C&I Measure Life Study: Project MA19C02-B-EUL Final Report

Massachusetts Program Administrators and Energy Efficiency Advisory Council

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1 EXECUTIVE SUMMARY

This Executive Summary provides a high-level review of evaluation results for the Massachusetts Commercial and Industrial Measure Life Study (MA19C02-B-EUL, also formerly known as Project 91). In this section, we state the study objectives, summarize the evaluation approach, and present key findings, considerations, and recommendations. The more detailed findings appear in Section 2.

Table 1-1. Technologies and Research Objectives

<table>
<thead>
<tr>
<th>EE Technology</th>
<th>Research Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Understanding lighting manufacturer methods for estimating LED measure lives</td>
</tr>
<tr>
<td>Commercial unitary HVAC equipment</td>
<td>Revising EUL estimates for unitary HVAC equipment developed under Project 73, Track D</td>
</tr>
<tr>
<td>Custom projects and add-on measures</td>
<td>• Determining whether the PAs are treating measure lives properly in their custom project screening tools</td>
</tr>
<tr>
<td></td>
<td>• Understanding methods for estimating measure lives for add-on measures</td>
</tr>
<tr>
<td>Commercial gas heating equipment</td>
<td>• Informing the estimation of EULs for commercial gas heating equipment</td>
</tr>
<tr>
<td></td>
<td>• Determining whether this equipment is subject to early replacement (ER) frequently enough to change the current default replace-on-failure (ROF) assumptions; and</td>
</tr>
<tr>
<td></td>
<td>• Exploring the feasibility of a program which would compensate the installation contractors for sending in photos of manufacturer nameplates for the equipment they remove</td>
</tr>
</tbody>
</table>
The evaluation team completed interviews with 11 manufacturers who together accounted for about two-thirds of the Massachusetts 2018-2019 C&I Upstream Initiative sales. The interviews were completed in January and February of 2020.

The team completed interviews with 15 Massachusetts HVAC contractors who had recent experience replacing commercial boilers and furnaces. Most of the interviews were completed in Q4 2019.

The team reviewed whether the PA’s Custom Screening Tool (CST) for custom projects was using measure life estimates correctly and checked the consistency and reliability of its sources for measure life estimates. We also interviewed PA representatives about how they use measure life information in the CST.

The team improved on an innovative EUL estimation method which it had developed for Project 73 Track D (Measure Life Methods). Method improvements included estimating Massachusetts’ historical cooling load and a more precise way of imputing ages for HVAC equipment with missing manufacture dates.

The team reviewed over 20 Technical Reference Manuals (TRMs) as well as recent measure life studies commissioned by utilities and other stakeholders which focused on the measure lives of add-on or O&M measures.
How manufacturers define the end of life for their LED products:

Almost all the manufacturers base their measure life estimates on how long their LED products take to depreciate to 70% of their original lumen level. For example, an LED with a rated lifetime ($L_{70}$) of 30,000 hours would have been tested to reach 70% of its original lumen output at 30,000 hours of use.

Tests have shown that some LED lighting components can fail catastrophically long before this 70% lumen depreciation level is reached. One manufacturer representative said that lumen depreciation is used to define the end of life for a LED product rather than catastrophic failure because such failures are dependent on a wide range of factors and are therefore hard to test for.

Two representatives said that increasing cost competition has reduced the number of LED products offered with longer estimated lives because extended testing can be expensive. The adjoining figure shows factors the manufacturers said could cause their products to fail before their rates measure lives.

Product quality concerns:

Two representatives claimed that Design Lighting Consortium (DLC) quality specifications, which most rebate programs require, are not tough enough and have only set a floor above which there are many variations in product quality. “You shouldn’t set the bar too low to create capitalism. ... You’ve got people selling absolute junk out there,” said one manufacturer representative. “It has become a race to the bottom,” said another. A third representative said that “IES TPC (the Illuminating Engineering Society’s Testing Procedures Committee) activity is beginning to consider both product reliability and product quality assessment methods as a means to provide the industry and customers with a basis for evaluation of basic quality. But again, the variations in use conditions across the range of lighting products makes it very difficult to create much more than guidance and not a firm standard at this time.”

How manufacturers estimate how long their LED products will last:

All but one of the manufacturer representatives said they use the Illuminating Engineering Society’s (IES’s) LM-80 testing protocols. LM-80 is a method for measuring the lumen maintenance of LED packages, arrays, and modules (i.e., the LED light source) at various temperatures. It specifies a minimum testing period of 6,000 hours, although 10,000 hours is preferred. It also requires testing at a minimum of 1,000-hour increments.
The contractors estimated early replacement (ER) rates of 20%-21% for commercial gas heating equipment. The average estimate of the contractors for early replacement of commercial boilers was 21% and their average estimate for the early replacement of commercial furnaces was 20%.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Commercial Gas Boilers (Average Age in Years)</th>
<th>Commercial Gas Furnaces (Average Age in Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removed equipment had totally failed or was near failure</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Removed equipment had some useful life remaining</td>
<td>19</td>
<td>17</td>
</tr>
</tbody>
</table>

The average age of removed equipment: The interviewers asked the HVAC contractors about the average age of the commercial gas heating equipment they had removed in the past year. The following table shows that the contractors estimated that the equipment they deemed to have useful life remaining was only 2-3 years younger than the equipment deemed at or near failure.

How contractors defined end of life for commercial gas heating equipment: The following figure shows how the contractors defined the end of useful life for commercial gas heating.

Program for sending in photos of nameplates from removed equipment: The evaluation team asked the contractors if they were interested in a program that would pay them to email in pictures of the manufacturer nameplates of the commercial HVAC equipment they removed, along with brief descriptions of the equipment's condition.

Two-thirds of the contractors said they would participate in such a program with another 20% saying that their participation would depend on program requirements. When asked about the minimum amount the program could pay them per emailed nameplate photo to get them to participate, the average incentive estimate was $36.
The Custom Screening Tool (CST) is using correct measure life assumptions with a few exceptions: The evaluation team determined that the CST lifetime savings calculations correctly followed the framework guidance for dual baseline lifetime savings at the measure and project (all measure) level. The combination of program and measure type led to the correct measure event type.

However, the CST classified add-on measures as a single baseline only, while the baseline framework requires dual baseline treatment for add-on measures with an EUL that exceed two-thirds the RUL of the host equipment.

There are some inconsistencies in the EULs being used by the CST, the eTRM, and the TRM: When the evaluation team compared the EUL estimates being used by the CST, the eTRM, and the TRM, for selected measures, they found some inconsistencies. Similar inconsistencies were found for the AMLs. For example, the CST EUL is less than the eTRM for chillers, while greater for furnaces.

The flexibility of the CST’s EUL assignment option could lead to EULs and Adjusted Measure Lives (AMLs) being mis-assigned: The evaluation team observed that users of the CST are typically offered a choice of two or more EULs for a given measure. This flexibility is necessary given the range of measures that could be included within a measure category in the CST. For example, building envelope measures could include a short-lived garage bay door seal and a long-lived roof insulation measure that would each have a different EUL.

However, this flexibility means that CST users who are not carefully consulting the 2019-2021 MA electronic Technical Reference Manual (eTRM) could assign the wrong EUL to a given measure. There is a similar risk that AMLs would be assigned incorrectly as well.

A gap exists in the evaluation of second period baselines and out-year factors (OYF): While the custom impact evaluation teams are focusing more attention on individual implementer measure life assumptions and how they align with TRM and eTRM sources, an evaluation gap exists in the evaluation of the second period baseline since the current impact evaluation does not include that task in its scope.

Since the determination of the second period baseline is a derivative of baseline research, determining the second period baseline and the OYF could logically fall under the scope of future measure baseline research and maintained in the Baseline Repository.
Deemed values were the most frequently used methods for assigning EULs to add-on and Operations and Maintenance (O&M) measures. More than 80% of the TRMs the evaluation team reviewed used deemed values for add-on and O&M EULs. For the add-on measures there was a narrower range of deemed EUL values across TRMs for the same types of equipment. In contrast, the deemed EUL values for the O&M measures had more variation across TRMs for the same equipment types.

The revised EUL analysis produced results that were slightly higher than those produced previously under Project 73 Track D. The revised analysis, which used a new cooling installation index and updated imputations for unitary HVAC equipment with missing manufacture dates, gives an EUL of 8.6 years. Estimates using the cooling installation index with the prior study’s alternative imputation method give an EUL of 9.8 years. These EULs are slightly higher than those from the Project 73 Track D analysis, which mostly ranged from 6-8 years.

However, the updated estimates are still lower than the current TRM EUL (12 years).

EULs for add-on and O&M measures using formulaic approaches have their own challenges. Formulaic approaches, where EUL/RUL estimates are adjusted based on site-specific conditions, should, in theory, produce more accurate EUL estimates for add-on measures. For example, formulaic approaches ensure the EUL of the add-on measure does not exceed the RUL of the host equipment.

However, it is difficult to apply them by relying only on project tracking data and documentation. Often interviews are needed to collect the EUL and RUL estimates for the host and add-on equipment.

Deemed value EULs for add-on and O&M measures may be overstating the actual lifetimes of these measures.

- A 2017 DNV GL study that applied an interview-based method for determining measure lives for add-on measures and O&M measures in 30 C&I sites found an average ex post EUL of 9.1 years compared to a ex ante EUL of 16.6 years. The most common reason for the reduction in the EULs was that the remaining useful life of the host equipment was shorter than the ex ante EULs of the add-on equipment and it was unlikely the add-on equipment would be reused on another piece of host equipment.

- Over two-thirds of the states that used deemed EULs for add-on and O&M measures derived these measures from the same 4 studies. Not only were these sources dated (most were 10-15 years old), but most of the EULs in them were derived from even older secondary sources rather than primary research such as persistence studies.
Keep the EUL for commercial unitary HVAC equipment at 12 years: When the EUL for commercial unitary HVAC equipment was reduced from 15 to 12 years in 2018 in response to the EUL analysis conducted under Project 73 Track D, the reduction was dependent on improvements in the EUL analysis method that were to be conducted in 2019. The revised EUL analysis conducted under Project MA19C02-B-EUL did estimate EULs that were slightly higher (9-10 years) than those estimated under Project 73 Track D (6-8 years). However, the updated estimates are still lower than the current TRM EUL of 12 years. The improved EUL estimation method still has some limitations, as discussed in the detailed findings of this report. For this reason, the evaluation team is not advocating it be reduced below 12 years. However, the team believes that the EULs of 9-10-years that emerged from the improved 2019 analysis also suggest that this EUL should not revert to the 15-year estimate that was used prior to 2018.

Keep the EUL for commercial furnaces at 18 years: The HVAC contractors estimated the average age of the commercial furnaces they removed that still had some useful life remaining to be 17 years. They estimated the average age of the commercial furnaces they removed that were at or near failure to be 19 years. Since the 19-year average is close to the current EUL in the TRM of 18 years, we recommend that this EUL remain unchanged.

Reduce the EUL for commercial boilers to 20 years. As noted, the HVAC contractors estimated the average age of the commercial boilers they removed with some useful life remaining at 19 years. They estimated the average age of the commercial boilers they removed that were at or near failure to be 22 years. Both these estimates are below the current EUL in the Massachusetts TRM of 25 years.

Increase the assumed ER rate for commercial and commercial furnaces. As noted, this study found an ER rate of 21% for commercial boilers and 20% for commercial furnaces. Another recent Massachusetts study that involved interviews with both HVAC contractors and end users found an ER rate of 18% for commercial boilers and 11% for commercial furnaces.¹ Since two different evaluation studies have come out with similar results that are well above the default assumption of 0% we think the PAs should increase the ER rates for these measures. One approach would be to simply average the ER rates of the two studies. However, one commenter on the draft report argued that the study, which incorporated both end user and contractor estimates, likely reflected a broader range of ER considerations than a study based only on contractor perspectives.

The impact evaluation team should continue reviewing site-specific EUL assumptions: The impact evaluation team should continue to provide meaningful feedback regarding EUL assumptions observed at individual

¹ MA C&I Early Replacement Study—Interview Findings Memo; February 4, 2020; To: Massachusetts Electric & Gas Program Administrators; From: C&I Market Assessment Team (Cadeo and Navigant). The memo presented the ER rate as 13% of total boiler projects, with 23% of the total projects being new construction. It also presented the ER rate as 6% for total furnace projects with 44% of the projects being new construction. The 18% and 11% ER rates represent the adjusted ER rate once these new construction projects are removed from the denominators.
sites and communicate those findings through the monthly Baseline Advisory Group (BAG) meetings with stakeholders and in the final evaluation report.

**Improve the Custom Screening Tool (CST):** The CST tool is an excellent choice for implementing dual baseline principles since it is consistently used by all PAs for screening custom projects. The PAs should make improvements in the next CST revision, perhaps after the results of the current impact evaluations are complete, to do the following:

- Expand the CST measure list to include other high frequency measures not included in the current list or to more narrowly define the measure reducing the number of EUL options.
- Add dual baseline treatment for add-on measures.
- Align CST EULs and OYF with eTRM EULs factors.

**Improve the eTRM:** In the next eTRM revision, the PAs should provide further clarification on what measure life applies to an ER or lost opportunity measure, and clean-up values and references where there may be errors.

**Document EUL assumptions:** PAs should document in the project file the rationale for classifying a measure as unique and for a site-specific EUL or RUL. Likewise, the team suggests that PAs document the rationale for allocating complex project savings between measures. These documents should be included in the project file.
Consider making the estimation of outyear factors the responsibility of the baseline team. As noted, an evaluation gap exists in the evaluation of the second period baseline since the current impact evaluation does not include that task in its scope. Since the determination of the second period baseline is dependent on baseline research, determining the second period baseline and the OYF would logically fall under the scope of future measure baseline research and maintained in the Baseline Repository.
2 DETAILED FINDINGS
This section of the report describes the detailed findings of the various research tasks for the Massachusetts Commercial and Industrial Measure Life Study.

2.1 LIGHTING MANUFACTURER MEASURE LIFE METHODS
This section provides findings from in-depth interviews with lighting manufacturers concerning the methods they use for estimating measure lives for their LED products.

2.1.1 Research Objectives
Since most TRMs derive their EUL estimates for LED lighting from equipment life estimates provided by manufacturers, the objective of this research activity was to better understand how lighting manufacturers derive these measure life estimates.

2.1.2 Methodology
The primary source of information for this research task was a set of in-depth interviews with the largest lighting manufacturers that DNV GL completed in January and February of 2020. The work plan stated that DNV GL would attempt to complete interviews with the 10 largest manufacturers participating in the Massachusetts C&I Upstream Initiative based on their sales through the Initiative. The Plan further stated “if we are unable to complete interviews with all of the top ten manufacturers, we will attempt to complete our target number of ten interviews by reaching out to the next tier of manufacturers (ranked 11-20) which by themselves account for 16% of the Initiative energy savings and 17% of the incentive dollars.”

DNV GL was able to complete interviews with 8 of the 10 large lighting manufacturers and with 2 other manufacturers ranked in the top 15 in terms of 2018-2019 C&I Upstream Initiative sales. In addition, one of the manufacturers in the top 10 responded to the LED measure life questions from the interview guide in writing. The largest manufacturer was the only one in the top 10 who did not respond to DNV GL’s measures life questions either through a phone interview or a detailed written response. However, this largest manufacture did provide a couple of pieces of information on their LED measure life estimation methods via email without responding directly to the interview questions. The 11 manufacturers who responded to the interview questions either by phone or in writing accounted for about two-thirds (64%) of 2018-2019 C&I Upstream Initiative sales.

