FINAL REPORT

Impact Evaluation of PY2016 Massachusetts Commercial & Industrial Small Business Initiative: Phase I

Massachusetts Program Administrators and Energy Efficiency Advisory Council

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1 EXECUTIVE SUMMARY

This Executive Summary provides a high-level review of key findings from the Impact Evaluation of the 2016 program year of the Massachusetts Commercial and Industrial (C&I) Small Business Initiative, conducted by ERS and DNV GL as part of the DNV GL evaluation team for the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants. In this section, we state the study objectives, summarize the evaluation approach, and present results, conclusions, and recommendations.

1.1 Overview of objectives

The primary objective of this impact evaluation is to quantify the electric energy savings and demand reduction of lighting measures incented by the Massachusetts C&I Small Business (SB) Initiative (hereafter referred to as "the Initiative"). This enables the PAs to assess whether the Initiative is achieving the expected savings, and to identify any recommendations for improvement. Evaluated savings are quantified through on-site inspection, monitoring, and analysis of lighting measures within a sample of custom and prescriptive electric SB projects. This study is the first of two phases in the SB impact evaluation plan; Phase I addresses lighting measures, which represent 90% of the total program-reported kWh savings in 2016. Phase II will address other end-uses.

The evaluation team also developed additional RRs and factors that are described in forthcoming sections of this report:

- Connected kW RR
- Installation rate RR
- Delta watts RR
- Hours of use RR
- Summer and winter on-peak hours and coincidence factors
- % on-peak kWh
- kWh and summer and winter kW HVAC interactive effects

Additional evaluation objectives include:

- Research on how each PA processes custom measures within the SB Initiative.
- Assessment of lighting quality and potential lost opportunities.
- Assessment of potential lost opportunities from lighting control measures, including motion-based occupancy sensors and daylight dimming controls.
- Estimation of the potential impact of early replacement dual baseline methods on program savings, as a dual baseline paradigm is expected to be implemented in 2019.

1.2 Summary of approach

The evaluation team's approach and methodology was consistent with the procedures and protocols developed during the previous round of SB impact evaluation last conducted of the 2010-2011 program years (PY2010-11). This study required onsite visits and metering of lighting hours-of-operation ("HOU") for a randomly selected sample of 105 customer facilities that participated in the Initiative in PY2016. In addition to onsite metering, our team investigated baseline issues, collected a comprehensive inventory of lighting and HVAC characteristics, and gathered additional information related to the objectives identified in Section 1.1. A high-level synopsis of the evaluation approach is as follows:

Sample design. Our team investigated Initiative changes since the PY2010-11 evaluation and determined the customer sample frame to develop a sample design that meets the desired statistical precision targets for key savings parameters such as energy and peak demand savings, as well as other factors such as peak coincidence factors and HVAC interactive effects.

Data collection and analysis. Data collection for this impact evaluation included a physical inspection and inventory of installed products, interviews with facility personnel, observation of site operating conditions and equipment, characterization of HVAC systems, and short-term metering of lighting HOU.

Lighting quality and controls potential. The evaluation team assessed lighting quality by measuring light levels, color rendering index and correlated color temperature reviews, lighting power densities (LPDs), and an assessment of light quality in terms of light levels, light uniformity, and color rendering index. Additionally, to estimate potential savings from missed opportunities related to lighting controls, evaluators identified and characterized manually-controlled fixtures that would be appropriate candidates for automatic lighting control.

1.3 Summary of findings and conclusions

Table 1-1 presents the initiative's final statewide realization rates for kWh, summer and winter peak kW, and connected kW savings, as well as the relative precisions at the specified confidence intervals.

Table 1-1. Final SB Initiative lighting realization rates by savings type

Savings	Statewide RR	Relative Precision
Annual kWh	95.1%	±4.7% (90% confidence interval)
Summer peak kW	90.6%	±2.5% (80% confidence interval)
Winter peak kW	102.8%	±11.8% (80% confidence interval)
Connected kW	97.2%	±1.4% (80% confidence interval)

Evaluators determined that lighting measures in the Small Business Initiative achieved approximately 95% of the reported electric energy savings. Demand savings results varied, with lower evaluated savings than reported for summer kW but higher evaluated savings for winter kW. Table 1-1 also illustrates that, save for the winter peak kW savings, the evaluation team achieved the statistical targets considered in the sample design: ±10% relative precision at the 90% confidence interval for kWh and at the 80% confidence interval for kW. Please note that the RRs in Table 1-1 are not recommended for prospective application; rather, the evaluator's recommended prospective values are discussed in Sections 1.5 and 5.2.

Table 1-2 further examines the kWh RR, dissecting it among five discrepancy categories considered across all site analyses. The discrepancy categories are further defined in Section 4.1. Please note that tracking and reported gross savings are comprehensively defined in Appendix F. In summary, tracking gross savings are defined as the base savings based on fixture quantity, wattage, and operation values (hours of use, coincidence factors). Tracking savings do not incorporate HVAC interactive effects or other final adjustment factors. Reported gross savings, as featured in Table 1-2, involve the product of the tracking gross savings with adjustment factors for prior evaluation results, including HVAC interactive effects.

Table 1-2. Examination of statewide energy realization rate for SB lighting measures

Savings Parameter	Energy - Statewide	
	kWh	% Gross
Gross Savings (Reported)	103,763,076	
Documentation Adjustment	(3,540,016)	-3.4%
Technology Adjustment	4,326,629	4.2%
Quantity Adjustment	(726,346)	-0.7%
Operational Adjustment	(1,687,524)	-1.6%
HVAC Interactive Adjustment	(3,494,815)	-3.4%
Adjusted Gross Savings	98,641,004	95.1%
Gross Realization Rate	95.1%	
Relative Precision	±4.7%	
Confidence Interval	90%	
Error Ratio	0.284	

Section 4.2 examines the key contributors to energy and demand discrepancies by the five categories in Table 1-2. Notable contributors include:

- For some projects, insufficient tracking data led evaluators to attribute savings differences to the **documentation** category.
- Evaluators found differences between the vendors' assumed preexisting fixture wattage and those recommended by the 2013-15 Massachusetts TRM.[1] Overall, evaluators found higher preexisting fixture wattages, leading to additional savings classified as **technology** adjustments.
- In some cases, interactive HVAC impacts were not claimed in spaces determined by the evaluators as mechanically cooled, resulting in **HVAC** discrepancies.
- Some facility types, such as restaurants and meeting halls, featured lower-than-expected **operation** than anticipated by the implementation vendors.

[1] Appendix A Table 56 of the MA TRM contains rated fixture wattage recommendations for a variety of fixture types and sizes. http://ma-eeac.org/wordpress/wp-content/uploads/TRM_PLAN_2013-15.pdf

Table 1-3 presents the statewide savings factors determined in this study. Sections 1.5 and 5.2 further explain the evaluation team's recommendations for applying the results of the evaluation retrospectively and prospectively.

Table 1-3. Statewide factors for SB lighting measures

Savings Parameter	PY2016 Overall (Statewide)	
	Value	Precision at 80% Confidence
Installation Rate (Quantity Adjustment)	99.3%	±0.6%
Delta Watts (Technology Adjustment)	104.2%	±5.8%
Connected kW Realization Rate	97.2%	±1.4%
Summer kW Realization Rate	90.6%	±2.5%
Winter kW Realization Rate	102.8%	±11.8%
Summer Coincidence Factor	57.0%	±14.1%
Winter Coincidence Factor	57.9%	±8.3%
Summer kW HVAC Interactive Effect	108.4%	±1.7%
Winter kW HVAC Interactive Effect	99.4%	±0.8%
kWh Factors (Precisions at 90% confidence)		
kWh HVAC Interactive Effect	102.4%	±6.3%
Hours of Use Realization Rate	98.4%	±3.9%
% On Peak kWh	71.2%	±10.2%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.00408	

1.4 Conclusions

The evaluation team found that the SB Initiative generates significant electric energy savings through its lighting fixture upgrades and controls measures.[2] Table 1-3 shows that the Initiative is reasonably accurate in its parameter-specific assumptions on installation rate, delta watts and hours of operation. Through on-site inventories and metering among a sample of 105 SB facilities upgraded in PY2016, evaluators determined that the Initiative's contractors track the measures comprehensively and clearly. Aside from a small number of anomalous cases, the upgraded fixtures still remain in operation and are well-liked by the customers.

[2] When compared with PY2010-11 evaluation results, this study's kWh RR of 95% was 7% lower; however, PY2010-11 tracking data did not appear to incorporate HVAC interactive savings as comprehensively as PY2016 tracking data, thereby skewing the comparison of results.

The penetration of LED technology in nonresidential settings is growing rapidly. Based on an examination of the measures implemented among the sample of 105 projects assessed in this study, evaluators found that the Initiative has aggressively adopted LED measures, which comprised over 99% of the lighting installations in PY2016. Evaluation results indicate that the Initiative's contractors generally submit realistic savings estimates and have mostly documented their assumptions comprehensively. Nonetheless, the evaluation team has identified recommendations and considerations for the Initiative in this rapidly evolving market, as outlined in the next sections.

With an imminent transition from an early replacement approach to a dual baseline approach for determining lifetime savings in Massachusetts, evaluators assessed the impact of this transition to lifetime savings. Assuming a 15-year effective useful life (EUL) for lighting measures[3] and a remaining useful life (RUL) of 5 years (33% of EUL), with a placeholder "out-year factor" of 60%[4], evaluators estimate that the dual baseline approach reduces lifetime savings by 15% as compared with the lifetime savings from the traditional retrofit/early replacement single baseline approach assuming a reduced 13-year EUL. Table 1-4 illustrates a comparison between the traditional lifetime savings approach and the dual baseline approach expected to be adopted soon. Other concurrent studies—P75 for the out-year factor and P73D for RUL—should provide market and lifetime data that better inform this assessment; however, at the time of this writing, these studies' results were not fully available for incorporation in this analysis.

Table 1-4. Comparison of SB lifetime kWh savings: early-replacement vs. dual baseline

Parameter	Evaluated Gross Lifetime Savings Comparison	
	Traditional Lifetime Savings	Dual Baseline Savings
Gross first-year kWh savings (reported)	103,763,076	103,763,076
kWh realization rate	95.1%	95.1%
Gross first-year savings (evaluated)	98,641,004	98,641,004
Effective useful life (EUL)	13	15
Remaining useful life (RUL)	N/A	5
Out-year factor	N/A	60%
Evaluated gross lifetime savings (kWh)	1,282,333,052	1,085,051,044

Section 4.3 provides additional explanation behind the lifetime savings calculation.

To further aid the Initiative in maximizing savings in future program years, evaluators assessed missed savings opportunities of two types—potential wattage reduction due to over-illumination and additional savings from automatic controls measures. Evaluators found average foot-candle readings higher than recommended for two major usage classifications, detailed further in Section 4.4 and Appendix D. Significant additional savings (12% of PY2016 reported kWh) could be realized from the over-lit usage groups if the lumen output was adjusted to reflect the mid-point of the foot-candle range recommended by the Illuminating Engineering Society of North America (IESNA). Such adjustment could occur through the installation of lower-lumen-output lamps and ballasts and/or the installation of dimming or tuning controls. The evaluation team encountered barriers to customer adoption of lower illumination levels—primarily, customers are generally satisfied with their existing lighting and are concerned about negative impacts to

[3] Per 2016-18 Massachusetts TRM – Plan Version, http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf

[4] Per P73A Portfolio Model Methods and Assumptions – Electric and Natural Gas memorandum. The "out-year factor" reflects changes in industry standard practice at the time of remaining useful life expiration.

business from reduced light levels. However, customers also indicated that they generally defer to contractors for best practices on lighting technology and illumination levels. Contractor training to recognize, sell, and implement more aggressive illumination reduction and control strategies will be critical to surpassing these barriers and achieving these additional savings.

For automatic controls, evaluation field staff identified occupancy sensors as the most prominent candidate, particularly among space types such as offices, storage rooms, and bathrooms. Evaluators estimated that the total potential savings for occupancy sensors amounted to approximately 1.5% of PY2016 program-reported savings.

1.5 Recommendations

This section presents recommendations from this study. Recommendations are organized by:

- Retrospective application of results (PY2018)
- Prospective application of results (PY2019 and beyond)
- Process-related recommendations
- Future research recommendations

This evaluation study generated savings factors for lighting measures that are recommended for adoption by the Initiative, both retrospectively and prospectively. To provide context on how the PAs calculate savings, and subsequently how the evaluation findings might be incorporated, Appendix F provides an overview of the savings algorithms and parameter definitions inherent within current PA tracking data.

1.5.1 Retrospective application of results

For retrospective application of evaluation results to PY2018, we recommend that the PAs apply the RRs in Table 1-5 to **reported** gross kWh and peak kW savings to fully incorporate the findings from this study. Section 5.2.1 contains additional information on retrospective application of factors, and Appendix F provides a definition of reported gross savings as compared with tracking gross savings.

Table 1-5. Final retrospective lighting realization rates for the Initiative for PA use (PY2018)

Savings Parameter	Formula Term	Retrospective Recommended Value	Relative Precision at Specified Confidence Interval
Gross Energy (kWh) Retrospective RR	$RR_{r,kWh}$	95.1%	±4.7% (90% confidence)
Gross Summer Peak Demand Retrospective RR	$RR_{r,skW}$	90.6%	±2.5% (80% confidence)
Gross Winter Peak Demand Retrospective RR	$RR_{r,wkW}$	102.8%	±11.8% (80% confidence)

1.5.2 Prospective application of results

Acknowledging that the PAs' tracking protocols and preferences might vary, the evaluation team has identified two options for the PAs to prospectively apply evaluation results. The two mutually-exclusive options are detailed in the next sections.

Regarding lighting controls, the evaluation team recommends that the results from the prior lighting controls-specific study (2014)[5] are continued to be applied by the PAs. This study's population (PY2016) featured only 1% kWh savings contribution from lighting controls, and the evaluation sample design subsequently did not segment specifically for lighting controls; rather, overall statewide results were determined for SB lighting measures altogether. Therefore, we do not recommend application of any results from this evaluation study to controls measures moving forward. The factors tabulated in Sections 1.5.2.1 and 1.5.2.2 should be prospectively applied to lamp and/or ballast replacement measures only.

1.5.2.1 Wholesale approach

The wholesale option involves the application of prospective RRs directly to **tracking** gross savings, *not* to the reported gross savings, as the prospective RRs in Table 1-6 incorporate the HVAC interactive effects factors (see Table 1-3) as well as any non-HVAC adjustments determined through evaluation (see Table 1-2). The equations below illustrate the application of prospective wholesale factors to tracking gross savings.

$$Evaluated\ Gross\ kWh\ Savings = Tracking\ Gross\ kWh\ Savings \times RR_{p,kWh}$$

$$Evaluated\ Gross\ kW\ Savings_{Summer} = Tracking\ Gross\ kW\ Savings_{Summer} \times RR_{p,skW}$$

$$Evaluated\ Gross\ kW\ Savings_{Winter} = Tracking\ Gross\ kW\ Savings_{Winter} \times RR_{p,wkW}$$

Table 1-6. Final prospective lighting RRs for the Initiative for PA use (2019 and beyond)

Savings Parameter	Formula Term	Prospective Recommended Value
Gross Energy (kWh) Prospective RR	$RR_{p,kWh}$	100.9%
Gross Summer Peak Demand Prospective RR	$RR_{p,skW}$	92.7%
Gross Winter Peak Demand Prospective RR	$RR_{p,wkW}$	102.4%

PA tracking databases and benefit-cost calculator templates appear to accommodate such prospective RR factors. These values should replace the 102%, 100%, and 100% small C&I lighting measure RRs for kWh, summer peak kW, and winter peak kW, respectively, previously recommended to the Initiative.

1.5.2.2 Individual factor approach

As an alternative to the above method, we recommend that the PAs replace individual factors within their tracking systems factors with evaluated factors, as illustrated in the following fixture savings formulas:

$$Evaluated\ Gross\ kWh\ Savings = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times HOU_{Tracking} \times RR_{HOU} \times HVAC\ Interactivity_{kWh}$$

[5] Retrofit Lighting Controls Measures Summary of Findings. DNV GL. 2014. http://ma-eeac.org/wordpress/wp-content/uploads/Lighting-Retrofit-Control-Measures-Final-Report.pdf

$$Evaluated\ Gross\ Peak\ kW\ Savings_{Summer} = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times CF_{Summer} \times HVAC\ Interactivity_{skW}$$

$$Evaluated\ Gross\ Peak\ kW\ Savings_{Winter} = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times CF_{Winter} \times HVAC\ Interactivity_{wkW}$$

where,

$Conn.kW\ Savings_{Tracking}$ = Connected kW savings claimed by implementer

$HOU_{Tracking}$ = Hours of use (HOU) claimed by implementer

The remaining savings factors are provided in Table 1-7 below: the proposed new peak demand savings factors, HVAC interactive effects factors, and RRs for HOU and connected kW.

Table 1-7. Proposed new savings factors for prospective use (PY2019 and beyond)

Savings Factor	Formula Term	Prospective Recommended Value	Relative Precision at Specified Confidence Interval
Connected kW RR	$RR_{Conn\ kW}$	97.2%	±1.4% (80% confidence)
HOU RR	RR_{HOU}	98.4%	±3.9% (90% confidence)
kWh HVAC Interactive Factor	$HVAC\ Interactivity_{kWh}$	102.4%	±6.3% (90% confidence)
Summer CF	CF_{Summer}	57.0%	±14.1% (80% confidence)
Winter CF	CF_{Winter}	57.9%	±8.3% (80% confidence)
Summer kW HVAC Interactive Factor	$HVAC\ Interactivity_{skW}$	108.4%	±1.7% (80% confidence)
Winter kW HVAC Interactive Factor	$HVAC\ Interactivity_{wkW}$	99.4%	±0.8% (80% confidence)

Using the individual factor approach, evaluation results would be reflected within all tracking savings estimates and would not require wholesale application of prospective RRs.

