MA C&I MARKET CHARACTERIZATION ON-SITE ASSESSMENTS AND MARKET SHARE AND SALES TRENDS STUDY

Volume I – Main Report

Massachusetts Program Administrators Research Team and Energy Efficiency Advisory Council EM&V Consultants

Date: November 2016
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EXECUTIVE SUMMARY

The DNV GL team, made up of DNV GL, Itron, Inc., APPRISE, Inc., ERS, Inc., and NMR, undertook the Massachusetts Commercial and Industrial (C&I) On-site Assessments and Market Share and Sales Trends (MSST) Study to help the Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) better understand the Commonwealth’s existing C&I building and equipment stock, and to identify the greatest opportunities for expanding the statewide energy efficiency program portfolio and encouraging Massachusetts businesses to make further energy efficiency improvements.

To complete this study effort, the DNV GL team conducted comprehensive on-site assessments of C&I buildings associated with 800 electric accounts. The buildings were of 13 different business types, including the most complex facility types in the market—hospitals, college campus buildings, manufacturing facilities, and professional sports venues (see Table 1).

Our sample was divided into 3 electric consumption categories1 for each business type: < 500,000 kWh, 500,000-4,500,000 kWh, and > 4,500,000 kWh. We collected data on 9 distinct equipment types at each of the 800 sites2, and surveyed a total of 43,420 individual pieces of end-use equipment and 1,592 industry-specific pieces of equipment, each with their own set of variables.3 The study collected information on the highest priority electric and non-electric-fueled end uses, including lighting, heating, ventilation, air conditioning (HVAC), refrigeration, and domestic water heating systems.4 We also summarize findings for kitchen equipment, office equipment, energy management system (EMS) equipment, and on-site generation systems. For process-related equipment we provide information on compressed air systems, process heating, process refrigeration/cooling, injection molding machines, wastewater treatment systems, motors/drives, and others. As part of the MSST Study, we also present recent (2009-2015) purchase information for lighting, HVAC, water heating, and EMS, and assess sales trends and market shares for recently purchased standard and high-efficiency equipment for these equipment types.

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1 Consumption is based on electric billing data and does not include net metering or on-site electricity production from on-site photovoltaics
2 Sites are defined according to customer accounts. The portion of a building or business served by an electric account would be considered the “Site”
3 Variables included systems’ age, condition, and efficiency levels as well as information on building operating practices.
4 High-priority end uses were identified through stakeholder feedback and annual energy efficiency program savings.
Table 1: Number of on-site visits completed by business type (not weighted\textsuperscript{5})

<table>
<thead>
<tr>
<th>Business type\textsuperscript{6}</th>
<th>On-sites completed</th>
<th>Share of completed on-sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>4%</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>10%</td>
</tr>
<tr>
<td>Food sales</td>
<td>47</td>
<td>6%</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>8%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>8%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>3%</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>8%</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>10%</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>15%</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>7%</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>9%</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>9%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>4%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

As part of the data collection efforts, the DNV GL team inventoried vital business and equipment information to the extent possible, including equipment make and model data. Teams of analysts used make and model data to conduct desktop research in order to correlate all the make and model data collected with equipment efficiency, wattage, and/or size information.

To conduct the analysis, the DNV GL team created a sophisticated set of 96 distinct weights to expand the 800-site sample to the total Massachusetts electric customer population. In summing up 32 building equipment categories (such as internal lighting and external lighting) by size, business type, and kWh usage, these weights achieved a level of precision and bias-elimination superior to traditional weighting approaches, which merely compute a single weight to relate the sample data back up to the population.

To assess the distribution of equipment efficiencies across the state, we researched the federal efficiency standards and lighting information from the Consortium of Energy Efficiency and gathered information about the PA Energy Efficiency Program incentive standards. We collected the information necessary to evaluate and classify each of the different measures (lighting, cooling, heating, and water heating) according to federal standards (at, below, or above), by fuel, unit size, and technology type. We then compiled the information on federal standards, purchase date, fuel type, technical specifications, customer size, and program participation in a meaningful format so that readers could see trends and act on them.

The body of this report presents the results of the C&I On-Site Assessments and MSST Study. It also includes information on PA-sponsored program eligibility requirements relative to installed equipment efficiencies to highlight where opportunities for savings remain, where PAs may need to adjust programs to

\textsuperscript{5} The distribution of the sample size at the business type level was selected to be representative of the C&I population based on PA billing data. The results of the analysis at the business type level were ultimately weighted up to be representative of the total number of businesses in that category; however, this may differ from the actual population of these types of customers in MA.

\textsuperscript{6} Business type categories are defined similarly to the categories used for the U.S. Energy Information Administration’s (EIA) Commercial Buildings Energy Consumption Survey (CBECS) with minor modifications. See [http://www.eia.gov/consumption/commercial/building-type-definitions.php](http://www.eia.gov/consumption/commercial/building-type-definitions.php)
propel the market further forward, and where PAs may need to introduce programs or improve education to help motivate Massachusetts businesses to purchase more high-efficiency technologies.

The findings in this report allow for a deep, nuanced understanding of C&I customer equipment stock efficiency, behaviors, and areas for potential energy efficiency improvements throughout Massachusetts. These findings will also be used for other ongoing and future study efforts, including the enhanced C&I Customer Profile and the Assessment of the Share of Incentivized High Efficiency Equipment.

SUMMARY OF RESULTS AND KEY OBSERVATIONS

This section summarizes our key findings, either as unweighted estimates or as estimates weighted by number of businesses (respondent weight) or by kWh usage, and presents high-level results and observations.

C&I customer electric energy usage

The customer information section of this report includes information on annual electricity consumption, square footage, energy use intensity (EUI), and building and business age. The data show that manufacturing and industrial businesses consume more electricity than any of the other 13 Massachusetts business types, and account for 19% of the electricity consumed by Massachusetts businesses. Other businesses consuming a large share of electricity in Massachusetts include offices (16%) and retail establishments (12%). The share of electricity consumption can be compared to the distribution of number of businesses. Manufacturing and industrial businesses account for only 3% of Massachusetts businesses in the sample population, while office and retail represent 25% and 28% of businesses, respectively.

The energy usage of businesses can also be compared to regional data using an electric EUI, which is the ratio of electricity consumption to floor square footage. For this study, we calculated EUIs by both business type and annual electricity consumption category. In Massachusetts, businesses with larger annual electricity consumption had a higher average EUI. Businesses consuming more than 4,500,000 kWh annually had an average EUI of 29 kWh/square foot; businesses consuming 500,000 to 4,500,000 kWh had an average EUI of 15 kWh/square foot; and businesses consuming less than 500,000 kWh had an average EUI of about 5 kWh/square foot.

Massachusetts businesses with the highest EUIs were food sales and food service businesses, followed by manufacturing and industrial businesses and hospitals. Business with the lowest EUIs were education, other,7 and public assembly businesses. We found that average EUIs by business type in Massachusetts tend be lower than the regional average from the 2012 Commercial Buildings Energy Consumption Survey (CBECS), except for hospitals and warehouses.

Lighting

Lighting is one of the largest sources of energy consumption for many business types. The lighting data collected through the C&I Customer On-site Assessments provide information on the interior and exterior lighting types and the controls found within the different business types and sizes, as well as information on

7 “Other” includes agriculture-based businesses, airplane hangars, crematoriums, laboratories, data centers, etc.
efficiency of the current stock of lighting technologies. The MSST Study provides information on purchasing trends in the current lighting market. Our estimated lighting findings include:

- Office and retail segments have the largest number of lamps overall.
  - The number of linear lamps in office or retail businesses is larger than the total number of lamps in any other individual segment. Offices in Massachusetts have slightly more than 10 million linear lamps, while retail has slightly fewer than 10 million linear lamps.
  - Office and retail businesses each have more than half a million of both CFL and LED lamps.8
- Lodging and public assembly segments have the largest number of CFLs: lodging has over 2 million, and public assembly has over 1.5 million.
- Food service and public assembly have the largest number of incandescent bulbs.9
  - Over half of the bulbs in food service businesses are incandescent, for a total of nearly 1.5 million incandescent bulbs.
  - Public assembly businesses have over 1 million incandescent bulbs.
- LED lamps have a growing presence in Massachusetts businesses.
  - Offices, retail, lodging, public assembly, other, and food service all have over a half million LED lamps installed.

The DNV GL team found that substantial improvements in lighting efficiency have been made in Massachusetts businesses. This is evidenced by the reduced share of base efficiency linear options, such as T12 and 700-Series T8 lamps, in recent purchase data as well as the reduced share of CFLs in the ICLH (incandescent, CFL, LED, and halogen) technologies relative to the overall existing lighting stock. The data show that CFL purchases have been replaced by LED purchases. Massachusetts businesses are also increasingly purchasing linear LEDs, the most efficient lighting option, to replace linear fluorescents.

Nevertheless, many business segments still have a large share of base efficiency linear lighting technologies (T12 and 700- and 800-Series T8s).10 The five business types with the highest share of base efficiency linears are offices, retail, education, other, and public assembly. PA-sponsored programs should examine these findings closely and assess whether or not to target information and incentive programs at these business types to encourage the replacement of inefficient linears with Tier 2 fluorescent and TLED lamps. Additionally, incandescent bulbs still have a 49% share in the recent (2009-2015) purchase data, and were often found in the food service and public assembly segments. PA-sponsored programs should encourage the replacement of incandescent bulbs with LED alternatives.11 This could yield particularly impressive savings in the food service sector, where lighting hours of use can be substantial; however, it should be noted that the location of the incandescent lamps was often not captured, and LED use may be limited by the space the lamps serve.12 PA-sponsored energy efficiency programs should also continue to promote Tier 2 LED lamps, and to educate customers on the benefits of these lamps relative to older 800-Series T8 lamps.

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8 This statement refers to A-line LEDs. Linear LEDs are included in the linear lamps.
9 It should be noted that it can be difficult to distinguish the new A-line halogens from incandescents during visual inspections.
10 Federal standards largely eliminated the production of T12 and 700-Series T8 in 2012, making 800-Series T8s the base efficiency option going forward.
11 However, it should be noted that for some refrigeration applications, fluorescents and LEDs are not appropriate due to because of low air temperatures.
12 The Massachusetts TRM does not list lighting hours of use by business type, instead stating that LED lives are 10-13 years (see http://ma-eeac.org/wordpress/wp-content/uploads/TRM_PLAN_2013-15.pdf. The New York TRM lists the lighting hours per year for a food service establishment as 4,182 to 6,456. This is one of the longer hours of use in the New York TRM (see
Lighting controls

The field data collection and analysis of lighting controls yielded the following findings:

- 77% of the existing stock of interior lighting is manually controlled by simple wall switches, and 70% of interior lamps purchased since 2009 are manually controlled or controlled by a switch.
- Photo cells, time clocks, or photo cells with time clocks are used to control 33% of the existing stock of interior incandescent lamps and 13% of high-intensity discharge (HID) lamps. Of interior lamps purchased since 2009, 30% of incandescents and 50% of HIDs are controlled by photo cells, time clocks, or photo cells with time clocks.
- Since lighting controls have the potential to substantially reduce customer lighting electricity usage, significant energy savings may be achievable by converting a larger share of lighting from manual to electronic control.

HVAC systems

HVAC systems represent a significant portion of energy use and peak demand within the C&I sector. The C&I Customer On-site Assessments collected extensive field data on HVAC systems, from which it will be possible to measure progress toward improved HVAC efficiency in the C&I sector. The MSST Study’s analysis of HVAC system purchases from 2009-2015 includes information on these systems’ efficiency.

The majority of businesses in Massachusetts are cooled by split and packaged cooling systems. Many businesses also have smaller window/wall or packaged terminal air conditioner (PTAC) units. Chillers are used in fewer businesses (1%) but account for cooling across approximately 20% of business square footage. The efficiency analysis of split and packaged systems in Massachusetts businesses found that 30% of the existing stock of units are above standards, while 53% of recent purchases were above standards. The substantial share of high-efficiency purchases applied to most sized systems, though limited evidence indicates that medium-sized commercial units (135-239 kBtuh) were less commonly purchased above standards.

Nearly 40% of cooling units in Massachusetts businesses are PTAC and window/wall units. These units average 1.2 tons and are designed to cool either a room or a relatively small area. These units were largely found in campuses, lodging, and hospitals. PA-sponsored programs do not currently offer commercial rebates for high-efficiency PTAC and window/wall units under the prescriptive program, but these measures can receive incentives as custom retrofit projects. Given the prevalence of these units, the PAs may want to explore offering incentives for high-efficiency versions of these units.

The majority of Massachusetts businesses heat their facilities using furnaces. Boilers and furnaces are both crucial to heating business area; these technologies often heat facilities individually and in combination with each other or other equipment. Boilers and furnaces were both found as heating choices in more than 50% of business square footage. The DNV GL team’s efficiency analysis of recently purchased of split and packaged heating systems found that the majority of small furnaces in Massachusetts businesses exceed the federal standard of 78 AFUE. Many small furnaces, 25%, in Massachusetts exceed the 95 AFUE requirement to receive a program incentive. Where cost-effective, PA-sponsored programs should continue to focus on increasing the adoption of extremely high-efficiency options.
During the analysis of make and model information for small furnaces, the DNV GL team found that many of these systems publish their efficiency information in units of thermal efficiency or steady state efficiency. The units for the federal efficiency standards, however, are annual fuel utilization efficiency (AFUE). Working to ensure that manufacturers are aware of federal standards and the units associated with these standards will help to clarify system efficiency for Massachusetts customers seeking to purchase high-efficiency systems.

While nearly all recently purchased small furnaces and water-source heat pumps were found to be above federal efficiency standards, most of the recently purchased large furnaces were found to be at standards. Standards for large furnaces were implemented in 2004. PAs should look into the need and potential for developing cost-effective programs to educate consumers and encourage the installation of high-efficiency large furnaces.

The DNV GL team also found that approximately 50% of businesses are undertaking preventative maintenance. Preventative maintenance is more common among businesses with higher energy consumption, and reactionary maintenance is more common among businesses with smaller energy consumption. The PAs should consider additional outreach and education to help increase the share of businesses using regular preventative maintenance to improve HVAC efficiency.

Energy management systems

The study was designed to collect information on energy management systems (EMSs). EMS is a broad term that describes a network combining local distributed control with centralized coordination and management to monitor, control, and optimize energy usage throughout a business facility. Since much of the data reported in this study relates to the EMS equipment and controls, which are commonly referred to as building automation systems (BASs), these data are reported using the term BAS. The C&I On-site Assessments collected data on the existence and characteristics of EMSs in Massachusetts businesses.

The DNV GL team’s analysis of the EMS data found that:

- 277 out of the 800 businesses surveyed have a BAS.
- Approximately 50% of Massachusetts C&I electricity usage is associated with businesses using a BAS.
- Over 80% of business electricity consumption for businesses with more than 4,500,000 kWh annual usage is at businesses with a BAS; over 55% of consumption for businesses with 500,000 to 4,500,000 kWh is at businesses with a BAS; and approximately 10% of consumption for businesses with more than 500,000 kWh is at businesses with a BAS.
- BASs are associated with the highest portion of energy consumption in hospitals, education buildings and campuses, manufacturing and industrial buildings, offices, other, public assembly, and warehouses. BASs are associated with the lowest portion of energy consumption in food sales and retail businesses. The relatively low share of BASs in food sales and retail may represent a PA program opportunity.
- HVAC units and HVAC pumps/fans are the most commonly BAS-controlled end uses.
- A higher share of HVAC pumps/fans, indoor lighting, on-site generation, and process equipment is controlled with newer (post-2009) BASs than with older BASs.

Water heating

The C&I Customer On-site Assessments and the MSST Study document the share of different types of water heater systems, as well as the efficiency of these systems. Water heaters analyzed for this report are
grouped as standard storage, instantaneous or tankless, heat pump, boiler/central plant, or other. The field data indicate that little, if any, energy efficiency improvement has been made recently in water heaters for Massachusetts businesses. We found only 15% of existing water heaters and 10% of recently purchased water heaters to be above standards.

Improving the efficiency distribution of water heaters in Massachusetts businesses may require providing customers and trade allies with additional knowledge of the energy savings potential of high-efficiency systems. While PA-sponsored programs offer incentives for gas water heaters, the efficiency requirements for these incentives are substantially higher than federal efficiency requirements. While the federal efficiency requirements for many types of water heaters depend on tank capacity, program energy efficiency requirements do not factor in tank capacity. PAs may want to investigate the need to adjust the gas water heater energy efficiency program requirements in this regard.

The study found that more than 50% of the water heaters in Massachusetts businesses were electric. Storage water heaters were the dominant type of both electric and gas water heaters. The PAs may want to investigate the cost-effectiveness of offering an electric water heater program to encourage customers to install high-efficiency electric water heaters.

The study also found that a substantial share of water heaters being purchased by Massachusetts businesses are not covered by current federal standards. Many of the water heaters without applicable standards were both commercial- and residential-sized electric water heaters. The residential-sized electric water heaters were largely 2- to 20-gallon units commonly referred to as point-of-use water heaters. Preliminary data indicate that these units are increasingly being installed, and that they may be replacing larger sized electric units. Developing a better understanding of the energy consumption of units not currently covered by standards would help determine the energy usage of these units, in order to decide whether these units should be incorporated into future PA-sponsored energy efficiency programs.

### Refrigeration

Refrigeration systems represent a significant source of energy usage within the non-residential sector. Within select commercial segments, namely food sales, refrigerated warehouses, retail, and food service businesses, refrigeration usage accounts for a significantly higher share of whole business usage than for the average commercial customer.

Highlights of the field data collection and analysis include:

- Nearly all food sales and food services businesses have refrigeration equipment, and 70% of retail facilities have refrigeration equipment.
- The majority of linear feet of refrigerated cases were medium-temperature or refrigerated cases.
- 48% of refrigerated display cases had metal doors and 40% had double-glazed glass doors.
- T-12 lamps were present in over 40% of refrigerated cases in retail segments.
- Food service has many small-size walk-ins; warehouses and manufacturing each have fewer large walk-ins.
- Incandescent bulbs were present in over 50% of refrigerated cases and walk-ins across three building types, and had at least a 25% incidence in seven building types. Replacing incandescent lighting in
refrigerated cases and walk-ins with LED technologies represents a significant energy efficiency opportunity, since it can reduce usage associated with both lighting and refrigeration.\textsuperscript{13}

**Kitchen equipment and refrigerated vending machines**

The DNV GL team documented the saturation of kitchen equipment in Massachusetts businesses. Offices, food service buildings, and lodging buildings house 50\% of kitchen equipment. The types of equipment found in these three business types differ substantially. For office and lodging, microwaves and coffee machines represent over 50\% of the kitchen equipment. In food service, however, microwaves are only 10\% and coffee makers are only 11\% of kitchen equipment; ovens are 22\%; fryers are 13\%; ranges are 7\%; and other kitchen equipment is 11\%. The Massachusetts PA-sponsored kitchen equipment energy efficiency offerings are extensive. As expected, these programs are not focused on microwaves and coffee makers; they offer rebates for ovens, fryers, ranges, dishwashers, and other electric- and gas-fueled appliances. These programs should focus on improving the efficiency of kitchen equipment where this equipment is most commonly found: in food service, education, food sales, hospitals, and public assembly.

We also collected information on the number of refrigerated vending machines at Massachusetts business. The majority of refrigerated vending machines are found in office, retail, and education sites.

**On-site generation**

The DNV GL team collected information on the on-site generation equipment in use at Massachusetts non-residential facilities. Of the 800 sites surveyed, 340 had on-site generation, 313 had emergency/backup generation, 42 had renewable generation, 16 had co-generation, and 7 had non-power\textsuperscript{14} generation systems.

Our analysis of the on-site generation data led to several high level findings:

- For campuses, education, healthcare, hospitals, lodging, and offices in Massachusetts, on-site generation is fairly common. The largest share of on-site generation is for backup or emergency generation; the business types where on-site generation is most common likely represent segments where emergency generation is frequently required by regulation.
- Backup and emergency generation is fueled 65\% of the time by diesel and 28\% of the time by natural gas.
- Internal combustion engines (ICEs) account for 95\% of the backup or emergency generation in Massachusetts businesses. ICEs are a well-understood technology from both an engineering and a maintenance perspective, and provide a good backup source of power during emergencies.
- Solar accounts for 99\% of the renewable generation at Massachusetts businesses.
- In Massachusetts businesses, the average size of renewable generation is 101 kW; backup or emergency generation average capacity is 129 kW; and the average capacity for cogeneration is 458 kW.

**ONGOING PROJECT VALUE**

The C&I On-site Assessments is the largest evaluation study ever undertaken for the Massachusetts PAs. It was designed to collect verified on-site information and create a baseline for energy consuming equipment.

\textsuperscript{13} However, it should be noted that the location of the incandescent lamps was often not captured, and LED use may be limited by the space the lamps serve.

\textsuperscript{14} Non-power generation systems refers to those on-site generation systems that do not produce electricity (e.g. solar thermal, biomass boilers, etc.)
To complete the project, the DNV GL team employed innovative recruitment and sampling strategies, collected a wealth of data, conducted extensive research, and designed a sophisticated weighting system that can help guide Massachusetts energy efficiency programs for years to come.

It is one thing to collect data, conduct research, and perform data analysis on such a monumental scale. It is quite another to transform these technical efforts into a cohesive, compelling story that helps the PAs, EEAC, and others understand existing customer facilities and identify the greatest opportunities for Massachusetts businesses to make energy efficiency improvements.

The value of this project’s findings, processes, and observations are by no means limited to Massachusetts, but extends into the energy efficiency community nationwide. Future studies all across the country can take advantage of the extensive work done through the C&I On-site Assessments and MSST Study, as more and more states and jurisdictions strive to duplicate Massachusetts’s unmatched achievements in energy efficiency.
1 INTRODUCTION

The DNV GL team, made up of DNV GL, Itron, Inc., APPRISE, Inc., ERS, Inc., and NMR, designed the Massachusetts Commercial and Industrial (C&I) Market Characterization Study to help the Massachusetts Program Administrators (PAs) better understand the Commonwealth’s existing C&I building and equipment stock, and to identify potential ways to expand the statewide energy efficiency program portfolio. The C&I Market Characterization Study consisted of two projects, carried out from 2014-2016:

- Project I: The C&I Customer Telephone Survey (2014), which gathered information from 943 customers through a telephone survey
- Project II: The Massachusetts C&I Customer On-Site Assessments (2014-2016), which collected equipment-specific information for customer facilities

Our goal was to conduct comprehensive on-site assessments of 800 C&I facilities across 189 strata in Massachusetts. The DNV GL team assessed the most complex facility types in the market, such as hospitals, college campus buildings, manufacturing facilities, and professional sports venues. Field staff collected raw premise-level data on specific building equipment types. This included systems’ age, condition, and efficiency levels as well as information on building operating practices. The sample was divided into 14 business-type categories across electric PA territories, with 3 size categories for each business type: less than 500,000 kWh, 500,000-4,500,000 kWh, and greater than 4,500,000 kWh. In all, the DNV GL team recruited 955 sites to reach our goal of visiting 800 C&I facilities across Massachusetts.

The study focused on understanding the highest priority electric and non-electric-fueled end uses, based on stakeholder feedback and annual energy efficiency program savings. These end uses included: lighting, HVAC, refrigeration, and water heating systems. For industrial and manufacturing customers, the DNV GL team collaborated with the PAs to develop a separate survey instrument designed to capture a broad range of equipment information.

This report presents the results of the C&I On-Site Assessments. It also includes results from the C&I On-site Assessments’ sister project, the Market Share and Sales Trends (MSST) Study. The DNV GL team designed the MSST Study to analyze information collected during the C&I On-site Assessments on recently purchased high-priority equipment, so that we could determine the efficiency distribution of that equipment.

1.1 Key findings and observations

The findings included in this report allow for a deep, nuanced understanding of C&I customer equipment stock, behaviors, and areas for potential energy efficiency improvements throughout the Commonwealth of

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15 We also include information on other end uses such as compressed air motors, energy management systems, process-type equipment, and on-site generation systems, but emphasize the high-priority end uses.

16 It is not possible to gather detailed information on all process equipment found in Massachusetts; the information we captured is intended to provide a general picture of the types of equipment found in different manufacturing facilities.
Massachusetts. We provide key findings for the various equipment types we assessed at the beginning of each section. Our central findings and observations are:

**Massachusetts building energy use intensities (EUI)** - The electric EUIs developed for Massachusetts businesses in the study indicate that the average EUI\(^{17}\) in Massachusetts is lower than the national averages from the U.S. Energy Information Administration’s Commercial Building Energy Consumption Survey (CBECS). The Massachusetts Clean Energy and Climate Plan for 2020 proposes to use energy rating and labelling of buildings to create a market for energy efficiency and reduced energy usage in buildings. The EUIs developed as a part of this study can contribute to the development of a business EUI baseline that Massachusetts can use to develop an energy usage rating system specific to in-state businesses. Natural gas EUIs assessed as part of this study are not as reliable, however, due to the difficulty in matching customer gas accounts with the customer premises inventoried and quantifying the associated consumption; we therefore suggest not using these for baseline purposes.

**Lighting** – Massachusetts businesses have made substantial improvement to lighting efficiency in recent years. This is evidenced by the reduced share of T12 and less efficient 700-Series T8 lamps and CFLs in more recent purchase data relative to the existing stock of all linear and incandescent, CFL, LED, and halogen (ICLH) technologies. While T12 lamps make up 12% of linear technologies in Massachusetts businesses, and are present in 54% of businesses, T12 lamp purchases from 2009-2015 represent less than 1% of recent linear lamp purchases. 700-Series T8 lamps represent 40% of linear technologies purchased prior to 2009, 16% of purchases from 2009-2011, and less than 1% of purchases from 2012-2014. Massachusetts businesses choosing to purchase efficient linear technologies are increasingly choosing Tubular LEDs (TLEDs\(^{18}\)), the most efficient option. Prior to 2012, TLEDs were seldom observed in the Massachusetts commercial sector. From 2012-2014, TLEDs represented 18% of linear purchases.

The study also found that that ICLH lamps account for 25% of the indoor lamps in Massachusetts businesses. The recent purchase shares, however, showed a marked decline in CFL lamps (6%) and an increase in LEDs (44%) among recent purchases. The large share of recently purchased LEDs and the small share of recently purchased CFLs may indicate that Massachusetts businesses are rapidly retrofitting incandescent and CFL lamps with LEDs.

**Heating, ventilation and air conditioning (HVAC)** - The majority of businesses in Massachusetts are cooled by split and packaged cooling systems, and Massachusetts businesses are commonly purchasing cooling systems above current federal standards. Nearly 40% of cooling units in Massachusetts businesses are packaged terminal air conditioners (PTAC) and window/wall units. These units average only 1.2 tons and are designed to cool either a room or a relatively small area. The PA-sponsored program does not currently offer commercial rebates for high-efficiency PTAC and window/wall units under the prescriptive program, but these measures can receive incentives as custom retrofit projects. Given the prevalence of these units, PA-sponsored programs may want to look into offering incentives for high-efficiency versions of these measures.

The majority of Massachusetts businesses heat their facilities using furnaces. Boilers and furnaces are both crucial to heating business area; these technologies often heat facilities individually and in combination with each other or other equipment. Boilers and furnaces were both found as heating choices in more than 50%

\(^{17}\) EUI calculations are based on electric consumption data according to customer billing records and do not take into account net metering or on-site electricity production from on-site photovoltaics.

\(^{18}\) For the purposes of this analysis linear LED fixtures are included as part of TLEDs.
of business square footage, with a variety of technologies dividing the remainder. Our analysis found that
the majority of small furnaces in Massachusetts businesses exceed the federal standard of 78 AFUE, and
many small furnaces in Massachusetts exceed the 95 AFUE requirement to receive a PA-sponsored program
incentive. Where cost-effective, PA-sponsored programs should continue to focus on increasing adoption of
extremely high-efficiency options.

While nearly all recently purchased small furnaces and water-source heat pumps were found to be above
federal efficiency standards, most of the recently purchased large furnaces were found to be at standards.
Standards for large furnaces were implemented in 2004. PAs should look into the need and potential for
developing cost-effective programs to educate consumers and encourage the installation of high-efficiency
large furnaces.

**Water heating** - The field data from the C&I Customer On-site Assessments and MSST Study indicate that
little, if any, energy efficiency improvement has been made in water heaters in Massachusetts businesses in
recent years. The observable data indicate that 9% of the existing stock of standard storage and
instantaneous water heaters is above standards and that 9% of recent purchases are above standards.

PA-sponsored programs offer incentives for gas water heaters. The efficiency requirements for PA-sponsored
program incentives, however, are substantially higher than federal efficiency requirements. While the federal
efficiency requirements for many types of water heaters depend on tank capacity, PA-sponsored program
energy efficiency requirements do not factor in tank size. PAs may want to investigate the need to adjust
the gas water heater energy efficiency requirements for PA-sponsored programs in this regard.

Our study also found that more than 50% of the water heaters in Massachusetts businesses were electric.
Storage water heaters were the dominant type of both electric and gas water heaters. The PAs may want to
investigate the cost-effectiveness of offering an electric water heater program to encourage customers to
install high-efficiency electric water heaters.

**2014 telephone survey comparison to on-site assessment findings** – In 2014 DNV GL conducted a
telephone survey of C&I Customers in Massachusetts to gain a better understanding of their purchasing
practices. In that survey we had also asked about the types of equipment they had in their facilities. The
respondents to the C&I Customer Telephone Survey were customers from 2011 PA billing data; the sample
was based on electric demand categories (kW). Overall, there were 943 responses to the telephone survey;
over half of respondents were smaller sized customers (customers with an average demand below 200kW).

The DNV GL team compared the C&I Customer On-site Assessment results to the results from the C&I
Customer Telephone Survey. While that survey focused on understanding customer operations and
maintenance practices as they pertain to energy-using equipment rather than on the equipment itself, there
were areas of the study where direct comparisons of results could be made including: lighting, HVAC cooling
and HVAC heating systems, EMS, and hot water systems.

Interestingly, although there were some similarities between the survey and assessment data, overall the
comparison results show vast discrepancies between self-reported data and verified on-site data regarding
linear lighting technologies, the number of LED lamps at customer facilities, and types of water heating
systems being used. This suggests that in surveys seeking to gather technology-specific data, self-reported
data should generally be considered unreliable. Throughout this report, we have noted the comparisons of
the telephone survey results to the on-site assessment results in each of applicable section.
1.2 Background and objectives

Building on the Project I telephone survey results, the C&I Customer On-site Assessments gathered on-site data in order to provide a clearer understanding of the existing C&I building market in Massachusetts, and through the MSST Study, to assess market share and sales trends for recently purchased equipment. The ultimate goal of these studies was to provide confirmed customer-level information that can be used to help focus the Massachusetts C&I energy efficiency programs’ efforts as they continue to grow and expand offerings in the coming years.

The on-site data collection efforts focused primarily on collecting information on major electric and non-electric energy end-uses. Lighting, HVAC, motors, and drives remain the dominant sources of savings for the electric programs, while HVAC and hot water production are the dominant sources of savings for gas programs. Information on refrigeration systems, compressed air systems, other process-type equipment, and on-site generation was also collected from businesses where these systems were found. The raw data collected during the site visits included system information such as equipment age, condition, and level of efficiency, as well as premise-level information such as general business type, operational schedules, and maintenance practices.

The field data collection efforts were divided into two segments:

- Wave 1 data collection - August 2014-November 2014
- Wave 2 data collection - February 2015-December 2015

In order to develop a comprehensive cross-section of data from a range of facility types and sizes, the DNV GL team conducted 800 site visits in total. The team completed 350 sites in Wave 1 and 450 sites in Wave 2. Wave 2 data collection required careful management of the sample to ensure that we collected an adequate representation of medium and large customers, and visited a representative sample of customers within each PA’s service territory. Many of the large business-type strata had a limited sample to work with. Large customers were also the most difficult to recruit. The DNV GL team devised a number of strategies to overcome these challenges and recruit the desired number of businesses. Our recruitment strategies are detailed further in 1.3.

In May of 2015, the DNV GL team provided an interim results report to the PAs with equipment market penetration data to help set the program goals for the 2016-2018 Massachusetts Joint Statewide Three-Year Electric and Gas Energy Efficiency Plan. The data from this study will be used for other study efforts as well, including the enhanced C&I Customer Profile, where it will:

- **Validate PA-provided data.** Confirmed on-site data will be used to update the Evaluation Database and provide a higher degree of accuracy of the categorical attributes.
- **Linking fuels and account IDs.** This provides the PAs with validated existing pairings of gas and electric customers.
- **Linking customer-level data.** Individual customers with multiple accounts at a single location may be captured in the database using C&I Customer On-site Assessment data.
- **Pairing the onsite equipment data with accounts in the Evaluation Database.** As more data are accrued, it will be possible to build more informed hypotheses and enhance our understanding of these customers.
- **Joining the sample design and full billing population.** By associating the C&I Customer On-site Assessment sample with the full billing population and leveraging the data captured at the
representative sites, we will be able to provide an enhanced level of geographic information showing where technologies are likely to exist in Massachusetts. Identifying potential geographic sub-clusters of a specific technology can help guide the PAs’ marketing and implementation program activities going forward.

The data from this study can also be useful for supporting updates to energy conservation measure baselines, or assessing prospective additional energy efficiency opportunities at program participant sites, which can be extrapolated to the statewide population.

In this report we summarize the findings from the C&I Customer On-site Assessments for highest-priority electric and non-electric end uses: lighting, HVAC, water heating, and refrigeration. We also summarize findings for kitchen equipment, office equipment, energy management systems (EMSs), and on-site generation systems. For process-type equipment we provide information on compressed air systems, process heating, process refrigeration/cooling, injection molding machines, wastewater treatment systems, motors, and others. We also present recent (2009-2014) purchase information for lighting, HVAC, water heating, and EMS, and assess sales trends and market shares for recently purchased standard and high-efficiency equipment.

Further, the DNV GL team compared the C&I Customer On-site Assessment results against the results from the C&I Customer Telephone Survey completed in 2014. This sort of comparison can be helpful in understanding how reliable self-reported data are when considering them for future studies. The respondents to the C&I Customer Telephone Survey comprised of customers from 2011 PA Billing Data and the sample was based on electric demand categories (kW). Overall there were 943 responses to the telephone survey with over half of the respondents being smaller sized customer (customer with an average demand below 200kW). That survey was more focused on understanding customer operations and maintenance practices as they pertain to energy using equipment and less so on the equipment itself. Lighting, HVAC cooling and HVAC heating systems, EMS, and hot water systems are the areas where direct comparisons of data, based on the available analyses, can be made between the two studies. We have noted the comparisons of the telephone survey results to the on-site assessment results in the findings of each of these chapters. While there were some similarities in reported data, the comparisons indicate that when seeking technology-specific data, self-reported data is generally unreliable. The results show vast differences in self-reported information on linear lighting technologies, the amount of LEDs found at customer facilities, and types of water heating systems in place.

### 1.3 Study approach

The process for the C&I Market Characterization Study was developed based on guidance and feedback from the PAs and the Energy Efficiency Advisory Council (EEAC) Consultants. Figure 1-1 provides the overall approach to the study. The DNV GL team developed the research agenda to allow for the immediate execution of a phased on-site data collection approach, with interim results analysis at the conclusion of Wave 1, and final analysis and report at the conclusion of Wave 2.

With the approval of the project work plan, the DNV GL team devised a sample for the study and worked with the PAs, the EEAC Consultants, and PA implementation staff to develop a data collection instrument. The instrument was based on a similar instrument used in California so that data from the two study areas could be compared if desired. The instrument was designed to collect general premise-level information, including building ownership type, operating hours, business specific characteristics, and maintenance
practices for HVAC equipment, as well as extensive information on the major energy end-using equipment within a building. This includes:

- Heating and cooling equipment
- Lighting
- On-site generation equipment
- Hot water equipment
- Energy management systems
- Motors and drives

These systems represent the electric and gas prescriptive measure end-uses that resulted in the most energy savings for energy efficiency programs according to 2012 program tracking data. Refrigeration, compressed air, and other process equipment modules were also included to capture information on those systems as well.

Upon approval of the data collection instrument, the DNV GL team initiated the Wave 1 data collection activities in August 2014. At the time, data collection was also getting underway for several PA-specific technical potential studies, including studies by Unitil, National Grid, and Cape Light Compact. The recruitment efforts involved coordinating scheduling site visits with these other concurrent studies in order to minimize the burden to customers.

The DNV GL team planned the Wave 1 data collection efforts to initially focus on smaller customers in order to ensure that practices and protocols were well understood by field staff before going to larger, more complex customer sites. Also, site visits to Unitil and National Grid customers were prioritized in order to obtain the information needed to support the technical potential studies. In the Cape Light Compact territory, the DNV GL team worked with the recruiter for their technical potential study to gain access to overlapping sites at the same time so as not to overburden Cape Light Compact customers with multiple requests for access to facilities. The Wave 1 sample was not originally intended to include larger complex sites such as hospitals, industrial facilities, and college campuses; however, field staff did visit a number of these sites at the end of Wave 1 due to the needs of the potential technical studies.
Following the completion of the Wave 1 data collection efforts, the DNV GL team compiled and analyzed the data in aggregate to determine market trends and penetration of equipment types in the commercial and to a more limited extent the industrial building market. The C&I On-site Assessments Interim Results Report, issued in May 2015, provided information collected during the Wave 1 data collection efforts to help inform the 2016-2018 Massachusetts Joint Statewide Three-year Electric and Gas Energy Efficiency Plan.

The Wave 2 data collection efforts commenced in February 2015. Wave 2 was primarily focused on recruiting and collecting data from customers with 500,000 kWh – 4,500,000 kWh annually and customers with greater than 4,500,000 kWh annual use.

Larger customers tend to be more difficult to recruit for these types of study efforts because it is often a challenge to find the right contact and often once the right contact is reached, they need to seek

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The Enhanced Customer Database refers to the Customer Profile Database developed annually by DNV GL. It involves the collection, organization and analysis of the energy efficiency project tracking data and billed energy usage data for all Massachusetts C&I electric and gas customers.
authorization from upper level management for our staff to visit the facility. To assist with recruitment of
this segment, the DNV GL team engaged PA account managers from Eversource and National Grid who work
closely with many of the customers being recruited. In these type of efforts it can be useful to leverage their
relationships to collect additional contact information and have them assist in encouraging customer
participation in the study. As part of our outreach to account managers we:

- Provided an introductory letter to the account managers in March 2015 summarizing the study and its
  objectives
- Provided a list of large customers that we would be attempting to recruit in the upcoming months in
  respective PA territories
- Followed up with both Eversource and National Grid account managers to further review the study intent
  and methods, and answer any questions they may have about the study

As data collection progressed for Wave 2, the DNV GL team continued to refine recruitment strategies while
being careful not introduce a selection bias. We did this by identifying customer in the randomized sample
who were likely to be contacted by recruiters. We then engaged account managers who had relationships
with these customers to:

- Identify contacts at property management firms who manage multiple properties within the sample
- Arrange for the account managers to speak to site contacts at several large buildings where the contact
  asked to speak directly with a representative from the PAs prior to them participating in the study
- Gather information on the active chain accounts and work with National Grid and/or Eversource account
  managers to try to convert those chains to successful recruits

In July, 2015, the DNV GL team directly engaged the National Grid sales representative who works with
many of the chain retailers and grocers in the state on the active recruitment list. That sales representative
volunteered to reach out to many of these customers directly to inform them of these efforts.

As the recruitment of customers for Wave 2 proceeded it became clear that relying on account managers
would not be enough and standard protocols for recruiting needed to be expanded in order to achieve the
goal of 800 on-sites. The DNV GL team undertook several additional actions to help improve recruitment
results, including:

- Adjusting recruitment procedures to maximize the likelihood of reaching customer contacts (e.g., USPS
  Priority mailing introductory letters to customer contacts and allow recruiters more flexibility on the
  timing of calls)
- Offering site summary reports as an additional incentive
- Allowing for some flexibility in the quotas for various strata when recruiting
- Having the recruitment staff schedule conference calls with field staff and the site contacts to improve
  the efficiency of converting recruits to scheduled sites
- Having recruitment staff follow up with recruits that were not reached by field staff for scheduling within
  four calls

The additional strategies that the DNV GL team implemented internally also proved effective. Scheduling
conference calls between the recruiter, field staff and site contact improved the speed of scheduling and
completing site visits. Offering summary reports to customers who requested a copy of the information
collected from their facilities resulted in an additional 15 recruits. Overall, the DNV GL team recruited 955
customers to complete 800 site visits. Forty-three of the customers recruited were determined to be non-
responsive to requests to schedule a visit after initial recruitment, and another 39 sites cancelled after being recruited. Table 1-1 provides a summary of the final disposition of the recruitment efforts.

**Table 1-1: Final disposition of customer recruitment efforts**

<table>
<thead>
<tr>
<th>By consumption categories</th>
<th>Completed site visits</th>
<th>Customers contacted</th>
<th>Customers recruited</th>
<th>Refused</th>
<th>No response</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;500,000 kWh</td>
<td>310</td>
<td>5290</td>
<td>345</td>
<td>548</td>
<td>35</td>
</tr>
<tr>
<td>&gt;4,500,000 kWh</td>
<td>107</td>
<td>766</td>
<td>143</td>
<td>226</td>
<td>34</td>
</tr>
<tr>
<td>500,000 - 4,500,000 kWh</td>
<td>383</td>
<td>4070</td>
<td>439</td>
<td>636</td>
<td>55</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>10126</strong></td>
<td><strong>927</strong></td>
<td><strong>1410</strong></td>
<td><strong>124</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>By business type</th>
<th>Completed site visits</th>
<th>Customers contacted</th>
<th>Customers recruited</th>
<th>Refused</th>
<th>No response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>37</td>
<td>1025</td>
<td>47</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Education</td>
<td>62</td>
<td>469</td>
<td>70</td>
<td>40</td>
<td>6</td>
</tr>
<tr>
<td>Food sales</td>
<td>56</td>
<td>657</td>
<td>59</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>Food service</td>
<td>60</td>
<td>799</td>
<td>64</td>
<td>108</td>
<td>4</td>
</tr>
<tr>
<td>Healthcare</td>
<td>55</td>
<td>713</td>
<td>69</td>
<td>119</td>
<td>14</td>
</tr>
<tr>
<td>Hospitals</td>
<td>26</td>
<td>515</td>
<td>37</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>442</td>
<td>69</td>
<td>94</td>
<td>8</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>69</td>
<td>1045</td>
<td>90</td>
<td>152</td>
<td>21</td>
</tr>
<tr>
<td>Office</td>
<td>82</td>
<td>1015</td>
<td>94</td>
<td>195</td>
<td>12</td>
</tr>
<tr>
<td>Other</td>
<td>56</td>
<td>475</td>
<td>65</td>
<td>70</td>
<td>9</td>
</tr>
<tr>
<td>Public assembly</td>
<td>55</td>
<td>446</td>
<td>59</td>
<td>66</td>
<td>4</td>
</tr>
<tr>
<td>Retail</td>
<td>76</td>
<td>766</td>
<td>83</td>
<td>142</td>
<td>7</td>
</tr>
<tr>
<td>Unknown</td>
<td>84</td>
<td>1320</td>
<td>96</td>
<td>167</td>
<td>12</td>
</tr>
<tr>
<td>Warehouse</td>
<td>22</td>
<td>439</td>
<td>25</td>
<td>95</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>10126</strong></td>
<td><strong>927</strong></td>
<td><strong>1410</strong></td>
<td><strong>124</strong></td>
</tr>
</tbody>
</table>

The DNV GL team proceeded to visit each of the 800 sites and inventory the major energy consuming equipment. Field staff were onsite to collect the desired information for no more than one day. When necessary, multiple surveyors were deployed to the same site to ensure that the information was captured within that timeframe. Certain buildings posed significant challenges to field staff, including buildings that were part of a campus of multi-metered buildings, large buildings with limited access; and facilities that required special clearances. For these situations, field staff used sampling protocols.

For multi-metered buildings, wherein the energy consumption of individual tenants was monitored by a private (not utility-owned) sub-meter, field staff were to:

- Survey all common and other accessible areas
- Survey unique tenant spaces representing a significant percentage of building floor area
• Identify tenants with similar space requirements and floor areas, business hours, and equipment needs, and collect information from a sample of these tenants that was a best representation of the site

For large facilities and/or facilities with limited access, field staff collected information on approximately 1/3 of the facility. Field staff noted in the data collection instrument that the information is a sampling of the equipment onsite and indicated the percentage sampled. During the data compilation phase, equipment counts were scaled up based on the area surveyed and the total area represented by the sample.

For campus situations (e.g., colleges and universities, and large hospitals), the DNV GL team developed a sampling protocol similar to that for large facilities, wherein a building or buildings (3 maximum) best representing that campus account were identified based on feedback from the site contact. The information collected from these facilities was then scaled up to represent the premise as a whole.

The DNV GL team then compiled and analyzed the data from Wave 1 and Wave 2. In preparation for the analysis, an extensive quality control (QC) process was used. After being uploaded to the DNV GL On-Site Assessment Master Database, all sites were assigned to a senior engineer who was responsible for the QC review. The QC reviewer:

• Conducted a review of general site parameters to understand site conditions and the scope of the assessment based on business type and equipment inventoried
• Reviewed notes to look for irregularities about the site visit
• Reviewed each section of the data collection instrument for completeness
• Reviewed large equipment for accuracy
• Reviewed any sampling procedures performed at the site when access to certain areas could not be obtained

If there were questions, the QC staff would seek clarification from the field surveyor; any identifiable trends or issues that could compromise the quality of the data were discussed with the field team during weekly calls.

During the analysis, the data were verified again to ensure quality and consistency. This involved checking the number of records for each data point once the master dataset was exported for analysis, running a proc-univariate function to look at minimum, maximum and median results for key variables, checking for outliers, and assessing whether or not the means were sensible. Further, we checked for missing values, negative values, and that percentages were correct. Finally, we checked to make sure that the number of sites or records matched what was expected, ensured there were no duplicate entries, and confirmed that the equipment found in the buildings matched the business type. Once we were comfortable with these results, the DNV GL team proceeded with report development.

The results of the C&I Customer On-Site Assessments are summarized in this final report. For the on-site assessment/market characterization aspects in general, we summarize major energy end-use equipment found in the existing buildings market, distinguishing between program participants and non-participants where possible. We also note potential opportunities and challenges in the market based on significant variations in the results across business and customer size segments. We include:

• A summary of customer and equipment characteristics
• A general comparison of the C&I customer telephone data and the C&I on-site data collection efforts
• An estimate of the building electricity and natural gas use intensity (kBtu/sf) for each business type based on verified square footage, and consumption data provided in the customer billing database.

For the MSST aspects of the report, we include the efficiency and recent purchase information available from the on-site assessments. We also include:

• Estimates of recent sales of high-priority measures found in the C&I market (lighting, HVAC, water heating, and refrigeration)
• The distribution of various levels of efficiency for recent sales of high-priority measures found in the C&I market
• The distribution of recent sales of high-priority measures by business size, energy efficiency program participation, and business type, as well as the time period for recent measures, to allow for a review of when these measures were installed

The C&I Customer On-site Assessments results did not assess the differences between customers in the various PA territories or geographic locations, or based on other key demographics. Much of this information was collected, however, and may be used for future study efforts.

1.4 Sample design

The DNV GL team designed the original sample based on two separate frames: the 2013 C&I billing data and the 2011 C&I billing data. A third sampling frame was added to accommodate the needs of a technical potential study in Cape Light Compact territory. The sample represented customers geographically distributed across the state of Massachusetts. It was not based on PA customer territories; however, recruitment was tracked so that a sample of customers proportional to the customers served by each PA was visited in each electric PA territory. The key information required to develop the sample for the on-site assessments included business type and annual consumption.

Because PA electricity sales cover the entire state of Massachusetts (minus those areas served by municipal electric utilities) and natural gas customer accounts cannot be readily matched to electric customer accounts, the sample is based on electric accounts. The total population of electric accounts in the 2013 billing and tracking database was 313,340. To avoid contacting accounts with little to no energy consumption, the DNV GL team removed accounts with annual consumption of less than 2,000 kWh. This resulted in a decrease of 84,017 accounts in the population. The average annual energy usage in each of these accounts was less than 800 kWh; altogether, they represented less than 0.25% of the total annual consumption in the billing data. The resulting population from this exercise was 229,323 accounts.

There are certain challenges inherent in collecting data from manufacturing/industrial, large hospitals, and college campuses. Due to this, and our understanding that the PAs currently work closely with these customers, these business types were not prioritized for the Phase I data collection sample; however, the evaluation team did collect data from some of these types of customers due to the needs of the individual...
PA technical potential studies. The shortfall from the desired total number of site visits for these customers was made up in 2015 in the Wave 2 data collection efforts.

According to the 2013 data set, approximately 78% of customer records were associated with a business type. A statewide sample of 800 accounts was selected to represent the C&I market including the customers in Cape Light Compact territory. The sample was allocated to strata in a manner that maximizes precision of resulting estimates. Strata in the sample were defined by business type and usage (kWh) categories.

The DNV GL team used our Model Based Statistical Sampling (MBSS) program\(^2\) to develop a stratified random sample of the population of C&I accounts in which business type and consumption category served as the strata. Our sample design was composed of 14 business type categories as defined in Table 1-2, including other and unknown, and split education and healthcare between campus and non-campus accounts and hospital and non-hospital accounts respectively. The building type classifications follow closely the definitions used for CBECs. The sample design also included 3 consumption categories, with breaks set so that each group contained approximately 1/3 of the population’s energy usage. Table 1-3 provides a breakdown of the account size groupings used in the sample.

Table 1-2: Business type classification definitions

<table>
<thead>
<tr>
<th>Business type</th>
<th>Definition</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>K-12 buildings used for academic or technical classroom instruction, such as elementary, middle, or high schools, and classroom buildings on</td>
<td>elementary or middle school high school preschool or daycare adult education career or vocational training</td>
</tr>
<tr>
<td>Campuses</td>
<td>College or university facilities located on or as part of an education campus including those buildings not used for classrooms</td>
<td>college or university buildings</td>
</tr>
<tr>
<td>Food sales</td>
<td>Buildings used for retail or wholesale of food</td>
<td>grocery store or food market gas station with a convenience store convenience store</td>
</tr>
<tr>
<td>Food service</td>
<td>Buildings used for preparation and sale of food and beverages for consumption</td>
<td>fast food restaurant or cafeteria bar catering service or reception hall</td>
</tr>
<tr>
<td>Health care (outpatient)</td>
<td>Buildings used as diagnostic and treatment facilities for outpatient care. Medical offices are included here if they use any type of diagnostic medical equipment (if they do not, they are categorized as an office building)</td>
<td>medical office (see previous column) clinic or other outpatient health care outpatient rehabilitation veterinarian</td>
</tr>
<tr>
<td>Hospitals</td>
<td>Buildings used as diagnostic and treatment facilities for hospital</td>
<td>hospital</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business type</th>
<th>Definition</th>
<th>Includes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lodging</td>
<td>Buildings used to offer multiple accommodations for short-term or long-term</td>
<td>inpatient rehabilitation</td>
</tr>
<tr>
<td></td>
<td>residents, including skilled nursing and other residential care buildings</td>
<td></td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>Buildings that are industrial or manufacturing based</td>
<td>manufacturing or industrial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>waste water or water treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>assembly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>brewery/winery/distillery</td>
</tr>
<tr>
<td></td>
<td></td>
<td>chemical production</td>
</tr>
<tr>
<td>Office</td>
<td>Buildings used for general office space, professional office, or</td>
<td>administrative or professional office</td>
</tr>
<tr>
<td></td>
<td>administrative offices</td>
<td>government office</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mixed-use office</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bank or other financial office</td>
</tr>
<tr>
<td></td>
<td></td>
<td>police station</td>
</tr>
<tr>
<td>Other</td>
<td>Buildings that are agricultural or other miscellaneous buildings that</td>
<td>agriculture</td>
</tr>
<tr>
<td></td>
<td>do not fit into any other category</td>
<td>airplane hangar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>crematorium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>laboratory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>telephone switching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>energy / telecommunications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>data center or server</td>
</tr>
<tr>
<td></td>
<td></td>
<td>farm</td>
</tr>
<tr>
<td>Public assembly</td>
<td>Buildings in which people gather for social or recreational activities,</td>
<td>social or meeting</td>
</tr>
<tr>
<td></td>
<td>whether in private or non-private meeting halls</td>
<td>recreation (e.g. gymnasion, health club, bowling alley, ice rink, field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>house, indoor racquet sports)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>entertainment or culture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(e.g., museum, theater, cinema, sports arena, casino, night club)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>library</td>
</tr>
<tr>
<td></td>
<td></td>
<td>funeral home</td>
</tr>
<tr>
<td>Retail</td>
<td>Buildings used for the sale and display of goods other than food</td>
<td>retail store</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rental center</td>
</tr>
<tr>
<td></td>
<td></td>
<td>enclosed mall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>strip shopping center</td>
</tr>
<tr>
<td>Warehouse</td>
<td>Buildings used to store goods, manufactured products, merchandise, raw</td>
<td>refrigerated warehouse</td>
</tr>
<tr>
<td></td>
<td>materials, or personal belongings (such as self-storage)</td>
<td>non-refrigerated warehouse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>distribution or shipping center</td>
</tr>
</tbody>
</table>
Table 1-3: C&I account size groupings

<table>
<thead>
<tr>
<th>Size grouping</th>
<th>MWh</th>
<th>Accounts</th>
<th>Percent of population (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500 MWh</td>
<td>8,887382</td>
<td>221,325</td>
<td>32%</td>
</tr>
<tr>
<td>500 – 4,500 MWh</td>
<td>9,555,718</td>
<td>7,216</td>
<td>34%</td>
</tr>
<tr>
<td>&gt;4,500 MWh</td>
<td>9,310,284</td>
<td>782</td>
<td>34%</td>
</tr>
</tbody>
</table>

Not every business type category contained accounts for every consumption category. We used MBSS to estimate the optimal sample size for each stratum based on the variability of the kWh between customer accounts within the stratum and the total stratum kWh.