Table 2-1 shows the LED measure life questions that the interviewers asked the lighting manufacturers.
<table>
<thead>
<tr>
<th>Interview Question</th>
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</table>
| T1. For the LED products you sell through the Massachusetts C&I Upstream Lighting Initiative, how did your company estimate how long they will last?  
T1A. [IF NOT ALREADY MENTIONED] What are your criteria for defining the end-of-life for your LED products? |
| T2. Do your company’s estimates of how long its LED products will last vary by the type of LED product?  
T2A. [IF YES] For which lighting products do your estimates of measure life vary? |
| T3. One widely adopted method for testing lumen maintenance in LEDs is LM-80. Are you familiar with this testing method?  
T3A. [IF YES] Does your company use this LM-80 testing method?  
T3B. [IF "NO"] "Why don’t you use this method?” |
| T4. Several independent entities -- such as the Design Lighting Consortium (DLC), ENERGY STAR, the Department of Energy (DOE) CALiPER program, and the California Lighting Program Coordination Group -- commission testing of LED product measure lives. Does their research influence how your company estimates the measure lives of its own LED products?  
T4A. [IF YES] Which outside lighting research has influenced your measure life estimates for LED products? |
| T5. Does your company offer warranties for any of its LED products?  
T5A. [IF YES] What kind of warranties?  
T5B. [IF YES] What information are these product warranties based on? |
| T6. What kind of performance issues might cause the lives of your LED products to deviate from your estimated measure lives? |
| T7. Do you ever compare the predicted lifetimes of your LED products with those of your competitors?  
T7A. [IF YES] What sort of comparisons have you done? |

A secondary activity of this research task was to do a literature review of LED testing methods. The main purpose of this review, as indicated in the work plan, was to familiarize the DNV GL interviewers with these testing methods before they interviewed the lighting manufacturers. In addition, some of the findings from that literature review have been incorporated into this report.

### 2.1.3 Lighting Manufacturer Methods for LED Measure Lives

This section summarizes findings from the lighting manufacturer interviews concerning their methods for measuring the lifespans of their LED products. The main research objective of this task was to better understand these methods since they are the foundation for the EULs in the Massachusetts TRM and many other state TRMs.²

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² The Stage 3 workplan reads: "The P73-D study found that many Technical Reference Manuals (TRMs) derive their measure lives for LED lighting from equipment life estimates provided by manufacturers. This research activity would involve focused in-depth interviews with representatives of lighting manufacturers who can explain how these measure life estimates were derived.”
2.1.3.1 Defining the End of Measure Life for LEDs

The interviewers asked the manufacturers what criteria they use for defining end-of-life for their LED products. The large majority mentioned L70 which is the time for the light output of the LED to depreciate to 70% of its original value at room temperature. For example, an LED with a rated lifetime (L70) of 30,000 hours would have been tested to reach 70% of its original lumen output at 30,000 hours of use. There is also a statistical element to this estimation of end of measure life. A couple of manufacturer representatives mentioned using a B50 standard, which means that 50% of the LED products they tested had reached L70 lumen depreciation at the rated hours.

"The 70% level is a long-standing threshold in the lighting industry as a boundary for visual perception of loss in light level by users," said one manufacturer representative. "End of life is set by the certifying body by lumen output on the day it fails. If it is reduced by 30% or more it's a dead fixture," said another representative.

Some manufacturing representatives emphasized that the L70 standard is very different than a catastrophic standard and LED products can last much longer than their rated life. "LEDs can emit light for extremely long time periods if operated within their limits and used in systems that are well engineered for materials compatibility and electrical and environmental robustness," said one representative. "Time to burnout is not well defined as an industry and would only be reflected in LED FIT (failures in time) rates which would be exceedingly low on an individual device basis."

Yet other tests have shown that LED lighting components can also fail catastrophically long before the 70% lumen depreciation level is reached. The most common failures involve the semiconductor, the interconnects (bond wire, ball, and attachment), and the package (encapsulant, lens, lead frame, and case).3

One manufacturer representative said that lumen depreciation is used to define the end of life for a LED product rather than catastrophic failure because such failures are dependent on a wide range of factors. "There is not yet an obvious path for a unified approach to failure-rate-based life factors due to the wide range of application conditions under which products are applied," he said. "IES TPC [the Illuminating Engineering Society's Testing Procedures Committee] activity is beginning to consider both product reliability and product quality assessment methods as a means to provide the industry and customers with a basis for evaluation of basic quality. But again, the variations in use conditions across the range of lighting products makes it very difficult to create much more than guidance and not a firm standard at this time."

The interviewers asked the manufacturer representatives whether their estimates of how long their LED products last varies by the type of LED product. Most of the representatives said they do vary measure life estimates for their products. Three of the representatives mentioned that the quality of the LED components they purchase affects the measure lives they assign to certain LED products. For example, they might manufacture premium products with higher quality components for customers who demand a longer-lived product for reasons such as difficult maintenance conditions while also selling shorter-lived products into more cost competitive markets.

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The representatives also mentioned lighting application as another determining factor in differentiating their measure life estimates. For example, several mentioned using different measure life estimates for exterior vs. interior fixtures or for industrial vs. non-industrial applications.

Two representatives said that increasing cost competition has reduced the number of LED products offered with longer estimated lives. "We've tested a number of lamps out to 8,750 hours for ... a 30,000-hour or more lifetime ... and we have taken a few lamps out to 12,500 hours of continuous testing, which support, 50,000-hour lifetimes. And you could design enough margin in them to support a longer lifetime," said one of these representatives. "But the costs to do it versus the value that you're really providing the customer sometimes is debatable. So, in general, I would say most of our products are just the 25,000-hour lifetime.” “In early days, we had all kinds of different numbers [measure life estimates],” said the other representative. “But cost cutting is always going to shave lifetimes closer to a specified limit.”

2.1.3.2 Deviations from Predicted Measure Lives

The interviewers asked the lighting manufacturer representatives: "What kind of performance issues might cause the lives of your LED products to deviate from your estimated measure lives?” They mentioned many different factors as Figure 2-1 shows. The most-cited factors included higher temperatures; dirty, corrosive environments; lighting products being used in applications they were not designed for; and problems with installation.
Figure 2-1. Why LED Products Might Fail Before Rated Life

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>High temperatures</td>
<td>55%</td>
</tr>
<tr>
<td>Dirty, corrosive environment</td>
<td>55%</td>
</tr>
<tr>
<td>Inappropriate application</td>
<td>55%</td>
</tr>
<tr>
<td>Installation problems</td>
<td>45%</td>
</tr>
<tr>
<td>Poor power quality</td>
<td>36%</td>
</tr>
<tr>
<td>Incompatible controls</td>
<td>27%</td>
</tr>
<tr>
<td>Higher HOU than product designed for</td>
<td>18%</td>
</tr>
<tr>
<td>Poor quality components</td>
<td>18%</td>
</tr>
<tr>
<td>Damaged sockets</td>
<td>18%</td>
</tr>
<tr>
<td>Other factors*</td>
<td>36%</td>
</tr>
</tbody>
</table>

Note: The sum of the percentages exceeds 100% because multiple responses were allowed.
*Other factors included damage in shipment, lamp orientation, and natural variability in the product mix.

It is important to note that these were factors the manufacturer representatives cited as reasons why their own products might fail before their predicted measure lives. The representatives also mentioned quality problems with their competitor’s products. One representative mentioned working with the Design Lighting Consortium (DLC) to close what his company viewed as “loopholes” in the DLC standards. These perceived loopholes included the lack of minimum surge temperatures and minimum ambient temperature ratings for high/low fixtures used in industrial applications “Utilities are always worried about shutting people out [of the LED market], but if you don’t have the right quality product you’re not helping,” he said. “You shouldn’t set the bar too low to create capitalism. … You’ve got people selling absolute junk out there.” “It has become a race to the bottom,” said another representative who also claimed that utility midstream incentive programs value cost over quality.
2.1.3.3 Measuring End of Life for LED Products

The interviewers asked the lighting manufacturer representatives how they estimated how long their LED products would last. Eleven of the 12 respondents said they use IES’s LM-80 testing protocols. LM-80 is a method for measuring the lumen maintenance of LED packages, arrays, and modules (i.e., the LED light source) at various temperatures. It specifies a minimum testing period of 6,000 hours, although 10,000 hours is preferred. It also requires testing at a minimum of 1,000-hour increments. A few of the manufacturers mentioned that both the DLC and the ENERGY STAR® programs specified LM-80 testing.

Many lighting manufacturer representatives mentioned TM-21 in conjunction with LM-80. TM-21 provides guidelines for using LM-80 data to estimate the light source lumen maintenance beyond the LM-80 test period. LM-80 and TM-21 are designed to work hand in hand, with TM21 using the LM-80 data, along with in-situ temperature performance data, to project the lumen maintenance of an LED light source. Table 2-2 shows the relationship between maximum product life claims and tested lumen maintenance after 6,000 hours. Table 2-3 shows how long LEDs must be tested if they have claims of extended lives.

Table 2-2. ENERGY STAR LED Standard Test Requirements

<table>
<thead>
<tr>
<th>Maximum Life Claim (Hours to L70)</th>
<th>Minimum Lumen Maintenance After 6,000 Hours</th>
<th>Status After Completion of Test Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000</td>
<td>86.7%</td>
<td>Final certification testing completed</td>
</tr>
<tr>
<td>20,000</td>
<td>89.9%</td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td>91.8%</td>
<td></td>
</tr>
<tr>
<td>30,000</td>
<td>93.1%</td>
<td></td>
</tr>
<tr>
<td>35,000</td>
<td>94.1%</td>
<td>Interim certification; continue testing per below</td>
</tr>
<tr>
<td>40,000</td>
<td>94.8%</td>
<td></td>
</tr>
<tr>
<td>45,000</td>
<td>95.4%</td>
<td></td>
</tr>
</tbody>
</table>

In addition to the 11 manufacturer representatives who responded to all the measure life questions, a twelfth representative, who represented the large lighting manufacturer in the Massachusetts C&I Upstream Initiative also provided a limited amount of information on their testing practices in an email.
Table 2-3. ENERGY STAR LED Extended Lifetime Test Requirements

<table>
<thead>
<tr>
<th>Maximum Life Claim (Hours to L70)</th>
<th>Test Duration (Hours)(^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30,000</td>
<td>7,500</td>
</tr>
<tr>
<td>35,000</td>
<td>8,750</td>
</tr>
<tr>
<td>40,000</td>
<td>10,000</td>
</tr>
<tr>
<td>45,000</td>
<td>11,250</td>
</tr>
<tr>
<td>50,000</td>
<td>12,500</td>
</tr>
</tbody>
</table>

Some lighting manufacturer representatives mentioned other testing protocols in addition to LM-80. These included LM-79, which is a method for taking electrical and photometric measurements of solid-state products. It covers total flux (light output), electrical power, efficacy, chromaticity, and intensity distribution. A couple of the representatives also mentioned LM-84. This method, which is similar to LM-80, was developed by the IES to test the life of the whole LED system. TM-28 is the testing protocol that serves a similar function for LM-84 in allowing projections of measure lives beyond the LM-84 test period.

The interviewers asked the manufacturer representatives whether measure life testing research from independent entities—such as the DLC, ENERGY STAR, the DOE CALiPER program, and the California Lighting Program Coordination Group—influenced how their own companies estimated the measure lives products. Most representatives said these independent entities have influenced their practices in various ways. Many mentioned how ENERGY STAR and the DLC have made the LM-80 and TM-21 testing protocols standard practice in the industry. These entities have also influenced warranty practices, as discussed in the next section.

Several representatives said they have had to develop a dedicated LED product line for the California market to comply with the state’s stricter Title 20 lighting standards. They explained that they had to develop a California-specific line because these products were too expensive to be sold competitively in other parts of the country.

2.1.3.4 Warranty Practices

The interviewers asked the manufacturer representatives whether they offered warranties for their LED products. All 11 said that they did. The length of the warranties ranged from 2 to 10 years.

The interviewers also asked the representatives what factors determined the length of the warranties. Several noted that ENERGY STAR and DLC require minimum warranties (3 and 5 years respectively) and since lighting rebate programs require products that meet ENERGY STAR or DLC standards, warranties of this length have become commonplace.

\(^5\) Prescribed test duration is the total ON time of the LED lighting product and shall not include the OFF time.
The representatives of manufacturers who offered warranties longer than these required minimums said they based these warranties on the design of the product and its expected operating hours so that premium products with higher quality components would have both longer expected lifetimes and longer warranties than their baseline products. Several reported doing additional reliability testing beyond the standard LM-80 and TM-21 tests in the preproduction stage which informed the warranty offer. A few representatives also said that after production their company kept quality control records such as failure rates or the number of product returns. “Internally we use our DfR [Design for Reliability] methods to design and validate acceptable failure rates to support our warranty commitment to the customer. Over time we collect warranty return data and assess the actual warranty performance,” said one representative.

One representative explained how his company would use these data on failures and returns in conjunction with financial data. “Some financial metrics can go into that,” he said. “Say if we hit 90% reliability and 90% confidence, my insurance company can put so much reserve out there for this type of product. I’m going to make this many and I have this much money in case I need to warranty so much product.”

2.2 HVAC CONTRACTOR PERSPECTIVES ON COMMERCIAL GAS HEATING MEASURE LIVES

This section provides findings from in-depth interviews with 15 Massachusetts HVAC contractors who participated in the Massachusetts Upstream HVAC initiative.6 The majority of these interviews were completed in the fourth quarter of 2019.

2.2.1 Research Objectives

The primary objectives of these interviews were to:

- Collect information that can inform the estimation of the EULs of Massachusetts HVAC equipment besides those being generated by the EUL analysis discussed later in this report.

- Collect information needed to determine whether heating equipment such as furnaces/boilers are subject to early replacement (ER) frequently enough to change the current default replace-on-failure (ROF) assumptions of replace on-failure to new assumptions reflecting an ER/ROF blend.

- Explore the feasibility of developing a “nameplate bounty” system which would compensate the installation contractors for sending in photos of manufacturer nameplates for the equipment they remove. In subsequent discussions with the PAs, it was determined that they were most interested in HVAC contractor perspectives on the measure lives of commercial natural gas boilers and furnaces and so the interview guide focused on these technologies.

2.2.2 Methodology

The sample frame for these HVAC contractor interviews was a list of 487 Massachusetts HVAC contractors who participated in the C&I Upstream HVAC Initiative in 2018. The evaluation team attempted to complete interviewers in 2 different phases. The first phase was in March 2019 when it was thought that some of the ER/ROF results could be used in the PA’s 2019 planning assumptions. When further discussion among the PA

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6 These were contractors who installed equipment which had received midstream price discounts from the C&I Upstream HVAC. Since these midstream discounts were targeted at distributors, the contractors likely were not as invested in the program as might be the case for a downstream program.
and EEAC representatives concluded that any such ER/ROF assumptions must include both HVAC contractor and end user perspectives, the HVAC contractor interviews were postponed until a second phase of interviews in the fourth quarter of 2019. The evaluation team faced significant challenges in completing these interviews which included:

- Because many of the interview questions focused on the age of commercial boilers and furnaces which contractors had recently encountered or removed, the interviewers had to restrict their interviews to contractors with current or recent field experience. These contractors were inherently difficult to reach because they spent most of their time out in the field and would only return to the office occasionally.

- Many HVAC contractors in the sample frame did not sell commercial gas boilers or furnaces.

- The Massachusetts C&I Upstream HVAC Initiative focused its price discounts and its program outreach efforts primarily on HVAC distributors. This likely had two negative impacts on contractor response rates. First since the prices discounts directly benefited distributors rather than contractors, the contractors were likely less invested in this Initiative than they would have been for a program with a downstream design. Second since the third-party implementation contractor for the Initiative was focused on the HVAC distributors rather than the contractors, the contractor list they provided to the evaluation team had very limited contact information. For example, only 24% of the contractors in the sample frame had email addresses and only 2% had contact names. Therefore, when the evaluation team sent out an email notification to the contractors in Q4 2019 seeking their cooperation on the upcoming phone interviews, it mostly had to rely on emails obtained from contractor websites. These emails were for generic company inboxes rather than emails that would go to a specific contact at the company.