1.5.3 Initiative process recommendations

Standardized TLED wattages. The PAs should work with vendors to standardize how savings from tube LEDs (TLEDs), in particular "plug and play" TLED retrofits of fluorescent fixtures, are classified and tracked. As TLEDs were emerging when the 2013-15 MA TRM was completed, its standard fixture wattage table does not address TLEDs; therefore, evaluators found variation among vendors in how TLED fixture wattage was estimated. Many such TLED projects were classified as "custom" simply because no appropriate measure code was available in prescriptive templates. Evaluators often found differences between the vendor's fixture wattage assumption and that determined from DesignLights Consortium (DLC) reference and/or independent review of the manufacturer's specification sheets, particularly for "plug and play" TLED retrofits that reuse the preexisting fluorescent ballasts. Evaluators found that approximately 20% of TLED installations in the PY2016 sample were "plug and play," with the remainder of TLEDs classified as a whole-fixture replacement (new lamps and ballast). The PAs should provide more comprehensive guidance to vendors on when to classify fixtures as prescriptive or custom, how to estimate custom fixture wattages appropriately (e.g., through DLC reference), and which supporting documentation should be included in the application.

1.5.4 Future research recommendations

Dual baseline lifetime savings. In 2019, Massachusetts will transition to a dual baseline approach for calculating lifetime savings. This study estimated the impacts of such a transition to dual baseline lifetime savings but referenced a placeholder out year factor of 60%. The P75 LED Market study will provide more accurate and granular data on the anticipated C&I LED market as compared with existing technologies. Additionally, the P73D study may provide more Massachusetts-specific research on remaining useful life (RUL) for C&I lighting systems. This information should be paired with the granular, fixture-level evaluation data available from this study to refine the lifetime savings impact.

Phase II: non-lighting measures. As this study represents only Phase I of the Small Business Initiative impact evaluation, we recommend that Phase II is executed as soon as possible. This study examined performance of only lighting measures (fixtures and controls), but as the penetration of LEDs grows rapidly, the Initiative must look to non-lighting technologies to diversify their measure offerings and compensate for more limited lighting fixture savings in future program years. Phase II should include an assessment of potential non-lighting opportunities among major measure categories such as refrigeration, HVAC, envelope, and DHW.

1.6 Considerations

Lighting controls savings tracking. Consider more standardized protocols for reporting and tracking controls-only measures. Within the PY2016 data, evaluators found two primary methods used by the PAs to track lighting controls savings: (1) embedding controls savings in the same tracking line item as associated fixture savings, and (2) separating the controls-only savings in a different line item. Option (2) is recommended, as it minimizes the risk of double-counting savings, as long as the post-fixture-upgrade wattage is used in the controls savings calculation. Relatedly, the PAs should also consider implementing within application spreadsheets a flag that indicates when connected kW savings are claimed for controls-only measures. Evaluators found multiple cases of connected kW claimed for occupancy sensor measures, which strictly reduce run-time fixture operation, not wattage. However, we acknowledge that such an approach may be necessary within the tracking systems to claim any peak kW savings. As the Small C&I Initiatives continue to adopt more lighting operational measures, we recommend that the PAs standardize the tracking of controls savings among its contractors and carefully confirm that any tracked connected kW claims are not leading to savings double-counting.

Operating hours assumptions. The Initiative allows the implementation vendors to claim fixture operating hours based on site-specific data collection. The program-level results of this evaluation indicate generally accurate operating hours assumptions—the overall operation adjustment resulted in only a 1.6% reduction in kWh savings. Therefore, we recommend that this site-specific operating hours approach is continued. However, should the Initiative or its contractors rely on the MA TRM for operating hours assumptions, we recommend that the facility-level results of this study (Table 4-3) are considered and possibly pooled with other C&I lighting studies' data as the TRM is continually updated.

Light level reduction savings potential. Consider more comprehensive training for implementation contractors to (1) identify overly high illumination levels; (2) explain and sell the reduced-lumen system to the customer, emphasizing how sufficient lumen levels are maintained for specific tasks; and (3) properly install lower-lumen-output lighting and/or controls when appropriate. The Initiative should consider standardizing the contractors' on-site protocols to include assessment of light levels and lighting quality. Our study found significant savings potential, representing 12% of program-reported kWh in PY2016, for light level reduction among two IESNA task types: B (e.g., storage, mechanical room, restaurants) and C (e.g., hallways, restrooms, offices, common areas). The success of such lumen reduction strategies is highly dependent on the contractor's ability to identify such opportunities and properly adjust the system output to maintain customer satisfaction. It may be possible to implement such lumen reduction measures prescriptively and with minimal customer disruption, for example by replacing ballasts and lamps with lower-lumen-output equivalents when appropriate.

Controls savings potential. Implementation vendors should more frequently implement occupancy sensor controls options for fixtures in intermittently used spaces that might feature unnecessarily high run hours. Such spaces include enclosed offices, conference rooms, storage areas, and bathrooms, per our research discussed in Section 4.5.

2 INTRODUCTION

This document presents the final report for the Impact Evaluation of the Massachusetts Commercial and Industrial (C&I) Small Business (SB) Initiative, also referred to as “the Initiative” in this document. As part of the DNV GL evaluation team, ERS and DNV GL completed this study for the Massachusetts electric Program Administrators (PAs) with the guidance of the Massachusetts Energy Efficiency Advisory Council (EEAC) Consultants.

2.1 Background

The Massachusetts SB Initiative is one of the delivery methods used by PAs to increase the market penetration of energy-efficient technologies among small commercial and industrial customers. The Initiative leverages vendors under contract with the PAs to provide turnkey services for recruiting customers, identifying and implementing energy efficiency opportunities, processing incentives, and estimating energy and demand savings per project. All four electric PAs and six natural gas PAs in the state are participating in the Initiative with a limited number of vendors under contract with one or more PAs.

The Initiative’s efficiency measure offerings for electric customers primarily consist of retrofits to facility lighting systems, such as replacing fixtures and ballasts and installing lighting controls, but also include measures for refrigeration, HVAC, and other systems. Some PAs offer on- and/or off-bill financing options to help customers finance their share of the cost of installing improvements. PAs offer incentives up to 80% of the total project costs.

In 2016, the SB Initiative contributed 8% of the statewide annual electric energy and summer peak demand savings, as reported in the PAs’ 2016 Energy Efficiency Annual Reports.[6] The four electric PAs—Cape Light Compact (CLC), Eversource Energy, National Grid USA, and Unitil—offer measures to their small business electric customers.

The SB Initiative offers both custom and prescriptive measures. As an initial information-gathering exercise, the evaluation team interviewed PA implementation staff on how each PA classifies measures as custom or prescriptive. The PY2010-11 evaluation included prescriptive lighting measures only, but not custom measures. That evaluation studied non-control lighting measures and found that this group of measures achieved a realization rate of 102% for electric energy.[7] A C&I lighting controls evaluation study was completed in 2014 and included small business customers.[8]

2.2 Study objectives

The primary objective of this impact evaluation is to quantify the electric energy savings and demand reduction of lighting measures incented by the Massachusetts C&I Small Business Initiative. Evaluated savings are quantified through on-site inspection, monitoring, and analysis of lighting measures within a sample of custom and prescriptive electric SB projects. As savings from lighting measures represent a

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6 Per PA 2016 annual reports found on the Massachusetts Energy Efficiency Advisory Council website, http://ma-eeac.org/results-reporting/annual-reports/. Please note that savings shares reflect evaluated savings in 2016 only.

7 Non-Controls Lighting Evaluation for the Massachusetts Small Business Direct Install Program: Multi-Season Study. The Cadmus Group. 2012. http://ma-eeac.org/wordpress/wp-content/uploads/Non-Controls-Lighting-Evaluation-for-the-Massachusetts-Small-Business-Direct-Install-Initiative-Multi-Season-Study.pdf

8 Retrofit Lighting Controls Measures Summary of Findings. DNV GL. 2014. http://ma-eeac.org/wordpress/wp-content/uploads/Lighting-Retrofit-Control-Measures-Final-Report.pdf

significant majority of SB savings,[9] only lighting measures are assessed in Phase I of the SB impact evaluation.

Section 4.1 provides the statewide realization rates for SB energy efficiency lighting and lighting controls measures, both custom and prescriptive, for customers implementing lighting upgrades in 2016. The evaluation team also developed additional RRs and factors that are described in forthcoming sections of this report:

- Connected kW RR
- Installation rate RR
- Delta watts RR
- Hours of use RR
- Summer and winter on-peak hours and coincidence factors
- % on-peak kWh
- kWh and summer and winter kW HVAC interactive effects

Additional evaluation objectives include:

- Assessment of how each PA handles custom measures, both lighting and non-lighting, within the SB Initiative. In 2015, DNV GL completed a SB process evaluation. In that process evaluation, which studied the 2013 program year, it was found that there were some inconsistencies in how PAs tracked savings either by measure type or by track (prescriptive/custom). This evaluation included discussions with PA implementers to inquire about program tracking prior to this work plan.
- Assessment of lighting quality and potential lost opportunities associated with lighting measures through the measurement of light levels, visual assessment of color rendering index (CRI) and correlated color temperature (CCT) specifications reviews, calculation of lighting power densities, and an assessment of light quality in terms of light levels, glare, light uniformity, and CRI.
- Assessment of potential lost opportunities from advanced lighting control measures, including motion-based occupancy sensors and daylight dimming controls.
- Estimation of the potential impact of a dual baseline approach to calculating lifetime savings, as a dual baseline paradigm is expected to be implemented in 2019.

[9] Per PY2016 SB initiative tracking data, lighting comprised over 90% of total program kWh savings (prescriptive and custom combined, controls included).

3 METHODOLOGY

The evaluation team's approach and methodology was consistent with the procedures and protocols developed during the previous round of SB impact evaluation last conducted on program years 2010 and 2011. As described in the next sections, the impact evaluation involved on-site visits and metering of lighting hours of use for a randomly selected sample of projects at participating small businesses.

3.1 Determining the customer sample frame

Table 3-1 presents the electric savings for the 2016 Small Business Initiative. A total of 3,627 accounts participated in the Initiative in 2016, producing an estimated 111,513 MWh of annual energy savings.

Table 3-1. 2016 PY small business energy savings by end use

End-Use	Custom		Prescriptive		Total	
	kWh	%	kWh	%	kWh	%
Building Shell	0	0%	3,672	0%	3,672	0%
Hot Water	24,604	0%	162,505	0%	187,109	0%
HVAC	1,353,964	3%	901,128	1%	2,255,092	2%
Lighting	35,545,974	85%	66,545,682	95%	102,091,655	92%
Lighting Controls	118,059	0%	851,211	1%	969,271	1%
Motors/Drives	283,868	1%	409,156	1%	693,024	1%
Other	256,087	1%	53,237	0%	309,324	0%
Process	827,165	2%	51,210	0%	878,375	1%
Refrigeration	2,669,251	6%	896,537	1%	3,565,788	3%
Refrigeration Lighting	500,367	1%	59,753	0%	560,121	1%
Total	**41,579,340**	**100%**	**69,934,091**	**100%**	**111,513,430**	**100%**

The majority of these savings (63%) is from prescriptive measures with the balance from custom measures. Lighting savings dominate SB activity, representing more than 94% of savings when refrigeration lighting[10] is included.

3.1.1 Comparison of prescriptive and custom projects

A preliminary review of the specific measures installed and savings calculation methodologies combined with interviews with the PAs, found little difference in lighting measures characterized as prescriptive versus custom in the tracking data.

In the process of planning this study, the evaluation team consulted implementers from three PAs to inquire about their tracking methods and treatment of prescriptive and custom lighting measures. All PAs noted a transition to LED fixtures, which was not as prevalent in the prior PY2010-11 impact evaluation. All three PAs also confirmed that the majority of their custom SB lighting projects were similar to prescriptive in how the savings are estimated. For the most part, lighting projects that get tracked as custom do so because they do not have the exact product codes (often LED) in their prescriptive measure lists. According to

10 LED cooler or freezer case lights of various watts and lengths.

National Grid, the measure lists were planned to be updated in 2017, so that their vendors can more consistently enter all products into the prescriptive applications.

The evaluation team also reviewed a very small sample of custom lighting project files to confirm the savings calculations match the prescriptive lighting calculations. In this preliminary assessment of a selection of 13 sets of project files, no significant differences in savings calculation methods were observed among PAs. For these reasons, the evaluation sample was designed to develop statewide results, and custom and prescriptive lighting were combined in the sample design.

3.2 Sample design

Table 3-2 presents the tracked energy and peak demand savings by Program Administrator (PA) for all lighting measures (including de-lamping and refrigerator lighting) reported in 2016.

Table 3-2. PY2016 lighting energy and peak demand savings by PA

Administrator	Accounts	Energy (kWh)	Summer Peak Demand (kW)	Winter Peak Demand (kW)
CLC	150	968,417	241	145
Eversource	1,886	59,066,310	10,632	6,336
National Grid	1,506	42,250,598	9,009	5,665
Unitil	84	1,477,749	318	241
Total	**3,626**	**103,763,076**	**20,200**	**12,386**

The primary goal of this sample design was to determine the annual energy savings impacts of lighting activity in PY2016 with ±10% precision at the 90% confidence interval at the state level. This sample design established the need for 100 sites, equally distributed across five strata, to achieve the desired precision around energy savings. An alternative design was developed to estimate summer peak demand savings impacts with ±10% precision at the 80% confidence interval at the state level which is related to the ISO-NE FCM portfolio precision requirement This design offered 105 sites, equally distributed across five strata, to achieve the desired precision around summer peak demand savings. The PAs and EEAC decide to pursue the latter option to target both 90/10 around energy and 80/10 around summer peak demand.

The evaluators used Model Based Statistical Sampling (MBSS) techniques (described in greater detail in Appendix A) to develop the sample design; assuming an error ratio of 0.8 and defining the sampling unit as an account (i.e., a facility as opposed to a project application). The 0.8 error ratio was estimated based upon the results of the prior PY2010-11 SB lighting impact evaluation. Table 3-3 shows the resulting on-site sample design. The first column shows the strata number while the second column indicates the maximum site level savings in that stratum. The third column totals the number of sampling units (accounts) in each stratum. The fourth column shows the number of sites in the sample. The sample size required to achieve the 80/10 summer peak demand precision threshold was 105 sites, divided evenly among the five strata. The final column of Table 3-3 presents the case weights that were used to extrapolate the savings estimates for the on-site sample to the population estimates.

Table 3-3. On-site sample design by stratum

Stratum	Maximum Savings (kWh)	Maximum Savings (Summer kW)	Sampling Units (Accounts)	Sample Size	Case Weight
1	174,105	2.76	1,848	21	88.0
2	63,388	5.55	784	21	37.3
3	160,124	10.48	486	21	23.1
4	228,894	20.11	336	21	16.0
5	876,619	138.30	172	21	8.2
Total			**3,626**	**105**	**-**

Please note that, within Stratum 1, there were two projects that consisted almost entirely of exterior lighting measures and therefore featured low summer kW savings but comparatively high kWh savings. While the sample was initially designed on kWh savings, the evaluation team assessed the initial sample design's likelihood of achieving the 80/10 confidence/precision target for summer peak kW savings. As the two exterior lighting sites were found to skew the higher savings strata's kW savings values, the evaluation team decided to classify those two anomalous projects into Stratum 1.

3.2.1 Recruitment and sample replacements

Sites were recruited via telephone and email (when available). Judging that advance letters would be more beneficial than participation incentives, we sent an advance letter of introduction prior to recruitment, and did not budget for incentives. Recruitment was limited to five attempts per customer. If after five attempts no contact was made and our phone messages and emails were not returned, the site was replaced by a similar-stratum site from the back-up sample. Table 3-4 presents the final disposition of the recruitment calls based on the disposition codes provided in The American Association for Public Opinion Research's (AAPOR) Standard Definitions[11]. Based on the AAPOR algorithms, we calculated a 77.8% response rate and an 11.8% refusal rate for the on-site recruitment; therefore, we do not estimate non-response bias to be significant for this study.

Table 3-4. Final on-site visit recruitment disposition

Code	Disposition Description	Total
1.1	Complete	105
2.1	Refusal	14
2.2	Non-Contact	34
Total Customers Called		**153**

3.3 Data collection and analysis

Data collection for the impact work included physical inspection and inventory, interviews with facility personnel, observation of site operating conditions and equipment, and short-term metering of lighting HOU. Evaluators attempted to determine pre-existing fixture characteristics from interviews with facility staff while performing the onsite data collection. Our data collection instrument is included in Appendix B. We retained several components from the PY2010-11 evaluation, and added additional questions to address baseline topics related to preexisting operating condition and remaining useful life.

[11] http://www.aapor.org/AAPOR_Main/media/publications/Standard-Definitions20169theditionfinal.pdf.

The evaluation team combined the data gathered during the site visit with the tracking data provided by the PAs to estimate gross savings realization rates for annual kWh, annual hours of use, delta watts, HVAC interactive effects, and summer and winter peak coincidence factors. All reporting at this level was sample-weighted and statistically representative of the population or appropriate population sub-groups; post-stratification was performed based on our sample design.

Our overall measurement and evaluation plan is detailed below.

3.3.1 Measurement, verification, and analysis methodology

A key task in the onsite engineering assessment was the installation of measurement equipment to aid in the development of independent savings estimates. The type of measure influences the measurement strategy used. In the context of an energy analysis, most efficiency measures can be characterized as either time-dependent or load-dependent. Time-dependent equipment typically runs at constant load according to a time-of-day operating schedule. Mathematically, hour-of-day and day-of-week operation are usually the most relevant variables in the energy savings analysis of these measures.

Lighting is most prevalently a time-dependent measure. Therefore, the evaluation team deployed a variety of time-of-use loggers to characterize the operation of upgraded lighting fixtures, as further detailed in Section 3.3.3.