Once the sample sizes were established, members of each stratum were then randomly assigned a contact order for the on-site data collection. We also use this system to estimate expected relative precisions for the sample design, given a particular error ratio. DNV GL used an error ratio of 0.5 to estimate expected relative precisions, and an error ratio of 0.7 to estimate “worst case” expected relative precisions. These bounds follow typical sampling design practices for evaluation studies. For this study, acceptable relative precisions were considered to be approximately 20% or below. Table 1-4 provides an overview of the sample design according to business type.

Table 1-4: C&I Account on-site survey sample

<table>
<thead>
<tr>
<th>Category</th>
<th>Est. relative precisions: error ratio = 0.5 / error ratio = 0.7</th>
<th>Total sample accounts</th>
<th>Pop. accounts</th>
<th>Pop. Kwh</th>
<th>% pop. Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>12% / 17%</td>
<td>57</td>
<td>4,749</td>
<td>1,666,811,540</td>
<td>6%</td>
</tr>
<tr>
<td>Campuses</td>
<td>11% / 16%</td>
<td>49</td>
<td>1,338</td>
<td>656,953,269</td>
<td>2%</td>
</tr>
<tr>
<td>Food sales</td>
<td>12% / 17%</td>
<td>57</td>
<td>5,315</td>
<td>1,398,450,191</td>
<td>5%</td>
</tr>
<tr>
<td>Food services</td>
<td>13% / 18%</td>
<td>55</td>
<td>11,069</td>
<td>1,131,448,176</td>
<td>4%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>13% / 18%</td>
<td>53</td>
<td>8,851</td>
<td>1,402,332,066</td>
<td>5%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>11% / 15%</td>
<td>41</td>
<td>578</td>
<td>566,177,884</td>
<td>2%</td>
</tr>
<tr>
<td>Lodging</td>
<td>13% / 19%</td>
<td>55</td>
<td>2,543</td>
<td>717,456,796</td>
<td>3%</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>13% / 18%</td>
<td>69</td>
<td>20,195</td>
<td>5,120,059,900</td>
<td>18%</td>
</tr>
<tr>
<td>Office</td>
<td>13% / 18%</td>
<td>74</td>
<td>57,135</td>
<td>6,230,533,829</td>
<td>22%</td>
</tr>
<tr>
<td>Other</td>
<td>18% / 25%</td>
<td>52</td>
<td>10,774</td>
<td>809,637,097</td>
<td>3%</td>
</tr>
</tbody>
</table>
The sample was made up of 3 groups:

- **C&I customer telephone respondents** - During the C&I Customer Telephone Survey (based on the 2011 C&I billing frame) the DNV GL team collected responses from 443 customers who indicated that they would be willing to participate in the on-site assessments. These customers were from a randomized sample used for the telephone survey and were contacted first for the C&I Customer On-site Assessments study.

- **Cape Light Compact technical potential study group** – This consisted of a randomized sample of Cape Light Compact customers who were recruited by Cape Light Compact and its contractor for the Cape Light Compact 2014 Penetration, Potential and Program Opportunity Study. The DNV GL team joined the Cape Light Compact representatives to collect data from 45 Cape Light Compact customers in Wave 1.

- **Customer from 2013 C&I billing data** – Customers drawn from the 2013 billing frame made up the remainder of the accounts required for the study.

The 3 sample groups were combined following the study and weighted accordingly. After the sample was selected, some additional editing of the sample frame was done to identify and remove duplicate businesses as well as businesses that were otherwise out of scope of this evaluation (e.g., telecommunications towers and equipment). This reduced the target population to 205,422 businesses with a total annual energy consumption of 26,341,285,385 kWh. The sample weighting discussed in the next section used this revised target population information in the development of the final sample weights.

### 1.5 Sample weighting

To create unbiased population estimates, 3 sample weights were created for all businesses considered respondents to this data collection effort. Data from the 800 responding businesses were used to generate business-level, site-level, and kWh-level weights for this analysis. In most instances, a responding business reflected data for a single site in the original sample frame. There were some cases where a responding business included data for more than one site. The 800 responding businesses in this study accounted for 897 sites and 1,790,106 MWh in the original target population.

In general, a sample weight is a numeric quantity assigned to each respondent that is greater than or equal to 1.00, and expresses the amount of the target population that a particular responding business represents.
The sample weight is greater than 1.00 so that each respondent represents at least itself in the estimation process.

As noted in the previous section, the sample for this study was selected from 3 sources:

- Massachusetts C&I Customer Telephone Survey
- Cape Light Compact 2014 Penetration, Potential and Program Opportunity Study
- Massachusetts 2013 C&I billing data

The samples from the Massachusetts C&I Customer Telephone Survey and the Massachusetts 2013 C&I billing data were randomly selected from a sample frame that covered the same target population (i.e., those geographical areas served by National Grid, Eversource, and Unitil). The sample from the Cape Light Compact Technical Potential Study was selected from a frame that covered businesses in the Cape Light Compact region. The important things to note are:

1. The samples from the 3 sources cover the entire target population of interest (i.e., businesses across the Commonwealth of Massachusetts with annual energy consumption greater than 2,000 kWh).23
2. Since every business in the target population had some non-zero chance of being selected for this study, estimates generated from the respondent data are not necessarily biased due to some feature inherent in the study’s sample design. In other words, there is no target population coverage bias in the estimates generated from this study.

The final target population for this study included 250,796 businesses and 250,893 sites. Billing data revealed that the businesses in the target population had an annual energy consumption of 28,332,050 MWh.24 This covered 99.7% of electricity sold by the PAs in 2013.

As noted above, 3 sample weights were created for each of the 800 responding businesses: one for business-level estimates, a second for site-level estimates, and a third for kWh-level estimates. The business-level weight was created in a manner that allows data from the 800 responding businesses to expand to the business-level target population of interest (i.e., the 250,796 businesses). This sample weight accounts for differences between the distribution of the respondents and the population by several characteristics of interest, such as building type (campus, education, food sales, etc.) and PA region. This sample weight was used to create estimates of business-level statistics in this study, such as percent of businesses by varying types of HVAC equipment and percent of businesses with an EMS. This weight was also used to estimate the distribution of equipment types in the population, such as lamps, cooling systems, heating systems, and the distribution of total linear feet of refrigeration cases.

We derived the site-level weight and kWh-level weight using the business-level weight, so that all weights were as consistent as possible. This ensured that estimates generated with the business weight, site weight, and kWh weight would not contradict one another. In other words, if estimates were formed from any two small sub-samples of the 800 responding businesses, and all businesses in the two groups had the same number of sites and same amount of energy consumption, then logically one would expect business-level, site-level, and kWh-level means and ratio estimates to be the same. The site-level weight included an

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23 Not including customers served by municipal electric and gas utilities.
24 These numbers represent the final counts of the survey eligible population by kWh size and industry based on additional supplementation of the sample using more current billing records than what was available at the time of the original sample design.
additional factor that reflected the total number of sites a business represents, and the kWh weight included an additional factor (annual kWh consumed) that we created to show the impact of some characteristics or attributes with respect to the total kWh consumption in the population. For the kWh sample weight, the energy consumption considered (kWh) was annual kWh consumption from the PA billing records. The site-level and kWh-level sample weights were created so that the weighted number of sites and weighted kWh consumption derived from the 800 responding businesses equaled the corresponding population totals for several customer characteristics of interest, such as building type and provider region.

We created all weights as the product of several factors. These factors included:

- A factor that reflected the sites’ original probability of being selected into one of the 3 sources: the Massachusetts C&I Customer Telephone Study, Massachusetts 2013 C&I Billing Data, and the Cape Light Compact potential study samples
- A factor that accounted for non-responding sites
- A factor that accounted for the overlap between the C&I Customer Telephone and Massachusetts 2013 C&I Billing Data target populations
- A factor that ultimately calibrated the business-level, site-level, and kWh-level sample weights to the original target population

In the 4-foot linear lamp analysis, there were a number of unknowns associated make and model numbers of the lamps. To adjust for these unknowns, a factor that accounted for non-responding sites within each of the three study samples was created. This adjustment was created independently between the three studies, so that ultimately, the sample weights expanded the respondents from each study back to their full appropriate target population. More information on this weighting adjustment is provided in Appendix A.

The final calibration of the sample weights adjusted the weights so that the weighted sample correctly summed to the total number of businesses, the total number of sites, and the total kWh use of the target population. We did this for each stratum, including building type (campuses, education, food sales, etc.), PA, and kWh usage category. We also ensured that the weights correctly summed the program participants to the total number of participants that year. Additional technical details of the weight creation process are provided in Appendix A.
2 CUSTOMER OVERVIEW

During the C&I Customer On-site Assessment data collection efforts the DNV GL team collected information about the businesses and the buildings that were surveyed during the visits. This chapter provides an overview of the Massachusetts C&I customers who participated in the study.

2.1 C&I customer on-site assessment distribution (un-weighted)

The distribution of the customers who participated in the on-site visits across the 14 business types is listed in Table 2-1. It should be noted that customers were recruited according to the business types indicated in study sample and that the recruitment team followed the designated quotas for each strata as closely as possible. This table presents the number of completed site visits according to the business types observed in the field and reallocates the previously “unknown” customer classifications to the confirmed business type category. Overall, approximately 38% of the sites visited were reclassified from the original classification to the field-confirmed classification, excluding the unknown category. The office business type category saw the greatest increase from field confirmations, gaining 36 sites. The average was +/- 10 sites reclassified across the various business type categories.

Table 2-1: Number of on-site visits completed by sample-defined and field-confirmed business type

<table>
<thead>
<tr>
<th>Business type</th>
<th>Targeted completed sites by business type</th>
<th>Sites visited per sample-defined business type</th>
<th>Sites visited per on-site field-confirmed business type</th>
<th>Net +/-</th>
<th>Total sample defined business types reclassified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>49</td>
<td>37</td>
<td>35</td>
<td>-2</td>
<td>11</td>
</tr>
<tr>
<td>Education</td>
<td>57</td>
<td>60</td>
<td>79</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>Food sales</td>
<td>57</td>
<td>55</td>
<td>47</td>
<td>-8</td>
<td>14</td>
</tr>
<tr>
<td>Food service</td>
<td>55</td>
<td>60</td>
<td>63</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Healthcare</td>
<td>53</td>
<td>55</td>
<td>62</td>
<td>7</td>
<td>21</td>
</tr>
<tr>
<td>Hospitals</td>
<td>41</td>
<td>25</td>
<td>20</td>
<td>-5</td>
<td>14</td>
</tr>
<tr>
<td>Lodging</td>
<td>55</td>
<td>60</td>
<td>60</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>69</td>
<td>69</td>
<td>83</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Office</td>
<td>74</td>
<td>81</td>
<td>117</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

25 Business types are based upon the building type definitions used for the Energy Information Agency’s Commercial Building Energy Consumption Survey (CBECS). https://www.eia.gov/consumption/commercial/building-type-definitions.cfm

26 The original business type classification was based upon data from PA’s billing system provided to DNV GL for the 2013 C&I Customer Profile Study. The building type field in customer billing databases is often based on the SIC or NAIC code for the business and it may not properly reflect the specific use of the building. For example, the offices of a manufacturer may be classified as manufacturing however, for purposes of this study the site would be re-classified from manufacturing to office.
### Business type

<table>
<thead>
<tr>
<th>Business type</th>
<th>Targeted completed sites by business type</th>
<th>Sites visited per sample-defined business type</th>
<th>Sites visited per on-site field-confirmed business type</th>
<th>Net +/-</th>
<th>Total sample defined business types reclassified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>52</td>
<td>58</td>
<td>59</td>
<td>1</td>
<td>41</td>
</tr>
<tr>
<td>Public assembly</td>
<td>51</td>
<td>51</td>
<td>73</td>
<td>22</td>
<td>25</td>
</tr>
<tr>
<td>Retail</td>
<td>69</td>
<td>78</td>
<td>72</td>
<td>-6</td>
<td>43</td>
</tr>
<tr>
<td>Warehouse</td>
<td>38</td>
<td>21</td>
<td>30</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Unknown</td>
<td>80</td>
<td>90</td>
<td>*distributed above</td>
<td>-90</td>
<td>90</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>800</strong></td>
<td><strong>800</strong></td>
<td><strong>800</strong></td>
<td><strong>222</strong></td>
<td><strong>357</strong></td>
</tr>
</tbody>
</table>

*Unknown business types excluded to illustrate changes across business types

10 Average net +/- by business type (excluding unknown)

14.6% Net change for all business types (excluding unknown)

37.6% Gross change for all business types (excluding unknown)

The 800 businesses with on-site data collection can also be viewed by energy consumption (kWh) and square footage. The business kWh size was determined by the businesses’ 2013 annual consumption. The data collection included a large number of businesses with annual energy consumption below 4,500,000 kWh (Table 2-2).

### Table 2-2: Number of on-site visits completed by business kWh size

<table>
<thead>
<tr>
<th>kWh size</th>
<th>Targeted On-sites completes</th>
<th>On-sites completed</th>
<th>Share of completed on-sites</th>
<th>Overall sample targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 500,000</td>
<td>287</td>
<td>313</td>
<td>39%</td>
<td>293</td>
</tr>
<tr>
<td>500,000 to 4,500,000</td>
<td>301</td>
<td>382</td>
<td>48%</td>
<td>286</td>
</tr>
<tr>
<td>Larger than 4,500,000</td>
<td>212</td>
<td>105</td>
<td>13%</td>
<td>221</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>800</strong></td>
<td><strong>100%</strong></td>
<td><strong>800</strong></td>
</tr>
</tbody>
</table>

Disaggregating the businesses by square footage also indicates that about 86% of the businesses have small- and medium-sized square footage (Table 2-3).
Table 2-3: Number of on-site visits completed by business square footage

<table>
<thead>
<tr>
<th>Size in square feet</th>
<th>On-sites completed</th>
<th>Share of completed on-sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5,001</td>
<td>175</td>
<td>22%</td>
</tr>
<tr>
<td>5,001 to 10,000</td>
<td>73</td>
<td>9%</td>
</tr>
<tr>
<td>10,001 to 25,000</td>
<td>88</td>
<td>11%</td>
</tr>
<tr>
<td>25,001 to 50,000</td>
<td>121</td>
<td>15%</td>
</tr>
<tr>
<td>50,001 to 100,000</td>
<td>128</td>
<td>16%</td>
</tr>
<tr>
<td>100,001 to 200,000</td>
<td>101</td>
<td>13%</td>
</tr>
<tr>
<td>200,001 to 500,000</td>
<td>72</td>
<td>9%</td>
</tr>
<tr>
<td>Greater than 500,000</td>
<td>41</td>
<td>5%</td>
</tr>
<tr>
<td>Unknown(^{27})</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>100%</td>
</tr>
</tbody>
</table>

Considerable efforts were made to recruit and successfully complete on-site visits for the high energy usage (larger) customers. Prior to starting recruiting efforts, sample data for the high energy-usage customers were reviewed by account representatives to determine if additional or more up-to-date site contact information was available. In many cases, account representatives contacted the high-usage businesses site contacts personally to inform them of the study in hopes of aiding with the recruiting effort. Several high-usage businesses were recruited this way.

The DNV GL team to maximize the successful recruitment and completion on-site visits. For business categories with annual energy consumption of less than 500,000 kWh and 500,000 to 4,500,000, the target number of completes was 0.1% and 4% respectively of the total available population of customers in these size-related classifications. For the high energy usage businesses, the 221 target completes were 29% of the total 770 available high energy usage businesses in the sample frame.

The DNV GL team often performed considerable background research in attempts to identify a valid site contact capable of authorizing a site visit whenever the provided contact was not responsive to call efforts. Sites were contacted up to 15 times at a frequency no greater than every two to three days before being deemed non-responsive. Field data collection effort recruiting was extended considerably past the planned completion date in attempt to recruit every possibly high energy usage site still capable of being recruited. The same efforts were made to recruit business groups where site visit completion rates fell below the target number. Characterizing the number of on-site visits by EE program participation using program tracking data from 2011 to 2014, a total of 462 (58%) of businesses did not participate in EE programs and 338 businesses did (42%).

\(^{27}\) This site was a park with no building associated with it.
2.2 C&I customer on-site assessments distribution (weighted)

Population based estimates of the distribution of types of businesses in Massachusetts were developed by applying weights to the C&I customer on-site sample. Figure 2-1 compares the distribution of business kWh versus number of businesses in Massachusetts by business type. The kWh-weighted distribution of businesses shows the share of weighted consumption by business type. These data indicate that manufacturing or industrial businesses are the most common, with 19% of business electricity consumption followed by office at 16% and retail at 12%. The site-weighted distribution shows that retail accounts for 28% of Massachusetts businesses followed by offices at 25% of businesses. Manufacturing or industrial businesses make up only 3% of the businesses but 19% of the business kWh.28

Figure 2-1: Distribution of businesses

*Results are weighted using the kWh-level and the site-level sample weight.

**These data represent 800 total sites.

Figure 2-2 illustrates the weighted distribution of C&I electricity consumption by customer size. The sample design for the study developed the three customer consumption-size categories such that each size represents approximately one-third of the C&I kWh consumption. The sample design incorporated more data collection points with customers with annual usage below 50,000 kWh (293) and customers with annual

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28 For the analysis by business type, a customer's weight is dependent upon the business type in the utility customer information system. If the customer's building type found on-site differs from the building type in the customer information system, the building type will be updated for the analysis but will maintain the original weight.
usage of 500,000 kWh to 4,500,000 kWh (286) relative to large customers (221) to account for the significantly greater number of customers in these categories.29 The prior Table 2-2 provides a completed site distribution showing that more on-sites were completed with customers who had annual usage below 4,500,000 kWh than the original sample design due to the difficulty gaining access to larger customers. The pie chart on the left in Figure 2-2 shows the kWh weights designed so the three business-size categories each reflect approximately one-third of the population, consistent with the Massachusetts C&I customer frame. The pie chart on the right provides the site-weighted distribution of the on-site survey by the three consumption size categories, which shows that the majority of Massachusetts C&I customer sites use less than 500,000 kWh.

Figure 2-2: Distribution of C&I customer electricity (Annual kWh) consumption

![Pie chart showing distribution of C&I customer electricity consumption](image)

- Greater than 4,500,000
- 500,000 to 4,500,000
- Less than 500,000

*Results are weighted using the kWh-level and site-level sample weight.

**These data represent 800 total sites.

***The results are rounded.

Figure 2-3 shows the distribution of square footage in Massachusetts businesses. The y-axis of this graph is the share of electricity usage for each square footage category using kWh weights. These data indicate that

---

29 The definitions of small, medium, and large were developed to allocate one-third of the annual electricity consumption to each group. This approach was chosen for sampling purposes. These definitions differ from other analyses in Massachusetts.
approximately 15% of businesses have a square footage in excess of 500,000, and slightly more than 12% of businesses have a square footage of 5,000 or less.

**Figure 2-3: Distribution of C&I customer square footage**

*Results are weighted using the kWh-level sample weight.*

**These data represent 799 total sites. They do not include the single park site which had no building on the premise.*

Figure 2-4 illustrates the kWh-weighted distribution of the C&I square footage by premise type, where a business premise indicates whether the business occupies an entire building, part of a building, a small multi-building cluster, or a larger multi-building campus. For each square footage grouping or bucket, the share of square footage (y-axis) sums to 100%, illustrating how the square footage in the grouping is distributed across premise types. Businesses with less than 10,000 square feet are more likely to occupy part of a building or a single building. While small multi-building clusters do not dominate any square footage size bracket, they are most common in the span of 10,000 to 100,000 square feet. The single building share is largest for the 100,000 to 200,000-square-foot building. Campuses grow in importance as the business square footage exceeds 200,000 square feet.
Figure 2-4: Distribution of C&I customer square footage by premise type

*Results are weighted using the kWh-level sample weight.

**These data represent 787 total sites. There were 13 sites where the premise type was not recorded.

The distribution of business square footage, kWh weighted, by age of building construction is shown in Figure 2-5. In Massachusetts, 67% of businesses and 56% of kWh are associated with buildings that were constructed prior to 1978. In contrast, 5% of businesses and 9% of electricity consumption are associated with buildings constructed from 2006 to 2015. Figure 2-5 illustrates that pre-1978 construction represents the largest share of square footage in all square footage size categories, and represents more than 50% building square footage except in the ranges of 50,001-100,000 and 100,001-200,000 square feet.
Figure 2-5: Distribution of C&I customer square footage by year of building construction

![Bar chart](chart.png)

*Results are weighted using the kWh-level sample weight.

**These data represent 416 total sites.

Figure 2-6 illustrates the distribution of business square footage, kWh weighted, by the year the business was established. In Massachusetts, 31% of businesses and 49% of kWh are associated with businesses that were established prior to 1978. In contrast, 27% of businesses and 16% of electricity consumption are associated with businesses that were established from 2006 to 2015. This comparison could imply that older businesses have had the time and opportunity to develop and expand, leading their energy usage share to exceed their share of businesses while newer businesses are more common, but small and consume less electricity. Figure 2-6 illustrates that businesses established prior to 1978 appear to be associated with larger square footage, this finding is consistent with these businesses representing a larger share of energy consumption than their share of businesses. These data also indicate that businesses established since 2005 have a higher incidence in smaller square footage locations, consistent with the relatively smaller share of consumption relative to business establishments.
C&I customer energy usage intensities

Energy usage intensities (EUIs) were estimated by analyzing the business energy consumption and the square footage. The EUI is a key metric used by ENERGY STAR to benchmark buildings, and expresses a building’s energy consumption as a function of its size and is calculated by dividing the total energy consumed by the building in one year by the total gross floor area of the building. Benchmarking often reviews whole-facility energy usage of multiple types of energy.

For this analysis, the DNV GL team was able to adequately estimate electrical EUI for businesses in Massachusetts. While field staff did collect natural gas account information and meter numbers, developing natural gas EUI’s was more challenging. Estimates of natural gas EUI’s based on customer accounts that

---

30 Consumption is based on electric billing data and does not include net metering or on-site electricity production from on-site photovoltaics
were able to be confirmed are provided below un-weighted for informational purposes only and should not be considered representative of the natural gas customer population in Massachusetts.\textsuperscript{31}

Average electric EUIs were developed by both building type and building size as shown in Table 2-4 and Table 2-5, weighted by the number of sites.\textsuperscript{32} These EUIs were calculated using the larger of the 2013 energy consumption or the 2014 energy consumption. We provide similar EUI data by business type from the U.S. Energy Information Administration’s CBECS 2012 database. The CBECS data provide an opportunity to compare the Massachusetts whole building energy intensities to those estimated for buildings across the United States. It is also important to note that energy efficiency and advancements in design of energy consuming products, have contributed to declining EUIs across the United States.\textsuperscript{33}

Table 2-4: Electric energy usage intensities by building type

<table>
<thead>
<tr>
<th>Business type</th>
<th>Electric energy usage intensity (kWh/ft\textsuperscript{2})</th>
<th>CBECS 2012 (Northeast Region)\textsuperscript{34}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>11.72</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>4.59</td>
<td>8.7</td>
</tr>
<tr>
<td>Food Sales</td>
<td>32.51</td>
<td>52.8</td>
</tr>
<tr>
<td>Food service</td>
<td>33.20</td>
<td>44.9</td>
</tr>
<tr>
<td>Healthcare</td>
<td>11.78</td>
<td>17.7</td>
</tr>
<tr>
<td>Hospitals</td>
<td>27.22</td>
<td>26.3</td>
</tr>
<tr>
<td>Lodging</td>
<td>7.68</td>
<td>13.9</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>28.52</td>
<td>-</td>
</tr>
<tr>
<td>Office</td>
<td>11.43</td>
<td>16.9</td>
</tr>
<tr>
<td>Other</td>
<td>5.45</td>
<td>47.5</td>
</tr>
<tr>
<td>Public assembly</td>
<td>5.12</td>
<td>15.37</td>
</tr>
<tr>
<td>Retail</td>
<td>7.57</td>
<td>16.3</td>
</tr>
<tr>
<td>Warehouse</td>
<td>8.03</td>
<td>4.52</td>
</tr>
</tbody>
</table>

*Results are weighted using the site-level sample weight.

**These data represent 799 total sites. The one facility without a physical building at the site is not included.

The whole business average EUIs by business type in Massachusetts are found to be lower than the national averages from the 2012 CBECS. The lower EUIs in Massachusetts may be due, at least in part, to Massachusetts long running energy efficiency programs. The Massachusetts EUIs may also be lower than the

\textsuperscript{31} The study sample design was based on customer electricity consumption. Designing the sample based on electricity ensured that the study had an estimate of electricity consumption for all study customers and weights were developed based on kWh. Matching gas consumption to electricity consumption on a customer level can be challenging and not all customers have a natural gas account. Natural gas accounts were matched to electric accounts were possible, but it is not clear if customers without matched natural gas accounts represent incomplete matches or customers without natural gas accounts. Natural gas weights were not developed.

\textsuperscript{32} Site weighting implies that the customer’s energy consumption and square footage have been weighted to represent the number customers in the in the strata. The weighting is based on customers, not on kWh in the strata.


\textsuperscript{34} The data in the blank cells represent business types that are not directly comparable between the CBECS database and the current study. The CBECS study has health care broken into inpatient and outpatient; for comparison the inpatient is compared to hospitals and the outpatient is compared to healthcare. The CBECS category mercantile, which is a combination of enclosed and strip malls and retail other than malls, was used as comparison to retail. The business type specific CBECS Northeast Region data are from the 2012 microdata files and can be found at http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata
national averages due to weather that requires less cooling than the national average and potentially a
different distribution of the size of businesses. Care must be taken when comparing EUIs across building
types to national averages. Many variables can contribute to differences, including how NAIC codes are
mapped to building type, and how the data is collected.

Table 2-5 lists the average whole building electric energy intensity by the business kWh size. These data
indicate that the average energy intensity in Massachusetts businesses increases with customer size when
customer size is measured by customer energy usage.

**Table 2-5: Electric energy usage intensities by kWh classification**

<table>
<thead>
<tr>
<th>kWh size</th>
<th>Energy usage intensity (kWh/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger than 4,500,000</td>
<td>28.86</td>
</tr>
<tr>
<td>500,000 to 4,500,000</td>
<td>14.85</td>
</tr>
<tr>
<td>Less than 500,000</td>
<td>5.02</td>
</tr>
</tbody>
</table>

*Results are weighted using the site-level sample weight.

**These data represent 799 total sites. The one facility without a physical building at the site is not included.

For natural gas EUIs, the DNV GL team reviewed the account numbers and the meter numbers collected on
site. Of the 800 customer sites visited, field staff was able to collect natural gas account and/or meter
information from 379 businesses. DNV GL analysts were then able to match field collected information from
231 businesses (61%) with accounts in the C&I Customer Billing Database using the following steps:

1. For each electric account, we used the city name from the electric billing data for each site to determine
   the likely gas PA (some accounts could be either National Grid or Eversource, but the PAs’ account IDs
   are different enough that we could distinguish which gas PA the customer should be assigned to).

2. We formatted all gas account IDs collected during the on-sites to be consistent with the C&I evaluation
database IDs.

3. Gas account numbers were merged to provide the annual therm usage for each account.

4. For all sites that did not successfully merge via electric account, we then attempted to merge by meter
   ID.35

5. Meter IDs were correctly formatted and a merge was done using the meter IDs in the billing data.
6. For any matched meter IDs, the corresponding account ID was pulled from the C&I Evaluation database.
7. The newly acquired gas account ID was then associated with the total annual consumption for the
   account.
8. The gas account number and annual consumption was then merged onto the primary gas account file

Because the analysis and weighting for this study were based on kWh consumption and electric customer
population, we determined that weighting the gas EUI data would likely yield misleading results. It should
also be noted that the area (sf) of the business or businesses using natural gas may not match the business
areas served by electric account. Many times this was unable to be confirmed in the field.

35 Note: Only Berkshire Gas and Columbia Gas provided meter IDs in their 2013 billing data, so these were the only possible PAs this would work for.
With these factors in mind, Table 2-6 and Figure 2-7 present the natural gas EUIs (kBtu/sf) for participants in the C&I On-site Assessment by kWh consumption group. We also provide data from the U.S. Energy Information Administration’s CBECS 2012 database for the Northeast census region for reference. Food service has the highest gas EUI among all business types and is likely driven by the presence of gas cooking equipment. Not surprisingly, the lowest EUI in both this study and the CBECS database is for warehouses. The EUI for retail found in this study is considerably higher than the EUI in the CBECS database; this may be due to a higher incidence of gas heating and water heating.

Table 2-6: Natural gas energy use intensities by business type (un-weighted)

<table>
<thead>
<tr>
<th>Business type</th>
<th>&lt;500,000 kWh (kBtu/sf)</th>
<th>&gt;4,500,000 kWh (kBtu/sf)</th>
<th>500,000 - 4,500,000 kWh (kBtu/sf)</th>
<th>Overall avg. (kBtu/sf)</th>
<th>CBECS 2012&lt;sup&gt;36&lt;/sup&gt; (kBtu/sf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>38</td>
<td>86</td>
<td>16</td>
<td>45</td>
<td>-</td>
</tr>
<tr>
<td>Education</td>
<td>49</td>
<td>34</td>
<td>35</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Food sales</td>
<td>22</td>
<td>58</td>
<td>38</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Food service</td>
<td>274</td>
<td>471</td>
<td>324</td>
<td>134</td>
<td></td>
</tr>
<tr>
<td>Healthcare</td>
<td>31</td>
<td>62</td>
<td>57</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>Hospitals</td>
<td></td>
<td>134</td>
<td>91</td>
<td>119</td>
<td>111</td>
</tr>
<tr>
<td>Lodging</td>
<td></td>
<td>16</td>
<td>70</td>
<td>59</td>
<td>37</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>49</td>
<td>88</td>
<td>130</td>
<td>112</td>
<td>-</td>
</tr>
<tr>
<td>Office</td>
<td>24</td>
<td>9</td>
<td>31</td>
<td>23</td>
<td>35</td>
</tr>
<tr>
<td>Other</td>
<td>19</td>
<td>159</td>
<td>100</td>
<td>113</td>
<td>108</td>
</tr>
<tr>
<td>Public assembly</td>
<td>47</td>
<td>24</td>
<td>77</td>
<td>61</td>
<td>48</td>
</tr>
<tr>
<td>Retail</td>
<td>235</td>
<td>13</td>
<td>124</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Warehouse</td>
<td>29</td>
<td>0</td>
<td>8</td>
<td>12</td>
<td>27</td>
</tr>
</tbody>
</table>

*Results are un-weighted.

**These data represent 231 sites. One facility, a central plant for a hospital, is not included because the total square footage of the hospital served was not recorded.

<sup>36</sup>NG data represent only business types that are directly comparable between the CBECS database and the current study. The CBECS study has health care broken into inpatient and outpatient; for comparison the inpatient is compared to hospitals and the outpatient is compared to healthcare. The CBECS category mercantile, which is a combination of enclosed and strip malls and retail other than malls, was used as comparison to retail. The business type specific CBECS Northeast Region data are from the 2012 microdata files and can be found at http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=micr0data
2.4 Market Share and Sales Trend (MSST) Study: on-site customer distribution with new measures (un-weighted)

The MSST Study used data collected during the C&I Customer On-site Assessment to develop a better understanding of purchases of lighting, HVAC, water heating, and energy management equipment from 2009-2014 by C&I customers in Massachusetts. These four equipment types are referred to as high priority equipment. Table 2-7 depicts the number of businesses where on-sites were completed (column 2) and the number of these businesses that purchased high priority equipment during the 2009–2015 timeframe to qualify them as recent purchasers (column 3). The data in Table 2-7 indicate that approximately 90% of C&I customers purchased new equipment from 2009 to 2015. A given business may have purchased multiple types of high priority equipment.
Columns 4 through 7 indicate the number of businesses that have recent purchases of high priority equipment by end use. These data indicate that a large percentage of C&I customers in Massachusetts, over 90%, have recently purchased new high-priority equipment. Out of those businesses purchasing new equipment, lighting measures were most frequently purchased. This finding is consistent with the relatively shorter expected life of non-LED lighting relative to HVAC, domestic hot water (DHW) heating, and EMS. The larger number of customers purchasing lighting measures may also be influenced by lighting's typically lower average cost relative to non-lighting measures analyzed in this study.

Table 2-7: Number of businesses with recent purchases

<table>
<thead>
<tr>
<th>Business type</th>
<th>On-sites completed</th>
<th>New purchases (2009-2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>All sites</td>
</tr>
<tr>
<td>Campuses</td>
<td>35</td>
<td>32</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>76</td>
</tr>
<tr>
<td>Food sales</td>
<td>47</td>
<td>45</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>57</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>59</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>52</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>71</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>101</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>52</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>68</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>65</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>723</td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.

Table 2-8 provides information on the number of businesses making recent purchases by the size of the business where size is determined by 2013 electricity consumption (kWh). Table 2-9 shows the number of businesses making recent purchases by square footage. These data show that there was not much variation in the percent of sites with new purchases in each size category. The majority (88%) of small sites where

37 Many businesses purchased multiple items within a given end use. The data presented in Table 2-7, however, only count a given business once within a given end use regardless of how many measures are purchased within the end use. The distribution of purchased measures is analyzed later. A customer is counted multiple times if it installed multiple end uses.
on-site data were collected had purchased equipment from 2009-2014, while 92% of medium sites and 91% of large sites were found to have recently purchased equipment.

The distribution of the end use of recent purchase, however, does appear to differ by customer energy consumption. Lighting was purchased frequently by all customer sizes, consistent with the shorter life of non-LED lighting and its lower cost relative to the other end uses. The un-weighted numbers indicate that businesses with annual energy consumption above 500,000 kWh were more likely to purchase HVAC equipment than smaller businesses. Businesses with annual consumption of 500,000 kWh to 4,500,000 were more likely to purchase water heating systems than other businesses. A higher share of the un-weighted businesses with annual consumption greater than 4,500,000 kWh purchased EMS than businesses with annual consumption of 500,000 kWh to 4,500,000 kWh, which were more likely to purchase EMS than businesses who consumed less than 500,000 kWh annually.

Table 2-8: Number of businesses with recent purchases by business kWh size

<table>
<thead>
<tr>
<th>Business kWh size</th>
<th>On-sites completed</th>
<th>New purchases (2009-2014)</th>
<th>All sites</th>
<th>lighting</th>
<th>HVAC</th>
<th>DHW</th>
<th>EMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 500,000</td>
<td>313</td>
<td>274 238 121 87 12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500,000 to 4,500,000</td>
<td>382</td>
<td>353 279 215 158 122</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larger than 4,500,000</td>
<td>105</td>
<td>96 76 66 27 64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>723 593 402 272 198</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.

Table 2-9: Number of businesses with recent purchases by business square footage

<table>
<thead>
<tr>
<th>Business square footage</th>
<th>On-sites completed</th>
<th>New purchases (2009-2014)</th>
<th>All sites</th>
<th>lighting</th>
<th>HVAC</th>
<th>DHW</th>
<th>EMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unknown</td>
<td>1</td>
<td>1 1 0 0 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 5,001</td>
<td>175</td>
<td>152 133 58 42 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5,001-10,000</td>
<td>73</td>
<td>63 51 30 32 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10,001-25,000</td>
<td>88</td>
<td>77 69 34 26 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25,001-50,000</td>
<td>121</td>
<td>110 87 73 49 22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50,001-100,000</td>
<td>128</td>
<td>121 93 79 49 41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100,001-200,000</td>
<td>101</td>
<td>94 73 56 34 45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200,001-500,000</td>
<td>72</td>
<td>67 56 48 30 47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greater than 500,000</td>
<td>41</td>
<td>38 30 24 10 28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>723 593 402 272 198</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.
3 LIGHTING EQUIPMENT

One of the central goals of the C&I Customer On-site Assessments and the MSST study was to document the baseline distribution of existing lighting measures within businesses and the efficiency distribution of new (2009 and later) lighting purchases. Lighting represents one of the largest sources of energy use for many business types. In addition, lighting measures represent a technology long targeted by energy efficiency programs and recent technology code updates.

The lighting data collected during the on-site assessments provide an indication of the progress achieved in replacing inefficient measures with newer, more efficient technologies and also provides information on the current lighting market. These data may also serve as inputs for future potential studies that could provide the PAs with a detailed picture of the remaining achievable lighting energy savings potential. Lighting equipment data collected on-site were classified as one of 8 lighting types: linear fluorescent, compact fluorescent, LED, halogen, incandescent, high intensity discharge (HID), neon, or other lighting. LED lamps used as replacement for linear fluorescents are referenced in this report as tubular LEDs (TLEDs) and classified as linear fluorescents, while non-linear LEDs are treated as a separate lighting category and reported in the ICLH (Incandescent, CFL, LED, Halogen) section. Lighting data installed in indoor and outdoor spaces were analyzed and have been reported separately.

3.1 Lighting findings

Highlights from the analysis of the lighting data, for the existing stock and recently purchased lighting are provided in the sub-section below. The remainder of the section provides additional details, context, and findings.

- Linear lighting, including linear fluorescents and newer linear LEDs and TLEDs, account for 74% of the existing stock of indoor lighting in Massachusetts businesses. Linear lighting is often associated with area or ambient lighting in businesses.
  - Linear lamps include traditional linear fluorescent and tubular LEDs. Tubular LEDs account for 2.65% of linear lamps or 2% of all lamps.
  - Linear lighting represents 58% of recently purchased lighting.
  - High-efficiency linear lighting typically has longer expected hours of life than many other types of lighting, potentially accounting for the difference between the 74% existing share and the 58% share of recently purchased linear lighting.
- Office and retail segments have the largest number of lamps.
  - The number of linear lamps in office or retail businesses is larger than the total number of lamps in any other individual segment. Offices in Massachusetts are estimated to have slightly more than 10 million linear lamps while retail is estimated to have slightly less than 10 million.
  - The large number of linear lamps in office and retail and the current share of base efficiency lamps (see Figure 3-3) in these segments offers a large energy savings potential for Massachusetts businesses and PA-sponsored programs.
  - Office and retail businesses are estimated to each have more than half a million CFL and LED lamps (see text box below).  

38 This statement refers to A-tube LEDs. Linear LEDs are included in the linear lamps.
Lodging and public assembly are estimated to have the largest number of CFL lamps.
- Lodging is estimated to have over 2 million CFLs.
- Public assembly has over 1.5 million CFL lamps.
- Food service and public assembly have the largest number of incandescent bulbs.\(^{39}\)
  - Over half of the bulbs in food service are estimated to be incandescent. The respondent weighted data leads to an estimate of nearly 1.5 million incandescent bulbs in food service businesses in Massachusetts.
  - Public assembly is estimated to have over 1 million incandescent bulbs.
- Replacement of incandescent bulbs with LED lamps could provide substantial savings in food service, where lighting hours of use can be substantial.\(^{40}\)
- LED lamps were found to have a growing presence in Massachusetts businesses.
  - Offices, retail, lodging, public assembly, other, and food service are each estimated to have over half a million LED lamps installed.

Figure 3-1 below illustrates the estimated count of lamps by business type and lighting technology. This figure provides detail on both the distribution of lamp counts by business segment and the distribution of lighting technology. These data will help PA-sponsored programs target lighting programs to segments with large quantities of bulbs. We highlight lamp types prominent in different segments.

---

39 It should be noted that it can be difficult to distinguish the new A-line halogens from incandescents during visual inspections.

40 The Massachusetts TRM does not list lighting hours of use by business type, instead stating the LED measure lives are 10-13 years (see [http://ma- eeic.org/wp-content/uploads/TRM_PLAN_2013-15.pdf](http://ma-eeic.org/wp-content/uploads/TRM_PLAN_2013-15.pdf)). The New York TRM lists the lighting hours per year for a food service establishment as 4,182 to 6,456. This is one of the longer hours of use in the NY TRM (see [http://www3.dps.ny.gov/W/PSCWeb.nsf/ca7cd46b41ed01f0525685800545955/06f2fee55575bd8a852576e4006f9af7/$FILE/TRM%20Version%203%20-%20June%202015.pdf](http://www3.dps.ny.gov/W/PSCWeb.nsf/ca7cd46b41ed01f0525685800545955/06f2fee55575bd8a852576e4006f9af7/$FILE/TRM%20Version%203%20-%20June%202015.pdf) page 196-197).
Figure 3-1: Lamp count by business type and technology

Linear lamps are 74% of the existing stock of lamps and 58% of recent purchases. In addition, these lamps have long been the target of federal efficiency improvements and PA-sponsored energy efficiency programs. Given their dominance in non-residential lighting and energy efficiency programs, collecting additional...

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 35 sites for campuses, 78 education sites, 46 food sales sites, 63 food service sites, 62 healthcare sites, 20 hospitals, 59 lodging sites, 81 manufacturing or industrial sites, 116 offices, 59 other businesses, 73 sites for public assembly, 72 retail sites, and 30 warehouses.
information on the efficiency distribution of these lamps was a high priority of the study. Make and model lookups were undertaken to better understand the efficiency distribution of 4-foot linear lamps. Figure 3-2 illustrates the efficiency distribution of interior 4-foot linear lamps for lamps purchased in 2008 and earlier, for those purchased from 2009 to 2011, and for those purchased from 2012 to 2014. For linear lamps, T12s are the least efficient option, followed by 700- and 800-Series T8s. Federal standards largely eliminated production of T12 and 700-Series T8 in 2012, making 800-Series T8s the base efficiency option going forward. For this report, T12 and 700 and 800-Series T8s are classified as base efficiency lamps while Tier 0-2 fluorescents, Tier 2 LED, and T5 are classified as high-efficiency linears.

Figure 3-2: Linear efficiency distribution, 4-ft linear lamps – interior lighting – by time period

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

** These data represent 728 sites.

***The 4-foot linear efficiency distribution was also analyzed by business size where size is delineated by annual electricity consumption.

Viewing the distribution of linear lamps by their purchase period clearly indicates that there is a trend toward higher efficiency purchases.

- 15% of the bulbs purchased 2008 and earlier are T12 lamps, but nearly no T12 lamps were found to have been purchased since 2009.
- 54% of businesses were found to have at least one T12 lamp, indicating that many businesses have T12s but that these lamps are generally being replaced with higher efficiency lamps on burnout.

- 40% of the pre-2009 bulbs are 700-Series or first-generation T8s; 16% of linears purchased from 2009 to 2011 were 700-Series T8s and only 1% of linears purchased 2012-14 were first-generation T8s.

- During the 2012-2014 period, purchases of base efficiency lamps (lamps in the T12, 700 or 800-Series T8 groups) were largely 800-Series T8s.

- High-efficiency linear lamp purchases prior to 2012 tended to be Tier 1 T8s or T5s.
  - Prior to the CEE reclassification of high-efficiency lamps into tiers, high-efficiency T8s were classified as high performance and reduced wattage T8s. The reclassification into tiers moved many of the high performance T8 lamps into the Tier 1 classification and reduced wattage lamps into Tier 0. The tier classifications are dependent on lumens-per-watt calculations and lamps previously classified as high-performance generally have higher lumens per watt.

- The rising importance of Tier 2 LED lamps is clearly illustrated in the data.
  - 18% of purchases from 2012 to 2014 were Tier 2 LED lamps. Almost no linear LEDs were found to have been purchased prior to 2012.

- PA-sponsored energy efficiency programs should continue to focus on increasing the share of Tier 2 LED lamps and on educating customers on the benefits of these lamps relative to older 800-Series T8 lamps.

- These data indicate that businesses with less than 500,000 kWh annual electricity consumption have a large share of their linear lamps as T12s (20%) and 700-Series T8s (49%) and their recent purchase data indicates that they purchase the largest share of 700-Series T8 lamps (13%).

- In contrast, businesses with less than 500,000 kWh annual electricity consumption have the largest share of 800-Series T8s in their existing stock and recent purchases. Businesses with consumption 500,000-4,500,000 and over 4,500,000 kWh were observed to have (36% and 60%, respectively), and to purchase (40% and 48%, respectively), a large share of their linears as 800-Series T8 lamps.

- If T12, 700-Series and 800-Series T8s are grouped together as base efficiency linear lamps, customers with less than 500,000 kWh annual consumption have the highest share of base efficiency linears in their existing stock and the lowest share in their recent purchases.
  - Customers with over 4,500,000 kWh purchased the highest share of base efficiency lighting between 2009 to 2014 at 48% while customers with 500,000 to 4,500,000 purchased 44% base linears.

Table 3-1 illustrates the maturing distribution of high-efficiency linear lamps (Tier 0-2 and T5 lamps). Customers with 500,000 to 4,500,000 kWh have the largest share of high-efficiency T8 lamps (36%), while customers with annual consumption of less than 500,000 kWh and customers with annual consumption above 4,500,000 kWh have 21% and 24%, respectively. The recent purchase distribution differed substantially by customer usage category.

- Customers with less than 500,000 kWh had the largest shares across the various customer size distribution of recently purchased Tier 2 LED (17%). The very low share of base efficiency linear lamps purchased by smaller customers implies that these customers will have a higher share of their purchases represented in the high-efficiency lighting.

- Customers with 500,000 to 4,500,000 kWh also have a high share of recently purchased Tier 2 LED linear lamps (13%) while customers with more than 4,500,000 kWh appear to be purchasing Tier 1 linears as their high-efficiency choice.
PA-sponsored upstream lighting programs incorporated LED linear lamps in 2015; the large share of Tier 1 linears purchased by larger customers during 2009-2014 partially represent the lamps incentivized by the program.

The PAs may consider developing an aggressive custom lighting retrofit approach that can be expedited at a time when large customers would normally re-lamp to ensure that all cost effective retrofits are addressed.

**Table 3-1: Linear efficiency distribution by business kWh usage 4-ft linear lamps – interior lighting**

<table>
<thead>
<tr>
<th>Linear Efficiencies</th>
<th>Existing Stock</th>
<th>Linear Purchased 2009 to 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>500,000 kWh</td>
<td>500,000 - 4,500,000 kWh</td>
</tr>
<tr>
<td>T12</td>
<td>20%</td>
<td>2%</td>
</tr>
<tr>
<td>700 Series700-Series T8</td>
<td>49%</td>
<td>17%</td>
</tr>
<tr>
<td>800 Series800-Series T8</td>
<td>4%</td>
<td>36%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>4%</td>
<td>18%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>14%</td>
<td>14%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0.8%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>T5</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Other</td>
<td>1.3%</td>
<td>0.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**The existing stock data represent 276 sites in the <500,000 kWh category, 365 sites in the 500,000-4,500,000 kWh category and 97 sites in the >4,500,000 kWh category. The recent purchase data represent 84 sites in the <500,000 kWh category, 126 sites in the 500,000-4,500,000 kWh category and 28 sites in the >4,500,000 kWh category.

Aggregate efficiency distribution of linear lamps was also analyzed by business type. For this analysis, T12 and 700 and 800-Series T8s are classified as base efficiency lamps while Tier 0-2, Tier 2 LED, and T5 are classified as high-efficiency linears. Figure 3-3 illustrates the efficiency distribution of linears by business type.

- Analyzing linear lamps by business type the five business types with the highest share of linears include: offices with 21% of linears in Massachusetts businesses, 20% in retail, 16% in education, 12% in other, and 9% in public assembly (see Figure 3-8).
- Of the five businesses with the highest share of linears, 94% of linears in public assembly are base efficiency (T12, 700 and 800-Series T8), 88% in retail, 86% for offices, 49% in other businesses, and 35% in education.
- In public assembly, 51% of linear lamps are T12. Other segments with high shares of T12s include manufacturing and industrial (23%) and lodging (20%).
- For offices and retail, the high share of base efficiency linears is largely 700-Series T8s.
- PA-sponsored programs should target information and incentive programs at public assembly, retail and offices to encourage the replacement of inefficient linear lamps with Tier 2 fluorescent and TLED lamps.

- High-efficiency technologies. The large share of high-efficiency linears in these segments clearly indicates that high-efficiency technologies are readily available.

**Figure 3-3: Linear lighting by business type and linear efficiency groupings**

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.*

**These data represent 35 sites for campuses, 78 education sites, 46 food sales, 60 food service sites, 59 healthcare sites, 20 hospitals, 51 lodging sites, 80 manufacturing or industrial sites, 115 offices, 53 other businesses, 68 sites for public assembly, 70 retail sites, and 30 warehouses.*

Incandescent, CFL, LED, and halogen lamps (ICLH) account for approximately 25% of indoor lamps in Massachusetts businesses. ICLH lamps are often associated with task and accent lighting within businesses (see Figure 3-5 below).

- Incandescent lamps, a base efficiency technology, account for 6% of the roughly 25% of existing stock of lighting.
• CFL and LED (non-tubular) lamps, high-efficiency options, account for 11% and 7% of the roughly 25% of existing stock of lamps respectively.

• CFLs represent only 3% of recently purchased lamps while LED represent 18% of recent purchases with linears representing the majority of recent purchases (see Figure 3-49).

• These data indicate that Massachusetts businesses are knowledgeable about the benefits of LEDs and are increasing the share of LED lamps in their task and accent lighting. The PA-sponsored program should continue to support the replacement of incandescent, and halogen lamps with LEDs.

The efficiency distribution of ICLH lamps was analyzed by business type and is shown in Figure 3-4.

The businesses with the largest share of ICLH lamps include: public assembly with 23% of ICLH lamps in Massachusetts businesses, 20% in lodging, 13% in food service, 12% in offices, 10% in retail and 10% in other (see Figure 3-16). The businesses with the largest share of recently purchased ICLH lamps include food service with 24%, public assembly with 20%, offices with 14%, and lodging and other businesses with 12% each (see Figure 3-59).

• Food service was found to have the highest share of inefficient incandescent lamps at 66% of their ICLH lamps (see Figure 3-4). Public assembly also has a high share of incandescent lamps at 33% of their ICLH lamps.

• Warehouses and food sales have a large share of non-tubular LEDs (61% and 48% respectively), but they have few ICLH lamps.

• Lodging and campuses have the highest share of CFL lamps, at 79% and 72%, respectively.

• Food service likely has a large average hourly usage for their ICLH lamps, increasing the likelihood that switching from incandescent to LED may be cost effective and offer high levels of energy savings. The potentially lower hours of use for lodging and public assembly may reduce the energy savings potential in these segments relative to food service customers. The large share of incandescent lamps in public assembly, however, may warrant additional focus from PA-sponsored programs.
ICLH lamps were analyzed by customer size. Table 3-2 lists the distribution of ICLH lamps by customer size.

- Businesses with annual kWh consumption between 500,000 and 4,500,000 kWh have a larger share of incandescent bulbs (31%) compared to businesses with less than 500,000 annual kWh (23%) and businesses with more than 4,500,000 kWh (4.5%).  
  - 27% of ICLH bulbs are in businesses with 500,000 to 4,500,000 kWh and 66% are in businesses with less than 500,000 kWh. Savings potential for LED replacements exists in these size segments.
- LEDs represent 41% of ICLH lamps for businesses with more than 4,500,000 annual kWh, 27% for businesses with 500,000 kWh to 4,500,000 annual kWh, and 21% businesses with less than 500,000 annual kWh.  
  - LEDs have made substantial inroads into the ICLH lighting in Massachusetts, with businesses with larger annual kWh consumption leading the transition to LEDs. Given the dominance of ICLH lighting in businesses with less than 4,500,000 annual kWh consumption, PA-sponsored programs targeting
the installation of LEDs in businesses with annual kWh below 4,500,000 may produce lighting savings.

**Table 3-2: ICLH distribution by business kWh Usage – interior lighting**

<table>
<thead>
<tr>
<th>ICLH Efficiencies</th>
<th>&lt; 500,000 kWh</th>
<th>500,000 - 4,500,000 kWh</th>
<th>&gt; 4,500,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent</td>
<td>23%</td>
<td>31%</td>
<td>4.5%</td>
</tr>
<tr>
<td>CFL</td>
<td>44%</td>
<td>41%</td>
<td>48%</td>
</tr>
<tr>
<td>LED</td>
<td>25%</td>
<td>27%</td>
<td>41%</td>
</tr>
<tr>
<td>Halogen</td>
<td>8%</td>
<td>1.6%</td>
<td>6.4%</td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight.

**The existing stock data represent 264 sites in the <500,000 kWh category, 323 sites in the 500,000-4,500,000 kWh category, and 87 sites in the >4,500,000 kWh category.

The lighting field data collection also collected information on lighting controls.

- The analysis of lighting and lighting controls found that 77% of the existing stock of interior lighting is manually controlled. Looking exclusively at interior lamps purchased since 2009, 70% of lamps are manually controlled.
  - An increasing share of lamps are controlled by a device other than a switch.
  - Substantial energy savings potential may be achievable if a higher share of lamps could be converted from manual control to a more active automated control type.
- Photo cells, time clocks or photo cells with time clocks are used to control 33% of the existing stock of interior incandescent lamps and 13% of HID. Looking at interior lamps purchased since 2009, 50% of HID are controlled by photo cells, time clocks, or photo cells with time clocks.
  - An increasing share of interior HID, typically a relatively high wattage bulb, are controlled. These lighting controls have the potential to substantially reduce the lighting electricity usage for customers.

The following sections provide additional findings and details associated with the highlights listed above. The lighting section includes additional information on linear lighting, ICLH, lighting controls, exit signs, and exterior lighting.

### 3.2 Interior lighting data

Table 3-3 provides a count of the interior lighting types surveyed by business type. The table also provides a count of on-site surveys completed for specific lighting technologies. These data provide some indication of the different types of interior lighting technology currently used in Massachusetts businesses.