- Smaller HVAC companies often used third-party answering services to field calls rather than having their own administrative staff. These third-party answering services were less likely to pass on an interview request from an evaluator than traditional administrative staff.

Due to these challenges, as well as the normal difficulties of reaching HVAC contractors during the heating season, the evaluation team was only able to complete 15 of its target 30 interviews. However, the consistency of the responses for many of the key measure life questions indicated that a larger sample may not have changed the overall findings in any significant direction.

### 2.2.3 Defining the End-of-Measure Life for Commercial Gas Heating Equipment

The interviewers asked the HVAC contractors whether they have a concept of equipment being at the end of its useful life that does not simply mean the equipment is broken and cannot be fixed, but instead means the equipment is too old or unreliable to extend its life much further. All the contractors said that they do think of equipment in these terms.

The interviewers then asked the contractors what criteria they use to determine the equipment is at the end of its useful life. As Figure 2-2 shows, two thirds of the respondents cited equipment age as a criterion. When asked what that age was, the mean estimate was 19 years (using the midpoint for estimates given in ranges) and the median was 18 years. These estimates are very close to the current EUL in the
Massachusetts TRM of 18 years for commercial furnaces but are lower than the current EUL in the TRM of 25 years for commercial boilers.

**Figure 2-2. How HVAC Contractors Define End-of-Useful Life for Commercial Gas Heating**

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of equipment</td>
<td>67%</td>
</tr>
<tr>
<td>Repair costs</td>
<td>53%</td>
</tr>
<tr>
<td>Safety concerns due to structural damage</td>
<td>27%</td>
</tr>
<tr>
<td>Reduced performance</td>
<td>13%</td>
</tr>
</tbody>
</table>

Note: The sum of the percentages exceeds 100% because multiple responses were allowed.

The contractors cited some exceptions to these “rules of thumbs” for the age of equipment they deem to be at the end of its useful life. Two of them said that their recommendations for replacing older equipment might vary depending on the maintenance record of the equipment, with more frequently maintained equipment likely to last longer. Two of the contractors said that older style boilers such as cast-iron boilers, can last 30 years with proper maintenance.

A couple of contractors claimed that newer equipment is not lasting as long as older equipment. One gave an end of useful life age range of 10-20 years for newer equipment and 20-30 years for older equipment. Two of the contractors theorized that the shorter lives of newer equipment might be due to its greater complexity with more possible things that could break down. One contractor noted that with older boilers there was not much to repair beyond the motor. One contractor claimed that the higher the energy efficiency of the equipment, the shorter its lifetime.
A little more than half of the contractors also cited significant repair costs as a criterion for deeming equipment to be at the end of its useful life. However, they varied in how they defined these costs to be significant. For example, one contractor defined significant repair costs as 20% of the cost of a new unit while another said he only replaced commercial gas equipment when the repair costs exceeded the cost of a new unit. Others referred vaguely to the critical stage as being when repairs were “uneconomical.”

The contractors also cited other factors that were related to both equipment age and repair costs. Two mentioned that replacement parts for older equipment were more difficult to find and more expensive. One contractor said that many of the technicians who know how to repair the older equipment are retiring.

Four contractors mentioned safety concerns as other criteria for deeming a gas boiler or furnace at the end of its useful life. These included signs of deterioration on the units such as cracks, leaks, bad seals or gaskets, and rust problems. Two contractors also mentioned reduced equipment performance as another criterion.

2.2.4 HVAC Contractor Knowledge of Equipment Age

The interviewers asked the HVAC contractors how often they had “a good idea” of the age of the commercial gas boilers or furnaces they were removing. The average contractor estimate was 85% of the time.

The interviewers asked the contractors how they get a good idea of the age of the equipment they remove. Figure 2-3 shows that all mentioned using manufacturer nameplates to identify the age. Some mentioned that with older models the manufacture date is usually on the nameplate but sometimes it is just a serial number which they must look up online or call the manufacturer about. More than one-fourth of the contractors said they recognize older equipment models based on their many year of experience in the field. One-fifth reported using historical installation/maintenance records to date the equipment.
2.2.5 Frequency and Causes of Early Replacement

The interviewers asked the HVAC contractors: “In the past year, about what percentage of the time were you replacing a boiler in a commercial, institutional, or industrial building which had some useful life remaining?” They asked the same questions about commercial furnaces. The average estimate of the contractors for early replacement of commercial boilers was 21% and their average estimate for the early replacement of commercial furnaces was 20%.

The interviewers then asked the contractors whether these rates of early replacement would have been different in cases where the customer was receiving an energy efficiency rebate for the new equipment. Over half (55%) of the contractors said the early replacement rates would have been higher with the rebate. One contractor specifically mentioned Massachusetts having a rebate program that encourages early replacement of equipment.
The interviewers asked the contractors for common reasons why people in commercial, institutional, or industrial buildings have their boilers or furnaces replaced with useful life remaining. Figure 2-4 shows they mentioned a variety of reasons with the most common being the desire to get a more energy efficient boiler or furnace and the fear that equipment would fail. One contractor said that customers who have boilers that provide both heat and hot water are more likely to replace them earlier because the consequences of failure are greater.

**Figure 2-4. Reasons Why Commercial Customers Do Early Replacement**

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desire to get more efficient unit</td>
<td>36%</td>
</tr>
<tr>
<td>Fear equipment will fail</td>
<td>36%</td>
</tr>
<tr>
<td>High repair costs</td>
<td>29%</td>
</tr>
<tr>
<td>Building retrofit/expansion</td>
<td>29%</td>
</tr>
<tr>
<td>Reduced performance of unit</td>
<td>14%</td>
</tr>
<tr>
<td>Other reasons*</td>
<td>29%</td>
</tr>
</tbody>
</table>

Note: The sum of the percentages exceeds 100% because multiple responses were allowed. *Other reasons included contractor recommendation, switching from oil to natural gas, companies which have policies to replace HVAC equipment every 10-15 years, and receiving rebates for energy efficient replacements.

The contractors were asked whether there were any customer types who are more likely to have their commercial boilers or furnaces replaced with some useful life remaining. Ten of the 15 contractors did identify certain customer types who were more likely to do early replacement.

Figure 2-5 shows they identified a wide range of customers likely to do this, with the most cited being customers who face greater consequences from equipment failure and managers of office buildings. The contractor examples of customers who face greater consequences from equipment failure included colleges,
medical facilities, or drug companies with sensitive laboratory facilities for whom a loss of heat could be catastrophic. The contractors mentioned office buildings because these are often managed remotely by large companies who have policies for regular equipment replacement and because the large number of tenants in a commercial office building increases the likelihood of complaints when a loss of heat occurs.

**Figure 2-5. Customer Types Who Are More Likely to Do Early Replacement**

<table>
<thead>
<tr>
<th>Customer Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers with greater risk from equip. failure</td>
<td>50%</td>
</tr>
<tr>
<td>Office building property managers</td>
<td>40%</td>
</tr>
<tr>
<td>Customers with more financial resources</td>
<td>30%</td>
</tr>
<tr>
<td>Customers replacing equip. on regular schedule</td>
<td>30%</td>
</tr>
<tr>
<td>Healthcare facilities</td>
<td>20%</td>
</tr>
<tr>
<td>Institutional customers</td>
<td>20%</td>
</tr>
<tr>
<td>Other customer types*</td>
<td>20%</td>
</tr>
</tbody>
</table>

Note: The sum of the percentages exceeds 100% because multiple responses were allowed. *Other customer types included industrial customers and large chain retailers.

The interviewers also asked the HVAC contractors whether there were any customer types who are less likely to have their commercial boilers or furnaces replaced with some useful life remaining. Almost two-thirds (62%) of the contractors said that there were. The customers they mentioned included smaller independent businesses like restaurants or hotels who pay for the HVAC replacements out of their own budgets (versus larger companies where equipment replacement decisions and payments are made at a corporate level), lower quality office buildings (Class B and C) that do not bring in the higher lease payments that can pay for early replacement, governments and school systems which often have tight budgets, and strip malls that often defer maintenance because it increases their overhead costs and makes them less competitive.
2.2.6 The Age of Removed Equipment

The interviewers asked the HVAC contractors about the average age of the commercial gas heating equipment they had removed in the past year that: 1) had totally failed or were nearly failure; or 2) had some useful life remaining. Table 2-4 shows that the contractors estimated that the equipment they estimated to have useful life remaining was only 2-3 years younger than the equipment that was deemed at or near failure. These estimates are also close to the 18-year EUL for commercial gas furnaces and the 25-year EUL for commercial gas boilers.

Table 2-4. Average Age of Removed Equipment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Commercial Gas Boilers (Average Age in Years)</th>
<th>Commercial Gas Furnaces (Average Age in Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removed equipment had totally failed or was near failure</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>Removed equipment had some useful life remaining</td>
<td>19</td>
<td>17</td>
</tr>
</tbody>
</table>

2.2.7 What Happens to Commercial Gas Equipment After Removal

The evaluation team was interested in knowing what happens to commercial gas heating equipment after it is removed and whether any of this equipment resurfaces in the secondary market, as is the case with many refrigerators. Nearly all (14 of the 15 respondents) said that all the removed equipment gets scrapped with occasional salvaging of motors, if they are in good condition, and copper. One contractor said that 90% of the commercial heating equipment gets scrapped, but some big boilers are reused.

2.2.8 Whether New Equipment Costs are Rising

One PA representative was interested in knowing whether recent increases in U.S. tariffs might have increased the cost of new HVAC equipment, which might influence decision-making on equipment replacement. The interviewers asked the HVAC contractors whether they had noticed significant increases in the cost of new commercial boilers or furnaces in the past year. Slightly over half (53%) said that equipment costs had increased in the past year with an average estimated increase of 8%. When asked to explain the causes of these recent price increases, most of the contractors mentioned the trade wars increasing metal prices and increases in labor costs.
2.2.9 Program for Sending in Photos of Nameplates from Removed Equipment

The interviewers told the HVAC contractors that the Massachusetts PAs were considering a program that would pay HVAC contractors to email pictures of the manufacturer nameplates of the commercial HVAC equipment they removed, along with brief descriptions of the equipment’s condition. They then asked the contractors if they would be interested in participating in such a program.

Figure 2-6 shows that two-thirds of the contractors said they would participate in such a program with another 20% saying that their participation would depend on program requirements or they were just not sure.

The interviewers also asked the contractors about the minimum amount the program could pay them per emailed nameplate photo to get them to participate. The average incentive estimate was $36 with some contractors willing to do it for free and with one contractor asking for $100 per submission. Several contractors said that the right incentive amount would vary depending on how much paperwork was required.

One contractor said he would be willing to participate if the program created an easy-to-use app that would allow him to submit the information on his smart phone without having to create a separate email. Another contractor was wondering how the program would define a commercial installation. Could it be any boiler or furnace installed in a commercial application? Or would there be a minimum BTU threshold?

**Figure 2-6. Contractor Interest in Program for Sending in Photos of Nameplates from Removed Equipment**

![Pie chart showing contractor interest](chart.png)
2.3 THE TREATMENT OF MEASURE LIVES IN CUSTOM PROJECTS

This section describes the findings from research conducted on how the Massachusetts PAs are using measure life assumptions in their screening tools for customer projects. These findings were originally issued in a November 27, 2019 memorandum.

2.3.1 Research objectives

The purpose of this research was to identify inconsistencies and areas of improvement in the application of measure life assumptions for custom energy efficiency projects in this first year of the dual baseline roll-out. PAs also asked that the following 5 researchable questions be addressed:

- Are the PAs using the appropriate method for accounting for dual baseline in custom project categories?
- What types of equipment should differ from their prescriptive counterparts (e.g., custom process chillers vs. prescriptive space cooling chillers)?
- Does an “add on” measure get the full new construction measure life, (e.g., does a variable frequency drive or VFD get the 15-year new construction measure life or the 13-year retrofit measure life?)?
- What method should be used to weight the lives of multiple measures for comprehensive design/whole building projects?
- If a project has multiple measures with different measure lives, is there a tipping point where they should split out the measures or adjust the measure life?

2.3.2 Background

The Baseline Framework inaugurated a more rigorous practice for evaluating retrofit (early replacement (ER) measures) using dual baseline calculations for estimating lifetime savings. Dual baseline calculations accounts for market changes between the year the measure was installed and a future market when the original equipment would have been replaced. Lost Opportunity (LO) measures, including new construction and replace on failure (ROF), use a single baseline.

Correct calculation of gross lifetime savings requires determining four steps:

1. Determine if the measure is a single or dual baseline measure.
2. Select the correct effective useful life (EUL) for the measure.
3. Select the correct outyear factor (OYF) for a dual baseline measure.
4. Use the correct calculations.

Starting in 2019, PAs are required to use dual baseline calculations to determine lifetime gross savings for retrofit projects, unless it can be established that the baseline would not have changed over time due to evolving codes or standard practice. Prior to 2019, dual baseline effects were factored into the measure life for a few measures as an adjusted measure life (AML). For example, in the 2016-2018 Massachusetts TRM, a linear lighting measure has two possible lives of 13 years and 15 years for the ER and lost opportunity measure event type, respectively.

The goal of evaluating the lifetime savings is to improve estimates of program lifetime savings over time, not to determine a lifetime savings realization rate. This process evaluation is one component of providing improved lifetime savings estimates.

2.3.3 Methodology

This assessment included these data collection activities:

- **Interview knowledgeable parties**: The evaluation team interviewed knowledgeable PA staff to better understand procedures and processes related to custom lifetime savings calculations. The team also interviewed the project leads for the custom natural gas and electric gross impact evaluation teams and the CI Impact Area Lead to determine the procedures and processes used by the evaluation teams to calculate lifetime savings. Additional information was obtained through email communications.

- **Custom screening tool review**: The evaluation team examined the calculations in the custom screening tool (CST) Version 1.0 since this is the source of dual baseline lifetime savings estimates used in tracking savings beginning in 2019. Program implementers are required to screen every custom project using this tool to ensure it is cost-effective. The CST output is used by PAs to support tracking lifetime savings.

- **Cross-checked assumptions**: The evaluation team collected EUL, OYF, and adjusted measure life (AML) assumptions in the MA TRM and those used by the PAs and the DNV GL custom impact evaluation team in estimating lifetime savings. Where an AML was not directly available, the evaluation team calculated the AML as a function of the EUL and OYF. The evaluation team matched individual measures by measure names manually, since there is not a uniform measure identification method used by all parties. Values were compared across the datasets to check for consistency between them.

The data sources included:

- **Baseline Framework**. The Baseline Framework is the authoritative source of methods for treating dual baseline measures for Massachusetts. It was issued in 2017.

- **2019_Statewide_Custom_Screening_Tool_v1.00 (CST)**. Each custom project undergoes cost-benefit screening using a state-wide screening tool. The measure by measure EUL and OYF assumptions in the tool were extracted for the comparison.


- **2019-2021 MA electronic Technical Reference Manual (eTRM)**. The eTRM is an electronic database that provide methods, formulas, and default assumptions for estimating energy, peak demand, and other resource impacts from energy efficiency measures.

- **PY2016 Custom electric and impact evaluations**. The evaluation team reviewed the EUL assumptions used in PY2016 for sites selected for impact evaluations (P79 and P89). Although, dual baseline methods were not implemented in 2016, the PAs were reporting EULs which could be compared.

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8 [https://etrm.anbetrack.com/#/workarea/home?token=6d6c45766e692f527044](https://etrm.anbetrack.com/#/workarea/home?token=6d6c45766e692f527044)
2.3.4 Comparison of Methods

The following section compares measure life methods.

