MA19R15-E 2019 RESIDENTIAL LIGHTING ON-SITES

FINAL

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SUBMITTED TO:
The Electric and Gas Program Administrators of Massachusetts

SUBMITTED BY:
NMR Group, Inc.

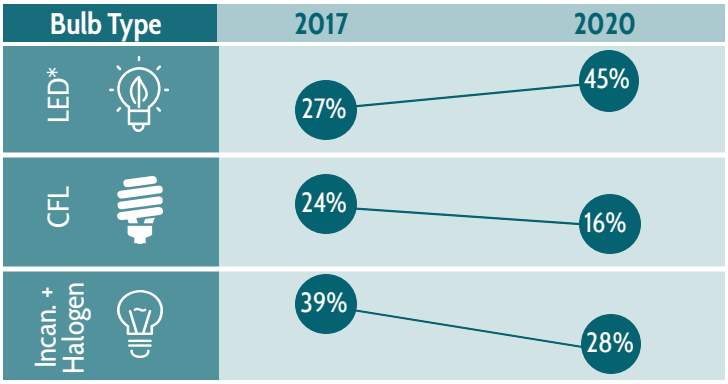
NMR Group, Inc.

Massachusetts Residential Lighting On-Site Study

The goal of this study was to update estimates of lighting saturation and other market indicators. The data came from on-site lighting inventories conducted in Massachusetts homes that are part of the Residential Baseline Study (RES1). NMR, in collaboration with Guidehouse, visited 309 homes between February and June 2017. They revisited 199 of these homes and performed new visits in 102 homes between October 2019 and March 2020. The study compared socket saturation as well as bulb replacement and storage behavior across these visits. The results indicate that households in Massachusetts continue to shift their lighting towards LED overall; however, the rate of the shift is uncertain due to a high concentration of direct install participants in the 2020 RES1 baseline sample.

2020 Saturation Rates

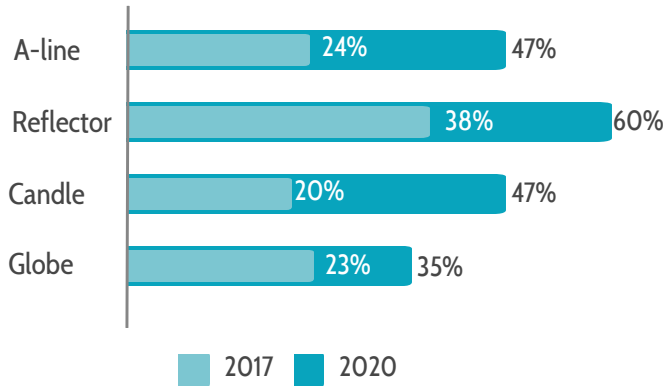
In 2020, efficient bulb saturation (the percentage of sockets filled with LEDs or CFLs) was 61%, compared to 28% for incandescent and halogen bulbs. Overall, LED saturation was 45% in 2020, composed of ENERGY STAR LEDs (37%), non-ENERGY STAR LEDs (3%), and LED fixtures (5%).



*LED saturation ranged from 39% to 45% in 2020.

LED Saturation by Shape

LED saturation increased from 2017 to 2020 for all bulb shapes, while saturation of CFL, incandescent, and halogen bulbs decreased. In 2020, reflectors had the highest LED saturation (60%) of all bulb types, followed by A-lines (47%) and candles (47%).



Newly Installed Replacement Bulbs (%) 2017-2020

LED bulbs (66%) were the most common replacement bulb installed in Massachusetts households, followed by incandescent and halogen bulbs (17%) and CFLs (11%).

Households replaced 9% of all LEDs installed; bulb failure was cited as the most common reason for replacing the LED.

94% of all replacement LEDs were new to the home, compared to 74% of incandescent and halogen bulbs.

	LED	CFL	Incan + Halogen
A-line	65%	16%	19%
Reflector/ Flood	83%	5%	12%
Candle	78%	2%	20%
Globe	58%	4%	38%

Threats to Validity

Direct Install Participation

41% of households in the 2020 study participated in at least one PA-sponsored direct install program since 2015. Of the 199 households visited for the study in 2017, 37% were verified direct install participants. Because the 45% saturation estimate includes a disproportionate number of direct install participants, it is likely a high-end estimate of actual statewide saturation.

LED Saturation

39% Excluding Direct Install

45% Including Direct Install

54% Direct Install Only

Including direct install participants in the overall saturation estimate boosts socket saturation.

Table of Contents

EXECUTIVE SUMMARY **1**
OVERALL ASSESSMENT 1
KEY FINDINGS 2
Massachusetts Socket Saturation Trends 2
ENERGY STAR LEDs 3
Saturation by Shape 4
Panel Visits – Changes in Bulb Types over Time 5
Storage Behavior 5
CONSIDERATIONS AND GUIDANCE 6
SECTION 1 INTRODUCTION **7**
1.1 STUDY OBJECTIVES 7
1.2 METHODOLOGY 8
1.2.1 Study Limitation: Direct Install Program Participation 8
SECTION 2 CHANGES IN SOCKET SATURATION OVER TIME **9**
2.1 SATURATION BY HOUSEHOLD 9
2.1.1 ENERGY STAR LED Saturation 12
2.1.2 Saturation by Bulb Shape 13
2.1.3 Saturation by Demographics 14
2.2 ROOM-BY-ROOM SATURATION 15
2.2.1 Room-by-Room LED Saturation 2017 vs. 2020 15
2.2.2 Room-by-Room Saturation by Shape 16
2.2.3 Room-by-Room Specialty Bulb Saturation 18
SECTION 3 PENETRATION **19**
3.1 BULB PENETRATION 20
3.2 ROOM-BY-ROOM ANALYSIS 21
SECTION 4 REPLACEMENT BEHAVIOR **22**
4.1 BULB CHANGES 2017-2020 23
4.1.1 Bulb Replacement Behavior 24
4.1.2 Delta Watts 27
4.1.3 Bulb Replacement by Shape 28
4.1.4 Additional Detailed Bulb Replacement Behavior 29
4.1.5 Bulbs Replacing LEDs 34

SECTION 5 RECENT PURCHASES 35
5.1 SOURCES OF NEWLY ACQUIRED LEDS 35
5.2 PURCHASES BY ENERGY STAR STATUS 37
SECTION 6 STORAGE BEHAVIOR 38
6.1 STORED BULBS 38
6.2 STORED BULB STATUS 39
SECTION 7 LED SATISFACTION 40
APPENDIX A METHODOLOGY 41
A.1 WEIGHTING SCHEME 41
A.2 ON-SITE LIGHTING INVENTORIES – PANEL VISITS 42
A.3 BULB CATEGORIZATION 44
APPENDIX B DIRECT INSTALL 45
B.1 EFFECT OF DIRECT-INSTALL PARTICIPANTS ON SATURATION ESTIMATES 47
APPENDIX C SATURATION – ADDITIONAL DETAILED ANALYSIS 48
C.1 SATURATION BY HOUSEHOLD 48
C.2 SATURATION BY DEMOGRAPHICS 51
C.3 ENERGY STAR LED SATURATION 54
C.4 LINEAR FLUORESCENT SATURATION 55
C.5 SATURATION OF SPECIALTY SOCKETS 55
APPENDIX D PENETRATION – ADDITIONAL DETAILED ANALYSIS 56
D.1 ROOM-BY-ROOM ANALYSIS – DETAILED ANALYSIS 56
D.2 ROOMS WITHOUT ENERGY-EFFICIENT BULBS 59
APPENDIX E BULB REPLACEMENT BEHAVIOR 61
E.1 AVERAGE BULB REPLACEMENT BY HOUSEHOLD 61
E.2 EMPTY SOCKETS 62
E.3 BULB REPLACEMENT BEHAVIOR BY DEMOGRAPHIC VARIABLES 63
E.4 NEWLY INSTALLED BULBS 65
APPENDIX F LED PURCHASES AND SATISFACTION 66
F.1 SOURCES OF BULBS BY INCOME AND HOME TYPE 66
F.2 LED SATISFACTION 67
APPENDIX G STORAGE 69
APPENDIX H DEMOGRAPHICS 71

Figures

FIGURE 1: SATURATION IN MASSACHUSETTS OVER TIME (2009-2020)[1] 2
FIGURE 2: ENERGY STAR LED SATURATION 2016-2020 3
FIGURE 3: RES1 BASELINE SATURATION BY BULB SHAPE AND TYPE 4
FIGURE 4: REPLACEMENT BULBS, 2017-2020 5
FIGURE 5: SATURATION RATES OVER TIME, 2009-2020 10
FIGURE 6: RES1 BASELINE SATURATION, 2017 VS. 2020[1] 11
FIGURE 7: LED BULB SATURATION 2009-2020 WITH ENERGY STAR LEDS 2016-2020 12
FIGURE 8: RES1 BASELINE SATURATION BY BULB SHAPE AND TYPE 13
FIGURE 9: SATURATION BY DEMOGRAPHICS 14
FIGURE 10: ROOM-BY-ROOM LED SATURATION 2017 VS. 2020 15
FIGURE 11: SATURATION BY BULB SHAPE AND ROOM TYPE, 2020 17
FIGURE 12: SPECIALTY BULB SATURATION AND LED SATURATION BY ROOM TYPE, 2020[1] 18
FIGURE 13: PENETRATION BY BULB TYPE OVER TIME 20
FIGURE 14: LED PENETRATION BY ROOM TYPE, 2017-2020 RES1 BASELINE 21
FIGURE 15: REPLACEMENT BULBS, 2017-2020 26
FIGURE 16: BULB REPLACEMENT BY SHAPE (2017-2020) 28
FIGURE 17: OVERALL BULB REPLACEMENTS 30
FIGURE 18: WHAT REPLACED WHAT 31
FIGURE 19: BULBS REPLACING LEDS 34
FIGURE 20: ENERGY STAR STATUS OF LEDS PURCHASED IN 2019 37
FIGURE 21: ON-SITE VISITS OVER TIME 43
FIGURE 22: TIMING OF ON-SITE VISITS 43
FIGURE 23: ENERGY STAR LEDS 54
FIGURE 24: LED PENETRATION BY ROOM TYPE, 2017 + 2020 56
FIGURE 25: CFL AND INCANDESCENT + HALOGEN PENETRATION BY ROOM TYPE, 2017 + 2020 58
FIGURE 26: REPLACEMENT BULBS BY DEMOGRAPHIC 63
FIGURE 27: LED REPLACEMENT BEHAVIOR BY INCOME, 2016-2020 *SIGNIFICANTLY 64
FIGURE 28: COMPARISON OF 2020 RES1 BASELINE WITH CENSUS 72

Tables

TABLE 1: PANEL REPLACEMENT BULB SUMMARY 2017-2020 (UNWEIGHTED) 23
TABLE 2: BULB REPLACEMENT 24
TABLE 3: REPLACEMENT BULBS BY BULB SOURCE 24
TABLE 4: REPLACEMENT INCANDESCENT AND HALOGEN BULBS BY BULB SHAPE AND SOURCE 25
TABLE 5: DELTA WATTS BY REPLACEMENT BULB TYPE 27
TABLE 6: REASONS FOR BULB CHANGE* 32
TABLE 7: REASONS FOR BULB TYPE CHANGE BY REPLACEMENT BULB TYPE[1,2] 33
TABLE 8: LED BULBS OBTAINED 2016-2020 36

TABLE 9: STORED BULBS BY BULB TYPE OVER TIME....39
TABLE 10: STORED BULBS STATUS....39
TABLE 11: LED SATISFACTION....40
TABLE 12: LED SATISFACTION BY BULB SHAPE[1]....40
TABLE 13: ON-SITE VISIT WEIGHT SCHEME....41
TABLE 14: SATURATION BY SOCKET AND MEAN AND MEDIAN SATURATION BY HOUSEHOLD, 2020....42
TABLE 15: STATEWIDE PROGRAM PARTICIPATION....45
TABLE 16: RES1 BASELINE DIRECT-INSTALL PROGRAM PARTICIPATION BY YEAR (UNWEIGHTED)....46
TABLE 17: 7-YEAR PANEL DIRECT-INSTALL PROGRAM PARTICIPATION BY YEAR (UNWEIGHTED)....47
TABLE 18: COMPARISON OF SATURATION RATES BY VERIFIED DIRECT INSTALL (DI) PROGRAM PARTICIPATION (UNWEIGHTED)....47
TABLE 19: COMPARISON OF SATURATION RATES, 2013–2020....50
TABLE 20: SATURATION BY DEMOGRAPHICS....52
TABLE 21: STATEWIDE SOCKET COUNTS BY ROOM TYPE[1]....53
TABLE 22: STATEWIDE HOUSEHOLD COUNTS BY ROOM TYPE....53
TABLE 23: INSTALLED LINEAR FLUORESCENTS....55
TABLE 24: SATURATION OF SPECIALTY SOCKETS BY BULB TYPE....55
TABLE 25: ROOMS WITHOUT ENERGY-EFFICIENT BULBS....59
TABLE 26: REASONS FOR NOT INSTALLING ENERGY-EFFICIENT BULBS....60
TABLE 27: 2020 PANEL REPLACEMENT BULBS....61
TABLE 28: EMPTY SOCKETS, 2017-2020....62
TABLE 29: NEWLY INSTALLED BULBS IN RES1 HOUSEHOLDS....65
TABLE 30: LEDS OBTAINED BY DEMOGRAPHIC (PANEL HOUSEHOLDS ONLY)....67
TABLE 31: LED SATISFACTION....67
TABLE 32: REASONS FOR LED DISSATISFACTION....68
TABLE 33: LED SATISFACTION BY BULB SHAPE*....68
TABLE 34: STORED BULBS BY INCOME AND HOME TYPE....69
TABLE 35: REASON FOR STORAGE BY BULB TYPE....70

Executive Summary

This report presents the results of the 2020 Massachusetts Residential Lighting On-Site Study conducted by NMR Group, Inc. (NMR) for the Massachusetts Electric Program Administrators (PAs). The Massachusetts Energy Efficiency Advisory Council consultants (EEAC) also advised study planning, analysis, and reporting. The overall goal of the study was to update estimates of lighting saturation in Massachusetts. The data for this study came from on-site lighting inventories conducted between October 2019 and March 2020 in Massachusetts homes that are a part of the Guidehouse-led Residential Baseline Study. This report compares the results of this study, referred to as ***2020*** or ***2020 (RES1 Baseline)***, to previous visits to many of the same homes in 2017 and, for certain analyses, to a different set of homes, referred to as the ***7-Year Panel.*** Throughout the report, we refer to the saturation and penetration of various lighting technologies. Saturation is the percentage of sockets filled with a specific bulb type. Penetration is the percentage of homes with one or more of a specific lighting technology. Additional methodological details are included in Section 1.2 and Appendix A.

Overall Assessment

Evidence from this study suggests the following:

- Light Emitting Diode (LED) saturation in 2020 was 45% in RES1 Baseline homes, an increase from 2017 when saturation was 27% in the Baseline study homes.
- Massachusetts households chose LEDs as replacements for two-thirds (66%) of bulbs replaced since the 2017 visit.
- Over one-third of all installed bulbs (37%) were ENERGY STAR® LEDs, and 92% of all LEDs that households recalled purchasing or obtaining in the last year were verified to be ENERGY STAR-certified.
- Saturation of specialty LED lamps in Massachusetts was highest for reflectors (60%), followed by candelabras (47%) and globes (35%).
- While compact fluorescent lamps (CFLs) and inefficient bulbs (halogens + incandescents) made up about equal proportions of non-LED A-line sockets, inefficient bulbs accounted for nearly all of the non-LED specialty bulbs.

However, the RES1 Baseline sample includes a disproportionately high number of households verified to have taken part in a PA direct install program between 2017 and 2020, which has important implications:

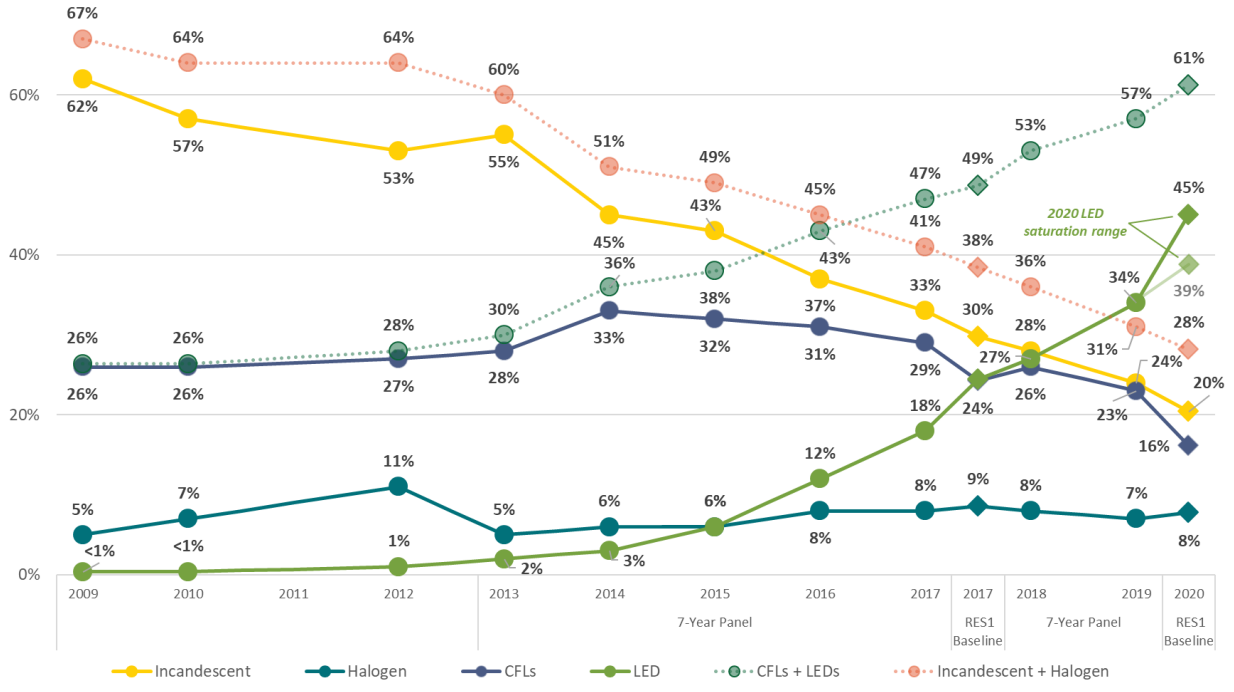
- Some of the observed changes to lighting use reflect program influence. Findings for socket saturation, bulb replacement, and newly purchased or obtained bulbs are the most at risk for bias.
- Socket saturation for households not taking part in a direct install program was 39%; therefore, NMR concludes that socket saturation in 2020 was likely between 39% and 45%.

KEY FINDINGS

Massachusetts Socket Saturation Trends

As Figure 1 shows, ***LED saturation has grown rapidly since 2014, increasing from 3% in 2014 to at least 39% and as high as 45% in 2020.*** Despite the decline in CFL saturation since 2014, saturation of efficient bulbs (CFLs and LEDs) reached 61% by 2020, while saturation of inefficient bulbs (incandescent and halogen) declined to 28%. Interior room socket LED saturations ranged from 49% (in bedrooms) to 58% (in kitchens). Exterior LED socket saturation was only 41%. Additional analysis related to saturation trends over time, including by room type, can be found in Section 2.

Figure 1: Saturation in Massachusetts Over Time (2009-2020)[1]



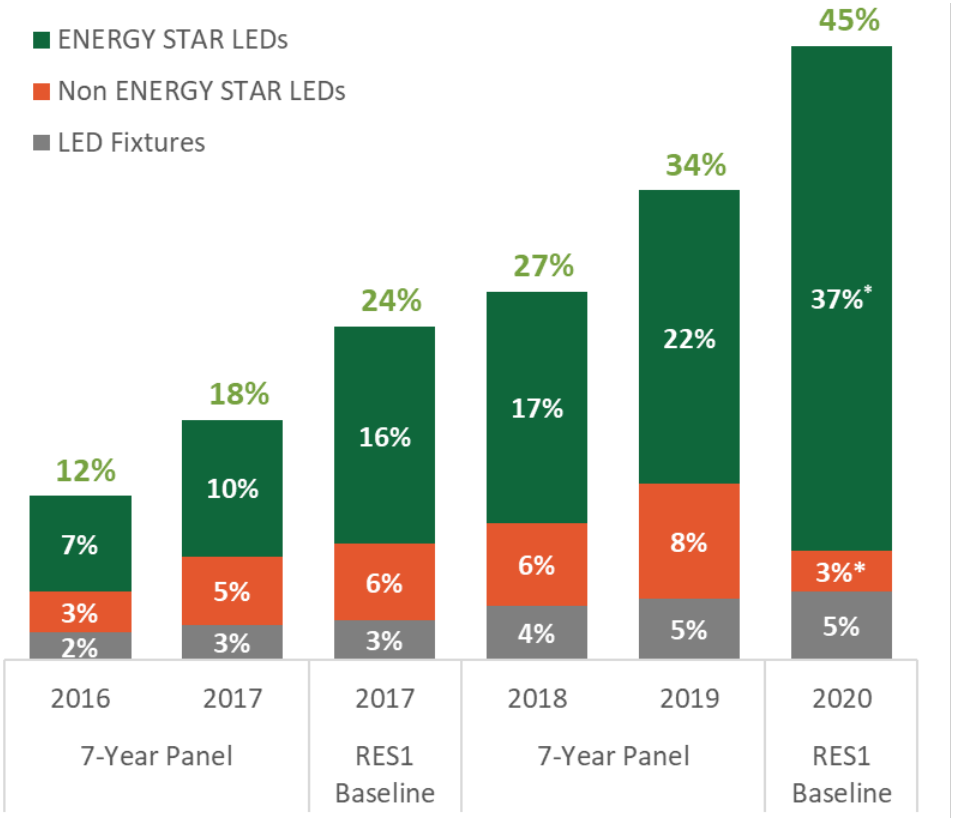
[1] Linear fluorescents, "other" bulb types, and empty sockets are not included in the figure.