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41 Data was collected at 800 customer sites but interior lighting information was collected at 794 customer sites.
Table 3-3: On-site survey lighting type site counts by business type – interior lighting

<table>
<thead>
<tr>
<th>Business type</th>
<th>Total count</th>
<th>Linear</th>
<th>CFL</th>
<th>LED</th>
<th>Incandescent</th>
<th>Halogen</th>
<th>Hid</th>
<th>Neon</th>
<th>Other lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>35</td>
<td>30</td>
<td>21</td>
<td>12</td>
<td>5</td>
<td>13</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Education</td>
<td>78</td>
<td>78</td>
<td>53</td>
<td>31</td>
<td>13</td>
<td>10</td>
<td>19</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Food sales</td>
<td>46</td>
<td>46</td>
<td>23</td>
<td>21</td>
<td>14</td>
<td>4</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>60</td>
<td>38</td>
<td>30</td>
<td>36</td>
<td>20</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>59</td>
<td>46</td>
<td>22</td>
<td>37</td>
<td>13</td>
<td>6</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>20</td>
<td>16</td>
<td>14</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Lodging</td>
<td>59</td>
<td>51</td>
<td>49</td>
<td>42</td>
<td>29</td>
<td>12</td>
<td>9</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>81</td>
<td>80</td>
<td>28</td>
<td>19</td>
<td>22</td>
<td>8</td>
<td>22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Office</td>
<td>116</td>
<td>115</td>
<td>73</td>
<td>42</td>
<td>43</td>
<td>21</td>
<td>15</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>53</td>
<td>35</td>
<td>19</td>
<td>24</td>
<td>9</td>
<td>12</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>68</td>
<td>54</td>
<td>40</td>
<td>37</td>
<td>22</td>
<td>12</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>70</td>
<td>36</td>
<td>26</td>
<td>29</td>
<td>9</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>30</td>
<td>14</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>794</td>
<td>765</td>
<td>495</td>
<td>337</td>
<td>310</td>
<td>140</td>
<td>143</td>
<td>13</td>
<td>22</td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.

**The counts indicate the number of instances the technology was found in the buildings that were visited.

***4 sites were omitted from the lighting analysis due to questions on data quality, 1 site only had exterior lighting, and 1 site (account) was only associated with mechanical equipment.

Our analysis of the lighting data begins by focusing on lighting in the aggregate by presenting information on the saturation of the different lighting technologies. Figure 3-5 illustrates the weighted shares of lighting technologies as a percentage of total interior lamps found in businesses. As depicted, just over 74% of all C&I lamps are linear technologies, followed by CFLs at 11% of lamps and LEDs at 7%.42

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42 Linear lamps include traditional linear fluorescent and tubular LEDs. Tubular LEDs account for 2.65% of linear lamps or 2% of all lamps.
*The results presented above are weighted using the respondent-level sample weight.

**These data represent lamp count data from 765 sites with linear lighting, 495 sites with CFLs, 310 sites with incandescent, 140 sites with halogen, 337 sites with LEDs, 143 sites with HIDs, 13 sites with neon and 22 sites with other lighting.

***Linear technologies include linear fluorescents and tubular LEDs.

Figure 3-6 illustrates the share of lamps by interior lighting technology and business type. These data indicate that linear fluorescents are the dominant lamp type for most business types. Massachusetts offices have the highest number of linear lamps, but linear lamps represent the largest share of lamps within the manufacturing and industrial (95%) and education (93%) segments. The observed linear lamps also represented multiple efficiency levels or generations of technology. Section 3.2.1 provides information on the different efficiency levels of the observed linear lighting and illustrates the distribution of these lamps in Massachusetts businesses.

Food service has a high share of incandescent (52%) and LED (19%) lamps. The high share of incandescent and LED lamps in food service may reflect a desire for a specific lighting color. Lodging has a high share of CFL (55%) and LED (15%) lamps. The high share of CFL and LEDs in lodging may indicate that this segment is an early adopter of technology and/or that labor costs associated with lamp replacement on burn-out in this segment has led to early adoption. For many lighting applications, LEDs are a substitute for incandescent and CFL lamps. While the current baseline of lamps in the food service and lodging segments lend support to the hypothesis that these customers are in the process of moving from incandescent and CFL lamps to LEDs, substantial potential for LEDs remains. There is also a lot of room for LEDs to be used in campuses and healthcare and public assembly sites where CFLs and incandescent lamps account for 20% or more of the current interior lighting technologies. More information on recent purchases of incandescent, CFL, and LED lamps is provided in Section 3.2.7.
Figure 3-6: Distribution of lamps by technology type and business type – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 35 sites for campuses, 78 education sites, 46 food sales, 63 food service sites, 62 healthcare sites, 20 hospitals, 59 lodging sites, 81 manufacturing or industrial sites, 116 offices, 59 other businesses, 73 sites for public assembly, 72 retail sites and 30 warehouses.

Figure 3-7 illustrates the distribution of lamps by technology type and business annual electricity consumption. These data indicate that linear technologies dominate the distribution of lamps for all business sizes; businesses whose annual electricity consumption exceeds 4,500,000 kWh have the largest share of linear lamps (83%) while businesses consuming less than 500,000 kWh or 500,000 – 4,500,000 kWh have linear lamp technologies in approximately 73% of their lighting applications. Few Massachusetts businesses with annual electricity consumption in excess of 4,500,000 kWh have a substantial number of incandescent
lamps. CFL and incandescent lamps are slightly more common in businesses with less than 500,000 kWh annually (12% CFL and 6% incandescent) and 500,000 – 4,500,000 kWh (11% CFL and 8% incandescent) than businesses with consumption in excess of 4,500,000 kWh (9% CFL and 1% incandescent). The larger incidence of incandescent bulbs in businesses with annual consumption below 4,500,000 is consistent with their larger incidence in food service and public assembly (illustrated in Figure 3-6), as these business types do not commonly consume more than 4,500,000 kWh annually. The share of interior lighting associated with non-tubular LED lamps is 7% across all business consumption sizes analyzed for this study.

**Figure 3-7: Distribution of lamps by technology type and business kWh usage – interior lighting**

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 312 sites in the <500,000 kWh category, 380 sites in the 500,000-4,500,000 kWh category and 102 sites in the >4,500,000 kWh.

### 3.2.1 Linear fluorescent lighting

Linear lighting was a focus of this study due to their dominance in most business types. Linear technologies have also been a significant focus of energy efficiency programs in Massachusetts and affected by recent code updates. Figure 3-8 illustrates the distribution of all linear lamps across business types, while Figure 3-9 provides similar information by business annual consumption. These figures provide perspective on the relative magnitude of the distributions. As shown below, offices comprise the greatest share of linear lamps of any business type, with 21% of all linear lamps installed in this segment. The retail segment has 20% of all linear lamps while education has 16%.
The results presented above are weighted using the respondent-level sample weight. Lamps represent all linear lighting.

These data represent 35 sites for campuses, 78 education sites, 46 food sales, 60 food service sites, 59 healthcare sites, 20 hospitals, 51 lodging sites, 80 manufacturing or industrial sites, 115 offices, 53 other businesses, 68 sites for public assembly, 70 retail sites, and 30 warehouses.

Analyzing the distribution of linear lighting by business annual kWh consumption, the numerous businesses with annual consumption less than 500,000 kWh have 63% of the linear lamps installed in Massachusetts businesses. While businesses with annual electricity consumption in excess of 4,500,000 kWh tend to have a higher volume of lamps per business, there are sufficiently fewer large businesses so they only account for 12% of the total share of indoor linear lamps. The business size groupings used for this study allocated Massachusetts business consumption into three equally sized groups, 1/3 of electricity consumption was less than 500,000 kWh, 1/3 was 500,000 to 4,500,000, and 1/3 of electricity consumption was in businesses.

The Customer Information Section of this report (Section 2) describes how customers with less than 500,000 kWh account for 32% of the non-residential electricity consumption but 97% of the non-residential customers. The dominant share of customers contributes to these customers dominating the distribution of linear lamps.
with usage greater than 4,500,000. Finding that the linear lamps installed in businesses with at least 4,500,000 annual kWh account for only 12% of all indoor linear lamps implies that linear lighting accounts for a smaller share of electricity consumption in larger businesses than in smaller businesses (where 1/3 of business electricity consumption is associated with 63% of linear lamps). This finding is not surprising, since many businesses with larger electricity consumption have non-lighting end uses and technologies that consume substantial energy but are not common in businesses with less electricity consumption.

Figure 3-9: Distribution of linear lamps by business kWh usage

*The results presented above are weighted using the respondent-level sample weight. Lamps represent all linear lighting.
**These data represent 292 sites in the <500,000 kWh category, 374 sites in the 500,000-4,500,000 kWh category and 99 sites in the > 4,500,000 kWh category.

3.2.2 Saturation of linear lamps by performance group

Traditionally, linear lamps have been described as T12, T8, and T5 lamps. T12 lamps represent older technologies with higher wattages while T8 and T5 lamps represent newer, more efficient forms of lighting. Figure 3-10 illustrates the distribution of all types and lengths of linear lamps in Massachusetts businesses, disaggregated by their T12, T8, T5, and TLED classifications. The current distribution of linear lighting in Massachusetts is largely T8 lamps (72%); T12 lamps represent 14% of linear lighting, T5 lamps are 6%, and TLEDs (including linear LED fixtures) make up only 3% of current linear lamps.

44 The Other efficiency grouping includes T10s and other types of linear lighting not already highlighted.
Figure 3-10: High-level linear distribution by lamp type – interior lighting

![Pie chart showing lamp type distribution](chart_image)

*The results presented above are weighted using the respondent-level sample weight. Lamps represent all linears.

**These data represent 765 sites.

Figure 3-11 shows the distribution of 4-ft linear lamp types. Not surprisingly, 79% of all 4-foot linear lamps found in Massachusetts businesses are T8s and 12% are T12s.
As shown in the figures above, T8 lamps are the most common type of linear lighting in Massachusetts businesses. 4-foot T8 lamps represent a wide range of technologies and efficiency levels which can be disaggregated into five levels of efficiency based on classifications using lookups of the manufacturer make and model numbers. Make and model lookups develop crucial secondary information needed to classify the efficiency level of 4-foot linear lamps. The improved lighting output (efficacy) and CRI allow customers to use either fewer lamps, lower ballast factors, or fewer fixtures when moving from first-generation T8 lamps to higher efficiency lamps. We note that the classification of T8 lamps does incorporate TLED linears as the CEE 4-foot efficiency levels include the highest efficiency linear fluorescent and TLED linears in their highest efficiency tier.

The on-site form used for this study was designed to collect the make, model, size specifications, and wattage information of linear bulbs in order to provide the data necessary to conduct the efficiency lookups. Lookup tables were then developed using the data collected on-site to determine the efficiency level of the observed linear technologies.

---

*The results presented above are weighted using the respondent-level sample weight. Lamps represent 4 foot linears.

**These data represent 738 sites.

45 This section of the report uses the common term efficiency to represent what lighting designers would term efficacy. These two terms are very similar for lighting applications, with efficiency used by the wider community and efficacy used by lighting designers and other professionals.

46 CRI is a measure of a lamp's ability to render color the same as sunlight. A CRI of 100 is equivalent to sunlight's rendering. An incandescent bulb typically has a CRI of 95. Higher CRI values are typically associated with better lighting characteristics.

47 Linear lighting energy usage is dependent on the ballast factor. The field data collection was not able to collect extensive information on ballast factors. The analysis of ballasts is limited and presented later in this section.
The final step of the make and model lookups is allocating the 4-foot linear technologies to one of seven performance groups in order of highest to lowest efficiency. These technologies were also classified as being either high or base efficiency. Information on the allocation of linear lamps high and base efficiency categories is shown below.

**High efficiency technologies:**

- **Tier 2:** 4-foot T8 Lamps with an efficacy, lumens per watt, of 100 and lamp life greater than or equal to 50,000 hours. This category includes very high efficacy fluorescent bulbs and TLED replacements for linear fluorescents. The TLED bulbs can fit into the same fixture housing as the linear fluorescent bulbs. The average wattage for linear fluorescents was 25 watts and 24.6 watts for TLEDs, indicating a probable greater TLED light output. Lamps found in this efficiency tier are reported under two separate categories – Tier-2 T8s and Tier-2 LEDs.
- **T5:** T5 lighting systems. Based on make and model lookups, the lamps were found to have a wattage range of 28 to 54 watts and have an average wattage of 29 watts. The wide range of wattage is due to standard and high output T5 lamps.
- **Tier 1:** 4-foot T8 Lamps with an efficacy (lumen per watt) of 95, and lamp life greater than or equal to 36,000 hours. Prior to recent updates in the classification system, many of these bulbs were classified as high performance linear lamps. The average wattage was 29.4 watts.
- **Tier 0:** 4-foot T8 Lamps with an efficacy (lumen per watt) of 90 and lamp life greater than or equal to 24,000 hours. Prior to recent updates in the classification system, many of these bulbs were classified as reduced wattage linear lamps. The average wattage was 28.7 watts.

**Base efficiency technologies:**

- **Standard 800-Series T8 lamps also designated as Second Generation T8 Lamps:** These lamps are traditionally 32 watt lamps with initial lumens 2,800-3,000 lumens, 82-86 CRI, and 20,000-24,000 hour rated life. For this study, the median mean lumens observed for Second Generation T8 lamps was 2,773. The efficacy is 87 lumens/watt and the averaged observed wattage was 31 watts.
- **Standard Series 700 T8 lamps also designated as First-generation T8 Lamps:** These lamps usually provide an initial lumens of at most 2,800, use 32 watts, have a CRI of 75-78 and typically have a 15,000-20,000 hour life rating. Lamps found in this study have a median mean lumens of 2,520. First-generation T8 lamps have the lowest lumens and shortest life of any T8 lamp with an efficacy of 79 lumens/watt.

**T12:** These are T12 bulbs, which were phased out of production as of July 2012, but are still available or in storage. The average wattage of 4-foot T12 lamps observed during the field data collection was 38 watts. Table 3-4 lists the efficiency and lamp length shares for linear technologies. The T8 technologies are allocated to 700-Series (First-generation), 800-Series (Second Generation), and Tier 0, 1, and 2 high-efficiency T8 lamps for the 4-foot lamps. The T8 8 foot and other length lamps continue to be grouped into one classification. The CEE classification of T8s into high-efficiency Tier 0-2 are 4-foot specific, limiting the study’s ability to disaggregate T8s of other lengths.

Table 3-4 illustrates that T8 lamps account for the largest share of linear lamps (72%), with eight foot T8s accounting for 2% of linear lamps, 64% are 4-foot T8s and 4% are T8s of other lengths. Ten percent of linear lamps are 4-foot T12 lamps and 4% are eight foot T12 lamps while 4-foot T5s account for 5% of linear lamps but T5s are relatively uncommon in eight foot lengths.
Table 3-4: Linear efficiency distributions for 4-foot, 8-foot, and other linear lamps – interior lighting

<table>
<thead>
<tr>
<th>Linear efficiency and size</th>
<th>On-site percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12, 8 Feet</td>
<td>4%</td>
</tr>
<tr>
<td>T8, 8 Feet</td>
<td>2%</td>
</tr>
<tr>
<td>T5, 8 Feet</td>
<td>0.4%</td>
</tr>
<tr>
<td>LED, 8 Feet</td>
<td>0.0%</td>
</tr>
<tr>
<td>T12, 4 Feet</td>
<td>10%</td>
</tr>
<tr>
<td>700 Series700-Series T8, 4 Feet</td>
<td>28%</td>
</tr>
<tr>
<td>800 Series800-Series T8, 4 Feet</td>
<td>18%</td>
</tr>
<tr>
<td>Tier 0, 4 Feet</td>
<td>6%</td>
</tr>
<tr>
<td>Tier 1, 4 Feet</td>
<td>12%</td>
</tr>
<tr>
<td>Tier 2, T8 4 Feet</td>
<td>1%</td>
</tr>
<tr>
<td>Tier 2, LED 4 Feet</td>
<td>2%</td>
</tr>
<tr>
<td>T5, 4 Feet</td>
<td>5%</td>
</tr>
<tr>
<td>Other, 4 Feet</td>
<td>0.6%</td>
</tr>
<tr>
<td>T12, Other Length</td>
<td>0.3%</td>
</tr>
<tr>
<td>T8, Other Length</td>
<td>4%</td>
</tr>
<tr>
<td>T5, Other Length</td>
<td>0.9%</td>
</tr>
<tr>
<td>LED, Other Length</td>
<td>0.5%</td>
</tr>
<tr>
<td>Other, Other Length</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 765 sites.

Given that the focus of the linear lamp efficiency disaggregation is on the characterization of T8 lamps into their five efficiency types and the most prevalent size is 4 feet, the remaining existing stock linear lamp analysis will focus on 4-foot linear technologies. In Table 3-4 above, 82% of linear fluorescents are four feet in length; 7% are eight feet in length and 11% are a length other than four or eight feet. The following sections provide additional detail on the 4-foot linear lamps.
Table 3-5 and Figure 3-12 present the efficiency distribution of 4-foot linear technologies. The efficiency analysis for linear technologies relies on the on-site data collection of make and model numbers in order to classify T8 lamps as Standard 700-Series, Standard 800-Series, Tier 0, Tier 1, or Tier 2. If the make and model numbers were not collected for linear lamps, the study was only able to describe the lamps as T12, T5, TLED, or T8. As previously noted, the CEE classification includes TLEDs in the Tier 2 group of T8 lamps. As such, given the ease of distinguishing an LED linear, these lamps were classified as Tier2 T8 lamps regardless of the availability of make and model numbers. This approach is similar to the classification approach used for T12 and T5 lamps.

4-foot linear technology data is presented in Table 3-5. The second column in Table 3-5 provides the distribution of T8s based on the on-site data collection effort, including those that could not be categorized. During the data analysis, it was found that Tier 2 T8 lamps were approximately 95% LED linears and 5% very high-efficiency linear fluorescents.

Table 3-5 indicates that approximately 12% of 4-foot linear technologies were T12 lamps, evidence that most Massachusetts businesses have replaced most of their 4-foot T12 lamps with newer, more efficient technologies. The finding that relatively few T12 lamps remain implies that most Massachusetts businesses have updated to T8 technologies, likely leading to a decline in their overall lighting electricity consumption.

Table 3-5 illustrates that 700-Series T8s are the most common 4-foot T8 (34%) identified in Massachusetts businesses. The second most common T8 is the second generation 800-Series T8 (22%). Combined, T12s and 700 and 800-Series T8s, lamps either below current standards (T12, 700-Series T8s) or at standard (800-Series T8s) are estimated to account for 68% of 4-foot linear lamps in Massachusetts businesses. This result suggests that while there have been significant achievements with regards to adoption of T8 technologies in Massachusetts, significant savings potential remains.

Previous research undertaken by CEE has shown that lamp and ballast combinations using Tier 0 and Tier 1 high-efficiency T8 lamps use approximately 20% less energy than first-generation systems through a combination of fewer lamps, lower ballast factors, and/or fewer fixtures. However, TLEDs in the Tier 2 classification show the greatest promise for per lamp savings in the future. CEE reports that TLEDs "represent the market with the single greatest potential for energy savings if there were a complete switch to LEDs."49

The on-site data showed that 2.7% of linear lamps could be classified as Tier 2 TLED lamps and 0.8% are Tier 2 linear fluorescents. The relatively small share of linears classified as Tier 2 suggests that PA-sponsored energy efficiency programs could realize substantial energy savings by encouraging customers to switch from T12 and base efficiency fluorescent T8s to TLED and Tier 2 linear fluorescents.

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48 While 4-foot T12 lamps account for only 12% of 4-foot linear technologies, many businesses have at least one T12. Looking across all T12 lamps regardless of length, 55% of businesses in Massachusetts have at least one T12. Focusing exclusively on 4-foot T12s, 45% of businesses have at least one T12. These numbers imply that many businesses are likely waiting for the lamps to burn-out to replace remaining T12 lamps.

3.2.3 Four foot linear lamp efficiency and business size

Analyzing linear lamp efficiency by business size can help identify businesses with the greatest savings potential.
Table 3-6 and Figure 3-13 present the 4-foot linear technology efficiency distribution by business annual kWh size. These data indicate that businesses with annual consumption of less than 500,000 kWh are substantially more likely to have 4-foot T12 lamps than businesses with higher annual electricity consumption. Eighteen percent of linear lamps in businesses with annual consumption below 500,000 kWh are T12s. Businesses with lower annual electricity consumption were also more likely to have first-generation T8s (49% of their linear lamps) compared to 800-Series T8s (which comprise 4% of linear lamps). Combining the base technology linear lamps, the study estimates that 73% of linear lamps in businesses with annual consumption of less than 500,000 kWh are T12 or 700 and 800-Series T8s. This finding is significant because it indicates that existing T12s are largely found in businesses with lower annual energy consumption and that these smaller businesses also have a substantial share of base efficiency T8s. This finding indicates that PA-sponsored programs have the potential to help these businesses move directly from an older, less efficient technology (T12s, 700 and 800-Series T8s) to highly efficient Tier 2 T8s (that includes both fluorescents with extremely high efficacy and TLEDs).

As seen in Table 3-6, businesses with annual consumption of 500,000 – 4,500,000 kWh and more than 4,500,000 kWh have only 2% of their linear lighting in T12 lamps. In the largest business size (4,500,000 kWh and higher), 67% of their linear lamps are first and second generation T8s (700 and 800-Series). For businesses with 500,000 to 4,500,000 kWh, the study identified 55% of their linears as T12s or early generations of T8s. The largest businesses, based on annual energy consumption, have a higher observed share of less efficient T8s than the two other business size categories. The larger share of first and second generation T8s in businesses with annual consumption above 4,500,000 kWh may provide the PA-sponsored energy efficiency programs with a savings opportunity associated with replacing less efficient T8s with Tier 1 and Tier 2 T8 and TLED lamps.

Businesses with annual consumption below 500,000 kWh annual electricity consumption and businesses with 500,000 to 4,500,000 kWh had 3% and 4% of their linear lighting as Tier 2 LEDs, the highest efficacy group. In contrast, businesses with more than 4,500,000 kWh have only 0.3% of their linears identified as Tier 2 LEDs during the on-sites. It is possible that the largest businesses were the first to switch T12 lamps for T8s, investing in first and second generation T8s and Tier 1 high-efficiency T8s. Businesses with less than 4,500,000 kWh may have switched out their T12s more recently, providing them with more options of higher efficiency lighting, including Tier 2 lamps.
### Table 3-6: Linear efficiency distribution by business kWh usage 4-ft linear lamps – interior lighting

<table>
<thead>
<tr>
<th>Linear efficiencies</th>
<th>&lt; 500,000 kWh</th>
<th>500,000 - 4,500,000 kWh</th>
<th>&gt; 4,500,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>20%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>700 Series700-Series T8</td>
<td>49%</td>
<td>17%</td>
<td>7%</td>
</tr>
<tr>
<td>800 Series800-Series T8</td>
<td>4%</td>
<td>36%</td>
<td>60%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>4%</td>
<td>18%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>14%</td>
<td>14%</td>
<td>21%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0.8%</td>
<td>0.0%</td>
<td>2%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>3%</td>
<td>4%</td>
<td>0.3%</td>
</tr>
<tr>
<td>T5</td>
<td>5%</td>
<td>8%</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>1.3%</td>
<td>0.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 276 sites in the <500,000 kWh category, 365 sites in the 500,000-4,500,000 kWh category and 97 sites in the > 4,500,000 kWh category.

### Figure 3-13: Linear efficiency distribution by business kWh usage – 4-ft linear lamps – interior lighting

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 276 sites in the <500,000 kWh category, 365 sites in the 500,000-4,500,000 kWh category and 97 sites in the > 4,500,000 kWh category.
3.2.4 Four foot linear lamp efficiency by business type

Understanding where T12s and inefficient first and second generation T8s are by business type can provide valuable information to help PA-sponsored programs target business segments with the highest need for linear lighting retrofits. Unfortunately, disaggregating the 738 customer sites where linear lighting data was collected into the 13 business types and nine efficiency categories (T12, 700-Series T8, 800-Series T8, Tier 0 T8, Tier 1 T8, Tier 2 T8, T5, Other, Unknown) would lead to very few records per category, potentially leading to conclusions that are not truly supported by the data.

In an attempt to provide information on the distribution of linear lamps by business type, while limiting the potential for the on-site data to misrepresent the true distribution of lighting in Massachusetts businesses, Figure 3-14 illustrates the distribution of an aggregated description of linear lamps by business type. The lighting in Figure 3-14 combines T12 lamps and base efficiency T8 lamps (base efficiency T8s include 700 and 800-Series T8s) and their linear lamps into one category. This group includes two lamp types that are below current linear standards (T12s and 700-Series T8s) and the lamp representing current linear standards (800-Series T8s). The high-efficiency T8 and T5 category is made up of lamps that currently exceed linear lighting standards (Tier 0-2 T8s, TLEDs and T5s). Figure 3-14 indicates that nearly all linear lamps in offices, public assembly, and retail are low and base efficiency linears. The data presented in Figure 3-8 showed that offices, retail, and public assembly account for 21%, 20% and 9% of the linear lamps in Massachusetts businesses, respectively. The substantial share of linear in offices, retail and public assembly, combined with the high share of lamps with low or base efficiency in this segment provides a potential target for PA-sponsored energy efficiency programs.
3.2.5 Four-foot linear lamp efficiency and energy efficiency program participation

Energy efficiency program participation may be associated with a higher likelihood that the business has more efficient linear technologies. The data presented in Table 3-7 indicate that businesses that have participated in PA-sponsored energy efficiency programs from 2011 to 2014 have a smaller share of T12 linear lighting (3%) relative to businesses that have not participated during this time period (15%). The substantially smaller share of T12 lighting in participant facilities may indicate that PA-sponsored programs have been effective at replacing inefficient lighting with more efficient options.

Figure 3-15 also shows that energy efficiency program participants have a larger share of their T8 lamps identified as second generation 800-Series T8s (42%) while non-participants have a larger share identified as first-generation 700-Series T8s (42%). The distribution of Tier 0 and Tier 1 T8 lamps is slightly skewed.

---

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 35 sites for campuses, 78 education sites, 46 food sales, 60 food service sites, 59 healthcare sites, 20 hospitals, 51 lodging sites, 80 manufacturing or industrial sites, 115 offices, 53 other businesses, 68 sites for public assembly, 70 retail sites and 30 warehouses.
toward participants with participants having 27% of their linear lighting in these high-efficiency categories while 20% of non-participant lighting is Tier 0 and Tier 1. The data for Tier 2 high-efficiency lines is disaggregated into Tier 2 fluorescent and Tier 2 TLED lamps. Participants are found to have a larger share of Tier 2 fluorescents lamps than non-participants while non-participants have a slightly larger share of TLED than participants.

Finding that the distribution of Tier 0-2 T8s is only slightly higher by PA-sponsored energy efficiency program participation may be due to the lack of upstream program data in this analysis. Upstream program participation is not tracked by customer account number, increasing the difficulty of matching participant data to specific customers. Since T8 lamps have been rebated through upstream programs in Massachusetts since 2011, future research will look at the share of Tier 0-2 T8 lamps incentivized by PA-sponsored energy efficiency programs including upstream program participants.

**Figure 3-15: Linear efficiency distribution by energy efficiency program participation, 4-foot linears – interior lighting**

*The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 317 EE participant sites, and 421 non-participant sites.

Table 3-7 lists the breakout of linear lighting efficiency by PA-sponsored energy efficiency program participation. The program participation identification used in Figure 3-15 indicated if the customer had participated in any PA-sponsored energy efficiency programs from 2011 to 2014. It further disaggregates program participation into those customers who received an incentive for installing a lighting measure (Energy Efficiency Participation – Lighting) and those who have received an incentive for installing a linear lighting measure (Energy Efficiency Participation – Linear Fluorescent). As the classification of the non-
participant sample changes from those not receiving any incentive (421 customers), to those not receiving a lighting incentive (486 customers) and then those not receiving a linear fluorescent incentive (582 customers) it increases in size while the size of the participant sample declines.

The more narrowly-defined specification of the energy efficiency program participation variable continues to maintain the observation that non-participants have a substantially larger share of T12 and 700-Series T8s than participant customers. Energy efficiency program participants appear to have less inefficient lighting and more high-efficiency lighting. Program participants, are shown to have a slightly higher share of Tier 2 linear fluorescents while the share of Tier 2 TLEDs is similar for participants and non-participants except for those with linear lighting participation. Across program participants and non-participants, however, the share of Tier 2 linear lighting is small, again highlighting the substantial lighting savings opportunity for PA-sponsored programs.

Table 3-7: Linear efficiency distribution by energy efficiency program participation, 4-ft linear lamps – interior lighting

<table>
<thead>
<tr>
<th>Linear efficiencies</th>
<th>EE participant</th>
<th>EE non-participant</th>
<th>Energy efficiency lighting participant</th>
<th>Energy efficiency lighting non-participant</th>
<th>Energy efficiency linear fluorescents participants</th>
<th>Energy efficiency linear fluorescents non-participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>3%</td>
<td>15%</td>
<td>3%</td>
<td>14%</td>
<td>6%</td>
<td>13%</td>
</tr>
<tr>
<td>700 Series700-Series T8</td>
<td>12%</td>
<td>42%</td>
<td>9%</td>
<td>40%</td>
<td>12%</td>
<td>36%</td>
</tr>
<tr>
<td>800 Series800-Series T8</td>
<td>42%</td>
<td>14%</td>
<td>42%</td>
<td>17%</td>
<td>35%</td>
<td>20%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>10%</td>
<td>6%</td>
<td>11%</td>
<td>6%</td>
<td>17%</td>
<td>6%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>17%</td>
<td>14%</td>
<td>15%</td>
<td>15%</td>
<td>5%</td>
<td>16%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>3%</td>
<td>0.0%</td>
<td>4%</td>
<td>0.0%</td>
<td>4%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>2%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>T5</td>
<td>10%</td>
<td>5%</td>
<td>12%</td>
<td>5%</td>
<td>15%</td>
<td>5%</td>
</tr>
<tr>
<td>Other</td>
<td>0.1%</td>
<td>1%</td>
<td>0.2%</td>
<td>0.9%</td>
<td>0.0%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The results presented above are weighted using the respondent-level sample weight. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 317 EE participant sites, and 421 EE non-participant sites, 252 Lighting EE program participant sites and 486 Lighting EE program non-participant sites, and 156 Linear Fluorescent EE program Participant Sites and 582 Linear Fluorescent EE program non-participant sites.

3.2.6 Linear ballasts

Magnetic ballasts were identified mainly in older, T12 linear fixtures. No T5 or TLED fixtures have magnetic ballasts and only a small share of T8 lamps (<1%) utilized these ballasts.

Table 3-8 details the distribution of ballasts by linear technology.

Table 3-8: Ballast type by lamp type for 4-foot linears - interior lighting

| Lamp type | Electronic ballast | Magnetic ballast | Unknown ballast |
|-----------|--------------------|------------------|----------------|--------------|
| T12       | 36%                | 60%              | 4%             |
The results presented above are weighted using the respondent-level sample weight.

**These data represent 705 sites.

Table 3-9 provides the distribution of commercial 4-foot linear ballasts by business type, while Table 3-10 details the distribution by kWh usage categories. As evidenced in these tables, electronic ballasts dominate, with a share greater than 90% in most business types. Manufacturing, public assembly, and food service establishments have the highest share of magnetic ballasts however, at 21%, 25%, and 20%, respectively.

Table 3-9: Ballast type by business type for 4-foot linears – interior lighting

<table>
<thead>
<tr>
<th>Business type</th>
<th>Electronic ballast</th>
<th>Magnetic ballast</th>
<th>Unknown ballast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>95%</td>
<td>1%</td>
<td>4%</td>
</tr>
<tr>
<td>Education</td>
<td>98%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>96%</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Food Service</td>
<td>73%</td>
<td>20%</td>
<td>7%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>96%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>90%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Lodging</td>
<td>94%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>77%</td>
<td>21%</td>
<td>2%</td>
</tr>
<tr>
<td>Office</td>
<td>89%</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>Other</td>
<td>58%</td>
<td>3%</td>
<td>39%</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>72%</td>
<td>25%</td>
<td>2%</td>
</tr>
<tr>
<td>Retail</td>
<td>91%</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>95%</td>
<td>0%</td>
<td>4%</td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. Lamps represent 4-foot linears.

**These data represent 34 sites for campuses, 77 education sites, 40 food sales, 55 food service sites, 56 healthcare sites, 20 hospitals, 42 lodging sites, 75 manufacturing or industrial sites, 110 offices, 46 other businesses, 60 sites for public assembly, 63 retail sites and 27 warehouses.

Table 3-10 presents the distribution of ballast types by business electricity consumption categories. Only 1% of all sites in the >4,500,000 kWh usage category have magnetic ballasts, while 11% of the sites in the <500,000 kWh usage category have magnetic ballasts. These findings are consistent with results presented earlier that show that businesses with <500,000 kWh annual electricity consumption had a larger share of T12 lamps than other businesses. The dual finding of a larger share of magnetic ballasts and T12s in
businesses with <500,000 kWh provides an opportunity for PA-sponsored programs to target these businesses for high-efficiency lighting and ballast retrofits.

**Table 3-10: Ballast type by business kWh consumption for 4-foot linears – interior lighting**

<table>
<thead>
<tr>
<th>Business size</th>
<th>Electronic ballast</th>
<th>Magnetic ballast</th>
<th>Unknown ballast</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500,000 kWh</td>
<td>79%</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>500,000 - 4,500,000 kWh</td>
<td>97%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>&gt; 4,500,000 kWh</td>
<td>98%</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. Lamps represent 4-foot linears.

**These data represent 257 sites in the <500,000 kWh category, 352 sites in the 500,000-4,500,000 kWh category and 96 sites in the > 4,500,000 kWh category.

3.2.7 Incandescent, CFL, LED, and Halogen (ICLH) Lamps

The ICLH section presents information on incandescent, CFL, LED, and halogen technologies currently installed in businesses in Massachusetts. These lighting technologies have been grouped together because each of these technologies have similar lighting applications. The results reported combine indoor and outdoor lighting systems and do not include exit signs.

Figure 3-16 illustrates the distribution of ICLH lamps by business type. These data indicate that 23% of ICLH lamps are found in public assembly, 20% in lodging, and 13% in food service businesses.

---

51 The LEDs discussed in this subsection represent screw-in and pin based light bulbs and do not include linear or TLEDs.
Figure 3-16: ICLH distribution by business type – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 33 sites for campuses, 63 education sites, 40 food Sales, 60 food Service sites, 59 healthcare sites, 18 hospitals, 58 Lodging sites, 52 manufacturing or industrial sites, 98 offices, 50 other Businesses, 66 sites for public assembly, 56 retail sites and 21 warehouses.

Figure 3-17 illustrates the distribution of ICLH lamps by business kWh size. These data indicate that 27% of ICLH lamps are found in businesses with 500,000 to 4,500,000 kWh of annual electricity consumption and 66% in businesses with less than 500,000 annual kWh. As with linear lighting, there are more ICLH lamps in businesses with less kWh because there are substantially more businesses of this size in Massachusetts than businesses with more than 4,500,000 kWh and lighting likely accounts for a larger share of energy usage for smaller businesses than larger businesses.
**Figure 3-17: ICLH lamp count distribution by business kWh usage – interior lighting**

- 27% of lamps are in the < 500,000 kWh category.
- 66% are in the 500,000 - 4,500,000 kWh category.
- 7% are in the > 4,500,000 kWh category.

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 264 sites in the <500,000 kWh category, 323 sites in the 500,000-4,500,000 kWh category and 87 sites in the >4,500,000 kWh category.

### 3.2.8 ICLH saturation by performance group

Figure 3-18 presents the share of ICLH lamps in each technology group. CFLs have the largest share of ICLH lamps with approximately 44% of these lamp types. LEDs’ share, at 26%, exceeds the observed share of incandescent bulbs (24%).

---

52 Note that the shares of ICLH lamps represent the distribution across ICLH lamps, not all lamps. As shown in Figure 3-5, interior LEDs represent 7% of all indoor lighting but represent 26% of ICLH lamps.
3.2.9 ICLH distribution by business type

Figure 3-19 presents the distribution of ICLH lamps by business type. These data indicate LEDs comprise 40% or more of the ICLH lighting in food sales, offices, retail and warehouses. CFLs represent 50% or more of the ICLH lamps in campuses (72%), education (59%), healthcare (66%), hospitals (79%), lodging (71%) and manufacturing (65%). Incandescent lamps account for 30% or more of ICLH lamps in food services (66%) and public assembly (33%). Recalling that the largest share of ICLH lighting is in public assembly, lodging, and food service, the high incidence of incandescent lamps in two of these three segments implies that a PA-sponsored program targeting the replacement of incandescent bulbs with LEDs may realize substantial potential in public assembly and food service businesses.

Note that Figure 3-19 reflects the percentage of business types with a given ICLH lamp type.
3.2.10 ICLH distribution by business kWh usage

Figure 3-20 presents the distribution of ICLH lamps by business electric consumption. These data indicate that businesses with annual kWh consumption between 500,000 and 4,500,000 kWh have a larger share of incandescent bulbs (31%) compared to businesses with less than 500,000 annual kWh (23%) and businesses with more than 4,500,000 kWh (4.5%). Combining the relatively high incidence of incandescent bulbs in businesses with annual consumption below 4,500,000 kWh with the finding that 27% of ICLH bulbs are in businesses with 500,000 to 4,500,000 kWh and 66% are in businesses with less than 500,000 kWh leads to the conclusion that a savings potential for LED replacements remains in these size segments.

The on-site data also illustrates that LEDs represent a substantial share of ICLH lamps in Massachusetts businesses. LEDs represent 41% of ICLCH lamps for businesses with more than 4,500,000 annual kWh, 27% for businesses with 500,000 annual kWh to 4,500,000 annual kWh, and 21% for businesses with less than 500,000 annual kWh. LEDs have made substantial inroads into the ICLH lighting in Massachusetts, with businesses with larger annual kWh consumption leading the transition to LEDs. Given the dominance of ICLH lamps in businesses with lower annual kWh consumption, the potential for energy savings through LED replacements is significant.
lighting in businesses with less than 4,500,000 annual kWh consumption, PA-sponsored programs targeting the
installation of LEDs in medium and smaller-sized businesses may produce lighting savings.

**Figure 3-20: ICLH lamp distribution by business kWh usage – interior lighting**

* The results presented above are weighted using the respondent-level sample weight.
** These data represent 264 sites in the <500,000 kWh category, 323 sites in the 500,000-4,500,000 kWh category and 87 sites in the >4,500,000 kWh category.

### 3.2.11 ICLH distribution by energy efficiency program participation

Figure 3-21 illustrates the distribution of ICLH lamps by program participation. These graphs illustrate that businesses that have not participated in EE programs between 2011-2014 have a greater share of their ICLH lamps in CFLs (45%) as compared to participants (40%), but non-participants have a substantially smaller share of LED lamps (21%) than participants (47%). In addition, non-participants have a substantially higher share of incandescent bulbs (28%) than participants (6%). Program participation appears to be positively associated with the share of LED lamps and negatively associated with incandescent lamps. Given the very low share of incandescent bulbs among participants, there are very few inefficient bulbs for PA-sponsored programs to replace among participant customers. The programs need to focus on expanding the customer base participating in the programs to further reduce the share of incandescent bulbs. For this study, PA-
sponsored program participation focused on traditional downstream programs. Participation in upstream lighting energy efficiency programs was not included as participation for this study. Future research will look at the share of recent purchases of high-efficiency lighting that were incentivized through the up and downstream PA-sponsored energy efficiency programs.

**Figure 3-21: ICLH Lamp distribution by recent energy efficiency program participation – interior lighting**

![Bar chart showing ICLH lamp distribution by recent energy efficiency program participation.]

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 292 EE program participant sites, and 382 EE program non-participant sites.

### 3.2.12 ICLH distribution by lamp base

Table 3-11 presents the share of ICLH lamps in each technology/base group by business type. Focusing on the four segments with the highest share of ICLH lamps, these lamps are evenly distributed across medium screw base and pin base in public assembly (41% and 41%) and more likely to be medium screw base than pin for lodging (73% and 17%), and office (50% and 36%) and less likely to be medium screw than pin base for food service (21% and 59%). All four segments include a large share of these lamps that are neither medium screw or pin base. Warehouse, offices, and education have the largest share of hardwired LED bulbs. Bulbs with an "other" base are often screw based bulbs with a base size different from medium. Pin based CFL and LED bulbs and fixtures are often viewed as limiting the return to incandescent lighting as incandescent bulbs are less frequently found with a pin base.
### Table 3-11: ICLH lamp distribution by lamp base by building type – interior lighting

<table>
<thead>
<tr>
<th>Technology</th>
<th>Campuses</th>
<th>Education</th>
<th>Food Sales</th>
<th>Food Service</th>
<th>Healthcare</th>
<th>Hospitals</th>
<th>Lodging</th>
<th>Manufacturing or Industrial</th>
<th>Office</th>
<th>Other</th>
<th>Public Assembly</th>
<th>Retail</th>
<th>Warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Screw Based</td>
<td>28%</td>
<td>21%</td>
<td>34%</td>
<td>21%</td>
<td>38%</td>
<td>29%</td>
<td>73%</td>
<td>59%</td>
<td>50%</td>
<td>59%</td>
<td>41%</td>
<td>62%</td>
<td>22%</td>
</tr>
<tr>
<td>Pin Based</td>
<td>62%</td>
<td>57%</td>
<td>16%</td>
<td>59%</td>
<td>51%</td>
<td>63%</td>
<td>17%</td>
<td>35%</td>
<td>36%</td>
<td>34%</td>
<td>41%</td>
<td>24%</td>
<td>23%</td>
</tr>
<tr>
<td>Hard Wired LED</td>
<td>2%</td>
<td>11%</td>
<td>31%</td>
<td>1%</td>
<td>3%</td>
<td>6%</td>
<td>1%</td>
<td>5%</td>
<td>10%</td>
<td>4%</td>
<td>1%</td>
<td>5%</td>
<td>15%</td>
</tr>
<tr>
<td>Other54</td>
<td>8%</td>
<td>0%</td>
<td>17%</td>
<td>18%</td>
<td>5%</td>
<td>1%</td>
<td>9%</td>
<td>0%</td>
<td>2%</td>
<td>2%</td>
<td>12%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0%</td>
<td>11%</td>
<td>2%</td>
<td>1%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>5%</td>
<td>3%</td>
<td>37%</td>
<td></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 33 sites for campuses, 63 education sites, 40 food Sales, 60 food Service sites, 59 healthcare sites, 18 hospitals, 58 Lodging sites, 52 manufacturing or industrial sites, 98 offices, 50 other Businesses, 66 sites for public assembly, 56 retail sites and 21 warehouses.

54 Other lamp base types include plug-in LED ropes, fuse-type lamps and other obscure lamp types.
Table 3-12 presents the share of ICLH lamps in each base group by business kWh usage size categories. This analysis shows that medium screw-based lamps have the highest share of the ICLH lamps found in the <500,000 kWh size segment, while pin-based lamps have the highest share of the 500,000-4,500,000 kWh segment. Pin-based lamps have more than half of all ICLH lamps in the >4,500,000 kWh size businesses. Business with greater than 4,500,000 kWh have the largest share of hardwired LED bulbs.

Table 3-12: ICLH lamp distribution by lamp base by business kWh usage – interior lighting

<table>
<thead>
<tr>
<th>Technology</th>
<th>&lt; 500,000 kWh</th>
<th>500,000-4,500,000 kWh</th>
<th>&gt; 4,500,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium screw based</td>
<td>57%</td>
<td>33%</td>
<td>33%</td>
</tr>
<tr>
<td>Pin based</td>
<td>26%</td>
<td>60%</td>
<td>51%</td>
</tr>
<tr>
<td>Hard wired LED</td>
<td>3%</td>
<td>2%</td>
<td>11%</td>
</tr>
<tr>
<td>Other</td>
<td>11%</td>
<td>3%</td>
<td>6%</td>
</tr>
<tr>
<td>Unknown</td>
<td>3%</td>
<td>2%</td>
<td>0%</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 264 sites in the <500,000 kWh category, 323 sites in the 500,000-4,500,000 kWh category and 87 sites in the >4,500,000 kWh category.

3.3 Ballast replacement

During the on-site data collection, the site contact was asked whether they replace ballasts similar to the original fixtures or install higher efficiency ballasts. Table 3-13 and Table 3-14 provide the site contact responses to this question, disaggregated by business type, weighted by site counts and kWh usage respectively.

Table 3-13: Ballast replacement relative efficiency by business type, site weight – interior lighting

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Similar Efficiency</th>
<th>Increased Efficiency</th>
<th>Don't Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>66%</td>
<td>34%</td>
<td>0%</td>
</tr>
<tr>
<td>Education</td>
<td>33%</td>
<td>67%</td>
<td>0%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>40%</td>
<td>43%</td>
<td>18%</td>
</tr>
<tr>
<td>Food Service</td>
<td>59%</td>
<td>18%</td>
<td>23%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>38%</td>
<td>49%</td>
<td>13%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>48%</td>
<td>52%</td>
<td>0%</td>
</tr>
<tr>
<td>Lodging</td>
<td>81%</td>
<td>5%</td>
<td>14%</td>
</tr>
</tbody>
</table>
As seen, a comparison of site and kWh weighted results indicate that larger warehouses and campuses tend to install ballasts of a similar efficiency, where the kWh weighted share of ballasts being replaced by similarly efficient ballasts is much larger than the site count weighted share. On the other hand, larger offices or office buildings with higher energy consumption, based on a comparison of the shares reported in Table 3-13 and Table 3-14, install fewer ballasts that are higher efficiency than those removed.

**Table 3-14: Ballast replacement relative efficiency by business type, kWh weight – interior lighting**

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Similar Efficiency</th>
<th>Increased Efficiency</th>
<th>Don't Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>48%</td>
<td>52%</td>
<td>0%</td>
</tr>
<tr>
<td>Education</td>
<td>33%</td>
<td>66%</td>
<td>1%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>51%</td>
<td>29%</td>
<td>20%</td>
</tr>
<tr>
<td>Food Service</td>
<td>54%</td>
<td>19%</td>
<td>27%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>47%</td>
<td>48%</td>
<td>5%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>53%</td>
<td>47%</td>
<td>0%</td>
</tr>
<tr>
<td>Lodging</td>
<td>71%</td>
<td>20%</td>
<td>9%</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>58%</td>
<td>34%</td>
<td>8%</td>
</tr>
<tr>
<td>Office</td>
<td>60%</td>
<td>33%</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>60%</td>
<td>34%</td>
<td>5%</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the site-level sample weight.

** These data represent 776 sites.
<table>
<thead>
<tr>
<th>Business Type</th>
<th>Similar Efficiency</th>
<th>Increased Efficiency</th>
<th>Don't Know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Assembly</td>
<td>39%</td>
<td>58%</td>
<td>4%</td>
</tr>
<tr>
<td>Retail</td>
<td>40%</td>
<td>41%</td>
<td>19%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>76%</td>
<td>23%</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>37%</td>
<td>54%</td>
<td>9%</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the kWh-level sample weight.

** These data represent 776 sites.

### 3.4 Interior HID lighting

This section focuses on high intensity discharge (HID), lighting in indoor spaces. During the on-site data collection, 141 customers had HIDs installed in their indoor spaces.

Figure 3-39 illustrates that approximately 27% of indoor HID lighting is in warehouses, 26% in the retail segment, and 15% is in other businesses. The substantial share of HID lighting in warehouses and retail is not surprising given that these lamps are frequently used in spaces with high ceilings or as high-bay lighting. Warehouses and retail commonly have spaces with high ceilings.
Figure 3-22: HID distribution by business type – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 13 sites for campuses, 19 education sites, 6 food sales, 3 food service sites, 6 healthcare sites, 7 hospitals, 8 Lodging sites, 22 manufacturing or industrial sites, 14 offices, 12 other businesses, 12 sites for public assembly, 12 retail sites and 7 warehouses.

Figure 3-23 illustrates the distribution of indoor HID lamps by business size. Similar to the findings for other lighting technologies, the majority of indoor HIDs are found in businesses with less than 500,000 kWh of annual electricity consumption. Businesses with less than 500,000 kWh of annual electricity consumption represent the largest share of businesses by business count and it is likely that lighting represents a larger share of electricity consumption at smaller businesses than larger businesses.
The results presented above are weighted using the respondent-level sample weight.

These data represent 31 sites in the <500,000 kWh category, 80 sites in the 500,000-4,500,000 kWh category and 30 sites in the >4,500,000 category.

Figure 3-24 presents a distribution of indoor HIDS by lamp types. HID technologies, ranked in order of highest to lowest efficiency include the following lamp types:

- Mercury vapor
- Standard metal halide
- Ceramic metal halide
- Pulse start metal halide
- High pressure sodium
- Low pressure sodium

Mercury vapor HIDS, the highest efficiency HID choice, account for only 2% of interior HIDS while standard metal halides account for 82% of these lamps.
Figure 3-24: HID lamp distribution – interior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 141 sites.

Figure 3-25 describes the distribution of interior HID lamps by business type and HID lamp type. Standard metal halides dominate the distributions of technology for almost all business types. Pulse start metal halides have a high share of the distribution of existing interior HID lighting in the food sales and lodging segments. Ceramic metal halides have a high share in public assembly and campuses. High-pressure sodium HID lamps, a relatively inefficiency HID, have a relatively high share of HID lamps in other businesses, manufacturing, and health care.
The results presented above are weighted using the respondent-level sample weight.

These data represent 13 sites for campuses, 19 education sites, 6 food sales, 3 food service sites, 6 healthcare sites, 7 hospitals, 8 Lodging sites, 22 manufacturing or industrial sites, 14 offices, 12 other businesses, 12 sites for public assembly, 12 retail sites and 7 warehouses.

Figure 3-26 describes the distribution of interior HID lamps by annual kWh usage. Standard metal halides once again dominate the distributions of technology for almost all size categories. High pressure sodium lamps have a 12% share of the distribution of existing interior HID lighting for the largest consumption category, 11% for medium sized businesses and 9% for customers with less than 500,000 annual kWh.
Figure 3-26: HID lamp distribution by business kWh usage – interior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 31 sites in the <500,000 kWh category, 80 sites in the 500,000-4,500,000 kWh category and 30 sites in the >4,500,000 category.

3.5 Lighting controls

During the C&I Customer On-site Assessments information was collected on the type of controls used for lighting measures. Types of controls observed included manual switches, continuous on (lighting controls that regulate lighting systems that are on 24 hours per day, 7 days per week [e.g., emergency lighting]), BAS, motion sensors, photo cell motion sensors, photo cell time clocks, daylighting, and other. For some lighting measures no information was collected on the type of control used. Table 3-15 below provides category groupings of the different lighting controls included in the analysis. The aggregated control group column was created to make the number of lighting controls more reasonable to present than the 18 detailed control types included in the field survey.

Table 3-15: Lighting control categories

<table>
<thead>
<tr>
<th>Detailed control type</th>
<th>Control group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous / 24 hour</td>
<td>Continuous / 24 hour</td>
</tr>
<tr>
<td>Manual on/off</td>
<td>Manual</td>
</tr>
<tr>
<td>Detailed control type</td>
<td>Control group</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Bi-Level or Multi-Level Switched</td>
<td>Manual</td>
</tr>
<tr>
<td>Timeclock</td>
<td>Photocell/Timeclock</td>
</tr>
<tr>
<td>Photocell</td>
<td>Photocell/Timeclock</td>
</tr>
<tr>
<td>Photocell / Motion Sensor - Wall Mounted</td>
<td>Photocell / Motion Sensor</td>
</tr>
<tr>
<td>Photocell / Motion Sensor - Ceiling mounted</td>
<td>Photocell / Motion Sensor</td>
</tr>
<tr>
<td>Photocell / Motion Sensor - fixture integrated</td>
<td>Photocell / Motion Sensor</td>
</tr>
<tr>
<td>Photocell Timeclock</td>
<td>Photocell/Timeclock</td>
</tr>
<tr>
<td>EMS (energy mgmt system)</td>
<td>EMS</td>
</tr>
<tr>
<td>Dimmer Switch</td>
<td>Manual</td>
</tr>
<tr>
<td>Twist-timer</td>
<td>Manual</td>
</tr>
<tr>
<td>Daylighting controls</td>
<td>Daylighting</td>
</tr>
<tr>
<td>Motion Sensor - wall mounted</td>
<td>Motion sensor</td>
</tr>
<tr>
<td>Motion Sensor - ceiling mounted</td>
<td>Motion sensor</td>
</tr>
<tr>
<td>Motion Sensor - fixture integrated</td>
<td>Motion sensor</td>
</tr>
<tr>
<td>Electrical panel / breaker</td>
<td>Manual</td>
</tr>
<tr>
<td>Lighting contractor*</td>
<td>Lighting contractor</td>
</tr>
</tbody>
</table>

*Lighting contractor refers to outside contractors hired to monitor and manage lighting systems

Figure 3-27 displays the distribution of lighting controls across all types of interior lighting. This graph indicates that most of the C&I interior lighting in Massachusetts is manually controlled (77%) while 23% are controlled by either EMS, motion sensors, PC-motion sensors (PC-MS), or PC-time clock (PC-TC). Figure 3-28 illustrates the distribution of lighting controls for each type of lighting. These data indicate that linears, the most common type of lighting in Massachusetts businesses (see Figure 3-5), are most commonly manually controlled, though a small share of linear technologies are also controlled by EMS or motion sensors. The large share of lighting that is manually controlled represents an opportunity for PA-sponsored programs to educate customers and increase the use of lighting controls.
Figure 3-27: Share of lighting controlled by alternative lighting controls – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 794 sites.
Figure 3-28 presents information on the share of lighting controlled by business type. Manual controls are found to control more than 50% of the bulbs for all business types. Manual controls are found on 55% of lighting for food service, a low across all business types and on 91% for lodging, a high across all business types. Campuses have the highest share of interior lighting controlled by motion sensors (16%) while education (13%) and food sales (10%) have the highest share of lighting controlled by EMS. Food service has the highest share of lighting controlled by photo cell time clocks (42%). Additional study may be needed to determine the barriers to adoption of lighting controls across different business types. Reducing these barriers and increasing the adoption of lighting controls represents a program opportunity.