2.3.4.1 Baseline Framework

The Baseline Framework is referenced in this study as the authoritative resource for dual baseline methods and procedures for Massachusetts evaluators. It is worth noting that although projects will be evaluated using the guidelines, PA C&I implementation staff and contractors are not compelled to follow them and may have a variety of legitimate reasons for not doing so, such as simplifying methods to make applications less complicated.

The Framework addresses the 4 components of dual baseline lifetime savings calculations that are summarized at a high level below (although the Baseline Framework should be referenced for a complete definition of terms and methods):

- A measure is treated as a dual baseline measure when the baseline is expected to evolve after the remaining useful life of the replaced equipment has passed. The Framework provides specific rules and flowcharts to aid in determining dual versus single baselines. Relevant to one of the research questions, an add-on measure uses a single baseline measure as long as the life of the add-on equipment is less than two-thirds the EUL of the host equipment.

- The EUL (and the remaining useful life, or RUL) is the average measure life of a population, not a site-specific value, unless the measure is unique. The default RUL is one-third of the EUL.

- The second period baseline is determined by expected changes in future codes or standards or in Industry Standard Practice (ISP). Measures which are unique or for which documentation supports a very long life are treated as single baseline. By default, the second period savings is 90% of first year savings and therefore the default OYF is 90%.

- The Framework specifies lifetime savings calculations.

2.3.4.2 eTRM and TRM Measure Life References

The technical resources referenced in this study are the authoritative Massachusetts resource for measure lives. Concerns have been raised about the quality and sources of the technical resource measure life estimates. The MA19C02-B-EUL C&I Measure Life Study team is currently developing alternative methods to estimate measure lives using information such as the age distribution of installed stock. However, until these new methods can be refined and used to produce updated values, the best available measure life estimates exist in the eTRM and TRM. Both the eTRM and TRM note that measure lives for custom measures can or should be determined on a case by case basis, however, this is not consistent with the Baseline Framework’s direction to use population averages unless a measure is unique.

The TRM version for Program Years (PY) 2016-2018 did not explicitly identify measures as single or dual baseline measures, however, it did distinguish differences in measure lives for some measures, reflecting dual baseline effects. The newest eTRM for PY 2019-2021 does explicitly incorporate Framework dual baseline elements. Most, but not all eTRM measures include an EUL, OYF, and AML. The evaluation team did observe irregularities in some of these values which are discussed later in this section.
2.3.4.3 Custom Screening Tool Methods

The PAs use a common statewide custom screening tool (CST) spreadsheet to screen custom measures for cost-effectiveness. The screening tool is a Microsoft Excel™ workbook field tool used by program implementation staff to qualify every custom project. The measure workbook inputs include project identification descriptors, first year energy and demand savings, project incremental and full installed costs, and the selection of the measure type (e.g., HVAC, compressed air) and the program type (e.g., retrofit or lost opportunity).

The CST allows the user to specify up to 10 unique measures as part of a single project submission. Each measure has unique measure inputs with a unique cost-effectiveness and lifetime savings calculations. There are also project level results calculated using the combined savings, costs, and measure lives. The key outputs of interest of the CST on a measure basis include the lifetime gross savings, the EUL for single baseline measures, the AML for dual baseline measures, an adjusted measure cost, and the measure benefit cost ratio (BCR).

The CST guides the users to the correct measure event type (ER, ROF, or add-on) and dual or single baseline through the combined selection of program type and measure type. Most of the program and measure type combinations allow the user to select from two or more possible EUL values. For example, the Building Shell measures in the Existing Building Retrofit program offer the user a selection of five EULs (5, 10, 15, 20, 25). There is also a field where the user can override the selection and enter in an alternate life.

On a project basis, which is the sum of all the individual measures (up to ten) entered for that project, the key output is the project lifetime gross savings and the project BCR. Measure output does not include a project AML, although that could easily be calculated with the outputs provided (as the ratio of lifetime savings to first year savings).

For dual base line measures, the SCT calculates an “Adjusted Measure Cost” which is equal to the full installed cost of the measure minus the “Deferment Credit”. In principle, the approach is correct, although the details of the calculation were locked and not reviewed.

Conclusions:

The CST lifetime savings calculations correctly follow the Framework guidance for dual baseline lifetime savings at the measure and project (all measure) level. The combination of program and measure type leads to the correct measure event type. The evaluation team did observe, however, that add-on measures are classified as a single baseline only, while the Baseline Framework requires dual baseline treatment for add-on measures with an EUL that exceed two-thirds the RUL of the host equipment.

Users of the CST are typically offered a choice of two or more measure lives. This is a necessity given the range of actual measures that could be included within a measure category in the CST. For example, building envelope measures could include a short-lived garage bay door seal and a long-lived roof insulation measure which would each have a different EUL. Users will have to refer to other resources, like the eTRM, for guidance in selecting the best EUL for these measures. While the range of EULs accommodates a range of measures it does not prevent a user from selecting an inappropriate EUL.

2.3.4.4 PA Lifetime Savings Estimating Methods

All PAs use the CST to screen customer projects for cost-effectiveness. It is also PA practice to disaggregate a single project into its constituent measures as much as possible and to enter them individually into the CST. PAs noted that for complex projects consisting of multiple measures, the technical assistance studies
and vendors do not always show a breakdown of energy savings by measure. At times, small measures are summed together and entered as a single number. In both cases, the PA engineers will select a measure life based on their judgment.

Once a project is screened and approved, the project information is entered into the PAs’ tracking systems. It is PA practice to enter each of the individual measures of a project into tracking rather than at a combined project level. The PAs enter measure impact savings as a first-year savings and the measure AML. PA tracking systems compute the lifetime savings of the measure as the product of the first-year savings and the AML. Most PAs enter the AML calculated by the CST although one PA’s procedure is to use the eTRM AML value rather than the CST calculated value, which may create inconsistencies noted later.

**Conclusions:**

It has been a long-standing practice for PAs to use custom screening tools to qualify projects. Embedding the dual baseline factors and calculations into the CST ensures dual baseline principles are now a standard part of custom measure qualification. CST mechanisms guide users to the correct measure event type and single or dual baseline, and it narrows the possible EULs for the measure. The tracking final lifetime savings does depend on the judgment of the user in selecting the most appropriate EUL and transcribing the AML (not the EUL) to tracking systems.

**2.3.4.5 Impact Evaluation Methods**

The PAs are required to implement more explicit and rigorous dual baseline practices in the 2019 program. Prior to 2019, the PAs applied a more limited form of dual baseline lifetime savings estimates using an AML. For example, the TRM specified a 15- and 13-year measure life for new construction and retrofit lighting fixtures, respectively. Both the PAs and the evaluators have been conducting activities to implement dual baseline principle. Table 2-5 summarizes implementation and evaluation activities related to dual baseline lifetime savings estimates by year.
### Table 2-5. Implementation and Evaluation Dual Baseline Calculation Activities

<table>
<thead>
<tr>
<th>YEAR</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Implementation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation year</td>
<td>PY17</td>
<td>PY18</td>
<td>PY19</td>
<td>PY20</td>
<td>PY21</td>
</tr>
<tr>
<td>Custom tool screening tool (CST)</td>
<td>Limited dual</td>
<td>Limited dual</td>
<td>New tool with explicit dual baseline calculations</td>
<td>New tool</td>
<td>New tool</td>
</tr>
<tr>
<td>Tracking</td>
<td>Limited</td>
<td>Limited</td>
<td>Dual</td>
<td>Dual</td>
<td>Dual</td>
</tr>
<tr>
<td>Technical resource</td>
<td>TRM</td>
<td>TRM</td>
<td>eTRM</td>
<td>eTRM</td>
<td>eTRM</td>
</tr>
<tr>
<td><strong>Evaluation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Custom PY evaluated</td>
<td>PY15</td>
<td>PY16</td>
<td>PY17</td>
<td>PY18</td>
<td>PY19</td>
</tr>
<tr>
<td>Dual baseline evaluation activities</td>
<td>Baseline Framework published</td>
<td>Revised site reports to include lifetime savings</td>
<td>Process review of PY19 dual baseline roll-out (this report)</td>
<td>Evaluators will estimate dual baseline lifetime gross savings and compile tables of EUL/RULs for PY17</td>
<td>Evaluators will compare PA estimated lifetime gross savings with evaluated lifetime savings and compile tables of EUL/RULs for PY19</td>
</tr>
<tr>
<td>Estimated dual baseline lifetime gross savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The PA estimates of dual baseline savings cannot be fully assessed until the PY2019 program is evaluated in 2020 or 2021 since the calculations were not implemented in tracking until 2019. However, the evaluators have been implementing Framework guidance since the PY2016 evaluation and providing feedback on how dual baseline impacts could impact lifetime savings in PY2016 and PY2017 impact evaluations. While lifetime savings will be evaluated in the current and future evaluations, there is no intention to apply a lifetime savings realization rate. The current assessment activities follow:

**PY2016 Impact Evaluation.** PY2016 was the first custom program year evaluated under the Framework guidance. The evaluation teams focused on developing protocols and training to consistently apply the
Framework in the selection of measure event type (ER, ROF, or add-on) and in defining ROF and new construction industry standard practice (ISP) baselines. The M&V site reports were revised to systematically communicate baseline assessments and lifetime savings. Custom impact evaluations led to the creation of the Baseline Advisory Group (BAG), which is composed of senior evaluators that review ambiguous baseline conditions and, working with stakeholders, refined protocols to reduce ambiguity. The program-level final custom reports included advisory gross program lifetime savings using dual baseline methods. The electric savings generally defaulted to tracking EULs, while the natural gas lifetime savings were computed using TRM EULs.

**PY2017 Impact Evaluation.** The custom evaluation teams are turning their attention to systematically comparing project EUL implementer assumptions with Framework practices and the 2016-2018 TRM EUL assumptions and to discuss ambiguous or unreferenced EULs with the BAG. The PY2017 evaluation found a 4% reduction in net lifetime savings due to inconsistent use of TRM-specified EULs.

The custom impact teams do not intend to research EULs or OYF values in the current PY2017 evaluation. The PY2017 did not require dual baseline calculations, so a comparison with tracking estimates are not meaningful. The impact teams will compare tracking EULs with the previous technical resource since that was the TRM at the time of program implementation.

**Conclusions.**

The impact evaluation teams prioritized implementing robust protocols for establishing evaluated measure event type and ISP baselines in the first year of the Baseline Framework and focused less on individual measure assumptions. This was appropriate, since the event type and ISP baselines were the most consequential element of the Framework. It appears the evaluation teams are now prepared to take a closer look at individual implementer measure life assumptions and how they align with TRM and eTRM sources.

The evaluation team does note, however, that an evaluation gap exists in the evaluation of the second period baseline since the current impact evaluation does not include that task in its scope. Since the determination of the second period baseline is a derivative of baseline research, determining the second period baseline and the OYF could logically fall under the scope of future measure baseline research and maintained in the Baseline Repository.

### 2.3.5 Comparison of Assumptions

After receiving the datasets (or via manual extraction from the TRM and eTRM), the evaluation team manually matched measures by name and compared the EUL, OYF, and AML for select measures. As can be seen in Figure 2-7, the number of measures in each resource is not the same. The three sources in Figure 2-7 do not include all the same measures nor do they identify them the same way. For example, the eTRM lists eight measures for food services, while the CST lists one measure.
2.3.5.1 Comparison of OYF

The OYF is used to calculate the second period saving and is intended to capture the baseline of a measure that would be installed in the future. The Framework specifies methods for establishing the second period baseline for non-unique measures using ISP research or by accounting for code or standards updates. The Framework does not specify measure specific OYFs, only the default OYF value of 90%.

The CST currently uses the default OYF value of 90% for all measures except for efficient lighting systems (OYF of 60%) and lighting controls (OYF of 85%). The value 60% for lighting is consistent with the results of a lighting market analysis published in August 2018. However, lighting market research updated the efficient lighting OYF to 85% in June 2019 and new draft OYF values (as of March 9, 2020) have been circulated based on the final market model which can be used to update the CST when blended with the replace on failure rates to calculate correct lifetime savings.

2.3.5.2 Comparison of EULs

Gross lifetime measure savings is a function of the EUL and the correct selection of the EUL is the primary source of uncertainty in the lifetime savings calculations (assuming first year savings has already been evaluated). Table 2-6 compares the EUL listed in the eTRM (which is the technical resource of record for PY2019) and the EUL in the CST for a selection of measures. We also included the MA TRM EUL value for comparison purposes.
Table 2-6. Comparison of EULs – Selected Measures

<table>
<thead>
<tr>
<th>Measure Name</th>
<th>CST EUL</th>
<th>Measure Name</th>
<th>2019 eTRM EUL</th>
<th>TRM EUL Values (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting – Interior</td>
<td>15</td>
<td>Lighting Systems Interior, Lost Opportunity (LO), &amp; Retrofit</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Lighting – (Small Business, Not applying dual baseline)</td>
<td>13</td>
<td>No Data (ND)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Lighting – Interior Controls</td>
<td>9</td>
<td>Lighting Controls, LO &amp; retrofit</td>
<td>10 &amp; 9</td>
<td>10</td>
</tr>
<tr>
<td>HVAC Equipment and Systems</td>
<td>15</td>
<td>Unitary AC, HVAC, LO</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>EMS/Controls, HVAC</td>
<td>5/10/15</td>
<td>Energy Management System, HVAC, retrofit</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Chillers</td>
<td>20</td>
<td>HE Chiller, HVAC, LO</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Compressed Air Equipment</td>
<td>15</td>
<td>HE Air Compressor, LO</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>VFD on HVAC Equipment</td>
<td>15</td>
<td>VFD, Motors/Drives, retrofit</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Boiler, HVAC</td>
<td>5/10/15 /20/25</td>
<td>Condensing Boiler</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Furnaces, HVAC</td>
<td>15/20</td>
<td>Furnace, Gas, HVAC, LO</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Equipment Insulation, HVAC</td>
<td>10/15/20</td>
<td>Pipe Wrap (Heating), HVAC retrofit</td>
<td>15</td>
<td>ND</td>
</tr>
<tr>
<td>Steam Trap, HVAC</td>
<td>6</td>
<td>Steam Trap, Water Heating Retrofit</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>O&amp;M/RCx, HVAC</td>
<td>1-5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Other</td>
<td>5 – 25</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

**Conclusions.**

It is apparent from Table 2-6 that there is no one-to-one correspondence between CST and eTRM measures. The CST typically uses broader measure categories than the eTRM (like "HVAC equipment" rather than "Unitary AC") which makes comparing EULs more challenging. The CST tool requires a knowledgeable user to select the correct EUL when two or more choices for a measure are offered, like for “EMS / Controls,

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9 O&M includes measures such as calibrating/reprogramming HVAC controls and boiler tune-ups.
HVAC”. While not all measure EULs can be compared, where they do, they do not necessarily match. For example, the CST EUL is less than the eTRM for the chiller, while greater for furnaces.

As noted, the PAs have rolled out a new technical resource using a new online database format called the eTRM. Like the previous TRM, the eTRM the compiles many parameters for about 200 measures. The eTRM works well as a resource, however, the evaluation team did find some irregularities. The eTRM seems to conflate measure life related terms using “Measure life”, “EUL” and “AML” somewhat interchangeably. Some values are clearly mislabeled. For example, in the eTRM, the Indoor Common Area Linear notes an 8-year EUL, which is reasonable for an AML but not an EUL.

The evaluation team believes there is a transcription error in the Lighting Control measure which cites a 10 year EUL and AML for a new construction measure and a 9 year EUL and AML for a retrofit measure; the correct value should be a 10 year EUL for both and 9 year AML for the retrofit measure. More details are provided in section 4.1.7 and 4.1.8.