ENERGY STAR LEDs

As the Massachusetts residential programs only support ENERGY STAR qualified LEDs, tracking ENERGY STAR saturation over time is an indicator of program influence (Figure 2). The saturation of ENERGY STAR-qualified LEDs grew from 16% in 2017 to 37% in 2020 in RES1 Baseline homes; note that the high participation rates in direct install programs influences the results. Likewise, the 7-Year Panel saw steady increases in ENERGY STAR LED saturation across all visits. In both panels in all years, the majority of LEDs were ENERGY STAR.

Figure 2: ENERGY STAR LED Saturation 2016-2020

(Base: All sockets)



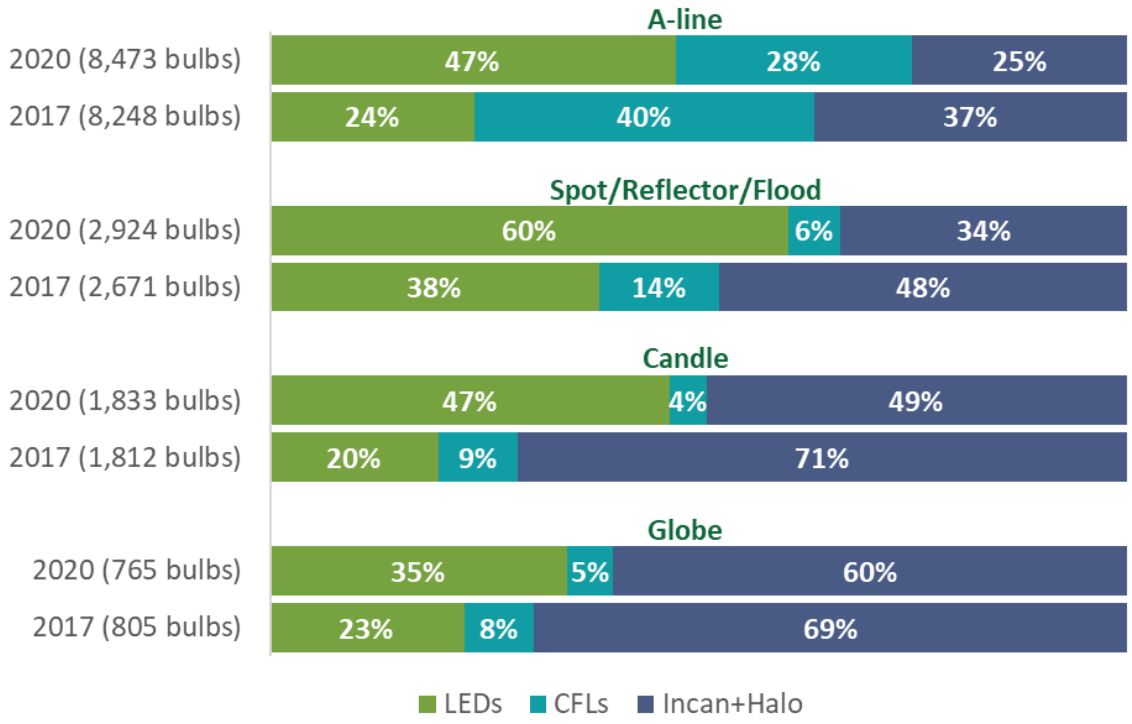
* Significantly different from 2017 RES1 Baseline Panel at the 90% confidence level.

Saturation by Shape

Figure 3 shows saturation by bulb shape in 2017 and 2020 for the RES1 sample. In 2020, LED saturation was highest for spot/reflector/flood bulbs (60%). LEDs made up nearly one-half (47%) of installed A-line and candelabra, and just over one-third (35%) of installed globes. In 2017, more A-line sockets were filled with CFLs (40%) than LEDs (24%), but, in 2020, LED saturation (41%) was higher than CFL saturation (31%). Inefficient bulbs (halogens + incandescents) were the second most common type of reflector, candelabra, and globe bulbs, while CFLs and inefficient bulbs were about equally likely to be among the installed A-line bulbs.

Figure 3: RES1 Baseline Saturation by Bulb Shape and Type

(Base: Installed bulbs, as noted for each bulb shape)

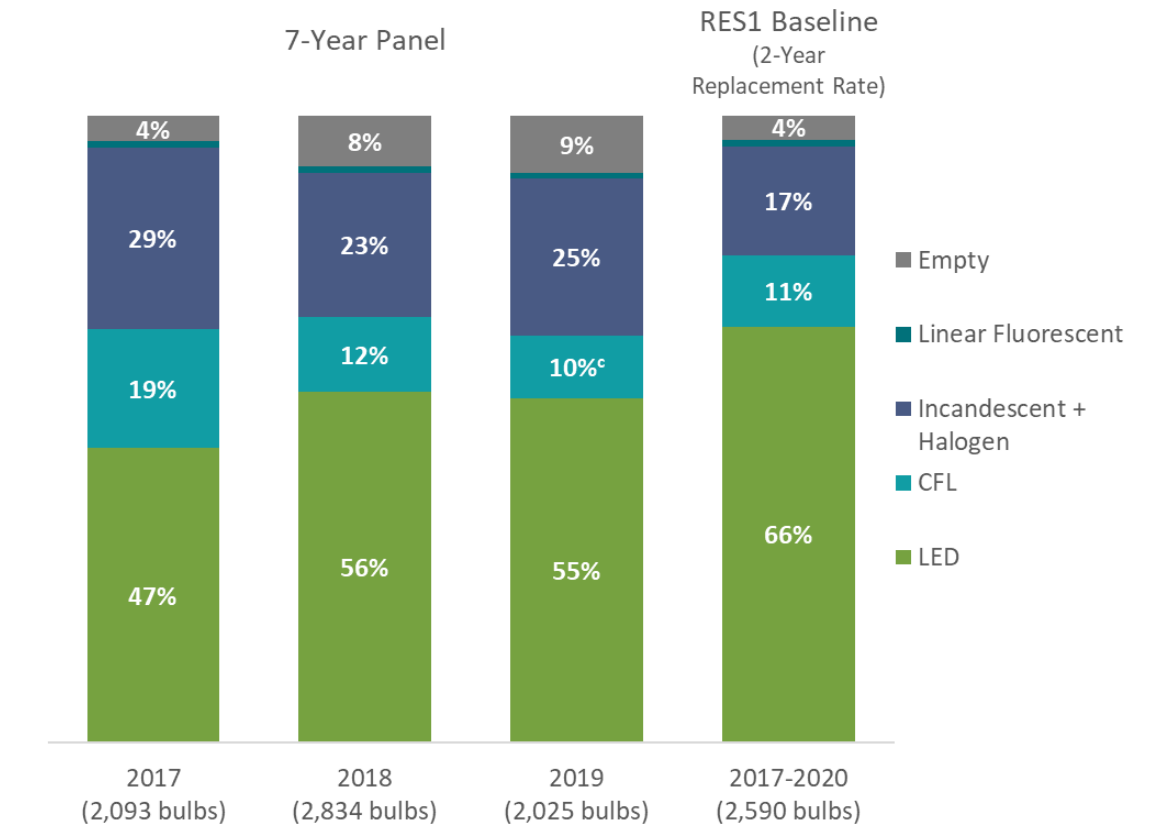


Panel Visits – Changes in Bulb Types over Time

The panel visits allow technicians to observe replacement behavior. As Figure 4 shows, LEDs were the most common replacement bulb between the two RES1 Baseline visits. Two-thirds (66%) of replacement bulbs installed since the initial visit to these panelists' homes were LED. As the RES1 Baseline panelists were last visited in 2017, it is important to note that the bar on the far right represents a two-year replacement rate, while results from the 7-Year Panel, shown here for reference, represent one year of replacement.

Figure 4: Replacement Bulbs, 2017-2020

(Base: Replacement bulbs; don't know/other bulbs excluded)



Storage Behavior

Across all bulb types, Massachusetts households stored an average of 18.1 bulbs – enough to fill nearly one-third of the 59 sockets in an average home. ***Inefficient bulbs (incandescent and halogen) remain the most commonly stored bulb type (50%).***

When examining changes in storage between 2017 and 2020, we observed that while most bulbs stored in 2017 remained in storage in 2020, customers did draw on stored bulbs to replace bulbs. ***Thirteen percent of all replacement bulbs came from storage.***

CONSIDERATIONS AND GUIDANCE

The high rate of direct install participation clouds the interpretation of the results presented in this study. This situation likewise limits our ability to provide meaningful considerations. We do offer guidance for future study planning.

Guidance 1: If the PAs continue to track socket saturation in the RES1 Baseline Panel, before entering the field, they should work with the relevant evaluation teams to agree upon a weighting scheme to correct for potential bias towards direct install participation. Likewise, they should make certain to collect the necessary data to implement this scheme.

Rationale: The Data Management Team provided information suggesting that about 5% of Massachusetts residential customers take part in a direct install program each year. However, the Data Management Team was unable to provide participation by the other demographic variables needed to create a weighting scheme. The lack of access to this information influenced the PAs' and EEAC consultants' decision to forego reweighting the data to correct for bias stemming from direct install participation. However, the resulting analysis provided limited clarity on the current state of the market at a time when such clarity may have been helpful in informing decisions about the future of residential lighting programs in Massachusetts and beyond. At the time of writing, it remains unclear if such information will be needed in the future.

Section 1 Introduction

This report presents the results of the MA19R15-E 2019 Residential Lighting On-sites Study. The Massachusetts Electric Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) Consultants asked NMR Group, Inc. (NMR) to complete this study to understand current lighting socket saturation and change in saturation and bulb use over time. The data for this study came from on-site lighting inventories of homes in Massachusetts that NMR and Guidehouse jointly conducted between October 2019 and March 2020. NMR conducted the lighting inventories in homes taking part in the Guidehouse-led Residential Baseline study and performed the analysis described in this report. Throughout this report, the Residential Baseline study is referred to as ***2020*** or ***2020 (RES1 Baseline)***. In contrast, results from the panel study NMR has conducted since 2014 is referred to as the ***7-Year Panel.***

1.1 Study Objectives

The goals of this study were to update estimates of lighting saturation in Massachusetts. The specific objectives included the following:

- Examine socket saturation by bulb type (Light Emitting Diodes [LEDs], compact fluorescent lamps [CFLs], halogens, and incandescents), including the presence of linear fluorescents.
- Identify installations of ENERGY STAR® qualified versus non-qualified LEDs.
- Determine what types of bulbs consumers use to replace those that burn out or are removed, based on recent visits to households previously visited in 2017.
- Provide information on various savings parameters, such as delta watts.
- Assess bulbs obtained by customers, including purchased bulbs and bulbs obtained through direct install programs.

1.2 METHODOLOGY

The data for this study came from on-site lighting inventories of 301 homes in Massachusetts completed between October 2019 and March 2020. Of these, 199 homes (hereafter, *panelists* or *panel homes*) had been previously visited in 2017 as part of the Massachusetts Residential Baseline study led by Guidehouse (formerly Navigant),[1] while 102 homes were new visits (hereafter, *new visits).*[2]

NMR weighted the on-site survey data to reflect the population proportions for home ownership (tenure) and education in Massachusetts based on the American Community Survey (ACS) Five-Year Estimates. Note that NMR trained the technicians who conduct the in-home visits to distinguish between halogens and incandescent bulbs by wattage, presence or absence of a filament, and other characteristics. However, technicians may still mischaracterize bulbs if they are unable to read or see the characteristics that allow for accurate identification. Therefore, we often combine the results for incandescents and halogens into an *inefficient* category. Additional methodological details can be found in Appendix A.

1.2.1 Study Limitation: Direct Install Program Participation

A large proportion of households in the 2020 sample participated in a PA direct install program (see Appendix B for more details). This high representation of direct install participants – many of whom took part between the 2017 and 2020 RES1 Baseline visits – limits the ability to draw conclusions about changes in lighting use among the broader residential population based on comparisons across the 7-Year Panel study and the 2017 and 2020 RES1 Baseline studies. The PA direct install programs direct Energy Specialist to swap out as many inefficient bulbs (halogens and incandescents) as possible when conducting a home energy assessment. Therefore, the socket saturation estimates described in this report are likely high-end estimates of statewide saturations. Likewise, the analysis of bulb replacement behavior should not be generalized to the residential population, as many of the replacements probably occurred during home energy assessments.

After considering how to proceed with the analysis and reporting for this 2020 sample, the PAs and EEAC Consultants opted not to adopt an alternative weighting scheme or perform analysis separately for households who had and had not taken part in a direct install program. They concluded that these efforts would not be necessary as the results from this report are limited in applicability to the Residential Retail Lighting Initiative, which targets new bulb purchases and savings which are not impacted by the existence of other LEDs within the home. Still, the potential influence of direct install participation on the results may be substantial. Therefore, throughout this report, NMR notes when the results may reflect such influence. Likewise, this report urges all reviewers to use caution when considering what the results imply for the general population of residential customers.

[1] RLPNC 16-11: Lighting Market Scan Memo

[2] Guidehouse had visited 42 of the new visit homes in 2018 but did not collect lighting data during those visits. Guidehouse added the remaining 60 homes to the residential baseline sample for the first time in 2019.

Section 2 Changes in Socket Saturation Over Time

In this section, we explore trends in socket saturation in Massachusetts using data from both the 2020 (RES1 Baseline) and the 7-Year Panel studies. This includes overall saturation, the saturation of ENERGY STAR-qualified LEDs, and room-by-room saturation.

Some of the most critical findings include the following:

- ***Since their introduction around 2010, LED saturation has increased from virtually 0% to as high as 45% of sockets in 2020.***
- ***Four out of five installed LEDs were ENERGY STAR-qualified (82%).***
- ***LED saturation was higher for reflector lamps than A-line lamps and other specialty lamps.***
- ***Efficient bulb saturation – LEDs plus CFLs – exceeded inefficient bulb saturation. Saturation levels were 61% for efficient bulbs; 28% for inefficient bulbs; and 11% for linear fluorescents, other bulb types, and empty sockets combined.***

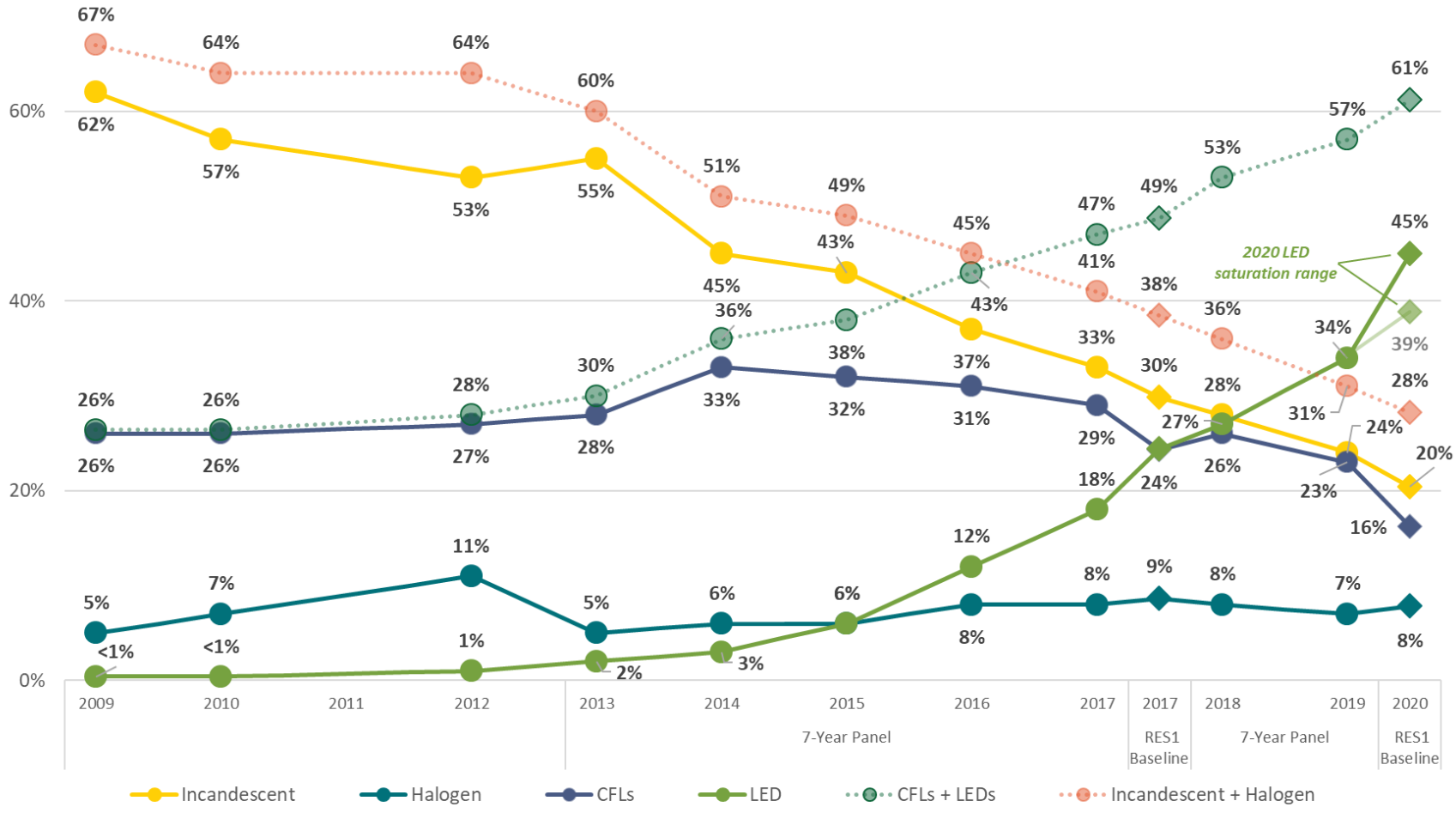
2.1 Saturation by Household

Figure 5 shows saturation for most bulb types from 2009 through 2020; the data represent a combination of stand-alone saturation studies (through 2012), the 7-Year Panel study (2013 to 2019), and the RES1 Baseline Study (2017 and 2020). To aid in understanding trends, we have interpolated data to represent 2011, a year when a study was not completed. The figure clearly shows that Massachusetts has experienced a steady increase in efficient bulb saturation (dotted green line) and a corresponding decrease in inefficient bulb saturation (dotted orange line). In 2020, saturation of efficient (CFL and LED) bulbs (61%) continued to exceed that of inefficient (incandescent and halogen)[3] bulbs (28%). LED adoption continued to drive the increase in efficient bulb saturation as CFL saturation has been on a slow but steady decline since 2014: from 33% in 2014 to 16% at in 2020.[4] LED saturation was 45% in the 2020 RES1 Baseline sample, but the direct install participation suggests that this should be considered a high-end estimate of statewide saturation. Removing PA-verified direct install participants from the analysis reduces LED saturation to 39%. Therefore, LED saturation for Massachusetts households is likely between 39% and 45%.

[3] Given the difficulty in distinguishing halogen bulbs from regular incandescent bulbs, we provide estimates for each separately and combined throughout this report.
[4] As discussed in detail in Section 4, in Massachusetts, 5% of removed CFLs were replaced by either an incandescent or halogen (Figure 19).

Figure 5: Saturation Rates Over Time, 2009-2020

(Base = all sockets)

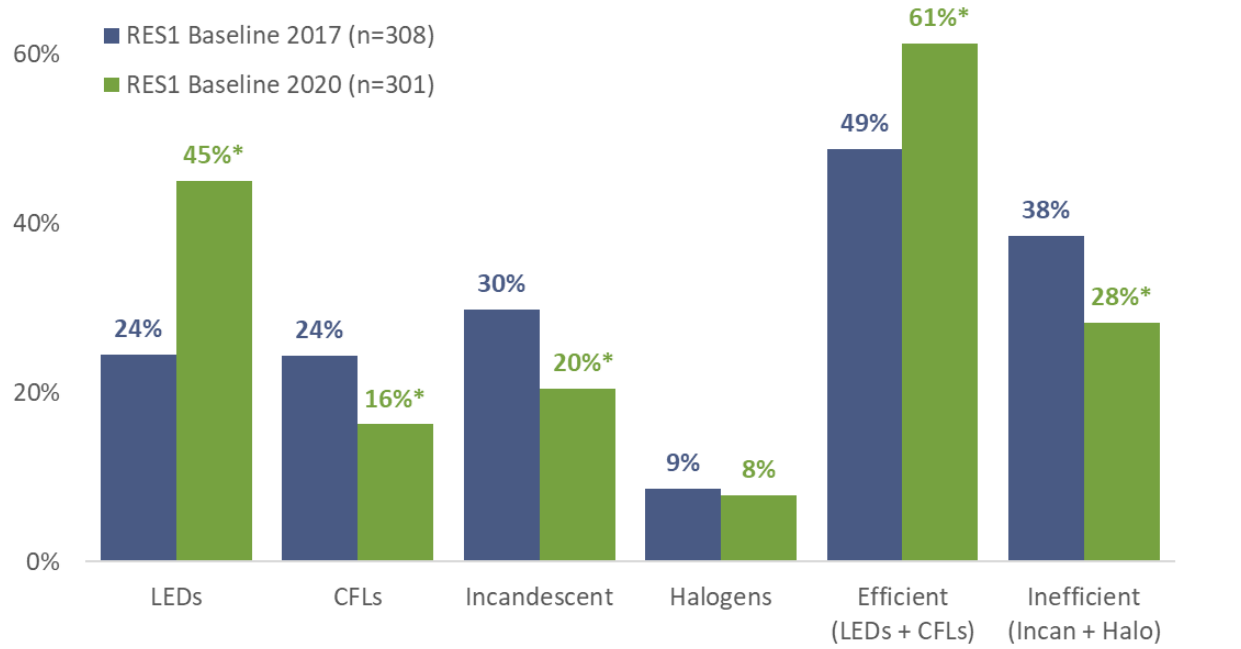


* Linear fluorescents, "other" bulb types, and empty sockets are not included in the figure.

Narrowing the focus to the RES1 Baseline sites (Figure 6) shows that LED saturation increased from 24% in 2017 to 45% in 2020; as stated above, note that an unknown portion of this increase reflects bulbs installed during home energy assessments.[5] Not surprisingly, both CFL saturation and incandescent saturation in 2020 were lower than in 2017 (24% vs. 16% for CFLs; 30% vs. 20% for incandescents).

Figure 6: RES1 Baseline Saturation, 2017 vs. 2020[1]

(Base: All sockets)



* Significantly different at the 90% confidence level.

