third party as a part of the 2015 High Efficiency Heating Equipment Impact Evaluation.

[19] NOAA Local Climatological Data is available at: https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/quality-controlled-local-climatological-data-qclcd. Ten of the 15 stations did not have data available for 2005, and therefore derived results from the most recent 14 years of data.

Weather Station	Existing HDD	Proposed HDD	Difference (%)	Existing CDH	Proposed CDH	Difference (%)
North Adams	5,234	5,724	+9%	2,524	3,318	+31%
Norwood Memorial	4,872	4,777	–2%	4,763	6,069	+27%
Otis ANGBb	4,718	4,614	–2%	2,588	2,011	–22%
Plymouth Municipal	4,559	4,600	+1%	2,138	4,087	+91%
Provincetown (AWOS)	4,368	4,268	–2%	2,195	1,616	–26%
Westfield Barnes Muni AP	5,301	5,185	–2%	3,784	6,003	+59%
Worchester Regional Arpt	5,816	5,465	–6%	1,753	2,928	+67%
Average	**4,768**	**4,739**	**–1%**	**2,859**	**3,737**	**+31%**

3.14 Low-Flow Showerhead (RES-WH-S)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: The team found a near 100% saturation for showerheads. The proposed EUL value is informed by over 400 replacements (out of nearly 6,500 respondents with showerheads) over a 2-year period. Details are shown in Table 3-20. Although the recommended value is more than double the existing TRM value, the previous value was informed by Massachusetts Common Assumptions, while the new value is based on nearly 100% saturation, a stable replacement rate, and Massachusetts-specific data collection.

Table 3-21: Low Flow Showerhead Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Low-Flow Showerhead	7	15

3.15 Low-Flow Showerhead with Thermostatic Valve (RES-WH-STV)

Parameter: EUL.
Explanation: The lifetime for the Showerhead with TSV should be consistent with our recommendation for the Low-Flow Showerhead measure.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: See the EUL discussion in Section 3.14. The RES 1 surveys ask about showerhead replacements in general and do not distinguish whether a thermostatic valve was included in the showerhead replacement. However, Uniform Plumbing Code (UPC) certification under IAPMO

standard IGC 244-2007a stipulates that TSV devices must meet 10,000 cycles without failure. Assuming 1.6 showers per day,[20] a TSV rated to 10,000 cycles would exceed the showerhead lifetime of 15 years. Table 3-20 shows a recommended EUL of 15 years for showerheads with TSVs.

Table 3-22: Low Flow Showerhead with TSV Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL – Low-Flow Showerhead w/ TSV	7	15

Parameter: Unit Energy Savings and Demand Savings.
Explanation: This measure combines the energy savings values from the Low-Flow Showerhead measure with the adjusted energy savings values from the Thermostatic Valve measure, accounting for differences in baseline flow rates.
Existing Source: 2014 National Grid Review of ShowerStart evolve, which also calculates savings for the Thermostatic Valve-only measure.
New Source: 2018 Home Energy Services Impact Evaluation savings data.
Methodology: The current calculation uses different, much higher savings data for the Low-Flow Showerhead portion of the savings than the TRM's current Low-Flow Showerhead measure. The current Low-Flow Showerhead measure relies on more current metered study data for savings values, using the 2018 Home Energy Services Impact Evaluation savings data. These savings values are not currently factored into the combination measure. The updated combined savings calculation uses these recent metered savings as the basis for the Low-Flow Showerhead portion of the savings. To accurately add the thermostatic valve savings, some adjustments were needed to the original calculation. The Thermostatic Valve-only measure calculates savings using a 2.5 gpm showerhead. The updated calculation assumes the same flow rate, 1.7 gpm, as the 2018 Home Energy Services Impact Evaluation. This adjustment results in lower thermostatic valve savings when added to a low-flow showerhead. The updated savings calculations accompany this memo in a databook built on the current two measures.

Table 3-23: Low-Flow Showerhead with Thermostatic Valve Savings Values

Parameter Name	Existing Savings Value	Proposed Savings Value
Electric (Single Family)	372 kWh	247 kWh
Electric (Single Family)	0.08 kW	0.06 kW
Gas (Single Family)	1.84 MMBtu	1.22 MMBtu
Oil (Single Family)	2.09 MMBtu	1.32 MMBtu
Other (Single Family)	1.84 MMBtu	1.22 MMBtu
Electric (Multifamily)	335 kWh	183 kWh
Electric (Multifamily)	0.09 kW	0.04 kW
Gas (Multifamily)	1.66 MMBtu	1.41 MMBtu
Oil (Multifamily)	1.88 MMBtu	1.44 MMBtu
Other (Multifamily)	1.66 MMBtu	1.41 MMBtu

[20] Biermayer, Peter J. Potential Water and Energy Savings from Showerheads. Lawrence Berkeley National Laboratory. 2006.

3.16 Pool Pump (RES-MAD-PP)

The pool pumps measured in the TRM does not provide algorithms for the calculation of energy savings. Instead, it refers to a spreadsheet-based calculator published by the ENERGY STAR program in 2013. The TRM states that savings are based on a set of six scenarios calculated using the ENERGY STAR calculator. The evaluation team was not able to recreate the TRM's savings values using the scenario inputs specified in the TRM. Rather than calculating and averaging multiple scenarios, the evaluation team recommends calculating savings based on a single baseline condition and two efficient conditions (one for two-speed pumps and one for variable-speed pumps). The team recommends revising several key inputs to the savings calculation and specifying new savings values calculated with these revised inputs. The team also recommends calculating savings with the following simple equations rather than relying on a separate calculator tool.[21]

$$\Delta kWh = UEC_{baseline} - UEC_{efficient}$$

$$UEC = \frac{days}{1000} * \left[\left(\frac{Q_{high} * 60}{EF_{high}}\right) * hours_{high} + \left(\frac{Q_{low} * 60}{EF_{low}}\right) * hours_{low}\right]$$

Where:
$UEC_{baseline}$ = Unit Energy Consumption per year for the baseline condition (kWh)
$UEC_{efficient}$ = Unit Energy Consumption per year for the efficient condition (kWh)
UEC = Unit Energy Consumption per year (kWh)
days = Annual days of operation, 122 days
Q_{high} = Flow rate at high speed, in gallons per minute (gpm)
EF_{high} = Energy factor at high speed, in gallons/Watt-hour
$hours_{high}$ = Daily operating hours at high speed
Q_{low} = Flow rate at low speed, in gallons per minute (gpm)
EF_{low} = Energy factor at low speed, in gallons/Watt-hour
$hours_{low}$ = Daily operating hours at low speed
60 = 60 minutes per hour
1,000 = 1,000 Watt-hours per kWh

Parameter: Operating days per year.
Explanation: The annual operating days of the pool pump. The annual operating days directly affect the energy consumption calculations. The current TRM assumption is 91 operating days (i.e., 3 months) per year.
Existing Source: Uncited.
New Source: Department of Energy (DOE) Technical Support Document.
Methodology: The ENERGY STAR calculator and the technical support document for DOE's 2017 pool pumps rulemaking categorize Massachusetts in the cool climate zone. Both sources assume that states in the cool climate zone see annual pool operation of 4 months (122 days) per year. See DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.11. The evaluation team recommends revising the operating days to 122 days.

Parameter: Pool size.
Explanation: The pool size describes the volume of water in the pool. Coupled with the flow rate and the number of turnovers per day, the pool size determines the daily operating hours for pool pumps.
Existing Source: Uncited.
New Source: DOE Technical Support Document.