**2.3.5.3 Comparison of AMLs**

The AML factors both the EUL and the OYF into a single factor. Table 2-7 compares the AMLs for the same measures presented in Table 2-6.

**Table 2-7. Comparison of AMLs – Selected Measures**

<table>
<thead>
<tr>
<th>Measure Name</th>
<th>CST AML</th>
<th>Measure Name</th>
<th>2019 eTRM AML</th>
<th>2016-2018 MA TRM AML</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting – Interior</td>
<td>11</td>
<td>Lighting Systems Interior, Lost Opportunity (LO), &amp; retrofit</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Lighting – (Small Business, Single)</td>
<td>13</td>
<td>No Data (ND)</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Lighting – Interior Controls</td>
<td>8.1</td>
<td>Lighting Controls, LO &amp; retrofit</td>
<td>10 &amp; 9</td>
<td>9</td>
</tr>
<tr>
<td>HVAC Equipment and Systems</td>
<td>14</td>
<td>Unitary AC, HVAC, LO</td>
<td>12</td>
<td>ND</td>
</tr>
<tr>
<td>EMS / controls, HVAC, Single</td>
<td>5/10/15</td>
<td>Energy Management System, HVAC, retrofit</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Chillers</td>
<td>18.7</td>
<td>HE Chiller, HVAC, LO</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Compressed Air Equipment</td>
<td>14</td>
<td>HE Air Compressor, LO</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>VFD on HVAC Equipment, Single</td>
<td>15</td>
<td>VFD, Motors/Drives, retrofit</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Boiler, HVAC</td>
<td>At EUL of 25: 23.3</td>
<td>Condensing Boiler, LO</td>
<td>25</td>
<td>ND</td>
</tr>
<tr>
<td>Furnaces, HVAC</td>
<td>14/18.7</td>
<td>Furnace, Gas, HVAC, LO</td>
<td>18</td>
<td>ND</td>
</tr>
<tr>
<td>Equipment Insulation, HVAC – Single</td>
<td>5/10/15</td>
<td>Pipe Wrap (Heating), HVAC retrofit</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Steam Trap, HVAC, Single</td>
<td>6</td>
<td>Steam Trap, water heating retrofit</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
Conclusions.

Like Table 2-6, AML values in Table 2-7 do not match for a variety of reasons, including those mentioned in the previous subsection. Additional reasons include:

- The eTRM does not always include a retrofit option (like the air-compressor measure) the CST does with dual baseline treatment. The eTRM reports 15 years for both the EUL and AML, while CST reports 15 and 14 for those values.

- The MA TRM provided dual baseline treatment for VFDs (reporting a 13-year life for retrofit measures), while the CST and the eTRM both treat VFDs as single baseline.

### 2.3.5.4 Past Compliance with TRM EULs

As part of PY2016 Custom Gas and Custom Electric Evaluation studies, the Ex Post team reviewed the measure life savings of the evaluated projects. The PY2016 estimates were not required to use dual baseline methods, but EULs were used to calculate single baseline lifetime savings. The evaluation team did find some discrepancies between EULs reported in the project’s files and the technical resource valid at the time of implementation, the 2016-2018 TRM.

For P79 the PY2016 Custom Gas Evaluation, the evaluation team found these discrepancies in EULs:

- National Grid used 18 years and 15 years for pipe and fittings insulation measures’ life. The evaluators used 15 years (the value provided in the 2016-2018 Massachusetts Technical Reference Manual (MA TRM)).
- Columbia Gas used 6 years for pipe and fittings insulation measures’ life. The evaluators used 15 years (the value provided in the MA TRM).
- Eversource used 3 years for steam trap repair measures life. The evaluators used 6 years (the value provided in the MA TRM). This was subsequently corrected.

As part of P80-PY2016 Custom Electric Evaluation study, the evaluators reviewed the measure life savings of the evaluated projects and determined discrepancies in EULs:

- Eversource used 5/9/13/17 years for lighting system measures’ life. The evaluators used 15 years for the EUL.
- National Grid used 13 years for lighting system measures’ life. The evaluators used 15 years.
- National Grid used 20 years for lighting system measures’ life. The evaluators used 15 years.
- For non-lighting measures, for 56% of the evaluated measures, there were no differences between the tracking and evaluated EUL values.

### 2.3.6 Discussion and Summary Conclusions

This section discusses each of the research questions and presents summary conclusions.

#### 2.3.6.1 PA Compliance with Baseline Framework

One purpose of this research is to identify inconsistencies and areas of improvement in this first year of the dual baseline roll-out. PA implementers have put into place dual baseline methods and assumptions via the CST which is a required step for every custom project. The CST tool correctly calculates lifetime savings and
the AML using the table driven EUL and OYFs. The PA practice of entering the CST AML into tracking for calculating dual baseline lifetime savings is appropriate. The evaluation team concludes that this is an efficient and effective mechanism for implementing dual baseline calculations.

However, the evaluation team also notes the following areas of concern where PAs could make improvements:

- The CST is currently configured to treat all add-on measures as single baseline, when relatively long-lived add-on measures will be evaluated using dual baseline calculations.

- It is possible that users might select an inappropriate EUL value when multiple choice EULs are offered since there is little guidance within the tool for further measure selection. The evaluation team did observe in the PY2016 impact evaluation that the PAs usually cited the correct EUL as defined in the TRM. The PY2017 findings should provide further insights into compliance.

- While not directly a subject of this study, the evaluation team found the eTRM’s treatment of measure lives confusing and in a few cases, inaccurate. The evaluation team suggests that the PAs consider revising how measure life data is presented in the eTRM. As one example, the EUL and AML for some measures are listed as equivalent for a retrofit measure. If a dual baseline treatment is required, parameters associated with a specific measure should always include an EUL, RUL, OYF and an AML.

- One PA references eTRM measure lives, which we believe could lead to errors since the eTRM is not always clear whether a reference AML is appropriate for a dual baseline measure or not. For example, a custom compressed air replacement measure should be treated as a dual baseline measure using a default OYF of 90%. The eTRM’s compressed air measures is a lost opportunity measure, not a retrofit, therefore the value listed as an AML in the measure life table should not be used for a retrofit measure.

2.3.7 Impact evaluation Framework implementation

The impact evaluation teams began implementing Framework principles in the PY2016 evaluation, which included defining team procedures and related training, modification to exiting reporting templates and the implementation of the BAG to ensure consistent approaches for defining the measure event type and baselines. The PY2017 found a 4% reduction in net lifetime savings due to inconsistent use of TRM specified EULs. The evaluation team observes that there is currently no evaluation activity related to developing non-default OYFs except for lighting. However, determining OYFs logically falls within the scope of baseline research.

2.3.8 Responding to Specific PA Questions Concerning the Treatment of Measure Lives for Custom Projects

As noted in the Background section, part of the scope for this custom measure life research was to answer some questions from the PAs about the treatment of measure lives for custom projects. The following subsections discuss these questions.

2.3.8.1 Prescriptive vs. Custom

PA researchable question: “What types of equipment should differ from their prescriptive counterparts (for example, custom process chillers vs. prescriptive space cooling chillers)?”

Evaluation team response: Without primary research to determine population averages, there is no basis for concluding a custom chiller has on average a longer (or shorter) life than a prescriptive chiller or that a process or HVAC cooling chiller should have different EULs.
However, since both the Framework (via a unique measure) and the eTRM allow for defining site specific measure lives, implementers can make a case for site specific EULs-RULs. The evaluation team recommends that the project files include documentation to support first, why the measure is unique and secondly, if it is unique, a rationale for a non-eTRM derived EUL.

The Framework and TRM and eTRM instructions for selecting a custom measure are not fully aligned. The Framework defines the EUL as a population average for custom measures, except for unique measures. The TRM and eTRM state that a custom measure EUL is established on a site-specific basis. While both the Baseline Framework and TRMs offer an avenue for site-specific EULs, the evaluation team has observed that custom project files rarely provide supporting data for either a TRM compliant or non-compliant EUL.

2.3.8.2 Add-On Measures

PA researchable question: "Does an "add on" measure get the full new construction measure life (e.g., does a VFD get the 15-year new construction measure life or the 13-year retrofit measure life?)?"

Evaluation team response: According to the Baseline Framework, an add-on measure with an EUL that is less than 2/3s of the EUL of the host equipment can be treated as a single baseline measure. Some examples are:

- A VFD has a 15-year EUL which is greater than two-thirds of an HVAC equipment host equipment EUL of 15 years. The VFD will be evaluated as dual baseline.
- A lighting control device has 10-year life which is equal to two-thirds of a lighting system EUL of 15 years. The lighting controls will be evaluated as a single baseline.

The CST, and in some cases the eTRM, treat all add-on measures (except lighting controls) as single baseline measures. For measures using the default OYF of 90%, the dual baseline impact on lifetime savings is small (about 7% less than the single baseline calculation). However, for lighting controls with an OYF of 60%, the dual baseline calculation impact is about a 23% reduction. We note though that the impact on lifetime savings between dual and single baseline treatment is likely to be small. The desk review results for the custom gas program showed a reduction of only 0.21% in lifetime program savings due to the application of dual baseline treatment to those add-on measures requiring that treatment.

2.3.8.3 Weighting Measures within a Project

PA researchable question: “What method should be used to weight the lives of multiple measures for comprehensive design/whole building projects?”

Evaluation team response: The project lifetime savings is equal to the sum of individual measure lifetime savings. The lifetime savings of a measure is the product of the first-year savings and the EUL (for lost opportunity) or AML (for retrofit) of the measure. Measures within a project should be weighted by the measure EUL or AML.

The current PA method of entering individual measures of a project into tracking ensures proper weighting of measures by measure life. For comprehensive projects, both the implementation and evaluation engineers must make a judgment about the contribution of individual measures to the total and weight those portions by the appropriate EUL or AML. The evaluation team suggests that the PAs include a document of the rationale for apportioning savings and assigning an EUL to the measures in the project file.
2.3.8.4 Tipping Point

PA researchable question: If a project has multiple measures with different measure lives, is there a tipping point where they should split out the measures or adjust the measure life?

Evaluation team response: There is not a hard and fast answer to this question. In the M&V of a site, the evaluation protocol will be to disaggregate the project into its constituent measures with similar measure lives. Implementation is not compelled by the Baseline Framework to follow this exact protocol. The evaluation team suggests that the PAs include a description of the rationale for apportioning savings and assigning an EUL to the measures in the project file.

2.4 REVISED AIR CONDITIONER EUL ANALYSIS IN MASSACHUSETTS

This section presents the findings from a revision of the EUL analysis for commercial unitary HVAC equipment that had been completed under Project 73 Track D. These findings originally appeared in a memorandum issued on November 7, 2019.

2.4.1 Introduction and Background

One research task for Project MA19C02-B-EUL (Project 91) C&I Measure Life Study was to produce EUL estimates by updating the prior (P73-D) analysis\(^\text{10}\) with revised inputs. The prior P73-D EUL analysis established a method for estimating EUL using the following inputs:

- The age distribution of equipment at a point in time: This is the proportion of observed equipment in each installation year category, based on Massachusetts site data collected in 2014 and 2015.
- The relative quantities of equipment installed each year: The number of units installed each year is the relative quantity times some constant factor. It is not necessary to know the constant factor.

The study methodology assumed the survival function for installed equipment followed a Weibull distribution. The method found the best-fitting Weibull curve that would produce the observed age distribution at the observation date, given the relative quantities installed each year.

The prior P73-D EUL analysis calculated the age distributions for various types of unitary HVAC equipment from manufacturer nameplate information collected from Project 41: The Massachusetts C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study (P41) and Project 55: Upstream HVAC Initiative Process Evaluation (P55). The P73-D evaluation team applied sampling weights to produce population age distribution estimates. The study also imputed missing age data.

The P73-D study attempted to adjust for the fact that equipment with missing age information might be older than equipment with known age. However, a potentially more realistic imputation approach was suggested as part of the study’s conclusions. This approach would consider the reason age is missing for a particular piece of equipment. A different imputation assumption applies if the age is missing for reasons likely to be related to age. In particular, nameplates that are illegible due to corrosion are likely to be older than legible nameplates with similar environmental exposure; serial numbers that don’t appear in our equipment data bases are likely to be for older units.

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\(^{10}\) Final Memorandum: Project 73 Track D: Expected Useful Life (EUL) Estimation for Air-Conditioning Equipment from Current Age Distribution, Results to Date; prepared for Massachusetts PAs and EEAC Consultants; prepared by Miriam Goldberg, Mike Witt, and Christopher Dyson, DNV GL; July 17, 2018.
The prior P73-D EUL analysis estimated the quantity of Massachusetts unitary HVAC equipment installed based on national data from AHRI and DOE sources. However, some reviewers of the analysis said that this presumed equivalency between national installation rates and Massachusetts installation rates was unrealistic since construction rates have been different in Massachusetts than in other parts of the country.

Accordingly, the present study updates the P73-D analysis in 2 ways:

- As the proxy for annual AC installation rates, this study uses the estimated commercial floorspace with new cooling installed each year. This includes both the cooled floorspace of new construction and floorspace for which cooling equipment is replaced.

- Age imputations were revised based on reasons age was missing.

The calculation of the cooling installation index was presented in a July 29, 2019 memo. Key findings are summarized in the next section. The revised age imputation approach and results are then presented. The final section of the memo provides the results of the updated EUL analysis with these revised inputs.

### 2.4.2 Key Results from the Cooled Floorspace Estimation

As described in the July 29 memo, the evaluation team estimated the new construction and existing cooled floorspace, NCCSFy and EXGCSFy, respectively, for each year y from 1985 through 2014. Using these series, we calculated a cooling installation index CII in year y for an assumed EUL as

\[ CII_y = NCCSF_y + EXGCSF_y / EUL \]

Essentially, this index represents the estimated million ft² of floorspace in the state requiring new cooling installations each year.

Figure 2-8 shows the resulting cooling installation index for EUL = 8, EUL = 13, and EUL = 15. The curves look very similar. Since new construction is 2% or less of existing floorspace in each year, the index is dominated by existing floorspace even with existing divided by the EUL.

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11 Project 91: Memorandum on cooled commercial floorspace in Massachusetts, July 20, 2019, from Christopher Dyson, DNV GL to Massachusetts PAs, EEAC Consultants.

12 A draft version of this memo was submitted for EEAC/PA review on October 25, 2019. This is the final version of this memo which addresses EEAC/PA comments.
For the EUL analysis, the magnitude of the cooling installation rate index does not affect the results, only the relative magnitude from one year to the next. To get a better sense of how sensitive the index is to the EUL assumption, we re-scaled the indices to express each as a percent of the sum over the 30 years. The result (Figure 2-9) indicates little sensitivity of this index to the EUL assumption over plausible EUL ranges.

The EUL analysis presented in Section 4 confirmed this lack of sensitivity to the initial EUL assumption used to construct the index.
2.4.3 Age Imputation

The age imputation begins by modelling age as a function of cooling equipment type and other building and equipment information, using the units with non-missing age. The basic age imputation from the P73-D analysis assumed this age distribution applied to the missing units as well. As noted in the introduction, there was some concern that units with missing age might tend to be older than units with non-missing age. To address this possibility, the P73-D calculated EULs with an alternative set of imputations, under which it was assumed that all units with missing age were older than eight years. This assumption essentially meant that the assumed distribution of the units with missing age was the modelled distribution for units at least that old.

After reviewing the information available with the lead engineer for the P41 and P55 baseline studies, we developed the following assumptions and assignments for different situations. The assumptions and percent of units in each category are shown in Table 2-8.