[1] Linear fluorescents, "other" bulb types, and empty sockets are not included in the figure.

[5] Unknown because direct install participants may have installed some LEDs on their own.

2.1.1 ENERGY STAR LED Saturation

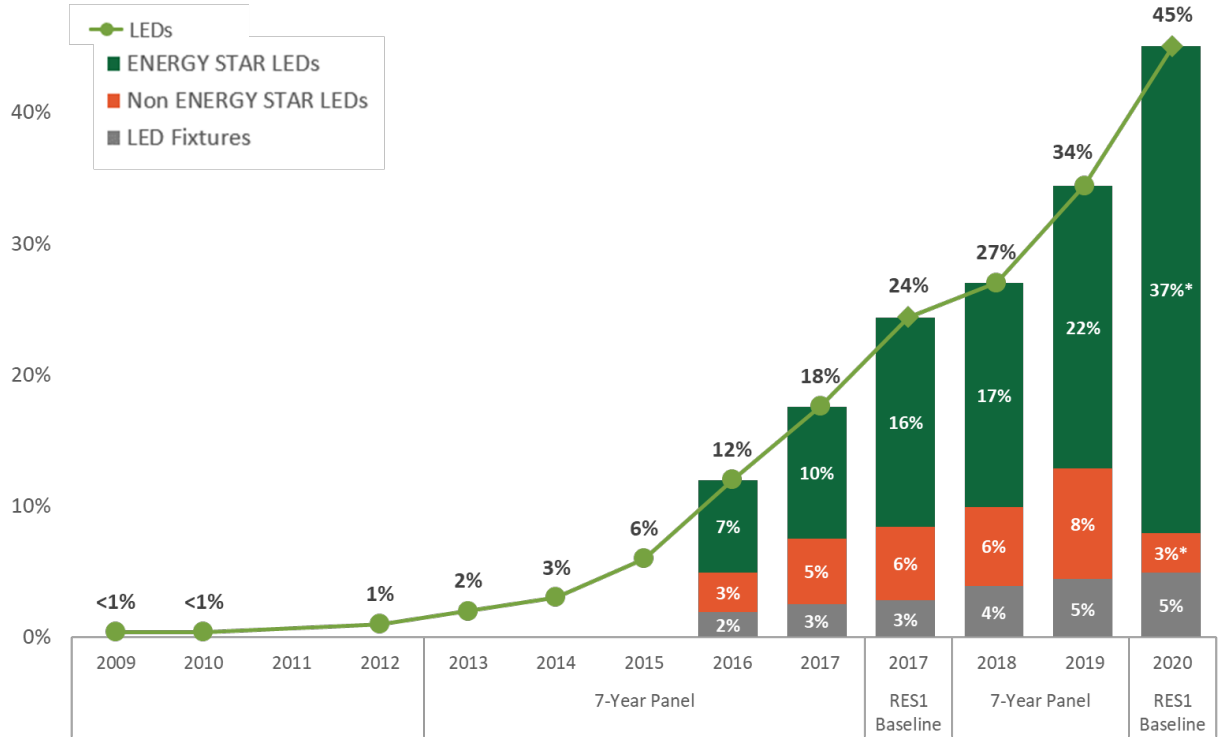
Starting with the 2016 Market Assessment, while on site, technicians collected model numbers for all screw-base LED bulbs.[6] Using these model numbers and the list of ENERGY STAR-qualified LED bulbs, we determined ENERGY STAR status for each LED bulb. Figure 7 provides the results of this analysis for the RES1 Baseline on-sites, the 7-Year Panel, and the on-site studies that occurred prior to the 7-Year Panel. We separated LED saturation into three distinct categories:

- ENERGY STAR qualified
- Non-ENERGY STAR qualified
- Integrated LED fixtures

Within the 2020 RES1 Baseline sample, ENERGY STAR LED saturation was 37%, which is likely an overestimate because direct install programs only provide ENERGY STAR qualified bulbs. In comparison, the 2019 7-Year Panel sample had 22% ENERGY STAR LED saturation and the RES1 Baseline Panel sites in 2017 had 16%. Non-ENERGY STAR LED saturation was the lowest since 2016, most likely because direct install households did not buy many LEDs – ENERGY STAR or otherwise – on their own because the program had provided them. The proportion of integrated LED fixtures remained low, at about 5% of sockets.

Figure 7: LED Bulb Saturation 2009-2020 with ENERGY STAR LEDs 2016-2020

(Base: All sockets)



* Significantly different from 2017 RES1 Baseline Panel at the 90% confidence level.

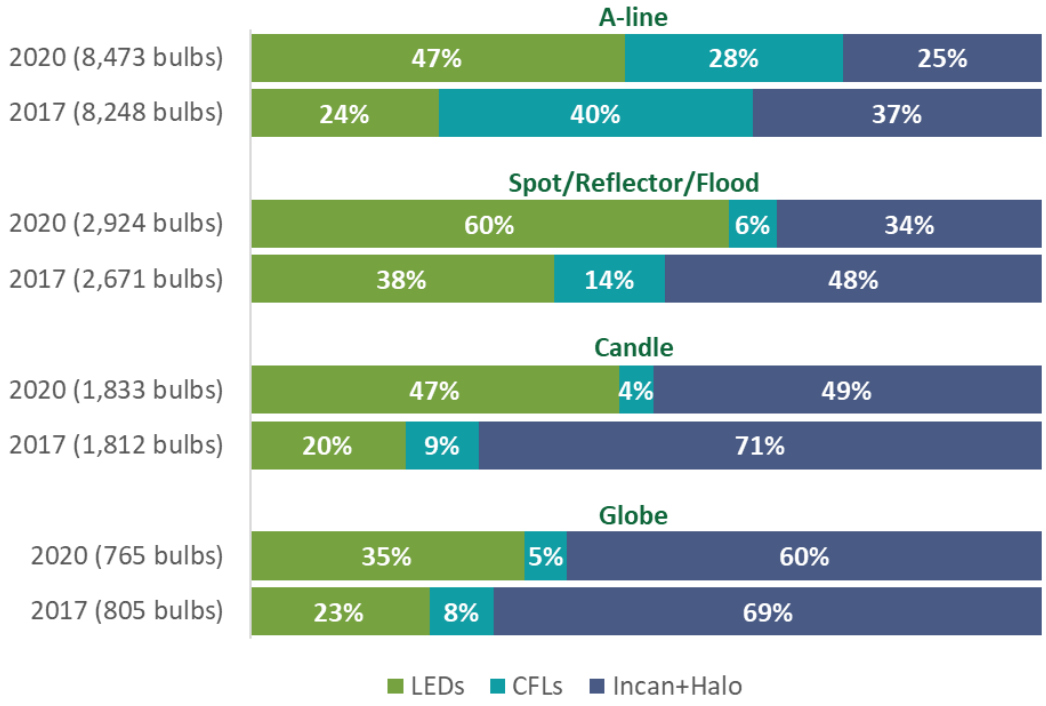
[6] Technicians did not collect model numbers for integrated LED fixtures.

2.1.2 Saturation by Bulb Shape

Figure 8 shows saturation for LEDs, CFLs, and combined incandescent and halogen bulbs by A-line, reflector, candelabra and globe shape in 2017 and 2020 RES1 Baseline sites. In 2020, LEDs made up nearly one-half (47%) of all A-line bulbs, three out of five (60%) reflector bulbs, nearly one-half (47%) of all candelabra-shaped bulbs, and more than one-third (35%) of all globe-shaped bulbs. While CFLs and inefficient bulbs (halogens + incandescents) make up about equal proportions of non-LED A-line sockets, inefficient bulbs account for nearly all of the non-LED specialty bulbs. The current saturation percentages represent substantial increases from the 2017 visits, but the high rates of direct install program participation limit the ability to generalize to the general residential customer population. However, the findings align well with the forthcoming *MA20R22-E Regional Lighting Sales Data* study, which suggested A-line sales of 69%, reflector sales of 93%, and globe and candelabra sales of 65%.

Figure 8: RES1 Baseline Saturation by Bulb Shape and Type

(Base: Installed bulbs, as noted for each bulb shape)

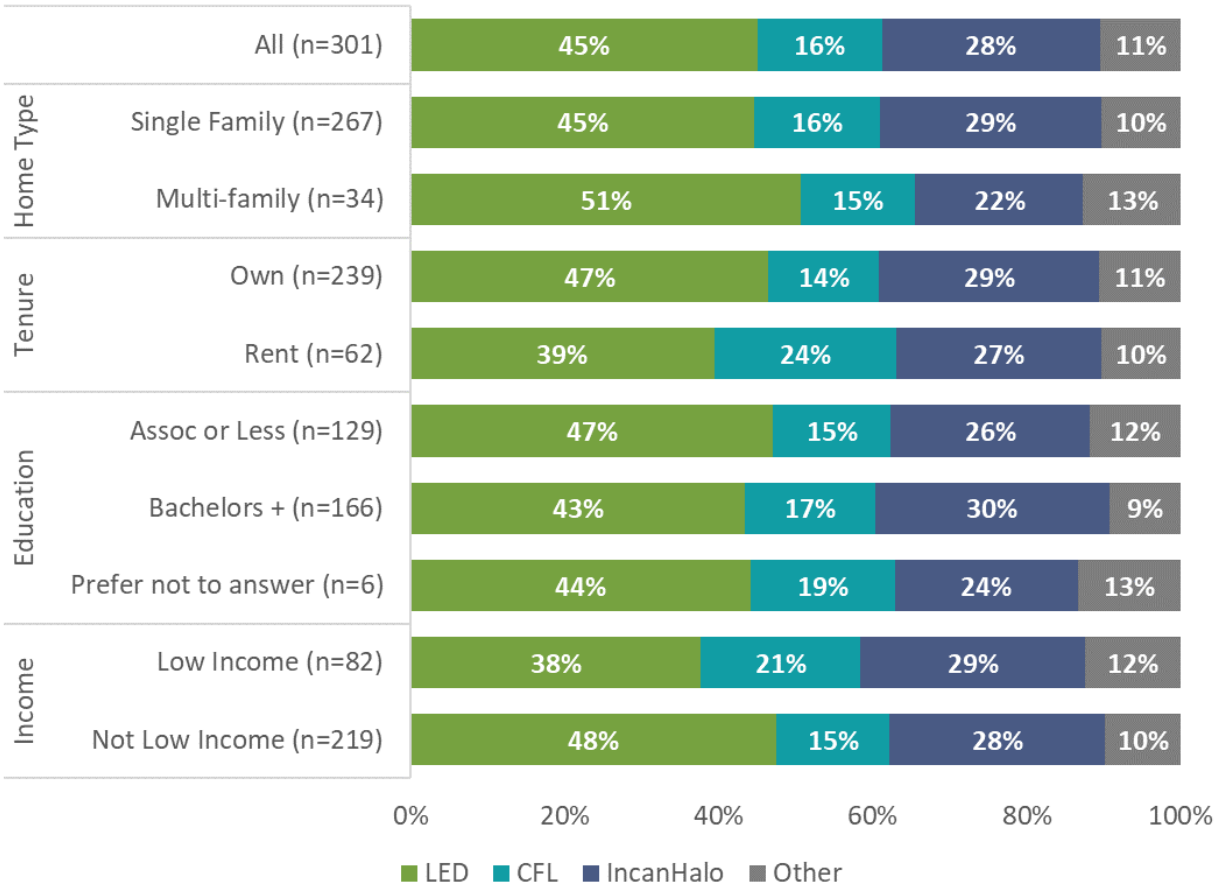


2.1.3 Saturation by Demographics

Figure 9 examines current saturation in the 2020 RES1 sample across demographics for CFLs, LEDs, and combined incandescent and halogen bulbs. As the figure shows, renters and low-income customers tend to have smaller proportions of LEDs and greater proportions of CFLs than owners and non-low-income households. However, the efficient bulb saturation (CFLs + LEDs) is about the same among all demographic groups. This implies that the PA programs have reached all demographic groups.[7] In addition, the replacement analysis in Section 4.1.4 suggests that households usually replace CFLs with LEDs. Thus, LED saturation in rental and low-income households will likely catch up to other households as CFLs burnout. For sample sizes and more detailed findings on saturation across select demographic variables, see Appendix B.

Figure 9: Saturation by Demographics

(Base: All sockets; number of households noted for each group)



[7] Although the LED saturation results are likely affected by direct install participation, the programs no longer install CFLs nor do they swap out CFLs for LEDs.

2.2 ROOM-BY-ROOM SATURATION

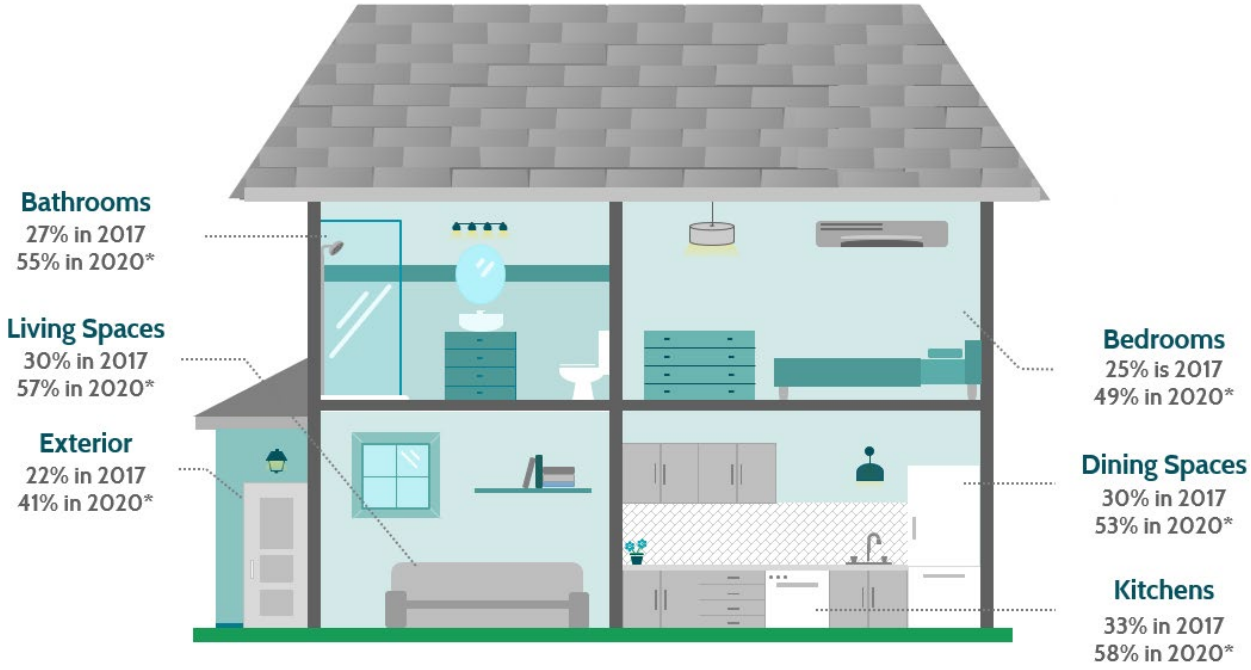
This section explores saturation by room type, with a focus on LED saturation. The results indicate a statistically significant increase in LED saturation in all room types since the 2017 RES1 study, noting that the increases reflect an unknown number of direct program installations.

2.2.1 Room-by-Room LED Saturation 2017 vs. 2020

Figure 10 shows LED saturation by room type for RES1 Baseline sites in 2017 and 2020. In 2020, nearly three out of every five sockets were filled by LEDs in both kitchens (58%) and living spaces (58%). LED saturation was nearly 50% or higher in all other interior rooms. Exterior sockets held the most potential to be filled with an LED, with LEDs installed in only 41% of sockets in 2020.

Figure 10: Room-by-Room LED Saturation 2017 vs. 2020

(Base: LED, CFL, Incandescent, and Halogen sockets only[1])



* Significantly different from 2017 RES1 Baseline at the 90% confidence level.
[1] Linear fluorescents, "other" bulb types, and empty sockets are not included in the analysis.

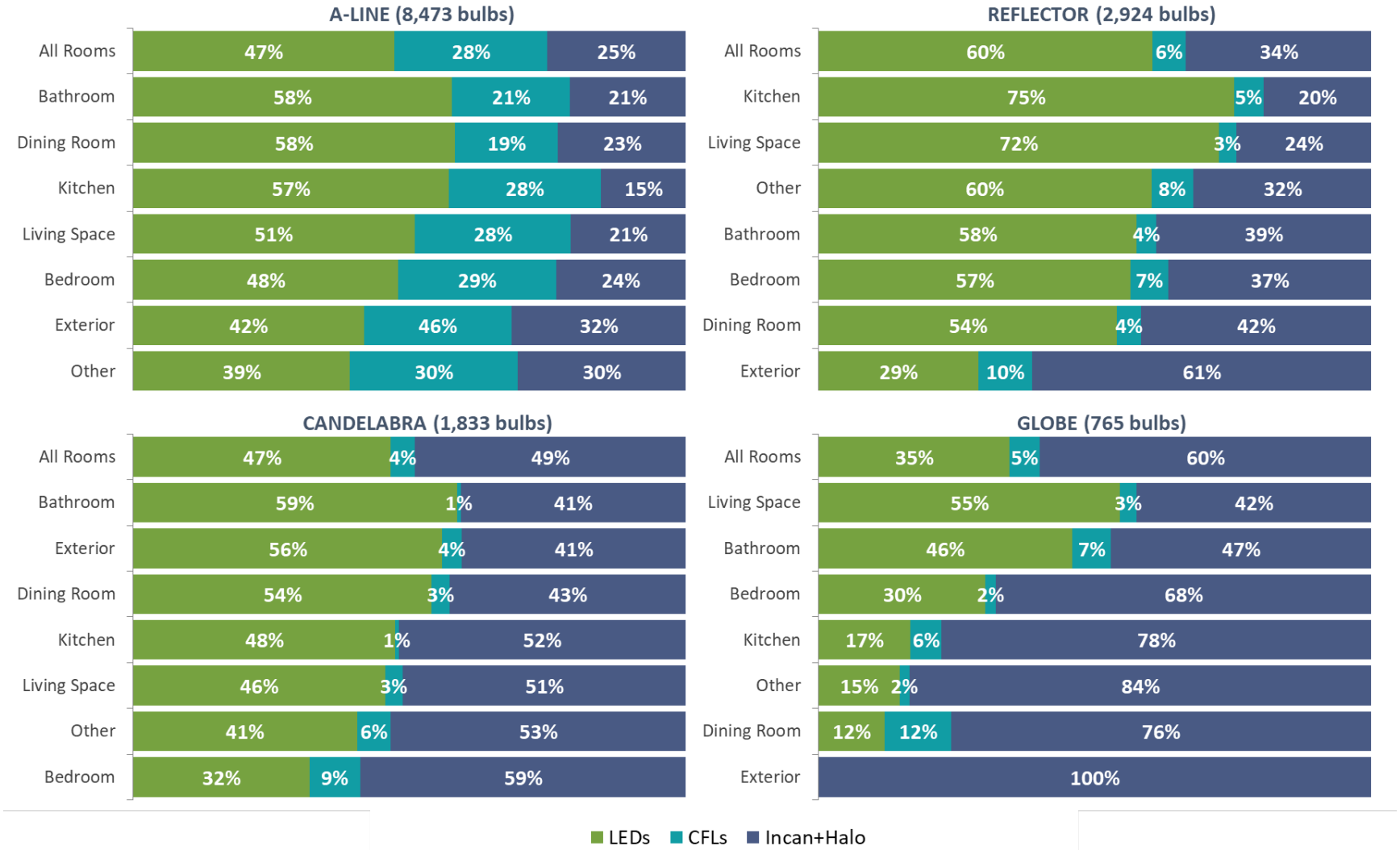
2.2.2 Room-by-Room Saturation by Shape

Figure 11 shows 2020 room-by-room saturation by bulb shape, excluding linear fluorescents, “other” bulb types, and empty sockets. This figure allows us to see which room types have greater and lesser concentrations of A-line, reflector, candelabra, and globe shaped LEDs installed. For example, the top left figure below only shows A-line sockets in participant homes, broken out by room type. In bathrooms, 58% of A-line bulbs were LEDs, 28% were CFLs, and 25% were incandescent and halogen bulbs.

Among sockets filled with A-line bulbs, LED saturation was highest in bathrooms (58%), dining rooms (57%), and kitchens (57%). Among sockets filled with reflector bulbs, LEDs dominated in both kitchens (75%) and living spaces (73%), while incandescents and halogens comprised more than three out of every five (61%) reflectors in exterior sockets. Among sockets filled with candelabra shaped bulbs, LEDs made up more than one-half of those in bathrooms (59%), exteriors (56%), and dining rooms (54%), while incandescents and halogens made up more than half in bedrooms (59%), “other” room types (53%), kitchens (52%), and living spaces (51%). Among sockets filled with globe shaped bulbs, living spaces were the only room type where LEDs were the majority (55%). Most “other” room types had predominately incandescent and halogen globe shaped bulbs.

Figure 11: Saturation by Bulb Shape and Room Type, 2020

(Base: Sockets by shape in each room type.[1,2])



[1] Linear fluorescents, "other" bulb types, and empty sockets are not included in the analysis.

[2] "Other" room types include basements, closets, foyers, garages, hallways, offices, utility rooms, and other less common room types.