[21] These equations are based on the energy consumption calculations described in DOE (2017) Direct Final Rule Technical Support Document, Section 7.3. Available at: https://www.regulations.gov/document?D=EERE-2015-BT-STD-0008-0105

Methodology: The team recommends using a single pool size value of 22,000 gallons. This is the average pool size used by the Consortium for Energy Efficiency[22] and the DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.3.

Parameter: Flow rate.
Explanation: The flow rate describes the volume of water moved by the pump over time. Coupled with the pool size and the number of turnovers per day, the flow rate determines the daily operating hours for pool pumps.
Existing Source: The TRM states flow rates of 64 gpm for baseline single-speed pumps, 66 gpm for efficient two-speed pumps, and 50 gpm for efficient variable-speed pumps. The source of these values is not cited, but the evaluation team notes that these flow rates align with the default assumptions in the ENERGY STAR calculator for pumps operating on Curve A (representing plumbing with a 2" pipe diameter).
New Source: DOE Technical Support Document.
Methodology: During the 2017 DOE rulemaking for pool pumps, DOE assessed the market for pool pumps and compiled flow rate information for currently available pumps. Through discussions with pool pump manufacturers and energy efficiency advocates, DOE learned that pump Curve C (representing plumbing with a 2.5" diameter) is representative of most in-ground pool installations. The DOE test procedure and standards for pool pumps are based on measurements taken on pump Curve C. The team recommends updating the flow rate values to represent pump performance on Curve C, using the following flow rates reported in DOE (2017) Direct Final Rule Technical Support Document, Table 5.8.1:[23]

- For baseline single-speed pumps: 71 gpm
- For efficient two-speed pumps: 71 gpm at high speed and 36 gpm at low speed
- For efficient variable-speed pumps: 57 gpm at high speed and 23 gpm at low speed

Parameter: Turnovers per day.
Explanation: Describes the number of times that the pool's contents are circulated through the filtration equipment in a 24-hour period. Coupled with the pool size and pump flow rate, the number of turnovers per day determines the daily operating hours for pool pumps. The TRM currently assumes 1.5 turnovers per day.
Existing Source: Uncited.
New Source: DOE Technical Support Document.
Methodology: In the course of DOE's 2017 rulemaking on pool pumps, DOE discussed turnover rates with a working group of pool pump manufacturers and efficiency advocates. DOE determined that in a cold climate zone such as Massachusetts, most pools operate with 1 or 2 turnovers per day. See DOE (2017) Direct Final Rule Technical Support Document, Table 7.3.9. Based on DOE's observations, the evaluation team recommends maintaining the current assumption of 1.5 turnovers per day.

Parameter: Daily operating hours.
Explanation: The daily operating hours of a pool pump describe the amount of time that pumps must run to maintain water clarity. The operating hours are a function of the flow rate, the pool size, and the number of turnovers per day. Two-speed and variable-speed pumps can achieve water filtration at low pump speeds, with intermittent high-speed operation to churn the pool water. As such, separate values are reported for high speed operating hours and low-speed operating hours. The TRM states operating hours of 8.5 hours/day for baseline single-speed pumps, 2

[22] CEE (2013) "CEESM High Efficiency Residential Swimming Pool Initiative." p.33 https://library.cee1.org/system/files/library/9986/CEE_Res_SwimmingPoolInitiative_01Jan2013_Corrected.pdf

[23] The team recommends using flow rate values reported for efficiency level 1 (EL1) as the baseline condition, EL3 as the two-speed efficient condition, and EL6 as the variable-speed efficient condition.

hours/day at high-speed and 12.5 hours/day at low-speed for two-speed pumps, and 2 hours/day at high-speed and 18 hours/day at low-speed for variable-speed pumps.

Existing Source: Uncited.

New Source: DOE Technical Support Document.

Methodology: DOE's 2017 analysis of pool pump energy consumption calculated daily operating hours as a function of pool volume, pump flow rate, and turnovers per day, using the following equation:

$$PPOH = \frac{V * N_{turns}}{Q * 60}$$

Where:
PPOH = daily pool pump operating hours
V = pool volume in gallons
N_{turns} = number of turnovers per day
Q = pump flow rate

Based on input from pool pump manufacturers and efficiency advocates, DOE assumed that two-speed and variable-speed pumps spend no more than two hours operating at high speed and the remainder of operating hours at low speed. The operating hours for single-speed pumps are calculated with the equation above at the high-speed flow rate. For two-speed and variable-speed pumps, the low-speed operating hours are calculated with the equation above at the low-speed flow rate, less two hours to account for time spent in high-speed operation.

Parameter: Energy factor (EF)

Explanation: The EF describes the efficiency at which a pump moves water, in terms of gallons per Watt-hour. Due to pump affinity laws, two-speed and variable-speed pumps exhibit higher efficiency when operating at low speeds. The TRM states separate efficiency values for baseline single-speed pumps and for the high- and low-speed operating states of efficient two-speed and variable-speed pumps.

Existing Source: Uncited, but aligns with the default assumptions in the ENERGY STAR calculator for pumps operating on Curve A (representing plumbing with a 2" pipe diameter).

New Source: DOE Technical Support Document.

Methodology: During the 2017 DOE rulemaking for pool pumps, DOE assessed the market for pool pumps and compiled efficiency information for currently available pumps. The team recommends updating the efficiency values to represent pump performance on Curve C, using the following values reported in DOE (2017) Direct Final Rule Technical Support Document, Table 5.8.1.[24]

- For baseline single-speed pumps: 2.0 EF
- For efficient two-speed pumps: 2.0 EF at high speed and 5.3 EF at low speed
- For efficient variable-speed pumps: 2.9 EF at high speed and 10.5 EF at low speed

Parameter: Energy savings.

Explanation: The energy savings represents the difference in energy consumption between the baseline single-speed pump and the efficient pump.

Existing Source: 2013 ENERGY STAR pool pumps calculator.

New Source: DOE Technical Support Document's savings calculation.

Methodology: While the evaluation team agrees with the methods used in the ENERGY STAR calculator, we recommend simplifying the analysis using the savings equations presented above. The application of these equations with the revised input values presented in Table 3-23 yields the revised savings values presented in Table 3-23. For reference, the calculated annual energy consumption is 2,001 kWh/year for baseline single-speed pumps, 1,166 kWh/year for efficient two-speed pumps, and 641 kWh/year for efficient variable-speed pumps.

[24] The team recommends using efficiency values reported for efficiency level 1 (EL1) as the baseline condition, EL3 as the two-speed efficient condition, and EL6 as the variable-speed efficient condition.

Parameter: Demand savings.
Explanation: The demand savings represents the difference in peak demand between the baseline single-speed pump and the efficient pump.
Existing Source: Navigant Demand Impact Model.
New Source: Navigant Demand Impact Model using updated inputs.
Methodology: The evaluation team recommends continuing to use the impact factors in the Navigant Demand Impact Model, but updating the calculation with the revised energy savings values reported in Table 3-23.

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 7% saturation for pool pumps. The proposed EUL value is informed by approximately 83 replacements (out of nearly 500 respondents with pool pumps) over a 2-year period. Details are shown in Table 3-23.