*The results presented above are weighted using respondent-level sample weight.

** These data represent lamp count data from 765 sites with linears, 495 sites with CFLs, 310 sites with incandescents, 140 sites with halogens, 337 sites with LEDs, 143 sites with HIDs, 13 sites with neons and 22 sites with other Lighting.
The results presented above are weighted using the respondent-level sample weight.

** These data represent 35 sites for campuses, 78 education sites, 46 food sales, 63 food service sites, 62 healthcare sites, 20 hospitals, 59 lodging sites, 81 manufacturing or industrial sites, 116 offices, 59 other businesses, 73 sites for public assembly, 72 retail sites and 30 warehouses.

Figure 3-30 illustrates the distribution of lighting controls by business size. For all three business sizes analyzed, manual switches are the most common type of lighting control, with the percentage decreasing as customer size increases. Businesses in the >4,500,000 kWh usage size category are shown to have the highest share, relative to the other two business sizes, of their lighting controlled by time clocks (14%), while businesses in the 500,000 to 4,500,000 kWh size category have the highest share of lighting controlled by EMS.
Figure 3-30: Lighting controls by business kWh usage – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 312 sites in the <500,000 kWh category, 380 sites in the 500,000-4,500,000 kWh category and 102 sites in the >4,500,000 kWh.

Figure 3-31 illustrates the distribution of lighting controls by recent energy efficiency participation. This figure illustrates that customers who have participated in EE programs from 2011 to 2014 controlled a smaller share of their lamps with manual switches and a larger share with motion sensor and photo cell motion sensors than customer that had not participated in programs.
3.5.1 Occupancy sensors

Figure 3-32 and Figure 3-33 depict the average number of occupancy sensors in commercial business spaces in Massachusetts by business type and business kWh usage size category, respectively. The analysis shows that warehouses have the highest average number of occupancy sensors per site, with 219 occupancy sensors, followed by hospitals with an average of 71 sensors. The large number of occupancy sensors per facility in warehouses and hospitals likely helps to reduce lighting energy usage in business types that tend to represent large buildings at least partially occupied 24/7. As expected the largest size category of >4,500,000 kWh usage has the highest average number of occupancy sensors with 197 sensors per site.
*The results presented above are weighted using the respondent-level sample weight.

** These data represent 35 sites for campuses, 78 education sites, 46 food sales, 63 food service sites, 62 healthcare sites, 20 hospitals, 59 lodging sites, 81 manufacturing or industrial sites, 116 offices, 59 other businesses, 73 sites for public assembly, 72 retail sites and 30 warehouses.
Figure 3-33: Average occupancy sensors per site by business kWh usage – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 312 sites in the <500,000 kWh category, 380 sites in the 500,000–4,500,000 kWh category and 102 sites in the >4,500,000 kWh.

3.6 Exit signs

Figure 3-34 and Figure 3-35 depict the distribution of exit signs by lamp type in commercial business spaces in Massachusetts by business type, and business kWh usage size category respectively. Across all business types and business sizes, LEDs are found to be a dominant exit lighting technology. Reflective paper exit signs are 45% of exit signs for other businesses and 38% for lodging. Incandescent exit signs are 40% in retail, 30% in manufacturing and industrial and 28% in warehouses. Incandescent exits signs represent 16% of exit signs for businesses with less than 500,000 kWh. Replacing an incandescent exit sign with an LED sign can lead to substantial savings given that these bulbs are required by the Occupational Safety and Health Administration to be on while the building is occupied. Exit signs typically have a high annual hours of use, often 8,760 hours.
Figure 3-34: Share of exit signs by lamp type and business type – interior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 33 sites for campuses, 66 education sites, 36 food sales, 59 food service sites, 50 healthcare sites, 18 hospitals, 44 lodging sites, 66 manufacturing or industrial sites, 104 offices, 46 other businesses, 61 sites for public assembly, 49 retail sites and 23 warehouses.
*The results presented above are weighted using the respondent-level sample weight.

** These data represent 339 sites in the <500,000 kWh category, 328 sites in the 500,000-4,500,000 kWh category and 88 sites in the >4,500,000 kWh.
3.7 Exterior lighting

This section presents the results of the exterior lighting data collected during the on-site visits, including signage. The broader lighting lamp categories are consistent with the indoor lighting categories in this study.

Table 3-16 provides a count of on-site surveys completed where outdoor lighting was surveyed by business type. The table also provides a count of on-site surveys completed for specific lighting technologies. It is important to recognize that the height and placement of outdoor fixtures can make it difficult to access the fixture to obtain the technical specifications required for this analysis.

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Total Count</th>
<th>Linear</th>
<th>CFL</th>
<th>LED</th>
<th>Incan</th>
<th>HAL</th>
<th>HID</th>
<th>Neon</th>
<th>Other Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>22</td>
<td>1</td>
<td>11</td>
<td>10</td>
<td>6</td>
<td>2</td>
<td>17</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Education</td>
<td>45</td>
<td>2</td>
<td>11</td>
<td>30</td>
<td>2</td>
<td>2</td>
<td>23</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Food sales</td>
<td>25</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td>1</td>
<td>13</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Food service</td>
<td>34</td>
<td>11</td>
<td>14</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>14</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Healthcare</td>
<td>40</td>
<td>4</td>
<td>17</td>
<td>16</td>
<td>13</td>
<td>5</td>
<td>26</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Hospitals</td>
<td>12</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lodging</td>
<td>38</td>
<td>4</td>
<td>25</td>
<td>23</td>
<td>8</td>
<td>3</td>
<td>18</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>57</td>
<td>2</td>
<td>25</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>45</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Office</td>
<td>60</td>
<td>5</td>
<td>23</td>
<td>21</td>
<td>9</td>
<td>8</td>
<td>35</td>
<td>0</td>
<td>1</td>
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<tr>
<td>Other</td>
<td>34</td>
<td>7</td>
<td>9</td>
<td>11</td>
<td>7</td>
<td>3</td>
<td>19</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Public assembly</td>
<td>47</td>
<td>6</td>
<td>14</td>
<td>22</td>
<td>13</td>
<td>6</td>
<td>35</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Retail</td>
<td>38</td>
<td>9</td>
<td>7</td>
<td>12</td>
<td>8</td>
<td>3</td>
<td>25</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Warehouse</td>
<td>16</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>468</td>
<td>55</td>
<td>157</td>
<td>198</td>
<td>88</td>
<td>46</td>
<td>291</td>
<td>3</td>
<td>12</td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.

**The counts indicate the number of instances the technology was found in the buildings that were visited. For example, at least 1 HID lamp was found in 23 of the 45 Education-type buildings visited.

Figure 3-36 illustrates the weighted shares of lamp technologies as a percentage of total lamps found in outdoor spaces in commercial establishments in Massachusetts. As depicted, just over 25% of all C&I exterior lamps are HID technologies, followed by CFLs and LEDs at 19%.
**Figure 3-36: Distribution of lamps by technology type – exterior lighting**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent lamp count data from 55 sites with linears, 157 sites with CFLs, 88 sites with incandescents, 46 sites with halogens, 198 sites with LEDs, 291 sites with HIDs, 3 sites with neons and 12 sites with other Lighting.

*** Linear technologies include linear fluorescents and TLEDs.

Figure 3-37 illustrates the lamp share of exterior lighting technologies by business type. These data indicate that HIDs, LEDs, or CFLs are the dominant lamp type for most business types. Food service establishments have the highest share of outdoor linear lamps at 46% of total food service exterior lighting, while HID lamps represent the largest share of exterior lamps within the warehouses (59%), manufacturing and industrial (52%), and hospital (51%) segments. Lodging has the highest share of exterior incandescent (30%), the education segment has the highest exterior share of LEDs (63%) lamps, while public assembly and offices have the highest share of CFLs (41%).
Figure 3-37: Distribution of lamps by technology type and business type – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.
** These data represent 22 sites for campuses, 45 education sites, 25 food sales, 34 food service sites, 40 healthcare sites, 12 hospitals, 38 lodging sites, 57 manufacturing or industrial sites, 60 offices, 34 other businesses, 47 sites for public assembly, 38 retail sites and 16 warehouses.

Figure 3-38 illustrates the distribution of outdoor lighting technologies by business annual electricity consumption. These data indicate that HID technologies have a substantial share of exterior lamps across all business sizes. For businesses whose annual electricity consumption exceeds 4,500,000 kWh, 36% of all outdoor lighting are HID lamps, while businesses consuming less than 500,000 kWh annually have 22% of all outdoor lighting as HID lamps and businesses consuming 500,000 – 4,500,000 kWh have a 38% share of HID. For business with annual consumption above 4,500,000 kWh the technology with the highest share of outdoor lighting was linear lamps with a 37% share.
3.7.1 HID lighting

This section focuses on high intensity discharge (HID), lighting in outdoor spaces. During the on-site data collection, 291 customers had HIDs installed their outdoor spaces and HIDs were the most common light observed outside, representing 25% of all outdoor lighting.

Figure 3-39 illustrates that approximately 25% of outdoor HID lighting is in the retail segment, 22% in other businesses, and 17% is public assembly.
Figure 3-39: HID distribution by business type – exterior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 17 sites for campuses, 23 education sites, 13 food sales, 14 food service sites, 26 healthcare sites, 10 hospitals, 18 Lodging sites, 45 manufacturing or industrial sites, 35 offices, 19 other businesses, 35 sites for public assembly, 25 retail sites and 11 warehouses.

Figure 3-40 illustrates the distribution of outdoor HID lamps by business size. Similar to the findings for other lighting technologies, the majority of outdoor HIDs are found in businesses with less than 500,000 kWh of annual electricity consumption. Businesses with less than 500,000 kWh of annual electricity consumption represent the largest share of businesses by business count and it is likely that lighting represents a larger share of electricity consumption at smaller businesses than larger businesses.
Figure 3-40: HID lamp count distribution by business kWh usage – exterior lighting

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 78 sites in the <500,000 kWh category, 169 sites in the 500,000–4,500,000 kWh category and 44 sites in the >4,500,000 category.

Figure 3-41 presents a distribution of outdoor HIDs by lamp types. HID technologies, ranked in order of highest to lowest efficiency include the following lamp types:

- Mercury vapor
- Standard metal halide
- Ceramic metal halide
- Pulse start metal halide
- High pressure sodium
- Low pressure sodium

Mercury vapor HIDs, the highest efficiency HID choice, account for only 4% of exterior HIDs while standard metal halides account for 46% of these lamps. PA-sponsored programs to help eliminate high and low-pressure sodium HID lamps could move toward improving the energy efficiency of exterior HID lamps. For many applications (but not all), LEDs offer a high-efficiency choice to replace HID lighting.
Figure 3-41: HID lamp distribution – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.
** These data represent 291 sites.

Figure 3-42 describes the distribution of exterior HID lamps by business type and HID lamp type. Standard metal halides dominate the distributions of technology for almost all business types. Pulse start metal halides have a high share of the distribution of existing exterior HID lighting in the education and public assembly segments.
*The results presented above are weighted using the respondent-level sample weight.

** These data represent 17 sites for campuses, 23 education sites, 13 food sales, 14 food service sites, 26 healthcare sites, 10 hospitals, 18 lodging sites, 45 manufacturing or industrial sites, 35 offices, 19 other businesses, 35 sites for public assembly, 25 retail sites and 11 warehouses.

Figure 3-43 describes the distribution of exterior HID lamps by annual kWh usage. Standard metal halides once again dominate the distributions of technology for almost all size categories. High pressure sodium lamps have a high share of the distribution of existing exterior HID lighting for the largest consumption category.
Figure 3-43: HID lamp distribution by business kWh usage – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 78 sites in the < 500,000 kWh category, 169 sites in the 500,000-4,500,000 kWh category and 44 sites in the > 4,500,000 kWh category.

3.7.2 Exterior lighting controls

Figure 3-44 presents the distribution of lighting controls used for all types of exterior lighting. This graph indicates that most of the C&I exterior lighting in Massachusetts is controlled by PC-time clock (PC-TC) (59%) while 28% are manually controlled and 8% are controlled by motion sensors (PC-MS).
Figure 3-45 shows the share of exterior lighting controlled by each type of control for each type of lighting. Recall from Figure 3-36 that 25% of outdoor lighting are HID, 19% are LED and CFL, and 18% are linear lamps. The data on exterior lighting controls indicate that 76% of exterior HID are controlled by photo cell time clock (PC-TC). These data indicate that linears, installed in outdoor spaces are most commonly manually controlled, while CFLs and LEDs in the same setting are more likely to be controlled by photo-cell time clocks.
Figure 3-45: Share of lighting control type by lighting type – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 468 sites.

Figure 3-46 depicts the distribution of exterior lighting controls for each business type. Photo cell time clocks followed by manual controls are seen to have a significant presence in most business types. The retail and lodging segments have the highest share of their exterior lighting controlled by photo cell motion sensors while campuses and food sales have the highest share of lighting controlled by EMS.
Figure 3-46: Lighting controls by lamp type – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.
** These data represent lamp count data from 55 sites with linears, 157 sites with CFLs, 88 sites with incandescents, 46 sites with halogens, 198 sites with LEDs, 291 sites with HIDs, 3 sites with neons and 12 sites with other Lighting.

Figure 3-47 presents information on the share of outdoor lighting controlled by kWh consumption range. Photo cell time clocks followed by manual controls are seen to have a significant presence in all business usage categories. Businesses with annual consumption of less than 500,000 kWh have the highest share of their exterior lighting controlled by photo cell - motion sensors of all size categories.
* The results presented above are weighted using the respondent-level sample weight.

** These data represent 22 sites for campuses, 45 education sites, 25 food sales, 34 food service sites, 40 healthcare sites, 12 hospitals, 38 lodging sites, 57 manufacturing or industrial sites, 60 offices, 34 other businesses, 47 sites for public assembly, 38 retail sites and 16 warehouses.

Figure 3-48 presents the share of outdoor lighting control type by energy efficiency program participation. Photo cell time clocks followed by manual controls are seen to have a significant presence among both participants and non-participants. Non-participants (30%) are seen to have a higher share of manual controls than participants (21%).
During the on-site data collection for the C&I On-site Assessments, site contacts were asked if they had purchased any lighting since 2009. The data collection also asked contacts about the age of equipment found in businesses. Using the self-reported information on recent purchases and the age of equipment, the MSST found recent purchase (2009-2015) of interior lighting equipment at 567 of the 800 surveyed sites and recent purchases of exterior lighting at 244 sites.\textsuperscript{55} Using the recent lighting purchase information, and business respondent weights, approximately 11,577,000 new linear lamps are estimated to have been purchased during the period 2009-2015 by all Massachusetts businesses. Businesses installing linear lighting were found to have installed on an average 181 linear fluorescent lamps across all business types and sizes in interior spaces and an average of 38 linear fluorescent lamps in exterior spaces.

Table 3-17 lists the number of sites where data that was collected as part of the C&I On-site Assessments supports the analysis of recent lighting purchases, making the customer also a lighting MSST customer. The data in Table 3-17 show the number of businesses by business type that recently purchased lighting measures. The recent purchase lighting analysis is disaggregated into linear lighting and ICLH bulbs. Of the 567 customers with recent purchases, 251 businesses purchased linear lamps and 499 purchased ICLH

\textsuperscript{55} Data collection occurred during 2014 and 2015. Given the timing of data collection and that some sites have 2015 data and some do not, the recent purchases are referred to and 2009-2015 and 2009-2014. The data collection for purchases in 2015 is not complete.
bulbs. The recent purchase section also describes the share of recently purchased bulbs by their lighting controls.

### Table 3-17: On-sites with recent purchases (2009-2015) – interior lighting

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Total surveyed sites with interior lighting</th>
<th>Total On-site Count with Recent Lighting Purchases</th>
<th>On-sites with 4-foot Linear Purchases</th>
<th>On-sites with ICLH Purchases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>27</td>
<td>13</td>
<td>25</td>
</tr>
<tr>
<td>Education</td>
<td>78</td>
<td>51</td>
<td>31</td>
<td>41</td>
</tr>
<tr>
<td>Food Sales</td>
<td>46</td>
<td>34</td>
<td>20</td>
<td>28</td>
</tr>
<tr>
<td>Food Service</td>
<td>63</td>
<td>50</td>
<td>13</td>
<td>49</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>49</td>
<td>15</td>
<td>49</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>14</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Lodging</td>
<td>59</td>
<td>45</td>
<td>16</td>
<td>45</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>81</td>
<td>46</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>Office</td>
<td>116</td>
<td>82</td>
<td>37</td>
<td>71</td>
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<tr>
<td>Other</td>
<td>59</td>
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<td>36</td>
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<tr>
<td>Public Assembly</td>
<td>73</td>
<td>56</td>
<td>22</td>
<td>53</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>52</td>
<td>24</td>
<td>42</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>20</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>794</strong></td>
<td><strong>567</strong></td>
<td><strong>251</strong></td>
<td><strong>499</strong></td>
</tr>
</tbody>
</table>

* The results presented above are un-weighted.

The analysis of the lighting recent purchase data begins by focusing on aggregate lighting, presenting information on the share of recent purchases by lamp types. Figure 3-49 illustrates the respondent-weighted lamp shares of recently purchased lighting technologies as the percentage of total lamp purchases found. The study found that approximately 68% of all recently purchased C&I lamps are linears. The high share of linear lighting in recent purchases is consistent with earlier analyses that stated that 71% of lamps in Massachusetts business are linear lamps. The consistent share of recent purchases and the existing baseline share implies that linear lamps are generally being purchased to replace existing linear lamps.
Figure 3-49 illustrates that LED that are not TLEDs represent 18% of recently purchased lamps. During the analysis of lighting in Massachusetts businesses, it was found that LEDs represent 7% of the existing baseline of all lamps. Finding that LEDs represent 18% of recent purchases indicates that these lamps are being purchased at a relatively high rate given their lower existing share. It is likely that LEDs are being purchased to replace CFLs and incandescent bulbs.

Figure 3-49 indicates that 20% of recently purchased interior lighting were found to be incandescent bulbs. Given the relatively short life of an incandescent bulb, the DNV GL Team decided to treat all incandescent bulbs as recent purchase bulbs. This approach may over count the share of incandescent recent purchases. Incandescent bulbs represent 6% of the existing baseline share of bulbs. Incandescent bulbs, however, have a shorter expected life than many of the other commercial lamps.

**Figure 3-49: Recent purchase distribution by lamp type – interior lighting**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 251 sites with linears, 79 sites with CFLs, 304 sites with incandescents, 10 sites with halogens, 252 sites with LEDs, 8 sites with HIDs, 1 site with neons and 1 site with other lighting.

Figure 3-50 illustrates the share of recently purchased lighting technologies by business type. These data indicate that linear technologies are 50% or more of recently purchased lamp for most business types,
except food service, healthcare, public assembly, other, and lodging. Recent purchases in food service and public assembly businesses were largely incandescent bulbs (70% for food service and 68% of public assembly) and LED (23% for food service and 16% for public assembly). These findings are consistent with results presented in Figure 3-6 that show that 52% of lamps in food service are incandescent and 19% are LED while 15% of lamps in public assembly are incandescent and 7% LED. Incandescent and LED lamps are a relatively large share of the existing stock and recent purchases for these segments. Lodging and other business types had the largest LED recent purchase share at 48% and 35% respectively. Incandescent are over 20% of recent purchases for food service, public assembly, lodging, and health care, potential segments to target for incandescent to LED lamp replacements. All four of these segments have a LED recent purchase share of at least 10%, indicating that many businesses in these segments are adopting LED bulbs.

**Figure 3-50: Distribution of recently purchased lamps by technology type and business type – interior lighting**

*The results presented above are weighted using the respondent-level sample weight. The lamps were purchased from 2009-2014.*

**These data represent 27 sites for campuses, 51 education sites, 34 food sales, 50 food service sites, 49 healthcare sites, 14 hospitals, 45 lodging sites, 46 manufacturing or industrial sites, 82 offices, 41 other businesses, 56 sites for public assembly, 52 retail sites and 20 warehouses.*

Figure 3-51 illustrates the distribution of recently purchased lamps by technology type and business size. These data indicate that linear technologies dominate the distribution of recently purchased lamps for all business sizes. Businesses with annual usage greater than 4,500,000 kWh have 70% of their recent
purchases in linear lamps (tubular LEDs are included in linear lamps) and 23% in LEDs. Recent purchases of LEDs were relatively high across all business electric size groups, 19% of recently purchased lamps for businesses with annual consumption of less than 500,000 kWh and 14% for businesses with annual consumption of 500,000 – 4,500,000 kWh. Once again, the recent purchase share for LEDs implies that all three business usage size groups are increasing their share of LEDs given that the largest size grouping had a 7% existing baseline share of LEDs, 7% for businesses with annual usage of 500,000 kWh to 4,500,000 kWh and 6% for businesses with annual usage below 500,000.

**Figure 3-51: Distribution of recently purchased lamps by technology type and business kWh usage – interior lighting**

*The results presented above are weighted using the respondent-level sample weight. The lamps were purchased from 2009-2014. ** These data represent 228 sites in the <500,000 kWh category, 265 sites in the 500,000-4,500,000 kWh category and 74 sites in the > 4,500,000 kWh category.

### 3.8.1 Recent purchases of linear technologies

The distribution of recently purchased linear lamps of all lengths that are used in interior spaces in C&I buildings in Massachusetts is dominated by T8s (76% of recent linear purchases) as depicted in Figure 3-52.
Figure 3-52: High level linear efficiency distribution of recently purchased linear lamps – interior lighting

* The results presented above are weighted using the respondent-level sample weight.
**These data represent 251 sites.

3.8.1.1 Recent purchases of 4-foot linear technologies

Figure 3-53 shows the same distribution for recently purchased 4-foot linear lamps that are used in interior spaces, where the share of T8s increases to 79% of recently purchased lamps. These figures also show that very few T12 lamps were purchased. Most T12 lamps and 700-Series T8 lamps were phased out of production in the summer of 2012, contributing to the very low share of these lamps purchased by Massachusetts businesses from 2009 to 2015.

For these graphs TLEDs are characterized as LED linears though they will be included as tier 2 T8s in other analysis. As seen in Figure 3-52 and Figure 3-53, TLEDs represent 12% of all recently purchased linear lighting and 9% of recently purchased 4-foot linear lamps.
Linear lighting technologies are the dominant source of lighting for non-residential customers and a key component of the MSST. Linear technologies also dominate non-residential recent lighting purchases from 2009-2015 (see Figure 3-49).

Figure 3-54 illustrates the distribution of recently purchased 4-foot linear lamps by business type and Figure 3-55 provides similar information by business sizes. The data collected on-site indicate that retail businesses purchased the largest share of linear technologies, followed by offices. This is consistent with the data from the existing stock where offices and retail have the largest share of linear lighting (see Figure 3-8). Businesses with annual consumption of less than 500,000 kWh had the highest share of recent purchases, at 62% of all 4-foot linear purchases. This finding is consistent with an earlier finding that stated that businesses with less than 500,000 kWh had 63% of the existing stock of linear lamps (see Figure 3-9).
Figure 3-54: Distribution of recently purchased linear lamps by business type, 4-foot lamps – interior lighting

*The results presented above are weighted using the respondent-level sample weight. The lamps were purchased from 2009-2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

** These data represent 13 sites for campuses, 31 education sites, 20 food sales, 13 food service sites, 15 healthcare sites, 6 hospitals, 12 lodging sites, 25 manufacturing or industrial sites, 35 offices, 13 other businesses, 21 sites for public assembly, 23 retail sites and 11 warehouses.
Figure 3-55: Distribution of recently purchased linear lamps by business kWh usage, 4-foot lamps – interior lighting

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 84 sites in the <500,000 kWh category, 126 sites in the 500,000-4,500,000 kWh category and 28 sites in the > 4,500,000 kWh category.

3.8.1.2 Recently purchased 4-foot linear lamps by performance group

Table 3-18 lists the efficiency distribution of recently purchased Linear Technologies. The technology order listed in Table 3-18 represents the efficiency order for T12 through Tier 2, LED from least energy efficient to most energy efficient. Table 3-18 indicates that almost none of the recently purchased linear technologies are T12 lamps and only 7% are 700-Series T8s. Recall that T12 and 700-Series T8s were generally phased out of production in 2012 by federal efficiency regulations.

The data presented in Table 3-18 indicate that Tier 1 T8s and 800-Series T8 have the largest share of recent linear technology purchases at 29% and 27% respectively. Tier 1 T8s represent a high-efficiency linear technology while 800-Series T8s represent a base technology following the phase out of T12s and 700-Series T8s. The share of recently purchased Tier 2 LEDs, the highest efficiency group, is also very high at 12%. These data indicate that a high share of Massachusetts businesses are purchasing Tier 1 and Tier 2 LED T8s. Figure 3-56 illustrates the information presented in Table 3-18. These data illustrate that 800-Series
T8s and Tier 1 T8s appear to be nearly tied for the most common T8 recently purchased by businesses in Massachusetts. Comparing the results in Figure 3-56 on the efficiency of recently purchased linear lamps to the distribution of efficiency for the existing stock of linear lamps illustrated in Figure 3-12, recent purchases are substantially more efficient than the existing linear lamp stock. The existing stock of linear lamps has 12% T12s while nearly no T12s were observed in recent purchases. 700-Series T8 lamps are 34% of the existing stock but only 7% of recent purchases. Lamps discontinued by federal standards (T12s and 700-Series T8s) show a substantial decline consistent with changing standards. There has also been a substantial increase in the share of TLED from 2.7% in the existing stock to 12% in recent purchases. Massachusetts businesses are purchasing efficient linear technologies.

Table 3-18: Recent purchase linear efficiency distribution, 4-foot lamps – interior lighting

<table>
<thead>
<tr>
<th>Linear Efficiencies</th>
<th>On-Site Data Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>0.03%</td>
</tr>
<tr>
<td>700 Series</td>
<td>7%</td>
</tr>
<tr>
<td>800 Series</td>
<td>27%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>10%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>29%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0.1%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>12%</td>
</tr>
<tr>
<td>T5</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

** These data represent 238 sites.
Figure 3-56: Efficiency distribution of recently purchased linear technologies, 4-foot lamps – interior lighting

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

** These data represent 238 sites.

Table 3-19 presents information on the break out of recent linear purchases by year groupings. The recent purchase year is self-reported and is subject to self-report error. To minimize the impact of these errors, the year of purchase has been grouped into the first half of the recent purchase time period (2009-2011) and the second half (2012-2014). Viewing the recent purchase data across these two time periods, there is a trend toward higher efficiency purchases. During the earlier time period, 16% of recently purchased linears were 700-Series T8s and 16% were 800-Series T8s. During the 2012-2014 period, the base efficiency lamps (lamps in the T12, 700 or 800-Series T8 groups) were purchased largely as 800-Series T8s.

High-efficiency linear lamp purchases during the 2009 to 2011 time period tended to be Tier 1 T8s or T5s. Prior to the CEE reclassification of high-efficiency lamps into Tiers, high-efficiency T8s were classified as high performance and reduced wattage T8s. The reclassification into Tiers moved many of the high performance T8 lamps into the Tier 1 classification and reduced wattage lamps into Tier 0. The Tier classifications are dependent on lumens per watt calculations and lamps previously classified as high performance generally have higher lumens per watt.

The high-efficiency linear lamps purchased from 2012 to 2014 are distributed across Tier 0, Tier 1, Tier 2 LED, and T5 lamps. The rising importance of Tier 2 LED lamps is clearly illustrated in these data. PA-
sponsored programs should continue to focus on increasing the share of Tier 2 LED lamps and educating customers on the benefits of these lamps relative to older 800-Series T8 lamps.

Table 3-19: Recently purchased 4-foot linear efficiency distribution by install year

<table>
<thead>
<tr>
<th>Linear Efficiencies</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>700 Series 700-Series T8</td>
<td>16%</td>
<td>1%</td>
</tr>
<tr>
<td>800 Series 800-Series T8</td>
<td>16%</td>
<td>36%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>0%</td>
<td>17%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>57%</td>
<td>14%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>0%</td>
<td>18%</td>
</tr>
<tr>
<td>T5</td>
<td>11%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights. Lamps designated as purchased since 2009 but without a specific year were not included in the by year breakdown.

** These data represent 219 sites.

Table 3-20 and Figure 3-57 present the recent purchase linear technologies by business size. The data indicate that businesses with less than 500,000 kWh annual electricity consumption purchase the largest share of 700-Series T8 lamps (13%) while businesses with 500,000 to 4,500,000 kWh purchase 4% of their linears in this category. In contrast, businesses with over 4,500,000 kWh were observed to purchase no or very few 700-Series lamps but had the largest share of 800-Series T8 lamps (48% of their linears were 800-Series). If T12, 700-Series and 800-Series T8s are grouped together as base efficiency linear lamps, customers with over 4,500,000 kWh purchased the highest share of base efficiency lighting at 48% while customers with 500,000 to 4,500,000 purchased 44% base and the smallest customers purchased only 13% base linears.

Turning to the distribution of high-efficiency recent purchases (Tier 0-2 and T5 lamps), customers with less than 500,000 kWh had the largest shares across the various customer size distribution of Tier 1 (47%), Tier 2 LED (17%), and T5 lamps (22%). The very low share of base efficiency linear lamps purchased by smaller customers implies that these customers will have a higher share of their purchases represented in the high-efficiency lighting. The efficiency distribution of recently purchased lamps observed in customers with less than 500,000 kWh differs substantially from the efficiency distribution observed for the existing stock of linears (see Table 3-6) for these customers. The data in Table 3-6 show that customers with less than 500,000 kWh use T12 lamps for 20% of their linear lighting and 49% are 700-Series T8s. The extremely high share of high-efficiency linear purchases by these customers, relative to their relatively high share of
base efficiency linears in their existing stock, indicates that these customers may have been late to move from T12 and 700-Series T8 lamps but that their recent purchases may be skipping the 800-Series and Tier 0 lamps to purchase the higher efficiency Tier 1 and Tier 2 options.

In contrast, the relatively large share of 800-Series T8 lamps purchased by customers with more than 500,000 kWh annual consumption indicates that these customers are not choosing to purchase high-efficiency linear lamps as frequently as smaller customers. PAs should work to ensure that their customer with over 500,000 kWh consumption are aware of the upstream PA-sponsored lighting program and the availability of rebates for Tier 2 LED lamps.

Table 3-20: Recent purchase linear efficiency distribution by business kWh usage – 4-foot lamps – interior lighting

<table>
<thead>
<tr>
<th></th>
<th>&lt; 500,000 kWh</th>
<th>500,000 - 4,500,000 kWh</th>
<th>&gt; 4,500,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>700 Series T8</td>
<td>13%</td>
<td>4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>800 Series T8</td>
<td>0.0%</td>
<td>40%</td>
<td>48%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>0.9%</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>47%</td>
<td>2%</td>
<td>46%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0.2%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>17%</td>
<td>13%</td>
<td>1.0%</td>
</tr>
<tr>
<td>T5</td>
<td>22%</td>
<td>16%</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

** These data represent 84 sites in the <500,000 kWh category, 126 sites in the 500,000-4,500,000 kWh category and 28 sites in the >4,500,000 kWh category.
Figure 3-57: Efficiency distribution of recently purchased linear technologies by business kWh usage, 4-foot lamps – interior lighting

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 84 sites in the <500,000 kWh category, 126 sites in the 500,000-4,500,000 kWh category and 28 sites in the > 4,500,000 kWh category.

3.8.1.3 Recently purchased 4-foot linear efficiency distribution by energy efficiency program participation

Table 3-21 and Figure 3-58 present the distribution of linear fluorescent technologies for EE program participants and non-participants. Energy efficiency program participation may be associated with a higher likelihood that the business has recently purchased high-efficiency linear technologies. The data collected onsite, however, indicate that businesses participating in PA-sponsored EE programs from 2011-2014 were less likely to purchase high-efficiency T8s and T5s than non-participants.

Table 3-20 and Figure 3-57 clearly indicate that customers larger than 500,000 kWh purchased a higher share of their linear lamps as 800-Series T8s during the period 2009-2014 than customers with less than 500,000 kWh of annual electricity consumption. Larger customers, however, are more likely to have participated in energy efficiency programs. The 45% share of linears purchased as 800-Series T8 lamps by program participants may represent the importance of larger customers in the energy efficiency participant population.
The EE program participation flag used for this analysis indicates if the business participated in traditional downstream PA-sponsored EE programs from 2011-2014 and is not specific to lighting or linear fluorescents. Very limited upstream program participation data was included in this study. The recent purchase data is from 2009-2015. The difference in the length of time covered by the EE participation flag and the recent purchase data may help to explain the findings in Table 3-21. The higher share of high-efficiency lamp purchases in the non-participant population may also be due to the general lack of upstream program participation data in this study. Linear lamps have been a component of the Massachusetts upstream programs since 2011 and Tier 2 LED linear lamps were added to the upstream program in 2015. The program participation flag used to develop Table 3-21 includes only very limited upstream participants. A future study will analyze the incentivized share of high-efficiency lighting purchases incorporating both the upstream and downstream programs.

**Table 3-21: Recent purchase linear efficiency distribution by energy efficiency program participation, 4-foot lamps – interior lighting**

<table>
<thead>
<tr>
<th>Linear Efficiencies</th>
<th>EE Participant</th>
<th>EE Non-Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>T12</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>700 Series</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>800 Series</td>
<td>45%</td>
<td>18%</td>
</tr>
<tr>
<td>Tier 0</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>Tier 1</td>
<td>15%</td>
<td>36%</td>
</tr>
<tr>
<td>Tier 2, T8</td>
<td>0.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Tier 2, LED</td>
<td>4%</td>
<td>16%</td>
</tr>
<tr>
<td>T5</td>
<td>24%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014. Lamps with unknown make and model efficiency information have been reallocated using the linear lighting weights.

**These data represent 139 EE participant sites, and 99 non-participant sites.
Figure 3-58: Recent purchase linear efficiency distribution by energy efficiency program participation, 4-foot lamps – interior lighting

*The results presented above have been weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 139 EE participant sites, and 99 non-participant sites.

3.8.1.4 **Ballasts on recently purchased linear lighting**

Table 3-22 provides the distribution of ballasts for recently purchased linear technology. Electronic ballasts account for nearly all of the recent purchases.

**Table 3-22: Ballast type for recently purchased 4-foot linear by lamp types - interior lighting**

<table>
<thead>
<tr>
<th>Lamp Type</th>
<th>Electronic Ballast</th>
<th>Magnetic Ballast</th>
<th>Unknown Ballast</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>95%</td>
<td>0.0%</td>
<td>5%</td>
</tr>
<tr>
<td>T12</td>
<td>93%</td>
<td>0.0%</td>
<td>7%</td>
</tr>
<tr>
<td>T5</td>
<td>99%</td>
<td>0.1%</td>
<td>1%</td>
</tr>
<tr>
<td>T8</td>
<td>99%</td>
<td>0.1%</td>
<td>1%</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 235 sites.
3.8.2 Recent purchases of ICLH technologies

The ICLH recent purchase (2009 to 2015) section presents information on recent purchases of incandescent, CFL, non-linear LED, and halogen technologies by businesses in Massachusetts. These technologies represent approximately 42% of the recently purchased lighting technologies used by non-residential customers for interior lighting (See Figure 3-49).

Figure 3-59 indicates that the food service (24%) and public assembly (20%) segments have made substantial recent purchases of ICLH lamps. The recent purchase data can be compared to ICLH lamps in the existing stock. Figure 3-16 illustrates that food service accounts for 13% of the existing stock of ICLH lamps while public assembly has 23% of the existing stock. The relative share of ICLH lamps in the existing stock is not inconsistent with food service and public assembly having such a substantial share of ICLH recent purchases, but recall from Figure 3-19 that food service (66%) and public assembly (33%) have a high share of incandescent lamps in their existing stock of ICLH lamps. Incandescent lamps have a shorter expected life than CFLs or LEDs leading businesses with these lamps to more frequently purchase lamps.56

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56 As stated previously, due to data limitations, the analysis has assumed that incandescent lamps observed during the field survey all represent recently purchased lamps. This assumption likely increases the share of ICLH lamps recently purchased by food service and public assembly relative to other segments with a small share of incandescent lamps.
Figure 3-59: Recent purchase ICLH distribution by business type – interior lighting

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 25 sites for campuses, 41 education sites, 28 food sales, 49 food service sites, 49 healthcare sites, 13 hospitals, 45 lodging sites, 32 manufacturing or industrial sites, 71 offices, 36 other businesses, 53 sites for public assembly, 42 retail sites and 15 warehouses.

The data illustrated in Figure 3-60 show that businesses with annual consumption of either less than 500,000 kWh or 500,000kWh-4,500,000 kWh account for most of the recently purchased ICLH lamps observed during the on-site visits. The recent purchase share of ICLH purchases is very similar to the existing stock distribution of ICLH lamps. Figure 3-17 illustrates that 66% of ICLH lamps in the existing stock are in businesses with less than 500,000 kWh, 27% for businesses with 500,000 to 4,500,000 kWh and 7% for businesses with more than 4,500,000 kWh. The recent purchase data is largely symmetrical to the existing stock distribution. These distributions may reflect the fact that lighting generally accounts for a higher share of electricity consumption for smaller businesses than for larger businesses with a wider array of electricity consuming equipment.
Figure 3-60: Recent purchase ICLH distribution by business kWh usage – interior lighting

Figure 3-61 shows that incandescent lamps represent most of ICLH recent purchases, followed by LEDs. All incandescent lamps found on-site were classified as recent purchases even where installation dates were not available. This assumption was made because of the short effective useful life of incandescent lamps, combined with the almost six year duration of the recent purchase time period.

The very high share of LED lamps relative to CFL lamp purchases illustrates the rising importance of LED lamps and the recent fall in CFL lamp’s share. Comparing the distribution of recent ICLH purchases with the distribution of the existing stock of ICLH lamps illustrated in Figure 3-18 clarifies the recent fall in the importance of CFL lamps in the Massachusetts business sector. Figure 3-18 illustrates that CFLs account for 44% of the existing stock of ICLH lamps while Figure 3-61 shows that CFLs are only 6% of ICLH recent purchases. LED lamps, however, account for only 26% of ICLH lamps in Figure 3-18 but represent 44% of

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* The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 206 sites in the <500,000 kWh category, 227 sites in the 500,000-4,500,000 kWh category and 66 sites in the > 4,500,000 kWh category.
recent purchases in Figure 3-61.\footnote{The 44\% market share of LEDs in the ICLH market does not imply that LEDs have a 44\% market share for lamp recent purchases. Figure 3-49 illustrates that LEDs market share for recently purchased lamps is 18\% across all lamp types.} These data clearly illustrate the rise in LEDs and the falling market share of CFLs relative to LEDs.

**Figure 3-61: Recent purchase efficiency distribution of ICLH lamps – interior lighting**

![Pie chart showing recent purchase efficiency distribution of ICLH lamps.](image)

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 499 sites.

**3.8.2.1 **Recent purchases of ICLH technologies by lamp base**

ICLH lamps can be characterized by their technology type and by their base type: pin-based, medium screw-based, LED hardwired, other, and unknown. Table 3-23 and Table 3-24 present the distribution of recently purchased ICLH lamps by business type and kWh usage respectively. Pin-based lamps dominate recent purchases of all ICLH lighting used in interior spaces in food service establishments in Massachusetts with a 61\% share, while screw-based lamps are dominant in the manufacturing sector with a 50\% share of all ICLH purchases. Education and food sales have the highest share of recently purchased LED hard-wired lamps.
Screw-based ICLH lamps account for 63% of all ICHL lamps among businesses with annual usage of less than 500,000 kWh usage, while pin-based lamps have the largest share of 63% among businesses with annual usage of 500,000 kWh – 4,500,000 kWh. Businesses with over 4,500,000 kWh have the largest share of hard wired LED lamps (21%).

Table 3-23: Recently purchased ICLH lamp distribution by lamp base by building type – interior lighting

<table>
<thead>
<tr>
<th>Technology</th>
<th>Campuses</th>
<th>Education</th>
<th>Food Sales</th>
<th>Food Service</th>
<th>Healthcare</th>
<th>Hospitals</th>
<th>Lodging</th>
<th>Manufacturing or Industrial</th>
<th>Office</th>
<th>Other</th>
<th>Public Assembly</th>
<th>Retail</th>
<th>Warehouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Screw Based</td>
<td>38%</td>
<td>19%</td>
<td>28%</td>
<td>18%</td>
<td>40%</td>
<td>32%</td>
<td>64%</td>
<td>52%</td>
<td>55%</td>
<td>86%</td>
<td>58%</td>
<td>72%</td>
<td>28%</td>
</tr>
<tr>
<td>Pin Based</td>
<td>52%</td>
<td>29%</td>
<td>18%</td>
<td>61%</td>
<td>31%</td>
<td>44%</td>
<td>6%</td>
<td>31%</td>
<td>24%</td>
<td>2%</td>
<td>6%</td>
<td>7%</td>
<td>0%</td>
</tr>
<tr>
<td>LED Hard Wired</td>
<td>5%</td>
<td>31%</td>
<td>30%</td>
<td>1%</td>
<td>11%</td>
<td>23%</td>
<td>1%</td>
<td>17%</td>
<td>17%</td>
<td>6%</td>
<td>2%</td>
<td>9%</td>
<td>20%</td>
</tr>
<tr>
<td>Other</td>
<td>5%</td>
<td>1%</td>
<td>25%</td>
<td>20%</td>
<td>16%</td>
<td>1%</td>
<td>30%</td>
<td>0%</td>
<td>4%</td>
<td>4%</td>
<td>29%</td>
<td>11%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown</td>
<td>0%</td>
<td>20%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>5%</td>
<td>1%</td>
<td>52%</td>
<td>0%</td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 25 sites for campuses, 41 education sites, 28 food sales, 49 food service sites, 49 healthcare sites, 13 hospitals, 45 lodging sites, 32 manufacturing or industrial sites, 71 offices, 36 other businesses, 53 sites for public assembly, 42 retail sites and 15 warehouses.

Table 3-24: Recently purchased ICLH lamp distribution by lamp base by business kWh usage – interior lighting

<table>
<thead>
<tr>
<th>Technology</th>
<th>&lt; 500,000 kWh</th>
<th>500,000 - 4,500,000 kWh</th>
<th>&gt; 4,500,000 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Screw Based</td>
<td>63%</td>
<td>26%</td>
<td>40%</td>
</tr>
<tr>
<td>Pin Based</td>
<td>5%</td>
<td>63%</td>
<td>30%</td>
</tr>
<tr>
<td>LED Hard Wired</td>
<td>7%</td>
<td>3%</td>
<td>21%</td>
</tr>
<tr>
<td>Other</td>
<td>23%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Unknown</td>
<td>3%</td>
<td>3%</td>
<td>0%</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight. These lamps were purchased from 2009 to 2014.

** These data represent 206 sites in the <500,000 kWh category, 227 sites in the 500,000-4,500,000 kWh category and 66 sites in the > 4,500,000 kWh category.

Due to the lack of information on the year of purchase for incandescent bulbs, it is not possible to present data on the distribution of recently purchased ICLH bulbs by lamp type and year. Figure 3-61, however, illustrates that 44% of the recently purchased ICLH bulbs are LEDs. LEDs are becoming an increasingly importing source of non-residential lighting and savings for PA-sponsored lighting programs. The increasing
importance of LED bulbs led to considerable interest in developing more information on the timing of LED purchases and the customers purchasing LED bulbs. Figure 3-62 illustrates an estimate of the count of LED bulbs that survey participants self-reported as installed in Massachusetts businesses from 2010 to 2014 by customer size. The vertical axis does not include a numerical count due to the use of respondent weighting, which was not explicitly designed to control for the unique attributes of purchases instead of stock-based weighting. Figure 3-62 illustrates our best understanding of the distribution of LED bulb purchases by year and customer size. These data indicate that customers with less than 500,000 annual kWh installed the largest number of LED bulbs during the 2010 to 2014 time period.58

Figure 3-62: Count of LED bulbs installed by year and customer size

*The results presented above are weighted using the respondent-level sample weight.

** The data represent 5 sites with LED purchases in 2010, 13 sites for 2011, 32 sites for 2012, 69 sites for 2013 and 141 sites with purchases in 2014.

Figure 3-63 illustrates the size of LED purchases relative to the existing stock of ICLH bulbs (the existing stock is held constant at the 2014 level and the LED share represent yearly purchases). These data indicate that purchases of LED in 2014 account for approximately 10% of the existing stock of ICLH bulbs for

58 The data presented in Figure 3-62: Count of LED bulbs installed by year and customer size support the conclusion that small-sized customers installed slightly more than 2 million LED bulbs, medium sized customers installed between 750,000 and 1 million LEDs, and large customer installed slightly less than 500,000 LED bulbs.
customers with less than 500,000 kWh annual usage, 8% for customers with 500,000 to 4,500,000 kWh and 29% for customers with more than 4,500,000 kWh. These data indicate that larger sized customers purchased a higher share of LEDs for their ICLH bulbs than other customers while the data presented in Figure 3-62 illustrates that there are substantially more LED lamps in the customers who consume less than 500,000 kWh annually. The low saturation of LED lamps for customers with less than 500,000 kWh implies that even with the large number of LEDs in businesses with less than 500,000 kWh, a large number of ICLH sockets still remain to be transitioned to LED lamps within this size segment.

**Figure 3-63: LED purchases as a share of the existing stock of ICLH bulbs**

*The results presented above are weighted using the respondent-level sample weight.

** The data represent 5 sites with LED purchases in 2010, 13 sites for 2011, 32 sites for 2012, 69 sites for 2013 and 141 sites with purchases in 2014.

### 3.8.3 Lighting controls on recently purchased lighting

Where possible, the DNV GL team collected information on the type of control used for all lighting measures. Types of controls included manual switch, continuous on, EMS, motion sensor, photo cell motion sensor, photo cell time clock, daylighting, and other. For some lighting measures, no information was collected on the type of control. Figure 3-64 displays the distribution of indoor lighting controls across all types of recently purchased lighting. This graph indicates that the largest share of recently purchased non-residential lighting in Massachusetts (70%) is manually controlled while 22% are controlled by either EMS, motion sensors, PC-
motion sensors (PC-MS), or PC-time clock (PC-TC). The 70% of recently purchased lighting manually controlled is slightly less than the 77% of all lighting that is manually controlled. These data indicate that new lighting has a slighting higher probability of having some sort of automated control than the existing base, but the potential for additional controls is extensive.

Figure 3-64: Share of recently purchased lighting controlled by alternative lighting controls – interior lighting

*The results presented above are weighted using the respondent-level sample weight. These controls were analyzed from lamps purchased from 2009 to 2015.

** These data represent 567 sites.

Figure 3-65 illustrates the distribution of lighting controls on recently purchased lamps for each type of lamp. These data indicate that recently purchased HIDs are almost equally likely to be manually controlled or controlled by photo cell-time clocks (PC-TC). The relatively high incidence of HIDs in outdoor lighting may contribute to their higher likelihood of control. Of all lighting types, LEDs are most likely to be on a continuous on setting though less than 10% of LEDs are continuously on.59 Given the lower energy use and

59 The controls analysis does not include exit signs that are required by OSHA to be continuously on while the building is occupied.
the longer expected life of LED bulbs, retrofitting bulbs that are continuously-on to LEDs is a cost effective and time saving retrofit.

**Figure 3-65: Lighting controls on recently purchased lamps by lamp type – interior lighting**

*The results presented above are weighted using the respondent-level sample weight. These controls were analyzed from lamps purchased from 2009 to 2014.*

**These data represent 251 sites with linears, 79 sites with CFLs, 304 sites with incandescents, 10 sites with halogens, 252 sites with LEDs, 8 sites with HIDs, 1 site with neons and 1 site with other lighting.*

***Lighting contractor refers to outside contractors hired to monitor and manage lighting systems.

Figure 3-66 illustrates the distribution of lighting controls on recently purchased lighting by business size. For recently purchased lighting in businesses with annual usage less than 500,000 kWh, 90% of newly purchased bulbs are manually controlled. Manual control declines substantial for new lighting in businesses with 500,000-4,500,000 kWh (37%) and those with more than 4,500,000 kWh of usage (39%). Businesses with a usage 500,000 kWh to 4,500,000 kWh have an 18% share of EMS. The highest share of time clocks (29%) was found at businesses with annual usage of exceeding 4,500,000 kWh.
3.8.4 Recently purchased indoor occupancy sensors

Figure 3-67 and Figure 3-68 depict the average number of occupancy sensors per site on recently purchased lighting in commercial business spaces in Massachusetts by business type, and business kWh usage size category respectively. The analysis shows that warehouses have the highest average number of occupancy sensors on recently purchased lighting per site with 268 occupancy sensors, followed by hospitals with an average of 207 sensors. This finding is consistent with the analysis of occupancy sensors in the existing stock, where warehouses and hospitals were also found to have the highest number of occupancy sensors. Warehouses and hospitals tend to operate out of larger sized buildings that may not need lighting for all areas during all hours of the day. As expected the largest size annual consumption category ( >4,500,000 kWh) has the highest average number of occupancy sensors on new lighting with 256 sensors per site.
Figure 3-67: Recently purchased occupancy sensors per site by business type – interior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 27 sites for campuses, 51 education sites, 34 food sales, 50 food Service sites, 49 healthcare sites, 14 hospitals, 45 lodging sites, 46 manufacturing or industrial sites, 82 offices, 41 other businesses, 56 sites for public assembly, 52 retail sites and 20 warehouses.
3.9 Exterior lighting – market share and sales trends

This section presents the results of the analysis of recently purchased lighting in outdoor locations. The on-site survey effort captured information regarding recent purchases of lighting fixtures installed in outdoor spaces as well as controls for outdoor lighting.

Table 3-25 provides a count of on-site survey completes that gathered information regarding recently purchased outdoor lighting by business type. The table also provides a count of on-site surveys completed for specific lighting technologies.
Table 3-25: On-sites with recent purchases (2009-2014) – exterior lighting

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Total On-site Count with Recent Exterior Lighting Purchases</th>
<th>On-sites with Recent Exterior HID Purchases</th>
<th>On-sites with Recent Exterior Linear Purchases</th>
<th>On-sites with Recent Exterior ICLH Purchases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>12</td>
<td>2</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Education</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>Food Sales</td>
<td>17</td>
<td>1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Food Service</td>
<td>18</td>
<td>1</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Healthcare</td>
<td>24</td>
<td>0</td>
<td>1</td>
<td>24</td>
</tr>
<tr>
<td>Hospitals</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Lodging</td>
<td>22</td>
<td>1</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>21</td>
<td>0</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Office</td>
<td>27</td>
<td>1</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Other</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>31</td>
<td>3</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>Retail</td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Warehouse</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>244</strong></td>
<td><strong>11</strong></td>
<td><strong>12</strong></td>
<td><strong>232</strong></td>
</tr>
</tbody>
</table>

*The results presented above are un-weighted.

**The counts indicate the number of instances the technology was found in the buildings that were visited. For example, at least 1 HID lamp was found in 30 of the 17 Food Sales-type buildings visited.

Figure 3-69 illustrates the respondent weighted lamp type shares of recently purchased lighting technologies as a percentage of all new lamps found in outdoor spaces in commercial buildings in Massachusetts. As shown, just over 43% of all recently purchased non-residential exterior lamps are non-linear LED technologies, followed by incandescent lamps at 35%, while HIDs have a share of only 2% of new lamps.
**Figure 3-69: Recent purchase distribution by lamp type – exterior lighting**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent lamp count data from 12 sites with linears, 17 sites with CFLs, 86 sites with incandescents, 4 sites with halogens, 150 sites with LEDs and 11 sites with HIDs.

*** Linear technologies include linear fluorescents and TLEDs

Figure 3-70 illustrates the distribution of recently purchased outdoor lighting by lamp type and business annual electricity consumption. These data indicate that LED technologies have a substantial share of the distribution of recently purchased lamps for all business sizes. Fifty eight percent of the recently purchased exterior lamps for businesses with annual electricity consumption from 500,000 to 4,500,000 kWh were LEDs, followed by 41% for businesses with less than 500,000 kWh and 26% for businesses consuming more than 4,500,000 kWh. Linear lighting accounts for 54% of recently purchased exterior lamps for businesses consuming more than 4,500,000 kWh and 31% for medium sized businesses. For businesses with less than 500,000 kWh of annual consumption, 43% of recently purchased exterior bulbs are incandescent lamps. Incandescent lamps in small businesses represent a potential energy savings target for PA-sponsored energy efficiency programs.
Figure 3-70: Distribution of recently purchased lamps by technology type and business kWh usage – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 94 sites in the <500,000 kWh category, 118 sites in the 500,000-4,500,000 kWh category and 32 sites in the >4,500,000 kWh category.

3.9.1 Recent purchases of exterior lighting controls

This section focuses on controls for recently purchased lighting installed in outdoor spaces. Figure 3-71 displays the distribution of lighting controls across all types of exterior lighting. This graph indicates that 56% of the non-residential recently purchased outdoor lighting in Massachusetts is controlled by PC-time clock, followed by 31% of new exterior lighting that is manually controlled. This distribution, however, represents a very slight drop in controls relative to the share of the existing base of exterior lighting controlled by PC-time clocks. Previous analysis in the existing exterior lighting sub-section found that 59% of the existing outdoor lamps were controlled by a PC-timer clock.
Figure 3-71: Share of recently purchased lighting controlled by alternative lighting controls – exterior lighting

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 244 sites.

Figure 3-72 illustrates the distribution of recently purchased outdoor lighting controls by business size. For all three business sizes analyzed, time clocks are the most common type of lighting control. Businesses in the >4,500,000 kWh usage size category are shown to have the highest share, relative to the other two business sizes, of their lighting controlled by time clocks (87%) followed by businesses in the 500,000 to 4,500,000 size category with a share of 61%.
Figure 3-72: Lighting controls on recently purchased lighting by business kWh usage – exterior lighting

The results presented above are weighted using the respondent-level sample weight.