2.2.3 Room-by-Room Specialty Bulb Saturation

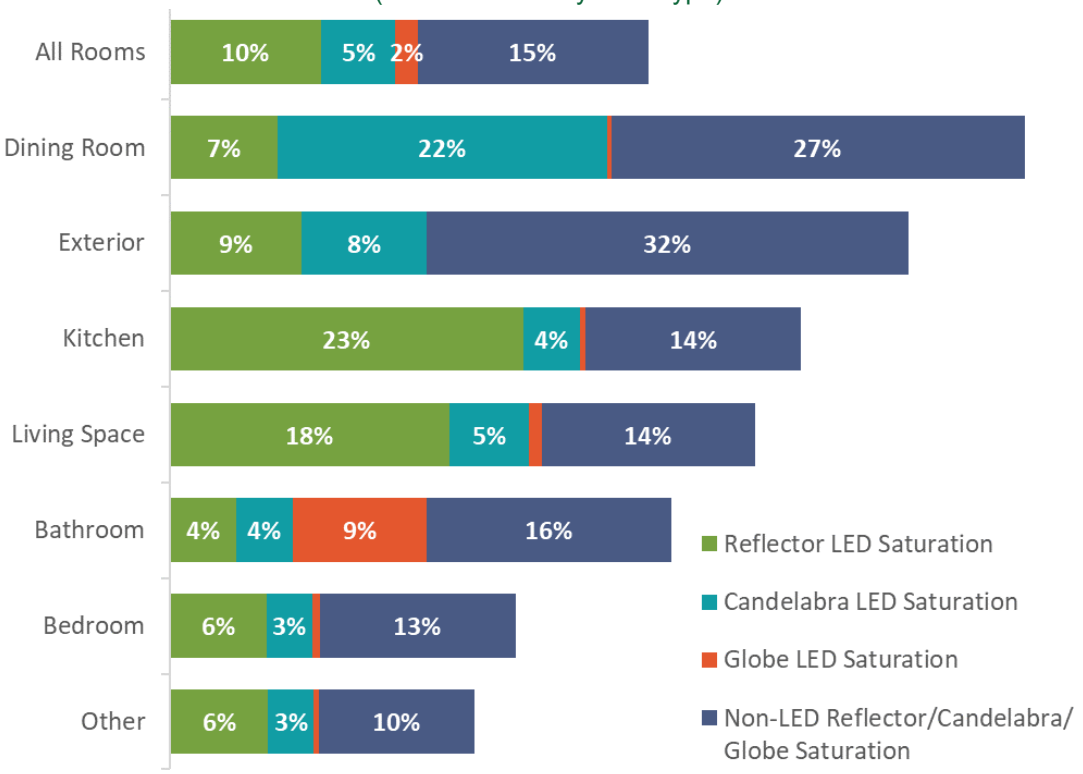
Figure 12 shows the proportion of sockets occupied by any reflector, candelabra, or globe shaped bulb (purple) by room type. The figure also shows the proportion of sockets occupied by a reflector LED (green), a candelabra shaped LED (teal), or a globe shaped LED (orange). For example, when looking at all dining room sockets, reflector, candelabra, and globe shaped bulbs (of any bulb type) made up 56% (purple); however, when focusing on LEDs in dining room sockets, the figure shows that 7% were LED reflectors (green), 22% were candelabra shaped LEDs (teal), and less than 1% were globe shaped LEDs (orange). The remaining 26% of sockets in dining rooms were non-LED reflector, candelabra, or globe shaped bulbs.

Reflector, candelabra, and globe shaped bulbs comprised 31% of all sockets in RES1 Baseline households in 2020. Examining these bulbs by room type, reflectors, candelabras, and globes filled approximately one-half of all sockets in dining rooms (56%) and exteriors (48%), and about two-fifths of all sockets in kitchens (41%) and living spaces (38%).

The proportion of sockets occupied by a reflector, candelabra, or globe LED varied across room types. Reflector LED saturation was highest in kitchens (23%) and livings spaces (18%), candelabra LED saturation was highest in dining rooms (22%), and globe shaped LED saturation was highest in bathrooms (9%).

Figure 12: Specialty Bulb Saturation and LED Saturation by Room Type, 2020[1]

(Base: Sockets by room type)



[1] The remaining percentages are A-lines or other bulb shapes of any technology.

Section 3 Penetration

Penetration (i.e., the percentage of homes using at least one of a particular bulb type) is an important indicator of how the market is advancing and, in this case, if the program is getting people to try LEDs. NMR has tracked LED penetration since the technology's introduction. LED penetration is nearly 100% – meaning there is at least one LED bulb in almost every household in Massachusetts – which is an indicator, along with saturation and other factors, of market progress. This section examines penetration rates by bulb type over time, including a room-by-room LED penetration analysis. While not immune to the effect, NMR believes that the overall household penetration rate is less influenced by direct install participation. It takes only a single installed LED for penetration to have occurred. However, room-specific penetration may be more sensitive to direct install participation.

Key findings from this section include the following:

- ***Penetration was 97% in 2020 RES1 Baseline homes, an increase from 83% in 2017. LED penetration has increased in every on-site study since 2013, when it was 12%.***
- ***Kitchens were the most common place to install at least one LED (85%), followed closely by bedrooms (83%), bathrooms (83%), and living spaces (82%).***

3.1 BULB PENETRATION

Figure 13 shows penetration by bulbs for both RES1 Baseline and 7-Year Panel homes from 2013 to 2020.

- At least one **LED** was present in nearly all homes (97%) in 2020 RES1 Baseline homes, which is up from 83% in 2017. Unsurprisingly, LED penetration increased the most out of all bulb types since 2013, soon after it was introduced to the market.
- **Halogens** were found in more than two-thirds (70%) of all homes in the RES1 Baseline study in 2020 but had the lowest penetration of all four bulb types examined.[8]
- **Incandescent** and **CFL** penetration have both steadily decreased over time but remained high; they were found in 92% and 93% of homes, respectively.

Figure 13: Penetration by Bulb Type Over Time

(Base: All households)

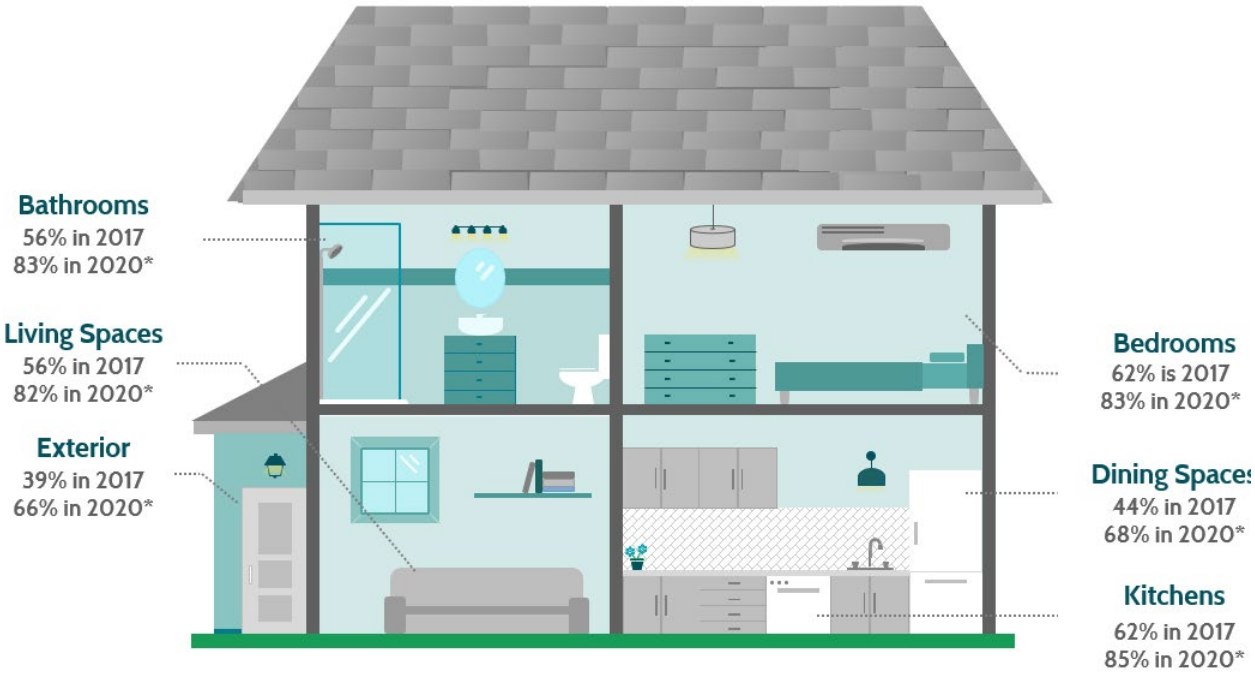
[8] Although we present separate penetration estimates for halogens and incandescents, we remind the reader that technicians may have difficulties accurately distinguishing halogens and incandescents. The most likely implications of any errors would be to understate halogen penetration and overstate incandescent penetration.

3.2 ROOM-BY-ROOM ANALYSIS

When calculating LED penetration by room type, we only included homes that had rooms of that type. For example, in the RES1 Baseline study in 2020, 176 homes had dining rooms, and 119 of those homes had at least one LED installed in dining rooms, resulting in a 68% penetration rate. LED penetration has increased at statistically significant rates in all room types in RES1 Baseline homes since 2017, although direct install penetration likely influences these results (Figure 14). Kitchens were the most common place to install at least one LED (85%), followed closely by bedrooms (83%), bathrooms (83%), and living spaces (82%). For additional details on room-by-room penetration by year, see Appendix C.

Figure 14: LED Penetration by Room Type, 2017-2020 RES1 Baseline

(Base: All households)



* Significantly different from 2017 RES1 Baseline Panel at the 90% confidence level.

Section 4 Replacement Behavior

In this section, we explore bulb replacement behavior based on panel visits (repeat visits to the same homes over time). NMR first visited these panel homes in 2017 as part of the RES1 Baseline Study. During the 2017 visit, technicians placed a mark on each installed bulb or noted that the socket was empty. During the 2020 visit, the technician compared the bulb installed now to what was there in 2017. Based on the markings inscribed on the bulbs during the previous visit, the technician designated each bulb as *New* (for bulbs that had been installed since the last on-site visit) or *Same* (for bulbs that were included in the 2017 on-site data and were the same in 2020). The technician also designated fixtures in the same manner.

The high rates of direct install program participation clearly influence the analysis of replacement behavior. In fact, panelists who took part in a direct install program replaced 18.4 bulbs between the 2017 and 2020 visits, compared to 13.4 bulbs for other panelists. Appendix E provides some information on replacement for verified direct install participants versus other panelists.[9] Finally, it is worth keeping in mind the caveat that it can be difficult to distinguish accurately between halogens and incandescents in the field.

Some key findings on replacement include the following:

- ***LEDs remained the most common replacement bulb type (66%), followed by inefficient bulbs (17% – incandescent and halogen combined).***
- ***LEDs were also the most common bulb chosen to replace any bulb type. Four-fifths (80%) of all removed LEDs were replaced with another LED, while 73% of CFLs, 63% of incandescents, and 57% of halogens were replaced with an LED.***
- ***Massachusetts households replaced 223 LEDs, which is 9% of all LEDs installed. Customers most often cited bulb failure as the reason for replacing the LED.***
- ***We observed some backsliding (efficient bulbs being replaced with inefficient). Ten percent of LEDs and 5% of CFLs were replaced with an incandescent or halogen. Householders who replaced LEDs with inefficient bulbs most often grabbed the bulbs from storage or said that they wanted to try a different bulb type due to dissatisfaction with the removed efficient bulbs.***

[9] NMR conducted this analysis when diagnosing the extent of the impact of direct install participation on the study results to help the PAs and EEAC Consultants decide how to proceed with treatment of the issue in this study.

4.1 BULB CHANGES 2017-2020

Sockets in which the bulb has been replaced since the previous visit are of special interest in the panel visits. This interest stems largely from the desire to understand customer (or direct install program) replacement behavior over time, especially to understand which types of bulbs LEDs are replacing. Table 1 summarizes overall replacement rates, including a breakdown of replacement by verified direct install participation. Not surprisingly, the direct install households replaced more bulbs on average (18.4) between visits than non-participants (13.4). Note that this study does not provide further detail on replacement for direct install participants versus other panelists.

Table 1: Panel Replacement Bulb Summary 2017-2020 (Unweighted)

Panel Year	Overall	Direct Install Participant (2017-2020)	Non-Participant
Homes	*199*	*54*	*145*
Baseline	February 2017 – October 2019		
Months	32		
Sockets Replaced	2,936	992	1,944
Sockets/Home	14.7	18.4	13.4
Sockets/Month	0.5	0.6	0.4
Homes Replacing	190 (95%)	52 (96%)	116 (80%)

4.1.1 Bulb Replacement Behavior

Table 2 provides an overview of saturation for the sockets that had bulbs replaced between 2017 and 2020. The table highlights saturation of these sockets before and after bulb replacement and provides the net change in saturation. LED bulbs had the highest net gain (+57%) and incandescent bulbs had the highest net decrease (-34%). Notably, while 30% of bulbs removed from sockets were CFLs, only 11% of removed bulbs were replaced by CFLs, for a net decrease of -19%.

Table 2: Bulb Replacement

(Base: Replacement bulbs 2017-2020)

Bulb Type	Massachusetts		
# of bulbs		*2,590*	
	Before (Replaced)	After (Replacement)	Net Change
LED or CFL	**39%**	**77%**	**+38%**
LED	*9%*	*66%*	*+57%*
CFL	*30%*	*11%*	*-19%*
Incandescent or Halogen	**56%**	**17%**	**-39%**
Incandescent	*47%*	*13%*	*-34%*
Halogen	*8%*	*4%*	*-4%*
Linear Fluorescent	1%	1%	--
Empty Socket	5%	5%	--

*Includes <1% of "don't know" bulbs.

Table 3 provides an overview of where replacement bulbs came from. Replacement bulbs are broken down into three categories: new to the home, from storage, or from another fixture. In 2020, almost all of the replacement LEDs were new to the home (94%), and about three-quarters of the incandescents and halogens (74%) were knew to the home. In contrast, only 38% of CFLs were new to home, while 62% were from storage or shifted from another socket.

Table 3: Replacement Bulbs by Bulb Source

(Base: Replacement bulbs installed in RES1 households, empty sockets excluded)

Bulb Type	Bulb Source			
	End of 2019 (2-year replacement rate, *n=301*)			
Bulbs	# of bulbs	New	Storage	Another Fixture
All replacement bulbs	*2,473*	*84%[bcd]*	*13%[bcd]*	*3%*
LED	1,719	94%[b]	4%[b]	2%
CFL	289	38%[d]	46%[d]	16%[bcd]
Incandescent & Halogen	446	74%[bcd]	23%[bcd]	3%
Fluorescent	18	17	1	--

Table 4 looks at replacement incandescent and halogen individually and breaks out the findings by bulb shape. While most replacement incandescents and halogens of all shapes were new to the home, specialty replacement incandescents were more likely to be newly purchased than A-line incandescents. Of course, the small sample sizes and the possible mis-identification of halogens and incandescents must be kept in mind.

Table 4: Replacement Incandescent and Halogen Bulbs by Bulb Shape and Source

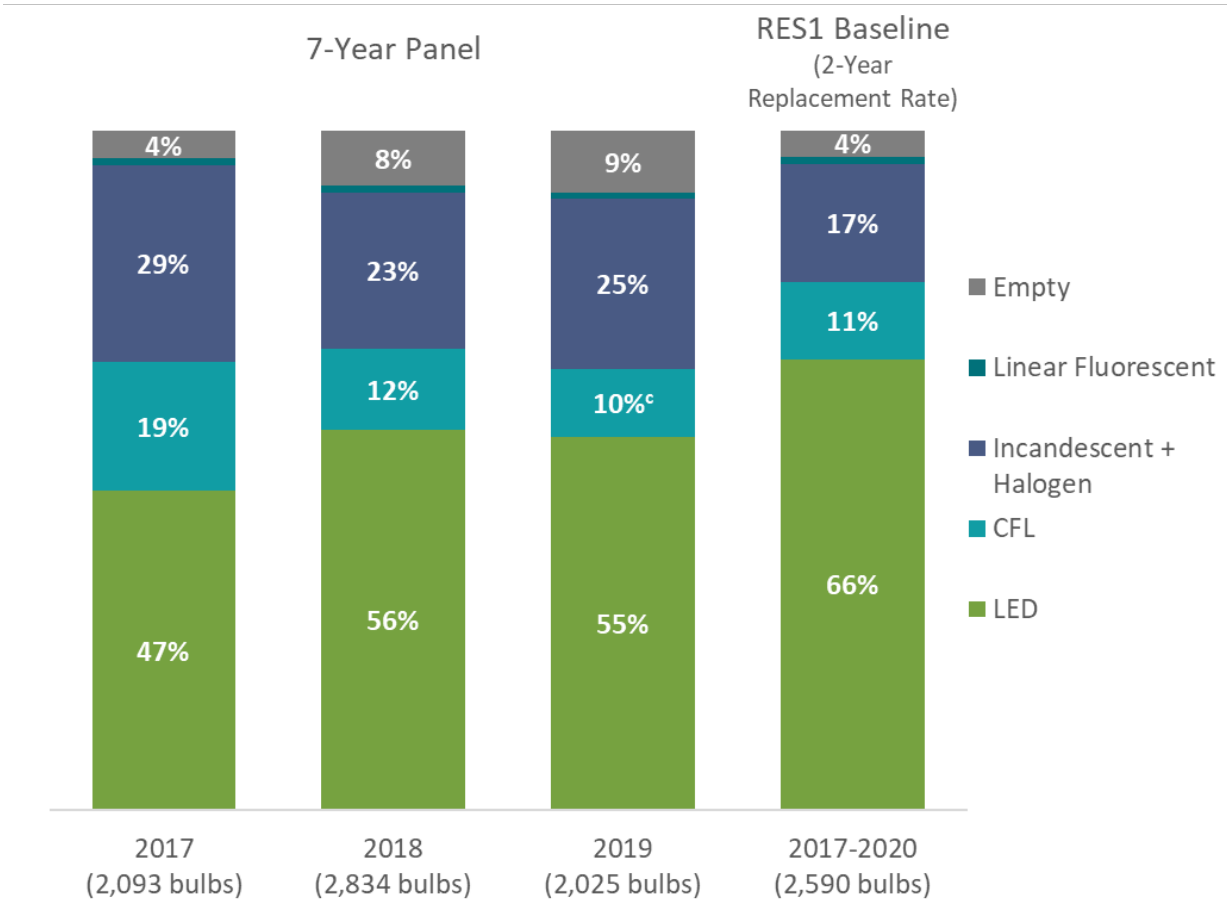
(Base: Replacement bulbs installed in RES1 households, empty sockets excluded)

Bulb Type	Bulb Source			
	End of 2019 (2-year replacement rate, *n=301*)			
Bulbs	# of bulbs	New	Storage	Another Fixture
All incandescent bulbs	*342*	*74%*	*23%*	*3%*
A-line	229	70%	26%	3%
Spot/Reflector/Flood	28	86%	7%	7%
Globe	40	83%	18%	--
Candle	44	82%	18%	--
All halogen bulbs	*104*	*74%*	*24%*	*2%*
A-line	80	75%	23%	3%
Spot/Reflector/Flood	19	58%	42%	--
Globe	6	83%	18%	--
Candle	0	--	--	--

Looking at the 7-Year Panel and the RES1 panel, we find that the proportion of replacement bulbs that were LEDs increased in both samples between 2017 and 2020 (Figure 15). Two-thirds of bulbs replaced by the RES1 Baseline panelists from 2017 to 2020 were LEDs. Note that the 7-Year Panel counted replacements annually, but the RES1 Baseline did so over two years.

Figure 15: Replacement Bulbs, 2017-2020

(Base: Replacement bulbs; don't know/other bulbs excluded)



4.1.2 Delta Watts

Overall, replacement bulbs reduced the average wattage of replaced sockets from 42.9 Watts to 18.0 Watts – a decrease of 24.9 Watts (Table 5). Newly installed replacement LEDs comprised the majority of the decrease.

Table 5: Delta Watts by Replacement Bulb Type

(Base: Replacement bulbs; don't know/other bulb technologies excluded)

Replacement Bulb Type	Delta Watts	Average Watts[1] (n = 2,590 replaced bulbs)
Starting Wattage (replaced sockets)	**111,050**	**42.9**
LED	- 57,413	
CFL	- 5,190	
Incandescent or Halogen	+ 2,921	
Linear Fluorescent	+ 59	
Empty Socket	- 4,795	
Total Decrease (replaced sockets)	**- 64,418**	**24.9**
Ending Wattage (replaced sockets)	**46,632**	**18.0**

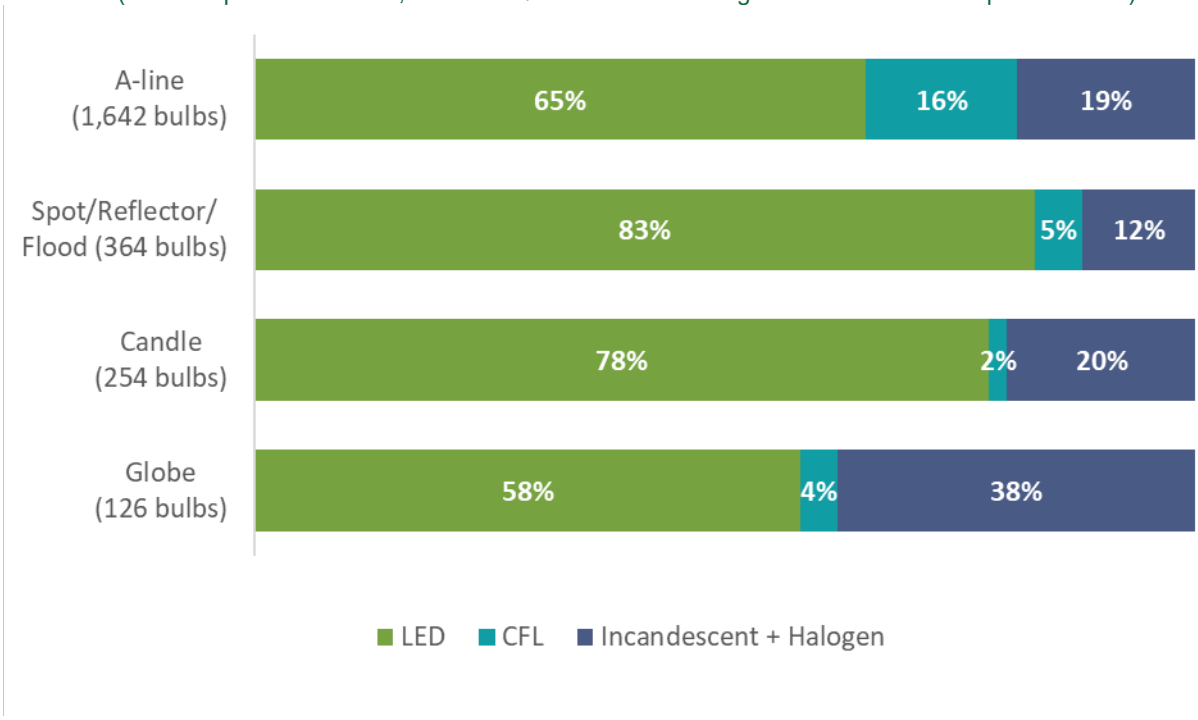
[1] Only calculated across bulb types.