Table 3-24: Pool Pump Updates

Parameter Name	Existing Value	Proposed Value
Operating days per year	91 days/year	122 days/year
Pool size (gallons)	20,000 to 23,000	22,000
Flow rates (gallons per minute)	Baseline: 64 Two-speed: 66 high, 33 low Variable Speed (VS): 50 high, unspecified low	Baseline: 97 Two-speed: 97 high, 48 low VS: 77 high, 31 low
Turnovers per day	1.5 turnovers	1.5 turnovers
Daily Operating Hours	Baseline: 8.5 Two-speed: 2 high, 12.5 low VS: 2 high, 18 low	Baseline: 5.7 Two-speed: 2 high, 9.5 low VS: 2 high, 15.7 low
EF	Baseline: 2.1 EF Two-speed: 2.0 high, 5.2 low VS: 4.0 high, 8.8 low	Baseline: 2.0 EF Two-speed: 1.9 high, 5.3 low VS: 2.9 high, 10.5 low
Energy Savings (kWh)	Two-speed: 842 VS: 1,062	Two-speed: 639 VS: 1,284
Demand Savings (kW)	Two-speed: 0.87 VS: 1.12	Two-speed: 0.67 VS: 1.35
EUL – Pool Pump (years)	10	6

3.17 Programmable Thermostat (RES-HVAC-PT)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the 2-year equipment replacement rate, as outlined in Section 2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.

Methodology: The team analyzed RES 1 data and found an 86% saturation for programmable thermostats. The proposed EUL value is informed by approximately 290 replacements (out of over 5,500 respondents with programmable thermostats) over a 2-year period. Details are shown in Table 3-24.

Table 3-25: Programmable Thermostat Effective Useful Life

Parameter Name	Existing	Proposed
EUL – Programmable Thermostat (years)	15	19

3.18 Quality Installation (QI) with Duct Modification (RES-HVAC-QIDM)

Parameters: Energy savings, demand savings.
Explanation: The savings values in the MA TRM do not match the values in the cited source *Market Research for the Rhode Island, Massachusetts, and Connecticut Residential HVAC Market*.
Existing Source: RLW Analytics (2002).[25]
New Source: RES 1 baseline survey.
Methodology: Neither the leakage reduction assumption nor the total savings values in the current MA TRM match the cited source, RLW (2002). The MA TRM assumes the leakage reduction is from 20% to 10% and saves 513 kWh, while the RLW report modeled energy and peak demand savings with a reduction in leakage assumption from 25% to 5% and savings of 212 kWh. The 212 kWh savings value represents a 15% savings in the predicted annual cooling energy for the average household (1,450 kWh) (RLW).

The team recommends applying a 15% savings factor to the annual cooling energy consumption for an average home with a CAC, which is 1,530 kWh according to Navigant (2018).[26] Recommended peak demand savings were calculated by dividing the electric energy savings by the cooling equivalent full load hours (EFLH) of 419 hours and multiplying by the on-peak coincidence factor of 0.346 (Navigant, 2018).[27] It is also recommended that the MA TRM update the leakage reduction assumption to align with the RLW Analytics assumption of 25% to 5%.

Table 3-26: Quality Installation (QI) with Duct Modification Parameter Updates

Parameter Name	Existing	Proposed
Electric Energy Savings (kWh)	513	230
Electric Demand Savings (kW)	0.85	0.18

3.19 Room Air Cleaner (RES-PL-RAC)

Parameters: Baseline Efficiency, High Efficiency, and Energy Savings.
Explanation: The room air cleaner energy savings should reflect the diversity of the models on the market.
Existing Source: Non-existent federal standard.
New Source: ENERGY STAR v1 Calculator baseline assumption.
Methodology: Previously, the baseline efficiency case cited a federal standard; however, there is no federal standard in place for air purifiers. The high efficiency case described an ENERGY STAR

[25] RLW Analytics (2002). **"**Market Research for the Rhode Island, Massachusetts, and Connecticut Residential HVAC Market."
[26] Navigant (2018). "RES 1 Baseline Load Shape Study."
[27] Navigant (2018). "Demand Impact Model."

v1 qualified air cleaner with a clean air delivery rate (CADR) of 51-100. The energy savings were calculated using the 2018 EPA Savings Calculator for ENERGY STAR Qualified Appliances and only a single capacity (CADR) value of 100 was used.

The baseline and high efficiency capacity of room air cleaners are measured in CADR/Watt (Dust), as described by ENERGY STAR v1, and the savings calculator is used to convert these values to kWh. The conventional efficiency used in the calculator is 1.0 CADR/Watt (Dust), which seems to be the value used in 2020 Illinois TRM and is applicable in this case. The TRM currently uses 3.0 CADR/Watt (Dust) as the high efficiency value which is higher than the ENERGY STAR requirement of 2.0 CADR/Watt (Dust). However, the ENERGY STAR average CADR/Watt (Dust) of models available in their US market database (approximately 170 models) is approximately 3.5 CADR/Watt (Dust). Hence, 3.0 CADR/Watt (Dust) seems reasonable and is recommended in Table 3-26. Note that the ENERGY STAR specification for room air cleaners is currently under revision and is expected to come into effect in July 2020. To calculate savings, the TRM previously used a fixed 100 CADR for the units, which results in a savings of 391 kWh. The team recommends using the midpoint of 51-100 (75) which results in savings of 293 kWh. Furthermore, the team recommends using different CADR ranges and selecting the midpoint of the range, instead of using a single range of 51-100. Table 3-27 provides recommended savings values for different room air cleaner capacity ranges.

Table 3-27: Room Air Cleaner Baseline and High Efficiency

Parameter Name	Existing Value ($CADR/Watt_{Dust}$)	Proposed Value ($CADR/Watt_{Dust}$)
Room Air Cleaner, Baseline Efficiency	1.0	1.0
Room Air Cleaner, High Efficiency	3.0	3.0

Table 3-28: Room Air Cleaner Savings

CADR Range	CADR Value in Calculator	Baseline Consumption (kWh)	High Efficiency Consumption (kWh)	Energy Savings (kWh)
51-100	75	441	148	293
101-150	125	733	245	488
151-200	175	1,025	342	683
201-250	225	1,317	440	877
Over 250	300	1,755	586	1,169

Parameter: EUL.
Explanation: The EUL for room air cleaners is currently 9 years in the MA TRM. Data from the RES 1 Baseline Study (26 replacements among 1,233 customers) suggests an EUL of 47 years. This value appears to be heavily influenced by changes in market saturation, and as such, Guidehouse does not recommend changing the existing EUL value.

3.20 Room Air Conditioner (RES-PL-ROOMAC)

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.

New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 57% saturation for room A/Cs. The proposed EUL value is informed by approximately 296 replacements (out of over 3,600 respondents with room A/Cs) over a 2-year period. Details are shown in Table 3-28.

Table 3-29: Room Air Conditioner Effective Useful Life

Parameter Name	Existing	Proposed
EUL – Room Air Conditioner (years)	8	12

3.21 Standalone Water Heater (RES-WH-SASWH)

Parameter: Baseline/Existing UEF, Early Retirement.
Explanation: Early retirement water heater efficiencies should reflect the actual units that customers are replacing, rather than a code-mandated value. Until 2017, water heater efficiencies were described by the EF metric. In 2017, the US DOE revised the water heater test procedure to use an efficiency metric called uniform energy factor (UEF). While the EF and UEF metrics cannot be directly compared, we compare them here using a calculator that estimates UEF ratings based on EF ratings.
Existing Source: Previously, the early retirement $UEF_{exist,ER}$ value was from an undocumented source.
New Source: RES 1 baseline survey.
Methodology: The team compiled a list of existing EF values for RES 1 households that had installed standalone gas water heaters since 2010. After applying an equipment degradation factor,[28] the group (n=70) had a mean EF of 0.58. This suggests that the older storage water heaters that are likely to be replaced by this measure (and still within the official measure lifetime of 10 years) should have an average EF of 0.58. This is higher than the value listed in the current TRM[29], but is consistent with the team's expectation that average installed baseline efficiencies should trend upward over time. The team then used two existing calculators[30] to convert EF to UEF, using the established MA portfolio weighting between medium-draw and high-draw units. See Table 3-29 for details.