** These data represent 94 sites from sites in the <500,000 kWh category, 118 sites from sites in the 500,000-4,500,000 kWh category and 32 sites from sites in the >4,500,000 kWh category.
4 HVAC EQUIPMENT

The C&I Customer On-site Assessments and the MSST Study documented the baseline distribution of existing heating, ventilation, and air conditioning (HVAC) equipment and the distribution of new heating and cooling equipment purchased from 2009 to 2015. HVAC equipment represent a significant fraction of energy use and peak demand within the C&I sector. The HVAC data collected during the on-site assessments provide an indication of the progress achieved in the installation of newer, more efficient equipment and provides information on the current C&I HVAC market. The on-site data also included information about HVAC system maintenance programs.

Table 4-1 presents the incidence of heating and cooling equipment and make and model data for the sample by business type. These data indicate that field data were collected from 800 businesses, cooling information was collected at 725 businesses while 772 businesses provided heating information. The final two columns provide information on the number of businesses where make and model information was collected. The make and model information for equipment was analyzed to determine the efficiency for these equipment.

Table 4-1: On-sites by business type and HVAC equipment

<table>
<thead>
<tr>
<th>Business type</th>
<th>Count of completed on-site surveys</th>
<th>Cooling sys. info collected</th>
<th>Heating sys. info collected</th>
<th>Make and model data collected for cooling</th>
<th>Make and model data collected for heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>33</td>
<td>34</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>76</td>
<td>78</td>
<td>67</td>
<td>53</td>
</tr>
<tr>
<td>Food Sales</td>
<td>47</td>
<td>42</td>
<td>46</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>Food Service</td>
<td>63</td>
<td>59</td>
<td>58</td>
<td>40</td>
<td>39</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>60</td>
<td>61</td>
<td>54</td>
<td>49</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>54</td>
<td>60</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>83</td>
<td>79</td>
<td>83</td>
<td>68</td>
<td>62</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>111</td>
<td>108</td>
<td>91</td>
<td>71</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>47</td>
<td>55</td>
<td>38</td>
<td>32</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>73</td>
<td>62</td>
<td>72</td>
<td>55</td>
<td>53</td>
</tr>
</tbody>
</table>

60 While it is likely that all or nearly all businesses have heating equipment and nearly all businesses have cooling equipment, the on-site surveyor was not able to collect this information for some facilities. In cases where the HVAC equipment was not able to be confirmed, the cooling and heating weights were set to zero. The weights for the customers with equipment was adjusted to account for locations with equipment whose information was not collected on-site.
<table>
<thead>
<tr>
<th>Business type</th>
<th>Count of completed on-site surveys</th>
<th>Cooling sys. info collected</th>
<th>Heating sys. info collected</th>
<th>Make and model data collected for cooling</th>
<th>Make and model data collected for heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail</td>
<td>72</td>
<td>58</td>
<td>70</td>
<td>33</td>
<td>42</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>24</td>
<td>27</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>725</strong></td>
<td><strong>772</strong></td>
<td><strong>588</strong></td>
<td><strong>537</strong></td>
</tr>
</tbody>
</table>

* The results presented above are un-weighted.

**The counts indicate the number of instances the technology was found in the buildings that were visited.

## 4.1 HVAC cooling findings

The research team identified several important cooling findings during their analysis. Figure 4-1 illustrates the distribution of cooling equipment in Massachusetts businesses based upon the on-site data. The text in the box shows the self-reported data from the C&I Customer Telephone Survey.

- The large majority of Massachusetts businesses use stand-alone non-central cooling equipment. The study found that 45% of cooling equipment is split and packaged ACs, 38% are PTACs and window/wall units, and approximately 1% are chillers.
- Split and packaged AC units are associated with businesses that represent 70% of Massachusetts business square footage while chillers are estimated to be found in businesses that represent 20% of business square footage (see Figure 4-10).61 Chillers cool substantially more square footage than their share of cooling units.
- PTACs and window/wall cooling units are common across all size of businesses but are concentrated in lodging, hospitals, and campuses where they likely provide cooling for small spaces within larger buildings.

### C&I Customer Telephone Survey Note:

According to the C&I Customer Telephone Survey:

- 66% of customers (site weighted) reported split or packaged AC equipment as being their primary source of cooling.
- 31% Reported PTAC's/window/wall units
- 3% reported chillers

These responses may be influenced by the larger number of small customers who participated in the telephone survey.

It’s also important to note that customers in the telephone survey only reported their primary cooling systems. For larger customers like hospitals, while many facilities may have split or packaged AC, they would not have been reported in the telephone survey

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61 A business may have multiple types of cooling and the business square footage would be associated with multiple cooling types such that the sum of cooled square footage will exceed 100%.
The field data collection gathered information on the make and model number of split and packaged air conditioners and heat pumps. These data were looked up to determine the efficiency of the cooling units. The data presented in Table 4-2 show that nearly ¾ of split and packaged units in Massachusetts businesses are very small sized system. The second most common size is small commercial units between 65 and 134 kBtuh.

The analysis found that a high share of Massachusetts businesses have high efficiency cooling units. The federal energy efficiency standards, the minimum efficiency requirements to receive a PA-sponsored program rebate in 2013 and the share of the existing stock and recent purchases above federal standards are listed in Table 4-2.
Table 4-2: Split and packaged federal and PA-sponsored program efficiency standards and share above federal standards

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Small (&lt; 65 kBtuh)</td>
<td>74%</td>
<td>13 SEER</td>
<td>14 SEER</td>
<td>31%</td>
<td>49%</td>
</tr>
<tr>
<td>Small (65-134 kBtuh)</td>
<td>15%</td>
<td>10.8 – 11.2 EER</td>
<td>11.3 - 11.5 EER</td>
<td>28%</td>
<td>75%</td>
</tr>
<tr>
<td>Medium (135-239 kBtuh)</td>
<td>7%</td>
<td>10.4-11 EER</td>
<td>10.9 – 11.7 EER</td>
<td>15%</td>
<td>33%</td>
</tr>
<tr>
<td>Large (240+ kBtuh)</td>
<td>3%</td>
<td>9.3-10</td>
<td>10.3 – 10.5 EER</td>
<td>36%</td>
<td>74%</td>
</tr>
</tbody>
</table>

*The distribution of systems presented above is weighted using the respondent-level sample weight.

The data in Table 4-2 support the conclusion that a large share of the existing stock of split and packaged AC and HP units are above federal standards that were implemented in 2008 and 2010. A very high share of recently purchased split and packaged cooling units exceed federal efficiency standards. Comparing federal baseline energy efficiency standards and PA-sponsored program efficiency standards required to receive a rebate, many PA-sponsored program levels are less than 10% higher than federal efficiency requirements. Given the very high share of recent purchases that exceed federal standards, PA-sponsored programs may want to consider raising the efficiency requirements to receive a PA-sponsored program incentive. Raising the efficiency requirements for program rebates may help to move the market to an even higher level of efficiency.

Figure 4-2 illustrates the distribution of split and packaged cooling efficiency by business type. In Figure 4-2 the efficiency for the different sized systems is grouped together and described as below, at, or above federal efficiency requirements. If the make and model information was not collected or it was not possible to determine the efficiency level, the units are listed as make and model missing or not found.

- 77% of split and packaged cooling in warehouses is above federal energy efficiency standards followed by 72% for lodging, 58% for campuses and 41% for other and healthcare businesses. These data indicate that many business types have a substantial share of their cooling units above federal standards.

⁶²Beginning in 2013, the PA-sponsored efficiency standards for small to large sized split and packaged systems include requirements based on IEER or an integrated energy efficiency ratio. The IEER is intended to represent the performance of the system when it is operating at different capacity levels. The study did not collect information on cooling system IEER.
64% of the split and packaged units are below federal standards in public assembly, 63% for retail, 50% for other, 45% for education, and 41% for manufacturing and industrial. The high share of units below standards for these business types provides a program opportunity for the PA-sponsored HVAC programs.

The federal standards for these measures were established in 2008 and 2010 and the Massachusetts TRM uses a 15-year measure life for these measures. It is likely that the cooling units observed to be below federal standards were purchased prior to the implementation of the federal standards used for this analysis.

*Figure 4-2: Split and packaged AC/HP efficiency ratings, by business type*

*The results presented above are respondent weighted.*

** These data represent 155 split and packaged cooling units in campuses, 542 in education, 185 in food sales, 133 in food services, 584 in healthcare, 232 in lodging, 519 in manufacturing or industrial, 762 in offices, 223 in other, 323 in public assembly, 152 in retail, and 77 in warehouses.
Figure 4-3 illustrates the distribution of efficiency for split and packaged air conditioning and heat pump units in Massachusetts businesses by business size.

- 50% of units in businesses with more than 4,500,000 kWh are found to be more efficient than required by federal energy efficiency standards.
- 39% of units in businesses with less than 500,000 kWh are found to be less efficient than current federal efficiency standards.

These data indicate that many large electricity consumers have invested in energy efficient cooling while businesses with annual consumption below 4,500,000 kWh have a larger share of inefficient units. Targeting PA-sponsored programs to public assembly, retail, education, food service, and manufacturing and industrial businesses with annual consumption below 4,500,000 kWh may lead to substantial improvements in the cooling efficiency of split and packaged air conditioning units in Massachusetts businesses.

*The results presented above are weighted using the respondent-level sample weight.*

** These data represent 598 systems found in facilities with Less than 500,000 kWh Usage, 3,256 system found in facilities with a kWh usage between 500,000 to 4,500,000 kWh, and 804 systems found in facilities with a kWh usage greater than 4,500,000 kWh.
The cooling analysis also examined the average capacity, using tons, by cooling equipment type.

- Centrifugal chillers were found to have the largest average capacity at 909 tons (see Table 4-7). These large sized units are infrequently found in Massachusetts businesses, but when used, each unit cools a substantial area.
- Window/wall units are the most frequently observed cooling units by the weighted count of observed units. The average capacity of these units is only 1.2 tons. These units are typically designed to cool small spaces or a room.
- Split system air conditioning units are a frequently observed cooling units in Massachusetts businesses. The average capacity of split system air conditioners is 6.7 tons. Packaged air conditioners, another common type of air conditioning in Massachusetts businesses, average 9.8 tons.

More information and details on the cooling equipment observed in Massachusetts businesses is provided in sections 4.3 through 4.5 below.

### 4.2 HVAC heating findings

The following section highlights findings from the analysis of the heating equipment data. Heating equipment was analyzed by type of equipment and type of fuel. For split and packaged heating equipment, an efficiency analysis compared the efficiency of heating units to federal efficiency standards.

- Split and packaged heating units are the most commonly observed heating sources, representing 41% of heating units. Smaller sized baseboard/space/unit heater units account for 24% of heating units, boilers represent 13% of units, 11% are split and packaged heat pumps, and 9% are PTAC/window/wall heating units.
  - As observed in Figure 4-4, boilers are approximately 10% of heating units across all size of Massachusetts business.
  - Split and packaged furnaces are most common in business with less than 500,000 kWh.
  - Split and packaged heat pumps are most common in business with more than 4,500,000 kWh.
  - PTAC and window/wall heating units are most common in businesses with 500,000 to 4,500,000 kWh. These units were found in campuses, lodging, and hospital where these units are used to heat a small space or a room.

Natural gas is the most common type of heating fuel in Massachusetts businesses (see Figure 4-28 and Figure 4-30).

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C&I Customer Telephone Survey Note:
According to the C&I Customer Telephone Survey:

- 24% of customers (site weighted) reported split or packaged (non-furnace) equipment as being their primary source of heating.
- 48% Reported that a furnace or boiler was their primary heating source.

Similar to cooling, these responses may be influenced by the larger number of smaller customers who participated in the telephone survey; however, the on-site assessment results show that boilers and split/package furnaces make up 52% of heating equipment in the market. This roughly aligns with the telephone survey results of 48%.
The federal energy efficiency standards for heating units are relatively old when looking at split and packaged furnaces. The federal standards were established in 1992 through 2010. The federal standards for small gas furnaces, the most common type of heating units, were established in 2007. PA-sponsored programs in Massachusetts help to lead the market by requiring substantially higher efficiency levels than those mandated by federal standards. For small gas furnaces, in 2012 PA-sponsored programs required an AFUE of 95% (federal standards were 78 AFUE) for receipt of incentives while larger furnaces required a thermal efficiency of 90%. In 2013 PA-sponsored programs required an HSPF of 8.5 (compared to 7.7 under federal standards) for small heat pumps, a COP of 3.4 and 3.2 for larger heat pumps and a COP of 4.6 for water source heat pumps. PA-sponsored program energy efficiency requirements for heating equipment are higher than federal efficiency requirements for the production and sale of equipment, helping to push the Massachusetts heating energy efficiency level far beyond the federal energy efficiency requirements and have likely contributed to the high share of heating equipment above federal standards.
The evaluation team analyzed the make and model number of split and packaged heating systems to develop a better understanding of the efficiency of the existing stock and recent purchases of these heating units. Determining the efficiency of heating units from make and model lookups is often very difficult to determine.

Developing a centralized database of make and model numbers and their efficiency levels and efficiency units for units rebated by the PA-sponsored program could help to develop a better understanding of what is currently being rebated. This database of make and model numbers and efficiency levels could also be used for future baseline studies.

Table 4-3 presents information on the efficiency distribution of split and packaged heating units by time period. The first four or left-most columns of the table help to illustrate the difficulty of lookups associated with heating units. Thirty percent of the unit purchased prior to 2008 have either missing or unknown efficiency. For units purchased in 2009-2011, the majority of units were found to have either unknown or wrong efficiency standards relative to federal efficiency standards. The data in the three right most columns of Table 4-3 illustrate that the heating units purchased by Massachusetts businesses are generally above federal efficiency standards if the model not found and unknown or wrong standards are reallocated proportional to the observed information.

Table 4-3: Efficiency of split and packaged heating units – by time period & reallocation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Standards</td>
<td>48%</td>
<td>23%</td>
<td>78%</td>
<td>55.9%</td>
<td>23%</td>
<td>94.0%</td>
</tr>
<tr>
<td>At Standards</td>
<td>12%</td>
<td>18%</td>
<td>5%</td>
<td>43.6%</td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td>Below Standards</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>5.1%</td>
<td>0.5%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Make Model Not Found</td>
<td>14%</td>
<td>7%</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown - Wrong Standards</td>
<td>16%</td>
<td>51%</td>
<td>3%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*these data are weighted by respondent weights.

- The analysis of recently purchased split and packaged heating units found that over 50% of recently purchased units were small furnaces.
  - Thirty four percent of recent purchases were water source heat pumps but these units were installed in only 8 sites where large number of units were installed.
• The efficiency of newly installed small furnaces almost always exceeded existing federal energy efficiency standards and approximately 20% of units have an AFUE that would likely make them eligible for PA-sponsored programs. Similarly, new water source heat pumps were generally purchased above both federal and PA-sponsored program requirements. The findings for these two types of heating equipment support the conclusion that Massachusetts customers have access to high efficiency heating equipment.
  - The share of small furnaces purchased above PA-sponsored program requirements, however, does not appear to increase between the existing and recent purchase analysis. These data may indicate that the market is failing to meet its full potential.
  - The PA-sponsored program needs to ensure that trade allies and customers are aware of the benefits of purchasing units at 95 and 97 AFUE. These levels far exceed federal efficiency requirements and provide Massachusetts customers with large heating savings.

• New large split and packaged furnaces and small heat pumps are almost always purchased below the energy efficiency requirements needed to receive PA-sponsored program incentives. Large furnaces are predominately packaged roof top units or large makeup air units with a heating component. Package roof top units are less frequently high efficiency condensing style furnaces.
  - A process analysis and/or market analysis may be necessary to understand why larger furnaces and small heat pumps do not tend to be purchased at efficiency levels approaching PA-sponsored program requirements.
  - It is likely that there is savings potential associated with reviewing the current programs for large furnaces, increasing awareness of the benefits of these units, and providing incentives for high efficiency purchases.

The efficiency analysis of split and packaged heating units also analyzed efficiency by customer size. Figure 4-5 illustrates the distribution heating efficiency by customer size.

• At most, 5% of heating units were found to be below standards.
• Most units with observed efficiency levels were above standards.
Heating efficiency can also be viewed by business type. Table 4-4 lists the efficiency distribution of split and packaged heating by business type. The first six left-most columns of data present the efficiency distribution as observed in the field data. Determining the efficiency of heating units, however, can be difficult due to special characters and many units list efficiency in incorrect units. The right most columns of Table 4-4 reallocate the efficiency data assuming the unknowns, missing, and wrong standards are randomly distributed consistent with the observed distribution.

- The largest share of units are above federal standards.
- Using the redistributed data, 97% of heating units in public assembly are above federal efficiency standards. 92% of units in retail, 87% in other, 84% in healthcare and 83% in food service are above standards.
- Hospitals, other businesses and campuses were found to have a high share of split and packaged units either below or at federal efficiency standards.
Table 4-4: Split and packaged heating efficiency distribution by business type

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>3%</td>
<td>36%</td>
<td>0%</td>
<td>55%</td>
<td>5%</td>
<td>8.3%</td>
<td>90.5%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Education</td>
<td>60%</td>
<td>21%</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>74.0%</td>
<td>26.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>31%</td>
<td>9%</td>
<td>3%</td>
<td>5%</td>
<td>38%</td>
<td>71.7%</td>
<td>20.9%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Food Service</td>
<td>37%</td>
<td>8%</td>
<td>0%</td>
<td>27%</td>
<td>20%</td>
<td>82.5%</td>
<td>17.0%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>64%</td>
<td>12%</td>
<td>1%</td>
<td>17%</td>
<td>7%</td>
<td>84.0%</td>
<td>15.2%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>8%</td>
<td>0%</td>
<td>26%</td>
<td>50%</td>
<td>8%</td>
<td>23.4%</td>
<td>0.0%</td>
<td>76.6%</td>
</tr>
<tr>
<td>Lodging</td>
<td>7%</td>
<td>1%</td>
<td>1%</td>
<td>53%</td>
<td>3%</td>
<td>78.5%</td>
<td>15.5%</td>
<td>6.0%</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>32%</td>
<td>11%</td>
<td>1%</td>
<td>5%</td>
<td>25%</td>
<td>72.9%</td>
<td>25.4%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Office</td>
<td>62%</td>
<td>2%</td>
<td>8%</td>
<td>10%</td>
<td>11%</td>
<td>86.8%</td>
<td>2.3%</td>
<td>10.9%</td>
</tr>
<tr>
<td>Other</td>
<td>22%</td>
<td>32%</td>
<td>10%</td>
<td>4%</td>
<td>31%</td>
<td>34.6%</td>
<td>50.5%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>65%</td>
<td>2%</td>
<td>0%</td>
<td>12%</td>
<td>21%</td>
<td>97.1%</td>
<td>2.8%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Retail</td>
<td>53%</td>
<td>5%</td>
<td>0%</td>
<td>27%</td>
<td>5%</td>
<td>92.0%</td>
<td>8.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>11%</td>
<td>3%</td>
<td>1%</td>
<td>76%</td>
<td>7%</td>
<td>71.6%</td>
<td>20.7%</td>
<td>7.7%</td>
</tr>
</tbody>
</table>

More information on heating equipment in Massachusetts businesses is found in Sections 4.6 to 4.8.

4.3 HVAC cooling

The cooling equipment data collected by the field staff were categorized into two categories, stand-alone HVAC units and large centralized HVAC systems. Stand-alone units are typically units between 1 and 20 tons, and include split and rooftop packaged units, as well as very small room-size air conditioners, window/wall units, PTAC units, and mini-split systems. Large HVAC systems include large central built up systems including chillers, gas engine units, and large split DX units over 20 tons. Table 4-5 shows the system types that were surveyed onsite for each HVAC category.
Table 4-5: HVAC cooling system types

<table>
<thead>
<tr>
<th>Stand-Alone HVAC Units</th>
<th>Large Central HVAC Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split System and Packaged System Air Conditioners</td>
<td>Chillers (Reciprocating, Screw/Scroll, Centrifugal, Absorption)</td>
</tr>
<tr>
<td>Split System and Packaged System Heat Pumps</td>
<td></td>
</tr>
<tr>
<td>Other: Window/Wall and PTAC Units</td>
<td>Gas Engine Units</td>
</tr>
<tr>
<td>Mini Split Air Conditioner and Heat Pump Units</td>
<td>Large Split DX Units</td>
</tr>
</tbody>
</table>

Stand-alone HVAC and large central HVAC systems were analyzed separately. The stand-alone systems at a site were aggregated into the following categories:

- **Split/packaged**: The business has only split or packaged AC, HP, or mini split cooling systems
  - A split AC system can also be characterized as an exterior condensing unit with interior evap coil and air handler.
  - A packaged AC system can also be characterized as a roof top unit (RTU).
  - Mini splits can be characterized as individual AC units.
- **Other**: The business has only window/wall units, or PTAC units.
- **Multiple System Types**: The business has both split/packaged units and units classified as “other.”
- **No Stand Alone Systems**: The business has no stand-alone HVAC systems.

This breakdown is shown in Figure 4-6, weighted by the site-level sample weight and by the kWh-level sample weight.
Figure 4-6: Businesses with varying types of stand-alone HVAC cooling equipment

*The results presented above are weighted using the site-level and the kWh-level sample weight.
** These data represent 781 sites.63

These data indicate that when analyzing stand-alone HVAC cooling, businesses having only split and packaged systems is the most common cooling configuration for C&I customers in Massachusetts, both weighted by kWh (64%) and by sites (50%). About 15% of the C&I customers in Massachusetts have no stand-alone cooling systems.

Table 4-6 presents the disaggregated distribution of stand-alone cooling by system type, site weighted. The data presented in Table 4-6 disaggregate the information presented in the right-most pie of Figure 4-6. The data in Figure 4-6 is presented at the business unit level while the data in Table 4-6 is presented at the cooling unit level. Because the data in Table 4-6 is at the cooling unit, the table does not include a share for no stand-alone cooling system or multiple systems.

Table 4-6 illustrates the on-site count and the weighted distribution of split and packaged systems with 23% split system AC, 22% package system AC, 3% split system HP, 2% package system HP, 5% mini-split AC, 2% mini-split HP, 4% water source HP, and less than 1% geothermal HP. These data also show that window/wall units have the largest share of stand-alone HVAC units at 29%. Window/wall cooling units are smaller units designed to cool relatively small spaces. It is likely that several window wall units would be

63 There were 19 sites without records in the Stand-Alone HVAC table.
needed to cool the square footage associated with most stand-alone commercial sized split and packaged systems.

**Table 4-6: Distribution of stand-alone HVAC systems**

<table>
<thead>
<tr>
<th>Stand-Alone System Type</th>
<th>Count</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split System AC</td>
<td>1,437</td>
<td>23%</td>
</tr>
<tr>
<td>Split System Heat Pump</td>
<td>679</td>
<td>3%</td>
</tr>
<tr>
<td>Package System AC</td>
<td>2,112</td>
<td>22%</td>
</tr>
<tr>
<td>Package System Heat Pump</td>
<td>364</td>
<td>2%</td>
</tr>
<tr>
<td>Window/Wall Unit</td>
<td>1,475</td>
<td>29%</td>
</tr>
<tr>
<td>Mini Split (AC Only)</td>
<td>663</td>
<td>5%</td>
</tr>
<tr>
<td>Mini Split Heat Pump</td>
<td>546</td>
<td>2%</td>
</tr>
<tr>
<td>PTAC</td>
<td>4,444</td>
<td>8%</td>
</tr>
<tr>
<td>Water Source Heat Pump</td>
<td>1,227</td>
<td>4%</td>
</tr>
<tr>
<td>Geothermal Heat Pump</td>
<td>61</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

*The distribution results presented above are weighted using the respondent-level sample weight. The count numbers are unweighted.

** These data represent 13,008 units.

The analysis also reviewed the distribution of large HVAC systems at a site, separately from the stand-alone units. These large HVAC systems were broken into the following categories:

- Elec motor/Engine-driven chillers: The business has only electric and/or gas-driven chillers
- Absorption chillers: The business has only absorption chillers
- Large split DX: The business has only Large Split DX units (over 20 tons)
- Other: The business has other uncategorized large HVAC systems
- Multiple system types: The business has multiple large HVAC system types.
- No large systems: The business has no large HVAC systems

This breakdown of businesses with large HVAC cooling equipment is shown in Figure 4-7, weighted by the site-level sample weight and by the kWh-level sample weight. Ninety-seven percent of sites, using the site-level sample weight, do not have large HVAC systems (defined above), at the facility. Large HVAC systems are rarely found in small-sized businesses (less than 500,000 kWh usage), which make up 97% of the C&I customers (see Figure 2-2).

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64 Data on stand-alone and large HVAC cooling systems were weighted separately, necessitating the separate analysis of these systems at the business level.
65 “Engine Driven Chiller” includes all gas, diesel, and electric motor-driven vapor compression cycle chillers. A variety of compressors are represented: reciprocating (up to about 700 tons), screw (about 100 to 1,000 tons), and centrifugal (about 350 to 5,000 tons).
66 These systems were listed as "Other" by the onsite surveyors.
67 Business with no large HVAC systems may have either a stand-alone HVAC system or no cooling system.
When comparing the C&I customer population by kWh consumption, 40% of the kWh is served by large HVAC systems. Facilities with large kWh consumption are more likely to have Large HVAC systems. Customers with large kWh consumption (greater than 4,500,000 kWh annually) represent 33% of C&I consumption in Massachusetts.

Figure 4-7 shows that 22% of the kWh of businesses in Massachusetts have an engine driven cooling system and 12% of businesses have multiple types of large cooling systems.

**Figure 4-7: Businesses with varying types of large HVAC cooling equipment**

Most businesses in Massachusetts do not have large HVAC systems (97% site weighted and 60% kWh weighted). Out of the 800 sites visited, only 223 sites were found to have large HVAC systems at the facility. The disparities between the site weighted and kWh weighted distributions show, as expected, that

---

68 There were 22 sites without records in the Large HVAC Cooling Equipment table.

69 Typically the larger units are found in large businesses. These large businesses tend to have smaller site weights and larger kWh weights. While 223 sites were found during the on-site data collection to have large HVAC systems, these larger sites have smaller site weights leading to the conclusion that only 3% Massachusetts commercial customers have large HVAC systems.
the larger HVAC systems are generally found in facilities with a much larger kWh usage, which have a large kWh weight but represent only a small fraction of the overall business population in Massachusetts.

The distribution of number of cooling units was also analyzed. When analyzing cooling units it is possible to combine the stand-alone and large sized units in a joint analysis. The stand-alone and large cooling units were disaggregated into split/package ACs, split/packaged heat pumps, minisplits, window/wall/PTAC, water/ground source heat pumps, large split DX, engine-driven chillers, absorption chillers and other. The other systems in Figure 4-8 included only systems from the large HVAC systems that were uncharacterized during data collection. The data in Figure 4-8 represent cooling units, not the distribution of systems across businesses, so there is no “none” category.

**Figure 4-8: Distribution of cooling equipment**

Over 50% of the cooling systems identified were split or packaged systems, which breaks down into 45% split/packaged ACs, 6% split/packaged heat pumps, and 5% minisplit ACs. A very small percentage of systems (1%) were classified as chillers. Chillers are few in number but with substantially larger capacities than the more common split/packaged and PTAC/window/wall units. The capacities of the larger chiller...
systems imply that even for a very large facility, only a few chillers are needed to meet the cooling loads. Cooling system types were also analyzed by business kWh usage, shown below in Figure 4-9.

**Figure 4-9: Distribution of cooling equipment by business kWh usage**

![Distribution of cooling equipment by business kWh usage](image)

*The results presented above are weighted using the respondent-level sample weight.*

** These data represent 13,654 units.

The large share of PTAC/window/wall units observed in all size of businesses is due in part to large quantities of these units needed to cool a given space. The increasing share as business size increases is due to the large number of these units in lodging, hospital, and campus businesses. Since window/wall and PTAC units typically cool a relatively small area within a business multiple units are required to cool the large spaces in these businesses.

Figure 4-10 shows the percent of the square footage served by each type of cooling system. This analysis was based on the square footage for the entire building. If a business was served by multiple HVAC units of the same type, the square footage of the business is only used once for that system type. This means that for systems like PTAC units which are designed to serve a small portion of the space, are analyzed as if they serve the entire facility. However, as demonstrated in Figure 4-9 above, the facilities which have these smaller system types also have large quantities of them serving multiple spaces within the facility. If a facility has multiple types of cooling equipment (e.g., packaged systems and engine-driven chillers), the
business square footage was counted for both system types. Accounting for square footage covered by the various systems in this way results in the total percent of square footage served summing to more than 100%.

**Figure 4-10: Percent of square footage served, by cooling equipment**

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 5,255 split/packaged units, 460 chiller systems, and 7,939 "other" units.

Over 70% of the square footage of the population is associated with businesses with split or packaged AC units, over 30% of square footage is in businesses with PTAC/window/wall units, and just over 20% of square footage is in businesses with engine-driven chillers. Engine-driven chillers account for only 1% of the total number of systems, yet they serve 20% of the population’s square footage due to their larger capacities and the larger size of the facilities that they occupy. Although the PTAC/window/wall system types are designed to serve smaller areas, they were associated with businesses that account for 30% of the square footage of Massachusetts buildings. As shown in Figure 4-10, large quantities of PTAC/window/wall system types were found to be in facilities with higher kWh usage, such as campuses and lodging facilities. These businesses are comprised of many smaller rooms that may be optimally served by these smaller individual units. It is likely that many businesses with PTAC/window/wall cooling units also have additional
cooling types and the PTAC/window/wall units may not be cooling the entire business square footage. For example, PTAC units are often found in lodging where split/packaged AC units may provide cooling for halls, offices, and meeting spaces.

4.3.1 Cooling capacity

The on-site data collection gathered information on cooling capacity or tonnage where possible. Table 4-7 lists the average tons per cooling unit by cooling system type. The systems are listed in order of declining average tonnage per unit. These data indicate that centrifugal chillers have the largest average tonnage followed by other large HVAC systems. These larger system cool larger spaces, but there are significantly fewer large units than smaller units (see Figure 4-8). Split and packaged air conditioning units were the most frequently observed cooling unit in Massachusetts businesses. These units are designed to cool a smaller area than chillers but more than PTAC or Window/wall units. For this analysis, air conditioning and heat pump units are classified as split and packaged units. These units were observed to have average capacities between 9.8 and 1.2 tons per unit. On average, heat pumps were found to be smaller than air conditioning units. These units, however, are very small and usually intended to only cool one room or a relatively small space. The average cooling capacity of window/wall units is 1.2 tons.

Given the share of units observed in the larger capacity units (typically called chillers), split and packaged units, and window wall units it is likely that split and packaged systems account for the largest share of air conditioning tonnage in Massachusetts businesses. These units are the subject of the efficiency analysis presented below.

Table 4-7: Cooling capacity per unit, by cooling system type

<table>
<thead>
<tr>
<th>Cooling system type</th>
<th>Average tons per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifugal Chiller</td>
<td>908.8</td>
</tr>
<tr>
<td>Other Large HVAC System</td>
<td>546.9</td>
</tr>
<tr>
<td>Screw/Scroll Chiller</td>
<td>134.8</td>
</tr>
<tr>
<td>Large Split DX</td>
<td>121.0</td>
</tr>
<tr>
<td>Reciprocating Chiller</td>
<td>117.0</td>
</tr>
<tr>
<td>Package System AC</td>
<td>9.8</td>
</tr>
<tr>
<td>Split System AC</td>
<td>6.7</td>
</tr>
<tr>
<td>Split System Heat Pump</td>
<td>4.8</td>
</tr>
<tr>
<td>Geothermal Heat Pump</td>
<td>3.1</td>
</tr>
<tr>
<td>Mini Split (AC Only)</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Placement of the cooling equipment, weather, or liability restrictions, or wear of the nameplate can limit the ability of the field staff to gather name plate information.
<table>
<thead>
<tr>
<th>Cooling system type</th>
<th>Average tons per unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini Split HP</td>
<td>1.7</td>
</tr>
<tr>
<td>PTAC</td>
<td>1.2</td>
</tr>
<tr>
<td>Window/Wall Unit</td>
<td>1.2</td>
</tr>
<tr>
<td>Package System Heat Pump</td>
<td>1.2</td>
</tr>
</tbody>
</table>

*These data are respondent weighted.

The capacity data were also used to examine the business total square footage per ton of cooling capacity in businesses where the tonnage data was available and the business only used one type of cooling. If the business used only chillers or large split DX units, the analysis found that Massachusetts businesses averaged 374 square feet per ton of cooling capacity. If the business used only split and package AC or HP, the businesses averaged 540 square feet per ton. Alternatively, if the business used only PTAC or window/wall units, the business averaged 1,754 square feet per ton. It is likely that businesses exclusively using PTAC and window/wall units for cooling have significant square footage that is not cooled or cooled adequately.

Table 4-8 lists the square footage per ton and the tons per square foot by business type for businesses where capacity was collected and only one type of cooling capacity was employed at the business. The restrictions associated with this analysis have significantly reduced the sample size and care should be taken into account when attempting to generalize these findings to the rest of Massachusetts businesses. Because many businesses in Massachusetts use more than one type of cooling the data in Table 4-8 includes only 197 of the original 800 sites. This is consistent with the finding that 12% of kWh have multiple types of large cooling and 16% of kWh have multiple types of stand-alone cooling (see Figure 4-6 and Figure 4-7).

The data in Table 4-8 show that hospitals have the least square footage per ton (or the most tons per square foot). Hospitals must keep their floor area cool at all times to ensure a comfortable and stable environment for their patients. Campuses and manufacturing and industrial businesses were found to have the largest average square footage per ton of cooling. The data for campuses should be extrapolated with caution as only five campus sites are included in this analysis. It is likely that Manufacturing and industrial businesses include both conditioned and unconditioned space. The inclusion of unconditioned space in the analysis will make the square footage per ton look larger than the actual averaged area cooled. This analysis is based on the business square footage independent of its conditioned status. The study focused on collecting information on business square footage and does not have consistent information on conditioned square footage.

The square footage per ton was also calculated by businesses size, where size is represented by annual kWh consumption. Businesses with annual electricity consumption larger than 4,500,000 kWh per year average 397 square feet per ton, businesses with 500,000 to 4,500,000 kWh average 532 square feet per ton and businesses with less than 500,000 kWh average 793 square feet per ton.

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71 The field data collection did not attempt to map business area to cooling unit so it is not possible to know the area served by distinct cooling units. The current analysis focused exclusively on businesses with only one type of cooling to eliminate issues associated with different types of cooling serving different square footages in the facility.
Table 4-8: Square footage per ton of cooling capacity for business with only one cooling type

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Square footage per ton</th>
<th>Tons per square foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>2120</td>
<td>0.47</td>
</tr>
<tr>
<td>Education</td>
<td>1903</td>
<td>0.53</td>
</tr>
<tr>
<td>Food Sales</td>
<td>407</td>
<td>2.46</td>
</tr>
<tr>
<td>Food Service</td>
<td>371</td>
<td>2.69</td>
</tr>
<tr>
<td>Healthcare</td>
<td>416</td>
<td>2.40</td>
</tr>
<tr>
<td>Hospitals</td>
<td>234</td>
<td>4.27</td>
</tr>
<tr>
<td>Lodging</td>
<td>678</td>
<td>1.47</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>1641</td>
<td>0.69</td>
</tr>
<tr>
<td>Office</td>
<td>444</td>
<td>2.25</td>
</tr>
<tr>
<td>Other</td>
<td>634</td>
<td>1.58</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>608</td>
<td>1.64</td>
</tr>
<tr>
<td>Retail</td>
<td>935</td>
<td>1.07</td>
</tr>
<tr>
<td>Warehouse</td>
<td>1076</td>
<td>0.93</td>
</tr>
</tbody>
</table>

*Data are weighted by respondent weight.

**These data represent field data collection from 5 campuses, 12 education sites, 13 food sales, 21 food service, 1 hospital, 11 lodging, 22 manufacturing or industrial, 36 offices, 15 other, 16 public assembly, 21 retail and 4 warehouses. These data are from 197 of the 800 sites with field data collection.

4.4 Split and packaged cooling systems efficiency

During the on-site data collection process the field staff collected make and model numbers from HVAC equipment where possible. For split and packaged air conditioning and heat pump systems the make and model numbers were used to determine the efficiency of the system. The efficiency rating for these systems depend upon system type and size. The minimum efficiency standards are set by the U.S. Department of Energy). The efficiency standards were compared to efficiency information collected for the observed cooling equipment, including equipment where the purchase dates were unknown.

Table 4-9 lists the federal efficiency standards used to classify systems for this report. These standards represent the standards in place during the field data collection period for this study. Comparison to current standards is necessary because the purchase date of equipment is not available for all units and a comparison to current standards provides information on the energy efficiency savings potential relative to
current standards. Cooling units observed in the existing stock with an efficiency level less than the standards listed in Table 4-9, may have been purchased prior to the compliance year and may have been compliant at the time of purchase.

The information presented in Table 4-9 shows that the federal efficiency standards for very small AC and HP units was established in 2008, six to seven years prior to field data collection. The federal efficiency standards for very small AC and HP units was updated in January 2015. The field data, weighted by site weights, indicate that 74% of the split and packaged AC and HP units in Massachusetts businesses are very small sized systems. The federal energy efficiency standards from small, medium, and large sized split and packaged AC and HP cooling units were established in 2010, four to five years prior to field data collection.

Table 4-9: AC and heat pump cooling efficiency standards and distribution of systems

<table>
<thead>
<tr>
<th>System Type</th>
<th>System Size</th>
<th>Standard Efficiency</th>
<th>Year of Compliance</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very small AC or Heat Pump</td>
<td>Less than 65 kBtuh</td>
<td>13 SEER</td>
<td>2008</td>
<td>74%</td>
</tr>
<tr>
<td>Small Commercial AC/HP</td>
<td>65 – 135 kBtuh</td>
<td>10.8-11.2 EER</td>
<td>2010</td>
<td>15%</td>
</tr>
<tr>
<td>Medium Commercial AC/HP</td>
<td>135 - 240 kBtuh</td>
<td>10.4-11 EER</td>
<td>2010</td>
<td>7%</td>
</tr>
<tr>
<td>Large Commercial AC/HP</td>
<td>240+ kBtuh</td>
<td>9.3-10 EER</td>
<td>2010</td>
<td>3%</td>
</tr>
</tbody>
</table>

*The distribution of systems presented above is weighted using the respondent-level sample weight.

Figure 4-11 illustrates the distribution of efficiency for AC and heat pump systems. Cooling units with efficiency levels below those listed in Table 4-9 were listed as below standards and units with efficiencies above those listed were categorized as above standards. The research team attempted to collect nameplate efficiency data for all surveyed units. For some cooling systems the make and model numbers could not be collected. For example, the nameplate may be worn off due to age and exposure to the elements or the systems may be positioned in a way that does not allow for

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72 Unless noted otherwise, references to standards throughout the remainder of the report, will be in regards to current standards listed in Table 4-9.

73 Field data collection was initiated in August of 2014 and concluded in September of 2015.

74 The efficiency standards for very small sized air conditioning units is regulated in SEER and the standard for larger units is regulated in EER. During the make and model lookup process we found several very small sized air conditioning units where only EER information was available and several large sized units where only SEER information was available. Instead of having these units be categorized as model not found, we used the following conversion to approximate an average EER and average SEER:

\[
EER = 1.12 \times SEER - 0.02 \times SEER^2
\]

\[
SEER = 1.12 - \sqrt{1.2544 - 0.08 \times EER}
\]

This equation was sourced from the following website: http://www.powerknot.com/how-efficient-is-your-air-conditioning-system.html.

75 Standards for very small split system heat pumps and single packaged AC/HPs are raised to a minimum SEER of 14, effective January 2015. The 2015 standard for split system air conditioners remains at a minimum SEER of 13.

76 Heating system efficiencies are discussed in Section 4.7.
data collection. Units whose make and model numbers were not collected on-site are described as "Make/Model Missing" in Figure 4-11.

The make and model numbers are used to determine the efficiency of the units. The format of the HVAC make and model numbers vary tremendously across manufacturers. Each manufacturer has a different numbering scheme, with each letter, number, or dash representing a characteristic unique to the specific manufacturer. The efficiency lookup process incorporated information from manufacturer product specification sheets, web searches, and efficiency data bases for high efficiency units including Energy Star, The Preston Guide, the CEE, and the California Energy Commission eligible product list. For many model numbers it was not possible to assign an efficiency rating. For example, the model number collected on-site was gathered from the air-handling unit but not the AC unit or the model number may be incomplete or the equipment was old and efficiency information was no longer available. For many model numbers, the research found that the model number was accurate but no efficiency information was available. Air conditioning systems with model numbers but no efficiency information were classified as "Make/Model Not Found" in Figure 4-11.

The efficiency analysis classified systems into efficiency levels based on the federal efficiency standards found in federal efficiency standards found in Table 4-9 and the cooling system’s size. Figure 4-11 shows the distribution of efficiency levels for each of these cooling categories. These data indicate that over 50% of small and medium sized split and packaged air conditioning and heat pump units in C&I facilities in Massachusetts are below the federal standards in effect at the time. Federal standards regulate the efficiency level requirements associated with unit production and/or importation of units. Given that the Massachusetts TRM lists the expected useful life of a split and packaged air conditioning unit as 15 years, it is likely that many of the air conditioning units that are observe to be below federal standards were purchased prior to the implementation of these standards. The share observed to be below federal standards were likely purchased meeting or exceeding the standards in place at the time of purchase.

When looking across the four size groups, the high share of split and packaged cooling units that are very small (74%) leads to the finding that 29% of all split and packaged AC and HP units are above standards, 14% at standards, and 36% below standards. Eleven percent of units were make and model missing and 8% were model not found. The relatively high share of units above standards is due in large part to the 31% of very small sized cooling units above standards combined with the finding that 74% of all split and packaged units are very small sized.
**Figure 4-11: Efficiency ratings for split/packaged AC and HP, by system size**

Very small-sized systems (less than 65 kbtuh) and large commercial-sized systems (greater than 240 kbtuh) have the smallest share of systems that are below standards, both at 29%, as well as the largest share of systems above standards (31% and 36%, respectively). Medium-sized systems (135-240 kbtuh) have a large share (80%) of systems below standards, while only 15% of the units exceed standards. For medium sized systems, the large share of commercial cooling systems that did not meet the efficiency standards relative to the other system sizes is not surprising given that the standards for small, medium, and large sized commercial systems were set in 2010. The relatively short time since the standards were implemented (there was four to five years between the implementation of these standards and field data collection) combined with a 15 year effective useful life (EUL) of these HVAC, helps to explain the relatively large share of small and medium sized cooling units below the current standards.77 Finding that 29% of all split and

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packaged AC and HP units are above standards and 14% are at standards likely implies that a substantial share of cooling purchases are more efficient than federal energy efficiency standards. An efficiency analysis of recent purchases is described in Section 4.7.

The very small sized cooling unit analysis is presented in Figure 4-12. The federal energy efficiency standards applied in the analysis of very small cooling units were initially implemented in 2008. The standards for very small sized systems increased from 13 SEER to 14 SEER in 2015. It was determined that the use of the updated standard to benchmark equipment in use since before 2015 would not be appropriate for this analysis.

The distribution of the systems by SEER and EER ratings helps to identify the size of cooling units with the highest remaining energy savings potential and quantifies the penetration of high efficiency equipment in the C&I market. The distribution of efficiency information by SEER and EER is provided in Figure 4-12 through Figure 4-15.

Very small-sized systems make up 74% of the stand-alone systems found in C&I buildings across Massachusetts. When comparing the efficiency buckets of very-small sized systems, only 29% of very small-sized systems were found to be below standards, less than 13 SEER. Given that the Massachusetts's TRM assumes a 15 year EUL for AC and HP units, finding that only 29% of identified units are below standards implemented six to seven prior to data collection implies that many Massachusetts businesses were likely purchasing cooling units with efficiency ratings above the previous standards. The data in Figure 4-12 also show that 17% of the existing stock of very small sized cooling units are listed as SEER 13 or “at standards”, 8% were found to be 14 SEER, 7% were 15 to 16 SEER, and 17% were 17 SEER or greater. Recalling that the federal efficiency standards for the very small sized systems was updated in 2015, we see that across all efficiency buckets, Figure 4-12 shows 32% of systems were above the 2008 standards; and that 24% of systems are above the 2015 standards. Massachusetts businesses using very small sized cooling equipment have a high share of the units that exceed the federal energy efficiency standards in place during field data collection and a surprising high share of units exceeding the new standards that were implemented at the end of field data collection. There were also 22% of systems where the efficiency of the units could not be classified, either due to the make and model missing, or not found through efficiency lookup efforts.
Small commercial systems (ranging between 65 kBtuh to 134 kBtuh) make up 15% of the stand-alone split and packaged HVAC units found in C&I buildings across Massachusetts. The standards for small sized commercial split and package AC and heat pump systems range between 10.8 and 11.2 EER, based on whether the system is an air conditioner or a heat pump, and whether the system has electric resistance, gas heating or no heating. The distribution of small commercial systems in Massachusetts businesses shows that the majority of systems (53%) are less than 10.8 EER, which is below federal energy efficiency standards originally implemented in 2010 and in-force during the period of field data collection. Of the 11% of systems between 10.8 to 11.2 EER, 80% just met the efficiency standards, while 16% were above standards and 4% were below standards. Twenty-seven percent of systems were found to be between 11.3 and 14.9 EER. Combining the systems in the 11.3 to 14.9 EER range with the units above standards in the 10.8 to 11.2 EER range implies that approximately 29% (.27+.11*.16) of small commercial cooling systems were found to be between 11.3 and 14.9 EER.

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78 The current federal energy efficiency standards for small commercial cooling units ranges from 10.8 to 11.2 EER. Each cooling unit configuration, however, has a specific EER based federal efficiency standard that depends on the exact system configuration. The analysis has used information on system configuration, in combination with federal efficiency standards, to determine the above, at, and below efficiency rating for units falling in the 10.8 to 11.2 EER range.
systems are above current federal energy efficiency standards. Finding that 29% of the existing stock of small commercial systems are above current federal energy efficiency standards likely implies that a very high share of recent purchases exceed current standards. See Section 4.3 for information on the efficiency distribution of recently purchased split and packaged AC and HP systems.

**Figure 4-13: Efficiency distribution of small commercial systems (65 to 134 kBtuh)**

![Efficiency distribution chart](image)

- Less than 10.8 EER
- 10.8 to 11.2 EER
- 11.3 to 14.9 EER
- 15 EER or Greater
- Unknown - Make/Model Missing
- Unknown - Make/Model Not Found

*The results presented above are weighted using the respondent-level sample weight.
** These data represent 713 systems.

The standards for medium sized commercial split and package AC and heat pump systems (between 135 and 239 kBtuh) range between 10.4 and 11 EER, depending on whether the system is an air conditioner or a heat pump, and whether the system has electric resistance, gas heating or no heating. The distribution of medium commercial systems in Massachusetts businesses (Figure 4-14) shows that the majority of these systems (64%) were below standards at less than 10.4 EER. Nineteen percent of the systems were between
10.4 and 11 EER, but out of these systems, 82% were still below standards, and only 7% at standards.\(^79\)

Only 13% of medium sized systems were rated above 11 EER. Medium sized cooling systems have 15\% (.13 + .19*.11) of cooling systems above standards, the smallest share of cooling units above federal energy efficiency standards in Massachusetts businesses.

**Figure 4-14: Efficiency distribution of medium commercial systems (135 to 239 kBtuh)**

![Efficiency distribution chart]

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 433 systems.

The standards for large commercial split and package AC and heat pump systems (240 kBtuh or greater) range between 9.3 and 10 EER, based on whether the system is an air conditioner or a heat pump, and whether the system has electric resistance, gas heating or no heating. Figure 4-15 shows that only one quarter (25\%) of large commercial systems in Massachusetts were found to be less than 9.3 EER or below standards. Only 9\% of large commercial systems were between 9.3 and 10 EER, and 24\% of those systems were at standards while 31\% were above standards. Thirty-three percent of systems were found to be 10.1 EER or greater. These data imply that 36\% (.33 + .09*.31) of large sized commercial split and packaged

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\(^79\) The current federal energy efficiency standards for medium sized commercial cooling units ranges from 10.4 to 11 EER. Each cooling unit configuration, however, has a specific EER based federal efficiency standard that depends on the exact system configuration. The analysis has used information on system configuration, in combination with federal efficiency standards, to determine the above, at, and below efficiency rating for units falling in the 10.4 to 11 EER range.
cooling units in the existing stock have an efficiency level above current federal energy efficiency standards. Once again, the high share of cooling units above current standards in the existing stock implies that a very high share of recent purchases are above current federal energy efficiency standards (See Section 4.3). For 33% for large systems the efficiency could not be identified.

**Figure 4-15: Efficiency distribution of large commercial systems (240 kBtuh or greater)**

*The results presented above are weighted using the respondent-level sample weight.*

**These data represent 420 systems.**

Figure 4-16 illustrates the efficiency rating of split and packaged cooling systems by business kWh usage. The largest share of systems that exceed efficiency standards are found in the facilities with over 4,500,000 kWh in annual usage.
Figure 4-16: Split and packaged AC/HP efficiency ratings, by business kWh usage

![Graph showing efficiency ratings by business kWh usage](image)

*The results presented above are weighted using the respondent-level sample weight.** These data represent 598 systems found in facilities with Less than 500,000 kWh Usage, 3,256 system found in facilities with a kWh usage between 500,000 to 4,500,000 kWh, and 804 systems found in facilities with a kWh usage greater than 4,500,000 kWh.

Figure 4-17 illustrates the distribution of split and packaged cooling efficiency by business type. These data indicate that 77% of split and packaged cooling in warehouses is above federal energy efficiency standards followed by 72% for lodging, 58% for campuses and 41% for other and healthcare businesses. These data indicate that many business types have a substantial share of their cooling units above federal standards. These data also show that 64% of the split and packaged units are below federal standards in public assembly, 63% for retail, 50% for other, 45% for education, and 41% for manufacturing and industrial. The high share of units below standards for these business types provides a program opportunity for the PA-sponsored HVAC programs. The federal standards for these measures were established in 2008 and 2010 and the Massachusetts TRM uses a 15-year measure life so it is likely that the cooling units observed to be below federal standards were purchased prior to the implementation of the federal standards used for this analysis.
Figure 4-17: Split and packaged AC/HP efficiency ratings, by business type

*The results presented above are respondent weighted.

** These data represent 155 split and packaged cooling units in campuses, 542 in education, 185 in food sales, 133 in food services, 584 in health care, 232 in lodging, 519 in manufacturing or industrial, 762 in offices, 223 in other, 323 in public assembly, 152 in retail, and 77 in warehouses.

Figure 4-18 illustrates the efficiency distribution of air conditioning systems by participation in PA-sponsored energy efficiency (EE) programs for all participants in EE programs, while Figure 4-19 displays the efficiency distribution of air conditioning systems for participants who received an incentive for an HVAC measure. Energy efficiency participants were defined as businesses that participated in a traditional PA-sponsored energy efficiency program from 2011 to 2014. The program participation largely reflects traditional or downstream programs since account-level data for upstream programs were not available at the time of the analysis. Additional HVAC units may have been rebated through these upstream programs. The PA-sponsored program transitioned to upstream HVAC incentives for commercial customers during 2013 and 2014.80

80 The program was implemented in April of 2013. Many HVAC distributors had likely already placed their cooling orders by April 2013. The upstream nature of the program was more fully implemented during the 2014 summer season.
The data presented in Figure 4-18 indicate that a greater share of EE program participants have cooling systems below standards (34%) than have equipment that exceeds the efficiency standards (26%). A higher share of non-participants have cooling systems that exceed efficiency standards (30%) than participants (26%). However, EE program participants, may have participated in programs associated with end-uses other than HVAC equipment. As shown in Figure 4-19, participants who received traditional downstream incentives for HVAC measures, have a higher share of cooling units that are above standards (44%) than customers that did not receive an HVAC incentive (29%). Figure 4-18 and Figure 4-19 illustrate different trends in HVAC efficiencies by customers who participate in any and all efficiency programs versus those who participate in HVAC-specific programs. These differences may indicate that participation in HVAC EE programs provide greater awareness to the customer on HVAC efficiency. Participation in a PA-sponsored program for an HVAC measure may contact the customer through an HVAC contractor or internal maintenance personnel familiar with PA sponsored HVAC programs. Exposure to PA sponsored HVAC programs likely increases awareness of the energy savings associated with high efficiency HVAC unit. It is likely that participation in general, non-HVAC PA sponsored energy efficiency programs does not provide the customer with the same level of understanding and knowledge of high efficiency HVAC energy savings potential as is acquired from participating in HVAC energy efficiency programs.

*The results presented above are weighted using the respondent-level sample weight.*

**These data represent 2,541 systems purchased by EE participants.*
* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,053 systems purchased by HVAC participants.

The average cooling capacities of the very small and commercial sized cooling systems was also analyzed, and is shown in Table 4-10.

**Table 4-10: Average and median cooling capacities for cooling systems**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Very small AC or Heat Pump</td>
<td>Less than 65 kBtuh</td>
<td>41,000</td>
<td>3.4</td>
<td>46,000</td>
<td>3.8</td>
</tr>
<tr>
<td>Small Commercial AC/HP</td>
<td>65 – 135 kBtuh</td>
<td>98,000</td>
<td>8.2</td>
<td>89,000</td>
<td>7.5</td>
</tr>
<tr>
<td>Medium Commercial AC/HP</td>
<td>135 - 240 kBtuh</td>
<td>190,000</td>
<td>15.8</td>
<td>179,000</td>
<td>14.9</td>
</tr>
<tr>
<td>Large Commercial AC/HP</td>
<td>240+ kBtuh</td>
<td>534,000</td>
<td>44.5</td>
<td>290,000</td>
<td>24.2</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight. The average and median capacities shown in kBtuh are rounded to the nearest 1000. The average and median capacities shown in tons are rounded to the nearest 0.1 ton.