4.1.3 Bulb Replacement by Shape

Figure 16 shows replacement behavior by bulb shape for sockets filled with LEDs, CFLs, incandescents, and halogens. Spot/reflector/flood bulbs had the highest LED replacement rate of all bulb shapes (83%), followed by candelabra bulbs (78%). Nearly two-thirds of replacement A-lines (65%), the most common bulb type, were LEDs. More than one-half of all replacement globe bulbs were LED (58%). We are unable to assess how many replacements occurred during a home energy assessment, but we are certain that the high number of direct install participants has influenced these results.

Figure 16: Bulb Replacement by Shape (2017-2020)

(Base: Replacement bulbs; don't know/other bulb technologies and other bulb shapes excluded)



4.1.4 Additional Detailed Bulb Replacement Behavior

Replaced bulbs (*before*) are bulbs that were recorded in the 2017 visit but were removed from the sockets when technicians returned for the 2020 visit. Replacement bulbs (*after*) are those bulbs installed in sockets in 2020 from which the bulbs had been removed.

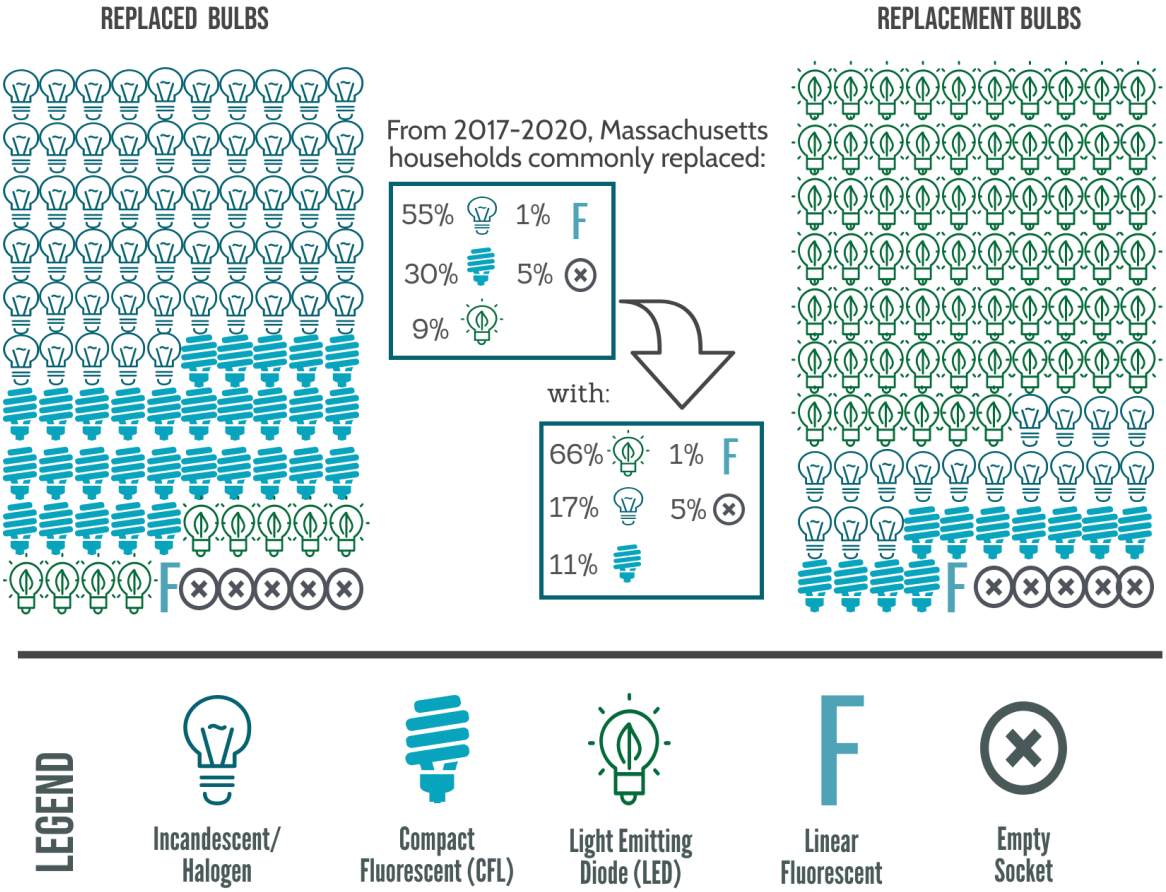
Replacement Trends

Figure 17 shows overall bulb replacement behavior. Incandescents were the most commonly replaced bulb (47%), the bulb with the shortest lifespan. This is followed by CFLs (30%) and LEDs (9%). As LED saturation has increased over the past few years, there are more LEDs in sockets that could be removed or replaced. One-third of replaced LEDs in Massachusetts (34%) were removed from their sockets due to failure. Other reasons given for removing LEDs included dissatisfaction with the bulb's function (15%) or appearance (8%), installing the bulb in another fixture (9%), or installing a more efficient bulb (8%).[10,11]

LEDs were the most common bulb type chosen as a replacement bulb (66%). Despite small sales shares[12] incandescents (13%) and CFLs (11%) served as the next two most common type of replacement bulb. As noted above, more than one-half of the replacement CFLs came from storage or another socket. This likely reflects the limited availability of CFLs on store shelves as well as consumers' reluctance to bring the few that remain into the home. About three-quarters of incandescents and halogens were newly purchased, although some incandescents may have been mistakenly identified with halogens.

[10] Reasons for bulb change are self-reported.
[11] All panelists who said they replaced an LED to install a more efficient bulb actually installed another LED in its place.
[12] NMR Group, Inc. 2020. *Regional Lighting Sales Data Analysis*. Forthcoming.

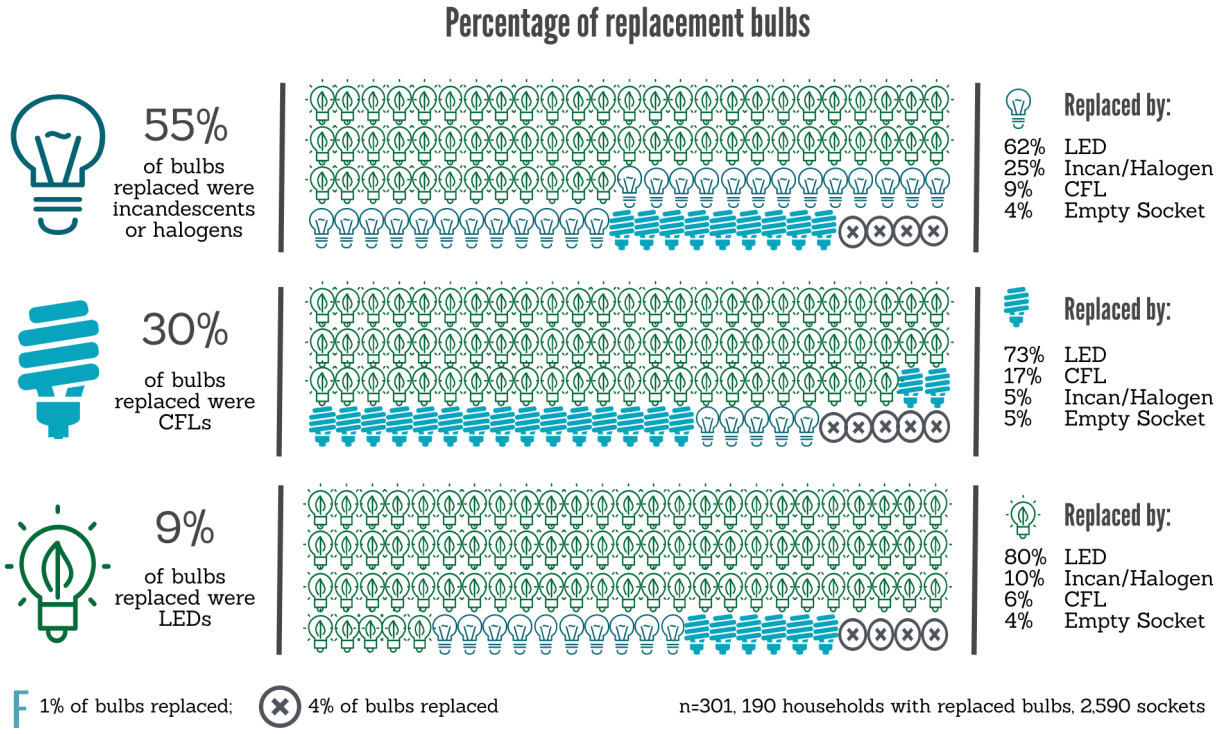
Figure 17: Overall Bulb Replacements



In Figure 18, we break down the replacement behavior by proportion of bulbs replaced for each bulb type. LEDs were the most commonly chosen replacement bulb for removed LEDs (80%), incandescents (63%), CFLs (73%), and halogens (57%). Ten percent of removed LEDs and 5% of removed CFLs were replaced by an incandescent bulb. This is an important indication that at least some households are willing to switch back to less efficient alternatives, a point we turn to in the next section.

For additional information about bulb replacement trends, newly-installed bulbs, and bulb replacement behavior by demographics, see Appendix E.

Figure 18: What Replaced What



Reasons for Bulb Replacement

As shown in Table 6, bulb failure was the most common reason panelists cited for changing bulbs (56%). The next most commonly cited reasons were Mass Save (22%) and the desire to use a more energy-efficient bulb (9%).

Table 6: Reasons for Bulb Change*

(All replacement bulbs)

Reasons for bulb type change	
Households (n)	*190*
Replaced bulb count	*2,590*
The bulb burned out/broke	56%
Mass Save installed a new bulb	22%
Wanted to use a more energy-efficient bulb	9%
Installed into an empty socket	4%
The previous bulb did not work well	3%
Moved bulb to another fixture	2%
I did not like the appearance of the previous bulb	1%
Other[13]	2%
Don't know	2%

*Multiple responses permitted, so responses sum to >100%.

[13] "Other" reasons given included: bulb was installed by a different energy-efficiency program or building management; householder wanted a brighter or dimmer bulb; householder wanted a "smart" bulb.

If a bulb was replaced by a bulb of a different technology type, we asked panelists about their decision to change technologies. In Table 7, we look at the reasons panelists gave for replacing inefficient bulbs (incandescent or halogen) with LEDs or CFLs, and efficient bulbs (LED or CFL) with incandescent or halogen bulbs. Most of the replacement LEDs were installed because the panelist wanted to use a more energy-efficient bulb (52%) and/or the LED was installed by Mass Save (42%), suggesting early replacement. In cases where an incandescent or halogen replaced an LED or CFL, panelists often cited the availability of the replacement bulb in storage, followed by a desire to try a different type of bulb or dissatisfaction with the appearance of the removed LED or CFL.

Table 7: Reasons for Bulb Type Change by Replacement Bulb Type[1,2]

(Base: Replacement bulbs in panel homes that were a different type than the bulb they replaced)

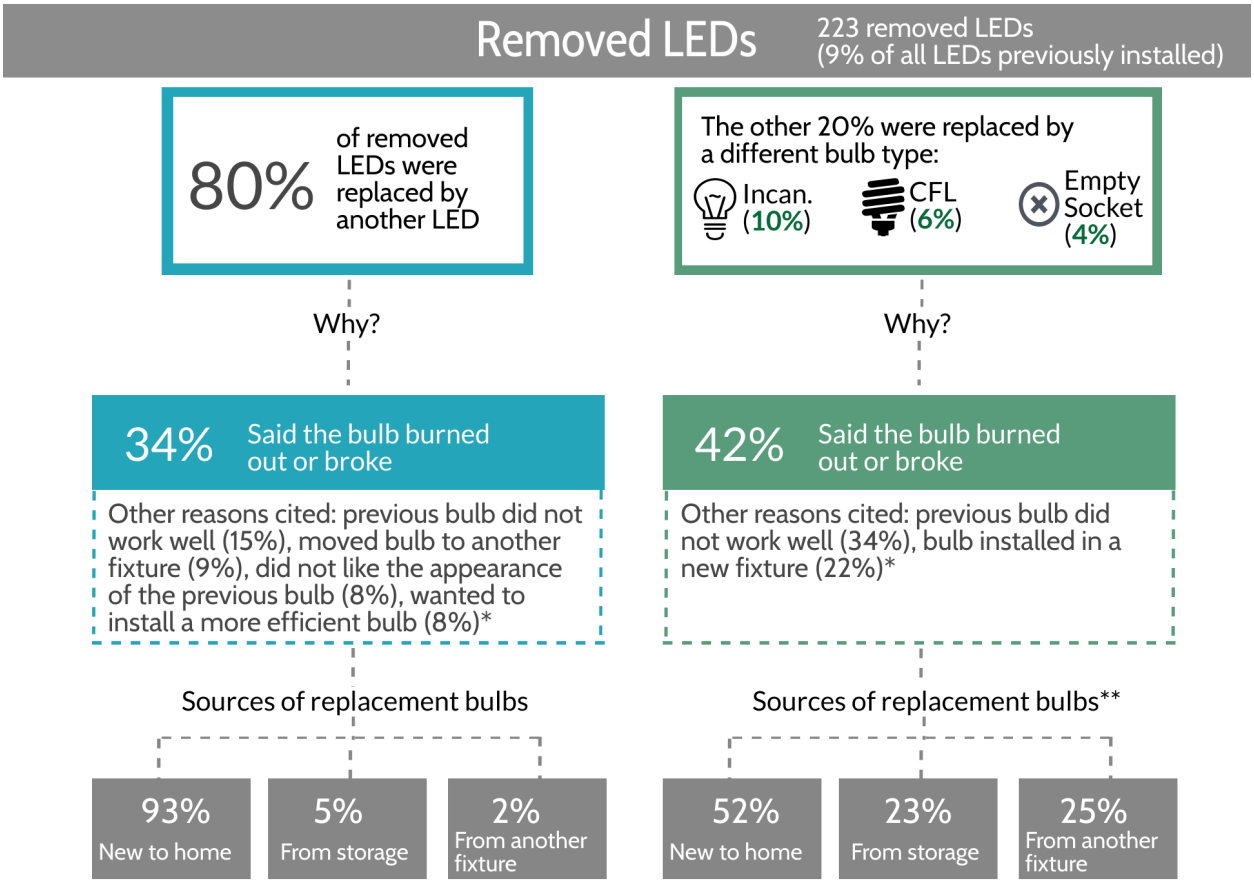
Reasons for bulb type change	Inefficient bulbs replaced with:		Efficient bulbs replaced with:	
	LED	*CFL*	*Incandescent*	*Halogen (count)*
Households (n)	*129*	*48*	*32*	*15*
Replaced bulb count	*878*	*120*	*49*	*18*
Wanted to use a more energy-efficient bulb	52%	26%	--	--
Mass Save (self-reported)	42%	7%[3]	--	--
Available in storage	6%	63%	50%	16
Did not like function and/or appearance of previous bulb	1%	--	4%	--
I wanted to try a different type of bulb	>1%	--	33%	1
Other	2%	--	0%	--
Don't know	2%	4%	13%	1

[1] Multiple responses permitted; some columns sum to >100%.
[2] Totals do not sum to 100% because more than one response was permitted per bulb.
[3] The PAs stopped installing standard CFLs in 2017; therefore, it is likely that this panelist was mistaken about the reason for changing this bulb type.

4.1.5 Bulbs Replacing LEDs

As Figure 19 shows, from 2017 to 2020, Massachusetts panelists removed 9% of all installed LEDs. Eighty percent of LEDs removed from a socket since the 2017 visit were replaced by another LED. When asked why the bulb was changed, the most common reason was bulb failure. While the majority of LEDs that were removed from a socket since the 2017 visit were replaced by another LED (80%), we observed some panelists replacing LEDs with inefficient lamps (backsliding). Ten percent of LEDs were replaced by an incandescent.

Figure 19: Bulbs Replacing LEDs



* Multiple responses permitted; totals (not shown here) do not sum to 100%.
** Empty sockets excluded.

Section 5 Recent Purchases

This section provides an analysis of recent bulb purchases based on findings from the on-site visits. While on site, technicians asked respondents to recall when and from where specific bulbs had been purchased. It is important to keep the self-reported nature of purchase source in mind when reviewing these results. For example, households may have reported obtaining a bulb from a direct install program that they actually bought at a store and vice versa.

- ***After Mass Save, home improvement stores, followed closely by mass merchandise stores, were the most commonly reported sources of LEDs for bulbs obtained in the past year, which is similar to past years.***
- ***Nine out of ten LEDs obtained in the past year in Massachusetts were ENERGY STAR-certified (92%).***

5.1 Sources of Newly Acquired LEDs

NMR technicians not only asked respondents when they purchased or obtained any new LED found in their homes but also asked them to recall where they had purchased or obtained the bulbs. This section looks at recent purchases by channel. It is important to note that while the number of newly acquired bulbs is based on observation by technicians, the source of bulbs is based entirely on self-reported data.

Table 8 refers to all bulbs purchased or obtained in the past year. Obtained bulbs include all purchased bulbs, bulbs installed by a landlord, and bulbs received through energy-efficiency programs. We refer to the previous year of the study (e.g., 2018 for the 2019 study year, 2017 for the 2018 study year, etc.) because the bulbs were purchased in the 2019 calendar year.[14] In 2019, two-fifths of all LEDs new to the home (40%) were either verified (30%) or self-reported (10%) to have been installed by Mass Save.

Similar to previous years, home improvement stores (e.g., Home Depot or Lowe's) were a common source of obtained LEDs (19%), followed by mass merchandise retailers (e.g., Walmart or Target, 16%). Compared to previous years, fewer LEDs were reportedly purchased at discount (1%), grocery (1%), and lighting and electronics stores (0%). Note that we did not test for statistical significance between the 2020 RES1 and 7-Year panel studies due to the high proportion of verified direct install participants in the 2020 RES1 sample. For further analysis of LED bulbs obtained last year, see Appendix F.

[14] On-site visits conducted for the 7-Year Panel were approximately twelve months apart and it may have been more straightforward for panelists to recall when and where they purchased LEDs. For the RES1 Baseline panel, on-site visits were 32 months apart (from the start of the first study in February 2017, to the start of the second study in October 2019), and self-reported LED purchases for 2019 may be less reliable.

Table 8: LED Bulbs Obtained 2016-2020

(Base: LEDs new to panel homes since the previous visit; year of purchase self-reported)

Bulb Source	RES1 Baseline	7-Year Panel		
	Obtained in 2019	Obtained in 2018	Obtained in 2017	Obtained in 2016
Sample Size	*199*	*330*	*381*	*315*
Homes with new LEDs	*58*	*171*	*186*	*172*
Bulbs Obtained	**704**	**1,391**	**1,654**	**1,606**
Avg. # Obtained	**12.1**	**8.1**	**8.9**	**9.3**
Mass Save (DI Verified)[1]	30%	0%	1%	5%
Mass Save (Unverified)[2]	10%	18%	25%	23%
Home Improvement	19%	30%	31%	36%
Mass Merchandise	16%	8%	7%	7%
Online	8%	7%	3%	8%
Hardware	5%	6%	6%	3%
Discount	1%	3%	6%	1%
Grocery	1%	4%	3%	1%
Other EE Program	<1%	7%	<1%	1%
Installed by an Electrician	<1%	1%	2%	<1%
Membership Club	--	4%	2%	4%
Lighting & Electronics	--	1%	3%	4%
Other[15]	<1%	6%	1%	4%
Don't know	9%	3%	9%	2%

[1] As self-reported by households verified to have taken part in a direct install program.
[2] As self-reported by households not verified to have taken part in a direct install program.

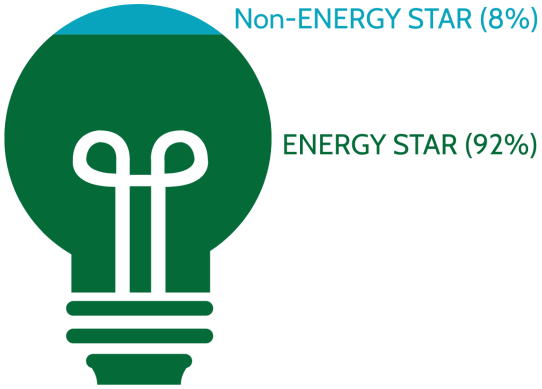
[15] "Other" includes bulbs purchased at retailers that do not fit into the other retail channels (e.g., Ikea, Habitat for Humanity ReStore, Goodwill), bulbs received as a gift from family members or friends, etc.

5.2 PURCHASES BY ENERGY STAR STATUS

To examine purchases by ENERGY STAR status, we looked at LEDs that households reported purchasing within the past year (Figure 20). In 2020, 92% of all LEDs purchased within the past year were ENERGY STAR LEDs.

Figure 20: ENERGY STAR Status of LEDs Purchased in 2019

(Base: LEDs new to panel homes purchased in 2019 – self-reported)



Section 6 Storage Behavior

As in years past, most households stored bulbs; 244 of the 301 RES1 Baseline households (81%) visited for the 2020 study had at least one bulb in storage. In this section, we present analysis related to storage, including in-service rates for LEDs, and a complete analysis of bulbs found in storage in on-site participant households. The storage analysis shows some signs of being affected by the high rates of direct install participation, but less so than the other topics addressed in this study.

- ***On average, households had enough bulbs in storage to fill about one-third of sockets. The majority of these bulbs were being stored for future use.***
- ***Incandescent bulbs were the most common type found in storage (42%), followed by LEDs, at 32%.***
- ***While most bulbs stored in Massachusetts during the 2017 visits remained in storage, we observed customers drawing upon stored bulbs as replacements, most commonly by bringing stored inefficient bulbs into service.***

6.1 Stored Bulbs

Massachusetts households stored an average of 18.1 bulbs in 2020 – enough bulbs to fill nearly one-third of the 59 sockets in an average home (Table 9). As in past studies, incandescent bulbs made up the majority (42%) of stored bulbs in RES1 Baseline homes in 2020. The reduction in stored incandescents between 2017 and 2020 in RES1 homes (57% to 42%) resembles the reduction from 2017 to 2020 among the 7-Year Panel (56% to 45%). Notably, according to RES1 households, over one-half (54%) of stored incandescents were being stored for future use. LEDs accounted for 32% of all stored bulbs, nearly all of which (96%) were being stored for future use. This is somewhat higher than in the 2019 7-Year Panel and could reflect some level of bulbs *left behind* during direct install home energy assessments. Table 35 in Appendix G shows more detail on participants reasons for storing bulbs by bulb type.