Table 3-30: Standalone Water Heater Early Retirement Baseline Efficiency

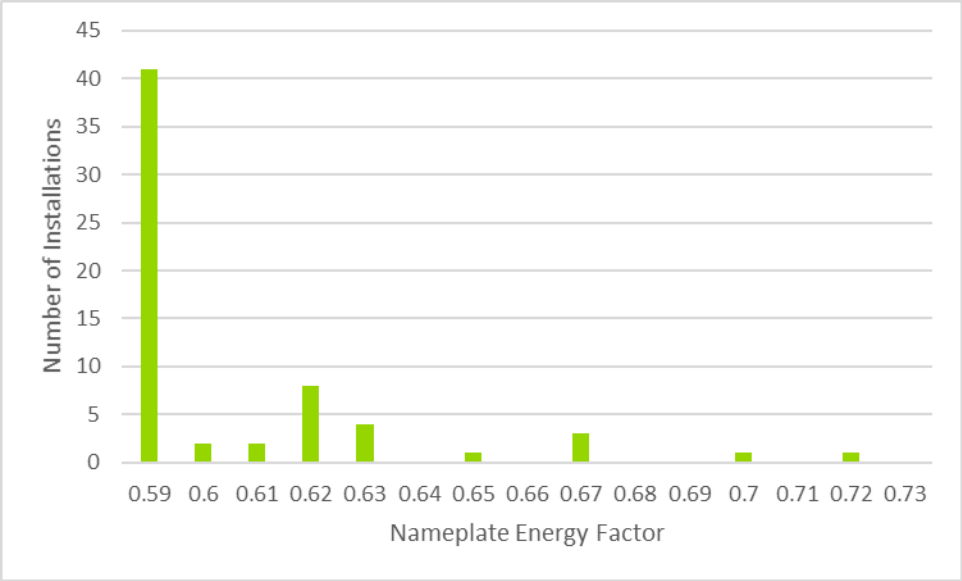
Parameter Name	Existing Value ($UEF_{exist,ER}$)	Proposed Value ($UEF_{exist,ER}$)
UEF_{exist} – Early Retirement	Medium Draw: 0.52 High Draw: 0.58 Blended: 0.55	Medium Draw: 0.56 High Draw: 0.60 Blended: 0.58

Parameter: Water Heater Baseline Efficiency, Replace on Failure.
Explanation: The baseline water heater efficiency should represent the typical efficiency of standalone gas water heaters recently installed by customers in the absence of the program, as long as the determined value is not superseded by the relevant code or federal standard.
Existing Source: Uncited.
New Source: Federal standard.

[28] The team applied a degradation factor of 0.005, which represents "professional annual maintenance".
[29] The program's prescribed early retirement baseline efficiency value of 0.55 UEF represents a blend of medium-draw products at 0.52 UEF and high-draw products at 0.58 UEF.
[30] RES19_Task7_WaterHeater_Characterization_v10.xlsx was used to convert from EF to UEF, and Water Heater UEF screening_2019-21_revised 2018.09.06.xlsx was used to weight by portfolio percentages of medium-draw vs. high-draw water heaters.

Methodology: The team analyzed the efficiencies of all standalone natural gas water heaters installed by RES 1 survey respondents and the subset of RES 1 respondents who were program nonparticipants and had installed a standalone gas water heater since 2010. Most of the sampled program nonparticipants installed units with an EF of 0.59; see Figure 3-1.

Figure 3-1: Installed Standalone Gas Water Heater EF (Non-Participants since 2010)



The mean EF for all nonparticipants who installed gas water heaters since 2010 (n=64), is 0.604. Federal standards for water heaters vary with the water heater's rated storage volume and draw pattern. The federal minimum standard is 0.58 UEF for a 40-gallon medium-draw water heater and 0.63 UEF for a 50-gallon high-draw water heater.[31] These values are consistent with the replace-on-failure efficiency values currently used by the program. The program's prescribed ROF baseline efficiency value of 0.60 UEF represents a blend of medium- and high-draw products. The team recommends no changes to these baseline values, as seen in Table 3-30.

Table 3-31: Standalone Gas Water Heater Replace on Failure Baseline Efficiency

Parameter Name	Existing UEF	Proposed UEF
Baseline EF – Replace on failure	Medium Draw: 0.58 High Draw: 0.63 Blended: 0.60	Medium Draw: 0.58 High Draw: 0.63 Blended: 0.60

Parameter: EUL.
Explanation: The team analyzed RES 1 data to determine the two-year equipment replacement rate, as outlined in Section 2.3.2. This gives Massachusetts- and program-specific values for EUL based on actual customer behavior.
New Source: RES 1 baseline survey.
Methodology: The team analyzed RES 1 data and found a 40% saturation for natural gas domestic hot water heaters. The team estimated an EUL of 10 years for standalone gas water heaters, based on observations of approximately 257 replacements per year (out of over 2,589 respondents with natural gas water heaters) over a 2-year period. Details are shown in Table 3-31.

[31] 10 CFR 430.32(d)

Table 3-32: Standalone Water Heater Effective Useful Life

Parameter Name	Existing		Proposed EUL
	EUL	Rolled Up Measure Life	
EUL – Standalone Water heater	13	10.2	10

3.22 Thermostatic Valve (RES-WH-TV)

Parameter: EUL.
Explanation: The lifetime for TSVs should be consistent with our recommendation for the Low-Flow Showerhead with TSV measure.
Existing Source: Massachusetts common assumptions.
New Source: RES 1 baseline survey.
Methodology: See the EUL discussion in Section 3.14. The RES 1 surveys ask about showerhead replacements in general and do not distinguish whether a thermostatic valve was included in the showerhead replacement. However, Uniform Plumbing Code (UPC) certification under IAPMO standard IGC 244-2007a stipulates that TSV devices must meet 10,000 cycles without failure. Assuming 1.6 showers per day,[32] a TSV rated to 10,000 cycles would exceed the showerhead lifetime of 15 years. Table 3-32 shows a recommended EUL of 15 years for TSVs.

Table 3-33: Thermostatic Valve Effective Useful Life

Parameter Name	Existing EUL (Years)	Proposed EUL (Years)
EUL –TSV	7	15

3.23 Variable Frequency Drive (RES-MAD-VFD)

Parameters: Energy Savings (kWh/HP), Summer Demand Savings (kW/HP_{SP}), Winter Demand Savings (kW/HP_{WP}).
Explanation: The demand savings values in the TRM did not match the values in the cited source, Cadmus (2014) *Variable Speed Drive Loadshape Project*. The energy savings values in the TRM match a different cited source, Chan (2010) *Formulation of a Prescriptive Incentive for the VFD and Motors & VFD impact tables at NSTAR,* but the source is 10 years old.
Existing Source: Energy savings are cited to Chan (2010)[33] and demand savings are cited to Cadmus (2014).[34]
New Source: Cadmus (2014).
Methodology: The team recommends using demand savings and energy savings values from the same source, Cadmus (2014), to be consistent and use the most up-to-date source. Table 3-33 summarizes the existing values in the MA TRM and the recommended values from Cadmus (2014).