Table 2-8. Age Imputation Assumptions and Proportion of Units in Each Category

<table>
<thead>
<tr>
<th>Reason for No Age Data</th>
<th>Imputation Assumption</th>
<th>Specific Assumption</th>
<th>Percent of Total</th>
<th>Percent of Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial number not in database</td>
<td>Old or obscure</td>
<td>50% same as non-missing 50% &gt; 15 years</td>
<td>3.49%</td>
<td>15.27%</td>
</tr>
<tr>
<td>Nameplate not clear</td>
<td>Age distribution older than non-missing</td>
<td>&gt; 10 years</td>
<td>2.72%</td>
<td>11.91%</td>
</tr>
<tr>
<td>No nameplate information</td>
<td>Some age related, some not</td>
<td>50% same as non-missing 50% &gt; 10 years</td>
<td>8.82%</td>
<td>38.59%</td>
</tr>
<tr>
<td>Model # recorded but not serial number</td>
<td>Most likely not age related</td>
<td>same as non-missing</td>
<td>7.82%</td>
<td>34.23%</td>
</tr>
</tbody>
</table>

Definitions in this table are:

- The designation “same as non-missing” means that the same imputation model fit to the units with non-missing age is assumed to apply to the units with missing age.
- The designation “> x years” means that the assumed distribution of the units with missing age is the same as the modelled distribution, conditional on being older than x. (For a given age a > x, the conditional probability of that old is the probability from the non-missing model, divided by the probability from that model of being older than x.)
- The designation “50% same as non-missing, 50% > x years” means that the assumed distribution was a 50-50 mix of the modelled distribution for non-missing units, and that distribution conditional on being older than x.

13 Other variables in the model were building type, consumption level, and whether the equipment was installed after 2008.
Thus, the estimated age distribution with the updated imputations is a mixture of the distributions assumed to apply to the different missing statuses, according to the estimated population proportion in each status. Figure 2-10 shows the age distributions for the units with non-missing data alone, and for all units using 3 different imputation methods:

**Figure 2-10. AC Unit Age Distributions with No Imputation and with 3 Imputation Methods**

The 3 types of imputations are defined as:

- **P73-D Basic imputations**, assuming the age model from the non-missing units applies directly to the missing units.
- **P73-D Alternative imputation**, assuming the units with missing age are at least 8? Years old
- **Updated imputations** from this study, based on the assumptions in Table 2-8.

The figure shows that the units with non-missing age data alone have larger fractions of newer units, resulting in lower EUL estimates. The updated imputations produce age distributions tending to older units than the basic imputation, but not as old as the alternative imputation from the P73-D work. This makes sense because the P73-D alternative imputation assumed that missing age data always indicated an older unit, while the review of reasons for missing age suggested that in many cases age was not a factor in the missing data.

The figure also shows that with all these methods there are only a very small fraction of units older than 25 years. Since almost no units this old were observed, imputing more substantial fractions of units in this age range would require other data sources or some very strong assumptions not based on the data.

**2.4.4 Revised EUL Estimates**

Figure 2-11 shows the observed age distribution of AC units, including the updated age imputations for those with missing age data. Also shown in the figure are the expected age distributions at the time of the
data collection, given the installation rates from the cooling installation index and the best fit Weibull survival function. As was seen in the P73-D analysis, the “weighted” estimation, which is theoretically a more accurate estimator, doesn’t fit the observed distribution as well as the “unweighted” estimation.

**Figure 2-11. Observed age Distribution and Expected Distributions Based on Cooling Installation Index and Best-Fit Weibull Curves**

Table 2-9 presents the EUL estimates from the prior study, using the AHRI/DOE installation rates, and those from the present study, using the floorspace-based cooling installation rate index. The present study results are based on the updated model estimates described above.

The table shows that for both the prior and updated results, the unweighted estimates have wider error bands than the design-weighted results. Because of the better fit to the observed data, we consider the unweighted results to be more meaningful, but recognize the greater uncertainty. Results based on units with non-missing age data only results are shown for comparison, but the full sample results are most meaningful.
The results that should be most meaningful, highlighted in green in the table, use the cooling installation index and the updated imputation. These results give an EUL of 8.6 years. Estimates using the cooling installation index the prior study’s alternative imputation method give an EUL of 9.8 years. However, the prior study’s alternative imputation, which assumes that all those with missing age are older than 8 years, is too generous. Our data review indicated many reasons for missing age data not likely to be age-related.
Even with this generous assumption, the updated estimates are still lower than the current TRM EUL (12 years), and lower than some reviewers believe is likely. It may be that, despite this belief, the estimates of 9 or 10 years for the AC EUL are in fact realistic. While many units can last a long time, others may be replaced after a short time for a variety of reasons.

If these estimates are lower than is realistic, there are a few possible reasons for this result:

- The age imputations may still be too conservative. As noted in Section 3, the observed ages include almost none greater than 25 years. If there are a non-trivial fraction of units older than 30 in the building stock, and all their age data are missing, imputation methods based on the observed ages can’t account for those units. Other sources of information, such as from vendor interviews, would need to be used to provide a basis for adjusting the imputations.

- The cooling installation index includes chillers as well as the unitary air conditioners that were the subject of this study. This could be introducing unknown distortions.

- The survival curve isn’t well described by any Weibull distribution. The actual distribution is likely some mixture of distributions, difficult to model.

### 2.5 COOLED COMMERCIAL FLOORSPACE IN MASSACHUSETTS

This section describes an analysis conducted under Project MA19C02-B-EUL to develop a more accurate estimate of the unitary HVAC equipment installed in Massachusetts over time. The analysis originally appeared in a memorandum that the evaluation team issued on July 2, 2019.

#### 2.5.1 Introduction

One research task for Project MA19C02-B-EUL (Project 91) C&I Measure Life Study is to develop annual estimates of total Massachusetts cooled commercial floorspace in place and newly constructed. This memorandum (memo) summarizes methods and results for that analysis.

Annual estimates of cooled commercial floorspace will be used to update expected useful life (EUL) estimates of Massachusetts unitary HVAC equipment installed in the commercial sector that came out of Project 73: Track D Measure Life Methods (P73 Track D). A 2018 research effort for P73 Track D study estimated EULs for this equipment. One critique of the initial approach was that it based its estimate of Massachusetts equipment installation rates on national annual sales data from the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and U.S Department of Energy (DOE). Massachusetts Program Administrator (PA) and Energy Efficiency Advisory Council (EEAC) representatives who reviewed the 2018 study questioned whether national sales data accurately reflected Massachusetts installation rates. Therefore, they authorized the current study to develop HVAC installation rates that are derived from Massachusetts data. These methodologies for estimating Massachusetts commercial square footage and cooled square footage over time could also be used for future Massachusetts commercial market or EUL estimation studies (e.g., using more current tax assessment/Dodge data and future Massachusetts C&I baseline data).

The current study developed indices based on cooled Massachusetts commercial floorspace that better reflect AC installation patterns in the state’s commercial sector. In particular, we assumed the sector’s AC
installations in each year are proportional to new commercial construction or floorspace (NC SF) and existing commercial floorspace (existing SF) that are cooled. This memo presents data sources, methods and results from this study.

2.5.2 Approach
This section describes our analytical approach including the data sources, estimation methods, findings and study limitations.

2.5.3 Overview
The analysis consists of the following main steps:

- **Total commercial floorspace by year:**
  1. Estimate an effective decay rate. Using data on annual new commercial floorspace construction, together with “snapshot” data from 2014 of the surviving floorspace from each construction year, estimate the effective decay rate. This is the annual net loss rate of existing floorspace. The effective decay rate reflects the combined effects of demolitions, floorspace converted to a non-commercial use, and floorspace converted from non-commercial to commercial use.
  2. Apply the effective decay rate to the 2014 snapshot to estimate the floorspace in place each year, from each construction-year cohort.

- **Cooled commercial floorspace:**
  1. Estimate the proportion of Massachusetts commercial floorspace cooled, as a function of year constructed and building type. This estimation uses a large national data set, with a regional (Census Division) adjustment.
  2. Apply the cooled floorspace proportion model to the Massachusetts floorspace by construction cohort data.

Before providing details of the estimation process, we review the data sources used.

2.5.4 Data
We used the following data sources in the analysis:

- **Tax assessor data:** These are data about commercial property characteristics, available from local tax assessors and published online. We used these data, which are compiled by the evaluation team’s C&I customer profiling project, to estimate existing floorspace in place. Currently, the evaluation team has state-wide tax assessor data that provides values of total floorspace in place in 2014, the year when the Project 41 field data for the study were collected. For about 20% of the state’s municipalities, the data are only available for years earlier than 2014. Thus, we have excluded data from these jurisdictions in the analysis. Since we only need to estimate something that is proportional to the state’s commercial floorspace that is cooled, the absence of such data is not a problem.

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15 Commercial sector AC installs are proxied by NC SF cooled + (existing SF Cooled)/EUL. The EUL process will be somewhat iterative, but as a first step we estimate new and existing floorspace in place in each year from 1985 until 2014.
16 Project 41: The Massachusetts C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study.
17 Examples of towns or jurisdictions missing 2014 tax data include North Andover, Needham, Carlisle, Burlington, and Cambridge.
18 Since the tax assessment data will get updated soon for a customer profiling study, the evaluation team did not consider it prudent to delay the current EUL study to compile these missing tax data.
• **F.W. Dodge data (Dodge data):** F.W. Dodge produces data for purchase on new construction projects, including project use type, project start dates, location and size by square feet. Apprise previously compiled Massachusetts Dodge data from 1996 through 2015 as part of the commercial profiling project. We used these data for Massachusetts annual commercial floorspace additions.

• **Commercial Buildings Energy Consumption Survey (CBECS) 2012 micro-data:** These data are from the Energy Information Administration’s national survey of commercial buildings. They provide information on cooled commercial floorspace by building type, size, construction year and census division. We used the micro-data—the data set of individually surveyed building—to estimate the percent of cooled commercial floorspace space in Massachusetts.

The installation rate index we developed is based on the annual existing and new cooled commercial floorspace derived from these data sources, as described below.

### 2.5.5 Estimation

This section describes our methods and results on Massachusetts cooled commercial floorspace in place and added each year.

#### 2.5.5.1 Total commercial floorspace by year

The F.W. Dodge data provide the floorspace newly added each year. The tax assessor data provide the floorspace in place in 2014, from each construction year cohort. Our goal is to estimate the floorspace in place in each prior year. To accomplish this, we used the two available sources to estimate the average annual loss rate. Once we determined an annual loss rate, we could use that rate to project backward from the existing floorspace in place in 2014 by construction-year cohort, to calculate the amount of existing floorspace in place in any given year, from each age cohort.

Dodge gives the year construction is initiated on a project, while the tax data give the year construction is completed. We estimated the completion year for the new construction data using the following assumptions:

- Construction of floorspace up to 500,000 ft² is completed within a year,
- Construction of floorspace between 500,000 and 1,000,000 ft² within two years, and
- Construction of floorspace above 1,000,000 ft² within three years

Thus, the first step was to calculate the annual effective loss or decay rate of commercial floorspace, using new commercial construction data from F.W. Dodge and 2014 existing commercial floorspace by year built from the tax assessor data. The amount of commercial floorspace added in 1996 based on the compiled Dodge data was only 86% of what the tax data reports as remaining in 2014 for this cohort. For almost all other years, the Dodge data total for the construction year exceeded the amount remaining in 2014, as would be expected. Therefore, we only used data from 1997 through 2014 from the two sources to calculate the decay rate.

Figure 2-12 shows the total 2014 commercial floorspace in place and added by year in Massachusetts. The light blue line labelled “Building Area Tax” is the total commercial floorspace of different construction-year cohorts in place in 2014, obtained from the tax assessor database. The dark blue line represents the

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19 The next round of CBECS data collection is scheduled to begin in April 2019, with initial published data available in mid-2020. Data sufficiently granular for our purposes will likely not be available until late 2020.

20 To make sure that the starting or addition of new floor space (SF0) and the deprecated end value (SF14) correspond to the same population, we used aggregate data for all Massachusetts commercial buildings using CBECS building definitions. These include Education, Food Sales, Food Service, Healthcare, Hospitals, Lodging, Office, Other, Public Assembly, Public Order and Safety, Religious Worship, Retail, Service, and Warehouse and Storage.
commercial floorspace added in each year, from F.W. Dodge. Each series is based on data from the municipalities reporting tax assessment data in 2014 or later.

As expected, the total commercial floorspace that remains in 2014 is a portion of the amount added in each year and follows the same pattern as the building area added. Moreover, the gap between the two generally narrows over the time as more of the newly added floorspace remained in place in 2014. Across the construction-year cohorts displayed, an average of 11.5 million ft² is added each year, and an average of 9.2 million ft² from each cohort remained in 2014. New construction activity has generally been declining since 2000.

**Figure 2-12. Total commercial Floorspace in Place and Added by Construction Year, for Buildings 1997 or Later**

To estimate the decay rate, we assumed commercial floorspace decreases at a fixed rate over time (exponential decay). In this case, the effective decay rate $d$ is defined by:

\[ SF_{2014c} = SF_{0c} (1-d)^{2014-c} \]

where:

- $SF_{0c}$ = floorspace (in square feet) constructed in year $c$, from F.W. Dodge data
- $SF_{2014c}$ = floorspace (in square feet) in place in 2014 that was built in year $c$, from tax assessor/CI profile data

The decay rate equation can be written as:

\[ \ln(SF_{2014c} / SF_{0c}) = (2014-c)\ln(1-d) \]

A no-intercept regression of:

\[ \ln(SF_{2014c} / SF_{0c}) = \beta(2014-c) + \epsilon_c \]

produces the estimate $\beta = \ln(1-d)$ and the decay rate given by $d = 1-e^\beta$.

The decay rate estimated by this method was 2.0% per year.
The decay rate allowed us to estimate the surviving floorspace from each construction year obtained from F.W. Dodge. This is a “forward method” that allows us to determine how much floorspace of a given year’s floorspace additions remain in subsequent year. For instance, for floorspace newly constructed in 2000 we obtained the amount of this space that remained for the years 2001 through 2014 using the estimated decay rate. Surviving floorspace of different vintages in each year were then added to obtain estimates of total commercial floorspace by year.

Alternatively, one can use a “backward method.” This method starts with the 2014 floorspace in place by year built and then projects backward how much was in place in each prior year using the estimated decay rate. We added floorspace of different vintages in each year, as in the forward approach, to construct total commercial floorspace by year.

A comparison of the commercial floorspace in place estimated using these two approaches indicates yearly values are nearly identical (Figure 2-13).

**Figure 2-13. Commercial floorspace by observation year, for buildings built 1997 or later**

The forward approach allowed us to estimate total commercial floorspace only from 1997 (the first year of reliable Dodge data) to 2014 (the observation year of the P41 commercial baseline study). The backward approach, on the other hand, made it possible to build annual estimates that go as far back as needed for the cooling equipment analysis. Thus, we based our final estimates of Massachusetts cooled commercial floorspace using the backward approach.

Figure 2-14 illustrates how the backward method is used to generate an estimate of total commercial floorspace for observation years 1985 to 2000. For illustration, results are shown only for observation years 1985 through 2000. The diagonal elements in the figure are additions in each year. The row values associated with each diagonal value represent decayed floorspace amounts of this addition. The total value at the bottom of each column is the sum of floorspace in place in that year, over all construction-year cohorts. These total values constitute total commercial floorspace that can be used to proxy the index of AC installation in the EUL calculation.

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21 Values have been adjusted upwards by 20% to account for the omitted tax districts.
More accurately, it is the total of cooled commercial floorspace estimated in this manner that provides this proxy. To move from total commercial floorspace to cooled floorspace, an additional step is required.

### 2.5.5.2 Total cooled commercial floorspace by year

As noted, for the EUL calculation the evaluation team needed estimates of total cooled commercial floorspace by year. One option considered for this estimation was the P41 data itself. However, there are only about 800 buildings in this data set across a wide range of building types and sizes. Even with about 800 sites, obtaining a good estimate of the relation between percent cooled and year built could be difficult.