Table 9: Stored Bulbs by Bulb Type Over Time

(Base: All on-site respondents)

	RES1 Baseline		7-Year Panel						
	2017	2020[3]	2013	2014	2015	2016	2017	2018	2019
Sample Size	*308*	*297*	*150*	*261*	*354*	*420*	*465*	*381*	*330*
Avg # of Stored Bulbs/Home[1]	**18.5**	**18.1**	**7.1**	**15.8**	**15.6**	**17.5**	**17.8**	**14.5**	**15.4**
Incandescent	57%	42%	66%	68%	64%	59%	56%	51%	45%
CFLs	22%	18%	31%	25%	27%	26%	24%	22%	21%
Halogen	6%	8%	3%	4%	5%	7%	9%	9%	9%
Fluorescent	2%	1%	1%	2%	1%	2%	2%	2%	2%
LEDs	13%	32%	<1%	2%	2%	5%	9%	16%	24%
Other[2]	0%	<1%	0%	0%	<1%	<1%	<1%	<1%	<1%

[1] In 2014, technicians found more bulbs in storage than had been found in previous years due to new quality control and data collection protocols.
[2] "Other" includes xenon, high pressure sodium bulbs, and mercury vapor bulbs.
[3] Four outliers – households with a total number of stored bulbs that was more than three standard deviations from the mean – were not included in this analysis.

6.2 Stored Bulb Status

NMR was able to track stored bulb status between visits using the same approach of marking bulbs during the 2017 visit and checking the status during the 2020 visit. There was a total of 5,160 bulbs in storage in RES1 Baseline Panel homes in 2020; 27% of the bulbs stored in 2017 were no longer in storage in 2020. Other notable results include the following:

- More than one out of every ten (15%) incandescent bulbs that had been in storage in 2017 were thrown out/recycled between the 2017 visit and the 2020 visit.
- Seven percent of LEDs that were in storage in 2017 were installed by 2020, and more than three out of five stored LEDs were newly purchased or obtained (62%).

Table 10: Stored Bulbs Status

(Base: RES1 Baseline panel sites)

Bulb Status 2020	LED	CFL	Incandescent	Halogen	Fluorescent	All
# of Bulbs	1,196	1,113	2,429	336	87	5,160
Same	19%	41%	55%	36%	42%	42%
New	62%	19%	16%	30%	40%	29%
Thrown Out/Recycled	2%	15%	15%	11%	7%	12%
Don't Know/Other	7%	11%	8%	12%	12%	9%
Installed in Fixture	7%	12%	4%	10%	-	7%
Previously Installed	2%	3%	2%	1%	-	2%

Section 7 LED Satisfaction

The study also explored LED satisfaction, which we do not believe is subject to bias due to direct install participation. In all households that had at least one LED installed, participants indicated their level of satisfaction with each model currently installed in their homes. Satisfaction with LEDs is an important market indicator for LED programs.

- ***Among households that had LEDs installed, satisfaction was high for both ENERGY STAR LEDs and non-ENERGY STAR LEDs.***

Respondents reported that they were "very satisfied" or "somewhat satisfied" with 93% of their LEDs (see Table 31 and Table 33 in Appendix E for more information on additional response categories). When examined by ENERGY STAR status (Table 11), respondents reporting that they were "very satisfied" or "somewhat satisfied" with both ENERGY STAR qualified (93%) and non-qualified LEDs (92%). Satisfaction was even higher (95%) for LEDs of unknown ENERGY STAR qualification. Notably, respondents were more likely to say they were "very satisfied" with ENERGY STAR LEDs than they were with non-qualified or unknown LEDs.

Table 11: LED Satisfaction

(Base: Respondents with at least one LED installed in the home)

Level of Satisfaction	ENERGY STAR LEDS	Non-ENERGY STAR LEDS	Don't know	All LEDs
Number of Bulbs	*4,292*	*491*	*1,367*	*6,151*
Very Satisfied	82%	77%	78%	81%
Somewhat Satisfied	11%	15%	17%	13%

* "Don't know" satisfaction responses excluded from table.

LED satisfaction was similar across the most common bulb shapes (Table 12).

Table 12: LED Satisfaction by Bulb Shape[1]

(Base: Installed LED bulbs or recessed cans)

Level of Satisfaction	A-Line	Reflector	Candelabra	Globe
Number of Bulbs	*3,652*	*1,314*	*776*	*256*
Very Satisfied	82%	79%	81%	83%
Somewhat Satisfied	12%	16%	14%	7%

[1] "Don't know" responses excluded from analysis. Other bulb shapes not shown in the table.

Appendix A Methodology

This appendix provides a detailed summary of the methodological approaches used for this study.

A.1 Weighting Scheme

NMR weighted the on-site survey data to reflect the population proportions for home ownership (tenure) and education in Massachusetts based on Public Use Microdata Sample (PUMS) from the ACS five-Year Estimates (Table 13). The guiding principles behind the schemes included:

- To maintain comparability with previous schemes dating back to 2008; this is very important for tracking changes in saturation, use, purchase, and storage behavior
- To reflect the population of Massachusetts
- To make certain that the panel data are treated properly (i.e., that the panel data correctly represent the population and what we want to compare over time)

Table 13: On-Site Visit Weight Scheme

Year	Tenure and Home Type	Households	Sample Size	Proportionate Weight
All Visits	*Total*	2,601,914	301	
	Owner-Occupied		239	
	Assoc Degree or Less	784,282	95	0.96
	Bachelor's Degree or Higher*	836,771	144	0.67
	Renter-Occupied	980,681	62	1.83

*Includes two respondents who preferred not to provide their education.

Panel Visits	*Total*	2,601,914	199	
	Owner-Occupied		167	
	Assoc Degree or Less	784,282	31	1.94
	Bachelor's Degree or Higher*	836,771	136	0.47
	Renter-Occupied	980,681	32	2.34

*Includes two respondents who preferred not to provide their education.

Table 14 provides the weighted estimates of total saturation by area. The table also provides the mean and median saturation at the household level. The greater the difference between the mean and median per household, the greater the discrepancy between households with a lot of that bulb type installed versus those with few. This difference was largest for incandescents, which likely demonstrates that there are still some households that are loyal to incandescents.

Table 14: Saturation by Socket and Mean and Median Saturation by Household, 2020

Bulb Type	Massachusetts (n=301)		
	Saturation	Mean	Median
LEDs	40%	44%	43%
Incandescent	22%	19%	13%
CFLs	18%	19%	14%
Halogen	9%	7%	4%
Fluorescent	7%	6%	3%

A.2 On-Site Lighting Inventories – Panel Visits

NMR visited 301 homes in Massachusetts to collect data on their lighting use, storage, and purchase behavior. Throughout the report, we compare the findings from the RES1 Baseline panel to previous data collected in Massachusetts as part of a long-term series of on-site data collection since 2009. Figure 21 provides an overview of on-site visits conducted during this period, and Figure 22 provides a summary of visit timing. NMR conducted the MA19R15-E 2019 Residential Lighting On-Site study visits at the end of 2019 and the beginning of 2020.

Prior to this study, NMR completed six waves of panel visits in Massachusetts (the 7-Year Panel). The panel in Massachusetts was first established in 2013, with 150 new on-site visits.

- **Panel Wave One:** In 2014, we returned to 111 of the homes first visited in 2013 as part of the Regional Hours-of-Use Study and visited an additional 150 homes for the first time.
- **Panel Wave Two:** In 2015, we returned to 203 homes – 89 first visited in 2013 and 114 first visited in 2014 – and went to an additional 151 homes for the first time.
- **Panel Wave Three:** In 2016, we returned to 270 homes – 77 first visited in 2013, 98 first visited in 2014, and 95 first visited in 2015 – and went to an additional 150 homes for the first time.
- **Panel Wave Four:** In 2017, we returned to 315 homes – 65 first visited in 2013, 83 first visited in 2014, 72 first visited in 2015, and 95 first visited in 2016 – and went to an additional 150 homes for the first time.
- **Panel Wave Five:** For the 2018 Market Assessment, we returned to 381 homes – 58 first visited in 2013, 74 first visited in 2014, 68 first visited in 2015, 78 first visited in 2016, and 103 first visited in 2017. No homes were visited for the first time in this wave.

- **Panel Wave Six:** For the 2019 Market Assessment, we returned to 330 homes – 53 first visited in 2013, 66 first visited in 2014, 63 first visited in 2015, 62 first visited in 2016, and 86 first visited in 2017. No homes were visited for the first time in this wave.

Figure 21: On-Site Visits over Time

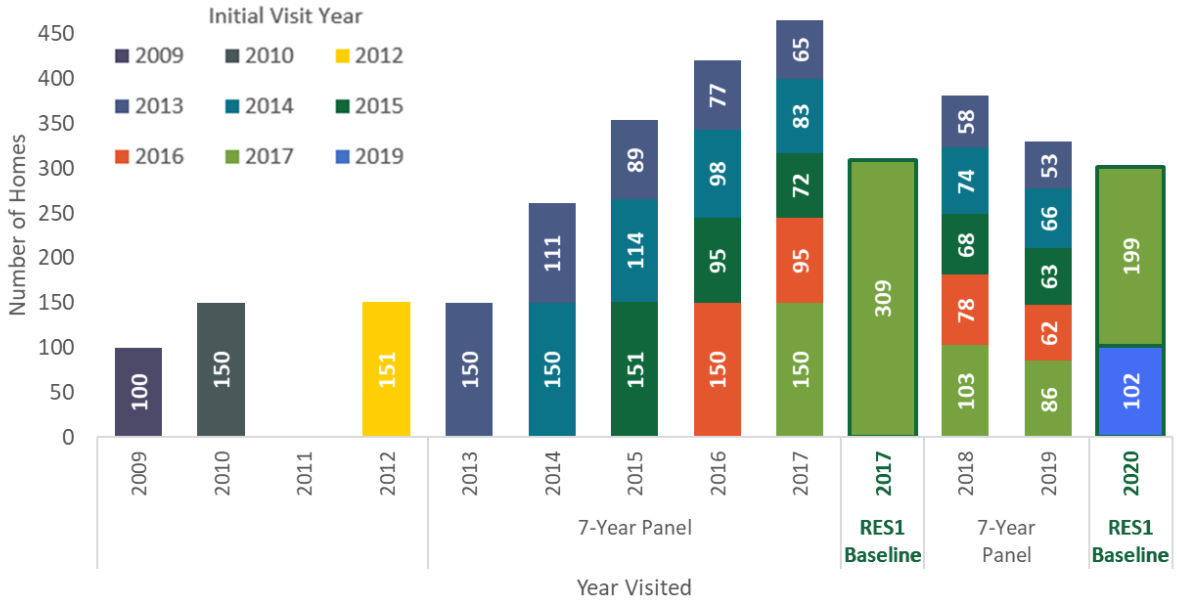
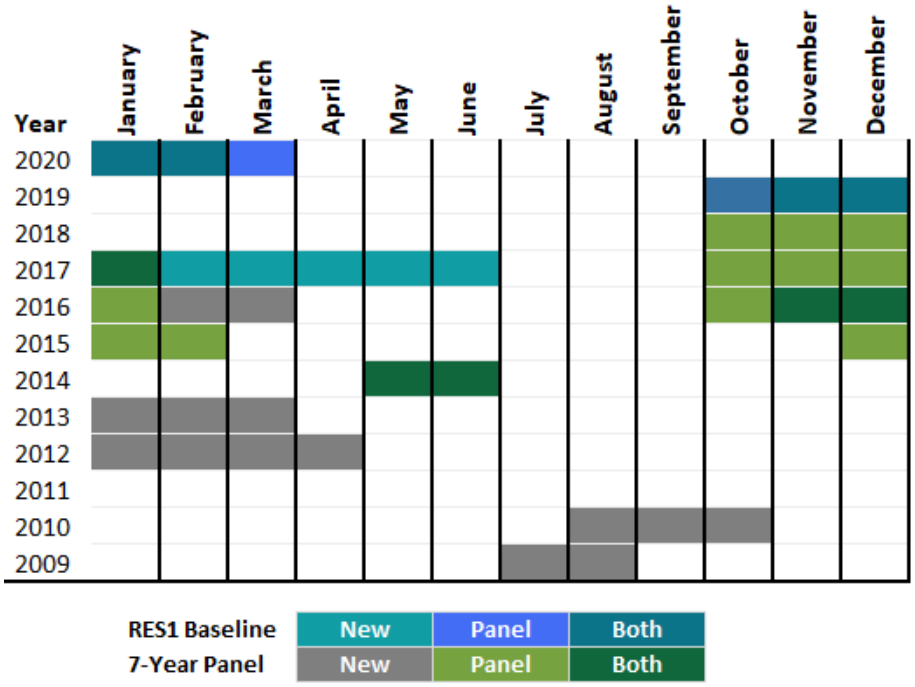


Figure 22: Timing of On-Site Visits



A.3 BULB CATEGORIZATION

On-site technicians are carefully trained in correct identification of bulb types, including the differences between incandescent and halogen lamps. When in doubt, technicians take a photo of the bulb and data cleaners are assigned to use wattage, model numbers, or other identifying features to distinguish bulb type. In some cases, technicians encounter out-of-reach bulbs or fragile fixtures and cannot closely inspect the lamps. In these cases, technicians make an educated guess by comparing the lamp to bulbs in storage or asking the homeowner. Due to careful adhesion to data collection and data cleaning protocols, we are confident we have correctly distinguished incandescent and halogen bulbs to the extent possible. For ease of interpretation of results, we present incandescent and halogen bulbs together in many figures throughout the report.

Appendix B Direct Install

Table 15 provides an overview of direct-install program participation by year of program participation. Based on an examination of participant records for the Home Energy Services Electric, Low-Income Single-Family Electric, Low-Income Single-Family Retrofit, Residential Home Energy Services, Residential Lighting, and Residential Multifamily Retrofit programs, we estimate that about 5% of the households in PA service areas participated in at least one direct install program each year from 2013 through 2018. Given this, we would expect our sample to include about 25% of households that participated in a direct-install program from 2015 to 2019.

Table 15: Statewide Program Participation

Year	# of Accounts Participating in Any Direct-Install Program	Total # of Residential Accounts	Participation Rate
2018	146,715	2,667,239	5.501%
2017	127,833	2,639,969	4.842%
2016	129,848	2,636,885	4.924%
2015	127,248	2,405,226	5.290%
2014	127,937	2,570,034	4.978%
2013	119,871	2,302,523	5.206%

NMR asked the PAs to verify participation in direct-install programs. Of 301 households in the sample, 41% had participated in at least one direct-install program since 2015 (Table 16).[16] Among panel homes that had been previously visited for the lighting saturation study in 2017 (n=199), 37% of households were verified program participants. Among new households that were added to the study since the 2017 lighting on-site study (n=102), 47% of households were verified program participants, indicating that the sample of new households in the study is biased towards program participation.

[16] NMR could not verify 9.3% of households in the sample because the account numbers could not be matched, or they were gas customers only.

On-site technicians also asked households whether they had ever participated in a program where someone came to their homes to install energy-efficient bulbs and, if so, when (the "self-report" column in Table 16).

Table 16: RES1 Baseline Direct-Install Program Participation by Year (Unweighted)

Year of Program Participation	Self-Report	Verified (Overall)	Verified (Panel)	Verified (New)
n	*301*	*301*	*199*	*102*
All Years	**50.2%**	**48.8%**	**44.2%**	**57.8%**
2020	--	1.0%	1.0%	1.0%
2019	6.6%	6.0%	5.0%	7.8%
2018	9.3%	16.3%	4.5%	20.6%
2017	8.0%	10.6%	8.0%	15.7%
2016	9.0%	7.0%	8.0%	4.9%
2015	2.7%	4.7%	4.5%	4.9%
2014	2.0%	1.3%	1.5%	1.0%
2013	1.3%	0.3%	0.5%	--
2012	--	1.3%	1.0%	2.0%
2011	0.7%	.3%	0.5%	--
Before 2011	4.7%		--	--
Unknown Year	6.0%	--	--	--
Non-Participant	49.8%	41.9%	46.7%	32.4%
Unmatched/Gas Only	--	9.3%	9.0%	9.8%

By comparison, Table 17 shows direct-install program participation by year for the 7-Year Panel from previous NMR lighting studies. To control for possible response bias, we worked with the PAs to verify participation for new visit and panelist households from 2014, 2015, 2016, 2017, and 2018 against the program records for direct-install programs and low-income and multifamily direct-install programs.[17] Looking at verified participation in direct-install programs, we found that the combined sample includes 22% confirmed direct-install participants. Note that our sample does not include any 2018 participants and only a few 2016 and 2017 participants. This likely means that the sample overrepresents historical direct install program influence and underrepresents more recent direct install influence on the residential lighting market in Massachusetts.

[17] Analysis was limited to households with initial visits in either 2016 or 2017 because NMR does not have account numbers for households first visited in 2013, 2014, or 2015.

Table 17: 7-Year Panel Direct-Install Program Participation by Year (Unweighted)

Year of Program Participation	Self-Report	Verified
All Years	**45%**	**22%**
2018	3.3%	--
2017	3.6%	.6%
2016	7.6%	1.5%
2015	6.4%	6.7%
2014	8.2%	3.0%
2013	3.9%	3.0%
2012	3.9%	2.1%
2011	2.1%	.3%
Before 2011	5.2%	5.1%
Unknown Year	1.2%	--
Non-Participant	55%	78%

B.1 Effect of Direct-Install Participants on Saturation Estimates

To assess the effect direct-install participants had on overall saturation estimates, NMR calculated overall saturation by bulb type with and without the 134 confirmed direct-install participants (Table 18). When direct install participants are removed, LED saturation is seven percentage points lower (39%) and the combined saturation of incandescent and halogen bulbs is seven percentage points higher. This leads us to conclude that actual saturation is somewhere between 39% and 45% of sockets.

Table 18: Comparison of Saturation Rates by Verified Direct Install (DI) Program Participation (Unweighted)

Sockets Containing	2020 (Excluding DI)	2020 (Including DI)	Difference	2020 (DI Only)
Sample Size	*167*	*301*	*N/A*	*134*
Total Sockets	*11,027*	*20,311*	*N/A*	*9,284*
Avg. # of Sockets	*66.0*	*67.5*	*N/A*	*69.2*
Incandescent	27%	21%	6%	14%
CFLs	15%	15%	--	15%
LED	39%	45%	-6%	54%
Fluorescent	7%	7%	--	7%
Halogen	9%	8%	1%	7%
Other/Don't Know	1%	1%	--	1%
Empty Sockets	3%	3%	--	2%

Appendix C Saturation – Additional Detailed Analysis

In this appendix, we expand on demographic findings presented in Section 2. We show saturation in Massachusetts over time (2009-2020), by room type, by bulb shape, and across demographic groups. We also look at saturation of linear fluorescent bulbs and bulb saturation in specialty bulb sockets. Note that we do not discuss the potential impacts of the high rates of direct install participation on the analysis of saturation by household demographics.

C.1 Saturation by Household

Table 19 provides the same data shown in Figure 5, as well as combined saturation figures for efficient and inefficient bulb types, the proportion of sockets occupied by specialty bulbs,[18] and notations for significant differences between years. Some of the additional highlights regarding saturation are summarized below.

- **LED** saturation increased sharply since 2014, increasing fifteen-fold from 2014 to 2020 (3% to 45%).
- **CFL** saturation increased steadily from 2009 to 2014; after peaking in 2014 at 33%, saturation has steadily declined each year. It was down to 16% in 2020.
- **Incandescent** saturation has decreased more than 40 percentage points (62% to 20%) between 2009 and 2020. The percent of sockets filled with incandescent bulbs decreased relatively from 2019 (24%) to 2020 (20%), with an average annual decline of approximately four percentage points.
- **Linear fluorescent** saturation has remained steady, at 7%, since 2017.
- **Halogen** saturation has been hovering around 8% since 2016. (Note that halogen and incandescent bulbs are very similar in appearance. We make every effort to train technicians to identify halogen bulbs but recognize that some bulbs labeled as incandescent are likely halogen, and vice versa. Therefore, we present all incandescent and halogen data separately and combined.)
- **Combined CFL and LED** saturation in 2020 was relatively higher (61%) than in the beginning of 2019 (57%). In 2009, combined CFL and LED bulb saturation accounted for more than one-quarter (26%) of all sockets in Massachusetts. In 2019, it accounted for three out of every five sockets (61%).

[18] Specialty bulbs include 3-way bulbs of any kind, dimmable CFLs and fluorescents, circline fluorescents, non-A-line LEDs, incandescent and halogen bulbs, and non-twist/spiral CFLs.