**4.5 Recent purchases of split and packaged cooling equipment**

Table 4-11 lists the number of completed on-sites visits, the number of sites where cooling system data was collected on-site, the number of sites where newly purchased cooling equipment was recorded and the number of sites where make and model numbers were collected for newly purchased cooling equipment. Out of the 725 sites with cooling data, 337 had purchased cooling equipment from 2009 to 2015. The weighted
sample data represents approximately 100,000 split and package HVAC systems purchased by Massachusetts businesses from 2009-2015.

Table 4-11: Number of business surveyed, cooling systems, and recent cooling system purchases

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Count of Completed On-Site Surveys</th>
<th>Cooling Information Collected</th>
<th>New Cooling Equipment</th>
<th>Make and Model Data Collected for Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>33</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>76</td>
<td>34</td>
<td>30</td>
</tr>
<tr>
<td>Food Sales</td>
<td>47</td>
<td>42</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Food Service</td>
<td>63</td>
<td>59</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>60</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>20</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>54</td>
<td>24</td>
<td>23</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>83</td>
<td>79</td>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>111</td>
<td>50</td>
<td>48</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>47</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>73</td>
<td>62</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>58</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>24</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>725</td>
<td>337</td>
<td>301</td>
</tr>
</tbody>
</table>

* The results presented above are un-weighted.

Figure 4-20 illustrates the efficiency distribution for recently purchased split and packaged cooling systems by system size. The standard efficiency rating information for these systems is provided in Table 4-9. Figure 4-20 lists the efficiency of the new split and packaged units relative to federal energy efficiency standards. The federal standards for very small cooling units (less than 65 btuh) were established in 2008 while energy efficiency standards for small, medium, and large split and packaged units were established in 2010.

The efficiency distribution of new cooling units, illustrated in Figure 4-20, can be compared to the efficiency distribution for all split and packaged units seen in Figure 4-11. The share of systems above standards increased substantially for all system size categories. The above standards share for small sized units increased from 28% in the existing stock to 75% for recent purchases and from 36% above standards for the existing stock of large sized units to over 70% for new large sized units. Comparing the efficiency of
very small sized cooling units, 31% of the existing stock of very small unit are above standards while 49% of recent purchases are above standards. This comparison illustrates the willingness of Massachusetts commercial customers to purchase cooling units at efficiency levels exceeding federal energy efficiency standards.

The results in Figure 4-20 also show that a large share of the medium-sized (between 135-239 kBtuh) systems do not meet the federal efficiency standards that were established in 2010. There are two reasons for this large share of medium sized units below standards. First, a large share of recently purchased medium sized units were purchased in 2009-2011, a year prior to, through a year after, the establishment of current standards. While these units are below current federal energy efficiency standards (implemented in 2010), these medium sized units were purchased as units compliant to the standards in effect at, or near the time of purchase. In addition, the field data for new medium sized units was limited to 90 units. The efficiency distribution of new medium sized units is influenced by a single site with a relatively large respondent weight that purchased a system below the 2010 standards.

**Figure 4-20: Split and packaged AC/HP efficiency ratings for recently purchased systems, by system size**

* The results presented above are weighted using the business-level sample weight.
** These data represent 1,065 systems.

Figure 4-21 illustrates the SEER level distribution of very small sized systems purchased from 2009 to 2015. The largest share (24%) of very small-sized systems were found to be SEER 14, which exceeds the 2008 base efficiency standards of SEER 13. Twenty-two percent of newly purchased very small sized systems in

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81 The share of recent very small sized purchases above federal standards likely exceed 49%. Twenty four percent of recently purchased very small sized units did not have make and model numbers and were therefore not eligible of an efficiency classification.
Massachusetts businesses met the 2008 base efficiency standard. Efficiency standards for very small sized systems were updated in 2015 to SEER14, however for this analysis, the 2008 standards are applicable. Forty-nine percent of these new very small systems were found to be above the standards, 14 SEER or greater.

For recently purchased very small sized units, the efficiency for 27% of systems could not be classified, either due to missing make and model information or efficiency information could not be found during the looked up process. For HVAC units commonly installed on the exterior of buildings, missing make and model numbers can indicate that a unit is older and the tag has been weathered. Because of this, we cannot assume that the distribution of existing older units with missing or unknown data is identical to the distribution of units with known data. For newer units, however, where weathering of the nameplate is unlikely, we can assume that the model missing represent units whose nameplates were inaccessible or unobservable due to their placement and that the model not found are randomly distributed across new units. If the model missing and not found for new equipment are redistributed in a share consistent with the observed distribution, 67% of newly purchased very small sized units are above standards, 30% at standards and 3% below. Of the 67% above standards, 33% are estimated to be SEER 14, the new standard efficiency level as of 2015. The share of above standard very small sized recently purchased cooling units is exceptionally high, representing the willingness of Massachusetts commercial customers to install high efficiency cooling equipment.
Figure 4-21: Efficiency distribution of new very small-sized systems (less than 65 kBtuh)

- Less than SEER 13
- SEER 14
- SEER 17 or Greater
- Unknown - Make/Model Missing
- Unknown - Make/Model Not Found

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 712 systems.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 3% of systems Less than SEER 13, 30% of systems at SEER 13, 33% of systems at SEER 14, 27% of systems SEER 15 or SEER 16, and 7% of systems SEER 17 or Greater.

This efficiency analysis for new very small-sized systems was also analyzed by two year purchase groups. The years 2009-2014 were divided into three equally time sized groups; systems purchased between 2009 and 2010 those purchased between 2011-2012 and systems purchased between 2013-2014. The majority of the systems purchased between 2009-2010 were found to be SEER 13 and 7% were purchased below the federal minimum standard of 13 SEER. The non-zero share of units purchased below federal efficiency standards is not surprising since the SEER 13 standard was implemented in 2008 and sales of units below 13 SEER in 2009 and 2010 likely represent sales of units produced prior to the implementation of the new standards. The finding that 22% of newly purchased very small cooling units were SEER 14 and higher during 2009 and 2010 indicates that Massachusetts businesses were interested in purchasing units substantially above code relatively soon after the code was implemented.

During 2011 to 2012, the share of very small sized cooling units purchased above federal energy efficiency code (13 SEER) jumped substantially relative to the 2009-2010 period. From 2011 to 2012, 87% of newly purchased units were found to be SEER 14 and higher. The extremely high share of very small split and packaged cooling units purchased above code indicates that high efficiency units were readily available.
during this time period and Massachusetts businesses are aware of the advantages of purchasing high efficiency cooling units. Unfortunately, the efficiency distribution for units purchased from 2013-2014 showed that make or model missing has a very large percentage (66%) of very small units purchased during this time period. The high share of model missing for units purchased from 2013-2014 was due in part to a small number of systems with very large respondent weights. The very high share of make and model missing for the 2013-2014 time period makes it difficult to extrapolate the direction of the market during this time period. It is interesting to note, however, that the observable share of SEER 17 or greater units installed from 2013 to 2014 appear to be approaching the exceptionally high share of these unit purchased from 2009 to 2011.

Currently the PA-sponsored program provides upstream incentive for very small units under a two tiered approach. The program offers a reduced incentive for units purchased at 14 SEER and 11.6 to 12 EER and a higher incentive for units purchased at 15 SEER and 12 to 12.5 EER and higher. Recall that the federal efficiency standards for very small units increased in 2015. Given the exceptionally high share of very small units purchased at 14 SEER and above during 2011 to 2012, the Massachusetts PAs may want to push the market even higher by offering a larger incentive to customers installing a 16 SEER or higher unit.

Table 4-12: Efficiency distribution by grouped year of new very small-sized systems

<table>
<thead>
<tr>
<th>Efficiency buckets</th>
<th>2009-2010</th>
<th>2011-2012</th>
<th>2013-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than SEER 13</td>
<td>7%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>SEER 13</td>
<td>62%</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>SEER 14</td>
<td>1%</td>
<td>58%</td>
<td>3%</td>
</tr>
<tr>
<td>SEER 15 to 16</td>
<td>10%</td>
<td>28%</td>
<td>6%</td>
</tr>
<tr>
<td>SEER 17 or Greater</td>
<td>11%</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>Unknown - Make/Model</td>
<td>2%</td>
<td>1%</td>
<td>66%</td>
</tr>
<tr>
<td>Missing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unknown - Make/Model</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not Found</td>
<td>7%</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Total</td>
<td>118</td>
<td>227</td>
<td>193</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

Figure 4-22 illustrates the EER distribution of small commercial cooling systems purchased by Massachusetts businesses from 2009 to 2015. Only 8% of recently purchased small commercial sized systems were found to be less than 10.8 EER, compared with 53% below 10.8 EER within the overall existing stock of small commercial systems. The majority of new small commercial systems (70%) were found to be between 11.3 and 14.9 EER, which is above the federal efficiency standards of 10.8 to 11.2 EER. Only 27% of existing
cooling systems were between 11.3 and 14.9. The PA-sponsored upstream HVAC and HP initiative rebates small commercial AC and HP units under a two-tiered system as of 2016, providing Tier 1 incentives for units above 11.5 EER and tier 2 incentives for those above 12 EER. From 2009 to 2014, Massachusetts businesses were largely purchasing cooling units above federal code and often above Tier 1 & 2 PA-sponsored program requirements when purchasing small commercial sized systems. Given the extremely high share of small cooling units found to be above federal code and above PA-sponsored program requirements, the PA sponsored energy efficiency programs should consider adopting higher efficiency requirements.

**Figure 4-22: Efficiency distribution of new small commercial systems (65 to 134 kBtuh)**

![Efficiency Distribution Chart](image)

- Less than 10.8 EER
- 11.3 to 14.9 EER
- 10.8 to 11.2 EER
- 15 EER or Greater
- Unknown - Make/Model Missing
- Unknown - Make/Model Not Found

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 185 systems.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 9% of systems Less than 10.8 EER, 19% of systems 10.8 to 11.2 EER, 72% of systems 11.3 to 14.9 EER, and <1% of systems 15 EER or greater.

The efficiency analysis for new small-sized systems was also by year of purchase, shown below in Table 4-13. There was a change in federal energy efficiency standards in 2010, which increased the efficiency standards from less than 9 EER (based on system type) to over 10.8 EER. Disaggregating the data into these three...
buckets illustrates that the majority of units purchased below the 2010 standards were purchased prior to and the year of the implementation of standards; 32% of the units purchased from 2009-2010 were above or at the former standard but below the 2010 minimum efficiency standards. There were no small sized units that were observed to be below the 2010 standards purchased in 2011-2012 and a few systems with a high respondent weight, were purchased in 2013-2014 with an EER less than 10.8, however the majority of newly purchased small sized were found to be greater than 10.8 EER. There is little evidence in the recent purchase data for small sized units that would indicate an increasing efficiency of units purchased during the 2009-2014 time period, though a high share of units are purchased above the 10.8-11.2 EER standards throughout the time period (35% for 2009-2010, 90% 2011-2012, and 27% for 2013-2014). Developing a Tier 3 incentive level within the PA-sponsored program could encourage customers to stretch even further above federal energy efficiency standards.\textsuperscript{82}

Table 4-13: Efficiency distribution by grouped year of new small-sized systems

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10.8 EER</td>
<td>32%</td>
<td>0%</td>
<td>22%</td>
</tr>
<tr>
<td>10.8 to 11.2 EER</td>
<td>19%</td>
<td>10%</td>
<td>50%</td>
</tr>
<tr>
<td>11.3 to 14.9 EER</td>
<td>35%</td>
<td>90%</td>
<td>27%</td>
</tr>
<tr>
<td>15 EER or Greater</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>14%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>42</td>
<td>55</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

Figure 4-23 illustrates the distribution of medium sized commercial cooling systems purchased by Massachusetts businesses from 2009 to 2015. The efficiency distribution of newly purchased medium-sized systems differs substantially from the distribution of new small-sized commercial systems. While the large majority of newly purchased small-sized systems were above code, the majority of newly purchased medium-sized systems (58%) were below the efficiency code of 10.4 to 11 EER. The high share of newly purchased units below code is due to two peculiarities in the data. First, one site that purchased a below standard unit has a relatively large respondent level weight. This site is effectively representing a large number of sites who, if they all purchased new units similar to this customer, would lead to a large share being purchased below current standards. Secondly, the current energy efficiency standards of 10.4 to 11 EER were implemented in 2010 which prohibits the production and import of units that do not meet the efficiency standards. Approximately 75% of these below code, recently purchased medium-sized commercial cooling units were purchased in 2009 or 2011, the remaining 25% of units were purchased since 2009 but the site contact was unsure of the precise year (this 75%/25% breakdown is unweighted). Many, if not all, 82 The PA-sponsored PA sponsored energy efficiency program incentivizes small commercial cooling and medium commercial cooling units at the same EER levels: Both cooling unit sizes are required to have an EER greater than 11.5 for Tier 1 rebates and greater than 12 EER for Tier 2 rebates. Effectively grouping these two sizes together may simplify the program at the cost of stretching the market for small sized cooling units.
of the medium sized units purchased that were found to be below the 2010 standards represent units sold prior to, or just after, the implementation of the 2010 standards.

Comparing the existing overall stock of cooling equipment and recently purchased units, we found a large increase in the share of medium sized systems (from 13% to 28%) in the 11.1 to 13 EER category. This indicates that despite the large number of units still found below standards, there was an increase in the share of systems above federal standards for recently purchases.

**Figure 4-23: Efficiency distribution of new medium commercial systems (135 to 239 kBtuh)**

- Less than 10.4 EER
- 10.4 to 11 EER
- 11.1 to 13 EER
- 13.1 to 15 EER
- Unknown - Make/Model Missing
- Unknown - Make/Model Not Found

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 90 systems.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 62% of systems Less than 10.4 EER, 8% of systems 10.4 to 11.0 EER, 29% of systems 11.1 to 13 EER, and <1% of systems 13.1 to 15 EER.

This efficiency analysis for new medium-sized systems was also grouped into buckets by year, shown below in Table 4-14. The recently purchased medium-sized systems were disaggregated into those purchased between 2009 and 2011, and those purchased between 2012 and 2014. Standards for these systems increased from around 8.5 EER to a minimum of 10.4 to 11.0 EER in 2010. As described above, most of the below 10.4 EER units were purchased in 2009-2011, indicating that these units were purchased while compliant with federal standards or just after. The units with efficiencies under 10.4 EER and installed in 2010 and 2011 likely represent units manufactured to standards but installed after the implementation of standards. This type of installation is compliant. Reviewing the 10.4-11 EER and 11.1 EER and above installations, there is a clear increase in efficiency of medium sized split and packaged systems installed during this time period. In addition, there is clear indication that Massachusetts businesses are frequently installing medium-sized cooling units that are above federal efficiency standards. In 2013, the PA-sponsored
program incentives were available for medium sized cooling units above 10.9 to 11.7 EER depending on the system configuration. In 2016 the program had adopted a tiered approach: Tier 1 incentives are available for units above 11.5 EER and Tier 2 incentives start at 12 EER. In 2016, the medium and small sized cooling efficiency incentive requirements under PA-sponsored programs appear to be equivalent. The high share of units purchased in the 11.1 to 13 EER group from 2012 to 2014 may support the program offering a third higher tier for medium sized units.

Table 4-14: Efficiency distribution by grouped year of new medium-sized systems

<table>
<thead>
<tr>
<th>Efficiency Buckets</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10.4 EER</td>
<td>48%</td>
<td>7%</td>
</tr>
<tr>
<td>10.4 to 11 EER</td>
<td>9%</td>
<td>20%</td>
</tr>
<tr>
<td>11.1 to 13 EER</td>
<td>35%</td>
<td>66%</td>
</tr>
<tr>
<td>13.1 to 15 EER</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td>36</td>
<td>35</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

Figure 4-24 illustrates the efficiency distribution of large-sized split and packaged cooling systems recently purchased by Massachusetts businesses. Almost all of the newly purchased large systems were above standards ranging from 10.1 to 12 EER. High efficiency units account for 71% of new large commercial systems compared to only 33% for the existing stock of large split and packaged HVAC units. The field data indicate that new large-sized systems are generally purchased at a higher efficiency than current federal standards. The PA-sponsored program incentive requirements for large sized cooling units purchased in 2013 was 10.3 to 10.5 EER depending on the system configuration and 10.5 EER in 2016.

For recently purchased large sized units, the efficiency for 24% of systems could not be classified, largely because the efficiency information could not be found during the look-up process. For HVAC units commonly installed on the exterior of buildings, missing make and model numbers can indicate that a unit is older and the tag has been weathered. Because of this, we cannot assume that the distribution of existing older units with missing or unknown data is identical to the distribution of units with known data. For newer units, however, where weathering of the nameplate is unlikely, we have assumed that the model missing represent units whose nameplates were inaccessible or unobservable due to their placement and that the model not found are randomly distributed across new units. If the model missing and not found for new equipment are redistributed in a share consistent with the observed distribution, 97% of newly purchased large sized units are above standards.
**Figure 4-24: Efficiency distribution of new large commercial systems (240 kBtuh or greater)**

- 2% 9.3 to 10 EER
- 0.4% EER 12.1 to 14.9
- 2% 10.1 to 12 EER
- 24% 10.1 to 12 EER
- 71% Unknown - Make/Model Not Found

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 78 systems.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 3% of systems 9.3 to 10.0 EER, 94% of systems 10.1 to 12.0 EER, and 3% of systems 12.1 to 14.9 EER.

This efficiency analysis for new large-sized systems was also grouped into buckets by year, shown below in Table 4-15. Systems were grouped into those purchased between 2009 and 2011 and systems purchased between 2012 to 2014. There does not appear to be any federal energy efficiency standards for these large-sized systems prior to 2010. There were a large share of systems purchased between 2012 and 2014 where the make and model number could not be looked up (62%). Unfortunately, efficiency data for large-sized, expensive units are often hard to find as the specifications of large-sized equipment can be proprietary.
Table 4-15: Efficiency distribution by grouped year of new large-sized systems

<table>
<thead>
<tr>
<th>Efficiency Buckets</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.3 to 10 EER</td>
<td>1%</td>
<td>12%</td>
</tr>
<tr>
<td>10.1 to 12 EER</td>
<td>83%</td>
<td>9%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>17%</td>
<td>62%</td>
</tr>
<tr>
<td>n</td>
<td>40</td>
<td>32</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

Figure 4-25 displays the distribution of new split and packaged system efficiency ratings, by business kWh usage. When compared to the existing stock of split and packaged systems, shown previously in Figure 4-16, new systems have fewer units that do not meet the current efficiency standards and a much larger share of systems, both above standards and listed at standards.

If the model missing and model not found share are reallocated using an approach consistent with the observed distribution (as discussed above, redistribution of HVAC efficiency for the existing stock adds to the uncertainty but is likely less problematic for newer purchases), 72% of split and packaged cooling systems purchased by Massachusetts businesses with less than 500,000 kWh of annual electricity consumption are above standards. For businesses consuming 500,000 kWh to 4,500,000 kWh, 51% of recent package and split system cooling purchases are above standards and 56% are above standards for businesses consuming greater than 4,500,000 kWh annually. The share of systems purchased above standards is above 50% of all business sizes if the model missing and model not found are reallocated. These data support the conclusion that Massachusetts businesses are highly aware of the benefits of purchasing high efficiency cooling units and that they often purchase units with energy efficiency ratings above current energy efficiency standards.
Figure 4-25: New split and packaged AC/HP efficiency ratings, by business kWh usage

![Chart showing efficiency ratings by business kWh usage](chart)

- Above Standards
- At Standards
- Below Standards
- Unknown - Make/Model Missing
- Unknown - Make/Model Not Found

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,065 systems.

Figure 4-26 shows the distribution of recently purchased split and packaged cooling systems by all types of EE participation and for customers who have received an incentive for HVAC EE participation. The EE participation analyzed for this study focuses on traditional non-upstream programs. EE participation includes customers receiving traditional incentives for all enduses, including HVAC. The HVAC EE participation focuses exclusively on the HVAC end-use participation but includes all HVAC measures including non-split and packaged measures that are analyzed in this section. The All EE participation group illustrated in this figure includes customers who participated in all EE programs.

Figure 4-26 indicate that non-participant customers are associated with a larger share of above-standards HVAC recent purchases than participant customers. The EE participation variables used in this analysis are based largely on traditional PA-sponsored downstream EE programs. Newer upstream programs offer incentives for most of the HVAC equipment analyzed here. The upstream program participation data, HVAC efficiency, and recent high efficiency cooling purchases will be analyzed as part of future work to determine the incentivized share of high efficiency installations using both traditional downstream and newer upstream...
program data. Given the recent energy efficiency focus on upstream programs, it is difficult to interpret the data presented in Figure 4-26.

**Figure 4-26: New split and packaged AC/HP efficiency ratings, by EE participation**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 726 systems purchased by all EE participants, 281 systems purchased by HVAC EE participants, out of 1,065 total systems.

4.6 Heating equipment

The field staff collected information on the type of heating equipment and heating fuel used in Massachusetts businesses. The types of heating equipment included in the study were split into two categories, stand-alone HVAC units and hydronic HVAC systems (including steam based systems and hot water). Table 4-16 lists the system types that were included in the heating category. The hydronic HVAC system category was composed solely of boilers combined with some method of heat distribution.
Table 4-16: HVAC heating system types

<table>
<thead>
<tr>
<th>Stand-alone HVAC units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split system and packaged system furnaces</td>
</tr>
<tr>
<td>Split system and packaged system heat pumps</td>
</tr>
<tr>
<td>Window/wall and PTAC units</td>
</tr>
<tr>
<td>Mini split heat pump units</td>
</tr>
<tr>
<td>Water-source and geothermal heat pumps</td>
</tr>
<tr>
<td>Baseboard heaters, unit heaters, and space heaters</td>
</tr>
</tbody>
</table>

Stand-alone HVAC and hydronic systems in businesses were analyzed separately. For the analysis, the stand-alone systems at a site were aggregated into the following categories:

- Split/packaged furnaces: The business has only split or packaged furnaces.
- Split/packaged heat pumps: The business has only split or packaged heat pumps.
- Other: The business has only window/wall units, PTAC units, mini-split units, electric baseboard unit, or space heaters.
- Furnace and heat pump: The business has both furnaces and heat pumps.
- Furnace and other: The business has some combination of furnaces and other systems.
- Heat Pump and other: The business has some combination of heat pumps and other systems.
- Three or more systems: The business has some combination of all three types of systems.
- No Stand alone systems: The business has no stand-alone HVAC heating systems.

The stand-alone heating breakdown is shown in Figure 4-27, weighted both by the site-level sample weight and the kWh-level sample weight. The kWh weight is used throughout the report as a proxy for business size.

These data indicate that having only split and packaged furnaces is the most common heating configuration for non-residential customers in Massachusetts, both weighted by kWh (36%) and by number of sites (44%). About 20% of the non-residential customers in Massachusetts have no stand-alone heating systems (16% site weighted and 25% kWh weighted).

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83 The structure of the survey form and the subsequent weight development necessitates that stand-alone and hydronic heating systems are analyzed separately when looking at the types of systems in businesses.

84 Many of the customers with no stand-alone systems have central hydronic heating systems.
Figure 4-27: Businesses with varying types of stand-alone HVAC heating equipment

* The results presented above are weighted using the site-level and kWh-level sample weight.

** These data represent 781 sites.

The distribution of heating fuels for stand alone systems is shown below in Figure 4-28 by both site weight and kWh weight. Gas was the most common heating fuel. Some of the larger facilities were found to have both electric and gas heating, while fuel oil was more often found in smaller facilities.
**Figure 4-28: Distribution of heating fuel for businesses with stand-alone HVAC heating equipment**

* The results presented above are weighted using the site-level and kWh-level sample weight.

** These data represent 623 sites.

Hydronic HVAC systems were classified as boilers. The breakdown of these systems versus sites with no hydronic heating is shown below in Figure 4-29. Only 27% of sites have hydronic heating, however, these sites account for just over half (51%) of the kWh usage. This indicates that similar to chillers, hydronic heating is generally found in facilities with large kWh usage or at larger customer sites.
The results presented above are weighted using the site-level and kWh-level sample weight.

** These data represent 787 sites.

The heating fuel type for hydronic boiler systems is shown in Figure 4-30. As with stand-alone systems, gas is the most common fuel type among hydronic systems. There was also a large site-weighted share which had systems fueled by fuel oil (26%).
Figure 4-30: Distribution of heating fuel for businesses with hydronic HVAC heating equipment

* The results presented above are weighted using the site-level and kWh-level sample weight.

** These data represent 372 sites.

Figure 4-31 illustrates the distribution of heating units for both the stand-alone and hydronic units. This analysis looks at the distribution of heating equipment units, therefore it is possible to analyze the distribution of distinct types of systems in the same analysis. The distributions presented above, analyzed the distribution of heating equipment in businesses where a business can have multiple types of heating equipment. Analyzing equipment at the business level necessitates the analysis to incorporate groups of systems (split/packaged furnaces and other heating, for example).

These data indicate that split and packaged furnaces units are the most frequently used heating units in Massachusetts businesses, representing 41% of the heating units. Given that Figure 4-27 illustrates that 44% of businesses are heated with only split and packaged furnaces and an additional 14% of businesses are heated by split and packaged furnaces plus “other” types of stand-alone heating (other includes PTAC/window/wall and baseboard/unit/space heating), it is clear that many businesses in Massachusetts rely on split and packaged furnaces for one of their heating sources. Figure 4-31 illustrates that baseboard/unit/space heaters represent 24% of units and PTAC/window/wall account for 9% of units. These heating units typically heat smaller spaces and many of these units may be necessary to heat a business. Boilers were found to be present in 27% of businesses (see Figure 4-29) and represent 13% of the heating units found in Massachusetts businesses. This findings supports a conclusion that boilers tend to be used to heat larger spaces and that fewer units are required to heat the space.
The heating equipment by business kWh usage is shown in Figure 4-32. Boilers are approximately 10% of heating equipment across all kWh usage categories, while split packaged furnaces are approximately 50% of heating equipment for businesses that were less than 500,000 kWh, 25% for businesses with 500,000 to 4,500,000 kWh and only slightly more than 10% or heating equipment for businesses with more than 4,500,000 kWh. For the largest sites, split and packaged heat pumps account for the highest share of heating equipment while window/wall/PTAC units are the largest share of heating equipment in mid-sized businesses. Baseboard/unit/space heating units represent over 20% of units in the smallest sized businesses and are approximately 10% of units for medium and large-sized units.

Finding that window/wall/PTAC and baseboard/unit/space heating units are relatively common types of heating equipment is similar to the finding that window/wall/PTAC equipment are commonly found as cooling units in mid-sized customers. Lodging, hospitals and campuses were found to have smaller units in individual customer rooms. Each individual unit heats only a small area, contributing to the large number of systems found. It is likely that many of these mid-sized customers have additional types of heating units. Figure 4-27 above showed that 14% of sites and 18% of business kWh is associated with customers who have both “other” heating (window/wall/PTAC baseboard/unit/space) and split packaged furnaces, supporting the conclusion that some types of mid-size businesses have found that having many small heating units for individual small spaces and larger stand-alone heating is optimal.
The heating equipment by business kWh usage, is shown in Figure 4-32. Boilers are approximately 10% of heating equipment across all kWh usage categories, while split/packaged furnaces are approximately 50% of heating equipment for businesses that were less than 500,000 kWh, 25% for businesses with 500,000 to 4,500,000 kWh and only slightly more than 10% or heating equipment for businesses with more than 4,500,000 kWh. For the largest sites, split and packaged heat pumps account for the highest share of heating equipment while window/wall/PTAC units are the largest share of heating equipment in mid-sized businesses. Baseboard/unit/-space heating units represent over 20% of units in the smallest sized businesses and are approximately 10% of units for medium and large-sized units.

Finding that window/wall/PTAC and baseboard/unit/-space heating units are relatively common types of heating equipment is similar to the finding that window/wall/PTAC equipment are commonly found as cooling units in mid-sized customers. Lodging, hospitals and campuses were found to have smaller units in individual customer rooms. Each individual unit heats only a small area, contributing to the large number of systems found. It is likely that many of these mid-sized customers have additional types of heating units. Figure 4-27 above showed that 14% of sites and 18% of business kWh is associated with customers who have both “other” heating (window/wall/PTAC baseboard/unit/-space) and split/packaged furnaces, supporting the conclusion that some types of mid-size businesses have found that having many small heating units for individual small spaces and larger stand-alone heating is optimal.
Figure 4-32: Distribution of heating equipment by business kWh usage

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,145 boilers, 2,540 split/packaged furnaces, 2,263 split/packaged heat pumps, 4,446 PTAC/Window/Wall Units, 1,583 Baseboard/Unit/Space heaters and 357 systems classified as “other.”

Figure 4-33 shows the square footage served by each heating equipment type. For this analysis, if a business had multiple types of heating equipment, the entire business square footage was associated with each type of equipment, as the field survey did not collect data on the percent of each building that each of the HVAC systems at the facility served. This approach leads to more than 100% of the square footage having heating systems. The “share” of square footage in Figure 4-33 is in excess of 150%, supporting the conclusion that businesses have multiple heating types in common.

Boilers and split/packaged furnaces were found to each serve over 50% of the non-residential square footage in Massachusetts businesses. Split/packaged heat pumps represented 17% of total square footage, while Baseboard/Unit/Space heating served 33%. Although these systems are generally smaller, there were many larger facilities found to have a large number of these smaller systems.
**Figure 4-33:** Percent of square footage served, by heating equipment

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,145 boilers, 2,540 split/packaged furnaces, 2,263 split/packaged heat pumps, 4,446 PTAC/Window/Wall Units, 1,583 Baseboard/Unit/Space heaters and 357 systems classified as “other.”

Figure 4-34 illustrates the distribution of heating fuel in Massachusetts businesses. These data illustrate that gas is the most common fuel used in heating. Split and packaged furnaces and boilers are commonly fueled by gas.
The heating fuel distribution by business kWh usage is displayed in Figure 4-35. Smaller facilities with less than 500,000 kWh of annual electricity consumption, tend to have gas heating units. Reviewing the distribution of heating units by customer size in Figure 4-32, the largest share of heating units in small-sized businesses are split and packaged furnaces that are largely fueled by gas. However, the larger facilities (over 500,000 kWh usage) have a much higher share of electric heating units (> 50%). The higher share of electric heating units in mid and large-sized businesses is due, at least in part, to the prevalence of PTAC/window/wall units for businesses with 500,000-4,500,000 kWh and split and packaged HP heating for businesses with more than 4,500,000 kWh. The large number of businesses in the small consumption size category also helps to explain how gas heating dominates in Figure 4-34 while mid and large-sized businesses have a high share of electric heating units in Figure 4-35.

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,145 boilers, 2,540 split/packaged furnaces, 2,263 split/packaged heat pumps, 4,446 PTAC/Window/Wall Units, 1,583 Baseboard/Unit/Space heaters and 357 systems classified as “other.”

85 For this analysis, the fuel used for each heating units is summed using the respondent weight for each unit. Because this analysis is done at the heating unit level, there are no dual fuel heating included in this analysis even though many customers were found to use both electricity and gas, or other fuel combinations, to heat their facility.
The distribution of heating fuels was also analyzed based on the square footage of the businesses (Figure 4-36). Since many business use more than one heating system and more than one heating fuel, the distribution of heating fuels by square footage sums to more than 100%. Over 85% of the square footage is served by gas heating, while slightly more than 30% is served by electric heating.
Figure 4-36: Percent of square footage served, by heating fuel

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1,145 boilers, 2,540 split/packaged furnaces, 2,263 split/packaged heat pumps, 4,446 PTAC/Window/Wall Units, 1,583 Baseboard/Unit/Space heaters and 357 systems classified as "other."

### 4.7 Split and packaged heating system efficiencies

The field staff collected make and model number information for split and package heating systems. This information was used to determine the efficiency of the observed units. The weighted field data for the units with make and model data indicate that split and packaged heating systems are found in 65% of businesses in Massachusetts.

The efficiency analysis compared the efficiency levels for the observed units to federal heating standards by system type, capacity and fuel. Table 4-17 lists the federal heating efficiency standards used in the heating efficiency analysis for the five types of heating equipment included in the efficiency analysis (small heat pumps, large heat pumps, water source heat pumps, small furnaces, and large furnaces). The heating efficiency standards used for the efficiency analysis were implemented between 1992 and 2010. A comparison to current standards provides an indication of potential energy savings that could be realized with the installation of equipment that meet or exceed the standard.

Table 4-17 presents the distribution or share of businesses with different types of split and packaged heating systems, conditional on the business having a split and packaged system. These data indicate that small furnaces are the most common type of split and packaged furnace found in Massachusetts businesses.
Table 4-17: Heating efficiency parameters and standards

<table>
<thead>
<tr>
<th>Classification</th>
<th>Equipment Type</th>
<th>Input Capacity [kBtuh]</th>
<th>Fuel Type</th>
<th>Efficiency Minimum</th>
<th>Efficiency Units</th>
<th>Year of Compliance</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Heat Pump (Less than 65 kBtuh)</td>
<td>Air-Cooled HP</td>
<td>&lt; 65</td>
<td>Elec.</td>
<td>7.7</td>
<td>HSPF</td>
<td>2008</td>
<td>4%</td>
</tr>
<tr>
<td>Large Heat Pump (65 or Greater)</td>
<td></td>
<td>≥ 65 and &lt; 135</td>
<td>Elec.</td>
<td>3.3</td>
<td>COP</td>
<td>2010</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 135</td>
<td>Elec.</td>
<td>3.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Source HP</td>
<td>Water-Source HP</td>
<td>&lt; 135</td>
<td>Elec.</td>
<td>4.2</td>
<td></td>
<td>2003</td>
<td>13%</td>
</tr>
<tr>
<td>Small Furnace (Less than 225 kBtuh)</td>
<td>Furnace</td>
<td>&lt; 225</td>
<td>Nat Gas</td>
<td>78</td>
<td>AFUE</td>
<td>2007</td>
<td>68%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 225</td>
<td>Fuel Oil</td>
<td>78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 225</td>
<td>Elec.</td>
<td>78&lt;sup&gt;87&lt;/sup&gt;</td>
<td></td>
<td>1992</td>
<td></td>
</tr>
<tr>
<td>Large Furnace (225 kBtuh or Greater)</td>
<td></td>
<td>≥ 225</td>
<td>Nat Gas</td>
<td>80</td>
<td>Thermal Efficiency</td>
<td>2004</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≥ 225</td>
<td>Fuel Oil</td>
<td>81</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The distribution presented above is weighted using the respondent-level sample weight.

The efficiency analysis of the split and package heating systems had several challenges. First, the efficiency ratings for many systems had to be converted into units consistent with efficiency standard ratings. For example, it was necessary to transform heat pump HSPF into COP or COP into HSPF.<sup>88</sup>

Second, the efficiency units for furnaces also varied with large and small units labeled in AFUE, thermal efficiency, or steady state. In cases where the unit for the federal efficiency standard was in thermal efficiency but that available efficiency information was not observed directly by the field staff, the thermal efficiency was calculated using the input and an output capacity.<sup>89</sup>

If efficiency units recorded in the field or found during the make and model lookup (e.g., AFUE, thermal efficiency, etc.) were not consistent with units for federal energy efficiency standards and could not be converted to the appropriate unit, the systems were classified as "Unknown – Wrong Standards". Unknown –

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<sup>87</sup> The current federal standards, put in place in 1992, note that the electric minimum efficiency is 78 AFUE. All electric furnaces where the research team was able to identify the efficiency was found to be 100% (as expected). A rated electric efficiency should be between 95% and 100%. Reduction in AFUE is due to heat loss through the chimney or other losses (not including heat losses through ducts or piping). As electric systems do not have chimneys, an AFUE efficiency lower than 100% will account for jacket heat loss.

<sup>88</sup> The following formula was used to convert the efficiency ratings: $\text{COP} = \frac{\text{HSPF}}{3.412}$

<sup>89</sup> The following formula was used to calculate thermal efficiency: $\text{Thermal Efficiency} = \frac{\text{Output Capacity}}{\text{Input Capacity}}$
Wrong Standards indicates that the available efficiency information or efficiency units provided by manufacturers or other sources was inconsistent with the units required by federal energy efficiency standards.

Data presented in Table 4-17 indicate that the respondent weighted field data show that 4% of split and packaged systems are small heat pumps, 1% are large heat pumps, 13% are water source heat pumps, 68% are small furnaces, and 14% are large furnaces. Given these data, there are substantially more small furnaces in Massachusetts businesses than other heating units analyzed during the efficiency analysis.

Figure 4-37 illustrates the efficiency distribution for split and packaged heating systems in C&I facilities in Massachusetts. The analysis found that 50% of small furnaces (less than 225 kBTU/h), 80% of large furnaces (225 kBTU/h or greater), 48% of small heat pumps (less than 65 kBTU/h), and 68% of water source heat pumps are found to be either at or above standards; however, large heat pumps had only a few systems identified as at or above standards. The high share of heating systems in Massachusetts businesses that are at or above standards implies that the current heating efficiency of C&I businesses in Massachusetts is high relative to federal standards. The age of existing standards (implemented 5 to 24 years ago), in combination with the high share of systems at or above standards, may imply that the federal efficiency standards need to be updated. PA-sponsored programs in Massachusetts help to lead the market by requiring substantially higher efficiency levels than those mandated by federal standards. For small gas furnaces, in 2012 PA-sponsored programs required an AFUE of 95% for receipt of incentives while larger furnaces required a thermal efficiency of 90%. In 2013 PA-sponsored programs required an HSPF of 8.5 (compared to 7.7 under federal standards) for small heat pumps, a COP of 3.4 and 3.2 for larger heat pumps and a COP of 4.6 for water source heat pumps. PA-sponsored program energy efficiency requirements for heating equipment are higher than federal efficiency requirements for the production and sale of equipment, helping to push the Massachusetts heating energy efficiency level far beyond the federal energy efficiency requirements and have likely contributed to the high share of heating equipment above federal standards.

90 Only 40 Large Heat Pumps were identified during the onsite visits, and for the majority of large heat pumps, it was not possible to identify their efficiency level. Therefore, caution should be exercised when drawing conclusions from the efficiency breakdown for these systems in Table 4-17.
The efficiency of split and packaged heating systems were also analyzed. The distribution of the efficiency of split and packaged heating systems is provided in Figure 4-38 through Figure 4-41.

Small furnaces have a federal minimum energy efficiency standard of 78 AFUE, for electric, natural gas, and fuel oil units. The electric efficiency standard was implemented in 1992 while the gas and fuel oil standards are from 2007. The federal energy efficiency standard is generally held to be exceptionally low, many market studies have found that it is difficult to find heating units currently produced and for sale at or below the federal energy efficiency standards. The "old age" of current federal standards, and the aggressive nature of Massachusetts programs likely contributes to the finding that only 3% of small split and packaged heating units were found to have an efficiency less than 78 AFUE. Twenty-nine percent of units had an efficiency from 78 to 87 AFUE. For systems between 78 and 87 AFUE, only 2% of these units are at standards (78 AFUE), while 98% of these heating units are above standards. Nearly 50% of small furnaces were identified as above standards (14% above 92 AFUE, 7% at 88-92 AFUE, 28.4% at 79 to 87 AFUE). For 25% of small furnace systems the efficiency was identified in units other than AFUE, which prevented
comparisons to federal energy efficiency standards. For an additional 22% of systems, the efficiency was not identified.

Efficiency standards for small furnaces have been the subject of considerable discussion. The current standard is 78 AFUE, however, no furnaces below 80 AFUE are being produced.\textsuperscript{91} In 2007 the Department of Energy (DOE) proposed increasing the standard level to 80 AFUE effective in 2015 but advocates pressed for more stringent standards. Higher standards for specific regions of the US were passed but the rulemaking was challenged by an association of natural gas utilities and equipment distributors. Retrofitting a furnace from 80 AFUE to 90 AFUE is moving to a condensing furnace that may require the additional expense to modify the furnace ventilation. Despite the added expense 35% of gas furnaces sold in 2012 had an AFUE of at least 90, indicating that the market is clearly moving in this direction.\textsuperscript{92}

Finding that 50% of the existing stock of small furnaces are above current federal standards indicates that there are numerous high efficiency technology options that customers are adopting. The PA-sponsored program encourages commercial customers to install new small furnaces with AFUE 95 and greater.

\textbf{Figure 4-38: distribution of efficiencies for furnaces less than 225 kBtuh}

\[\text{\begin{itemize}
  \item Less than 78 AFUE
  \item 78 to 87 AFUE
  \item 88 to 92 AFUE
  \item 93 AFUE or Greater
  \item Unknown - Make/Model Missing
  \item Unknown - Make/Model Not Found
  \item Unknown - Wrong Standards
\end{itemize}}\]

\*The results presented above are weighted using the respondent-level sample weight.

\** This distribution represents 1,167 furnaces less than 225 kBtuh

\textsuperscript{91} See https://www.eia.gov/todayinenergy/detail.cfm?id=14051.

\textsuperscript{92} See https://www.energystar.gov/index.cfm?c=partners.unit_shipment_data.
Figure 4-39 illustrates the efficiency distribution for large furnaces. The majority of large furnaces (76%) were found to have a thermal efficiency between 80 and 81. The minimum federal standards for natural gas fueled systems is 80 thermal efficiency and 81 thermal efficiency for fuel oil fueled systems. For systems listed as 80 or 81 thermal efficiency, 85% met standards, while 15% of the systems were above standards. Only 3% of systems were found to have a thermal efficiency of 82 or greater. Approximately 14% (.76*.15+.03) of the existing stock of large furnaces were observed to have a thermal efficiency above federal standards. Very few large furnaces were found to have thermal efficiencies above the PA-sponsored program requirement of 90% thermal efficiency for condensing furnaces up to 300 MBH. There was also a small fraction of large electric furnaces which do not have standards that regulate their efficiency and a small fraction where an efficiency type other than thermal efficiency was identified.

**Figure 4-39: Distribution of efficiencies for furnaces 225 kBtuh or greater**

- Less than 80 Thermal Efficiency
- 82 Thermal Efficiency or Greater
- Unknown - Make/Model Not Found
- No Standards
- 80 to 81 Thermal Efficiency
- Unknown - Make/Model Missing
- Unknown - Wrong Standards

*The results presented above are weighted using the respondent-level sample weight.

**This distribution represents 674 furnaces 225 kBtuh or greater.

The federal energy efficiency standard for small heat pumps is 7.7 HSPF, established in 2008. In Massachusetts the PA-sponsored program required an efficiency standard of 8.5 HSPF to receive a Tier 1 rebate in 2013 and a 90 HSPF to receive a Tier 2 rebate. HSPF is a seasonal efficiency, similar to what a SEER rating represents for air conditioners. In most cases the HSPF was identified during the make and model lookup, but for some units only a COP rating was found. These records were converted to their
seasonal efficiency rating. As shown in Figure 4-40, of the records where an efficiency was identified, 29% of them were below federal standards established in 2008. Finding a substantial share of units below the current federal standards does not imply that the units were non-compliant at the point of purchase given the 15 year measure life assumption in the MA TRM. Twenty percent of the existing stock were found to be between 7.7 and 8.3 HSPF, and of these units, 36% met the standard of 7.7 HSPF while 64% were above the standard with efficiencies greater than 7.7 HSPF. A large share (28%) of Small Heat Pumps were found to be above 8.9 HSPF. Combining units above standards in the 7.7 to 8.3 range with those above 8.9 HSPF, approximately 41% of Small Heat Pumps were found to be above federal standards. It is likely that the PA-sponsored program has helped move the efficiency of small heat pumps substantially above the federal energy efficiency standards. The efficiency level could not be identified for 23% of small heat pumps.

The large share of small heat pumps that were found to be above standards was very encouraging for the efficiency distribution of heating systems in Massachusetts businesses. Small heat pumps, however, made up only 4% of stand-alone split and packaged systems in C&I businesses in Massachusetts.

**Figure 4-40: Distribution of efficiencies for heat pumps less than 65 kBtuh**

*The results presented above are weighted using the respondent-level sample weight.

** This distribution represents 286 heat pumps less than 65 kBtuh.
Large heat pumps accounted for approximately 1% of the split and packaged heating. For large heat pumps the federal energy efficiency standards range from a 3.3 to a 3.2 COP, depending on the size of the system. To receive a PA-sponsored program rebate in 2013, the efficiency requirements were very similar to federal standards, a COP of 3.4 to 3.2 depending on the size of the system. For the majority of the large heat pump systems the efficiency could not be found during the lookup process. Given the limited efficiency data, no conclusions can be drawn regarding the current efficiencies of large heat pumps in Massachusetts businesses.

The efficiency distribution of water-source heat pumps is presented in Figure 4-41. Water-source heat pumps account for 13% of the packaged and split heating systems in Massachusetts businesses. Over 1,300 water-source heat pumps were observed in the field, leading to a weighted estimate of over 35,000 units across all C&I businesses in Massachusetts. However, the large observed quantity of these systems were observed in only 15 of the 800 facilities, indicating that large numbers of small units were installed in each site. Many of these systems were installed in hospitals, campuses, and lodging facilities, where a large number of units are designed to serve individual smaller rooms across the entire facility. In addition, finding water-source heat pumps at so few businesses during the field data collection, increases the potential that a single customer with a large weight may not be representative of the population of units.

Looking at the un-weighted data, the efficiency for 88% of water-source heat pumps could not be identified. In the weighted analysis however, the efficiency of 68% of units were found to be above federal energy efficiency standards of 4.2 COP. Given the few customers found to have water-source heat pumps, and the substantial influence of weights when analyzing this measure, caution must be used in drawing conclusions from their analysis.
Figure 4-41: Distribution of efficiencies for water source heat pumps

The results presented above are weighted using the respondent-level sample weight.

This distribution represents 1,359 water source heat pumps.

Figure 4-42 illustrates the efficiency of packaged and split heating systems by business electricity usage. The efficiency for 41% of heating systems could not be identified because we were either unable to determine this information during the make and model analysis, the efficiency units for the observed system were inconsistent, or make and model numbers were missing. 46% of the weighted packaged and split systems were found to be above federal energy efficiency standards while only 10% were at standards and 3% were below standards. When looking at the business kWh usage categories, the smallest usage category had the largest share of above standards. Both the medium and large kWh usage categories (500,000 to 4,500,000 kWh and greater than 4,500,000 kWh) had about 30% of their packaged and split units above standards.
Figure 4-42: Split and packaged heating efficiency ratings relative to federal standards, by business kWh usage

![Chart showing efficiency ratings by kWh usage](chart.png)

* The results presented above are weighted using the respondent-level sample weight.

** This distribution represents 409 systems identified in facilities with less than 500,000 kWh usage, 1,944 systems identified in facilities with a kWh usage between 500,000 to 4,500,000 kWh, and 1,173 systems identified in facilities with a kWh usage greater than 4,500,000 kWh.

Figure 4-43 illustrates the distribution of packaged and split system heating efficiency by PA-sponsored EE program participation. Information is provided for all EE participants and for customers that received an incentive for an HVAC measure. Participation in PA-sponsored EE programs or receiving an incentive for an HVAC measures does not appear to be associated with an increased likelihood of having a high efficiency packaged or split heating system.
Figure 4-43: Split and packaged heating efficiency ratings, by energy efficiency program participation

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 2,150 systems purchased by All EE participants, and 1,289 systems purchased by HVAC EE participants, out of a total of 3,526 systems.
4.8 HVAC heating – market share and sales trends

The analysis presented in this section focuses on sites with heating systems installed from 2009 to 2015 for the MSST study. Table 4-18 lists the number of on-sites by business type, the number of sites where heating system data was collected, the number of sites with newly purchased heating equipment, and the number of sites where make and model numbers were collected for newly purchased heating equipment. Of the 772 sites where heating information was collected, 288 had newly purchased heating equipment. The newly purchased heating equipment, when weighted represents approximately 80,000 heating split and packaged HVAC systems purchased by Massachusetts businesses from 2009-2015.

Table 4-18: Number of business with new HVAC heating systems

<table>
<thead>
<tr>
<th>Business Type</th>
<th>Completed On-site Surveys</th>
<th>Count of Bldgs with Heating Information</th>
<th>New Heating Equipment Information Collected</th>
<th>Make and Model Data Collected for Heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Businesses</td>
<td>35</td>
<td>34</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Campuses</td>
<td>79</td>
<td>78</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Education</td>
<td>47</td>
<td>46</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Food Sales</td>
<td>63</td>
<td>58</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Food Service</td>
<td>62</td>
<td>61</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td>Healthcare</td>
<td>20</td>
<td>20</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Hospitals</td>
<td>60</td>
<td>60</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>Lodging</td>
<td>83</td>
<td>83</td>
<td>34</td>
<td>33</td>
</tr>
<tr>
<td>Manufacturing or Industrial</td>
<td>117</td>
<td>108</td>
<td>32</td>
<td>31</td>
</tr>
<tr>
<td>Office</td>
<td>59</td>
<td>55</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>73</td>
<td>72</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Public Assembly</td>
<td>72</td>
<td>70</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Retail</td>
<td>30</td>
<td>27</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Warehouse</td>
<td>35</td>
<td>34</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>772</td>
<td>288</td>
<td>264</td>
</tr>
</tbody>
</table>

* The results presented above are un-weighted.

The unweighted count and the weighted distribution of recently purchased split and packaged heating systems by system type are shown in Table 4-19. The weighted new purchase data indicate that small
furnaces and water source heat pumps were the most commonly purchased new heating equipment. Water source heat pumps had a larger share of recent purchases (34%) than of existing stock (13%). Analyzing the make and model numbers collected from these systems supported the development of an efficiency distribution of recently purchased heating systems.

Table 4-19: Distribution of recently purchased HVAC heating systems, unweighted quantity and respondent weighted distribution

<table>
<thead>
<tr>
<th>System Type</th>
<th>Quantity Surveyed</th>
<th>Weighted Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Heat Pump (Less than 65 kBtuh)</td>
<td>98</td>
<td>3%</td>
</tr>
<tr>
<td>Large Heat Pump (65 or Greater)</td>
<td>22</td>
<td>1%</td>
</tr>
<tr>
<td>Water Source HP</td>
<td>596</td>
<td>34%</td>
</tr>
<tr>
<td>Small Furnace (Less than 225 kBtuh)</td>
<td>259</td>
<td>51%</td>
</tr>
<tr>
<td>Large Furnace (225 kBtuh or Greater)</td>
<td>134</td>
<td>11%</td>
</tr>
</tbody>
</table>

Figure 4-44 illustrates the efficiency distribution for recently purchased split and packaged heating systems, broken out by heating category. The standard efficiency rating information for these systems is provided in Table 4-17. The data presented in Figure 4-44 indicates that 42% of small furnaces (less than 225 kBtuh) and 79% of water source heat pumps were found to be above federal energy efficiency standards. Sixty percent of large furnaces (225 kBtuh or greater) and 29% of small heat pumps (less than 65 kBtuh) were purchased at federal standards. Only 3% of recently purchased small heat pumps and 1% of recently purchased large furnaces were identified to be below standards. The reason for these recently purchased units to be below standards is not clear, as they were manufactured several years after the standards were put into place. The efficiency information could not be identified for over 20% of all newly purchased heating system types, and for 94% of large heat pumps (65 kBtuh or greater). Small furnaces had the largest share of observed units where reported efficiency units were inconsistent with the required efficiency units (AFUE).
**Figure 4-44: Efficiency ratings for recently purchased split/packaged heating systems**

These recently purchased systems were also categorized by efficiency to demonstrate the range of efficiencies by heating system type. The distribution of the efficiency buckets are provided in Figure 4-45 through Figure 4-48.

Fifty-one percent of recently purchased stand-alone heating units in C&I businesses in Massachusetts were classified as small furnaces compared to 68% in the existing stock of split and packaged heating equipment. Current federal standards for these units require a minimum efficiency of 78 AFUE, for electric, natural gas, and fuel oil units. PA-sponsored programs required an efficiency of 95 AFUE to receive a Tier 1 incentive in 2013. The distribution of efficiency ratings for new small furnaces is shown in Figure 4-45. None of the newly purchased systems were found to have an efficiency below 78 AFUE. Nineteen percent of units had an efficiency between 78 and 87 AFUE. Out of these systems between 78 and 87 AFUE, less than 1% of these are at the efficiency standards, while the other 99% of the 19% of units with efficiency between 78 and 87 are above standards. Twenty-four percent had an AFUE efficiency greater than 88. For 47% of these small furnace systems the unit efficiency was identified in efficiency units other than AFUE, which made

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*The results presented above are weighted using the respondent-level sample weight. These data represent packaged and split system furnaces purchased from 2009 to 2015.

** These data represent 259 furnaces less than 225 kBtuh, 134 furnaces 225 kBtuh or greater, 98 heat pumps less than 65 kBtuh, 22 heat pumps 65 kBtuh or greater, and 596 water source heat pumps.
comparison to standards difficult. For an additional 11% of systems, the efficiency was not able to be determined.

The analysis found that 17% of newly purchased small furnaces are 93 AFUE or higher. Massachusetts businesses that are purchasing small furnaces appear to have access to many high efficiency options. The high efficiency options available may provide substantial energy savings potential when reflecting back on the older equipment that exists in the market (see Figure 4-38). The PA-sponsored programs’ high efficiency requirements (95 AFUE and higher) are likely helping to push the market toward higher efficiency units.

The efficiency analysis of newly purchased small furnaces found that less than one percent of newly purchased units were purchased at federal standards. All other newly purchased small furnaces where the efficiency was identified were found to be above federal standards. If the share of make and model missing, model not found, and wrong standards are distributed similar to observed units, nearly 100% of small furnaces are above standards. Redistribution of new small furnaces proportional to the observed furnace efficiencies would lead to an estimate that 44% of units are 78 to 87 AFUE, 16% are 88 to 92 AFUE and 40% are 93 AFUE and higher.