[32] Biermayer, Peter J. Potential Water and Energy Savings from Showerheads. Lawrence Berkeley National Laboratory. 2006.
[33] Tumin Chan (2010). "Formulation of a Prescriptive Incentive for the VFD and Motors & VFD impact tables at NSTAR."
[34] Cadmus (2014). "Variable Speed Drive Loadshape Project."

Table 3-34: Variable Frequency Drive Savings Values

Parameter	Pump Type	Existing Value	Proposed Value
Energy Savings (kWh/HP)	Chilled Water Pump	1,374	1,633
	Hot Water Circulating Pump	2,400	1,548
	Return Fan	1,374	1,788
	Supply Fan	1,319	2,033
	WSHP Circulating Loop	3,713	2,562
Summer Demand Savings (kW/HP_{SP})	Chilled Water Pump	0.174	0.183
	Hot Water Circulating Pump	0.091	0.096
	Return Fan	0.287	0.302
	Supply Fan	0.274	0.288
	WSHP Circulating Loop	0.218	0.229
Winter Demand Savings (kW/HP_{WP})	Chilled Water Pump	0.184	0.194
	Hot Water Circulating Pump	0.21	0.221
	Return Fan	0.26	0.274
	Supply Fan	0.252	0.265
	WSHP Circulating Loop	0.282	0.297

4. OTHER PARAMETERS WHERE NO UPDATE IS RECOMMENDED

This section describes measures and parameters that the team considered but for which the team does not recommend updated values. The following descriptions for each measure and parameter describe the team's reasoning for not updating the existing values.

4.1 Air Source Central Heat Pump and Air Conditioning Savings Parameters

The team identified three measures for which energy efficient performance ratings ($SEER_{EE}$) are based on program participant rebate data. The updates to $SEER_{EE}$ parameter values are handled by the PAs independently of this review, so this TRM review did not consider updates to $SEER_{EE}$ values for the following measures:

- Air Source Central Heat Pumps (RES-HVAC-ASHP)
- Central AC (RES-HVAC-CAC)
- DMSHPs (RES-HVAC-DMHP)

4.2 Fuel Switching/Energy Optimization Measures

The team identified four measures that involved fuel switching and would benefit from more recent savings values derived in the Energy Optimization Model Update (MA19R16-B-EO) that concluded in March 2020. However, the PAs and the evaluation team are conducting another energy optimization study that may result in further updates to energy optimization measures. This TRM review did not include updates to energy savings values for the following measures:

- Central Ducted Heat Pump Fully Displacing Existing Furnace (RES-HVAC-FSHP)
- Central Ducted Heat Pump Partially Displacing Existing Furnace, Oil (RES-HVAC-FSHP-P)
- Ductless Mini-Split Heat Pump with Integrated Controls – Fully Displacing Existing Boiler (RES-HVAC-DMSHP)
- Ductless Mini-Split Heat Pump with Integrated Controls – Partially Displacing Existing Boiler (RES-HVAC-FS-DMSHP-P)

4.3 DMSHP and DMSHP Quality Installation Verification

Our team examined the assumptions for equipment runtime for the DMSHP and DMSHP Quality Installation Verification measures. We compared the EFLH values in the TRM with EFLH values derived in the RES 1 Baseline Study. The TRM currently uses an EFLH of 218 hours, based on the Cadmus Group's *Ductless Mini-Split Heat Pump Impact Evaluation* (2016). The RES 1 Baseline Study estimates a higher EFLH of 417 hours for ductless mini-splits. However, the sample of ductless mini-splits in the Baseline Study is much smaller than the sample in Cadmus (2016), so our team does not recommend updating this value in the TRM. We recommend that the PAs study these EFLH values further by oversampling homes with DMSHPs in future iterations of the Baseline Study.

4.4 Refrigerator and Freezer Recycling Measures

Our team examined the assumptions for electricity savings and baseline efficiency used in the Refrigerator/Freezer Recycling measure (RES-A-RFR). The RES 1 Baseline Study measures energy consumptions of secondary refrigerators and freezers for homes in the sample that use these appliances. We considered whether Baseline Study data could be used to update these assumptions. Ultimately, we

assumed that data gathered from recycled appliances during implementation of these measures would provide a more accurate representation than data from the Baseline Study. We do not recommend updating the savings or baseline efficiency for the Refrigerator/Freezer Recycling measure.

4.5 Low Impact Measures

The team considered additional parameter updates for the following measures, but deprioritized them during the March 17 workshop because these measures contribute a small amount to overall program savings:

- Faucet Aerators (RES-WH-FA)
- Pipe Wrap, Water Heating (RES-WH-PW)
- Early Retirement Clothes Washers (RES-A-ERCW)
- Clothes Dryers (RES-A-CD)
- Heat Pump Quality Installation Verification (RES-HVAC-HPQIV)
- Heat Pump Digital Check-up/Tune-up (RES-HVAC-HPDCU)

5. NEXT STEPS

The evaluation team identified measures and parameters that could be updated through future studies or through additional data collection in future iterations of the Baseline Study. The team discussed potential future data collection activities with the PAs and EEAC consultants during the TRM workshop on March 17, 2020. This section incorporates the feedback received during that workshop and describes measures that could benefit from further study.

5.1 Future Evaluation Studies

The following measures would benefit from new primary data collection through dedicated evaluation studies:

- **Programmable Thermostats.** A study is underway to develop primary research-based estimates of annual programmable thermostat electric and gas savings to enhance the accuracy of the literature-review based deemed savings values currently in use.
- **Duct Sealing and Duct Insulation.** We assume participant data is collected by implementation vendors, and an evaluation study could use participant data in building simulations to estimate the impacts of these measures.
- **ECM Circulator Pumps.** Planning is in progress for an evaluation study that will examine circulator pumps.
- **Low-Flow Showerhead Energy Savings.** This TRM review recommended updates to several outdated parameter values for showerheads. A comprehensive evaluation study could provide a more holistic update for showerhead measures.

5.2 Future Baseline Study Activities

Future phases of the Baseline Study survey will gather more data that could improve baseline HVAC equipment efficiency recommendations. After the next phase of the Baseline Study survey concludes in 2021, the following parameters should be revisited.

- Boiler, Gas Forced Hot Water (RES-HVAC-BGFHW) – Baseline Efficiency, ROF and ER
- Boiler, Oil/Propane Forced Hot Water (RES-HVAC-BFHW) – Baseline Efficiency, ROF
- Central Air Conditioning (RES-HVAC-CAC) – Baseline Efficiency, ROF
- Furnace, Gas (RES-HVAC-FG) – Baseline Efficiency, ROF
- Furnace, Oil/Propane (RES-HVAC-FOP) – Baseline Efficiency for Oil and Propane, ROF

The following measure could benefit from additional data collection in future phases of the Baseline Study:

- **Room Air Cleaners** – Future phases of the Baseline Study could designate air cleaners as a “priority end use,” such that product nameplate data is gathered to inform an update to baseline efficiency assumptions.

APPENDIX A. HEAT RECOVERY VENTILATOR MEASURE REVIEW AND UPDATE

A.1 Literature Review of Potential HRV Savings Sources

The team reviewed three types of sources for residential HRV savings: Other state and regional TRMs, state and national energy code analysis, and other research publications.

A.1.1 State and Region TRMs

The review of state and regional TRMs focused on states surrounding Massachusetts summarized in Table A-1. Other than Massachusetts, only one state (Rhode Island) had a residential HRV measure. The Rhode Island TRM uses the same reported savings and GDS Associates report for its HRV measure.