- **Combined efficient (CFL, LED, and linear fluorescent)** bulbs accounted for more than two out of three (68%) sockets in 2020.
- **Combined inefficient (incandescent and halogen)** bulbs filled less than one-third (28%) of all sockets in Massachusetts in 2020 – down 39 percentage points since 2009.
- The proportion of sockets occupied by a **specialty LED** (LEDs that are not A-line shaped) has increased over the past few years, from 5% to 16% in 2020

Table 19: Comparison of Saturation Rates, 2013-2020

Sockets Containing	7-Year Panel					RES1 Baseline	7-Year Panel		RES1 Baseline
	2013	2014	2015	2016	2017	2017	2018	2019	2020
Sample Size	*150*	*261*	*354*	*420*	*465*	*308*	*381*	*330*	*301*
Total Sockets	**6,341**	**13,550**	**18,398**	**24,219**	**27,148**	**17,365**	**20,449**	**18,066**	**17,766**
Avg. Sockets per HH	**42**	**49**	**52**	**54**	**58**	**56**	**54**	**55**	**59**
Incandescent	55%[cdefghi]	45%[defghi]	43%[af]	37%[abcf]	33%[abc]	30%[abcdhi]	28%[abcd]	24%[abcdef]	20%[abcdefgh]
CFLs	28%[i]	33%[fhi]	32%[f]	31%[f]	29%	24%[bcdi]	26%[cd]	23%[bcde]	16%[abcdefgh]
Fluorescent	9%	9%	9%	8%	7%	9%	7%	7%	7%
Halogen	5%[f]	6%	6%	8%	8%	9%	8%	7%	8%
LEDs[**]	2%[cdefghi]	3%[cdefghi]	6%[abf]	12%[abcf]	18%[abcdf]	24%[abcdehi]	27%[abcde]	34%[abcdefg]	45%[abcdefgh]
Other[***]	2%	4%	4%	4%	4%	4%[hi]	4%[h]	<1%[bcdfg]	1%[cefg]
CFLs + LEDs	30%[cdefghi]	36%[defghi]	38%[af]	43%[ab]	47%[abc]	49%[abchi]	53%[abcde]	57%[abcdef]	61%[abcdefg]
CFLs + LEDs + Fluorescent	39%[cdefghi]	45%[efghi]	47%[af]	51%[a]	54%[abc]	58%[abci]	60%[abcde]	64%[abcde]	68%[abcdefg]
Incandescents + Halogen	60%[defghi]	51%[fghi]	49%[f]	45%[a]	41%[abc]	38%[abchi]	36%[abcde]	31%[abcdef]	28%[abcdefg]
Any Specialty Bulb	38%	40%	42%	42%	44%	41%	43%	42%	45%
Any Specialty CFL	8%	11%[i]	10%[i]	11%[i]	10%[i]	8%	9%[i]	9%[i]	5%[bcdegh]
Any Specialty CFL (not including A-line CFLs)	6%	9%[i]	8%[i]	8%[i]	8%[i]	7%	7%	6%	4%[bcde]
Any Specialty LED	2%[efghi]	2%[eghi]	4%[i]	5%[fi]	8%[abcdi]	10%[adi]	11%[abcd]	13%[abcd]	16%[abcdef]

[**] The LED category includes both LED bulbs and integrated LED fixtures.

[***]"Other" includes xenon bulbs, metal halide, sodium, empty sockets, and unknown bulb types.

[a] Significantly different from 2013 at the 90% confidence level.

[b] Significantly different form 2014 at the 90% confidence level.

[c] Significantly different from 2015 at the 90% confidence level.

[d] Significantly different from 2016 at the 90% confidence level.

[e] Significantly different from 2017 at the 90% confidence level.

[f] Significantly different from 2017 (RES1 Baseline) at the 90% confidence level.

[g] Significantly different from 2018 at the 90% confidence level.

[h] Significantly different from MA 2019 at the 90% confidence level.

[i] Significantly different from 2020 (RES1 Baseline) at the 90% confidence level.

C.2 SATURATION BY DEMOGRAPHICS

This section looks at saturation across select demographics for CFLs, LEDs, and combined incandescent and halogen bulbs in Massachusetts (Table 20, Table 21, and Table 22). Note that saturation percentages do not add up to 100% because fluorescent, “other” bulb types, and empty sockets are not shown in the table but were included in the saturation calculations. Saturation was similar when comparing households by income, education, tenure, and home type. RES1 households that owned their homes were less likely to have CFLs installed (14%) than RES1 households who rented their homes (24%).

Table 20: Saturation by Demographics

Demographic	Sample Size	# of Bulbs	# of Bulbs Statewide	Avg # of Sockets per HH	LEDs	CFLs	Incan. + Halogen
Income							
Non-Low-Income	219	13,261	114,368,961	61	48%	15%	28%
Low-Income	82	4,504	38,936,863	55	38%	21%	29%
Education							
Associate Degree or Less	129	7,785	67,300,361	60	47%	15%	26%
Bachelor's Degree or Higher	166	9,644	83,371,190	58	43%	17%	30%
DK/Refused	6	336	2,904,272	56	44%	19%	24%
Tenure							
Own/Buying	239	14,102	121,903,506	59	46%	14%[a]	29%
Rent/Lease	62	3,664	31,672,318	59	39%	24%	27%
Home Type							
Multifamily	34	1,071	9,255,723	42	51%	15%	22%
Single-Family	267	16,695	144,320,101	63	45%	16%	29%

* Rows do not sum to 100%; fluorescent, empty sockets, "Don't know" and "Other" bulb types not shown.
[a] Significantly different from Single-Family at the 90% confidence level.

Table 21: Statewide Socket Counts by Room Type[1]

Room Type	All Households		Multifamily		Single-Family	
	# of Sockets Statewide	Avg # of Sockets per HH	# of Sockets Statewide	Avg # of Sockets per HH	# of Sockets Statewide	Avg # of Sockets per HH
Bedroom	23,940,071	9.28	1,608,459	5.19	22,331,612	9.84
Bathroom	19,963,665	7.67	1,743,773	5.63	18,219,892	7.95
Living Space	19,049,520	7.51	1,737,627	6.44	17,311,893	7.63
Kitchen	19,668,921	7.63	1,706,464	5.97	17,962,457	7.84
Dining Room	7,489,847	5.53	359,035	4.81	7,130,812	5.57
Other	50,121,949	19.74	1,979,116	6.39	48,142,833	21.6
Exterior	13,341,850	6.6	121,249	1.4	13,220,601	6.83
Indoor	140,233,973	53.9	9,134,474	29.48	131,099,499	57.2

[1] When calculating average sockets by room type, we only included homes that had rooms of that type. Table 22 provides the population household counts by room type.

Table 22: Statewide Household Counts by Room Type

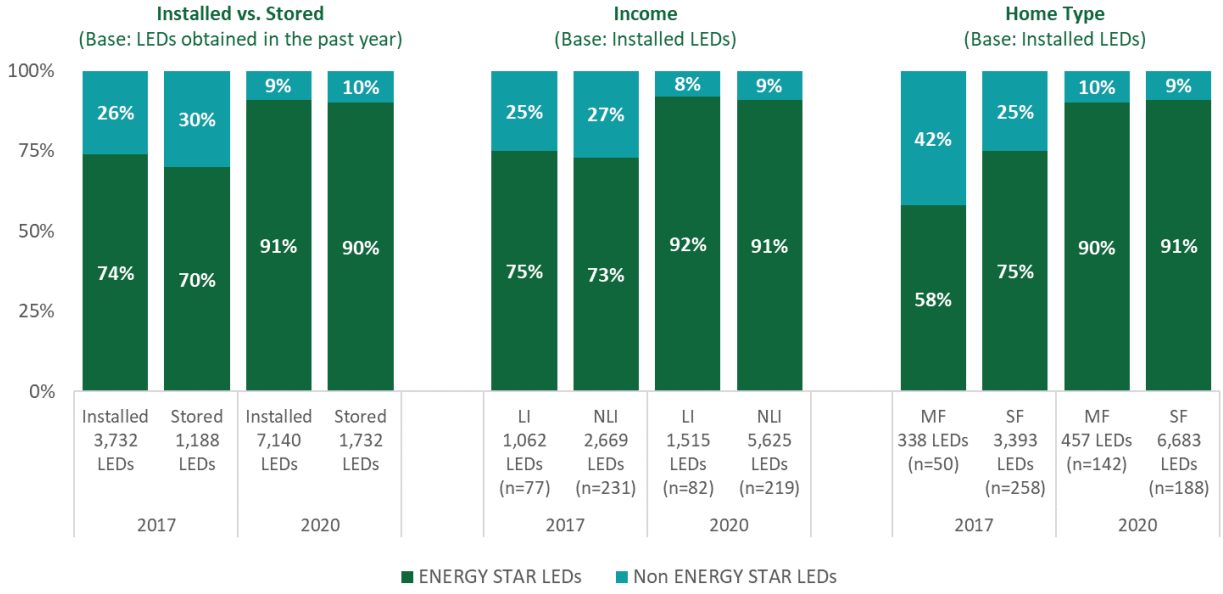
Room Type	# of Households		
	All	Multifamily	Single-Family
Bedroom	2,580,283	309,889	2,270,394
Bathroom	2,601,914	309,889	2,292,025
Living Space	2,537,941	269,992	2,267,949
Kitchen	2,577,838	285,813	2,292,025
Dining Room	1,354,922	74,620	1,280,302
Other	2,538,633	309,889	2,228,744
Exterior	2,022,248	86,384	1,935,864
Indoor	2,580,283	309,889	2,270,394

C.3 ENERGY STAR LED SATURATION

In Section 5.2, we looked at purchases by ENERGY STAR status. We also examined ENERGY STAR LEDs in other ways, as shown in Figure 23. The first chart below shows that out of all LEDs found in the home (not just those purchased within the past year), approximately nine out of ten of both installed (91%) and stored (90%) LEDs were ENERGY STAR in 2020. In 2017, three out of four (74%) installed LEDs were ENERGY STAR and seven out of ten (70%) stored LEDs were ENERGY STAR.

The second and third charts show the percentage of installed LEDs that were ENERGY STAR by income and home type. In 2020, approximately nine out of ten LEDs were ENERGY STAR in both low-income (92%) and non-low-income (91%) households, and approximately nine out of ten LEDs were ENERGY STAR in both multifamily (90%) and single-family (91%) households. In 2017, approximately three-quarters of LEDs installed in low-income (75%), non-low-income (73%), and single-family households (75%) were ENERGY STAR.

Figure 23: ENERGY STAR LEDs



C.4 LINEAR FLUORESCENT SATURATION

To better understand opportunities for increased efficiency among linear fluorescent bulbs, technicians categorized linear fluorescent bulbs as T4, T5, T8, or T12 based on a simple measurement of bulb diameter. As detailed earlier, fluorescents account for 7% of all bulbs in residential homes in Massachusetts; in particular, linear fluorescents account for 5% of all installed bulbs. As Table 23 shows, the majority of linear fluorescents were T12s in 2020 (61%).

Still, there appears to be some opportunity to improve efficiency by encouraging households to replace T12 lighting with higher efficiency alternatives. However, the extent of this opportunity is small in comparison to the overall residential lighting market (about 3% of the market). Finally, linear fluorescent conversion kits and replacement bulbs are generally not compatible with older magnetic ballasts often associated with T12 fluorescent lighting. Replacing older linear fluorescents with LEDs represents a higher level of effort and additional costs since it often requires fixture or ballast replacements, which require the assistance of an electrician.

Table 23: Installed Linear Fluorescents

Size	7-Year Panel				RES1 Baseline	
	2016	2017	2018	2019	2017	2020
Sample Size	*420*	*465*	*381*	*330*	*308*	*301*
# of Bulbs	1,593	1,639	1,336	1,146	1,441	1,108
T4	--	--	--	--	<1%	1%
T5	7%	8%	8%	9%	9%	12%[abc]
T8	29%	29%	28%	28%	22%[abcd]	20%[abcd]
T12	62%	57%	58%	57%	65%[bcd]	61%
Don't Know	2%	6%	6%	6%	3%[abcd]	7%[ae]

[a] Significantly different from 2016 at the 90% confidence level.
[b] Significantly different from 2017 at the 90% confidence level.
[c] Significantly different from 2018 at the 90% confidence level.
[d] Significantly different from beginning of 2019 (7-year panel) at the 90% confidence level.
[e] Significantly different from 2017 (RES1 Baseline) at the 90% confidence level.

C.5 SATURATION OF SPECIALTY SOCKETS

Table 24 shows saturation by lamp shape and specialty features. As the data show, LED saturation in Massachusetts was highest among reflector (54%) and dimmable (55%) specialty applications. LED saturation for candelabra- (47%), globe- (34%), and bullet-shaped (4%) bulbs was lower.

Table 24: Saturation of Specialty Sockets by Bulb Type

Shape/Feature	# of Bulbs	LEDs	CFLs	Incandescents	Halogen
Reflector/Flood	2,539	54%	7%	15%	24%
Candelabra	1,833	47%	4%	49%	0%
Globe	764	34%	6%	59%	1%
Bullet/Torpedo	488	4%	0%	0%	96%
Dimmable	1,222	55%	4%	24%	17%
3-way	481	46%	24%	27%	4%

* Rows do not sum to 100%; Fluorescent, "Don't know" and "Other" bulb types not shown.

Appendix D Penetration – Additional Detailed Analysis

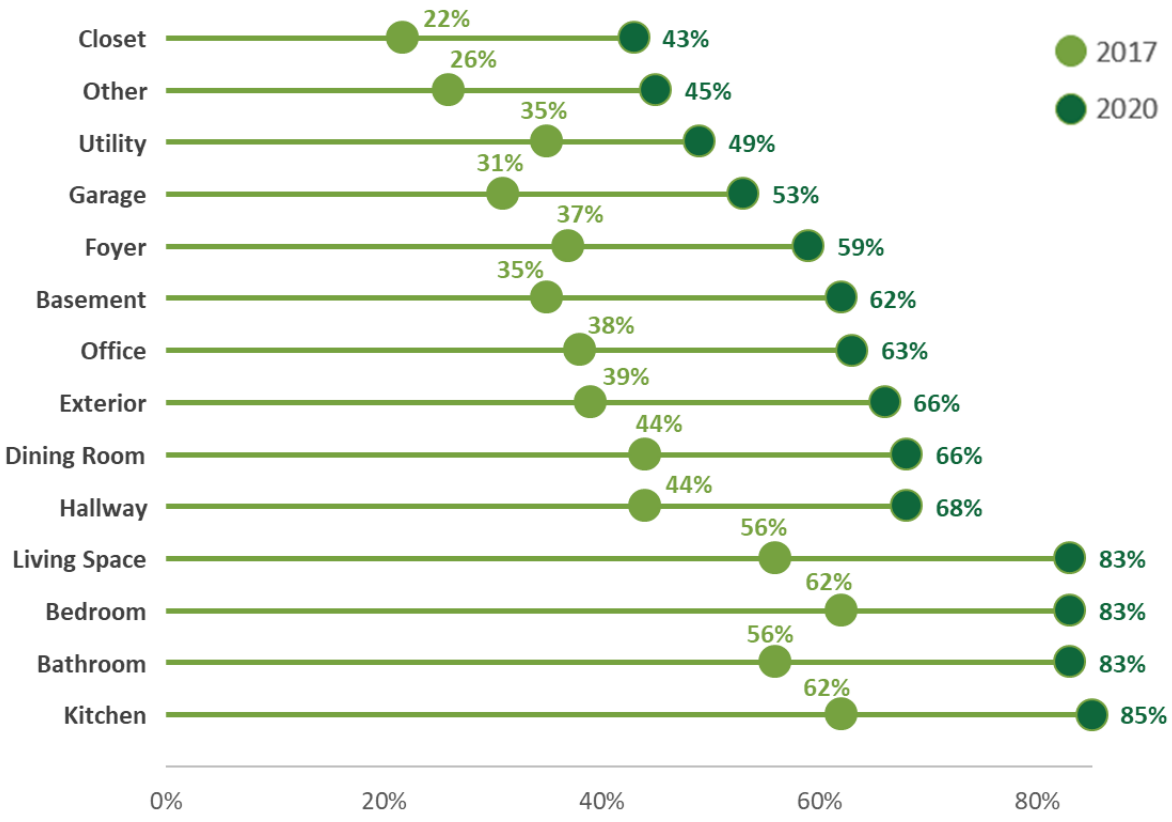
In this appendix, we expand on findings from Section 3. We show penetration for all bulb types; present additional room-by-room penetration figures for LEDs, CFLs, and incandescent and halogen bulbs; and explore reasons why householders do not have efficient bulbs installed in any of the five main room types (living rooms, bedrooms, bathrooms, kitchens, and dining rooms).

D.1 Room-By-Room Analysis – Detailed Analysis

LED Penetration

While Figure 10 compares LED penetration in 2017 and 2020 for selected room types, Figure 24 shows details for LED penetration in 2017 and 2020 for all room types. LED penetration increased in all room types since 2017. The biggest jump in LED penetration since 2017 occurred in bathrooms (56% to 83%), exteriors (39% to 66%), and basements (35% to 62%).

Figure 24: LED Penetration by Room Type, 2017 + 2020



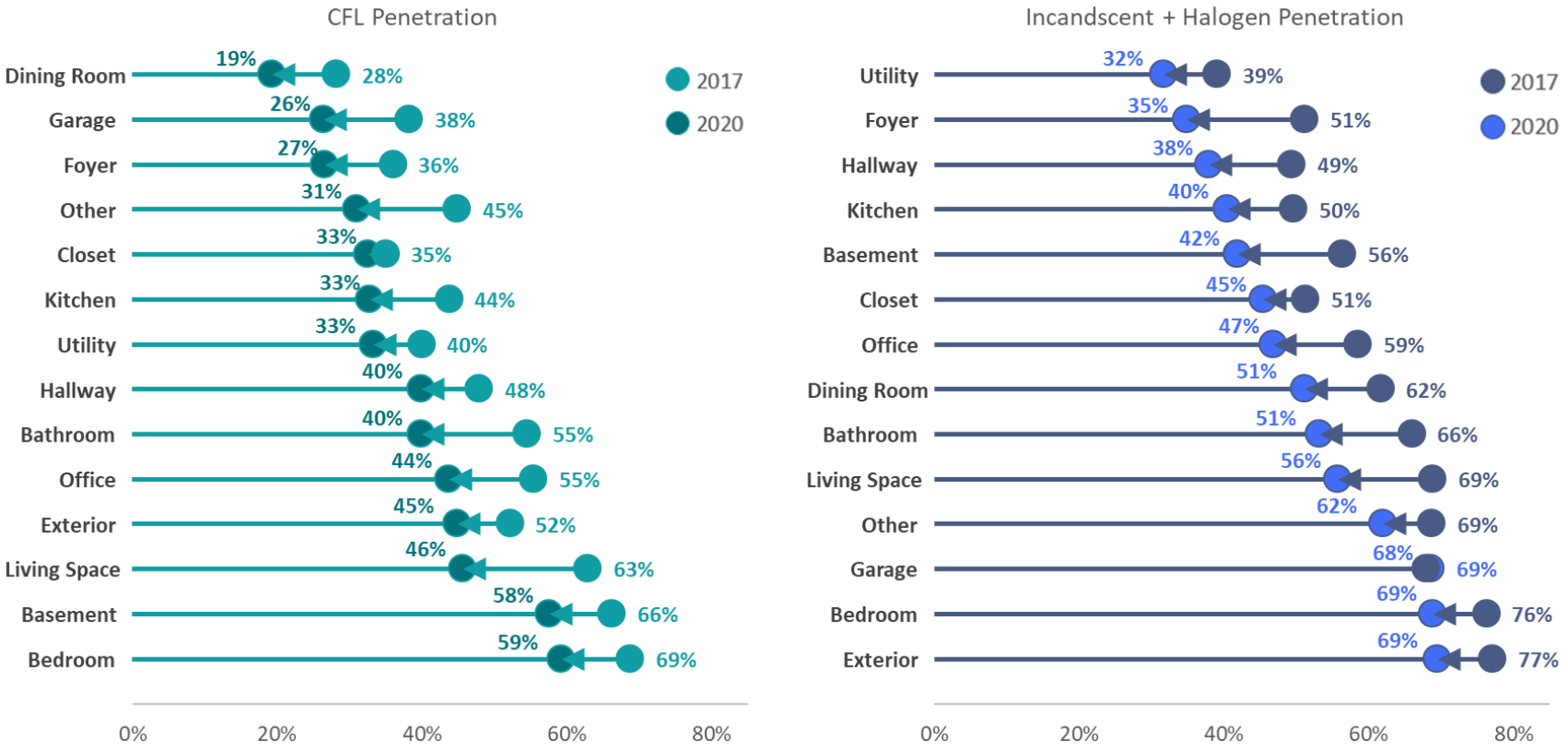
CFL Penetration

CFL penetration declined in all room types since 2017. Penetration in living spaces dropped the most (seventeen percentage points), followed by bathrooms (15 percentage points) and other room types (fourteen percentage points). CFL penetration was highest in bedrooms (59%) and basements (58%). The least common place to find a CFL (19%) was in dining rooms (Figure 25). This drop in penetration is in line with a steady decline in CFL saturation and is expected to continue as CFLs begin to exit the market.

Incandescent + Halogen Penetration

Inefficient bulb (incandescent and halogen) penetration has shown a general decrease over the past few years, which is in line with the decrease in inefficient bulb socket saturation. The biggest drop in inefficient bulb penetration since 2017 was seen in foyers (51% to 35%; 16 percentage points) and basements (56% to 42%; 15 percentage points) (Figure 25).

Figure 25: CFL and Incandescent + Halogen Penetration by Room Type, 2017 + 2020



D.2 ROOMS WITHOUT ENERGY-EFFICIENT BULBS

While on site, technicians identified if any of the five main room types (kitchens, living spaces, bedrooms, bathrooms, and dining rooms) did not have any LEDs or CFLs installed. As observed in the 7-Year Panel, in RES1 Baseline households in 2020, dining room was the most common room type without an LED or CFL (20%)(Table 25).[19]

Table 25: Rooms Without Energy-Efficient Bulbs

(Base: Respondents without CFLs/LEDs installed in certain rooms, excluding homes without that specific room type)

Room Type	7-Year Panel			RES1 Baseline
	2017	2018	2019	2020
Sample Size	*465*	*381*	*330*	*301*
Dining Room	47%[bcd]	36%[acd]	29%[abd]	20%[abc]
Bathroom	22%[cd]	18%[cd]	13%[ab]	13%[ab]
Kitchen	30%[bcd]	19%[ad]	16%[a]	12%[ab]
Living Space	17%[cd]	14%[cd]	10%[ab]	9%[ab]
Bedroom	14%[cd]	11%[d]	10%[a]	7%[ab]

[a] Significantly different from 2017 (7-Year Panel) at the 90% confidence level.
[b] Significantly different from 2018 (7-Year Panel) at the 90% confidence level.
[c] Significantly different from 2019 (7-Year Panel) at the 90% confidence level.
[d] Significantly different from 2020 (RES1 Baseline) at the 90% confidence level.

For rooms where no LEDs or CFLs were installed, technicians asked the householder why they did not have any efficient bulbs installed. Respondents could indicate multiple responses per room type. The reasons provided by RES1 Baseline households are summarized in Table 26.

The most common response given for not yet having installed an efficient bulb in a particular room type was that the householder planned to install an efficient bulb but had not yet done so (45%). Other common reasons were that they did not have any CFLs/LEDs (33%), the current bulbs had not burned out (32%), or CFLs/LEDs did not fit (20%).