In the current study, we estimated the proportion of the total floorspace that is cooled using model results based on 2012 CBECs micro-data. This data set has over 6,000 buildings. While they are not specific to Massachusetts, we used the full data set to estimate trends with year built and include a “New England” term to adjust to the area of interest. The CBECs micro-data has information on total floorspace and percent total floorspace cooled by census division, construction year, building type, and size.

Using this data, the evaluation team fitted a model to estimate percent floorspace cooled as a function of census division, construction year, building type. Our research found no relationship between the size of a building and the percentage of its floorspace that is cooled once building type was included in the model. Therefore, we excluded this variable from the final model. For confidentiality reasons, the CBECs public data do not report the exact year of construction for building built prior to 1946, about 11% of the sites in the data set. The model the evaluation team estimated took this distinction into account. Lack of specificity on floorspace built earlier than 1946 does not affect the EUL analysis.

The estimated proportion cooled model is given by:

\[
\text{%cooled} = \alpha_0 + \alpha_{BT}\text{BT} + \alpha_{CD}\text{CD} + \beta_{LD}\text{OLD} + \beta_y(1 - \text{OLD}) \times \text{YRC} + \epsilon
\]
In the equation:

\[
\%\text{cooled} = \text{percent commercial floorspace cooled for a building of building type BT and construction year YRC, in Census division CD}
\]

\[I_{BT} = \text{indicator variable for building type (based on principal building activity), 1 for a given building type BT, 0 otherwise}\]

\[I_{CD} = \text{indicator variable for Census division CD, 1 for a given census division CD, 0 otherwise}\]

\[I_{OLD} = \text{indicator variable for pre-1946 construction period, 1 if year constructed is before-1946, 0 otherwise}\]

\[YRC = \text{year constructed}\]

\[\alpha, \beta = \text{model parameters}\]

\[\varepsilon = \text{error term}\]

Model results provided estimates of the percent of commercial floorspace that is cooled in the New England Census division by building type and year constructed. We applied these values to the commercial floorspace values found in the tax assessor data to estimate 2014 cooled commercial floorspace values by year built and building type.

As expected, model results indicated that a greater percentage of floorspace in more recent buildings was cooled. Moreover, buildings in use for health care and lodging were cooled the most and those used for warehouse and storage were cooled the least. Figure 2-15 provides estimated percent cooled floorspace by building type. The value of the percent floorspace cooled for each building type varies over time although the amount cooled prior to 1946 is assumed to be a constant amount for each building type.
Our estimated effective decay rate described above was then applied to the cooled floorspace in place in 2014 to generate the total cooled floorspace in the years 1985 to 2014.

Figure 2-16 below presents the total and cooled commercial floorspace by year. For example, the figure indicates the presence of 1.09 billion ft² and 0.86 billion ft² of cooled commercial floorspace in 1985 and 2014, respectively, out of total commercial floorspace of 1.65 billion ft² and 1.28 billion ft² in each respective year. Thus, about two-thirds of total commercial floorspace was cooled over this time period. The figure shows a gradually narrowing gap between total and cooled floorspace, consistent with the increasing percent cooled by construction year indicated in Figure 2-16.

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22 Total and cooled commercial floorspace estimates include upward adjustment of model estimates by 20% to account for omitted tax districts.
Figure 2-16. Total and cooled commercial floorspace in place in Massachusetts by year

Figure 2-17 shows the amount of existing and new cooled floorspace by year (on different scales). The amount of cooled commercial floorspace added annually between 1985 and 2014 (right hand scale) was generally higher in earlier than later years during this period. New floorspace as a percent of existing floorspace was 3% in 1989 while this value fell to a low of 0.5% in 2011. Slower new floor additions combined with a 2% annual decay rate has meant declining total and cooled commercial floorspace in Massachusetts from 1985 to 2014.

Figure 2-17. Existing and New Cooled Commercial Floorspace by Year
2.5.6 Cooling Installation Rate Index from the Floorspace Estimates

The purpose of estimating commercial cooled floorspace by year is to provide an index for the rate of cooling equipment installations. It is not necessary to know the numbers of units installed, but to have an index such that the number installed in a given year is proportional to that index.

The assumption for the EUL analysis is that installations in a given year are proportional to the newly installed floorspace at one rate (new cooling installations per new square foot) and proportional to existing floorspace at another rate (replacement cooling installations per existing square foot). Roughly speaking, we expect the replacement rate to be the new installation rate divided by the EUL. Thus, use of this index as an input to the EUL estimation will required some iteration.

As initial inputs, we calculate the cooling installation index CII in year \( y \) for an assumed EUL as:

\[
CII_y = \text{NCCSF}_y + \frac{\text{EXGCSF}_y}{\text{EUL}}.
\]

Essentially, this index represents the estimated million square feet of floorspace requiring new cooling installations each year.

Figure 2-18 shows the resulting cooling installation index for \( \text{EUL} = 8 \), \( \text{EUL} = 13 \), and \( \text{EUL} = 15 \). The curves look very similar. Since new construction is 2% or less of existing floorspace in each year, the index is dominated by existing floorspace even with existing divided by the EUL.

**Figure 2-18. Cooled commercial Floorspace Indices by Year**

For the EUL analysis, the magnitude of the cooling installation rate index does not affect the results, only the relative magnitude from one year to the next. To get a better sense of how sensitive the index is to the EUL assumption, we re-scaled the indices to express each as a percent of the sum over the 30 years. The result, shown in Figure 2-19 indicates little sensitivity of this index to the EUL assumption over plausible EUL ranges.
2.5.7 Study limitations

The methods and assumptions we described in this memo do have certain limitations, most of which have been noted above. These limitations include the following:

- **Decay Rate**
  - We expect decay rates to depend on building type and size, but the data were too noisy to support separate estimates even by building type.
  - Buildings can change type and move in and out of the commercial sector over their lifetime. The estimated effective decay rate is net of those movements.
  - Demolition or conversion rates depend on the economy and are likely to have some of the same uneven patterns as we see for construction rates. The method used can’t account for that and estimates a single overall rate.

- The percent cooled backward projection is applied as if space that was cooled in 2014 was cooled from the time it was built, or at least as early as 1985. The method cannot account for existing uncooled floorspace having cooling installed in intermediate years.

2.6 A LITERATURE REVIEW OF MEASURE LIFE ESTIMATES FOR ADD-ON, O&M MEASURES

This section describes a literature and TRM review which was conducted under Project MA19C02-B-EUL (Project 91). These findings originally appeared in a May 15, 2019 memorandum.
2.6.1 Background, Research Objectives, and Methodology

One research task for Project MA19C02-B-EUL (Project 91) C&I Measure Life Study was to conduct a targeted study of best/current practices for measure lives assumptions for two categories of measures: add-on and operations and maintenance (O&M) measures.\(^{23}\) The Massachusetts Program Administrator (PA) representatives were particularly interested in knowing how jurisdictions outside Massachusetts estimated measure lives for these measures. The primary objectives of this review of technical reference manuals (TRMs) and program evaluation literature on measure lives include:

- Exploration of how various TRMs assign measure lives to add-on, and O&M measures; and
- Summary of recent studies/protocols for estimating add-on and O&M measure lives that DNV GL is familiar with.\(^{24}\)

This research will help the PA representatives and Energy Efficiency Advisory Council (EEAC) Consultants better understand standard practices surrounding these methods and definitions to set the stage for possible adjustments to the methods currently used in the Massachusetts TRM. One of the PA reviewers of this literature review wondered whether any of the O&M programs reviewed in the study had provisions for remote monitoring or an option for periodic revisits post-implementation. The evaluation team observed that while none of the TRMs provided information on such practices, this was a topic that could be researched in the future through targeted interviews with a few key states.

To gather the information in this study DNV GL reviewed over 20 TRMs as well as recent measure life studies commissioned by utilities and other stakeholders that focus on the measure lives of add-on or O&M measures. A bibliography of the key papers, reports, and TRMs referenced here appears at the end of this section.

2.6.2 Summary of Findings and Conclusions

The literature review identified 2 general approaches for assigning measure lives:

- A deemed or stipulated approach where a fixed value is assigned in every instance
- A formulaic approach where measure lives are adjusted based on site-specific conditions

The literature review revealed that deemed values are the most frequently used methods for assigning EULs to these add-on and O&M measures. Over 80% of the TRMs we reviewed used deemed values for add-on and O&M EULs. For the add-on measures there was a narrower range of deemed EUL values across TRMs for the same types of equipment. In contrast, the deemed EUL values for the O&M measures had more variation across TRMs for the same equipment types.

\(^{23}\) Add-on measures are devices added to existing systems often to improve their energy efficiency. Examples include: VFDs, boiler controls, heat exchangers, and lighting occupancy sensors. The Massachusetts C&I Baseline Framework defines them as: “Applies to measures that improve the efficiency of an existing system but does not replace it.” O&M measures are primarily those where the energy efficiency of the equipment is improved through cleaning and maintenance. Examples include boiler tune-ups, chiller tune-ups, compressed air leakage repair and steam trap maintenance. However, they can also encompass other energy-saving behaviors such as making energy-savings changes to Energy Management Systems and manually turning off lights in unoccupied spaces.

\(^{24}\) This study focused on summarizing the methods and sources of the EULs for the add-on and O&M measures for the different TRMs. However, it did not attempt to capture the actual EUL values for these measures beyond observations of general patterns (e.g., whether the range of EUL values across TRMs for the same equipment types were narrow or broad). The TRM review for Project 73 Track D (Measure Life Methods), which had a much larger budget, did capture the range of EULs for one add-on measure (VFDs) among other measures of interest to the PAs. It found that the VFD EULs in the Massachusetts TRM (13 years for lost opportunity and 15 years for retrofit) were very similar to those of the other states (13.9-year average). This was not coincidental since the source of the Massachusetts EULs was a 2005 ERS study which based its recommended EULs on averages of EULs from the TRMs of other states.
However, there were some exceptions to this general practice. Some jurisdictions used a formulaic approach to estimate the measure lives of the O&M measures. In addition, some TRMs considered the remaining life of the host equipment when estimating measure lives for add-on measures.

The large majority of the TRMs derived their EUL estimates for add-on and O&M measures from a limited number of source studies. For example, over two-thirds of the TRMs referenced the same four studies: ERS 2005, GDS 2007, KEMA 2009, and DEER.25

The objective of this research was to summarize standard practices for assigning measures lives to add-on and O&M measures and not to make specific recommendations on how the Massachusetts TRM’s current assignment of measures lives to these measure types should change. However, this research did lead us to a few conclusions.

The first conclusion is that deemed value EULs for add-on measures and O&M may be overstating the actual lifetimes of these measures. One piece of evidence for this was DNV GL’s implementation in 2017 of an interview-based method for assigning EUL’s to add-on and O&M equipment (the method is described later in this section). In 30 C&I sites where this interview-based method was employed, the average evaluated EUL for the add-on/O&M measure was 9.1 years. This compared to the average ex ante EUL of these measures of 16.6 years. The most common reasons for the reduction of the ex ante EULs was that the interviews had determined that the remaining useful life of the host equipment was shorter than the ex ante EUL of the add-on equipment and it was very unlikely the add-on equipment would be reused on another piece of host equipment.

A second reason for concern about the validity of these deemed EUL values is the lack of primary research to support them. As noted, the large majority of EUL values for add-on or O&M equipment in state TRMs come from the same short list of sources. Not only are these sources dated (most are 10-15 years old), but most of the EULs in them are derived from even older secondary sources rather than primary research such as persistence studies.

Another DNV GL evaluation (discussed later in this section) did find that the Energy Trust of Oregon’s deemed EUL of three years for industrial O&M measures was reasonable after an analysis of the likely persistence of the 68 individual O&M measures O&M. However, it is important to note that the measure-specific persistence estimates in the DNV GL analysis were based on secondary sources from a literature review. Therefore, they are susceptible to the same concerns about the lack of primary research already mentioned.

The second conclusion is that while formulaic approaches like the DEER method should, in theory, produce more accurate EUL estimates for add-on measures (e.g., by making sure the EUL of the add-on measure does not exceed the RUL of the host equipment), it is difficult to apply them by relying only on project tracking data and documentation. DNV GL chose its interview-based method primarily because program documentation contained sparse information on the age and vintage of either the existing host or the add-on equipment.

**2.6.3 Detailed Findings**

This section provides more detailed findings from the literature review.

25 Full citations of these reports appear later in the section.
2.6.3.1 Definitions

In addition to the definitions of add-on and O&M measures already provided, the following are definitions of other terms frequently found in the TRMs and related literature:

- **Effective Useful Life (EUL):** EUL is most often defined as the median number of years that an energy efficiency measure is likely to remain in place and operational after installation (i.e., the number of years after which 50% of the systems installed in a particular year will no longer be in service).  

- **Remaining Useful Life (RUL):** RUL is most often defined as the difference in years between the current age of the existing equipment and the estimated time of its replacement. State TRMs vary in their standards for assessing the RUL of existing equipment for early replacement situations. Some states use a blanket approach and assume that the RUL for all early replacement situations is one-third the EUL of new equipment. Other states, such as California and Illinois, assume a one-third EUL number when existing equipment installation dates are not available. Some states calculate RUL on an individual basis, subtracting age of equipment from EUL. Some states calculate RUL as a function of EUL and equipment age (considering that the longer a measure remains in place and operable, the longer its likely EUL). The Massachusetts Framework defines the RUL of the host for an add-on measure as two-thirds of the EUL of the host equipment.

- **Measure persistence:** Measures persistence involves the examination of exogenous factors such as override of efficiency controls, and measure-specific factors (e.g., condensate on heat exchangers in boilers) that impact measure life. However, the TRMs of states which said they considered measure persistence factors did not explain how these considerations manifested themselves in adjusted EULs and did not describe any studies they used to make such adjustments.

2.6.3.2 Common issues and information gaps

The literature review revealed that most TRMs and other industry documents cited just a few primary sources as the origins for their EULs for add-on and O&M measures. Most of these primary sources fall into one of the categories shown in Figure 2-10, which also displays the number of TRMs that use each type of source.

<table>
<thead>
<tr>
<th>EUL Sources</th>
<th>Number of TRMs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public funded research (DEER, DOE, PSCs, Universities, etc.)</td>
<td>15</td>
</tr>
<tr>
<td>Independent analysts’ studies (GDS, ERS, KEMA, etc.)</td>
<td>16</td>
</tr>
<tr>
<td>Estimates with no source</td>
<td>11</td>
</tr>
<tr>
<td>Trade publications (manufacturers, trade groups, etc.)</td>
<td>3</td>
</tr>
<tr>
<td>Other TRMs</td>
<td>13</td>
</tr>
</tbody>
</table>

26 Other, less common, definitions include: “The number of years that a measure is installed and will operate until failure,” “The age at which equipment is retired from service,” and “Number of years that energy savings will be realized (influenced by baseline change).”

27 This default approach is currently being reviewed in California.
The review of over 20 TRMs found that the most-frequently-referenced primary sources were EUL studies or reports, by independent analysts, published between 2007 and 2014. The most commonly cited sources (cited by over two-thirds of TRMs) included:

- ERS, Inc.’s “Measure Life Study”, November 2005
- CPUC’s Database for Energy Efficient Resources (DEER) 2008 or 2014
- KEMA’s “Focus on Energy: Business Programs – Measure Life Study”, August 2009

Some geographic differences were identified in the sources cited by the TRMs. Western states were most likely to cite publicly funded resources (DEER, DOE, etc.) or independent analyst studies (ERS 2005, GDS 2007, etc.). Midwestern & southern states were most likely to cite other TRMs or independent analyst studies (ERS 2005, GDS 2007, KEMA 2009, etc.). Mid-Atlantic and north-eastern states were most likely to cite independent analyst studies (ERS 2005, GDS 2007, KEMA 2009, etc.) or publicly funded resources (DEER, DOE, etc.).