Table A-1: State and Regional TRMs Reviewed for HRV Measures

State/Region	Document Type or Program	HRV Measure	Source
Rhode Island	TRM	Residential	GDS Associates (2009)
New York	TRM	No HRV measure	
Vermont	TRM	No HRV measure	
Mid Atlantic, NEEP	TRM	No HRV measure	
Minnesota	TRM	Commercial ERV Only	Calculation
Maine	TRM	No HRV measure	
Pennsylvania	TRM	No HRV measure	
New Jersey	Clean energy program	No residential HRV measure	
Pacific Northwest	RTF	No HRV measure	
Wisconsin	TRM	No HRV measure	

A.1.2 Residential Energy Codes

The literature review also investigated any state or national energy codes that require HRV to assess any comparable accompanying energy savings or cost-effectiveness analysis.

Energy codes sometimes include HRV/ERV as an optional path to meet ventilation requirements, Accordingly, energy code analysis reports did not focus on the energy savings from this equipment. The energy codes in Washington, the City of Seattle, Vermont, and Minnesota mention HRV/ERV as an option to meet ventilation requirements.

Some stretch codes or code proposals did include requirements for HRV for heat recovery purposes. NY Stretch code 2020 has a requirement for HRV in climate zones 5-7, but not required for climate zone 4. NYSERDA reviewed the cost-effectiveness of NY Stretch Energy Code in 2019 but did not report specific savings from HRV. This review stated that the energy impact was captured through energy modeling. The

draft 2019 Denver Green Code has three options for residential compliance. ERV are required by the net-zero approach. Denver only recently published this code requirement and did not publish any accompanying analysis.

DOE proposed an HRV requirement for the 2018 IECC, but it was ultimately not included. The accompanying analysis for this proposal was conducted by Pacific Northwest National Laboratory (PNNL), which concluded that HRVs are cost-effective in climate zones 6-8. The PNNL study used energy modeling to quantify energy savings and reported the savings in $/year. The team followed up with PNNL to get more information on heating equipment assumptions and the complete modeling results, but PNNL was not able to share their data.

A.1.3 Other Reviewed Publications

The literature review also looked at HRV related publications by government and efficiency organizations. Some of these studies reported energy savings but these sources were either older or less relevant than the current TRM source.

- Canada implemented an ENERGY STAR specification for residential HRVs in 2010. The accompanying documents did not include energy savings estimates.
- ENERGY STAR Homes' published program requirements do not include a ventilation requirement for single family or multi-family homes.
- The Home Ventilating Institute (HVI) maintains a directory of certified HRV and ERV models. Both the PNNL study and the NYStretch Code review referenced an HVI document, *H/ERV Cost Effectiveness: Building Energy Simulations and Economic Analysis for Single Family Detached Dwelling Units*, but this document does not appear to be publicly available.
    - The team used the HVI Certified Products Directory as a source of sensible and total recovery effectiveness for the ERV and HRV energy savings calculation.
- Efficiency Nova Scotia has a residential HRV incentive but did not publicly publish an associated TRM with values for energy savings.
- DOE Building Technologies Office's Impact of Residential Mechanical Ventilation on Energy Cost (2014) found an increase in energy cost of $0-$40 from using an ERV as a ventilation source but did not provide detail on the energy analysis other than yearly cost. This study used energy modeling to compare systems.
- HRV publications by the Consortium for Advanced Residential Buildings (CARB) and Florida Solar are older than the current source. Florida Solar evaluated southern hot/humid climates. CARB was a metered study in Chicago and reports electricity and gas consumption directly but was published in 2005.
- A National Institute of Standards and Technology publication on HVAC systems in net zero energy buildings reports savings in kWh, but the home is not representative of the average Massachusetts or national home.
- Berkeley Lab's review of ventilation technologies discusses options for ventilation and lists equipment costs for HRVs but does not report energy savings.

Many sources describe HRVs as energy efficient equipment, but their energy savings in a residential application does not have robust, publicly available data. Sources that do examine their energy savings use energy modeling, but the modeling results do not separate savings by equipment or make documentation publicly available.

The HRV energy savings calculation databook's "HRV Lit Review" tab includes additional reviewed sources of information and links to these documents or websites.

A.2 Measure Update for HRV

Since the literature review did not produce a recent and representative source for energy savings, the team constructed an engineering calculation to estimate HRV and ERV energy savings, supplemental to this report. The original TRM source for the HRV measure also used an engineering calculation, but this calculation databook was not available to compare or build upon. Energy modeling may be a more robust method to estimate savings, and future updates to the TRM values should consider funding a metered study or an energy modeling analysis.

The team built an energy savings calculation for HRVs and ERVs. ERVs can recover sensible (heat) and latent (moisture) energy from the exhaust stream, while HRVs only recovery sensible energy.

The savings calculation assumed a baseline of an ASHRAE 62.2 compliant fan exhaust system with no heat recovery. The efficient case was an ERV or HRV with the same ventilation rate and heat or energy recovery capabilities. The energy savings calculation used standard engineering HVAC equations for sensible and total heat transfer, accounting for the heat recovery efficiency of HRV and ERV. The calculator includes additional details and information sources for the calculation inputs.

The calculation for ERV also included cooling season savings since the moisture transfer capability of ERV reduces the cooling load for A/C systems. Ultimately, this calculation showed that the relatively mild Massachusetts summer temperatures resulted in small cooling savings for ERV. These cooling savings were smaller in magnitude than the increase in fan energy, so the overall electricity savings for ERV was negative.