3.3.2 Verification

Each site visit consisted of the verification of installed equipment, a discussion with facility personnel regarding the baseline characteristics of the measure,[12] and the collection and analysis of monitored data. Once on site, evaluators collected data to calculate savings estimates for lighting measures that were incentivized by the SB Initiative, including an inventory of the measures installed. If the rebated measure(s) were removed, we noted the reasons for removal.

Evaluators also gathered information on measure operating characteristics and general building operation characteristics, including information on heating and cooling systems to assess interactive effects. Field personnel collected data on post-project lighting controls, per the data collection form included as Appendix B. Information on the preexisting or baseline conditions was collected to increase the accuracy of savings calculations. To gather this, the field auditor sought to identify the person who is most knowledgeable about the lighting at each facility to ask questions, such as the following:

- What are the characteristics (type, wattage) of the lighting fixtures that were replaced by the rebated fixtures?
- Do you have any of these old bulbs/fixtures in storage for us to look at?
- Is there a part of your facility that still has similar old bulbs/fixtures in place?
- Is there an untreated space that is similar to the upgraded space we have looked at together?
- For fixtures with rebated lighting controls: What was the typical operational schedule for the fixtures before the controls were installed? Did the schedule vary seasonally or over the course of a year?

In order to capture whether the lighting upgrades are appropriately classified as retrofit or new construction, field auditors investigated whether the installation was part of a major renovation (i.e., ceiling grid removed, terminal air-conditioning units replaced, studs exposed, etc.) that would trigger a code baseline. In addition, field auditors interviewed the project contact(s) on reasons for the lighting upgrade, seeking to determine if

12 Additional questions since the PY2010-11 evaluation were added to the data collection instruments in order to better assess baseline issues raised during PA/EEAC discussions.

there any other site-specific reasons (e.g., systematic failure or incipient failure of overall lighting systems) may not have constituted a retrofit. Of the sample of 105 projects assessed in this study, evaluators determined that only one warranted a code baseline, as the lighting upgrade occurred during a major renovation. For this one project, the evaluated baseline reflected the latest code requirements and evaluation research[13] for lighting power density in commercial spaces.

In anticipation of future study needs, field auditors investigated the age and condition of the pre-existing lighting systems when they were replaced, along with a reliability indicator. This information could be helpful to inform remaining useful life (RUL) moving forward, as the recently completed Baseline Framework[14] suggests a move to a dual baseline approach for early replacement measures. Results on the evaluation team's survey findings related to baseline and RUL can be found in Appendix C.

3.3.3 Monitoring

Time-dependent measures typically call for the installation of time-of-use (TOU) lighting loggers[15] to measure hours of use. These small devices use specialized sensors – photocells in the case of lighting measures – to sense and record the dates and times that a device turns on and off. This TOU data was used to support the savings assessment of rebated fixtures and controls in two key ways:

1. To develop summer and winter peak coincidence factors
2. To develop annual hours of use

The measure scope influenced the appropriate number of loggers and systems monitored for each site. Factors that drove the number of installed loggers include the number of unique usage areas at the site, expected energy savings for each usage area, and the anticipated level of variation among the schedules within a particular usage area. When a project included more than fifteen unique measures and/or usage groups, evaluators relied on statistical sampling tools to most optimally deploy loggers among a selection of impacted lighting circuits.

Evaluators planned for each of the 105 sampled sites to include a minimum of 3 months of data collection. In some atypical cases, evaluators retrieved the loggers earlier than 3 months, due to seasonal business operation or other request from the customer. The data collection period commenced in August 2017, thereby including at least a month of summer operation.

3.3.4 Dual baseline assessment

The Baseline Framework identifies a rigorous process for evaluators to classify measures and, hence, assign them baselines. As part of this evaluation study, additional research was conducted to estimate the potential impact of a dual baseline approach on lifetime savings for small business lighting measures. Since it is likely in 2019 that all of the SB measures, except for controls and the rare cases of new construction/major renovation, will be treated as early replacement measures, this additional research focused on the dual baseline calculations required for early replacement measures. The dual baseline calculations require the parameters described in Table 3-5.

[13] The evaluation baseline also incorporated the findings from the recently completed P70 Code Compliance study.

[14] http://ma-eeac.org/wordpress/wp-content/uploads/MA-Commercial-and-Industrial-Baseline-Framework.pdf

[15] The evaluation team found that a small selection of rebated fixtures required performance measurement at the electric panel through the use of current transformers (CTs) deployed by qualified electricians. Such fixtures include those with dimming capability or otherwise inaccessible fixtures (e.g., high ceiling height).

Table 3-5. Dual baseline parameter sources and notes

Dual baseline parameter	Source in estimating impact of dual baseline	P69 research
Effective useful life (of new technology)	TRL Typically, 15 years for most lighting technologies	Gather site based data on the age and expected life of the previous equipment. The EUL of interest is that of the new equipment; however, past practices may inform expectations for the new equipment.
Remaining useful life	Apply default of EUL*33%	Related to the EUL, gather site based data on the additional years of service the customer expected from the old equipment.
Annual first period savings	Difference between existing and installed equipment	One of the primary outputs of P69. Used in calculating RR%.
Annual second period savings	Difference between future ISP and installed equipment	To eventually be informed by P75 LED Market study, which was incomplete at the time of this writing. This study's estimate references a 60% out-year factor from the P73A Portfolio Model Methods and Assumptions study.

Methods for determining effective useful lives and remaining useful lives are part of the scope of the P73D study. Nonetheless, the evaluation team gathered data related to equipment life in this study to enrich that study's more extensive research to support better estimates of these values; results from this data collection can be found in Appendix C. In order to provide an estimate of the savings difference between the early replacement baseline (the prior approach) and dual baseline (the new approach), Section 4.3 outlines a global dual baseline savings analysis for all projects sampled for this study.

3.3.5 Site analysis

Evaluators analyzed the data collected from TOU lighting loggers to develop TOU load profiles and estimate total run times during the monitoring period. Short-term metered data, like that obtained from the typical 3-month period used in this study, poses challenges in accurately expanding the data from the monitored period to a typical year or to specific periods of interest that do not coincide with the monitoring period (e.g., summer peak demand if metering is not done in the summer). In determining lighting schedules from TOU data, annual trends such as seasonal effects (e.g., daylight savings), production, and occupancy or sales fluctuations were assessed to the extent supported by the data. As a general rule, visual inspection of TOU data revealed explicable patterns that agree with other data sources, such as a retail facility's posted open hours. Each site visit included a detailed interview with the site contact to gather information that will be used to assist in the expansion of the short-term metered data.

The evaluation sample featured some projects with automatic lighting controls measures—most predominantly, motion-based occupancy sensors. For such measures, the pre-project operating profile differs from the post-project operating profile. The evaluators were able to determine the latter through on-site M&V, but the former required one of three derivation techniques, in order of preference:

- **Proxy profile** – The evaluators referenced a metered operating profile for a manually controlled fixture corresponding to a similar usage group. For example, if half of a participating office facility's enclosed offices received occupancy sensors while the other half did not, the other half's metered lighting operation was assumed to reflect the pre-project profile for the fixtures with occupancy sensors.
- **Higher-use baseline** – The evaluators analyzed the post-project profile's typical start and end times, as well as the maximum hourly lighting operation observed over any hour in a typical day, to estimate the pre-project, manually controlled operation. With this technique, the baseline profile features the maximum hourly operation applied to all hours between typical start and end times.
- **On-site interview** – The evaluators collected information from the facility representative on pre-project fixture operation. For example, if a warehouse previously activated and deactivated fixtures at the start and end of a shift, respectively, the evaluators assumed that the pre-project fixture operation reflected this schedule.

The data gathered on-site was compiled into site-specific spreadsheets for analysis. The savings were calculated as line-by-line comparisons of pre- and post-retrofit electrical use. Pre- and post-retrofit energy estimates were developed for each line item within each measure. Interactive cooling and heating effects of the installed measures were also calculated, utilizing engineering algorithms and site-specific HVAC characteristics where applicable. This component of the savings is described in further detail in the following section.

All analyses included an identification and quantification of discrepancies between the tracked and gross savings according to each adjustment categories, including: documentation/adherence to the TRM, technology, quantity, operation, and HVAC interaction.

3.3.6 HVAC interactive effects

When lighting equipment converts electrical energy to light, a significant amount of that energy is dissipated in the form of heat. Energy efficient lighting measures use less electrical energy for light thus giving off less to heat. Since installing energy efficient lighting adds less heat to a given space, a complete estimation of energy savings considers the associated impacts on the heating and cooling systems, or "HVAC interactive effects."

The HVAC interactive effects take into account the effect of the energy efficient lighting measures on their corresponding heating and cooling systems. Energy efficient lighting serves to reduce the heat gain to a given space and accordingly reduces the load on cooling equipment. However, this reduced heat gain has the added consequence of increasing the load on the heating system.

As part of the on-site methodology, evaluators interviewed facility personnel to ascertain the cooling and heating fuel, system type, and other information with which to approximate the efficiency of the HVAC equipment serving the space of each lighting installation. Field staff attempted to physically inspect HVAC equipment and gather nameplate data whenever possible. The evaluation team expressed the HVAC system efficiency in dimensionless units of coefficient of performance (COP), which reflects the ratio of work performed by the system to the work input of the system. Table 3-6 details the COP assumptions for general heating and cooling equipment types encountered in this study. Where site-specific information yields improved estimates of system efficiency, these were used in place of the general assumptions below.

Table 3-6. General heating and cooling COP assumptions

Cooling system type	COP
Packaged direct expansion (DX)	2.9
Window DX	2.7
Chiller < 200 ton	4.7
Chiller > 200 ton	5.5
Air-to-air heat pump	3.9
Water-to-air heat pump	4.4

Heating system type	COP
Air-to-air heat pump	1.5
Electric resistance	1.0
Water-to-air heat pump	2.8
Hot Water Boiler	0.77
Infrared	0.85
Steam Boiler	0.72
Warm Air	0.74
Unit Heater	0.75

Interactive effects are calculated at all sites where heating or cooling systems are in use, based on typical hourly outdoor air temperature and customer survey data on typical HVAC system operation by month of year and hour of day. Leveraging the 8,760 profile of hourly demand impacts, the evaluation team computed interactive effects during the hours that lighting and HVAC systems are assumed to operate in unison.

Evaluators utilized the Typical Meteorological Year 3 (TMY3) hourly dry-bulb temperatures for the weather station closest to each evaluated site as the balance-point criteria in this analysis. For each hour in a typical year, the evaluation team computed HVAC interaction according to the following equations:

Cooling kW Effects = 80% * Lighting kW Savings / Cooling System COP

Heating kW Effects = -80% * Lighting kW Savings / Heating System COP

The 80% value represents the assumed percentage of the lighting energy that translates to heat, which either must be removed from the space by the air-conditioning system or added to the space by the heating system during the aforementioned HVAC hours. This assumption is consistent with those established and employed in previous impact evaluations of lighting measures.[16] Also, heating factors are negative because electric heating interaction decreases gross lighting savings, while cooling interactive increases it.

3.4 Lighting quality assessment and missed opportunities

In just a few years, the Massachusetts energy efficiency Initiatives have shifted from fluorescent to LED technology. To determine how well this technology is working in the field, the evaluation team conducted a lighting quality and lost opportunities assessment. For example, some rebated installations are retrofits of existing fixtures designed for fluorescent lamps to a point source LED technology. How is this affecting lighting quality? How is it perceived by the customer? This technology transition raises questions:

- Are the spaces over-lit or under-lit compared to standards for the space and building type?
- What is the quality of the lighting with regards to lumen uniformity, glare, and rated CRI and CCT?
- What is the lighting power density?
- Would additional savings have been possible through reduced light levels that still meet the space requirements?

[16] The Upstream Lighting impact evaluation (P58) reviewed the 80% factor for LED lighting. The DNV GL team performed a brief review of the literature to investigate whether the 80% value used in calculating HVAC interactive effects should be updated since the study included only LED lighting. Detailed findings are included as Appendix C in the Upstream Lighting impact evaluation report, but in short, the DNV GL team identified several research sources that corroborated the 80% factor. Evidence supports that the lower absolute wattage value of LEDs, not a difference in light conversion efficiency, that makes LEDs "cooler" than their less efficient counterparts.

- Are occupants working in the new lighting environment satisfied?

As part of this task, the M&V teams assessed lighting quality and any lost opportunities associated with the measures through the measurement of light levels; assessment of glare, color rendering index (CRI) and correlated color temperature (CCT) specifications; and estimation of lighting power densities.

The evaluation team expanded the existing on-site scope using a protocol designed by ERS for National Grid New York[17] that is now in use for the evaluation of its custom and prescriptive lighting programs and was also used for the impact evaluation of the Upstream Lighting Initiative in Massachusetts (P58). The protocol adds additional lighting quality/light level inputs for the same spaces as those selected for loggers. The additional site scope includes the following:

- Light level measurements on task-oriented vertical and horizontal (such as a desktop, white board, or retail shelf)
- Description of space purpose for the selection of an appropriate light level standard for the space
- Additional light level measurements using a grid for those spaces perceived as having poor distribution of lighting
- For dimmable fixtures, an estimation of the position of the dimmer at the time of the site visit
- A series of brief questions for any occupant using the measured space addressing perceptions of glare, color rendition, and the quality of the previous lighting system

17 Joe Dolengo is the study manager for National Grid New York.

4 FINDINGS

The results presented in the following subsections include statewide-level realization rates (and associated precision levels) for annual kWh savings, percent on-peak kWh savings, and on-peak demand (kW) coincidence factors at the times of the winter and summer peaks, as defined by the ISO New England Forward Capacity Market (FCM). All coincident summer and winter peak reductions were calculated using the following FCM definitions:

- **Coincident summer on-peak kW reduction** is the average demand reduction that occurs during all hours between 1:00 p.m. and 5:00 p.m. on non-holiday weekdays in June, July, and August.
- **Coincident winter on-peak kW reduction** is the average demand reduction that occurs during all hours between 5:00 p.m. and 7:00 p.m. on non-holiday weekdays in December and January.

The adjusted gross energy savings and connected kW demand reduction are presented with their associated realization rate and relative precision for each lighting measure. These tables present results as adjustments to reported savings. Each of these five adjustments is described below:

- **Documentation / Adherence to the TRM adjustment**: This adjustment reflects the difference in savings when comparing the reported gross savings with theoretical, MA TRM-compliant savings using the relevant inputs (e.g., pre/post wattages, quantities, operational values, in-service rate, and prior RRs) tracked by the Initiative. In other words, the evaluators recreated the theoretical reported gross savings based on the tracking data available, and differences between this recreated value and the actual reported savings were classified as documentation differences. Additionally, this category covers any savings differences that could not be explained due to insufficient tracking data and/or supplementary custom project files.
- **Technology adjustment:** This adjustment reflects the change in savings due to the identification of a lighting technology (fixture type and wattage) at the site that differed from the technology represented in the initiative tracking system estimate of savings. Differences in baseline technology characteristics are also included in this category.
- **Quantity adjustment:** This adjustment reflects the change in savings due to the identification of a quantity of lighting fixtures at the site that differed from the quantity reflected in the initiative tracking system estimate of savings.
- **HVAC interaction adjustment:** This discrepancy category pertains to savings from the interaction between the lighting and HVAC systems among the sampled sites. The adjustment reflects differences in savings between the evaluator’s assessment of HVAC interactivity (see Section 3.3.6) and the evaluator’s recreation of the HVAC interactive savings that theoretically should have been reflected in the reported gross savings using tracked project information and prior evaluation factors.
- **Operational adjustment:** This adjustment reflects the change in savings due to measurement of lighting operation hours at the site that is different than represented in the tracking system estimate of savings. So as not to double-count savings, this final adjustment category accounts for any overlap in impacts from the preceding categories.

Also included in the results are savings factors for summer and winter on-peak coincidence factors, summer and winter kW HVAC interactive effect factors, a kWh HVAC interactive effect factor, the percent of energy savings during on-peak periods, and a non-electric heating HVAC interactive effect, which is presented in MMBtu/kWh saved. Relative precision levels and error bounds are calculated at the 80% confidence level for demand savings factors and values. For all kWh realization rates, the standard 90% confidence level is used.

4.1 Statewide results

Table 4-1 presents the statewide results for Small Business Initiative projects completed in 2016. Please note that tracking and reported gross savings are comprehensively defined in Appendix F. In summary, tracking gross savings are defined as the base savings based on fixture quantity, wattage, and operation values (hours of use, coincidence factors). Tracking savings do not incorporate HVAC interactive effects or other final adjustment factors. Reported gross savings, as featured in Table 4-1, involve the product of the tracking gross savings with adjustment factors for prior evaluation results, including HVAC interactive effects.