### 2.6.3.3 Unreported EUL Values

Two of the TRMs reviewed did not provide any EUL or RUL values for either add-on or O&M measures. Citations were often included for parameters in the savings algorithms but there was no mention of EUL or RUL values, nor any reference to sources to determine these values.

### 2.6.3.4 Uncited Values

Twelve of the TRMs that the evaluation team reviewed contained EUL values for add-on or O&M measures which listed the sources as either “staff estimates” or estimates with no sources (uncited values). In these cases, the methodologies behind the uncited EUL values (including staff estimates) were not provided and the values did not align with EULs for similar measures from more widely accepted sources.

### 2.6.3.5 Behavioral Programs

A previous literature review, which was part of Massachusetts Project 73 Track D Measure Life Methods study, found that there is a virtual absence of studies addressing persistence of O&M measures in educational or behavioral programs. Even the most widely-implemented type of energy efficiency behavioral programs—Home Energy Reports (HER) programs—did not have any broadly-accepted, comparable EUL values. According to the literature, the persistence of savings (or alternatively, the rate of savings decay after treatment) found in evaluations has varied widely across utilities and types of customers, making it extremely difficult to choose values that are broadly applicable. An Internet search of behavioral program evaluations found decay rate values ranging from a high of 46% to a low of 5% per year depending on utility and fuel type. Some programs applied a one-year EUL for each year that customers receive reports, ignoring savings that almost certainly continue after participants stop receiving reports. Currently Massachusetts limits the measure life of the OPower program to one year, with this limit based on a “vendor estimate.”

### 2.6.4 Measure Life Methods

The literature review revealed that there are two main methods of assigning EULs to add-on and O&M measures. The deemed value method assigns EULs solely based on measure type. The formulaic method

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assigns EULs based on measure type and other site-specific factors that impact the persistence of the measure. The following subsections describe these methods.

### 2.6.4.1 Deemed Values

The literature review found that the application of deemed values was the most common method of assigning EULs to add-on and O&M measures. Over 80% of the TRMs used deemed values for add-on or O&M EULs. The Massachusetts Baseline Framework recommends the use of deemed values since site-specific measure life information can be unreliable due to the faulty recall of the on-site contacts or poor documentation of equipment installation/purchase dates.²⁹

Massachusetts, California, and Wisconsin have the earliest-cited measure life studies and these sources (ERS 2005, GDS 2007, KEMA 2009, and DEER) are the most widely cited documents for add-on and O&M EULs. They are referenced in over two-thirds of TRMs. Many of the TRMs reviewed are circular-referencing and build off preceding TRMs, and retention or persistence studies. The ERS 2005 study is the most cited of the four primary sources. Deemed values are the simplest to use and are mostly consistent for similar add-on measures (demand controls for ventilation, boiler reset controls, occupancy sensors for lighting, etc.) but deemed EULs for O&M measures have significantly more variance.

### 2.6.4.2 DNV GL’s O&M Deemed Persistence Research

DNV GL’s recent research (DNV GL, 2017) for Energy Trust of Oregon (Energy Trust), refined the classification of O&M and add-on measures. Because there is little documentation on the persistence of savings from O&M, Energy Trust was assuming that industrial O&M savings persisted for an average of three years after intervention.

DNV GL conducted a detailed literature review and analysis to characterize the types of O&M measures and associated energy saving actions to identify the types of measures or actions that have reasonable persistence. A list of 68 common measures were studied including the following measure groups: heating, ventilation and air conditioning (HVAC); compressed air and compressed air programs, waste water treatment plant (WWTP) aeration blowers, boilers, steam traps, chillers and cooling towers, air abatement, process ovens, lighting, refrigerated spaces, and refrigeration warehouses. The measures generally fell into two categories:

- Maintenance (repairs, cleaning, routine checks)
- Controls (adjusting and optimizing schedules, set points, and control schedules)

DNV GL’s review of the available literature found that repairs have a higher persistence (longer EULs) than cleaning, routine checks, and the controls measures. It also found that the persistence of controls and optimization measures was dependent on the potential for the controls to be revised or overridden, reducing the efficiency gains.

For each of the O&M measures, DNV GL developed a rational for classifying measures using the findings in the literature:

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²⁹ “The estimated age at replacement is vulnerable to substantial measurement error, as it typically depends on recollections of installations five to twenty years prior, absent the production year being stamped on the nameplate, and the implementer having saved documentation of it such as by photographing the nameplate prior to removal or copying the original filed sales invoice. The evaluator should attempt to collect site-specific age at replacement to inform future research on measure EULs and RULs but should only provide the estimate if it is definitive and documented. It should not use it for project retrospective gross savings evaluation even if provided. For retrospective use in impact evaluation the evaluator should use the RUL value of one-third of the EUL unless evaluators previously have developed a program- or measure-specific RUL or the evaluation is of a unique measure that has exceptional available RUL data.”
- **Low persistence**: These are measures which are impacted by human control and control strategies (1 year)
- **Mid-range persistence**: Changes for these measures are possible but such changes are usually planned (2 years)
- **Highest persistence**: It is generally more difficult to change back these measures due to inefficient conditions, e.g., repair of leaks in a compressed air or steam system, or process changes which improve the quality of the product (3 years)

The research supported Energy Trust's default assumption of a three-year average for persistence of O&M measures. Of the 68 measures reviewed, more than half (59%) were classified as three-year persistence or greater. A recent evaluation report of Puget Sound Energy’s Industrial Systems Optimization Program (DNV GL et. al., 2017) found 97% of O&M measures still in place six to thirty months after being implemented, which further supported the three-year average EUL used by Energy Trust for their industrial O&M measures.

### 2.6.4.3 Formulaic values

A few of the TRMs or primary sources determine measure lives for add-on or O&M measures using a formulaic approach that requires the consideration of site-specific data. Some sources determined the EUL of add-on and O&M measures as a function of the EUL, age, and RUL of the host equipment or system. This is due to the perception that the longer a measure remains in place and operable, the longer its likely EUL. The following are some variations of the formulaic approach.

#### DEER Method

DEER provides the most widely referenced formulaic approach for determining EUL for add-on measures. With this approach, the EUL of add-on measures is a function of the RUL of the host system so that their maximum EUL is less than or equal to the RUL of the host system. Whenever the RUL of the host system is expected to be less than its EUL, if its installation date is unknown, it is assigned a default RUL of one-third its EUL and its associated add-on measures also receive this RUL as their EUL.

#### DNV GL’s Interview-Based Method

For DNV GL’s evaluation of two utility C&I programs for The Ontario Energy Board (OEB), it designed an approach to assign EULs to add-on measures based on customer interviews. The main reason for developing this interview-based method was that the program documentation contained sparse information on the age and vintage of either the existing host or the add-on equipment. This made it difficult to apply a method like the DEER method described above where the EUL of the add-on measure is a function of the RUL of the host system.

This method observed that add-on measures can have many potential periods within their prescribed EUL, such as:

- **Early Replacement (ER) Period 1**: The period where the existing add-on equipment (or none, if the existing equipment did not have any applicable add-on equipment) and existing host equipment could have continued operating in the same manner. During this period, the baseline would be the existing host equipment with the existing add-on (if any).
- **ER Period 2**: There could be a second ER period on rare occasions, for 2 reasons:
- If the existing add-on equipment would have failed or been replaced while the existing host equipment was still operating effectively. During this period, the baseline would be the existing host equipment with new standard efficiency add-on equipment.  
- If the existing host equipment failed, but the existing add-on equipment could have been used with the new host equipment. During this period, the baseline would be the new host equipment (whatever the customer will most likely install) with the existing add-on equipment.

- **Non-ER Period:** This is the period after both the existing host equipment and the existing add-on (if any) would have failed or had to have been changed/replaced. During this period, the baseline is the new host equipment with a new standard efficiency add-on.

- These periods are represented visually in Table 2-11. In this figure, the labels are defined as follows:
  - **Exist. Add-on RUL > 0:** Existing add-on equipment was early replacement.
  - **Exist. Host RUL > 0:** The add-on was installed on existing host equipment.
  - **EUL of New Add-on > RUL of Exist. Host:** The host equipment will be replaced during the life of the new add-on.
  - **New Add-on Compatible with New Host:** The new add-on equipment is practical to reuse with whatever replaces the existing host equipment, as determined by the questions in Figure 2-20.

### Table 2-11. Add-on Equipment Periods

<table>
<thead>
<tr>
<th>Scenario</th>
<th>ER Period 1</th>
<th>ER Period 2</th>
<th>Non ER Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Exist. Add-on RUL &gt; 0</td>
<td>Exist. Host RUL &gt; 0</td>
<td>EUL of New Add-on &gt; RUL of Exist. Host</td>
</tr>
<tr>
<td>3</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>4</td>
<td>yes</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>6</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>7</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>8</td>
<td>no</td>
<td>no</td>
<td>-</td>
</tr>
</tbody>
</table>

The DNV GL study determined the RUL and EUL for add-on measures by asking the questions shown in Figure 2-20. The purpose of these questions was to make sure the information provided by the customer was as meaningful, accurate, and consistent as possible.

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30 Note that the “new std. eff. add-on” case may not include an add-on at all. For example, the standard efficiency case for many motors is not to use a motor drive but to allow the motor to run by itself. Sometimes customers even replace an existing VFD-driven motor with one that does not have a VFD.
In 30 C&I sites where this interview-based method was employed, the average evaluated EUL for the add-on/O&M measure was 9.1 years. This compared to the average *ex ante* EUL of these measures of 16.6 years. The most common reasons for the reduction of the *ex ante* EULs was that the interviews had determined that the remaining useful life of the host equipment was shorter than the *ex ante* EUL of the add-on equipment and it was very unlikely the add-on equipment would be reused on another piece of host equipment.

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Note that 2 years were added to the final equipment life question response because there was a two-year delay between equipment installation and customer interviews. This time is adjusted accordingly.
HER Programs

For behavioral programs such as Home Energy Report (HER) programs, one method for calculating the EUL depends on two factors: the rate of savings decay after treatment, and the rate of attrition (e.g., customers moving) after treatment.\(^{32}\) If we assume that these rates remain constant over time, then the EUL (in years) for that HER program equals the following:

\[
EUL = \frac{1}{\text{Decay} + \text{Attrition} \ - \ (\text{Decay} \ \ast \ \text{Attrition})}
\]

2.6.5 Key references

The following is a list of the key sources we consulted in the literature review.


CPUC’s Database for Energy Efficient Resources (DEER) 2008 or 2014


GDS Associates, Inc.’s. 'Measure Life Report', June 2007


\(^{32}\) At this time, there is no universally-accepted way to calculate the EUL of HER programs, and what DNV GL provides here is simply one possible method of calculating EUL.
2.6.6 TRM review

As noted, the study the methods to assign EULs, and their sources, for add-on and O&M measures in over 20 TRMs. The methods and sources used to estimate EULs for add-on and O&M measures are listed in Table 2-12.

**Table 2-12. Comprehensive List of TRMs and Their EUL Approaches and Sources**

<table>
<thead>
<tr>
<th>TRM</th>
<th>Approaches for Add-On or O&amp;M EULs</th>
<th>Sources for Add-On/O&amp;M EULs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arkansas TRM 2017 v7</strong></td>
<td>Uses deemed values for EUL for add-on and O&amp;M measures</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td><strong>California Municipal TRM 2017</strong></td>
<td>Uses deemed values for EUL for add-on and O&amp;M measures</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), and independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td><strong>Colorado TRM 2017/2018</strong></td>
<td>Uses deemed values for add-on EULs and deemed or zero values for O&amp;M EULs</td>
<td>Most common sources are estimates with no citations, and independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td><strong>Hawaii TRM 2016</strong></td>
<td>Uses deemed values for add-on and O&amp;M EULs</td>
<td>Most common sources are estimates with no citations</td>
</tr>
<tr>
<td><strong>Illinois TRM 2018</strong></td>
<td>Uses deemed values for add-on and O&amp;M EULs</td>
<td>Most common sources are estimates with no citations, publicly-funded research (DOE, DEER, NYSERDA, etc.), independent analysts' studies (GDS, ERS, KEMA, etc.), trade publications, and other TRMs</td>
</tr>
<tr>
<td><strong>Indiana TRM 2015</strong></td>
<td>Uses deemed values for add-on EULs and O&amp;M measures</td>
<td>Most common sources are estimates with no citations, independent analysts' studies (GDS, ERS, KEMA, etc.), other TRMs, and trade publications</td>
</tr>
<tr>
<td><strong>Iowa TRM 2015</strong></td>
<td>Uses deemed values for add-on and O&amp;M EULs</td>
<td>Most common sources are estimates with no citations, independent analysts' studies (GDS, ERS, KEMA, etc.), publicly-funded research (DOE, DEER, NYSERDA, etc.), other TRMs, and trade publications</td>
</tr>
<tr>
<td><strong>Maine TRM 2018</strong></td>
<td>Uses deemed values for add-on EULs and O&amp;M measures</td>
<td>Most common sources are estimates with no citations, other TRMs, independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>TRM</td>
<td>Approaches for Add-On or O&amp;M EULs</td>
<td>Sources for Add-On/O&amp;M EULs</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Massachusetts TRM 2016-2018</td>
<td>Uses deemed values for add-on EULs and O&amp;M measures</td>
<td>Most common sources are independent analysts’ studies (GDS, ERS, KEMA, etc.), estimates with no citations</td>
</tr>
<tr>
<td>Mid-Atlantic TRM 2018</td>
<td>Uses deemed values (or no values)(^{33}) for EUL for add-on and O&amp;M measures</td>
<td>Most common sources are independent analysts’ studies (GDS, ERS, KEMA, etc.), publicly-funded research (DOE, DEER, NYSERDA, etc.), and other TRMs</td>
</tr>
<tr>
<td>Minnesota TRM 2018</td>
<td>Uses deemed values (or no values) for EUL for add-on and O&amp;M measures</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), other TRMs</td>
</tr>
<tr>
<td>New Jersey TRM 2018</td>
<td>Uses deemed values (or no values) for EUL for add-on and O&amp;M measures</td>
<td>Most common sources are estimates with no citations</td>
</tr>
<tr>
<td>New Orleans TRM 2017</td>
<td>Add-on measures use EUL of host-equipment or one-third of the host and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.)</td>
</tr>
<tr>
<td>New York TRM 2018</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), estimates with no citations, other TRMs, independent analysts’ studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Ohio TRM 2010</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), other TRMs, and independent analysts’ studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Ontario Energy Board TRM 2017</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), other TRMs, independent analysts’ studies (GDS, ERS, KEMA, etc.)</td>
</tr>
</tbody>
</table>

\(^{33}\) “No value”
<table>
<thead>
<tr>
<th>TRM</th>
<th>Approaches for Add-On or O&amp;M EULs</th>
<th>Sources for Add-On/O&amp;M EULs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvania TRM 2017</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), other TRMs, independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Rhode Island TRM 2016</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Texas TRM 2017</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are publicly-funded research (DOE, DEER, NYSERDA, etc.), independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Vermont TRM 2015</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are estimates with no citations, independent analysts' studies (GDS, ERS, KEMA, etc.)</td>
</tr>
<tr>
<td>Wisconsin TRM 2017</td>
<td>Add-on measures and O&amp;M measures use deemed values</td>
<td>Most common sources are estimates with no citations, independent analysts' studies (GDS, ERS, KEMA, etc.), publicly-funded research (DOE, DEER, NYSERDA, etc.), and other TRMs</td>
</tr>
</tbody>
</table>
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