Table A-2: Heat Recovery Ventilator Updates

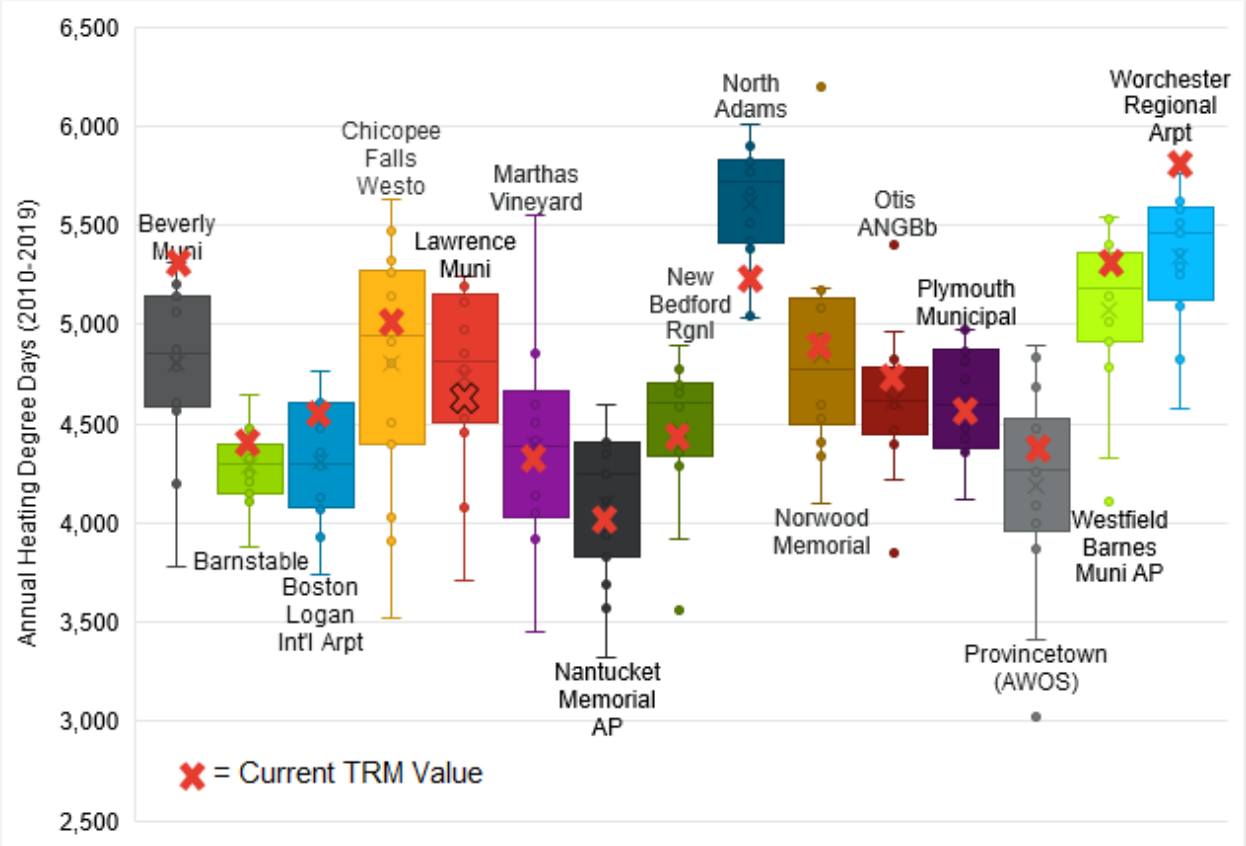
Parameter Name	Existing Value	Proposed Value
HRV Gas Savings (MMBtu)	7.7	8.6
HRV Electricity Savings (kWh)	-133	-171
HRV Demand Savings (kW)	-0.10	-0.02
ERV Gas Savings (MMBtu)	No existing value	8.8
ERV Electricity Savings (kWh)	No existing value	-127
ERV Demand Savings (kW)	No existing value	-0.014

APPENDIX B. HEATING DEGREE-DAY AND COOLING DEGREE-HOUR ANALYSIS

The weather stations cited in the MA TRM are a mix of Class 1, Class 2, and Class 3 weather stations. Class 1 stations are the most stringent in terms of distances from influential heat sources, requirements for shading, and other factors that could unduly influence temperature readings. There are five different weather station classifications, with Classes 1, 2, and 3 all providing high quality results. NOAA estimates the temperature error for each type of site (1, 2, and 3) as 1°C or lower.[35] Beyond the NOAA-estimated error bounds, the team did not evaluate additional sources of error for each weather station.

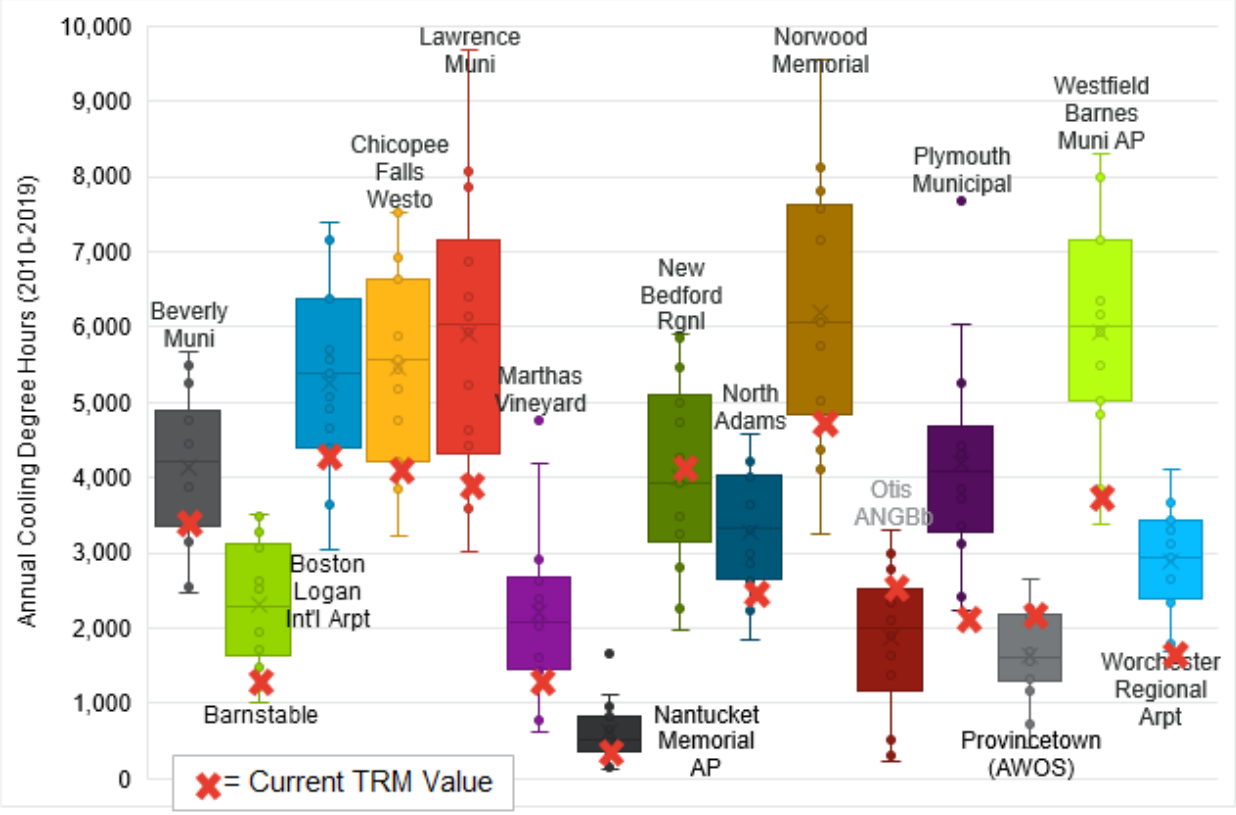
To arrive at a new representative HDD or CDH value for each site, the team examined the most recent 15 years of temperature data, as this is assumed to represent the latest actual weather conditions, given the advancing state of global climate change. Box and whisker plots of each weather station's previous 15 years can be seen in Figure B-1 and Figure B-2. Maximum and minimum values are represented by the whiskers extending from the box, which itself represents the upper and lower quartiles of the data. The median value is the dividing line within the box. The values for individual years are represented by circles and current TRM values are represented by a red **X**.

Figure B-1: Heating Degree-Days, Box and Whisker Plot, Reference Weather Stations



[35] NOAA (2002). "Climate Reference Network (CRN): Site Information Handbook." p.6. Available at: https://www1.ncdc.noaa.gov/pub/data/uscrn/documentation/program/X030FullDocumentD0.pdf

Figure B-2: Cooling Degree-Hours, Box and Whisker Plot, Reference Weather Stations



The team determined that the median value from each dataset would be more representative than the mean value of the 15-year period. This way, a single year of high or low values would not have a large impact upon the overall recommendation.

The team also considered the impacts of climate change moving forward. Scientific projections indicate the temperature increases are likely to continue but the exact rate of increase is not known. The team plotted the 15-year progression for each weather station to determine if significant trends exist. Aside from year-over-year variation (experienced to some degree across all weather stations), the HDD trend is too flat to be seen in Figure B-3, with some hint of a CDH increase shown in Figure B-4.