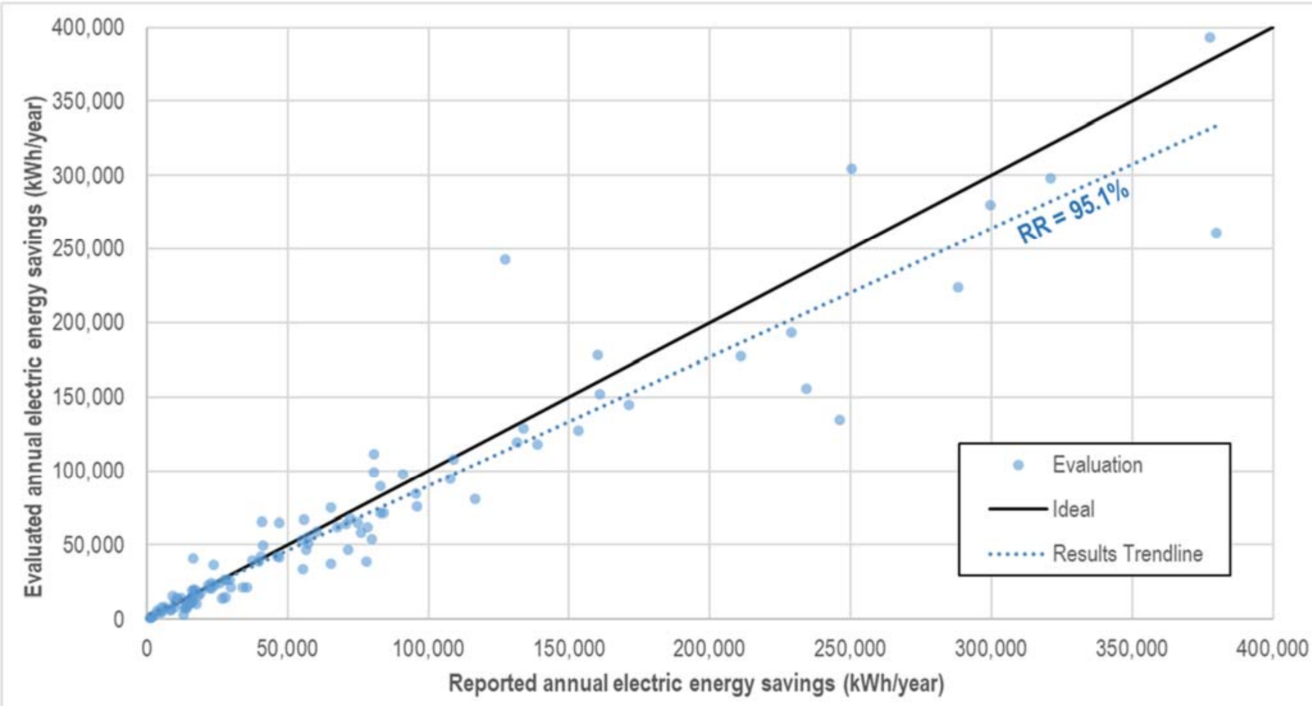
Table 4-1. Summary of statewide energy realization rate for SB lighting measures

Savings Parameter	Energy - Statewide	
	kWh	% Gross
Gross Savings (Reported)	103,763,076	
Documentation Adjustment	(3,540,016)	-3.4%
Technology Adjustment	4,326,629	4.2%
Quantity Adjustment	(726,346)	-0.7%
Operational Adjustment	(1,687,524)	-1.6%
HVAC Interactive Adjustment	(3,494,815)	-3.4%
Adjusted Gross Savings	98,641,004	95.1%
Gross Realization Rate	95.1%	
Relative Precision	±4.7%	
Confidence Interval	90%	
Error Ratio	0.284	

The statewide kWh realization rate was 95% with a relative precision of ±4.7% at the 90% level of confidence, indicating that the evaluation sample sufficiently achieved the kWh precision target set forth in Section 3.2. Additionally, the evaluation results indicated a significantly lower error ratio than predicted (0.8), indicating less variability in site-level results than anticipated. The lower error ratio also suggests more consistent and accurate savings tracking and estimation by the Initiative and its contractors, as compared with the prior PY2010-11 evaluation cycle. This study’s error ratio can be used to inform future evaluation samples, such as possible rolling evaluation samples as the Initiative evolves, barring any major changes in program design or operation.

Figure 4-1 illustrates the comparison of evaluated (y-axis) and reported (x-axis) annual kWh savings for each of the 105 sites in the evaluation sample. Ideally, the evaluated savings would always match the reported savings; this ideal is shown as a solid black line on the charts.

Figure 4-1. Comparison of reported and evaluated annual kWh savings



As illustrated in the figure, many of the sampled projects featured evaluated savings that did not deviate significantly from the reported savings and thus feature a RR near 100%. However, some of the largest projects featured more significant deviation, for reasons examined in the next section. Among the largest projects, the prevalent drivers of the RRs were: differences in wattage assumptions as compared with field-verified information and the MA TRM's fixture wattage recommendations, differences in HVAC interactivity due to fewer mechanically cooled spaces, and differences in operation as compared with the vendor's assumptions. Appendix E contains each of the site-level RRs for kWh and kW along with each site's most prevalent difference category.

Table 4-2 presents the statewide savings factors resulting from this study. All relative precisions were calculated at the 80% confidence interval for demand. The summer on-peak coincidence factor was 57.0%, with a relative precision of ±14.1% at the 80% level of confidence. The on-peak winter coincidence factor was 57.9%, with a relative precision of ±8.3% at the 80% level of confidence. The table also provides savings factors for on-peak summer and winter kW HVAC interactive effects, kWh HVAC interactive effect, HOU realization rate, and percent on-peak kWh.

Table 4-2. Summary of statewide SB lighting savings factors

Savings Parameter	PY2016 Overall (Statewide)	
	Value	Precision at 80% Confidence
Installation Rate (Quantity Adjustment)	99.3%	±0.6%
Delta Watts (Technology Adjustment)	104.2%	±5.8%
Connected kW Realization Rate	97.2%	±1.4%
Summer kW Realization Rate	90.6%	±2.5%
Winter kW Realization Rate	102.8%	±11.8%
Summer Coincidence Factor	57.0%	±14.1%
Winter Coincidence Factor	57.9%	±8.3%
Summer kW HVAC Interactive Effect	108.4%	±1.7%
Winter kW HVAC Interactive Effect	99.4%	±0.8%
kWh Factors (Precisions at 90% confidence)		
kWh HVAC Interactive Effect	102.4%	±6.3%
Hours of Use Realization Rate	98.4%	±3.9%
% On Peak kWh	71.2%	±10.2%
Non-Electric		
Heating HVAC Interaction Effect (MMBtu/kWh)	-0.00408	

Overall, the evaluation team found lower levels of summer coincidence than assumed by PAs, but higher levels of winter coincidence.[18] Evaluator measurement of lighting operation led to an overall, weighted average annual hours of use value 1.6% lower than that assumed within tracking data.

4.2 Key drivers

The following sections present the reasons the realization rate deviated from 100%, as illustrated in Table 4-1. These discrepancies are aggregated into the five categories introduced at the beginning of Section 4. Select examples of text (in italicized quotes) are provided directly from site-specific explanations of RRs prepared by the field auditors.

The section concludes with a comparison of this study’s key operating values (HOU and CFs) with MA TRM recommendations, as well as an investigation of performance by lighting measure type.

[18] Per the MA TRM, Cape Light Compact and Unitil assume summer coincidence factors of 0.72 for lighting measures, while Eversource and National Grid assume 0.73. All utilities assume a winter coincidence factor of 0.44.

4.2.1 Documentation adjustment

Evaluators found issues regarding documentation and/or adherence to the Massachusetts TRM, leading to a 3.4% reduction in evaluated kWh savings. Below are some explanations and examples (in italics) within this category.

- Of the 105 projects sampled for evaluation, 9 featured insufficient tracking data needed to recreate a savings value that complies with the Massachusetts TRM. In these cases, the difference between evaluated and reported savings was attributed to the documentation category.
  - *"Neither baseline nor proposed fixture information was provided for analysis line items 4, 9 and 19. For that reason these fixtures were unable to be identified or located, despite thorough searching during the site visits and asking the facility contact during interviews."*
- When sufficient tracking data was available to recreate the TRM-compliant savings, evaluators found differences between this value and the reported savings. Nearly every project featured such differences, albeit insignificant in several cases. More significant differences occurred with peak kW savings: in some cases, evaluators found higher reported summer/winter peak kW savings than reported connected kW savings, due to misapplication of TRM-recommended coincidence factors. These instances were also classified under the documentation category.
  - *"The source of the reported Winter Peak Demand savings (33.98 kW) is not clear; the custom worksheets in the project files only show 6.09 kW. It is clear that the tracked peak demand savings values did not incorporate appropriate coincidence factors."*

4.2.2 Quantity adjustment

Differences between evaluated and reported fixture quantities, in pre- and/or post-project conditions, led to a slight (-0.7%) adjustment to evaluated kWh savings. Below is one site-specific example related to a quantity difference.

- Evaluators assessed 11 projects that featured fixture line items that could not be found on-site, despite a comprehensive inventory on both logger deployment and retrieval visits.
  - *"Only two fixtures were found in the store instead of three as reported by the tracking system, resulting in a 5% decrease in savings."*

4.2.3 Technology adjustment

Evaluators encountered differences between the fixture wattages identified on-site and those documented in program tracking data, resulting in a 4.2% increase in evaluated kWh savings.

- Technology savings adjustments arose from different wattages inventoried by evaluators as compared with the tracked project information. In particular for some projects, evaluators determined differences between the MA TRM-recommended fixture wattages for pre-existing fluorescent tubes and the wattages assumed by vendors.
  - *"After a review of the vendor codes and the wattage table codes used in the analysis, it is apparent that for some baseline fixture types the applicant used higher existing wattages than listed in the TRM."*

- Counteracting the above difference that resulted in an overall savings increase were "plug-and-play" LED tube retrofits, in which the preexisting fluorescent ballasts are reused to support new LED lamps. Evaluators found 7 instances of savings differences due to the resulting ballast inefficiency not properly accounted for in the applicant's fixture wattage estimate.
    - *"An additional reason for the connected kW savings discrepancy is that the initial analysis did not include the post-install ballast inefficiency resulting from plug-and-play LEDs, resulting in decreased savings."*

4.2.4 HVAC interactivity adjustment

Field auditors inventoried site-specific heating and cooling nameplate data whenever possible, and surveyed facility management on HVAC operation, in order to extrapolate interactive cooling and heating impacts over a full year. Savings differences amounting to -3.4% (kWh) arose between the evaluator's assessment and the reported savings assumption on HVAC interaction, which were embedded in the overall RR factors applied to tracking savings. In general, the HVAC adjustment reflects the evaluator's assessment of site-specific HVAC interactivity and operation as compared with the theoretical, reported HVAC interactive impacts as determined from tracking data and prior evaluation results.

- Evaluators encountered facilities, or spaces within facilities, that were not mechanically cooled. However, the reported savings included cooling savings for these line items, resulting in savings differences. In particular, some projects claimed interactive savings for typically unconditioned spaces such as exterior, basement, boiler room, and attic.
    - *"The reason for discrepancy is primarily due to the reported savings including interactive cooling savings, but we determined through inspection and survey that this space is not cooled."*
    - *"Additionally, the reported savings reflected an assumption that the exterior fixtures would contribute to interactive heating and cooling savings, which resulted in the interactive cooling and heating savings discrepancies."*
- Two sites with electric heating, not the fossil fuel heating reflected in TRM heating interactivity factor, were included in the evaluation sample. This led to negative electric impacts due to reduced waste heat from the fixtures.
    - *"One reason for discrepancies could be due to an assumption made in the initial analysis that heating was run off of natural gas when it is actually electric."*

4.2.5 Operation adjustment

At each sampled site, evaluators deployed lighting loggers among a representative selection of usage groups. This metered operation data often differed between vendor assumptions on annual hours of use and coincidence factors reflected in tracking data. Such differences were expected, as the vendor assumes operating hours based on discussions with the site contact and/or references to the TRM, whereas evaluators determine the actual operation through at least 3 months of measurement. Such differences resulted in a 1.6% decrease to evaluated kWh savings.

- 8 sites in the evaluation sample featured seasonal operation that did not appear to be considered by the applicant; such differences were classified within the operation category. In general, seasonality led to lower evaluated savings than reported.

- *"This is a retail store in Provincetown, MA with a very seasonal operational schedule. According to the owner, the store operates until late hours in the summer months and operates only a few hours, if open, during the winter. There are many days during the winter when it is closed due to no customers, or bad weather conditions."*

- 2 facilities featured dimmable fixtures that reduced the full-load operating profile of the fixtures as compared with tracking assumptions.
  - *"This project was completed in a bar with recessed lights on a set cycle with 2 dimmed levels. The bar lights were 100% on during the night and reduced to about 70% brightness in the morning and then to 40% brightness in the evening to maintain a dark ambience. The evaluators used CT+Hobo loggers to map these dimming steps and create a corresponding full-load operation profile. The difference in savings is due in large part to lower post installation hours of operation than what had been anticipated by the applicant, which can be attributed to the dimming levels and usage pattern."*
- Some facility types, such as restaurants and meeting halls, featured lower-than-expected operation during the summer peak window of 1:00 p.m. to 5:00 p.m.
  - *"This site is a restaurant that is open from 4:30 p.m. to 9:30 p.m. Wednesday through Monday from Memorial Day to Labor Day and Wednesday through Sunday the rest of the year. The restaurant fixtures operate for fewer hours than the tracking data assumes, in particular during the summer peak window."*
- Other facilities, such as retail, restaurants, and exterior lighting among many facility types, featured higher-than-expected operation during the winter peak window of 5:00 p.m. to 7:00 p.m.
  - *"The winter peak kW is high because all of the exterior lights are on during winter nights (most fixtures are controlled by photocells or a clock)."*

For each of the facility types encountered in this study, Table 4-3 compares the evaluation's weighted average annual HOU and coincidence factors and those recommended in the MA TRM (indicated in the second row). Evaluation averages are weighted by connected wattage and reflect all line items included in the 105 sampled projects. While vendors are instructed to collect site-specific information to inform tracked operating hours estimates, they are also allowed to reference the TRM's typical operating hours recommendations by facility type. Evaluators observed that the tracking savings generally reflected the former: site-specific information collected at the time of project implementation. Overall, evaluators determined that, if all PY2016 hours assumptions reflected the MA TRM by facility type, the operation adjustment would have decreased from -2% to -6%, resulting in a lower program-wide kWh RR. Therefore, as discussed in Section 5.2, we recommend the Initiative and its contractors continue to track and incorporate site-specific operating hours estimates when possible.

Table 4-3. Comparison of evaluation HOU and CFs with MA TRM recommendations

Facility Type	Count of Tracked Line Items in Sample	PY2016 Evaluated Weighted Ave. Hours	MA TRM Hours	PY2016 Evaluated Weighted Ave Summer CF	PY2016 Evaluated Weighted Ave Winter CF
MA TRM	N/A	N/A	See below	0.73†	0.44
Evaluation Weighted Average – Overall	**3,589**	**3,434**	**N/A**	**0.57**	**0.58**
Automotive Facility	205	2,976	4,056	0.58	0.44
Dining: Bar Lounge/Leisure	42	3,146	5,110	0.45	0.43
Dining: Family	19	4,050	5,110	0.44	0.54
Dormitory	310	3,661	3,056	0.45	0.51
Exercise Center	87	3,974	N/A††	0.67	0.69
Gymnasium	5	4,709	N/A††	0.83	0.83
Healthcare-Clinic	382	3,787	N/A††	0.74	0.49
Hospital	42	2,752	8,036	0.73	0.49
Manufacturing Facility	227	4,438	2,857	0.76	0.49
Multi-Family	24	7,968	7,665	0.98	0.98
Office	800	2,766	3,610	0.48	0.35
Other	290	3,533	3,951	0.55	0.50
Religious Building	102	1,635	1,955	0.28	0.32
Retail	564	3,975	4,089	0.73	0.69
School/University	303	3,455	2,596	0.75	0.57
Sports Arena	14	5,164	N/A††	0.66	0.94

Facility Type	Count of Tracked Line Items in Sample	PY2016 Evaluated Weighted Ave. Hours	MA TRM Hours	PY2016 Evaluated Weighted Ave Summer CF	PY2016 Evaluated Weighted Ave Winter CF
Warehouse	63	2,990	3,759	0.68	0.61
Workshop	110	3,321	4,730	0.74	0.71

† Eversource and National Grid use a summer CF of 0.73, while CLC and Unitil use a value of 0.72.

†† Certain evaluator facility groups could not be paired with a corresponding TRM facility category.

4.2.6 Performance by measure type

Upgrades to LEDs represented a significant majority of program savings in 2016. Multiple measure types exist within the LED category, such as tube LED (TLED) retrofits, screw-in LEDs, and LED replacements of high-intensity discharge (HID) systems such as metal halides. Additionally, the Initiative incented controls measures that reflect the operational savings from devices such as occupancy sensors and daylight dimming controls. Evaluators investigated if the performance of any such measure categories significantly differed from the statewide results overall; this analysis is summarized in Table 4-4.

Table 4-4. kWh savings performance by measure category

Measure Category	Share of Reported Savings	kWh RR
TLED	58%	80%
LED HID replacement	24%	98%
Screw-in LED	14%	98%
Controls measures	4%	132%
Other (e.g. T8, CFL)	<1%	119%

Please note that the values in Table 4-4 not statistically expanded back to the population of PY2016 participants and reflect only the 105 projects sampled for evaluation. Evaluators therefore do not recommend application of these factors prospectively or retrospectively. Nonetheless, the table illustrates interesting variation in performance among fixture types:

- TLEDs featured an unweighted kWh RR 15% lower than the state-wide value. In the cases of plug-and-play LEDs, evaluators often found that the appropriate ballast inefficiency of the re-used fluorescent ballast was not considered in the post-project fixture wattage value.
- HID and screw-in replacement RRs more closely resembled the state-wide value.
- Controls savings performed markedly better than state-wide. Evaluators determined a controls-induced average hours reduction of 45% (weighted by connected kW) as compared with the 30% reduction value recommended by the MA TRM. However, the evaluation analysis involved ex post data collection and assumptions on pre-project operation. Additionally, lighting controls represented only 1% of PY2016 reported savings. For these reasons, we do not recommend that the program apply of any controls-specific factors examined above.

4.3 Dual baseline savings

In addition to developing statewide RRs for first-year kWh and kW savings, this study also intended to estimate the lifetime savings of the Small Business Initiative under a dual baseline approach, which is expected to be adopted by PAs in 2019 and beyond. First, as a comparative reference, the lifetime savings under the current early-replacement paradigm can be defined as follows:

$$Lifetime\ Savings_{ER} = Evaluated\ firstyear\ savings\ \times EUL_{ER}$$

where,

$Evaluated\ firstyear\ savings$ = Evaluated savings (kWh or kW) determined through this study, per Tables 4-1 and 4-2

EUL_{ER} = Effective useful life for retrofit measures (**13 years** for all lighting types except screw-in CFL, as recommended by the MA 2016-18 plan[19])

Under a dual-baseline approach, the lifetime savings are defined as:

$$Lifetime\ Savings_{Dual} = Evaluated\ firstyear\ savings\ \times\ (RUL + Out\ Year\ Factor\ \times\ [EUL_{NC} - RUL])$$

where,

RUL = Remaining useful life, assumed to be **33% × EUL_{NC}** (defined below)

$Out\ Year\ Factor$ = Assumed factor of **60%** representing the difference between future ISP and currently installed equipment[20]. This value will eventually be informed by the P75 LED Market study, which was incomplete at the time of this writing.