**Figure 4-45: distribution of efficiency ratings for new furnaces less than 225 kBtuh**

*The results presented above are weighted using the respondent-level sample weight. These data represent packaged and split system furnaces purchased from 2009 to 2015.*

**This distribution represents 259 furnaces less than 225 kBtuh.**

***If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 44% of systems 78 to 87 AFUE, 16% of systems 88 to 92 AFUE, and 40% of systems 93 AFUE or Greater.*
The efficiency analysis for new furnaces less than 225 kbtuh was also analyzed by year of purchase (Table 4-20). The analysis looked at systems purchased between 2009 and 2011, and systems purchased between 2012 to 2014. The majority of systems installed between 2009-2011 were found to have a heating efficiency unit different than the efficiency units used in the federal and PA-sponsored program energy efficiency standards. The efficiency information for 2012 through 2014 illustrates that at least 30% of recent purchase have an AFUE of 93 or greater, indicating the Massachusetts businesses are purchasing units with efficiency standards far in excess of federal standards and that a substantial share may have qualified for PA-sponsored program rebates by having efficiency levels of 95 AFUE and higher.

<table>
<thead>
<tr>
<th>Efficiency Buckets</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>78 to 87 AFUE</td>
<td>22%</td>
<td>8%</td>
</tr>
<tr>
<td>88 to 92 AFUE</td>
<td>2%</td>
<td>24%</td>
</tr>
<tr>
<td>93 AFUE or Greater</td>
<td>4%</td>
<td>30%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>0%</td>
<td>27%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown - Wrong Standards</td>
<td>72%</td>
<td>10%</td>
</tr>
<tr>
<td>Total</td>
<td>99</td>
<td>106</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

Larger furnaces represent 11% of packaged and split heating systems purchased from 2009 to 2015. Figure 4-46 illustrates the observed efficiency distribution of newly purchased large furnaces. Only 1% of recently purchased large furnaces had a thermal efficiency less than 80. The federal thermal efficiency standards for large natural gas units is 80, while those for fuel oil units is 81. PA-sponsored programs provide incentives for condensing furnaces at and above 90% thermal efficiency in 2013. Sixty-three percent of newly purchased large furnaces were found to be have a thermal efficiency of either 80 or 81. Nearly all of the newly purchased units (96%) with thermal efficiency ratings of either 80 or 81 were found to be at standards while the remaining 4% were above standards. An additional 9% of units had a thermal efficiency of 82 or greater which exceed the federal efficiency standards. A small fraction of units either had no established efficiency standard (e.g., electric heating units), or had standards reported in a unit other than thermal efficiency.

While the evaluation has generally not redistributed the make/model missing, not found or wrong standards due to concerns that units in these buckets are not randomly distributed similar to the observed efficiencies, the assumption is far more likely to hold for newly purchased units. If the share of make and model missing,
model not found, and wrong standards are distributed similar to observed units, nearly 100% of small furnaces are above standards. If the new large furnaces are redistributed proportional to the observed furnace efficiencies, the estimated distribution would be that 1% of units have less than 80 thermal efficiency, 86% are 80 to 81, and 13% have a thermal efficiency of 82 and higher. It is likely that, at most, only an extremely small share of units would be eligible for PA-sponsored program incentives (requires a thermal efficiency of 90 or higher).

**Figure 4-46: Distribution of efficiency ratings for new furnaces 225 kBtuh or greater**

![Distribution of efficiency ratings for new furnaces 225 kBtuh or greater](image)

*The results presented above are weighted using the respondent-level sample weight. These data represent packaged and split system furnaces purchased from 2009 to 2015.*

**This distribution represents 134 furnaces 225 kBtuh or greater.**

***If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 1% of systems Less than 80% Thermal Efficiency, 86% of systems 80 to 81% Thermal Efficiency, 13% of systems 82% Thermal Efficiency or Greater, and <1% of systems with No Standards.*

The efficiency analysis for new furnaces 225 kBtuh or greater was analyzed separately for units purchased between 2009 and 2011, and units purchased between 2012 to 2014 (Table 4-21). A large percentage of new systems purchased across both year groups were found to have a thermal efficiency between 80-81. There was only one unit found across all years, to have a thermal efficiency less than 80%. No real change in efficiency across the two year buckets was identified, as the federal standards were last updated in 2004. Very few large furnaces were purchased with the extremely high efficiency levels necessary to receive a PA-
sponsored program incentive. From these data, it does not appear that an increasing share of larger furnaces would be eligible for PA-sponsored program incentives.

Table 4-21: Efficiency distribution by grouped year of new furnaces 225 kBtuh or greater

<table>
<thead>
<tr>
<th>Efficiency Buckets</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 80 Thermal Efficiency</td>
<td>0%</td>
<td>5%</td>
</tr>
<tr>
<td>80 to 81 Thermal Efficiency</td>
<td>78%</td>
<td>86%</td>
</tr>
<tr>
<td>82 Thermal Efficiency or Greater</td>
<td>15%</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>7%</td>
<td>4%</td>
</tr>
<tr>
<td>Unknown - Wrong Standards</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>66</td>
<td>37</td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

New small heat pumps make up 3% of newly purchased packaged and split systems in Massachusetts businesses. Figure 4-47 illustrates the efficiency distribution of small heat pumps purchased from 2009 to 2015 as determined from the make and model analysis. The current federal energy efficiency standards are 7.7 HSPF and PA-sponsored energy efficiency programs required a HSPF of 8.5 to receive an incentive in 2013. Only 3% of newly purchased units have an efficiency below federal standards and 33% of units had an efficiency between 7.7 to 8.3 HSPF. Less than 1% of units were found to have an efficiency higher than 8.3 HSPF. These data indicate that the field data collection did not observe many new small heat pumps meeting the PA-sponsored program energy efficiency requirements. For the majority of newly purchased small heat pumps (64%) it was not possible to determine the efficiency level.

If the newly purchased share of heat pumps designated as make and model missing and not found is reallocated proportional to the observed efficiency distribution, 7% of recently purchased small heat pumps are below standards, 92% are at 7.7 to 8.3 HSPF and less than 1% are purchased with an HSPF above 8.3. From the field data collection and analysis, it appears that very few to none of the observed recently purchased units were eligible for a PA-sponsored program incentive.
The results presented above are weighted using the respondent-level sample weight. These data represent packaged and split system heat pumps purchased from 2009 to 2015. This distribution represents 98 heat pumps less than 65 kBtuh. If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 7% of systems less than 7.7 HSPF, 93% of systems 7.7 to 8.3 HSPF, and <1% of systems 8.9 HSPF or greater.

This efficiency analysis for new heat pumps less than 65 kBtuh was analyzed by year with systems disaggregated into those purchased between 2009 and 2011, and systems purchased between 2012 to 2014 (Table 4-22). Across both year ranges, a large percentage of the efficiencies was not able to be identified. The later years had a high percentage of systems that were either at or above the federal energy efficiency standard efficiencies, put in place in 2008.
Table 4-22: Efficiency distribution by grouped year of new heat pumps less than 65 kBtuh

<table>
<thead>
<tr>
<th>Efficiency Buckets</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 7.7 HSPF</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>7.7 to 8.3 HSPF</td>
<td>7%</td>
<td>42%</td>
</tr>
<tr>
<td>8.4 to 8.8 HSPF</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>8.9 HSPF or Greater</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown - Make/Model Missing</td>
<td>0%</td>
<td>37%</td>
</tr>
<tr>
<td>Unknown - Make/Model Not Found</td>
<td>93%</td>
<td>18%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>42</strong></td>
<td><strong>49</strong></td>
</tr>
</tbody>
</table>

* The results presented above are weighted using the respondent-level sample weight.

The efficiency findings for new larger air source heat pumps is not presented due to the small number of newly purchased units observed during the field data collection (22 units). Large heat pumps made up less than 1% of the new stand-alone split and packaged HVAC units purchased in C&I buildings across Massachusetts.

Figure 4-48 illustrates the distribution of new water source heat pumps. These water source heat pumps accounted for 34% of the new systems purchased in C&I buildings across Massachusetts. The existing federal energy efficiency standard for water source heat pumps is 4.2 COP, while PA-sponsored programs required a COP of 4.6 or higher to receive an incentive in 2013. Similar to the distribution of the existing stock of water source heat pumps, the majority of these (75%) were found to be between 4.9 and 5.3 COP, with an additional 4% greater than 5.3 COP. These units are considered all above federal standards and above the energy efficiency requirements set to receive an incentive within the PA-sponsored programs. If the newly purchased water source heat pumps with make and model missing and not found are reallocated proportional to the observed efficiency distribution, 94% of units would be expected to have an efficiency between 4.9 and 5.3 COP and 5% would have a COP greater than 5.3.

Figure 4-48 illustrates the distribution of new water source heat pumps, very few facilities were found to have these heating systems during the field data collection. Newly purchased water source heat pump systems were observed in only eight sites.\(^93\) Care must be taken when discussing the applicability of the efficiency of these units to other systems in Massachusetts businesses.

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\(^93\) Seventy percent of these recently purchased units (unweighted) were found in a single lodging facility.
Figure 4-48: Distribution of efficiency ratings for new water source heat pumps

*The results presented above are weighted using the respondent-level sample weight. These data represent packaged and split system heat pumps purchased from 2009 to 2015.

** These data represent 596 water source heat pumps.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show <1% of systems Less than 4.2 COP, 94% of systems 4.9 to 5.3 COP, and 5% of systems 5.4 COP or Greater.

Figure 4-49 illustrates the efficiency distribution of recently purchased split and packaged heating systems by business kWh usage. These data indicate that the study was not able to determine the efficiency distribution of most newly purchased systems for businesses with more than 500,000 kWh of annual usage. For systems where it was possible to determine the efficiency of newly purchased heating systems, the large majority were above current standards.
**Figure 4-49: Efficiency ratings for recently purchased split/packaged heating systems by business kWh usage**

* The results presented above are weighted using the respondent-level sample weight. These data represent package and split system heating purchased from 2009-2015.

** These data represent 156 systems < 500,000 kWh, 478 systems 500,000 – 4,500,000 kWh, and 475 systems > 4,500,000 kWh.

### 4.9 HVAC maintenance

The field staff collected self-reported information on the maintenance of HVAC systems. Figure 4-50 illustrates the distribution of maintenance as preventative, reactionary, and unknown. For the distribution weighted by sites, maintenance is approximately evenly divided between preventative and reactionary HVAC maintenance. When weighted by kWh, however, 76% of maintenance is described by site contacts as preventative, indicating that larger facilities typically undertake preventative maintenance while smaller facilities are more reactionary.
Figure 4-50: HVAC maintenance

*The results presented above are weighted using the kWh-level and site-level sample weight.

** These data represent 774 sites.

Figure 4-51 displays who typically performs the HVAC maintenance. Maintenance for over 60% of the sites are performed by contractors, while approximately one-third of the sites reported that they have in-house staff performing the maintenance. The distribution of facilities with in-house staff is similar when weighted by sites and weighted by kWh usage, which demonstrates that the size of the facility does not have much of an impact on who does the HVAC maintenance at the facility.
Figure 4-51: HVAC maintenance personnel

*The results presented above are weighted using the kWh-level and site-level sample weight.

** These data represent 724 sites.
5 ENERGY MANAGEMENT SYSTEMS

An energy management system (EMS) is a network of locally distributed controls and sensors with centralized coordination and management of environmental and lighting equipment in a facility. At a minimum, an EMS can be used to control and monitor the activity of equipment including lighting, HVAC, water heating and process equipment. There is a wide variation in the capabilities of these systems, and often system control architectures, dashboards, and communications protocols are proprietary with custom implementations.

The most advanced systems incorporate an energy information system (EIS) with integration of decision support, process analysis, self-diagnostics, energy optimization, external third-party controls, and demand response abilities (used to power down non-critical loads during peak grid events). Multiple retail locations or campus buildings could be managed in coordination, and industrial applications can include SCADA data interfaces. At a minimum, most EMSs will centrally control on/off functionality and scheduling, with basic features for recording utility load profiles and system logs.

During the data collection process, often the term “EMS” was used interchangeably with a range of automated building control products that might otherwise use alternative industry nomenclature: building automation system (BAS), energy management and control system (EMCS), building management and control system (BMCS), and building management system (BMS). The definition provided to site contacts was that for the purpose of this study, an EMS is any centralized building control system that controls equipment operation based on schedules and desired temperature set points, and does not include programmable thermostats.

The C&I On-Site Assessments collected fundamental data on EMSs to provide the PAs with a better understanding of the current baseline of EMS equipment saturation. This information is useful for future energy efficiency (EE) and demand response (DR) program planning, and for future potential studies.94

5.1 Energy management system findings

The analysis of the EMS data led to the following findings:

- Approximately 50% of the business-level electricity usage in Massachusetts is associated with an EMS. The 50% of business-level electricity usage with EMS can be further broken down into 36% of electricity usage with EMS installed from 2009 to 2014, and 14% of electricity usage with EMS installed prior to 2009.
- Over 80% of business electricity consumption for businesses with more than 4,500,000 kWh annual usage is by businesses with an EMS—over 55% for businesses with 500,000-4,500,000 kWh and approximately 10% for businesses with less than 500,000 kWh.
- EMSs are found in businesses associated with 70% of the electricity consumption in campuses, 71% of education, 90% of hospitals, 58% of manufacturing and industrial, 55% of offices, 70% of other, 55% of public assembly, and 59% of warehouses. EMSs were only associated with businesses accounting for 27% of food sales electricity consumption and 11% of retail. The relatively low share of EMS in food sales and retail may represent a program opportunity.

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94 The results presented in the EMS section are weighted with the kWh-level sample weights.
The number of end uses controlled by EMS is 3.2 end-uses for newer systems and 3.0 end-uses for older systems. For both newer and older EMS, the end uses with the highest probability of EMS control include HVAC, HVAC auxiliary pumps and fans, and central plants.

5.2 Energy management system data

During the on-site assessment, field staff collected data on the existence and composition of EMSs in businesses where EMSs were found. In all, 277 sites of the 800 surveyed were found to have EMS.

Figure 5-1 and Figure 5-2 present the distribution of EMS by the business annual electricity (kWh) usage ranges and business area (square feet). These illustrations clearly indicate that businesses in the 500,000-4,500,000 annual kWh and >4,500,000 annual kWh ranges are more likely to have an EMS than businesses with less energy consumption, and that businesses with larger square footage are more likely to have an EMS than businesses with smaller square footage. They also suggest that the larger a business is, either in energy consumption or square footage, the more likely it is to have an EMS. These data support the conclusion that approximately 50% of business-level energy consumption in Massachusetts is associated with businesses using an EMS.

C&I Customer Telephone Survey Note:

According to the C&I Customer Telephone Survey only 5% of the businesses reported having energy management systems. Both studies show that the larger the business the more likely it is to have an EMS; approximately 30% of business over 25,000 sf in area had EMS, according to the telephone survey.

In both studies EMS is most like to control heating and cooling (75% telephone respondents / 86% on-site assessments), and auxiliary systems. 42% of telephone respondents indicated that the EMS controls lighting, while the on-site assessments showed that lighting was control by EMS less than 30% of the time.

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95 The information presented in this section of the report provides information on all BASs, both old and newer systems. Information on newer systems will be highlighted later in the section.

96 The data were analyzed by the < 500,000 kWh, 500,000-4,500,000 kWh, and > 4,500,000 kWh divisions because these divisions allocate the annual kWh consumption of Massachusetts businesses into three equal buckets based on total kWh consumption. The sample design for the project was based on this disaggregation, and the reporting has followed the sample design.

97 The 50/50 split in business energy consumption is kWh-level weighted.
Figure 5-1: Businesses with EMS by kWh usage

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 313 businesses <500,000 kWh, 382 businesses between 500,000 and 4,500,000 kWh, and 105 businesses >4,500,000 kWh for a total of 800 businesses.
Figure 5-2: Businesses with EMS by square footage size

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 800 sites.

Figure 5-3 illustrates the distribution of EMS by business type, using kWh weights. These data provide the share of total business electricity consumption that is associated with businesses that have an EMS, by business type. These data estimate that EMSs are associated with more than 50% of the businesses’ consumption for campuses (70%), education (71%), hospitals (90%), manufacturing and industrial (58%), office (55%), other (70%), public assembly (55%), and warehouses (59%). Surprisingly, food sales and retail have a relatively small share of businesses with EMS. The small share of EMS in food services (2%) is not surprising given the small size of most of these businesses.

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98 The information presented in Figure 5-3 does not describe the percent of electricity consumption that is controlled by an BAS because not all of a business’s energy consumption is necessary controlled by an BAS.
Figure 5-3: Businesses with EMS by business square footage

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 800 sites—34 campuses, 79 education, 47 food sales, 63 food services, 62 healthcare, 20 hospitals, 60 lodging, 83 manufacturing or industrial, 117 office, 59 other, 73 public assembly, 72 retail, and 30 warehouses.

Figure 5-4 presents the share of businesses with EMS by participation in a PA-sponsored EE program (participated during 2011-2014). These illustrations indicate that EE program participants have a much larger share of businesses with EMS (62%) than non-participants (37%). This suggests that EE programs may be working to drive the installation of EMS in businesses or that those businesses with EMS understand their energy usage more clearly and are more interested in EE program participation. This may also be an indication that programs target the largest customers who tend to have EMS. Whichever it may be, this may be an area for future investigation to better understand what the reasons are behind these results and what the implications are for the programs.
**Figure 5-4: Businesses with EMS by recent EE program participation**

<table>
<thead>
<tr>
<th>EE Program Participant</th>
<th>Non-EE Program Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>38%</td>
<td>37%</td>
</tr>
<tr>
<td>62%</td>
<td>63%</td>
</tr>
</tbody>
</table>

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 338 EE program participant and 462 non-participant sites. Of the 277 EMS sites, 173 participated in a PA-sponsored EE program and 104 had not participated from 2011-2014.

### 5.3 EMS controlling entity

During the study we collected information on the means of controlling and operating the EMS. Figure 5-5 illustrates that the vast majority of EMSs were found to be controlled by on-site personnel (84%). The study also collected data on whether the EMSs had a single central controller or was designed with distributed controls. Figure 5-6 shows that there were more EMSs with distributed controls (58%) than a single central control (42%).
Figure 5-5: Entity controlling/operating EMS

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 277 sites.
5.4 EMS training

Field staff asked site contacts about who provided training for operating the EMS where the EMS was controlled by on-site personnel. Figure 5-7 shows that 51% of training for these businesses is provided by the EMS equipment vendor, while 30% claimed to use in-house staff to train users. Information on who is providing EMS training can be used to help focus EMS education programs designed to optimize the energy savings potential.
5.5 End uses controlled by an EMS

For customers with an EMS, the on-site data collection field staff obtained information on the end uses controlled by that EMS. Figure 5-8 shows that, among businesses with EMS, 86% of systems are used to control their HVAC units, 74% percent control their HVAC auxiliary pumps and fans, and over 40% are associated with the control of a central plant – a distinguishable centralized network of heating and cooling systems. In other words, just over 42% of the population with EMS, have a central plant. Less than 30% of customers with an EMS use the system to control lighting and water heating.

*The results presented above have been weighted using the kWh-level sample weight.

**These data represent 224 sites.
The on-site data collection effort also obtained information on whether or not the EMS had a central computer front end that allows for local control and monitoring of the system’s specifications. Figure 5-9 shows that almost all (92%) of the systems had a central computer front end, while 4% did not, and 4% were uncertain. This is similar to the finding in Figure 5-5 that showed 5% of EMSs are controlled at a remote central headquarters.

Figure 5-8. End uses controlled by EMS

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 277 sites.

5.5.1 EMS with central computer front end
Figure 5-9: Businesses with EMS central control computer front end

- Central Control Computer Front End
- No Central Control Computer Front End
- Don’t Know

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 274 sites.

5.5.2 EMS end/control point device types

There were two primary end/control point device types in businesses with EMS. Figure 5-10 shows that electronic or DDC controls, which provide precise control using solid-state technologies, were found in 85% of EMS. Pneumatic controls, which use compressed air to regulate pressure supplied to controlled devices, were found in 39% of EMSs. The overlap is due to some business having both types of controls at the same facility.
5.5.3 EMS controls and features

During the on-site data collection effort, we obtained information on the control capability features of the EMS used to implement site-specific control strategies. Figure 5-10 shows that:

- 85% of EMS featured basic control functions such as time and temperature set points.
- Over 60% of EMSs had data trending capabilities, which can gather data from different systems and establish efficiency trends.
- A little under half of systems had optimized start/stop, which starts the equipment as late as possible, and shuts down equipment as early as possible.
- 46% of systems had reset optimization, which optimizes equipment with real time reset adjustments.
- 39% of systems had demand/load limiting controls, which limit the monthly peak billing demand charge based on electric rates.

*The results presented above are weighted using the kWh-level sample weight.

**These data represent 274 sites.
5.6 Energy management systems – market share and sales trends

5.6.1 New energy management systems

The on-site data collection gathered information on the age of the EMS. Systems purchased from 2009 through 2014 are considered new EMSs. Of the 277 businesses with EMSs, 198 were found to have new EMS equipment.

Figure 5-12 shows the percentage of old and new EMSs that fall into the three business kWh usage categories. These data indicate that approximately 55% of new EMSs are in businesses with more than 4,500,000 kWh of annual usage, and less than 5% of new EMSs are in businesses with less than 500,000 kWh. In comparison, slightly less than 50% of older EMSs are in the largest-sized businesses and approximately 15% of older EMSs are in the smallest-sized businesses. These data support the conclusion that newer EMSs are more concentrated in larger-sized businesses than older EMSs.
**Figure 5-12. Businesses with new EMS (2009 or Later) Distribution of old and new EMS by business kWh usage for businesses with EMS (new EMS = 2009 or later)**

*The results presented above are weighted using the kWh-level sample weight.*

** These data represent 23 businesses <500,000 kWh, 172 businesses between 500,000-4,500,000 kWh, and 82 businesses >4,500,000 kWh.

Figure 5-13 shows the percentage of businesses within a kWh range that have new versus old EMS for businesses with EMS. Figure 5-13 clearly indicates that given that a business has an EMS, businesses in the 500,000 kWh-4,500,000 kWh range and with >4,500,000 kWh usage are more likely to have newer EMSs than older systems. These data also indicate that, among businesses with EMS, approximately 72% of these systems based on energy consumption are recent purchases. In addition, the EMS data supports the following conclusions:

- 50% of the business-level electricity consumption is associated with businesses without an EMS.
- 36% of business-level electricity consumption is associated with businesses that have installed EMSs in the last 7 years.
- 14% of business-level electricity consumption is associated with businesses that have an older EMS.
The 277 businesses with EMS were also analyzed by business type, and according to whether the EMS was new or old (Figure 5-14). These data indicate that the new EMSs are distributed across all business types. Other businesses are the only business type with a majority of older EMS. The EMSs found in warehouses and in food service are 100% new EMSs. Recall from Figure 5-3 that food sales and retail had a relatively small share of business kWh associated with businesses with an EMS. The data in Figure 5-14 indicate that the majority of the EMSs in food sales and retail are newer EMSs. These segments of the commercial population may provide a program opportunity to increase the share of energy consumption associated with energy optimization controls.
*The results presented above are weighted using the kWh-level sample weight.

** The 277 businesses with EMSs are disaggregated into 22 campuses, 53 education, 11 food sales, 2 food services, 15 healthcare, 16 hospitals, 14 lodging, 29 manufacturing and industrial, 56 offices, 19 other, 20 public assembly, 12 retail, and 8 warehouses.

Of the 277 businesses with EMSs, the traditional PA-sponsored program tracking data support the conclusion that 173 businesses participated in EE programs from 2011 to 2014, while 104 sites did not participate in traditional PA-sponsored programs during this time period. Since the traditional PA-sponsored program tracking data do not include reference to sites that have participated in upstream PA-sponsored programs, it is likely that some of the 104 non-participant sites participated in programs during the 2011-2014 time period. Figure 5-15 illustrates the distribution of new and old EMSs by program participation. Customers with new EMSs have a slightly larger share of recent program participants (64%) than customers with old EMSs (59%). These data may indicate that participation in traditional EE programs is influencing the decision to install an EMS, since about two-thirds of customers installing new EMSs were program participants. These findings suggest that EE programs could influence additional advanced EMS installations. The receipt of PA-sponsored program rebates for EMSs will be analyzed in future research using these data.
Figure 5-15. Businesses with new EMS, by EE program participation

*The results presented above are weighted using the kWh-level sample weight.

** These data represent 173 EE program participant and 104 non-EE program participant sites.

5.6.2 Changes in end uses controlled by EMS over time

By disaggregating the EMS into new versus old systems, it was possible to determine whether the end uses controlled by the systems differ by system age. The on-site data indicate that the average number of end uses controlled by new systems (3.2) is slightly higher than that controlled by old systems (3.0).

Figure 5-16 presents the share of end uses controlled by EMS for new versus old systems. These data illustrate that newer systems are more likely to also control on-site generation, and process equipment and less likely to control domestic hot water and outdoor lighting than older EMSs. Also worth noting is that field staff identified that less than 1% of exterior lighting systems were controlled by a central EMS in Figure 3-44. The findings here are based on discussions with facility contacts and when asked the question “What is controlled by the EMS?” the site contact may have included exterior lighting because exterior lights are typically on automated systems (photo cells and time clocks).
Figure 5-16. End uses controlled by EMS

*The results presented above are weighted using the kWh-level sample weight.

** These data represent 277 sites—173 new EMS and 104 older EMS.
6 DOMESTIC WATER HEATING EQUIPMENT

The C&I On-Site Assessments and the MSST Study documented the baseline distribution of existing domestic water heating equipment within businesses, and the efficiency distribution of new water heater purchases. Water heaters analyzed in this report were categorized as standard storage, instantaneous or tank-less, heat pump, boiler/central plant, district steam via heat exchanger, or other. Commercial and residential unit types were identified through data collection. Water heating equipment used for space heating applications is included in Section 4, and process water heating equipment is discussed in Section 11.

The analysis looked at the efficiency of storage and instantaneous units by federal efficiency requirements implemented in 2003 and 2004. Residential and commercial domestic water heaters are defined by DOE energy conservation standards, and manufacturers must follow specific test procedure methods to demonstrate compliance. Residential efficiency standards are specified in the Code of Federal Regulations (CFR) at 10 CFR 430.32(d). Commercial efficiency standards are specified at 10 CFR 431.110.

6.1 Domestic water heater findings

The analysis of water heaters in Massachusetts businesses led to several interesting findings. The field data were analyzed across several domains of interest including the type of water heater, the water heater fuel, business type and size, the efficiency and age of the water heaters, and information on PA-sponsored program participation and efficiency requirements for PA-sponsored rebates.

Analyzing the types of water heaters found in Massachusetts businesses led to the following findings:

- 89% of water heaters are storage units.
- 5% of water heaters are instantaneous units.
- 5% of water heaters are central plant systems.

Central plant systems were most common in hospitals, campuses, education, and health care.

Analyzing water heater fuels and water heater types led to some unanticipated findings:

- 53% of businesses use only electricity to fuel their water heater units.
- 31% of businesses use only natural gas to fuel their water heater units.
- 56% of storage water heaters are electric and 89% of electric water heaters are storage units.

C&I Customer Telephone Survey Note:

According to the C&I Customer Telephone Survey:

- 57% of customers (site weighted) reported having traditional storage tanks.
- 6% Reported using tankless systems
- 2% reported using heat-pump water heaters
- Centralized boiler systems make up the remaining 35%

The proportion of use of the more non-traditional systems (tankless and heat-pump systems) aligns well with the findings of the on-site assessments. Where telephone respondents seem to have some uncertainty of the type of system the have is with the traditional storage systems and central plant type systems. This may indicate that telephone surveys can be fairly reliable for newer technologies, but less so for traditional systems.

The large share of electric water heaters is due in large part to their majority representation in storage water heaters.

The Massachusetts TRM lists the EUL of a storage water heater as 7 years, implying that most of the existing stock of water heaters is anticipated to have been installed since the implementation of the current set of federal standards. PA-sponsored program offers rebates for natural gas water heaters but not for electric-fueled water heaters although these can be covered under a custom program. The requirements for PA-sponsored program rebates substantially exceed federal requirements. Residential gas storage units have a federal requirement of an energy factor\(^{100}\) (EF) between 0.48 and 0.63, where the 0.48 EF applies to a 100-gallon unit and 0.63 applies to a 20-gallon unit (the federal standard is a tank capacity of 0.67-0.0019* tank capacity). The PA-sponsored program requirement is a 0.67 EF, and does not appear to vary by tank capacity. The commercial gas storage unit has a federal requirement of 0.80 thermal efficiency (TE) while the PA-sponsored program requires a 0.95 TE for a rebate. The residential instantaneous water heater has a federal efficiency requirement of 0.62-0.00132* tank capacity, while the PA-sponsored program requirement ranges from 0.82 EF (Tier 1) to 0.95 EF (Tier 2).

Figure 6-1 shows the distribution of efficiency distribution by type of water heating equipment.

**Figure 6-1: Water heater efficiency by technology**

![Figure 6-1: Water heater efficiency by technology](image)

*The results presented above are weighted using the Respondent-level sample weight.

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\(^{100}\) An energy factor (EF) is an energy efficiency metric for appliances under the DOE's minimum energy conservation standards which defines the overall energy efficiency based on the amount of output produced per unit of fuel consumed over a typical day. For water heaters, the energy factor is based on three factors: 1) the recovery efficiency, or how efficiently the heat from the energy source is transferred to the water; 2) stand-by losses, or the percentage of heat lost per hour from the stored water compared to the content of the water; and 3) cycling losses.
Table 6-1 lists the efficiency distribution of the existing stock of water heaters in Massachusetts businesses relative to federal standards. As anticipated, a very small share of units is below standards; the largest share is at standards, and approximately 10% are above standards. The share above federal standards increases to 23% for businesses with annual consumption 500,000 to 4,500,000 kWh, and 27% for businesses with more than 4,500,000 of consumption. There is a relatively large share of residential storage electric units sized 2 to 20 gallons with no applicable federal efficiency requirements. These units are often referred to as point-of-use units.

Table 6-1: Distribution of the efficiency of water heaters by business kWh

<table>
<thead>
<tr>
<th>Efficiency relative to federal standards</th>
<th>All businesses with water heaters</th>
<th>Less than 500,000 annual kWh</th>
<th>500,000 to 4,500,000 annual kWh</th>
<th>4,500,000 + annual kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above standards</td>
<td></td>
<td>9%</td>
<td>8%</td>
<td>23%</td>
</tr>
<tr>
<td>At standards</td>
<td></td>
<td>30%</td>
<td>30%</td>
<td>34%</td>
</tr>
<tr>
<td>Below standards</td>
<td></td>
<td>4%</td>
<td>4%</td>
<td>1%</td>
</tr>
<tr>
<td>No standards*</td>
<td></td>
<td>2%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>No standards – commercial electric*</td>
<td></td>
<td>1%</td>
<td>1%</td>
<td>6%</td>
</tr>
<tr>
<td>No standards – residential electric*</td>
<td></td>
<td>16%</td>
<td>17%</td>
<td>9%</td>
</tr>
<tr>
<td>Make and model missing</td>
<td></td>
<td>22%</td>
<td>22%</td>
<td>14%</td>
</tr>
<tr>
<td>Make and model not found</td>
<td></td>
<td>17%</td>
<td>19%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Data is weighted by respondent weights. The data includes 336 water heaters observed at businesses with less than 500,000 kWh annual usage, 853 at businesses with 500,000-4,500,000 kWh, and 304 at businesses with over 4,500,000 kWh.

* No applicable Federal efficiency requirements

Table 6-2 presents information on the efficiency distribution of water heaters by business type. Public assembly has the largest share of water heaters below federal efficiency requirements. These may represent a program opportunity. 20% of water heaters in health care businesses are commercial electric units that do not have a federal efficiency standard; these units may offer a program opportunity.

Residential electric units without federal efficiency standards represent over 20% of water heater units in manufacturing, retail, and offices. While these units do not have federal efficiency standards, they may represent efficient units, as these point-of-use units are 2- to 20-gallon units that may use limited energy. Point-of-use water heaters are often located at the point of water use and therefore do not incur losses associated with a distribution system. Education and food service have the largest share of water heaters found to be at standards. These may represent a program opportunity.
Table 6-2: Distribution of the efficiency of water heaters by business type

<table>
<thead>
<tr>
<th>Business type</th>
<th>Above standard</th>
<th>At standard</th>
<th>Below standard</th>
<th>No standard</th>
<th>No standard – commercial electric</th>
<th>No standard residential electric</th>
<th>Model missing</th>
<th>Model not found</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>30%</td>
<td>28%</td>
<td>4%</td>
<td>1%</td>
<td>2%</td>
<td>1%</td>
<td>5%</td>
<td>29%</td>
</tr>
<tr>
<td>Education</td>
<td>9%</td>
<td>75%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>11%</td>
<td>3%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>13%</td>
<td>39%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>18%</td>
<td>18%</td>
</tr>
<tr>
<td>Food service</td>
<td>17%</td>
<td>54%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>24%</td>
<td>2%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>10%</td>
<td>24%</td>
<td>0%</td>
<td>0%</td>
<td>20%</td>
<td>8%</td>
<td>17%</td>
<td>21%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>13%</td>
<td>10%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>15%</td>
<td>62%</td>
</tr>
<tr>
<td>Lodging</td>
<td>7%</td>
<td>29%</td>
<td>3%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>50%</td>
<td>11%</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>4%</td>
<td>9%</td>
<td>0%</td>
<td>1%</td>
<td>2%</td>
<td>32%</td>
<td>47%</td>
<td>4%</td>
</tr>
<tr>
<td>Office</td>
<td>11%</td>
<td>19%</td>
<td>2%</td>
<td>0%</td>
<td>1%</td>
<td>25%</td>
<td>15%</td>
<td>26%</td>
</tr>
<tr>
<td>Other</td>
<td>24%</td>
<td>23%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>13%</td>
<td>19%</td>
<td>20%</td>
</tr>
<tr>
<td>Public assembly</td>
<td>17%</td>
<td>12%</td>
<td>19%</td>
<td>0%</td>
<td>0%</td>
<td>3%</td>
<td>1%</td>
<td>48%</td>
</tr>
<tr>
<td>Retail</td>
<td>3%</td>
<td>29%</td>
<td>2%</td>
<td>0%</td>
<td>0%</td>
<td>26%</td>
<td>24%</td>
<td>16%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>2%</td>
<td>70%</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
<td>5%</td>
<td>21%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Data is weighted by respondent weights. Data collection at campuses collected data from 113 water heaters, 89 education, 55 food sales, 77 food services, 80 health care, 26 hospitals, 246 lodging, 151 manufacturing or industrial, 268 offices, 145 other, 84 public assembly, 111 retail, and 48 warehouses.

The efficiency distribution of water heaters can also be examined by water heater age (see ).

- Across all time periods, the largest share of units are observed to be at federal standards.
- Water heaters purchased since 2009 do not appear to have a larger share of units purchased above federal standards. These data indicate that Massachusetts businesses have not been actively seeking out high efficiency units when they purchase new water heaters.
- There has been an increasing share of point-of-use (no standards – residential electric) water heaters purchased. Point-of-use water heaters represent only 11% of the units purchased in 2008 and earlier, but they represent 20% and 27%, respectively, of units purchased 2009-2011 and 2012-2014. Point-of-use or electric water heaters with 2- to 20-gallon capacities may represent an efficiency choice from a consumer’s point of view.
Table 6-3: Distribution of the efficiency of water heaters by water heater age

<table>
<thead>
<tr>
<th>Efficiency relative to federal standards</th>
<th>Unknown age</th>
<th>Purchased 2008 and earlier</th>
<th>Purchased 2009-2011</th>
<th>Purchased 2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above standards</td>
<td>7%</td>
<td>10%</td>
<td>8%</td>
<td>11%</td>
</tr>
<tr>
<td>At standards</td>
<td>21%</td>
<td>26%</td>
<td>41%</td>
<td>56%</td>
</tr>
<tr>
<td>Below standards</td>
<td>1%</td>
<td>7%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>No standards</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>No standards – commercial electric</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>No standards – residential electric</td>
<td>17%</td>
<td>11%</td>
<td>20%</td>
<td>27%</td>
</tr>
<tr>
<td>Make and model missing</td>
<td>36%</td>
<td>18%</td>
<td>21%</td>
<td>1%</td>
</tr>
<tr>
<td>Make and model not found</td>
<td>18%</td>
<td>27%</td>
<td>4%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Data is weighted by respondent weights. Water heaters with unknown age are 226 units; aged 2008 and older are 936 units; aged 2009-2011 are 152 units; and aged 2012-2014 are 179 units.

The efficiency distribution can also be analyzed by the type of unit and unit age. presents information on the efficiency distribution of water heaters relative to the federal efficiency requirements for the existing stock of water heaters and for water heaters purchased since 2009.101

Table 6-4: Efficiency distribution of existing and new water heaters by type of water heater

<table>
<thead>
<tr>
<th>System type</th>
<th>Efficiency relative to federal standards</th>
<th>Existing stock</th>
<th>Purchased 2009-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial gas storage</td>
<td>Above standards</td>
<td>18%</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>At standards</td>
<td>54%</td>
<td>73%</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>28%</td>
<td>4%</td>
</tr>
<tr>
<td>Residential gas storage</td>
<td>Above standards</td>
<td>5%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>At standards</td>
<td>73%</td>
<td>88%</td>
</tr>
</tbody>
</table>

101 The existing stock of water heaters includes the recently purchased water heaters.
<table>
<thead>
<tr>
<th>System type</th>
<th>Efficiency relative to federal standards</th>
<th>Existing stock</th>
<th>Purchased 2009-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Instantaneous gas</td>
<td>Unknown</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Above standards</td>
<td>45%</td>
<td>88%</td>
</tr>
<tr>
<td></td>
<td>At standards</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>55%</td>
<td>12%</td>
</tr>
<tr>
<td>Residential electric storage</td>
<td>Above standards</td>
<td>21%</td>
<td>29%</td>
</tr>
<tr>
<td></td>
<td>At standards</td>
<td>28%</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>35%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Highlights from and additional data described in the following sections include:

- Commercial gas storage units
  - There has been no increase in the share of water heaters above federal standards when comparing the existing stock of water heaters to those newly purchased.
  - Approximately 10% of the existing stock of commercial gas units met or exceeded the PA-sponsored program requirement of 95% TE, while only 7% of recent purchases met this requirement.

- Residential gas storage units
  - A small increase was observed in the share of units above federal standards for recent purchases relative to the existing stock.
  - Neither the existing stock nor new purchases have units above the PA-sponsored program requirements.

- Residential gas instantaneous units
  - The share of units qualifying for the PA-sponsored program and having an energy factor of 0.95 or above increases from 13% in existing stock to 88% in recent purchases.

- Residential electric storage units
  - The share above federal standards for the existing stock and recent purchases remains in the 20-30% range. The PA-sponsored program does not offer electric storage water heater rebates.

The analysis of the efficiency of recently purchased water heaters relative to the existing stock indicates that there has not been a substantial improvement in the efficiency of units purchased from 2009 to 2014 except for residential gas instantaneous water heaters. Unfortunately, instantaneous units account for only 5% of the recent purchases and the existing stock of units. The findings from this analysis lead to the following findings and observations:

- The efficiency of water heaters in Massachusetts businesses is not undergoing substantial improvement.
• It may be necessary to determine if it is cost effective to implement or modify programs in order to
improve customer and trade ally understanding of the benefits of high-efficiency water heaters.
• The current efficiency requirements for PA-sponsored program rebates for residential sized gas water
heaters may be too high. The PA-sponsored program requirements do not appear to incorporate the
efficiency adjustments associated with tank size that are part of federal efficiency requirements.
  - Adjustments to less stringent requirements for PA-sponsored program rebates may be necessary to
encourage purchases above federal standards.
  - Market research may be needed to ensure that PA-sponsored program rebate requirements are
consistent with unit availability.

Or given the recent changes in standards, combined with evidence that vendors are selling to and
businesses are buying to code, this time may represent an opportunity for the utilities to offer education
and rebate programs to try to change the selling and buying behaviors associated with residential gas
water heaters in Massachusetts businesses.

• Electric water heating units are popular in Massachusetts businesses.
  - Point-of-use electric water heaters (2- to 20-gallon storage tanks) are growing in popularity. These
units represented 16% of water heaters in the existing stock and 24% of recent purchases. These
units are more commonly found in businesses with less than 500,000 kWh than in larger businesses.
These units are advertised as energy efficient, but they do not have federal efficiency standards.
Research may be needed to ensure that these units are as efficient as high efficiency electric storage
water heaters with slightly larger tanks.
  - PA-sponsored program does not currently offer PA-sponsored program rebates for electric water
heaters. Given that 53% of businesses use electric units, focusing on improving the efficiency of
these units or encouraging customers to switch into a more efficient type of unit may provide a
potential cost-effective program opportunity.

The following sections provide additional information and detail on the highlights presented above.

6.2 Domestic water heating data
During data collection, we recorded water heating manufacturer and model numbers where possible. These
data, combined with equipment information lookups, were used to characterize the efficiency distribution of
water heaters in Massachusetts businesses.102

Table 6-5 presents information on the total number of on-site visits conducted by business type, and the
number of on-sites where information on water heating equipment was collected. Of the 800 site visits
conducted, we collected information on water heating equipment from 738 businesses. Water heating
information was not able to be collected for 37 facilities,103 and there were an additional 25 sites where
either no water heating equipment was present or it was served by another meter that was not part of the
sampled account. The weights for these facilities for water heating was set to zero so that the analysis of the
remaining water heating units was not affected. The far-right column in Table 6-5 lists the share of water

102 The efficiency analysis was completed for commercial-sized gas storage water heaters, residential-sized gas and electric storage water heaters,
and residential sized gas instantaneous water heaters. The efficiency evaluation focused on these units due to available data on efficiency levels
and standards and the quantity of different types of water heating units observed during the field data collection.

103 There were various reasons why water heating information could not be collected at some sites, including issues with the time onsite and lack of
access to rooms where water heating equipment is stored.
heating units where both manufacturer and model information were recorded. For example, 4 of the campus sites visited did not have a domestic water heater within the account premise, so water heater data was collected onsite from 31 of the 35 campus sites. Of the 31 campus sites with water heating information, manufacturer and model numbers for the water heating equipment were collected for 86% of the sites.

<table>
<thead>
<tr>
<th>Business type</th>
<th>On-sites</th>
<th>Counts of on-sites with hot water data**</th>
<th>Percent of WHs with available make and model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campus</td>
<td>35</td>
<td>31</td>
<td>86%</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>78</td>
<td>79%</td>
</tr>
<tr>
<td>Food Sales</td>
<td>47</td>
<td>45</td>
<td>66%</td>
</tr>
<tr>
<td>Food Service</td>
<td>63</td>
<td>63</td>
<td>84%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>62</td>
<td>83%</td>
</tr>
<tr>
<td>Hospital</td>
<td>20</td>
<td>20</td>
<td>90%</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>59</td>
<td>81%</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>72</td>
<td>83%</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>104</td>
<td>80%</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>44</td>
<td>79%</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>69</td>
<td>80%</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>66</td>
<td>78%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>25</td>
<td>74%</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>738</td>
<td>80%</td>
</tr>
</tbody>
</table>

* The results presented above are unweighted.

** These counts indicate the number of sites where water heating was identified in the buildings that were visited.

† There are 37 sites where water heating was not identified or collected. The DHW weight for these sites have been set to zero.

### 6.3 Domestic water heater system type

For the purpose of this study, water heaters were classified as storage, instantaneous or tank-less, heat pump, boiler/central plant, district steam via heat exchanger, or “other.” Figure 6-2 illustrates the distribution of these system types across the non-residential sector in Massachusetts. Storage water heaters were found to represent 89% of water heaters in the Massachusetts C&I market.

---

104 Account premises (electric accounts) may be associated with part of a building, a whole building or multiple buildings. Its possible the DWH systems may not be located on the premises for this reason.
Figure 6-2: Water heater system type

* The results are weighted using the respondent-level sample weight.

** These data represent 1,925 units.

Figure 6-3 provides information on the distribution of water heating units by business type. These data indicated that storage water heaters represented the majority of units for all business types other than hospitals where central plant hot water units (including boilers) and shared services were the dominant sources of hot water. Hospitals were also the only business segment where district steam via heat exchangers were found. As expected, hospitals, campuses, education, and health care have the largest share of central plant units.

105 The distribution of water heaters by business type aggregates all units observed during the field data collection to a business type. An individual business may have multiple water heating units and types. If a site has multiple water heating units or types, all will be weighted by the customer’s respondent weight. The percent in Figure 6-3 represent the share of water heater units with the specific technology by business type.
Figure 6-3: Water heating system types by business type

* The results are weighted using the respondent weight.

** These data represent 1,384 storage water heaters, 109 instantaneous water heaters, three heat pump water heaters, 397 central plant/shared service units, 30 units using district steam and a heat exchanger, and 2 unknown system types.

Figure 6-4 illustrates the water heater type by business kWh usage.\textsuperscript{106} Storage tank units are the most common water heater type for each business usage category. The greatest presence for central plants is seen in businesses with an annual consumption between 500,000 and 4,500,000 kWh; however, central plant units account for only 5% of the respondent-weighted domestic water heater units identified on site.

\textsuperscript{106} The data in Figure 6-4 are respondent-weighted; these data represent the percent of water heater units with a given technology by business kWh consumption.
Figure 6-4: Water heater system type by business kWh usage

* The results are weighted using the respondent sample weight.

** These data represent 1,384 storage water heaters, 109 instantaneous water heaters, three heat pump water heaters, 397 central plant/shared service units, 30 units using district steam and a heat exchanger, and two unknown system types.

6.4 Domestic water heater fuels

Figure 6-5 shows the type of fuel used in C&I businesses for domestic hot water in Massachusetts. While businesses can have multiple water heaters, providing the opportunity for businesses to have units fueled by multiple fuels, most businesses use only one type of fuel to power their water heaters.107 The data in Figure 6-5 indicate that electricity is the most common water heater fuel in Massachusetts businesses, followed by gas-fueled water heaters. In addition, 9% of the facilities surveyed did not have domestic hot water units at the facility.108 In some cases there was no hot water use at the facility. In other cases, the hot water system was served through a meter that was not part of the surveyed premise.

107 Gas includes propane and natural gas.
108 Account premises (electric accounts) may be associated with part of a building, a whole building or multiple buildings. Its possible the DWH systems may not be located on the premises for this reason.
The results are weighted using the site sample weight.

These data represent 763 total sites.

Figure 6-6 illustrates the distribution of fuel types across water heater units. The data can be used to conclude that over 89% of electric-based units are storage water heaters. Electric storage water heaters represent 56% of all storage water heaters in Massachusetts businesses. Storage water heaters account for 89% of water heaters. Using the share of electric storage water heaters combined with the share of storage water heaters leads to the conclusion that 50% of all water heaters are electric storage water heater. If 56% of water heaters are electric, \( 0.50/0.56 = 89\% \), or electric storage water heaters are 89% of electric water heaters. In comparison, 100% of heat pump water heaters are electric; however, heat pumps represent only 3% of electric water heaters. When considering the efficiency of electric water heaters, it is important to remember that 89% of electric water heaters are storage water heaters; these types of water heaters are the predominate type within businesses that use electricity to heat their water. Boiler and central plant units were commonly fueled by natural gas (64%) or fuel oil (28%).
Figure 6-6: Share of water heater fuels by system types

- **The results are weighted using the respondent-level sample weight.**
- **These data represent 1,338 storage water heaters, 109 instantaneous water heaters, three heat pump water heaters, 397 central plant/shared service units, 30 district steam units, and two units classified as other.**

# 6.5 Storage and instantaneous water heater efficiency information

During the on-site data collection effort, the surveyors collected make and model number information for storage tank and tank-less water heater units. This information was used to determine the efficiency distribution of water heaters in Massachusetts businesses. The efficiencies for all of the water heating equipment in the analysis were compared to the current federal water heater efficiency standards, which is necessary because the purchase date of equipment is not available for all units. This comparison also provided some information on the energy efficiency savings potential relative to current standards.

Table 6-6 lists the federal water heater efficiency standards used. The standards for water heaters vary by system type, capacity units, fuel, size, and system usage (domestic hot water and service hot water). Furthermore, water heaters with a tank capacity under 20 gallons and commercial electric units are not currently regulated. These types of water heaters will appear as water heaters with “no standards” in the efficiency presentation.
Table 6-6: Storage and instantaneous water heater efficiency parameters and standards\textsuperscript{109, 110}

<table>
<thead>
<tr>
<th>Standard type</th>
<th>Equipment type</th>
<th>Input capacity</th>
<th>Input capacity units</th>
<th>Fuel type</th>
<th>Tank capacity</th>
<th>Efficiency minimum</th>
<th>Efficiency units</th>
<th>Year of compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Res - WH</td>
<td>Storage water heater</td>
<td>≤ 75</td>
<td>Kbtuh</td>
<td>Nat. gas</td>
<td>20 to 100 gal</td>
<td>0.67- (0.0019* tank cap)</td>
<td>Energy factor</td>
<td>2004*</td>
</tr>
<tr>
<td>Res - WH</td>
<td>Storage water heater</td>
<td>≤ 105</td>
<td>Kbtuh</td>
<td>Fuel oil</td>
<td>≤ 50 gal</td>
<td>0.59- (0.0019* tank cap)</td>
<td>Energy factor</td>
<td>2004*</td>
</tr>
<tr>
<td>Res - WH</td>
<td>Storage water heater</td>
<td>≤ 12</td>
<td>Kw</td>
<td>Elec.</td>
<td>20 to 120 gal</td>
<td>0.97- (0.00132* tank cap)</td>
<td>Energy factor</td>
<td>2004*</td>
</tr>
<tr>
<td>Res - WH</td>
<td>Instantaneous</td>
<td>&lt; 200</td>
<td>Kbtuh</td>
<td>Nat. gas/propane</td>
<td>&lt; 2 gal</td>
<td>0.62- (0.0019* tank cap)</td>
<td>Energy Factor</td>
<td>2004*</td>
</tr>
<tr>
<td>Res - WH</td>
<td>Instantaneous</td>
<td>≤ 12</td>
<td>Kw</td>
<td>Elec.</td>
<td>&lt; 2 gal</td>
<td>0.93- (0.00132* tank cap)</td>
<td>Energy Factor</td>
<td>2004*</td>
</tr>
<tr>
<td>Com - WH</td>
<td>Storage water heater</td>
<td>N/a</td>
<td>N/a</td>
<td>Nat. gas</td>
<td>&gt; 100 gal</td>
<td>0.8</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
<tr>
<td>Com - WH</td>
<td>Storage water heater</td>
<td>&gt; 75</td>
<td>Kbtuh</td>
<td>Nat. gas</td>
<td>N/A</td>
<td>0.8</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
<tr>
<td>Com - WH</td>
<td>Storage water heater</td>
<td>N/a</td>
<td>N/a</td>
<td>Fuel oil</td>
<td>&gt; 50 gal</td>
<td>0.78</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
<tr>
<td>Com - WH</td>
<td>Storage water heater</td>
<td>&gt; 105</td>
<td>Kbtuh</td>
<td>Fuel oil</td>
<td>N/A</td>
<td>0.78</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
<tr>
<td>Com – WH</td>
<td>Instantaneous</td>
<td>≥ 200</td>
<td>Kbtuh</td>
<td>Nat. gas/propane</td>
<td>N/A</td>
<td>0.8</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
<tr>
<td>Com – WH</td>
<td>Instantaneous</td>
<td>&gt; 210</td>
<td>Kbtuh</td>
<td>Fuel oil</td>
<td>N/A</td>
<td>0.78</td>
<td>Thermal efficiency</td>
<td>2003</td>
</tr>
</tbody>
</table>


\textsuperscript{110} No minimum thermal efficiency is dictated for commercial electric storage water heaters. The current standards only regulate the Maximum Standby Loss.
The PA-sponsored commercial programs provided rebates for high-efficiency natural gas water heaters. For natural gas tank-less or instantaneous units, the rebates were based on a two tier system requiring units to have an energy factor of 0.82 for a Tier 1 rebate and 0.95 for a Tier 2 rebate. The requirements for the PA-sponsored program instantaneous residential sized natural gas units substantially exceeds the federal requirement of a 0.62 energy factor. For condensing units with 75 to 300 kBTU, PA-sponsored programs required a 95% thermal efficiency or higher to receive a rebate, which is substantially higher than the 80% thermal efficiency requirement of federal standards. Receipt of a PA-sponsored program rebate for a storage natural gas water heating unit required an energy factor of 0.67 or greater. The PA-sponsored program rebate efficiency requirement is higher than the federal efficiency requirements, though the degree to which the PA-sponsored program standards exceed the federal standards is difficult to directly determine. This is because federal standards are dependent on the tank capacity but the PA-sponsored program requirements are not. There do not appear to be PA-sponsored program rebates available for electric water heaters. Given that electric water heaters represent 53% of water heaters in Massachusetts businesses, these units may represent a program opportunity.

Due to the differences in water heating efficiency standards between gas and electric units, as well as the difference in efficiency units between commercial and residential DHW units, the following classifications were used to identify DHW efficiency: commercial gas, residential gas storage, residential gas instantaneous, and residential electric storage.

Figure 6-7 presents the distribution of water heater system types relative to the federal efficiency standards for units, fuel types, and sizes where federal standards are applicable. There is a substantial share of water heater units without applicable federal efficiency standards. (The distribution of all tank and instantaneous systems, including those without federal efficiency standards, is presented in Figure 6-12.) In Figure 6-7, units listed as “Unknown – model not found” are units for which the make and model numbers were collected, but efficiency information for the unit was unavailable, or other information needed to classify the unit was missing. “Unknown – model missing” represents units where model numbers could not be collected during the on-site effort.