[19] Since dining rooms were not present at all sites, this figure represents the number of households with no efficient bulbs in their dining room out of households with a dining room.

Table 26: Reasons for Not Installing Energy-Efficient Bulbs

(Base: Respondents without LEDs/CFLs installed in at least one of five rooms; living space, bedroom, bathroom, kitchen, and dining room)

Reason	RES1 Baseline
Sample size	*301*
Homes with no CFLs/LEDs in at least one room type	*96*
I have not installed CFLs/LEDs but plan to	45%
I do not have any CFLs/LEDs	33%
Current bulbs have not burned out	32%
CFLs/LEDs did not fit	20%
I do not like CFLs/LEDs	9%
Management/landlord installs bulbs	8%
CFLs do not work with dimmer/3-way	6%
Fixture requires specialty bulbs	2%
DK/Other	11%

*Multiple responses recorded; does not sum to 100%.

Appendix E Bulb Replacement Behavior

In this appendix, we expand on findings from Section 4. We compare average bulb replacement between direct install and non-direct install households, explore replacement choices for empty sockets, and examine differences in bulb replacement behavior and all newly-installed bulbs across demographic groups.

E.1 Average Bulb Replacement by Household

Table 27 delves further into average bulb replacement by household. To examine the impact of direct-install participation on the results, we examined data separately for verified direct install participants. Because replacement bulbs are defined as those installed between our first visit in 2017 and this study's visit in 2020, this table considers direct install households as those that were verified to have participated in a direct install program in 2017, 2018, or 2019.[20] Households that participated in a direct-install program reported installing six more replacement bulbs (17.7), on average, than a household that did not participate in a direct install program (11.4). Direct install participants installed 14.9 replacement LEDs, compared to 6.5 in households that did not participate in a direct install program, and 8.6 among panelists overall.

Table 27: 2020 Panel Replacement Bulbs

	Direct Install (Verified)	Non-Direct Install	Overall
Panel Households	*54*	*145*	*199*
Households replacing bulbs	*52*	*138*	*190*
% Replacing Bulbs	*96%*	*95%*	*95%*
Overall	17.7	11.4	13.0
LED	14.9	6.5	8.6
CFL	1.3	1.5	1.4
Incandescent	0.9	2.0	1.7
Halogen	0.2	0.6	0.5
Fluorescent	--	0.1	0.1
Empty Socket	0.4	0.6	0.6

[20] 54 households were verified to have participated in a direct install program in 2017, 2018, or 2019; however, we only observed replacement bulbs in 52 of these homes. The discrepancy could be due to the program intervention occurring in early 2017 before we first visited the home or in late 2019 after the on-site visits were complete.

E.2 EMPTY SOCKETS

Overall, 2% of all sockets in panel households were observed to be empty in both 2017 and 2020. Sockets in Table 28 were either empty in 2017 and were filled with a bulb as of 2020 ("bulbs that replaced empty sockets") or contained a bulb in 2017 that was removed before the 2020 visit ("empty sockets replaced the following removed bulbs"). LEDs were the most common type of bulb installed in empty sockets (72%), followed by CFLs (22%). Incandescents were the most common bulb type replaced by an empty socket (50%), followed by CFLs (33%).

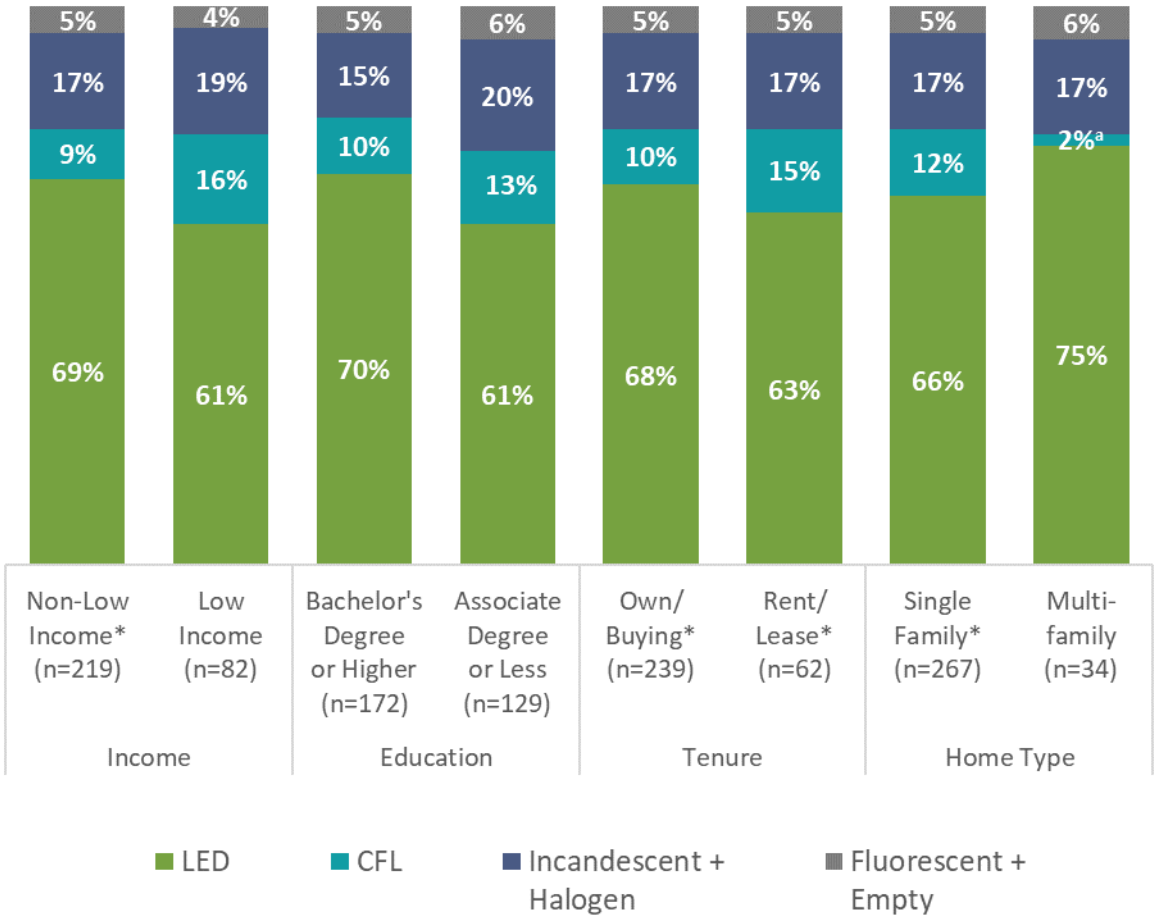
Table 28: Empty Sockets, 2017-2020

Bulb Type	Bulbs that replaced empty sockets:	Empty sockets replaced the following removed bulbs:
Total Empty Sockets 2018	*130*	*115*
% of Total Replaced Bulbs	*5%*	*5%*
Incandescent	19%	50%
CFL	22%	33%
Fluorescent	12%	5%
Halogen	2%	9%
LED	72%	7%

E.3 Bulb Replacement Behavior by Demographic Variables

We explored replacement behavior by education, income, home type, and tenure to determine if replacement behavior varied by demographic characteristics (Figure 26). In previous years, we observed that highly educated householders, non-low-income householders, homeowners, and householders in single-family dwellings were more likely than others to install replacement LEDs. However, among this panel, the only difference in replacement behavior we observed was between home types: multifamily households installed fewer CFLs as replacement bulbs (2%) than single-family households (12%). Because we did not find high levels of LED replacement due to direct install participation (see Table 30), this finding likely means that multifamily households are *catching up* to single-family households in LED adoption.

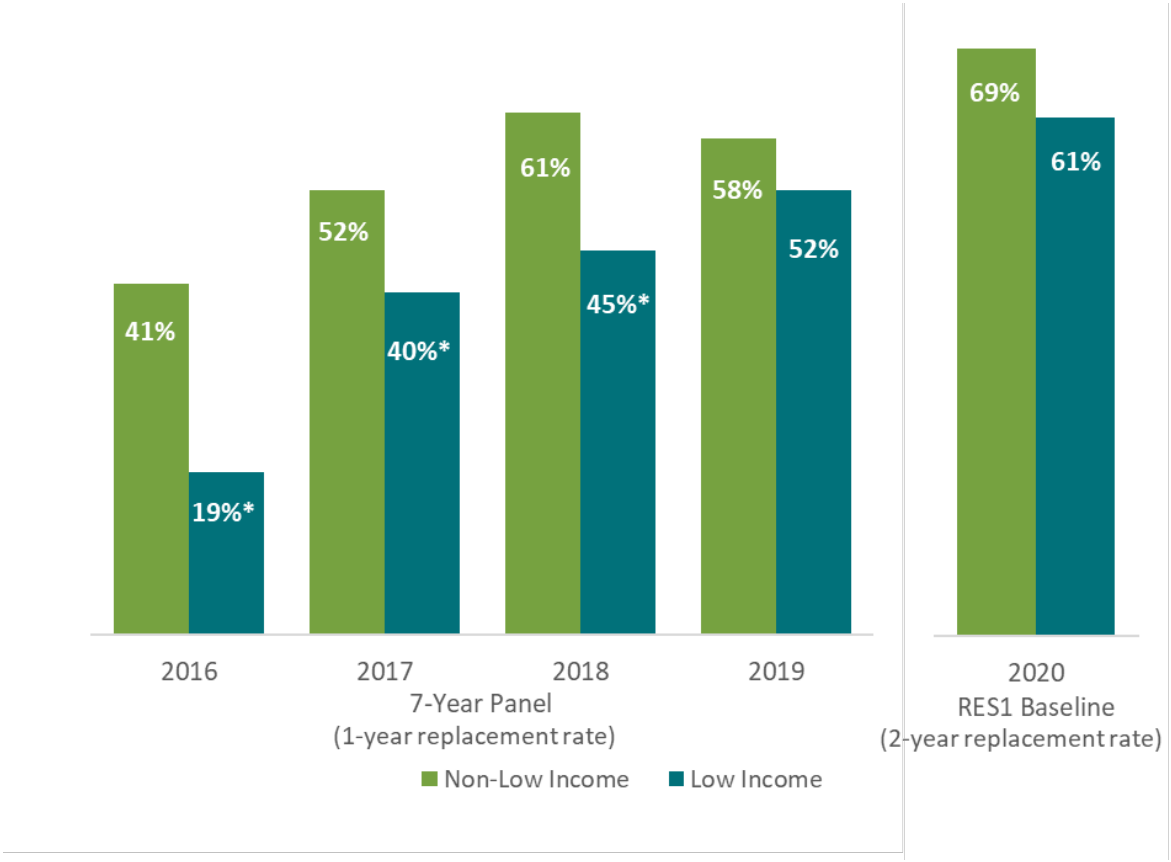
Figure 26: Replacement Bulbs by Demographic



[a] Significantly different from Single Family at the 90% confidence level.
*Includes <1% "don't know" bulbs.

Figure 27 shows that non-low-income households installed more LEDs as replacement bulbs than low-income households from 2016-2020. However, the gap between these rates appears to be closing, as evidenced in both the 2019 7-Year Panel data and the 2020 RES1 Baseline data.

Figure 27: LED Replacement Behavior by Income, 2016-2020 *Significantly



*Significantly different from Non-Low Income at the 90% confidence level.

E.4 NEWLY INSTALLED BULBS

Table 29 shows bulbs in 2020 that had been newly installed in Massachusetts panel households since the previous visit in 2017. The *Replacement (no empty)* column shows the bulbs that were newly installed in sockets since the previous visit, excluding sockets where a bulb was removed but had not yet been replaced (empty sockets). The *new fixtures* column comprises bulbs in fixtures (and sockets) that are new to panel households in 2020. *Total* examines replacement bulbs and bulbs in new fixtures together.

More than two-thirds (70%) of all bulbs installed since 2017 were LEDs. For each bulb type, a similar proportion of bulb types were installed in new fixtures as were installed as replacements for existing fixtures (e.g., 72% of all bulbs installed in fixtures that were new to the house were LEDs, similar to the proportion of LEDs installed as replacement bulbs in existing fixtures [69%]). It is important to note that the most recent data covers a two-year replacement period and the increase in newly installed LEDs might be conservative compared to a hypothetical estimate of bulbs replaced in 2020 only.

Table 29: Newly Installed Bulbs in RES1 Households

Bulb Type	Replacement (No Empty)	New Fixtures	Total
Households Replacing Bulbs	*189*	*147*	*192*
Bulb Count	*2,472*	*791*	*3,263*
LED or CFL	**81%**	**81%**	**81%**
LED	*69%*	*72%*	*70%*
CFL	*12%*	*9%*	*11%*
Incandescent or Halogen	**18%**	**17%**	**18%**
Incandescent	*14%*	*14%*	*14%*
Halogen	*4%*	*3%*	*4%*
Linear Fluorescent	1%	2%	1%

Appendix F LED Purchases and Satisfaction

In this appendix, we show the sources of new bulbs in the home by income and home type, expanding the analysis first reported in Section 5. In addition, we provide the full-length tables (including "neither satisfied nor dissatisfied," "somewhat dissatisfied," and "very satisfied") for information presented in Table 11 and Table 12 In Section 7.

F.1 Sources of Bulbs by Income and Home Type

If a technician recorded an LED as new to the home in 2020 (not observed during the 2017 visit), they asked householders when they purchased or received the bulb. For bulbs purchased or received in 2020, the technician asked the householder where they had purchased the bulb. Table 30 shows these responses broken out by income and home type. In 2020, low-income households purchased and/or received more LEDs (14.3), on average, than non-low-income households (11.3). Single-family households reported obtaining an average of 12.5 bulbs per household compared to 8.8.[21] Low-income households were more likely to have purchased their LEDs at mass merchandise stores (such as Walmart or Target) than non-low-income households (34% and 7%, respectively) and non-low-income households were more likely to have purchased their LEDs online (12%) or at hardware stores (8%) than low-income households (0% for both retail channels). Multifamily households were more likely to have purchased LEDs at mass merchandise stores (36%) than single-family households (15%). Furthermore, multifamily households did not recall receiving any LEDs from Mass Save, while single-family households reported that one-third of their LEDs (33%) were installed through the program.[22]

[21] Single-family households are generally larger than multifamily units and have more sockets to fill.
[22] Single-family households reported that an additional 11% of their LEDs were obtained through Mass Save, but we were unable to verify their program participation.

Table 30: LEDs Obtained by Demographic (Panel Households Only)

(Base: All LED bulbs obtained in panel households)

Bulb Source		Income		Home Type	
	All	Low-Income	Non-Low-Income	Multifamily	Single-Family
Sample Size	*199*	*51*	*148*	*25*	*174*
Households with new LEDs	*58*	*17*	*41*	*6*	*52*
Bulbs Obtained	**704**	**240**	**464**	**53**	**651**
Avg # Obtained	**12.1**	**14.1**	**11.3**	**8.8**	**12.5**
Mass Save – DI Verified Participation	30%	31%	30%	--[b]	33%
Mass Save – DI Unverified Participation	10%	6%	13%	--[b]	11%
Home Improvement	19%	21%	18%	--[b]	21%
Mass Merchandise	16%	34%[a]	7%	36%[b]	15%
Online	8%	--[a]	12%	7%	8%
Hardware	5%	--[a]	8%	--[b]	6%
Grocery	1%	1%	<1%	--	1%
Discount	1%	2%	--	--	1%
Other	1%	--	1%	--	1%
Don't Know	9%	6%	11%	57%[b]	5%

[a] Significantly different from Non-Low-Income at the 90% confidence level.
[b] Significantly different from Single-Family at the 90% confidence level.

F.2 LED SATISFACTION

As discussed in Section 7, RES1 Baseline respondents said that they were "very satisfied" or "somewhat satisfied" with almost all of their LEDs (94%). This section also provides more detail on respondents who voiced lower levels of satisfaction. (Table 31)

Table 31: LED Satisfaction

(Base: Respondents with at least one LED installed in the home)

Level of Satisfaction	ENERGY STAR LEDS	Non-ENERGY STAR LEDS	Don't know	All LEDs
Number of Bulbs	*4,292*	*491*	*1,367*	*6,151*
Very Satisfied	82%	77%	78%	81%
Somewhat Satisfied	11%	15%	17%	13%
Neither Satisfied nor Dissatisfied	6%	9%	4%	5%
Somewhat Dissatisfied	1%	<1%	1%	1%
Very Dissatisfied	0%	0%	0%	0%

* "Don't know" satisfaction responses excluded from analysis.

If a householder was "somewhat dissatisfied" or "very dissatisfied" with a type of LED bulb in their home, technicians asked them why (Table 32). This subset of respondents was small, representing four homes with about 60 installed bulbs. Reasons cited for LED dissatisfaction were that the LEDs were too bright or had poor lighting quality. One participant had a health condition that led to dissatisfaction with the LEDs installed in that home, but this person cited this condition for dissatisfaction with numerous bulbs.

Table 32: Reasons for LED Dissatisfaction

(Base: Respondents reporting they were "somewhat dissatisfied" with an LED [no "very dissatisfied" responses])

Reason	RES1 Baseline 2020
Number of Bulbs	*60*
Health Condition	61%
Too Bright	28%
Poor Lighting Quality	11%

RES1 Baseline households were very or somewhat satisfied with approximately nine out of ten LEDs of all bulb shapes in 2020. Respondents were neither satisfied nor dissatisfied with one out of ten (11%) globe shaped LEDs. (Table 33)

Table 33: LED Satisfaction by Bulb Shape*

(Base: Installed LED bulbs or recessed cans)

Level of Satisfaction	A-Line	Reflector	Candelabra	Globe	Linear Tube	Other
Number of Bulbs	*3,652*	*1,314*	*776*	*256*	*20*	*132*
Very Satisfied	82%	79%	81%	83%	100%	76%
Somewhat Satisfied	12%	16%	14%	7%	0%	11%
Neither Satisfied nor Dissatisfied	6%	5%	4%	11%	0%	8%
Somewhat Dissatisfied	1%	1%	1%	0%	0%	5%
Very Dissatisfied	0%	0%	0%	0%	0%	0%

* "Don't know" satisfaction responses excluded from analysis.

Appendix G Storage

Incandescents were the most common bulb type found in storage overall (42%) and across income types. In multifamily households, there were more LEDs in storage (37%) than incandescents (32%). However, there were no statistically significant differences in storage behavior between demographic groups compared in Table 34.

Table 34: Stored Bulbs by Income and Home Type

Bulb Source	All	Income		Home Type	
		Low-Income	Non-Low-Income	Multifamily	Single-Family
Sample Size	*297*	*80*	*217*	*34*	*263*
Total Stored Bulbs	*5,250*	*1,169*	*4,080*	*493*	*4,756*
Avg. # of Stored Bulbs	**17.7**	**14.6**	**18.8**	**14.5**	**18.1**
Incandescent	42%	46%	41%	32%	43%
LEDs	32%	26%	34%	37%	31%
CFLs	18%	22%	17%	25%	17%
Halogen	7%	6%	8%	5%	8%
Fluorescent	1%	1%	1%	<1%	1%
Other**	<1%	0%	<1%	0%	<1%

[a] Significantly different from Non-Low-Income at the 90% confidence level.
[b] Significantly different from Single-Family at the 90% confidence level.

For bulbs found in storage, on-site technicians asked participants their reason for storing each bulb. Nearly all (96%) LEDs were in storage for future use (Table 35).[23] At least two-thirds of CFLs, halogens, and linear fluorescents were also stored for future use. However, participants expected to use only one-half (54%) of stored incandescents. Again, we remind the reader that technicians may have mis-identified halogens and incandescents.

Table 35: Reason for Storage by Bulb Type

Reason for storage	All	LED	CFL	Incan-descent	Halo-gen	Fluo-rescent	Other/ DK
Total Stored Bulbs	*5,250*	*1,567*	*956*	*2,274*	*406*	*42*	*6*
For future use	71%	96%	70%	54%	69%	88%	0%
Do not plan to use	14%	1%	17%	23%	16%	2%	0%
Don't know	8%	2%	8%	11%	10%	10%	100%
Plan to throw out/recycle	7%	<1%	5%	13%	5%	0%	0%

[23] NMR removed four households from the stored bulb analysis because we identified them as outliers. These households they had an average of 186 bulbs in storage, 84% of which were incandescents. By comparison, in the other 297 households, 42% of stored bulbs were incandescent. Although we did not directly ask participants whether they were stockpiling incandescents in response to EISA, this assumption is supported by the data. More than four out of every five (81%) incandescent bulbs in storage in outlier households were being stored for future use, a large contrast to the 54% being stored for future use in non-outlier households.

Appendix H Demographics

Massachusetts census data comes from the 2018 ACS five-year estimates. Throughout the demographic section, NMR has tested for significant differences across samples using a two-tailed t-test. Significance is indicated in Figure 28 and discussed below.

On-site visits for the 2020 RES1 Baseline significantly differed from the ACS five-year estimates on several key demographic variables, including home type, tenure, education, age, and age of home.

Home Type: Nine out of ten (89%) on-site participants lived in single-family homes, which is significantly different from the Massachusetts 2018 ACS five-year estimates (79%).

Income: Nearly three-quarters (73%) of on-site participants were non-low-income, while just over one-quarter (27%) identified as low-income. This is similar to the Massachusetts 2018 ACS five-year estimates, which show that 70% of Massachusetts households are non-low-income.

Tenure: Four out of five (79%) on-site participants own their homes, which is significantly higher than the ACS five-year estimates (62%).

Education: More than one-quarter (28%) of on-site participants had attained an advanced or graduate degree, which was significantly higher than the state-wide ACS estimates for that category (19%). Fourteen percent of on-site participants had attained a high school degree or GED, which was significantly lower than the state-wide ACS estimates for that category (24%).

Age: On-site participants differed significantly from the ACS in three age groups: 18-30 (5% vs. 22%), 50-59 (23% vs. 18%), and 60-69 (22% vs 14%).

When Home Built: The build year of on-site homes were similar to those in the ACS. The only significant difference between the two groups was in homes built in the 1930s or earlier, which accounted for 33% of homes in the ACS estimates and 22% of homes in the on-site visits.

Figure 28: Comparison of 2020 RES1 Baseline with Census