EUL_{NC} = Effective useful life for new construction measures (**15 years** for all lighting types except screw-in CFL, as informed by the lost-opportunity EULs in the MA 2016-18 plan)

In Table 4-5, given the assumptions above, the lifetime kWh savings under the dual baseline approach are compared with lifetime kWh savings under the early replacement approach.

Table 4-5. Comparison of SB lifetime kWh savings: early-replacement vs. dual baseline

Parameter	Evaluated Gross Lifetime Savings Comparison	
	Traditional Lifetime Savings	Dual Baseline Savings
Gross first-year kWh savings (reported)	103,763,076	103,763,076
kWh realization rate	95.1%	95.1%
Gross first-year savings (evaluated)	98,641,004	98,641,004
Effective useful life	13	15
Remaining useful life	N/A	5
Out year factor	N/A	60%
Evaluated gross lifetime savings (kWh)	1,282,333,052	1,085,051,044

[19] "Massachusetts Technical Reference Manual: 2016-2018 Program Years – Plan Version," http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf

[20] As referenced from the P73A Portfolio Model Methods and Assumptions study.

As the 60% out year factor is a placeholder estimate for future P75 findings on ISP, we provide dual baseline savings estimates for 50% and 70% factors as well in Table 4-6, to illustrate how the lifetime savings might fluctuate based on forthcoming market research.

Table 4-6. Comparison of SB lifetime MWh savings: early-replacement vs. dual baseline

Lifetime Evaluated MWh Savings – Lighting Only	50% Out Year Factor	60% Out Year Factor	70% Out Year Factor
A – Early-replacement (PY2018 and previous)	1,282,333	1,282,333	1,282,333
B – Dual baseline (PY2019 and beyond)	986,410	1,085,051	1,183,692
Fraction of PY2016 evaluated lifetime savings (B÷A)	77%	85%	92%

Comprehensive research on industry standard practice for lighting at small businesses is not included in the scope of this study. However, findings from this study can be paired with research from the concurrent P75 LED Market study, which includes small business customers, to forecast what the industry standard practice will be at the conclusion of the RUL for the preexisting lighting. At the time of this writing, the P75 study's findings were not yet final. This study's results are sufficiently granular to be paired with the P75 results to inform a dual baseline savings estimation more reflective of current market dynamics in Massachusetts.

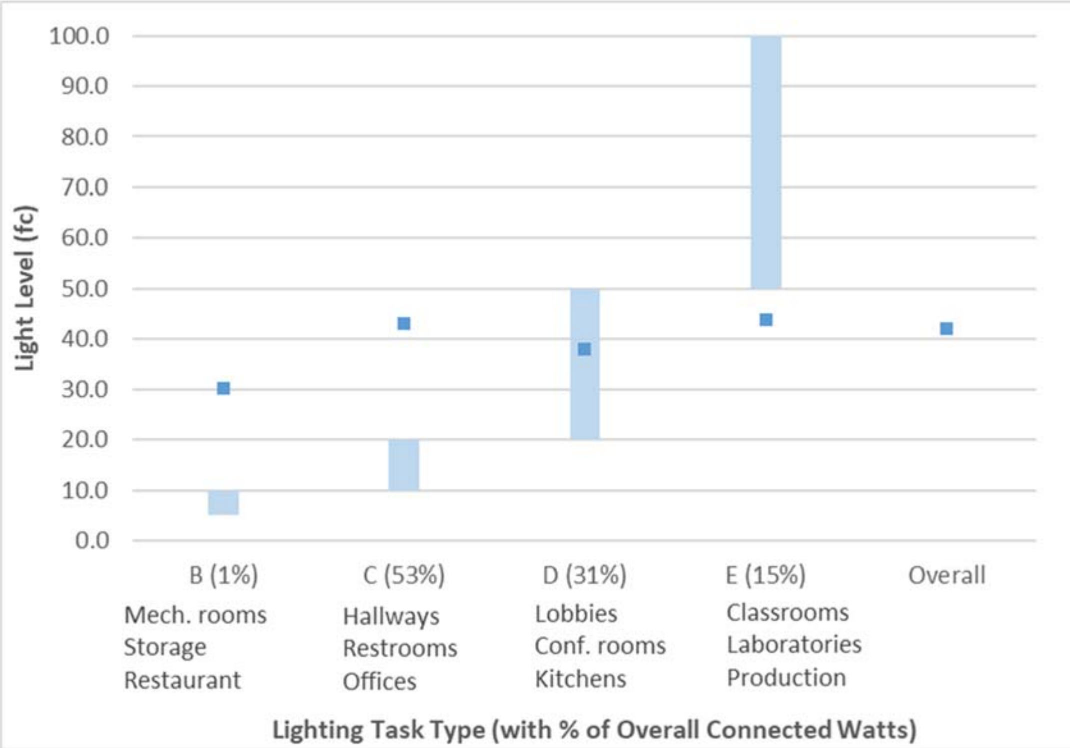
4.4 Lighting quality assessment

Lighting quality readings and field engineer assessments were conducted at each of the 105 facilities sampled for this study, covering a total of 677 unique spaces. While a more comprehensive narrative of evaluation findings is presented in APPENDIX D, this section provides a summary of our findings on lighting quality and potential illumination reduction.

Site auditors conducted light level measurements, when possible, for each fixture selected for time-of-use metering. Light-level spot measurements were taken at the height corresponding to the task for which specific illumination levels are needed (e.g., desk-level in a classroom). Within the evaluation sample, site auditors identified four primary IESNA task type categories (B, C, D and E[21]) out of a total of nine possible categories. Figure 4-2 shows the light level ranges for each of the observed IESNA task types. The light blue lines represent the given recommended range in foot-candles (fc). The dark blue markers represent the average recorded foot-candle value for each task type. The figure's x-axis also provides example space types included within each of the four task types examined, as well as the percent contribution to total post-project connected wattage from each task type.

[21] Appendix D contains additional information on the task type categories. B includes mechanical rooms, storage and restaurants; C includes hallways, warehouse, restrooms, and offices; D includes conference rooms, lobbies, manufacturing and kitchens; and E includes laboratories and classrooms.

Figure 4-2. Recommended IESNA task type light level ranges and average recorded values



This data shows that the average recorded light level for task types B and C are significantly higher than the IESNA recommended level. The average recorded light level for Task E was lower than the recommend level. The measured light level for Task D fell within the range of typical foot-candles.

Overall, lighting quality was assessed by field auditors as "good" for the overwhelming majority of the surveyed spaces. Lighting quality was graded as "poor" in only three metered spaces, all of which were bathrooms. Evaluators found no instances of noticeable glare or color rendering index (CRI) issues. Field auditors also surveyed the primary customer contact—managers, owners, and/or decision-makers—at each sampled site to assess their willingness to slightly reduce illumination to achieve additional savings.

Figure 4-2 suggests significant savings potential within two of the prevalent task types. Evaluators investigated this savings potential further, by calculating the average post-project wattage of all fixtures designated within the B and C task types. Next, evaluators assessed the potential wattage reduction of such fixtures if the lumen output was reduced to reflect the mid-point of IESNA's foot-candle recommendations for B and C task types. This analysis showed significant savings opportunity, representing 12% of program-reported kWh savings in PY2016. Task type C (offices, hallways, restrooms) shows the highest potential for light level reduction savings, due to its 53% contribution to overall post-project connected wattage. While there are uncertainties associated with this data collection and analysis (e.g., limited foot-candle measurements on site, unique customer usages that do not fit the IESNA classifications), the analysis shows that the significant savings potential warrants further research on lumen reduction options in non-residential settings as the prevalence of LEDs grows rapidly.

Our surveys with customers indicated barriers to adopting lower light levels. Namely, customers generally prefer the existing light levels and are concerned that lower light levels would impact their business. But as customers generally defer to contractors on lighting upgrade best practices, the savings potential from light level reduction is critically dependent on contractor recognition and quality installation to maintain customer satisfaction. Contractors should consider illumination reduction whenever appropriate, explain the energy savings benefits to the customers, and carefully select lower-lumen fixtures and/or more flexible dimming or tuning controls for appropriate task lighting. The Initiative can accelerate these opportunities with additional contractor training and standardization of on-site protocols to include light level assessment. While comprehensive lighting re-wiring may not be possible or practical, evaluators believe that achievable savings opportunity exists within the Initiative’s prescriptive model, for example by retrofitting existing normal-light-output (NLO) lamps and ballasts with reduced-lumen-output (RLO) equivalents when appropriate.

4.5 Controls savings potential

While collecting inventory and operation data on-site, the evaluation team also assessed potential missed savings opportunities related to installation of additional lighting controls. Evaluators considered a variety of control strategies, including motion-based occupancy sensors, photocell-based daylight dimming, stepped control, and programmable (timer) control, that might have led to additional program savings if identified by the installation contractor and agreed upon by the customer. For example, with regard to motion-based occupancy sensors, the field auditors considered fixtures as potential candidates when the following criteria were met:

- Fixtures currently manually controlled
- Fixtures located in intermittently-used spaces, such as conference rooms, storage areas, and bathrooms
- Fixtures found to operate significantly outside of the facility’s typical “open” hours, perhaps due to the manual switch being left “on”
- Fixtures at facilities with management willing to consider automatic lighting controls

As evaluators collected data by tracking line item, which often corresponded to a unique measure-space combination at a facility, the controls potential savings analysis was conducted by tracking line item as well. Of the automatic controls possibilities considered by the field team, motion-based occupancy sensor control indicated the highest potential savings. Table 4-7 illustrates the potential savings for occupancy sensors by space type.

Table 4-7. Potential savings from occupancy sensor controls by space type

Space Type	Total Line Items	Total with Controls Potential	Share	Total Watts Eligible for O.S.	Weighted Ave. Hrs. Reduction	Potential kWh Savings
Basement/Storage	324	74	23%	8,704	670	5,830
Bathroom	74	28	38%	2,600	1,386	3,603
Classroom	199	59	30%	8,047	657	5,284
Common Areas	217	29	13%	3,788	1,034	3,916
Conference	95	49	52%	4,783	729	3,486
Exercise	52	29	56%	23,409	1,149	26,900
Exterior	294	14	5%	602	1,296	780
Garage	62	0	0%	0	0	0

Space Type	Total Line Items	Total with Controls Potential	Share	Total Watts Eligible for O.S.	Weighted Ave. Hrs. Reduction	Potential kWh Savings
Hallway/Stairs	506	85	17%	8,469	2,135	18,085
Kitchen	58	15	26%	1,323	2,355	3,115
Office	725	253	35%	28,647	631	18,078
Other	349	9	3%	237	760	180
Production/Assembly	170	24	14%	3,790	802	3,038
Restaurant/Bar	60	11	18%	2,493	1,158	2,888
Restroom	156	32	21%	2,452	1,568	3,845
Retail	207	32	15%	3,986	854	3,403
Theatre	8	1	13%	352	565	199
Warehouse	111	11	10%	4,282	642	2,751
Total	**3,808**	**756**	**20%**	**107,976**	**976**	**105,411**

The savings potential calculation assumes a 30% reduction in operating hours from occupancy sensors, as recommended by the 2013-15 MA TRM. Among the 105 sites sampled for evaluation, we identified 1.4% additional kWh savings potential (unweighted) from occupancy sensors alone. Observations from the data include:

- Exercise spaces offered the highest potential for occupancy sensor savings as well as the highest share of potential line items. Such spaces include gymnasiums and rinks that require high LPDs, cover a broad square footage, and therefore feature comparatively high connected lighting wattage. Such spaces also might continuously operate, even when not in use, such as between practices or competitions.
- Intermittently-used spaces are featured predominantly in Table 4-7. Basement/storage, bathroom, conference rooms, and offices each feature line item shares greater than 30% and offer relatively significant kWh savings potential.
- 17% of hallways/stairs spaces were identified as potential candidates for occupancy sensors. Bi-level or dimming controls have been implemented successfully in stairwells, while staggered occupancy sensor control (e.g., every other fixture) or dimming control in hallways offers savings potential while keeping paths of egress illuminated for safety purposes.

While the MA TRM recommends a 30% hours reduction assumption from occupancy sensors, evaluators found a higher average reduction (45%, weighted by connected wattage[22]) that would correspond to even higher levels of potential savings. As LED fixtures continue to penetrate the small business market, with longer lives and higher reliability, the Initiative and its contractors should continue to consider other savings

[22] Please note that this study's scope did not include pre-project measurement of fixture operation. The controls savings analysis approach relied on the assumptions described in Section 3.3.5. Therefore, we do not recommend application of a new operation reduction factor for occupancy sensors, but have included results of our analysis for illustrative purposes.

sources, such as automatic lighting controls, to diversify program offerings and compensate for more limited fixture upgrade opportunities in the future.

Evaluators also examined savings potential for daylight dimming control, but determined only 2,652 kWh of savings potential among the sample of 105 projects. Barriers to this technology included lack of south-facing windows and customer unfamiliarity with the technology.

5 CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions, recommendations, considerations, and opportunities for future research.

5.1 Conclusions

As illustrated in Table 5-1, the Massachusetts Small Business Initiative's lighting measures generate significant electric energy savings. Evaluated demand savings results varied, with lower values for summer peak kW and connected kW, and higher evaluated values for winter peak kW. Evaluators are pleased that the results generally featured statistical precision better than the ±10% value targeted in the sample design, and the improved error ratio of 0.284 can be used to more economically design SB lighting evaluation samples in future studies. Please note that the RRs in Table 5-1 are not recommended for prospective application; rather, the evaluator's recommended prospective values are discussed in Section 5.2.

Table 5-1. Summary of statewide savings and RRs for SB lighting measures

Savings Parameter	PY2016 Reported Gross Savings (Lighting)	PY2016 Evaluated Gross Savings (Lighting)	RRs	Relative Precision
Annual kWh	103,763,076	98,641,004	95.1%	±4.7% (90% confidence interval)
Summer peak kW	20,200	18,301	90.6%	±2.5% (80% confidence interval)
Winter peak kW	12,386	12,733	102.8%	±11.8% (80% confidence interval)

Through on-site inventories and metering among a sample of 105 SB facilities upgraded in PY2016, evaluators determined that the Initiative's contractors track the measure savings comprehensively and accurately as compared with the evaluated values. Aside from a small number of anomalous cases, the upgraded fixtures still remain in operation and are well-liked by the customers.

The penetration of LED technology in nonresidential settings is expanding rapidly. Based on an examination of the measures implemented among the sample of 105 projects assessed in this study, evaluators found that the Initiative has aggressively adopted LED measures, which comprised over 99% of the lighting installations in PY2016. Evaluation results—in particular the scatter plot in Figure 4-1— indicate that the Initiative's contractors generally have submitted realistic savings estimates and have mostly documented their savings assumptions comprehensively. Nonetheless, the evaluation team has identified recommendations and considerations for the Initiative in this rapidly evolving market, as outlined in the next sections.

With an imminent transition from an early replacement approach to a dual baseline approach for determining lifetime savings in Massachusetts, evaluators assessed the impact of this transition to lifetime savings. Assuming a 15-year EUL for lighting measures[23] and an RUL of 5 years (33% of EUL), with a placeholder "out-year" factor of 60%[24], evaluators estimate that the dual baseline approach reduces lifetime savings by 15% as compared with the lifetime savings from the traditional retrofit/early replacement single baseline approach that uses the first-year savings with a reduced measure life of 13 years. Other concurrent studies—P75 for the out year factor and P73D for RUL—should provide market and lifetime data that better inform this assessment; however, at the time of this writing, these studies' results were not fully available for incorporation in this analysis.

To further aid the Initiative in maximizing savings in future program years, evaluators assessed missed savings opportunities of two types—wattage reduction due to over-illumination and additional savings from automatic controls measures. Evaluators found average foot-candle readings higher than recommended for two major usage classifications detailed further in Section 4.4 and Appendix D. Significant additional savings (12% of PY2016 reported kWh) could be realized from the over-lit usage types if the lumen output was adjusted to reflect the mid-point of the foot-candle range recommended by IESNA. Such adjustment could occur through the installation of lower-lumen-output lamps and ballasts and/or the installation of dimming or tuning controls. However, the evaluation team encountered barriers to customer adoption of lower illumination levels—primarily, customers are generally satisfied with their existing illumination levels and are concerned about negative impacts to business from reduced light levels. However, customers also indicated that they generally defer to contractors for best practices on lighting technology and illumination levels. Contractor training to recognize, sell, and implement more aggressive illumination reduction and control strategies will be critical to surpassing these barriers and achieving these additional savings.

For potential savings from automatic controls, evaluation field staff identified occupancy sensors as the most prominent candidate, particularly among space types such as offices, bathroom, and storage. Evaluators estimated that the total potential savings for occupancy sensors amounted to approximately 1.5% of PY2016 program-reported savings. While our analysis featured the MA TRM's hours reduction recommendation of 30% for occupancy sensors, this study estimated a higher reduction value of 45%, indicating possibly even higher potential savings from occupancy sensor control.

5.2 Recommendations

This section presents recommendations from this study. Recommendations are organized by:

- Retrospective application of results (PY2018)
- Prospective application of results (PY2019 and beyond)
- Process-related recommendations
- Future research recommendations

This evaluation study generated savings factors for lighting measures that are recommended for adoption by the Initiative, both retrospectively and prospectively. To provide context on how the PAs calculate savings, and subsequently how the evaluation findings might be incorporated, Appendix F provides an overview of the savings algorithms and parameter definitions inherent within current PA tracking data.