Figure B-3: Annual Heating Degree-Days, Time Series

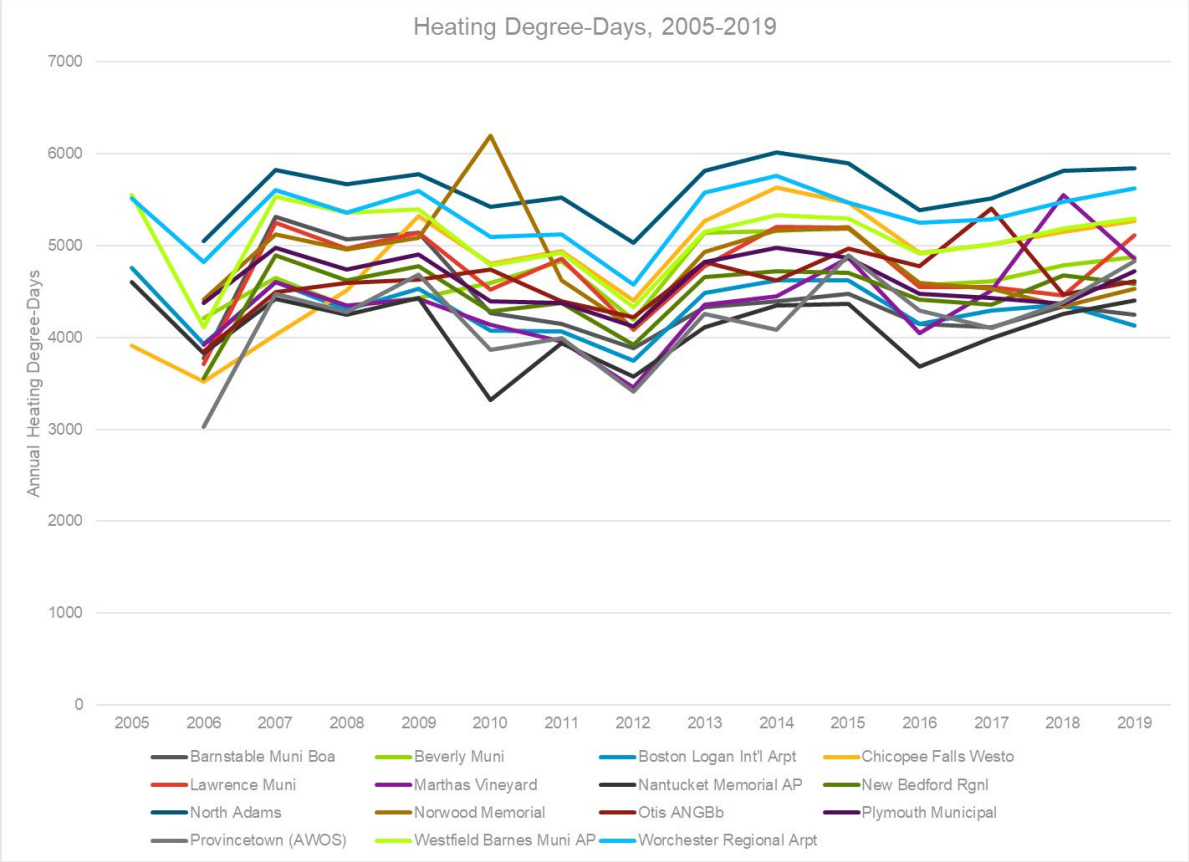
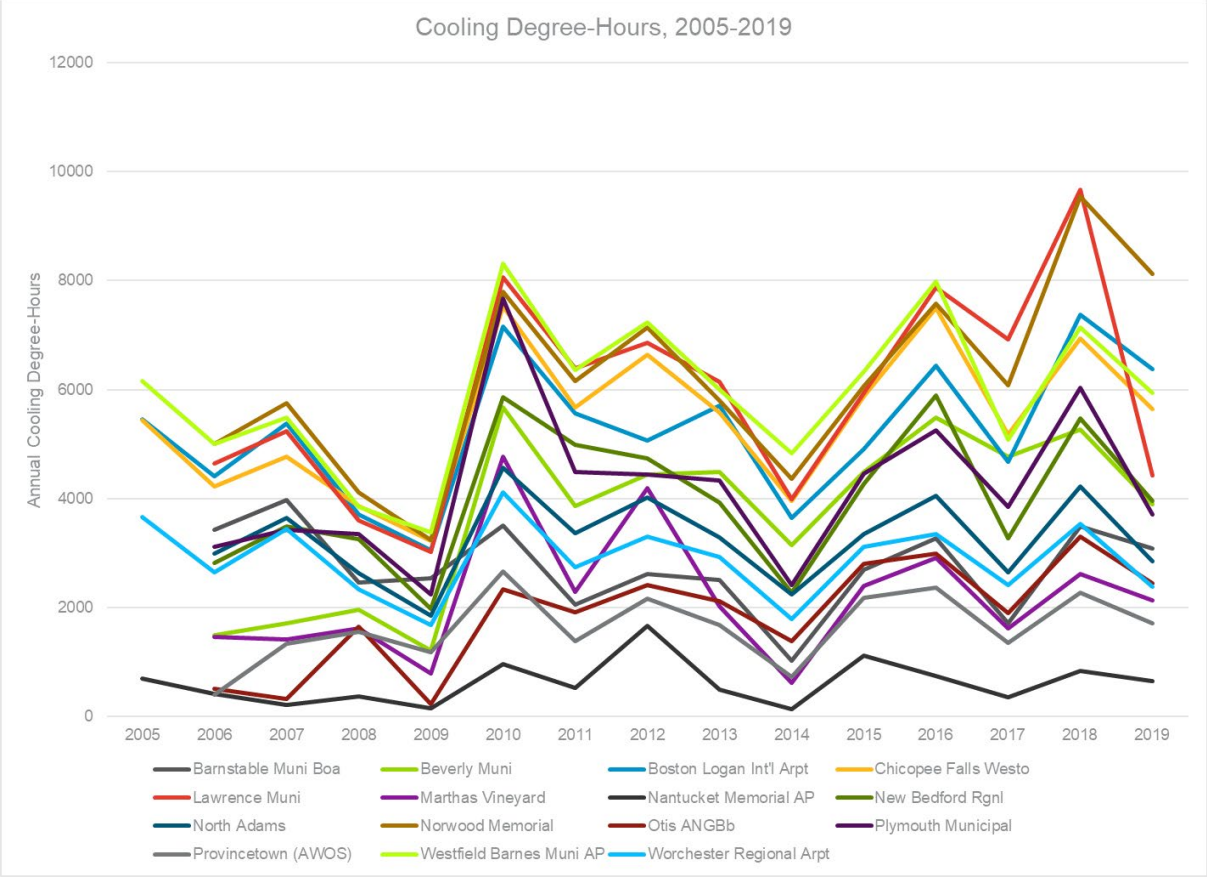


Figure B-4: Annual Cooling Degree-Hours, Time series



The weather stations appear to experience similar weather phenomena in any given year, with the normal variation expected of locations with different microclimates. Although the HDDs appear to be increasing slightly from 2005 to 2019, the aggregate values are 1% lower than the TMY3 values (not shown on the chart). For CDHs, a small increase within the 10-year period is more visible. It should be noted that the 2005 to 2019 recommended values are substantially different from the currently used TMY3 values, particularly for the CDHs. However, rather than attempting to extrapolate the rate of temperature increase into the future, it may be more prudent to simply update the numbers that populate this analysis every 10 years to maintain the most accurate representation of current weather data.