[23] Per 2016-18 Massachusetts TRM – Plan Version, http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf

[24] Per P73A Portfolio Model Methods and Assumptions – Electric and Natural Gas memorandum

5.2.1 Retrospective application of results

For retrospective application of results (PY2018), we recommend that the PAs apply the results in

$Evaluated\ Gross\ kW\ Savings_{Winter} = Reported\ Gross\ kW\ Savings_{Winter}\ \times\ RR_{r,wkW}$

where,

$Reported\ Gross\ kWh\ Savings$	$= Tracking\ Gross\ kWh\ Savings \times ISR \times SPF \times\ RR_{old,kWh}$
$Reported\ Gross\ kW\ Savings\ _{Summer}$	$= Tracking\ Gross\ kW\ Savings_{Summer} \times ISR \times SPF \times RR_{old,skW}$
$Reported\ Gross\ kW\ Savings_{Winter}$	$= Tracking\ Gross\ kW\ Savings_{Winter} \times ISR \times SPF \times RR_{old,wkW}$
$Tracking\ Gross\ kWh\ Savings$	$= \frac{(Qty_{Pre} \times W_{Pre} \times Hrs_{Pre} - Qty_{Post} \times W_{Post} \times Hrs_{Post})}{1000}$
$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Summer}}$	$= \frac{(Qty_{Pre} \times W_{Pre} \times CF_{Summer,pre} - Qty_{Post} \times W_{Post} \times CF_{Summer,post})}{1000}$
$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Winter}}$	$= \frac{(Qty_{Pre} \times W_{Pre} \times CF_{Winter,pre} - Qty_{Post} \times W_{Post} \times CF_{Winter,post})}{1000}$
ISR	= In-service rate (100% for direct-install)
SPF	= Savings persistence factor (100% for non-CFL screw-ins)
RR_{old}	= Realization rate determined through prior evaluation, including HVAC interactive effects (102% for kWh, 100% for summer peak kW, 100% for winter peak kW)

Additional terms in the equations above are defined in Appendix F.

Table 5-2 within the following equations to fully incorporate the findings from this study.

$$Evaluated\ Gross\ kWh\ Savings = Reported\ Gross\ kWh\ Savings\ \times\ RR_{r,kWh}$$

$$Evaluated\ Gross\ kW\ Savings_{Summer} = Reported\ Gross\ kW\ Savings_{Summer}\ \times\ RR_{r,skW}$$

$$Evaluated\ Gross\ kW\ Savings_{Winter} = Reported\ Gross\ kW\ Savings_{Winter}\ \times\ RR_{r,wkW}$$

where,

$Reported\ Gross\ kWh\ Savings$	$= Tracking\ Gross\ kWh\ Savings \times ISR \times SPF \times\ RR_{old,kWh}$
$Reported\ Gross\ kW\ Savings\ _{Summer}$	$= Tracking\ Gross\ kW\ Savings_{Summer} \times ISR \times SPF \times RR_{old,skW}$
$Reported\ Gross\ kW\ Savings_{Winter}$	$= Tracking\ Gross\ kW\ Savings_{Winter} \times ISR \times SPF \times RR_{old,wkW}$
$Tracking\ Gross\ kWh\ Savings$	$= \frac{(Qty_{Pre} \times W_{Pre} \times Hrs_{Pre} - Qty_{Post} \times W_{Post} \times Hrs_{Post})}{1000}$
$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Summer}}$	$= \frac{(Qty_{Pre} \times W_{Pre} \times CF_{Summer,pre} - Qty_{Post} \times W_{Post} \times CF_{Summer,post})}{1000}$
$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Winter}}$	$= \frac{(Qty_{Pre} \times W_{Pre} \times CF_{Winter,pre} - Qty_{Post} \times W_{Post} \times CF_{Winter,post})}{1000}$
ISR	= In-service rate (100% for direct-install)
SPF	= Savings persistence factor (100% for non-CFL screw-ins)
RR_{old}	= Realization rate determined through prior evaluation, including HVAC interactive effects (102% for kWh, 100% for summer peak kW, 100% for winter peak kW)

Additional terms in the equations above are defined in Appendix F.

Table 5-2. Final retrospective lighting realization rates for the Initiative for PA use (PY2018)

Savings Parameter	Formula Term	Retrospective Recommended Value	Relative Precision at Specified Confidence Interval
Gross Energy (kWh) Retrospective RR	$RR_{r,kWh}$	95.1%	±4.7% (90% confidence)
Gross Summer Peak Demand Retrospective RR	$RR_{r,skW}$	90.6%	±2.5% (80% confidence)
Gross Winter Peak Demand Retrospective RR	$RR_{r,wkW}$	102.8%	±11.8% (80% confidence)

5.2.2 Prospective application of results

Acknowledging that the PAs' tracking protocols and preferences might vary, the evaluation team has identified two options for the PAs to prospectively apply evaluation results. The two mutually-exclusive options are detailed in the next sections.

Regarding lighting controls, the evaluation team recommends that the results from the prior lighting controls-specific study (2014) [25] are continued to be applied by the PAs. This study's population (PY2016) featured only 1% kWh savings contribution from lighting controls, and the evaluation sample design subsequently did not segment specifically for lighting controls; rather, overall statewide results were determined for SB lighting measures altogether. Therefore, we do not recommend application of any results from this evaluation study to controls measures moving forward. The factors tabulated in Sections 5.2.2.1 and 5.2.2.2 should be prospectively applied to lamp and/or ballast replacement measures only.

5.2.2.1 Wholesale approach

The wholesale option is similar to the retrospective method described in Section 5.2.1 with one key difference. The prospective RRs will be applied directly to **tracking** gross savings, *not* to the reported gross savings, as the prospective RRs in Table 5-3 incorporate the HVAC interactive effects factors (see Table 4-2) as well as any non-HVAC adjustments determined through evaluation (see Table 4-1).

$$Evaluated\ Gross\ kWh\ Savings = Tracking\ Gross\ kWh\ Savings \times RR_{p,kWh}$$

$$Evaluated\ Gross\ kW\ Savings_{Summer} = Tracking\ Gross\ kW\ Savings_{Summer} \times RR_{p,skW}$$

$$Evaluated\ Gross\ kW\ Savings_{Winter} = Tracking\ Gross\ kW\ Savings_{Winter} \times RR_{p,wkW}$$

Table 5-3. Final prospective lighting RRs for the Initiative for PA use (2019 and beyond)

Savings Parameter	Formula Term	Prospective Recommended Value
Gross Energy (kWh) Prospective RR	$RR_{p,kWh}$	100.9%

[25] Retrofit Lighting Controls Measures Summary of Findings. DNV GL. 2014. http://ma-eeac.org/wordpress/wp-content/uploads/Lighting-Retrofit-Control-Measures-Final-Report.pdf

Gross Summer Peak Demand Prospective RR	$RR_{p,skW}$	92.7%
Gross Winter Peak Demand Prospective RR	$RR_{p,wkW}$	102.4%

PA tracking databases and benefit-cost calculator templates appear to accommodate such prospective RR factors. These values should replace the 102%, 100%, and 100% small C&I lighting measure RRs for kWh, summer peak kW, and winter peak kW, respectively, previously recommended to the Initiative.

5.2.2.2 Individual factor approach

As an alternative to the above method, we recommend that the PAs replace individual factors within their tracking systems with evaluated factors, as illustrated in the following fixture savings formulas:

$$Evaluated\ Gross\ kWh\ Savings = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times HOU_{Tracking} \times RR_{HOU} \times HVAC\ Interactivity_{kWh}$$

$$Evaluated\ Gross\ Peak\ kW\ Savings_{Summer} = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times CF_{Summer} \times HVAC\ Interactivity_{skW}$$

$$Evaluated\ Gross\ Peak\ kW\ Savings_{Winter} = Conn.kW\ Savings_{Tracking} \times RR_{Conn\ kW} \times CF_{Winter} \times HVAC\ Interactivity_{wkW}$$

where,

$Conn.kW\ Savings_{Tracking}$ = Connected kW savings claimed by implementer

$HOU_{Tracking}$ = Hours of use (HOU) claimed by implementer

The remaining savings factors are provided in Table 5-4 below: the proposed new peak demand savings factors, HVAC interactive effects factors, and RRs for HOU and connected kW.

Table 5-4. Proposed new savings factors for prospective use (PY2019 and beyond)

Savings Factor	Formula Term	Prospective Recommended Value	Relative Precision at Specified Confidence Interval
Connected kW RR	$RR_{Conn\ kW}$	97.2%	±1.4% (80% confidence)
HOU RR	RR_{HOU}	98.4%	±3.9% (90% confidence)
kWh HVAC Interactive Factor	$HVAC\ Interactivity_{kWh}$	102.4%	±6.3% (90% confidence)
Summer CF	CF_{Summer}	57.0%	±14.1% (80% confidence)
Winter CF	CF_{Winter}	57.9%	±8.3% (80% confidence)
Summer kW HVAC Interactive Factor	$HVAC\ Interactivity_{skW}$	108.4%	±1.7% (80% confidence)

Savings Factor	Formula Term	Prospective Recommended Value	Relative Precision at Specified Confidence Interval
Winter kW HVAC Interactive Factor	$HVAC\ Interactivity_{wkW}$	99.4%	±0.8% (80% confidence)

Using the individual factor approach, evaluation results would be reflected within all tracking savings estimates and would not require wholesale application of prospective RRs.

5.2.3 Initiative process recommendations

Standardized TLED wattages. The PAs should work with vendors to standardize how savings from tube LEDs, in particular "plug and play" TLED retrofits of fluorescent fixtures, are classified and tracked. As TLEDs were emerging when the 2013-15 MA TRM was completed, its standard fixture wattage table does not address TLEDs; therefore, evaluators found variation among vendors in how TLED fixture wattage was estimated. Many such TLED projects were classified as "custom" simply because no appropriate measure code was available in prescriptive templates. Evaluators often found differences between the vendor's fixture wattage assumption and that determined from DesignLights Consortium (DLC) reference and/or independent review of the manufacturer's specification sheets, particularly for "plug and play" TLED retrofits that reuse the preexisting fluorescent ballasts. Evaluators found that approximately 20% of TLED installations in the PY2016 sample were "plug and play," with the remainder of TLEDs classified as a whole-fixture replacement (new lamps and ballast). The PAs should provide more comprehensive guidance to vendors on when to classify fixtures as prescriptive or custom, how to estimate custom fixture wattages appropriately (e.g., through DLC reference), and which supporting documentation should be included in the application. TLED fixture retrofits (lamps and ballasts) are conducive for inclusion in future iterations of the TRM's fixture wattage recommendations table. Plug-and-play TLED retrofits (lamps only, with reused fluorescent ballasts) are more difficult to prescriptively predict using a standardized wattage table; therefore, plug-and-play TLEDs should likely be treated as custom, with supporting documentation submitted with the application to justify the vendor's assumption on power draw.

5.2.4 Future research recommendations

Dual baseline lifetime savings. In 2019, Massachusetts will transition to a dual baseline approach for calculating lifetime savings. This study estimated the impacts of such a transition to dual baseline lifetime savings but referenced a placeholder out year factor of 60%. The P75 LED Market study will provide more accurate and granular data on the anticipated C&I LED market as compared with existing technologies. Additionally, the P73D study may provide more Massachusetts-specific research on remaining useful life (RUL) for C&I lighting systems. This information should be paired with the granular, fixture-level evaluation data available from this study to refine the lifetime savings impact.

Phase II: non-lighting measures. As this study represents only Phase I of the Small Business Initiative impact evaluation, we recommend that Phase II is executed as soon as possible. This study examined performance of only lighting measures (fixtures and controls), but as the penetration of LEDs grows rapidly, the Initiative must look to non-lighting technologies to diversify their measure offerings and compensate for more limited lighting fixture savings in future program years. Phase II should include an assessment of potential non-lighting opportunities among major measure categories such as refrigeration, HVAC, envelope, and DHW.

5.3 Considerations

Lighting controls savings tracking. Consider more standardized protocols for reporting and tracking controls-only measures. Within the PY2016 data, evaluators found two primary methods used by the PAs to track lighting controls savings: (1) embedding controls savings in the same tracking line item as associated fixture savings, and (2) separating the controls-only savings in a different line item. Option (2) is recommended, as it minimizes the risk of double-counting savings, as long as the post-fixture-upgrade wattage is used in the controls savings calculation. Relatedly, the PAs should also consider implementing within application spreadsheets a flag that indicates when connected kW savings are claimed for controls-only measures. Evaluators found multiple cases of connected kW claimed for occupancy sensor measures, which strictly reduce run-time fixture operation, not wattage. However, we acknowledge that such an approach may be necessary within the tracking systems to claim any peak kW savings. As the Small C&I Initiatives continue to adopt more lighting operational measures, we recommend that the PAs standardize the tracking of controls savings among its contractors and carefully confirm that any tracked connected kW claims are not leading to savings double-counting.

Operating hours assumptions. The Initiative allows the implementation vendors to claim fixture operating hours based on site-specific data collection. The program-level results of this evaluation indicate generally accurate operating hours assumptions—the overall operation adjustment resulted in only a 1.6% reduction in kWh savings. Therefore, we recommend that this site-specific operating hours approach is continued. However, should the Initiative or its contractors rely on the MA TRM for operating hours assumptions, we recommend that the facility-level results of this study (Table 4-3) are considered and possibly pooled with other C&I lighting studies' data as the TRM is continually updated.

Light level reduction savings potential. Consider more comprehensive training for implementation contractors to (1) identify overly high illumination levels; (2) explain and sell the reduced-lumen system to the customer, emphasizing how sufficient lumen levels are maintained for specific tasks; and (3) properly install lower-lumen-output lighting and/or controls when appropriate. The Initiative should consider standardizing the contractors' on-site protocols to include an assessment of light levels and lighting quality. Our study found significant savings potential, representing 12% of program-reported kWh in PY2016, for light level reduction among two IESNA task types: B (e.g., storage, mechanical room, restaurants) and C (e.g., hallways, restrooms, offices, common areas). The success of such lumen reduction strategies is highly dependent on the contractor's ability to identify such opportunities and properly adjust the system output to maintain customer satisfaction. It may be possible to implement such lumen reduction measures prescriptively and with minimal customer disruption, for example by replacing ballasts and lamps with lower-lumen-output equivalents when appropriate.

Controls savings potential. Implementation vendors should more frequently implement occupancy sensor controls options for fixtures in intermittently used spaces that might feature unnecessarily high run hours. Such spaces include enclosed offices, conference rooms, storage areas, and bathrooms, per our research discussed in Section 4.5.

APPENDIX A. MBSS sampling methodology

The equations used to estimate the required sample sizes in this evaluation were based upon known data relationships and includes as inputs the Z constant (driven by the desired level of confidence, which is 1.645 for 90% and 1.282 for 80%), the population size (N), the required sample size before adjusting for the size of the population (n0), the error ratio (E) and the desired relative precision (R).

$$n_0 = \left(\frac{z \times E}{R}\right)^2 \qquad n_1 = \left(\frac{n_0}{1 + \frac{n_0}{N}}\right)$$

Using stratified ratio estimation, the most efficient sample was selected using the information that was available about the population. Stratified ratio estimation considers the ratio between the population total of y and the population total of x for any pair of variables x and y. Given a stratified sample of n customers for which both x and y are observed, the case weight of each customer i is defined as: $w_i = N_h / n_h$. Here N_h is the number of customers in stratum h in the population and n_h is the number of customers in stratum h in the sample. Then the stratified ratio estimator is calculated as

$$b = \frac{\sum_{i=1}^{n} w_i \, y_i}{\sum_{i=1}^{n} w_i \, x_i}$$

The standard error for the stratified ratio estimator *b* is calculated in two steps:

1. Calculate the residual $e_i = y_i - bx_i$ for each sample customer,
2. Calculate the standard error $se(b) = \frac{1}{\hat{X}} \sqrt{\sum_{i=1}^{n} w_i (w_i - 1) e_i^2}$ where $\hat{X} = \sum_{i=1}^{n} w_i \, x_i$.

If the true population mean of *x* is known, denoted μ_x, the ratio estimator for the population mean of *y* is given by the equations:

$$\hat{\mu}_y = b \, \mu_x$$

Similarly, if the true population total of x is known, denoted X , the ratio estimator for the population total of y is given by the equations:

$$\hat{Y} = b \, X$$

The standard error for the mean and population total are calculated using the following equations:

$$se(\hat{\mu}_y) = se(b) \, \mu_x$$

$$se(\hat{Y}) = se(b) \, X$$

Here $se(b)$ is the standard error of the stratified ratio estimator defined above. In each case, the error bound at the 80% level of confidence is calculated by multiplying the appropriate standard error by 1.282.

APPENDIX B. Field data collection forms

The following figures represent screenshots of the field auditors' data collection forms, covering fixture inventories, controls inventories, logger deployment sheets, lighting quality assessment tables, and customer/employee surveys.

Figure B-1. Fixture inventory screenshot

Site 1631 - 1a. Fixture Inventory																									
			Space Details					Baseline System via Tracking			Baseline System - Evaluators			Installed System via Tracking					Installed System - Evaluators					Ctl Potential	
ID	Inspected?	Metered?	Location (via Tracking)	Floor	Evaluator's Usage Group	Heated?	Cooled?	Fixture code	Fixture description	Qty	Fixture description/ code	Qty	Rated Lamp Watt	Presc Or Cust?	Cntrols?	Fixture code	Fixture description	Qty	Fixture description/ code	Ballast Description	Ctl Type	Qty	Rated Lamp Watt	Potential System: OS, T, DAY, N/A	% Tot Fixt W
1																									
2																									
3																									
4																									
5																									
6																									

Figure B-2. Controls inventory screenshot

Site 1631 - 1b. Controls Addendum																			
			Space Details			Baseline via Tracking			System via Evaluators				Installed via Tracking			Installed System via Evaluators			
ID	Inspected?	Metered?	Location (via Tracking)	Floor	Evaluator's Usage Group	Fixture description	Fixt. Qty	Annual Hrs	Old controls description	C'tld Fixt. Qty	Installed Rated Lamp Wattage	Est'd Annual Hours	Prescr. Or Cust?	Controls description	C'tld Fixt. Qty	Verified Control Type	Ctld Fixt. Qty	# Sensors	Description/Notes (e.g. pre-install schedule)

Figure B-3. Logger deployment sheet

Site 1631 - 2. Logger Deployment Sheet											
Inventory ID	Logger ID	Evaluator's Usage Group	General Space/Area Description	Specific Location in the Space	Any Automatic Controls in Usage Group? OS, Timer, Daylight, etc.	Measurement Type (Light % On, Light Level)	Frequency of Observations	Lighting Quality Measurements Taken? (see next pg)	Installed Date and Time	Removed Date and Time	Notes (e.g. presence of ANY controls in Usage Grp)

Figure B-4. Lighting quality assessment form

Site 1631 - 3. Lighting Quality Assessment																					
									Auditor Ratings			Owner/Manager Ratings				Occupant/Employee Ratings			
Parent Inventory ID	Metered Usage Group (per Logger Form)	Primary Task Type (see below)	Usage group's illuminated square footage	Dimmer Control (Y/N)	If Yes - Note Dimmer Control Position (%)	Fc Reading #1	Fc Reading #2	Fc Reading #3	Color Rendering Issues?	Glare Issues?	Lighting Quality Rating	Color Rendering Issues?	Glare Issues?	Lighting Quality Rating	Reliability Indicator	Color Rendering Issues?	Glare Issues?	Lighting Quality Rating	Reliability Indicator

Figure B-5. Customer survey

Site 1631 - 4. Owner/Manager and Occupant/Employee Surveys			
Site ID: 1631	Date:		Business Hours:
Site Name:		Site Address:	
Auditor name		Building square footage:	12000 sq ft
Site Contact:		Area Impacted by the projec	12000 sq ft

	Place "X" as needed
1	**Owner/Manager: Building Mechanical Systems**
1.01	Cooling system fuel (e.g., electric, natural gas, steam):
1.02	Cooling system type (e.g., window unit, RTU, chiller plant):
1.03	Cooling system nameplate/efficiency - specify units (e.g., COP, EER, kW/ton):
1.04	Cooling season start month:
1.05	Cooling system is enabled if OAT goes above: F
1.06	Heating system fuel (e.g., electric, natural gas, fuel oil):
1.07	Heating system type (e.g., furnace, boiler, heat pump, electric resistance):
1.08	Heating system nameplate/efficiency - specify units (e.g., COP, AFUE, HSPF):
1.09	Heating season start month:
1.10	Heating system is enabled if OAT goes below: F
2	**Owner/Manager: Building Operation**
2.01	What are the formal business hours of the facility (hours and days)?
2.02	Holidays observed: New Year's Day □,Dr. Martin Luther King, Jr. Day □,President's Day □,Patriots' Day □,Memorial Day □ Independence Day □,Labor Day □,Columbus Day □,Veterans' Day □,Thanksgiving Day □,Thanksgiving Friday □,Christmas Day □ Other [record the dates(s)] □
2.03	Do any of the occupants work during non business hours?
2.04	Do you have cleaning crews go through the facility in off hours?
2.05	Is there any seasonality to the facility hours? (e.g. typical plant shutdowns, extended Christmas, summer, tax season, etc.)
2.06	Were there any changes in the lighting schedule since the project was installed?
2.07	Are the monitored months typical for the facility operation?

Figure B-6. Customer survey (continued)

3	Owner/Manager: Baseline & RUL Survey
3.01	Were you the person that initiated and approved this project?
3.01a	*[If no]* Can you provide the name and contact information for that individual? *[Repeat 3.01 with that person.]*
3.02	Which other individual(s) or groups assisted you in the decision-making for this lighting upgrade? Examples include, CFO, lighting contractor, architect.
3.03	Were you aware of any other viable lighting replacement options at the time of the project?
3.04	What were the reasons for ultimately choosing the installed lighting type(s)? *[If multiple, ask them to rank by importance.]*
3.05	*[If conversion from fluorescent to LED tubes]* Did you experience any difficulties in converting from fluorescent tubes to LED?
3.06	*[If conversion from fluorescent to LED tubes]* Were the old ballasts reused and only the lamps replaced? Or were new ballasts installed
3.06	Has the quantity of light fixtures/lamps increased or decreased since participating in the program? *[If yes, record how many]*
3.07	Part of a major renovation? *[obtain square footage information]* *[Auditor seeking to answer whether renovation or addition is major enough to trigger code]*
3.07a	*[If part of a major renovation, check off all that apply]* What other equipment was replaced at the time of the renovation project? □ Ceiling grid removed □ Terminal AC units replaced □ Studs were exposed □ Anything else? *[Auditor to list what, if anything, else]* ____
3.08	Can you tell us a bit about the previous system? How well was it working?
3.09	What was the primary reason for the lighting replacement? *[Auditor seeking to understand whether there was some type of systemic failure, or incipient failure, of overall lighting systems]*
3.10	Do you know when the lighting was last updated before this project?
3.11	What was the age of the replaced equipment? *[This information will help inform measure life moving forward]*

Figure B-7. Customer survey (continued)

3.12	Based on your experience with similar lighting systems, about how many years do you think the removed fixture would have operated if left in place?
3.13	Do you have any of the older light fixtures still in operation?
3.14	Do you have any of the older lamps or ballasts still in storage?
3.15	*[If yes to either 3.12 or 3.13]* Do you mind if I briefly inspect the older lighting systems?
4	**Owner/Manager: Satisfaction Survey**
4.01	By our records, this project was completed about last year. What has been your experience with the new lighting to date?
4.02	Have there been any complaints or compliments from occupants, employees, or customers?
4.03	Any feedback from you or others on the brightness or clarity of the lighting?
4.04	If the light levels were reduced, would that have an impact on your business's operation?
4.05	Does your business require a specific level of lighting for its operations?
5	**Occupant/Employee: Satisfaction Survey #1**
5.01	By our records, this lighting upgrade was completed about a year ago. What has been your experience with the new lighting to date?
5.02	Do you have any comments on the brightness, quality, or clarity of the new lighting?
5.03	Overall are you satisfied with the new lights?
5.04	Can you tell us a bit about the old lighting? How well was the old lighting system working?

APPENDIX C. Baseline and RUL Data Collection

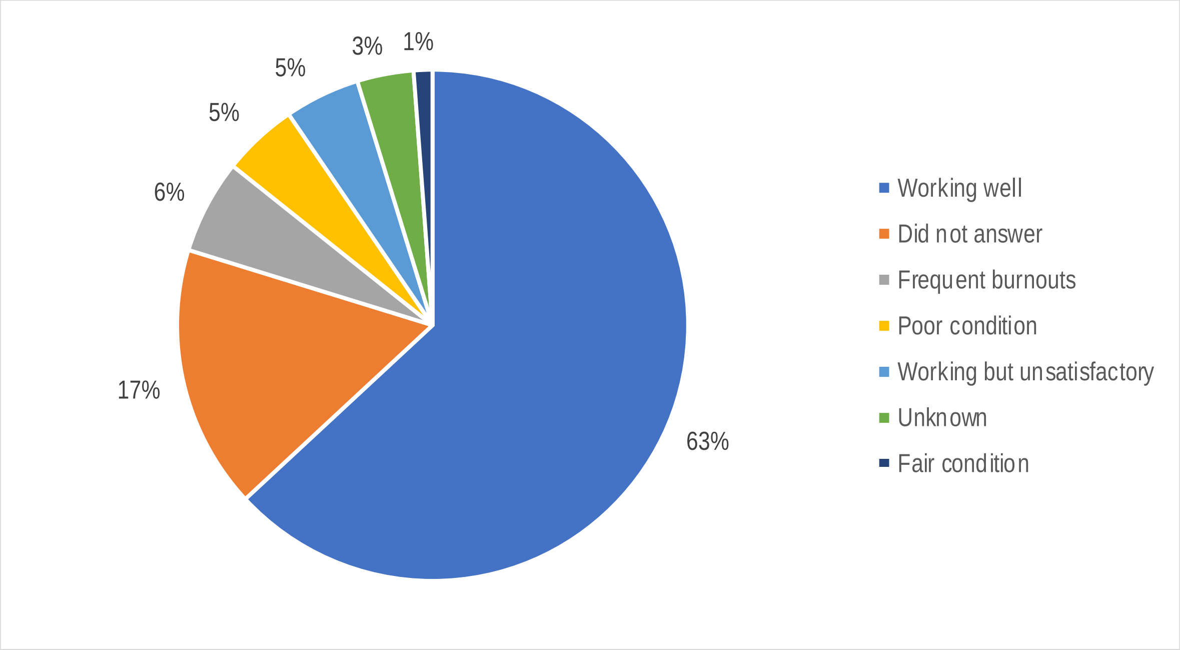
This appendix presents the findings from evaluator surveys with sampled customers to understand the condition of the pre-existing lighting systems. Of particular interest for this and other evaluation studies is an estimate of the potential remaining useful life (RUL) of the replaced lighting fixtures. This section presents the results of the site contact responses to the administered surveys.

Each site auditor administered surveys to primary customer contact(s) at each sampled facility. As part of this survey, several questions involved the condition and operability of the pre-existing lighting systems. These questions were designed to gather information on the following:

- The condition of the pre-existing lighting system and how it was performing
- The age of the pre-existing lighting system
- When the pre-existing lighting system was previously replaced
- The estimated amount of time (in years) which the pre-existing lighting systems could have continued operating before failure

Responses to these questions varied, with a wide range of customer knowledge and response reliability. While some facility contacts were strongly familiar with the pre-existing systems, others had only a cursory knowledge, or no useful information. Figure C-1 shows the breakdown of site contact responses when asked about the pre-existing lighting condition at their respective sites.

Figure C-1. Site contact responses to pre-existing lighting condition inquiry



As evident from Figure C-1, approximately 63% of all customers indicated that the pre-existing lighting systems were still functioning well. Another 17% were insufficiently familiar to offer a response. 11% of customers indicated poor condition or inoperability (e.g. lamp burnouts). Overall, this information generally supports continued use of the early replacement assumption and its baseline of preexisting conditions; however, the 11% indicating unsatisfactory prior operation might warrant further consideration of a blended baseline of early replacement and replace-on-failure baseline for the Initiative’s lighting measures.

Site auditors also collected responses of the site contacts' best estimations of the age of the pre-existing lighting systems at the time of lighting upgrade. Figure C-2 shows the breakdown of the 48 customers providing information on preexisting system age.

Figure C-2. Site contact estimations of pre-existing lighting fixture age

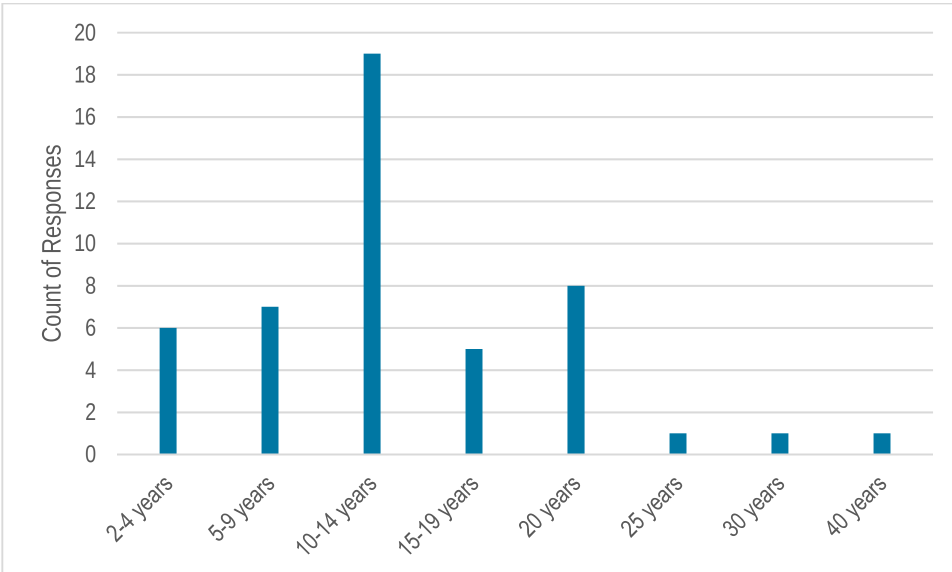
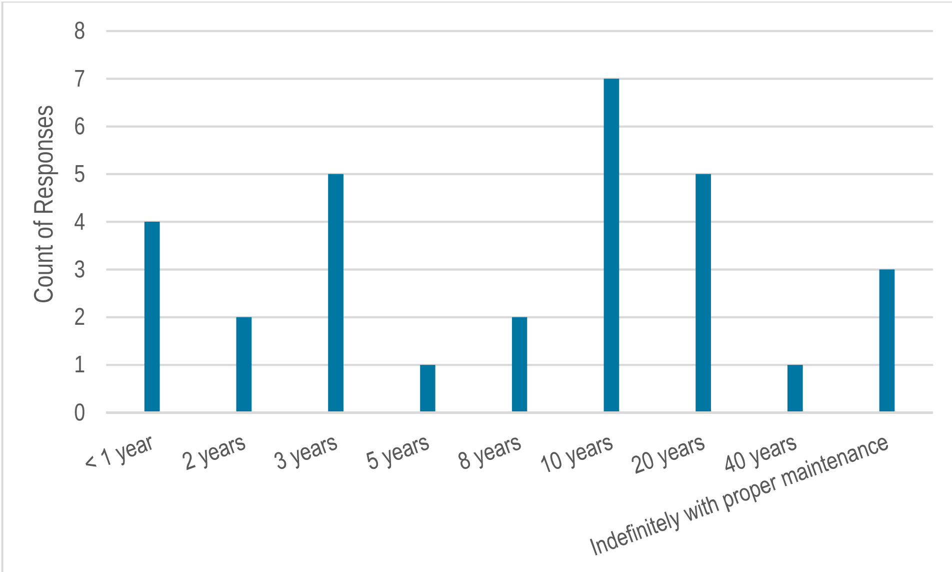


Figure C-2 shows that approximately two-thirds of the responses indicate that the lighting was replaced before the nominal expected useful life (EUL) of 15 years for lighting. These responses also further reinforce that an early replacement baseline is generally appropriate for small business lighting.

Customers found it more difficult to estimate the number of years that the preexisting lighting systems could have remained operable before failure. Nonetheless, site auditors gathered the facility contacts' best estimates of remaining useful life of the pre-existing lighting systems. Figure C-3 shows the breakdown of responses from the facility contacts who offered RUL estimations. Fewer site contacts were as confident in their RUL estimations as they were with other pre-existing lighting system questions.

Figure C-3. Site contact estimations of remaining useful life of lighting fixtures



While the direct assessment of RUL was not in the scope of this study, this information can be aggregated with other Massachusetts studies to strengthen the overall dataset on C&I lighting RUL. Figure C-3 somewhat aligns with the current assumption of RUL as one-third of the EUL, or 5 years. The concurrent Massachusetts Utilities P73D study has primarily been tasked with developing MA-specific RUL data. The P69 results will be aggregated with the P73D results to form a more robust set of data pertaining to RUL.

APPENDIX D. Lighting quality research

This appendix presents this study's findings from the data collection and analysis related to lighting quality and possible light level reduction. Lighting quality readings and field engineer assessments were conducted at each of the 105 facilities sampled for this study.

Lighting level ranges

Site auditors conducted light level measurements, when possible, for each fixture selected for time-of-use metering. Light-level spot measurements were taken at the height corresponding to the task for which specific illumination levels are needed (e.g., desk-level in a classroom). If lighting was poorly distributed, the site auditor took measurements within a grid.

Within the evaluation sample, site auditors identified four primary IESNA task type categories (B, C, D and E) out of a total of nine possible categories (A through I). Each task type corresponds to a given recommended foot candle range with A representing the lowest recommended range. Each subsequent task letter B through E represent tasks with increasing lighting output requirements. Table D-1 describes the typical spaces classified within the IESNA categories.

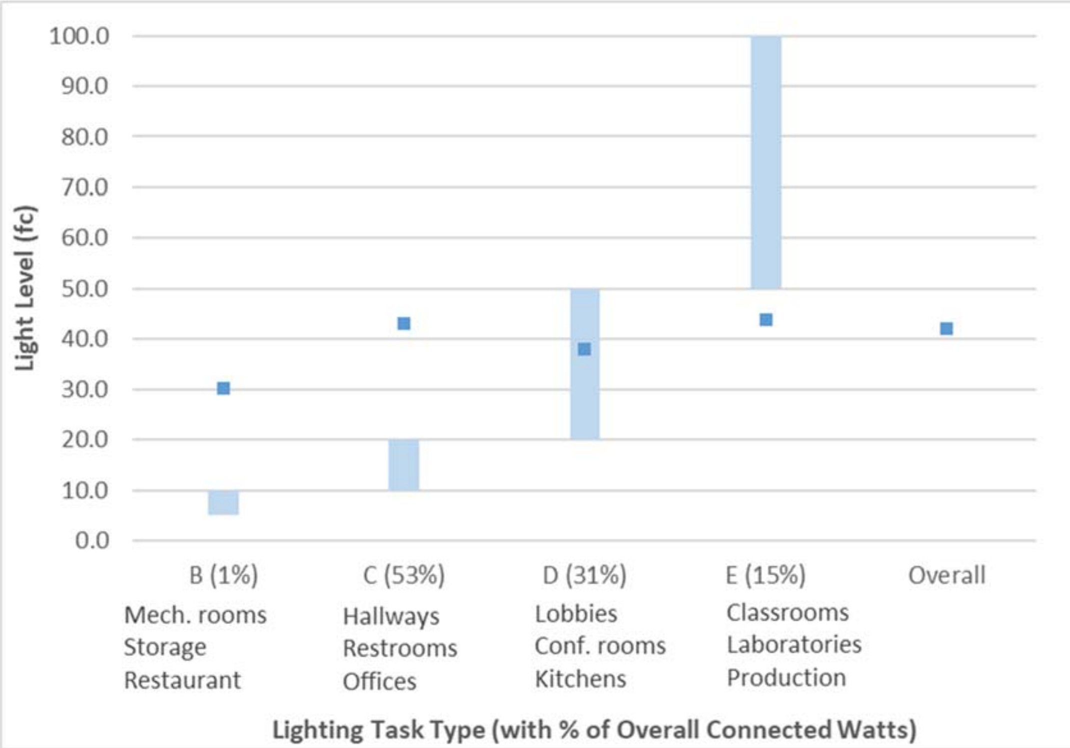
Table D-1. IESNA task type classifications

IESNA task type category[26]	Space types
B	Mechanical rooms, garage, storage, restaurants
C	Hallways, warehouse, restrooms, offices, common spaces in dorms
D	Offices, conference rooms, lobbies, library, manufacturing, and kitchens
E	library stacks, archives, laboratory, manufacturing, and classrooms

Figure D-1 shows the light level ranges for each of the observed IESNA task types. The light blue lines represent the given recommended range in foot-candles (fc). The dark blue markers represent the average recorded foot-candle value for each task type.

[26] The task type categories as defined by IESNA are complex and in many cases the field engineer assigned a task type category based on the data collected on-site (i.e., a hallway could have lighting from tasks C or D).

Figure D-1. Recommended IESNA task type light level ranges and average recorded values

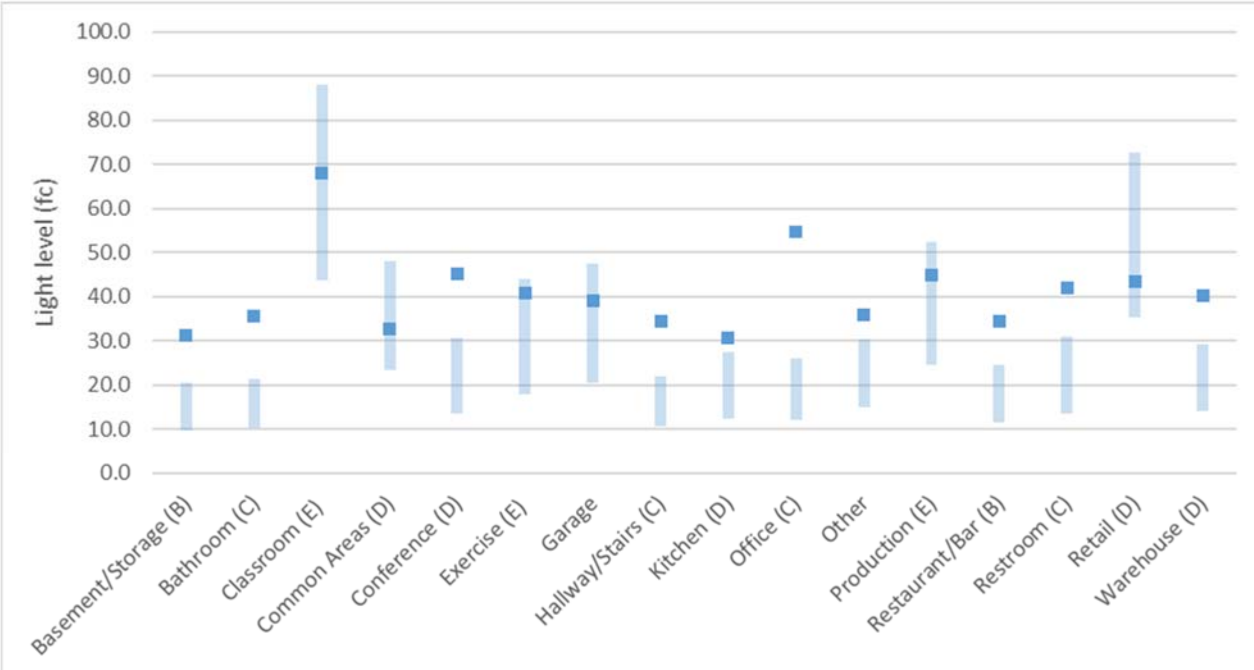


This data shows that the average recorded light level for task types B and C are significantly higher than the IESNA recommended level. The average recorded light level for Task E was lower than the recommend level. The measured light level for Task D fell within the range of typical foot-candles.

Evaluators analyzed the potential kWh savings if the average wattage of all fixtures labeled as B and C task types was reduced to reflect lumen output at the mid-point of the IESNA ranges. Evaluators estimated significant potential savings, amounting to 12% of program-reported kWh in PY2016. While there are uncertainties associated with this data collection and analysis (e.g., limited foot-candle measurements on site, different customer usages that are not reflected in the IESNA classification), the analysis shows that the significant savings potential warrants future research in other non-residential settings as the prevalence of LEDs grows rapidly.

When metering was performed in a space, each site auditor recorded light level readings, assigned the appropriate IESNA task type for that space, and labeled that space with an appropriate usage category. Figure D-2 illustrates the light level ranges for all site engineer-assigned usage categories in which light level readings were taken. As some space types could be classified within different IESNA categories depending on facility type, the maximum-minimum ranges vary across the study. The minimum and maximum recommended readings in foot candles (fc) are illustrated with light blue lines for the given usage category; the dark blue markers illustrate the average recorded value for each given task type in fc.

Figure D-2. Light level ranges and readings by space type



10 out of the 16 observed usage group types were found to exhibit higher average foot candle readings than recommended by IESNA. The classroom, common area, exercise, garage, production, and retail areas are the only usage areas where the average measured foot candle readings fall within the average recommended light level.

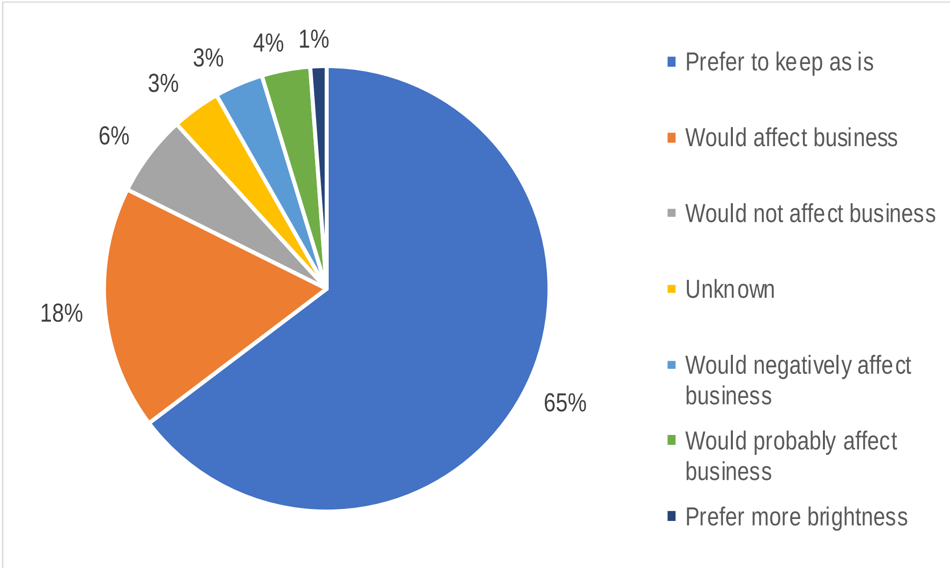
Site auditors reported that it was difficult to spot-measure light-level in spaces exposed to daylighting; the measurement approach in these spaces was not consistent and therefore omitted as to not impact final results.

Lighting quality assessment

Overall, lighting quality was assessed by field auditors as "good" for the overwhelming majority of the surveyed spaces. Lighting quality was graded as "poor" in only three metered spaces, all of which were bathrooms. Evaluators found no instances of noticeable glare or color rendering index (CRI) issues.

Field auditors also surveyed the primary customer contact—managers, owners, and/or decision-makers—at each sampled site to assess their willingness to slightly reduce illumination to achieve additional savings. Figure D-3 shows the breakdown in responses when the customer was asked if reducing lighting levels would impact the facility negatively or positively.

Figure D-3. Survey responses pertaining to light level reduction potential



Overall, two out of three customers preferred to keep the illumination levels as-is, with another 18% predicting that less light would affect business, and another 3% indicating it would negatively affect business. While many of the installed fixtures within the project sample consisted of plug-and-play TLED retrofits, many of the fixtures are hardwired, and more significant reductions of lighting levels might involve more invasive rewiring of the facility lighting systems, which is a further deterrent for many customers.

Lighting power density

Lighting power density (LPD) was also calculated for each usage category. The LPD values were calculated based on site auditor readings and measurements and have been compared with the 2012 IECC code (Table C405.5.2(2)) for each major space type encountered in this study. The results are shown in Table D-2.

Table D-2. LPD measurements by usage category

Usage Category	Measured LPD (W/sq.ft.)	Code LPD (W/sq.ft.)
Basement/Storage	1.56	0.41
Bathroom	1.10	1.00
Classroom	0.64	1.30
Common Areas	0.94	1.20
Conference	0.60	1.20
Exercise	1.59	0.90
Garage	0.44	0.30
Hallway/Stairs	2.39	0.70
Kitchen	1.09	1.20
Office	1.49	1.10
Production	0.85	1.30
Restaurant/Bar	0.41	1.30

Usage Category	Measured LPD (W/sq.ft.)	Code LPD (W/sq.ft.)
Restroom	0.47	1.00
Retail	0.71	1.60
Theater	2.73	2.60
Warehouse	0.64	0.60

Conclusion

The findings shown in Figures D-1 and D-2, as well as in Table D-2, suggest there is significant savings potential within several of the observed task types and usage categories where lighting has been replaced. However, given the potential barriers in play to achieve meaningful savings by reducing the light level at small businesses, we recommend that lighting contractors continuously consider lower light levels and engage customers early in the decision-making process in order to successfully sell such projects. We generally found that customers defer to the lighting contractors' recommendations on appropriate system upgrades. Careful guidance and explanation from contractors to customers that minor reductions in fixture lighting output will still result in sufficient illumination is critical to this measure's potential.

APPENDIX E. Site results

Site-by-site RRs are presented in Table E-1 for kWh, connected kW, and peak kW savings.

Table E-1. Site-level evaluation results

Evaluation ID	Annual kWh RR	Connected kW RR	Summer Peak kW RR	Winter Peak kW RR	Primary kWh Adjustment
2	25%	100%	14%	47%	Documentation
4	80%	88%	140%	0%	Technology
8	64%	94%	41%	82%	Quantity
115	99%	90%	156%	157%	Operation
230	57%	106%	45%	49%	Technology
287	83%	100%	127%	32%	HVAC Interactivity
359	87%	92%	47%	162%	Documentation
370	85%	72%	123%	158%	Operation
574	69%	88%	97%	135%	Operation
592	92%	106%	88%	116%	Documentation
727	102%	107%	45%	174%	Operation
870	53%	101%	36%	32%	Documentation
890	98%	100%	0%	227%	Documentation
896	88%	100%	114%	200%	Documentation
903	91%	100%	46%	36%	Documentation
973	107%	100%	108%	59%	Documentation
1008	115%	96%	151%	237%	Operation
1018	96%	98%	119%	170%	Operation
1038	84%	130%	108%	156%	Quantity
1041	67%	107%	103%	165%	Documentation
1094	106%	102%	59%	127%	Operation
1098	97%	97%	59%	193%	Documentation
1102	77%	100%	172%	103%	Documentation
1111	91%	100%	83%	149%	Technology
1147	104%	117%	160%	117%	Documentation
1161	93%	95%	115%	176%	Documentation
1184	84%	85%	70%	156%	Operation
1204	90%	97%	106%	105%	Documentation
1211	122%	97%	54%	221%	Operation
1247	50%	100%	15%	45%	Documentation
1284	85%	98%	55%	59%	Technology
1308	60%	91%	80%	54%	Documentation
1317	63%	109%	143%	245%	Documentation
1330	69%	53%	163%	229%	Operation
1398	93%	103%	122%	167%	Documentation

Evaluation ID	Annual kWh RR	Connected kW RR	Summer Peak kW RR	Winter Peak kW RR	Primary kWh Adjustment
1440	52%	96%	36%	207%	Technology
1445	77%	101%	127%	158%	Documentation
1451	70%	97%	88%	10%	Technology
1562	93%	103%	144%	237%	Operation
1567	90%	96%	31%	172%	Documentation
1575	83%	102%	100%	99%	Technology
1584	109%	101%	158%	184%	Technology
1624	120%	100%	176%	163%	Operation
1631	91%	100%	167%	210%	Documentation
1734	73%	107%	135%	114%	Documentation
1746	85%	100%	93%	23%	Documentation
1815	105%	100%	199%	332%	Documentation
1849	164%	100%	157%	190%	Operation
1947	114%	2269%	173%	197%	Documentation
2068	88%	5187%	58%	10%	Technology
2070	66%	100%	85%	34%	Documentation
2089	57%	84%	26%	8%	Technology
2127	69%	100%	51%	3%	Documentation
2128	105%	97%	53%	167%	Operation
2179	85%	94%	87%	100%	Documentation
2220	153%	99%	114%	138%	Operation
2235	83%	94%	5%	27%	Documentation
2238	79%	79%	78%	304%	Operation
2289	123%	67%	149%	102%	Operation
2291	88%	71%	82%	65%	Quantity
2347	51%	100%	14%	69%	Documentation
2382	58%	99%	72%	30%	Documentation
2403	91%	101%	115%	98%	Documentation
2417	97%	99%	78%	11%	Operation
2562	61%	70%	65%	140%	Technology
2580	94%	110%	110%	80%	Quantity
2582	101%	100%	67%	80%	Documentation
2596	138%	102%	387%	1%	Operation
2653	247%	99%	175%	221%	Operation
2661	75%	105%	64%	166%	Technology
2701	138%	100%	56%	24%	Operation
2704	80%	96%	94%	60%	Documentation
2732	115%	100%	117%	44%	Operation
2740	119%	96%	56%	16%	Documentation

Evaluation ID	Annual kWh RR	Connected kW RR	Summer Peak kW RR	Winter Peak kW RR	Primary kWh Adjustment
2750	78%	94%	67%	112%	Documentation
2754	98%	99%	62%	75%	Operation
2795	117%	91%	81%	122%	Operation
2800	161%	109%	148%	225%	Operation
2814	98%	94%	137%	46%	Documentation
2879	85%	91%	100%	116%	Operation
2919	191%	103%	100%	76%	Operation
2920	155%	100%	151%	198%	Operation
2932	55%	68%	66%	41%	Technology
2951	69%	100%	84%	48%	Documentation
2968	71%	74%	47%	71%	Technology
3036	85%	101%	113%	108%	Technology
3056	93%	89%	102%	105%	Operation
3059	88%	72%	86%	97%	Technology
3070	132%	99%	65%	55%	Documentation
3082	129%	100%	137%	173%	Operation
3089	108%	94%	76%	32%	Quantity
3094	106%	85%	146%	112%	Operation
3101	59%	61%	36%	59%	Documentation
3126	79%	100%	66%	78%	Documentation
3252	160%	98%	114%	111%	Operation
3289	109%	119%	84%	190%	Technology
3340	92%	100%	65%	107%	Documentation
3399	67%	80%	104%	124%	Documentation
3409	96%	100%	134%	115%	Documentation
3435	120%	104%	122%	100%	Operation
3442	89%	97%	66%	83%	Documentation
3545	111%	100%	186%	91%	Operation
3555	60%	100%	49%	196%	Documentation
3584	94%	102%	48%	94%	Documentation
3602	90%	100%	67%	18%	Documentation

APPENDIX F. Tracking Savings Algorithms for SB Lighting

In order to provide context for the application of evaluation results to the PAs' tracking savings, retrospectively and prospectively, we provide a summary of the savings algorithms for lighting measures, as recommended by the Massachusetts TRM.

Tracking savings are defined as the savings based on fixture quantity, wattage, and operation values (hours of use, coincidence factors). Tracking savings do not incorporate HVAC interactive effects or other final adjustment factors.

$$Tracking\ Gross\ kWh\ Savings = \frac{(Qty_{Pre} \times W_{Pre} \times Hrs_{Pre} - Qty_{Post} \times W_{Post} \times Hrs_{Post})}{1000}$$

$$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Summer}} = \frac{\boldsymbol{(Qty_{Pre} \times W_{Pre} \times CF_{Summer,pre} - Qty_{Post} \times W_{Post} \times CF_{Summer,post})}}{\boldsymbol{1000}}$$

$$\boldsymbol{Tracking\ Gross\ kW\ Savings_{Winter}} = \frac{\boldsymbol{(Qty_{Pre} \times W_{Pre} \times CF_{Winter,pre} - Qty_{Post} \times W_{Post} \times CF_{Winter,post})}}{\boldsymbol{1000}}$$

where,

$Tracking\ Gross\ Savings$ = Savings from lighting fixture or control measures that do not incorporate HVAC interactive effects or other final adjustment factors

Hrs = Fixture annual operating hours as claimed by vendor, or as referenced from MA TRM

CF = Coincidence factor determined through prior evaluation (0.72 or 0.73)

Reported savings involve the product of tracking gross savings with adjustment factors for prior evaluation results (including HVAC interactive effects).

$$Reported\ Gross\ kWh\ Savings = Tracking\ Gross\ kWh\ Savings \times ISR \times SPF \times RR_{kWh}$$

$$Reported\ Gross\ kW\ Savings_{Summer} = Tracking\ Gross\ kW\ Savings_{Summer} \times ISR \times SPF \times RR_{skW}$$

$$Reported\ Gross\ kW\ Savings_{Winter} = Tracking\ Gross\ kW\ Savings_{Winter} \times ISR \times SPF \times RR_{wkW}$$

where,

$Reported\ Gross\ Savings$ = Savings value incorporating adjustments for in-service rate, savings persistence, and prior evaluation results, including HVAC interactivity

ISR = In-service rate (100% for direct-install)

SPF = Savings persistence factor (100% for non-CFL screw-ins)

RR = Realization rate determined through evaluation, including HVAC interactive effects

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