Residential gas instantaneous water heaters have the highest percentage of units that are above standards, and also the highest percentage of units for which the efficiency could not be confirmed. Recall, however, that only 5% of water heaters in Massachusetts businesses are instantaneous units. Over 70% of commercial gas water heaters and over 75% of residential gas storage units met or exceeded the federal energy efficiency standards. Residential electric storage units have a more even distribution across efficiency categories, with 16% of the units below the federal efficiency standards, 28% meeting the standards, and 21% exceeding the standards. Recall that electric storage water heaters represent 50% of all water heaters in Massachusetts businesses. The high share of residential electric water heating units above federal energy efficiency standards clearly indicates that Massachusetts businesses are aware of, and have access to, high-efficiency choices. Finding that 16% of these units fall below federal standards is significant, given that the

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111 The Tier 2 rebate required an energy factor of 0.95 in 2011 and 2012. The Tier 2 energy factor requirements was reduced to 0.94 for 2013 and 2014.
112 In 2011, the PA-sponsored program included a Tier 1 incentive for storage natural gas water heating units with an energy factor of .62. In 2012, the efficiency requirement for the program jumped to .67.
113 There were 13 records of instantaneous electric hot water heaters whose tank capacity exceeds the 2 gallon capacity of residential instantaneous units. The majority of these systems were plug-in countertop or under counter instantaneous hot water heaters, which do not fall under the standards listed in Table 6-6. No efficiencies were identified for any of these 13 records.
standards were implemented in 2004, and that the MA TRM lists the expected useful life of a residential electric water heater as 7 years.\textsuperscript{114} The large share of residential electric water heaters and the share below federal efficiency standards provide a potential program opportunity.

**Figure 6-7: Storage and instantaneous water heater efficiency distribution comparison to federal efficiency standards**

* The results are weighted using the respondent sample weight.

** These data represent 322 commercial gas water heaters, 111 residential gas storage water heaters, 506 residential electric storage water heaters and 47 residential gas instantaneous water heaters.

Figure 6-8 through Figure 6-11 show the efficiency levels by equipment type. Beginning with Figure 6-8, we see the majority (56\%) of commercial gas water heaters were found to be in the 80\%-84\% range of thermal efficiency. Of the 56\% of units in this range, 96\% are at standards, with a thermal efficiency of 80\% for natural gas units. The data implies that 54\%.(56\%\times.96) of commercial gas water heaters can be classified as ”at standards.”

There was also a high share of units (10\%) with a thermal efficiency at or above 95\%. PA-sponsored programs provided rebates in 2013 for units with a thermal efficiency of 95\% or higher. Given this information and reflecting back on Figure 6-7, which indicates that a large share of commercial gas water heater

\textsuperscript{114} The EUL for a residential sized electric water heater is from the residential section of the MA TRM. These units are not in the commercial section of the TRM. See the ”Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures”, Oct 2012.
heaters are above standards (18%), it is clear that there are many water heaters available in the market with thermal efficiency levels substantially superior to current standards and a large share at or above PA-sponsored program requirements.

Three percent of the units had a thermal efficiency below 80%. Of these units, several were fueled by fuel oil, which has a lower thermal efficiency standard (78%). When comparing these commercial units to the federal standards (Figure 6-7), less than 1% of water heaters in the market are below the corresponding federal standards. It should be noted that the efficiency of 28% of the commercial gas water heaters was not able to be determined in the field or in follow-up desktop research.

**Figure 6-8: Water heater efficiency (%) distribution for commercial gas water heaters**

* The results are weighted using the respondent sample weight.
** These data represent 322 total commercial gas water heaters.

Figure 6-9 illustrates the energy factor for residential gas storage water heaters in Massachusetts businesses. The distribution of residential gas storage water heaters in businesses in Massachusetts shows that 49% of the units had an energy factor between 55% and 59%, and that 23% had an energy factor between 60% and 64%. The baseline energy factors for the storage water heaters observed on-site ranged from 48% to 63.2%. Given that the federal efficiency standards for residential water heaters over 20 gallons (see Table 6-6) is based on the tank capacity, it is difficult to directly observe the relationship between energy factor and efficiency distribution.
When comparing the energy factor and tank capacity to current standards, 73% of residential gas water heaters in commercial businesses meet the current efficiency standards, less than 1% are below current standards, and only 5% exceed standards. The PA-sponsored program efficiency requirements for these units was an energy factor of 0.67 or higher. Very few units observed in Massachusetts businesses meet the 2013 PA-sponsored program requirements to receive a rebate. Note that the federal efficiency requirements are dependent on the tank capacity, while the requirements for a PA-sponsored program rebate are not. Modifying the rebate to be dependent on the tank capacity may make the rebate more difficult to understand but it may also encourage more contractors to install units that are eligible for PA-sponsored program rebates.

The efficiency level for 21% of residential gas storage water heaters could not be determined due to missing data or the inability to locate information on the model efficiency. Note that for the residential units, the data in the pie charts show the efficiency ratings but efficiency standards are dependent on tank size. So Figure 6-9 does not depict the efficiency relative to standards.

**Figure 6-9: Water heater energy factor distribution for residential gas storage water heaters**

* The results are weighted using the respondent sample weight.

** These data represent 111 total residential gas storage water heaters. The efficiency units are efficiency factor.

The data for residential gas water heaters in Massachusetts businesses clearly support the conclusion that businesses have water heaters that meet federal efficiency standards. This measure may represent a technology for which PA-sponsored programs can attempt to change the practices of businesses and encourage businesses to invest in units above the federal standard efficiency.

The efficiency standards used for the residential gas water heater analysis were enacted in 2004 and updated in 2015. The share of water heater units that fall below the 2015 standards will increase because updated standards will lead to an improvement in the efficiency of future purchases as less efficient units
become obsolete. Given the recent changes in standards, combined with evidence that vendors are selling to and businesses are buying to code, this time period may represent an opportunity for the utilities to offer education and rebate programs to try to change the selling and buying behaviors associated with residential gas water heaters in Massachusetts businesses.

Figure 6-10 illustrates the efficiency distribution for residential electric storage water heaters found in businesses in Massachusetts. Thirty-five percent of these units had an energy factor between 90% and 94%, and 23% had an energy factor between 85% and 89%. Similar to residential gas water heaters, the standards for these units are calculated as a function of tank capacity, with current standards ranging from an energy factor of 81.16% (for 120-gallon units) to 94.36% (for 20-gallon units). Twenty-eight percent of the residential electric water heating units met federal efficiency standards, while 21% were above standards and 16% were below current standards. When compared to gas storage water heaters, electric storage water heaters have a substantially higher share above current federal energy efficiency standards, but both electric and gas units offer opportunities for improving the efficiency distribution. The efficiency for 35% of the residential electric storage water heaters in businesses in Massachusetts was not able to be determined from the make and model lookups.

For this analysis, the observed efficiencies were compared to 2004 standard energy factors. The 2015 standards update will eventually eliminate the availability of residential-sized electric water heaters with lower energy factors.
Figure 6-10: Water heater energy factor distribution for residential electric storage water heaters

* The results are weighted using the respondent sample weight.

** These data represent 506 total residential electric storage water heaters.

Figure 6-11 illustrates the distribution of energy factors for residential gas instantaneous water heaters in Massachusetts businesses. The on-site data collection effort observed only 47 residential instantaneous gas water heaters. The relatively small number of units indicates that these units do not currently provide a substantial share of the hot water heating in Massachusetts businesses, and when interpreting the findings for the efficiency, it should be noted that analysis results for these types of units may not be representative of the entire population across the state.

The efficiency findings for residential gas instantaneous water heaters show that 28% of these units had an energy factor between 80% and 84%, while 13% had an energy factor between 95% and 99%. The federal efficiency standards for these units are calculated as a function of tank capacity. Although instantaneous water heaters often have no storage tank, the standards are applicable to units that have up to a 2-gallon tank. The federal standards for these units are based on an energy factor of approximately 62%. Forty-four percent of residential gas instantaneous hot water units have an efficiency factor that is above federal standards. The PA-sponsored programs provided a two-tier incentive scheme for instantaneous water heaters in 2013. The Tier 1 incentive required an energy factor of 82% or higher, while the Tier 2 incentive was available for units with an 94% energy factor. The field data indicate that where it was possible to
classify the instantaneous water heater efficiency level, many units qualified for a Tier 1 rebate and 13% qualified for a Tier 2 incentive.

For the majority (53%) of the residential gas instantaneous water heaters, however, it was not possible to classify their efficiency due to a lack of information linking the make and model number with efficiency data (see Figure 6-11).\(^{115}\)

**Figure 6-11: Water heater energy factor distribution for residential gas instantaneous water heaters**

* The results are weighted using the respondent sample weight.
** These data represent 47 total residential gas instantaneous water heaters.

Figure 6-12 illustrates the efficiency distribution of storage and instantaneous water heaters observed across all the water heater data collected. These data indicate that the largest share of water heaters are represented by “Unknown – model not found” and “Unknown – model missing” making up 19% and 22%, respectively. Out of the remaining units found for which where efficiency make and model information was available, the largest share of units were found to be at current efficiency standards (30%).

Only 4% of water heaters were below current standards. As shown in Table 6-6, however, water heater energy efficiency standards are relatively old, having been implemented in 2003 and 2004. The analysis

\(^{115}\) Recall that only 5% of water heaters in Massachusetts businesses are instantaneous units.
found that 9% of the units were above standards. The relatively low share of units found to exceed the current energy efficiency standards is of interest given the long standing of current standards combined with data indicating that 30% of units have been purchased since 2008 (see Figure 6-12). The water heater standards associated with residential-sized water heaters were updated in April 2015, but that update is not reflected in the data presented here.

The share of water heaters in non-residential facilities that is not covered by current standards was broken out into residential electric units (16%), commercial electric units (1%), and other units (<1%), for a total of 19%. This could have implications for energy consumption if these units use substantial energy to supply hot water. These unit types include electric storage water heaters less than 20 gallons and electric storage water heaters with inputs over 25 kW. In total 158 of these unit types were observed; 136 which were under 20 gallons and 22 with inputs over 25 kW. All of units with inputs over 25 kW were located in businesses with annual usage over 500,000 kWh while the units under 20 gallons were seen across all business sizes. Given all the units not subject to energy efficiency standards are electric storage units the greatest savings potential would include converting the units to use natural gas where available and/or converting to higher efficiency technology types like heat pumps, or instantaneous water heaters. For the smaller units, the cost associated with plumbing gas and ventilation might make fuel switch type retrofits unappealing but conversions to instantaneous electric could be cost effective and appealing.

**Figure 6-12: Water heater efficiency distribution of storage and instantaneous water heaters**

* The results are weighted using the respondent sample weight.

** These data represent 1,493 total DHW units. Only storage water heaters and instantaneous water heaters are included in this analysis.

Figure 6-13 illustrates the distribution of efficiencies for storage tank and instantaneous units. Storage tank hot water heaters account for 95% of the units in the efficiency analysis and 89% of all water heating units.
in Massachusetts businesses. Storage water heaters include units that fall below, meet, or exceed federal efficiency standards. Instantaneous water heaters represent approximately 5% of water heaters in Massachusetts businesses. For the majority of the instantaneous units (90%), the model number was missing or the efficiency could not be found. Nameplate information is often found behind the cover, but field staff were instructed not to disassemble equipment. All identified units for which the efficiency data was available were at or above standards. The share of unknown efficiency in Figure 6-13 exceeds the share in Figure 6-11 because Figure 6-13 includes commercial electric units without standards and commercial gas units where the efficiency information was not found.

Figure 6-13: Water heater efficiency distribution by system type

* The results are weighted using the respondent sample weight.

** These data represent 1,384 storage water heaters and 109 instantaneous water heaters.
6.6 Domestic water heater energy efficiency program participation

As part of the study, the efficiency of water heaters owned by customers who had participated in PA-sponsored energy efficiency rebate programs were compared with the efficiency of water heaters at non-participant facilities. For this analysis, a participant was a customer that had participated in a PA-sponsored traditional rebate program from 2011-2014. The participation could have been for any measure or end use, and was not restricted to customers who participated in a water heating program. The data showed that program participants had a larger share of high-efficiency water heaters than non-participants. Fifteen percent of participant DHW units were above standards, 35% were at standards, and 5% were below standards, as seen in Figure 6-14. Only 7% of the non-participant units were found to be above standards, while 28% met standards, and 3% were below standards. Over 35% of participant units and almost 50% of the non-participant units had missing model information or had make and model numbers where efficiency lookups did not lead to efficiency values.

Figure 6-14: Water heater efficiency distribution of program participants and non-participants

* The results are weighted using the respondent sample weight.

** These data represent 675 water heaters at program participant businesses and 818 water heaters from non-participant businesses.

116 The energy efficiency program data included in this analysis includes traditional programs with very limited information from upstream programs. Customers are designated at participants if they have participated in PA-sponsored energy efficiency programs from 2011-2014. The participation designation is not dependent on the measure or end-use associated with the program participation. There were limited gas water heater rebates available in commercial programs during this time.
6.7 Domestic water heater age

Information on the water heater age was also collected as part of the C&I Customer On-Site Assessments. If field staff were unable to collect information on the age of water heaters at the facility, they were instructed to ask the site contact if the water heater had been purchased after or before January 1, 2009. Figure 6-15 illustrates the overall water heater age distribution, while Figure 6-16 illustrates the water heater age distribution by business type. The data indicated that 30% of observed water heaters qualified as newer water heaters (installed after 2008). A substantial share of the water heater age data was self-report. Unfortunately, many customers did not recall the age of their water heater and the information was not available on the water heater’s nameplate, leading to the relatively high share of water heating units with unknown age. Given the reliance of age information on customer recall, it is likely that the age distribution of the units of unknown age is not identical to those with known ages. It is likely that the unknown-age units are, on average, older than the units with known ages.

Figure 6-15: Water heater age distribution

* The results are weighted using the respondent sample weight.

** These data represent 1,925 total units.

Figure 6-16 illustrates the water heater age distribution by business type. The business type information indicates that food sales and healthcare have a 50% or higher share of new water heaters, while water heating units in education facilities are largely older units (over 50% installed prior to 2000). The share of new water heaters by business type may be associated with water usage at sites and available resources to
replace aging units. Food sales and healthcare may have a higher water usage rate than most business type, leading to the need to buy systems more frequently. Education facilities may lack the resources needed to update water heating units.

Figure 6-17 illustrates that businesses with annual usage between 500,000 and 4,500,000 kWh have the largest share of new water heaters.

**Figure 6-16: Water heater age distribution by business type**

![Water heater age distribution by business type](image)

* The results are weighted using the respondent-level sample weight.

* The results are weighted using the respondent-level sample weight.


6.8 **New domestic water heaters—market share and sales trends**

The data from the on-site data collection was analyzed to develop a better understanding of recent water heater units sales in the C&I sector in Massachusetts. For the MSST Study, the analysis presented focused on sites with water heaters installed between 2009 and 2014. Table 6-7 presents information on the number of on-sites completed, the number of on-sites with at least one new hot water heating system, and the number of on-sites where the manufacturer and model information of at least one of these units was recorded on-site. The data collected, analyzed, and weighted are representative of approximately 100,000 water heaters purchased by Massachusetts businesses from 2009 to 2014.\textsuperscript{117}

\textsuperscript{117} The estimate of 100,000 new water heaters over the 2009-2014 period was developed using respondent weights.
Table 6-7: New water heater on-site survey customer counts by business type and water heater data

<table>
<thead>
<tr>
<th>Building type</th>
<th>On-sites</th>
<th>On-sites with new hot water</th>
<th>On-sites where make and model was collected for the units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Food sales</td>
<td>47</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>29</td>
<td>24</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>23</td>
<td>21</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>31</td>
<td>30</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>24</td>
<td>22</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>272</strong></td>
<td><strong>244</strong></td>
</tr>
</tbody>
</table>

* The results presented above are unweighted.

Figure 6-18 illustrates the system type distribution for new water heaters. These data indicate that similar to the distribution of all units, the large majority of newly purchased water heaters are storage tank water heating units (89% of the existing stock are storage water heaters and 87% of new water heaters are storage). The share of instantaneous units is also similar across existing and new, with 5% of existing water heating units and 4% of new. Heat pump water heaters make up 6% of new water heaters, an increase from the 2% share they represent in the existing stock. Given that heat pumps make up such a small share of existing and new water heaters, it is not clear if the increasing share from existing to new represents a change in the market’s direction or may be influenced by the smaller sample size (n=1,925 for all existing stock and n=529 for recent purchases).
Figure 6-18: New water heater system type distribution

Table 6-8 presents information on the distribution of new units included in the efficiency analyses (column 2), the percent of units in each type category that are new (column 3), and the percent of units in each type category that were purchased prior to 2009 (column 4). Note that column 2 adds up to 100% by construction; it illustrates how the new units included in the efficiency analysis are distributed across the analyzed water heater types. Column 3 also adds up to 100%, but this is by accident; it illustrates the share of all units within a given type that are new. Within a given type of water heater, column 3 and column 4 add up to 100% by construction. The data in Table 6-8 do not include the central plant or shared services or water heaters that do not have applicable federal efficiency standards.\footnote{118}

The data in Table 6-8 indicate that the majority of new units analyzed in the efficiency analysis are residential-grade (42%) and commercial-grade (33%) gas units. The new residential-grade electric units represent only 24% of all new water heating units included in the efficiency analysis. Residential gas instantaneous units represent a very small share of new purchases (1%).

\footnote{118 New units that do not have federal efficiency standards are included in the estimate of the count of new units, the count of observed units found during the on-site data collection (see Table 6-7), and the disaggregation of units by type of system (Figure 6-18). They are not included in the efficiency analysis because they do not have a federal efficiency standard.}
Turning to the data in columns 3 and 4, new commercial and residential gas water heating units are approximately one-third of commercial and gas units; two-thirds were purchased prior to 2009. In comparison, only about 20% of residential electric units are new; 80% were purchased prior to 2009. The Massachusetts TRM lists the EUL for a tank water heater as 7 years. While finding that approximately 33% of units are replaced over a 6-year time horizon is reasonably consistent with a 7-year EUL, finding that only 20% of electric systems are new is surprising.

The data in Table 6-8 prompt the question, “Why do gas water heaters appear to be replaced more frequently than electric water heaters?” Potential answers include the following:

- Electric water heaters may last longer than gas water heaters.
- Gas water heaters may be used in businesses with more water use, leading to more water heater turnover.
- PA-sponsored programs provide incentives for gas water heaters, and these incentives may encourage customers to replace their gas water heaters prior to failure (PA-sponsored programs do not appear to provide incentives for electric water heaters).
- The PA-sponsored gas water heater incentives may encourage customers to switch from electric tank water heaters to gas tank water heaters.
- Customers may be replacing their electric water heater with an electric point-of-use water heater of 2-20-gallon capacity. These small-sized point-of-use units are not covered by federal efficiency standards, and are not included in the recent purchase efficiency analysis.

Field data collected during this project are supportive of two of the potential answers listed above. If customers are replacing their existing electric storage water heaters (unit that was larger than 20 gallons) with a POU unit, the data presented in Table 6-8 would make it appear that electric systems are replaced less frequently than gas units. The data collected in this study indicate that the share of electric POU water heaters is increasing. Electric POU water heaters represented 16% of the existing stock (see Figure 6-12) and 24% of recently purchased units (see Figure 6-24). In addition, reviewing the business types with gas and electric storage tank water heaters, a larger share of businesses in lodging, food service, hospitals, education and warehouses have gas water heaters than electric water heaters. For other business types, including retail, public assembly, offices, manufacturing and food sales, businesses have a larger share of electric water heaters than gas. The business types with a larger share of gas water heaters are also the business types likely to have higher hot water usage. These two findings help to explain why gas storage water heaters may be, or appear to be, replaced more frequently than electric storage water heaters (see Table 6-8).

Table 6-8: Distribution of new water heater units by efficiency categories

<table>
<thead>
<tr>
<th>System type</th>
<th>Distribution of new units</th>
<th>Percent of all units that are New</th>
<th>Percent of all units that are Purchased prior to 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial gas units(^{119})</td>
<td>33%</td>
<td>35%</td>
<td>65%</td>
</tr>
</tbody>
</table>

\(^{119}\) Commercial water heater types include, Gas storage, electric storage, propane storage, gas instantaneous, electric instantaneous, and boilers with indirect storage tanks.
### 6.9 Efficiency distribution for new storage tank and instantaneous water heaters—market share and sales trends

Efficiency data were analyzed separately for new storage tank and instantaneous water heaters, and compared to information on federal water heater standards (see Table 6-6). The data presented in Figure 6-19 indicate that for units for which efficiency data was found, almost no water heater units had efficiency below standards. This finding was anticipated due to the extended history of the current standards, and the finding supports the conclusion that older water heaters were not misidentified as newer units.

Similar to the distribution of all units, residential gas instantaneous water heaters made up the highest percentage of new units exceeding efficiency standards, but only account for 1% of the new units. The data in Figure 6-19 indicate that the majority of water heaters recently purchased by Massachusetts businesses meet standards. Since the water heater standards used for this analysis were implemented in 2003 and 2004, 11 to 15 years prior to data collection, the relatively small share of water heater purchases above standards may indicate that there is little market knowledge of the availability or benefits of higher-efficiency options, or that the costs of units above standard efficiency outweighs the benefit to the consumer.

Eighty-five percent of new commercial gas water heaters are at standards and 12% of new commercial gas water heaters are above standards. New residential gas storage units are mostly found at standards. Almost all new water heater units are found to be either at or above standards, except for less than 1% of the residential gas storage units.

<table>
<thead>
<tr>
<th></th>
<th>42%</th>
<th>33%</th>
<th>67%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential gas storage units</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential gas instantaneous units</td>
<td>1%</td>
<td>14%</td>
<td>86%</td>
</tr>
<tr>
<td>Residential electric storage units</td>
<td>24%</td>
<td>18%</td>
<td>82%</td>
</tr>
</tbody>
</table>

* The results are weighted using the respondent-level sample weight.

** These data represent 139 new commercial gas water heaters, 42 new residential gas storage water heaters, 117 new residential electric storage water heaters, and 35 new residential gas instantaneous water heaters.
Water heating units were also grouped according to system types to demonstrate the range of efficiencies by water heating technology. These are presented in Figure 6-20 through Figure 6-23.

The efficiency distribution of new commercial gas water heaters is similar to the distribution of all commercial gas water heaters in Massachusetts businesses. The majority (86%) of these new commercial gas units was found to be in the 80% to 84% range, with 85% meeting the federal thermal efficiency standard of 80%, and 12% exceeding the standards. The next largest share of units exceeding standards was the 7% of units between 95% and 99% efficiency. In 2013, the PA-sponsored program provided incentives for commercial gas water heaters with a thermal efficiency of 95% or higher.

All new commercial gas units either met or exceeded federal efficiency standards. Referring back to the analysis of all existing commercial gas water heaters, 54% of the existing stock of water heaters were at federal standards, 18% was above standards (and 10 percentage points of these 18% were 95-99% efficient or met the PA-sponsored program requirements), <1% was below standards, and 28% could not be identified (Section 6.5). The lack of growth in the share of high-efficiency commercial gas water heating equipment when comparing the existing stock to new purchases may indicate that consumers and vendors need to be made more aware of the high-efficiency water heater alternatives and benefits.
Figure 6-20: New water heater efficiency distribution for commercial gas water heaters

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 139 total commercial gas water heaters.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 1% of systems with an efficiency between 75% to 79%, 89% of systems with an efficiency between 80% to 84%, and 2% of systems with an efficiency between 90% to 94%, and 8% of systems with an efficiency between 95% to 99%.

New commercial gas water heater efficiencies were also grouped by year buckets, those purchased between 2009-2011 and those purchased between 2012-2014 (See Table 6-9). Almost all of the units purchased during the later time frame were found to have a thermal efficiency between 80% and 84%. For units purchased between 2009-2011, a large portion (23%) of systems were purchased with a thermal efficiency between 95% and 99%, making them units that would have been eligible for a PA-sponsored program incentive according to 2013 requirements. The field data collection found few new units purchased from 2012-2014 that met the PA-sponsored program eligibility requirements.
Table 6-9: New water heater efficiency distribution grouped by year for commercial gas water heaters

<table>
<thead>
<tr>
<th>Efficiency bucket</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>75% to 79%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>80% to 84%</td>
<td>61%</td>
<td>97%</td>
</tr>
<tr>
<td>85% to 89%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>90% to 94%</td>
<td>6%</td>
<td>0%</td>
</tr>
<tr>
<td>95% to 99%</td>
<td>23%</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown - model missing</td>
<td>2%</td>
<td>0%</td>
</tr>
<tr>
<td>Unknown - model not found</td>
<td>9%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>46</strong></td>
<td><strong>70</strong></td>
</tr>
</tbody>
</table>

* The results are weighted using the respondent-level sample weight.

Almost all of the new residential gas storage water heaters had an energy factor between 55% and 59% (see Figure 6-21). The federal energy factor standards for these units were calculated as a function of tank capacity, and range between 48% and 63.2%. In 2013, PA-sponsored programs required an energy factor of 67% for a PA-sponsored program incentive. When comparing newly purchased residential gas storage water heater units to the standards, 88% of newly purchased unit met current federal standards, 12% exceeded the federal standards, less than 1% of new residential gas storage units were below standards, and less than 1% of the units had missing make and model information.

The efficiency distribution of new residential gas storage units can also be compared with all existing residential gas storage units in Massachusetts businesses. Figure 6-7 presents data supporting the finding that 73% of the existing stock of residential gas storage water heaters in Massachusetts businesses were at the 2004 standard, less than 1% were below standards, 5% were above, and 21% of these units had missing make and model information. Comparing the data on new purchases (in Figure 6-21) with the data on the existing stock of residential grade gas water heaters in Figure 6-7, there has been very limited, if any, growth in the share of residential gas storage water heaters above federal standard water heaters.
Figure 6-21: New water heater efficiency distribution for residential gas storage water heaters

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 42 total residential gas storage water heaters.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 90% of systems with an efficiency between 55% to 59% and 10% of systems with an efficiency Greater than 59%.

**** New residential gas storage water heaters have not been presented by efficiency and purchase year ranges due to a lack of sample size.

As shown in Figure 6-22, 64% of new residential electric storage water heaters had an energy factor between 90% and 94%. The federal energy factor standards for these units were calculated as a function of tank capacity and ranges between 81.16% and 94.36%. The data indicate that 57% of new residential-sized electric water heater units in Massachusetts businesses met the federal standards, 29% were above standards, and 14% had undefined efficiencies, as shown in Figure 6-19. Within the existing stock of residential-sized electric water heaters, 28% met the efficiency standards, 21% exceeded the standards, 16% were below the standards, and 35% had undefined efficiencies. For storage tank units, residential electric units showed the largest increase in high-efficiency share between new and existing units.
Figure 6-22: New water heater efficiency distribution for residential electric storage water heaters

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 117 total residential electric storage water heaters.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 21% of systems with an efficiency between 85% to 89%, 74% of systems with an efficiency between 90% to 94%, and 5% of systems with an efficiency between 95% and 99%.

New residential electric storage water heater efficiencies were also grouped by year of purchase, those purchased between 2009-2011 and those purchased between 2012-2014 (see Table 6-10). The majority of units purchased between 2009-2011 were found to have an energy factor between 90%-94%, making most of these units at federal energy efficiency standards. For units purchased from 2012-2014, a larger share was purchased with an energy factor at 95% and higher, indicating that the share of higher-efficiency units may be rising.
Table 6-10: New water heater efficiency distribution grouped by year for residential electric storage water heaters

<table>
<thead>
<tr>
<th>Efficiency bucket</th>
<th>2009-2011</th>
<th>2012-2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>85% to 89%</td>
<td>5%</td>
<td>22%</td>
</tr>
<tr>
<td>90% to 94%</td>
<td>93%</td>
<td>34%</td>
</tr>
<tr>
<td>95% to 99%</td>
<td>0%</td>
<td>12%</td>
</tr>
<tr>
<td>Unknown - model missing</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>Unknown - model not found</td>
<td>2%</td>
<td>31%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>38</strong></td>
</tr>
</tbody>
</table>

* The results are weighted using the respondent-level sample weight.

New residential gas instantaneous water heaters, illustrated in Figure 6-23, are largely found to have energy factors between 95% and 99%. Although instantaneous water heaters often have no storage tank, the instantaneous water heater federal standards are applicable to units that have up to a 2-gallon tank. The federal standards for these units were based on an energy factor of approximately 62%. All of these new units where the efficiency was verified were found to be above federal standards. The 2013 PA-sponsored program requirements were an energy factor of 82% for a Tier 1 incentive and 94% for a Tier 2 incentive. Nearly all of the new gas instantaneous water heaters with verified efficiency information exceeded the Tier 2 incentive criteria. The findings for new residential gas instantaneous hot water heaters contrast with the findings for the existing stock of these units, for which 44% of the units were above federal standards and only 13% had an energy factor of 95% or above. The share of new and existing residential gas instantaneous water heaters is extremely small in Massachusetts businesses.
Figure 6-23: New water heater efficiency distribution for residential gas instantaneous water heaters

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 35 total residential gas instantaneous water heaters.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 100% of the systems between 95%-99% efficiency.

**** New Residential Gas Instantaneous water heaters have not been presented by efficiency and purchase year ranges due to a lack of sample size.

When combining the new storage and instantaneous units, the largest share (41%) of units met current federal efficiency standards. Thirty-seven percent of all new units were not governed by any efficiency standards, with this split out into 24% residential electric units, 3% commercial electric units, and 10% some other system type. Less than 1% of new units were found to be below the standards. Nine percent of new water heating units in Massachusetts businesses were above the standards put in place in 2003 and 2004, 5 to 11 years prior to the recent purchase analysis period (2009-2015).
Figure 6-24: New water heater efficiency distribution for storage and instantaneous water heaters

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 529 units.

*** If the systems with unknown efficiencies were reallocated proportional to observed efficiencies, the distribution would show 10% above standards, 48% at standards, <0.1% below standards, 10% no standards (other), 3% no standards (commercial electric), and 28% no standards (residential electric).

Figure 6-25 illustrates the efficiency distribution of new water heaters for PA-sponsored energy efficiency program participants versus non-participants. The distribution of these systems has reallocated the share of systems where the efficiencies were unknown, assuming that for new purchases, the unknown system efficiencies have the same distribution as the known efficiencies. Program participants were more likely to install equipment that met or exceeded efficiency standards (76% of program participants versus 55% of program non-participants). For non-participants, 45% met the efficiency standards. As with the existing stock analysis, in the comparison of efficiency levels for program participants and non-participants, participants in Massachusetts PA-sponsored programs may have participated in any type of PA-sponsored
program from 2011 to 2014. Participation does not imply that the customer received a rebate for a water heating unit.

**Figure 6-25: New water heater efficiency distribution of participants versus non-participants**

* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 240 participant units and 289 non-participant units.

Figure 6-26 illustrates the efficiency distribution of new electric and gas water heaters. The distribution of these systems has reallocated the share of systems where the efficiencies were unknown, assuming that for new purchases, the unknown system efficiencies have the same distribution as the known efficiencies. The highest share of the electric distribution was the “no standards” category, at 75% of newly purchased units. These units with “no standards” were broken out into 55% residential electric units, 6% commercial electric units, and 14% other. The current standards in place for commercial-sized electric tank units only regulate the maximum standby loss and not the system efficiency. The current federal standards for electric residential units do not include units with a tank capacity between 2 and 20 gallons. These units are commonly referred to as point-of-use water heaters. Point-of-use water heaters are often placed near the point of hot water use, reducing the water and heat loss associated with a larger storage system located far from where the water is used. All new electric water heaters either met or were above standards. Only 9% of new electric and gas water heaters purchased by Massachusetts businesses were above standards.
The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

These data represent 198 new electric units and 321 new gas units.

Figure 6-27 represents the efficiency of recently purchased water heating equipment at commercial establishments by kWh range of the business. Businesses with annual energy consumption above 4,500,000 kWh have the greatest share of above standards equipment while customers with less than 500,000 kWh appear to be more likely to purchase water heating units at federal standards. Businesses with more than 500,000 kWh were also more likely to purchase commercial electric water heaters without standards while smaller businesses were more likely to purchase residential point-of-use electric water heaters that do not have federal efficiency standards.
* The results are weighted using the respondent-level sample weight. These data are for water heaters purchased from 2009-2014.

** These data represent 226 units for <500,000 kWh, 704 units for 500,000-4,500,000 kWh, and 128 units for >4,500,000.
7 REFRIGERATION

Refrigeration systems represent a significant source of energy usage within the Massachusetts C&I sector. For certain commercial segments, refrigeration usage accounts for a significantly higher share of usage than for the average commercial business. This is generally the case within the food sales, refrigerated warehouses, and food service industries. The information collected on the distribution, quantity of refrigeration systems, types of technologies, and EE practices will help the PAs and EEAC Consultants better understand how energy usage is linked to existing refrigeration equipment, and how programs can be improved to help reduce refrigeration energy usage.

7.1 Refrigeration findings

The research team identified several important refrigeration findings during their analysis:

- Three business segments account for 78% of the linear feet of refrigeration cases. Food sales and food services each account for 28% of the linear feet, and retail has 22% of the linear feet of refrigerated cases.
- The recent rise of grocery offerings at retail stores has increased the linear feet of refrigeration in the retail segment. PA-sponsored energy efficiency programs need to ensure that the refrigeration end use is targeted and marketed in retail segments.
- Care must be taken when designing PA-sponsored EE programs for the 3 segments with the largest share of linear feet of refrigerated cases, as the distribution of case type varies substantially across these 3 segments. Upright reach-in cases account for 55% of linear refrigerated case feet in food sales, but only 39% in food services and 34% in retail. Food service has a 33% share of linear refrigerated case feet in under-the-counter reach-in cases and retail has a 30% share in open display cases (see Figure 7-6).
- Given the substantial share of refrigeration found in Retail segments, (22% of linear feet, see Figure 7-5), T12 lamps in refrigerated cases in retail may represent an EE opportunity. With T12s generally prohibited under EISA, the need to replace these lamps on burnout provides an opportunity for programs to encourage these businesses to retrofit to high-efficiency LED refrigerated case lighting instead of choosing a base efficiency fluorescent option.
- When looking at both walk-ins and refrigerated cases, incandescent bulbs were found to have an incidence over 50% across 3 building types, and at least a 25% incidence in 7 building types. This represents a significant EE opportunity, especially in the manufacturing and industrial sectors, and the education segments for both cases and walk-ins. Replacing inefficient lighting in refrigerated cases and walk-ins with LED technologies can reduce usage associated with lighting and refrigeration.

7.2 Refrigeration data

Table 7-1 presents information on the total number of on-sites completed and the number of on-sites where refrigeration data were collected. The data indicates that refrigeration was present in 100% of the food sales and food service businesses visited, but only 69% of the campus sites visited. The final column provides information on the share of all sites with refrigeration. These data imply that education sites, for example, account for 11% of the total share of refrigeration equipment observed.
Table 7-1. On-site survey customer counts by business type and refrigeration data

<table>
<thead>
<tr>
<th>Building type</th>
<th>On-sites</th>
<th>Counts of sites with refrigeration**</th>
<th>Share of sites with refrigeration by business type</th>
<th>Share of all sites with refrigeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>24</td>
<td>69%</td>
<td>4%</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>70</td>
<td>89%</td>
<td>11%</td>
</tr>
<tr>
<td>Food sales</td>
<td>47</td>
<td>47</td>
<td>100%</td>
<td>7%</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>63</td>
<td>100%</td>
<td>10%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>55</td>
<td>89%</td>
<td>8%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>18</td>
<td>90%</td>
<td>3%</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>55</td>
<td>92%</td>
<td>8%</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>59</td>
<td>71%</td>
<td>9%</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>82</td>
<td>70%</td>
<td>13%</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>41</td>
<td>69%</td>
<td>6%</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>60</td>
<td>82%</td>
<td>9%</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>55</td>
<td>76%</td>
<td>8%</td>
</tr>
<tr>
<td>Warehouses</td>
<td>30</td>
<td>19</td>
<td>63%</td>
<td>3%</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>648</td>
<td>81%</td>
<td>100%</td>
</tr>
</tbody>
</table>

* The results presented above are unweighted.

**The counts indicate the number of instances the technology was found in the buildings that were visited.

7.3 Refrigeration equipment

For this study, refrigeration systems were categorized into remote refrigeration systems and self-contained refrigeration. Remote refrigeration systems are systems in which the compressor and condenser are located outside the refrigeration unit itself. This includes systems that have a single compressor/condenser serving the individual unit itself, as well as central rack systems that serve multiple refrigeration units. Self-contained refrigeration refers to units where all refrigeration components are housed within the unit itself. Systems where this information was not gathered are described as unknown.
Figure 7-1 presents the share of businesses (kWh-weighted) with the different types of refrigeration systems. Note that remote refrigeration systems are concentrated in food sales, food services, and hospitals.\textsuperscript{120} While self-contained refrigeration systems are more common and are found in all business segments, the highest percentages are in food services, food sales, education, and campuses.

**Figure 7-1. Percent of businesses with refrigeration by type of refrigeration**

![Figure 7-1. Percent of businesses with refrigeration by type of refrigeration](image)

**7.4 Refrigerated cases**

During the on-site surveys, we collected information on many different types of cases, for both remote refrigeration and self-contained refrigeration case types.

Figure 7-2 illustrates the distribution of total linear feet of cases using highly disaggregated case descriptions. Reach-in multi-deck cases represent 47% of the linear feet of refrigerated cases, while under-the-counter reach-in cases have 19% of the linear feet of cases (the second highest share).

\textsuperscript{120} The information in Figure 7-1 presents the share of business kWh with a specific type of refrigeration. Later results will indicate that while few warehouses have remote refrigeration, warehouse RR systems are very large.
**Figure 7-2. Distribution of total linear feet of cases**

- Island, open, single-level narrow
- Island, open, single-level wide
- Island, open, island, single-level double
- Island, closed, single-level narrow
- Island, closed, single-level wide
- Island, closed, single level double
- Open Single-deck
- Open Multi-deck
- Reach-in Multi deck
- Closed rear-entry multi-deck
- Curved glass near entry multi deck
- Under counter Reach-in
- Blast Chiller
- Ice Bag Freezer
- Medical Lab Freezer
- Other

*The results are weighted using the respondent-level sample weight.

** These data represent 4,387 cases across 648 sites with refrigeration.

Table 7-2 provides a mapping of the descriptive on-site case categories to a set of aggregated or simplified case types. In the mapping, the under-the-counter reach-in remains the same while the reach-in multi-deck becomes an up-right reach-in case. For the other categories:

- Island cases are described as stand-alone open-top or glass-top cases that may hold produce, ice cream, deli meat, or cheeses. These may have single or multiple levels, and can be either built-in units or plug-in/moveable.
- Open display cases include open, upright display cases, with either single or multiple decks. These may hold eggs, fresh meat, or cheeses, and are typically situated around the outskirts of an open area.
- Upright reach-in cases are multi-deck systems that are closed-case systems with either glass or metal doors. These may be associated with walk-ins or may be found as commercial-style refrigerators, and can be kept at both freezer and refrigerator temperatures.
- Service cases can be pictured as those located in markets and can be associated with delis or meat counters. These allow for the customer to view the contents from one side, and the employee to access the case from the other side.
• Under-the-counter reach-ins will be about waist-high, and will allow for storage or provide a workspace over the refrigerated space. This may be useful in smaller restaurants or in situations where the additional storage space is necessary.

Table 7-2. Refrigeration survey description and mapping to simplified case type

<table>
<thead>
<tr>
<th>Survey refrigeration description</th>
<th>Simplified case type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Island, open, single-level narrow</td>
<td>Island case</td>
</tr>
<tr>
<td>Island, open, single-level wide</td>
<td>Island case</td>
</tr>
<tr>
<td>Island, open, island, single-level double</td>
<td>Island case</td>
</tr>
<tr>
<td>Island, closed, single-level narrow</td>
<td>Island case</td>
</tr>
<tr>
<td>Island, closed, single-level wide</td>
<td>Island case</td>
</tr>
<tr>
<td>Island, closed, single level double</td>
<td>Island case</td>
</tr>
<tr>
<td>Open single-deck</td>
<td>Open display case</td>
</tr>
<tr>
<td>Open multi-deck</td>
<td>Open display case</td>
</tr>
<tr>
<td>Reach-in multi-deck</td>
<td>Upright Reach-in</td>
</tr>
<tr>
<td>Closed rear-entry multi-deck</td>
<td>Service case</td>
</tr>
<tr>
<td>Curved glass near entry multi deck</td>
<td>Service case</td>
</tr>
<tr>
<td>Under the-counter reach-in</td>
<td>Under Counter reach-In</td>
</tr>
<tr>
<td>Blast chiller</td>
<td>Other/unlisted case</td>
</tr>
<tr>
<td>Ice bag freezer</td>
<td>Other/unlisted case</td>
</tr>
<tr>
<td>Lab-grade case</td>
<td>Other/unlisted case</td>
</tr>
</tbody>
</table>

Figure 7-3 depicts the distribution of total linear feet of cases by the aggregated or simplified case types. Figure 7-4 uses a bar graph to illustrate the same share of linear feet of refrigeration cases shown in Figure 7-3, while adding information on the average linear feet of the different types of refrigerated cases per refrigerated case by case types. The distribution of refrigerated cases illustrated in Figure 7-3 and Figure 7-4 shows that upright reach-in cases account for 47% of the linear feet of refrigeration cases. Upright reach-in cases may dominate the distribution of refrigerated cases because a high share of businesses with refrigeration have this type of case; the average business with this type of case has a substantial share of linear feet of these cases or both.

121 Standard residential style refrigerators are not included in the refrigerated cases analysis.
These data indicate that while the largest share of refrigerated cases in Massachusetts businesses consists of upright reach-in cases, the average length of an upright reach-in is relatively short—approximately 5 feet. In contrast, service cases and other/unlisted cases only account for 5% and 7%, respectively, of linear feet of cases, and their average lengths are over 11 feet.

**Figure 7-3. Distribution of total linear feet of refrigeration cases by simplified case type**

*The results are weighted using the respondent-level sample weight.

** These data represent 4,387 cases across 648 sites with refrigeration.
Figure 7-4. Distribution of the share of total linear feet and the average linear feet of refrigerated cases by case type

*The results are weighted using the respondent-level sample weight.
** These data represent 4,387 cases across 648 sites with refrigeration.

The linear feet of these cases can also be analyzed looking at the average linear feet of a case type per business, rather than the average linear feet per case. If businesses with upright reach-in cases tend to have several cases, even though upright reach-ins are relatively shorter, the average number of linear feet per business could be longer than for service and other/unlisted cases. Analysis of the linear feet of cases per business by case type led to a conclusion similar to those from the per-case analysis. Massachusetts businesses have an average of 6.6 linear feet of upright reach-in cases, 14.1 linear feet of other/unlisted, 14.6 linear feet of open display, and 14.9 linear feet of service cases.

Figure 7-5 illustrates the distribution of linear feet of refrigerated cases by business type. These data indicate that food sales, food service, and retail business segments hold the large majority share of refrigerated case linear feet, at 28%, 27%, and 22%, respectively. Only public assembly business segments hits 10%, while no other business segment breaks 5%.
Reflecting back on the data in Figure 7-1 and Table 7-1, we found that 100% of food sales and food service customers had refrigeration, while a significantly smaller share of retail customers had refrigeration. Traditionally, retail customers have not been a segment with a substantial amount of refrigeration; however, the recent rise in grocery offerings at retail stores has dramatically increased the linear feet of refrigeration in the retail segment. The finding that 22% of the linear feet of refrigerated cases are in retail businesses is due to the relatively large average case length in retail sites. The average case length for retail customers is 9.3 feet, compared to 7.5 feet for food sales.

The recent rise of refrigeration in retail is important for PA-sponsored EE programs, which need to ensure that the retail segment is included in targeting and marketing for refrigeration EE programs.

Figure 7-6 illustrates the distribution of linear feet of refrigerated cases by business type and case type. These data show that upright reach-in cases make up at least 50% of the share of refrigerated linear feet in 8 of the 13 business segments. For all other business types except warehouses, 122 upright reach-in cases

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122 A limited number of cases were found in warehouses (17), which makes it difficult to draw conclusions on the representative distribution.
make up the largest share of refrigerated linear feet. The substantial share of refrigeration represented by upright reach-in cases (47%) is due in large part to their importance in nearly all segments and their importance in the 3 business types with the largest share of refrigeration.

Within the 3 business types with the largest share of linear feet of refrigeration—food sales, food services, and retail—upright reach-ins represent 55% of the linear feet of refrigeration in food sales, 39% in food services, and 34% in retail. For food sales, the second largest share is island cases, at 19%. Under-the-counter reach-ins account for 33% of the linear feet at food service businesses and open display cases represent 30% of the linear feet at retail businesses.

**Figure 7-6. Distribution of linear feet of refrigeration cases by business type and simplified case type**

* The results are weighted using the respondent-level sample weight.

** These data reflect 165 cases at campuses, 230 cases in education sites, 1,181 cases in food sales sites, 412 cases in food service sites, 128 cases in healthcare sites, 53 cases in hospitals, 825 cases in lodging sites, 87 cases in manufacturing or industrial sites, 208 cases in offices, 466 cases in "other" sites, 459 cases in public assembly sites, 156 cases in retail sites, and 17 cases in warehouses.

Figure 7-7 illustrates the distribution of the total linear feet of refrigerated cases by business kWh usage and simplified case type. These data again illustrate that upright reach-in cases account for the largest share of linear feet of refrigeration cases across each business kWh category. Under-the-counter reach-ins represent the second highest share for sites with annual energy consumption of either less than 500,000 kWh or more than 450,000,000 kWh, while open display cases occupy this position in the remaining sites.
The different distribution of cases by customer size relates, at least in part, to the types of businesses commonly found in different kWh usage ranges. Food services tend to be smaller businesses with a relatively larger share of under-the-counter reach-in refrigeration. Food sales and retail are business types that commonly consume between 500,000 and 450,000,000 kWh annually, and substantially influence the distribution of refrigerated case linear feet for this business kWh usage. Here, the largest share of refrigeration (by linear feet) is made up of upright reach-in units; open display and island cases also have a substantial share.

**Figure 7-7: Distribution of linear feet of refrigerated cases by business kWh usage and simplified case type**

![Distribution of linear feet of refrigerated cases by business kWh usage and simplified case type](image)

* The results are weighted using the respondent-level sample weight.

**These data reflect 679 systems in businesses with annual consumption less than 500,000, 2,333 systems in businesses in the 500,000 to 450,000,000 annual consumption range, and 1,369 systems in businesses above 450,000,000 kWh.

Figure 7-8 illustrates the distribution of refrigerated cases by temperature and simplified case type. Cases were disaggregated into low and medium temperature cases. Low temperature cases were associated with temperatures needed for freezing their contents while medium temperature cases were more often associated with refrigeration.
The door type for refrigerated display cases was also collected during the on-site assessments. The distribution of display case door types by business types is shown in Figure 7-9. Out of the 3,688 cases where this information was collected, 48% had metal doors (fully metal doors with no glass) and 40% had double glazed glass doors. Few business types were found to have triple glazed doors outside of food sales (30%), and of those triple glazed doors, 23% were noted to have heater controls.

The two most common types of refrigerated display cases are upright reach-ins and under-the-counter reach-ins. Seventy-five percent of the under-the-counter reach-in units were found to have metal doors, while 37% of upright reach-ins had metal doors. These systems with metal doors are likely to be commercial-grade refrigeration units, typically found in kitchens, rather than the rows of doors found in grocery stores which are typically glass. Metal doors on refrigeration are very uncommon in food sales and only represent 22% of doors in retail. Metal doors are more common in food service, where they represent 47% of the door types. In education, health care, and lodging, metal doors represent more than 90% of the doors on refrigerated cases.

* The results are weighted using the respondent-level sample weight.

**These data reflect 902 low temperature cases and 2,117 medium temperature cases.
**Figure 7-9: Distribution of refrigerated case door types and heater controls by business type**

* The results are weighted using the respondent-level sample weight.

** These data represent 99 single glazed door cases, 917 double glazed door cases, 39 triple glazed with no heater controller door cases, 87 triple glazed with heater controller door cases, 45 triple glazed with no heater door cases, 5 quadruple glazed with no heater controller door cases, 17 quadruple glazed with heater controller door cases, 5 quadruple glazed with no heater door cases, and 2,456 metal door cases.

### 7.5 Walk-in refrigeration

Walk-in coolers and freezers can be either self-contained or supplied by remote refrigeration units. The size and distribution of walk-ins varies substantially by self-contained versus remote, so the statistics are presented separately.

Figure 7-10 illustrates the distribution of self-contained walk-in square footage by business type and the average walk-in square footage for sites with self-contained refrigerated walk-ins by business type. The square footage distribution sums to 100% across all business types.
The data presented in Figure 7-10 indicate that food service businesses have the highest share of total square feet for self-contained refrigerated walk-ins, yet have a much lower than average square footage per walk-in than many other business segments. Self-contained walk-ins in the manufacturing or industrial segment, however, have a high average square footage per walk-in (435 ft²), but the total percentage of walk-in square footage of the segment is small, making up only 6% of the total walk-in square footage share. These findings imply that there are few self-contained walk-ins found in the manufacturing or industrial segments, but where these walk-ins are found, they are large.

**Figure 7-10: Self-contained walk-ins square footage percent by business type and average walk-in square feet**

![Figure 7-10: Self-contained walk-ins square footage percent by business type and average walk-in square feet](image)

* The results are weighted using the respondent-level sample weight.
** These data represent 183 self-contained walk-ins.

Figure 7-11 illustrates the distribution of remote walk-in refrigeration square footage by business type, and the average walk-in square footage for facilities with remote refrigeration walk-ins by business type. The square footage distribution sums to 100% across all business types. These numbers indicate that retail and food sales businesses have the highest share of the square footage of remote refrigeration walk-ins with retail businesses, accounting for over 30% of retail and 22% of food sales remote refrigeration walk-in square footage. The average square footage per walk-in in retail and food sales, however, is not large,
averaging 305 and 289 square feet, respectively. Warehouses have a very high average square footage, just over 10,000, but make up just 4% of the total square footage.

**Figure 7-11: Remote refrigeration walk-ins square footage percent by business type and average walk-in square feet**

* The results are weighted using the respondent-level sample weight.

** These data represent 887 remote refrigeration walk-ins.

### 7.6 Refrigeration lighting

Data concerning the incidence of lighting in refrigerated display cases and walk-ins were collected by equipment type, to understand the primary lighting type for each type of display case. The refrigeration lighting information was not collected on a per-bulb or length basis.
Figure 7-12 illustrates the distribution of the incidence of different types of refrigeration lighting by business type. While the incidence of types of lighting differed substantially by business type, T8 lighting has the highest incidence, followed by incandescent and LED bulbs for refrigerated display cases.
Figure 7-12 illustrates that T8s were found in approximately 50% of refrigeration cases on campuses and in warehouses, and in 41% of refrigerated cases in food sales businesses. Incandescent bulbs were found in 59% of healthcare, 57% in education, and 48% in warehouse refrigeration cases. T12 lighting was found infrequently except in retail (43% of cases), other (26%), and hospitals (16%). Given the substantial share of refrigeration found in retail (22% of linear feet, see Figure 7-5), the incidence of T12 lamps in refrigerated cases in retail may represent an EE opportunity. With T12s generally prohibited under EISA, the need to replace these lamps on burnout provides an opportunity for programs to encourage these businesses to retrofit to high-efficiency refrigerated case lighting instead of choosing a base efficiency option.

LED refrigeration lighting is a high-efficiency option. Forty one percent of refrigerated cases on campuses were found to have LED lighting, followed by 30% in food sales and services businesses. Only 14% of refrigerated cases in retail were found to use LED lighting.\textsuperscript{123}

\textsuperscript{123} It should be noted that LEDs may not be feasible for some applications due to temperature performance related issues.
Figure 7-12: Simplified display cases – incidence of lighting types by business type

For walk-ins, incandescent bulbs had an incidence of over 50% in education and manufacturing/industrial, and over 25% in other, office, and healthcare walk-ins. Although CFLs are uncommon in display cases, CFLs represent the largest incidence of lighting in walk-ins for a number of business segments including campuses, food service, healthcare, offices, and warehouses. LED lighting technologies made up over 20% of the refrigeration walk-in lighting in several sectors including campuses, education, food sales, hospitals, lodging, public assembly, retail, and warehouses. Replacing lighting in refrigerated walk-ins with LED technologies may provide a PA-sponsored program opportunity for EE. More of the energy LED lighting uses produces light rather than heat, which reduces the amount of heat bi-product associated with less efficient lighting. If the lights in refrigerated walk-ins are left on for any length of time, the energy wasted by inefficient lighting impacts not only lighting usage but also refrigeration usage. LEDs in refrigerated walk-ins provide an opportunity to save on lighting as well as on refrigeration energy usage.
Retail businesses had the largest incidence of T12 lighting in walk-ins of all business segments in Massachusetts. The large share of walk-ins with T12 lighting in retail is consistent with the higher share of T12 lighting in retail cases illustrated in
Figure 7-12. The retail segment contains 22% of the case refrigeration linear feet (see Figure 7-5) and approximately 30% of the remote refrigeration walk-ins. The substantial incidence of refrigeration in retail highlights the opportunity to improve the efficiency of lighting in this segment.

Figure 7-13: Walk-Ins—incidence of lighting types by business type

*The results are weighted using the kWh-level sample weight.

** The lamp quantity was not collected, so these data represent the incidence of different lighting types in the businesses.
8 ON-SITE GENERATION AND RENEWABLE THERMAL SYSTEMS

During the C&I On-site Assessments, field staff collected information on the on-site generation equipment in use at Massachusetts C&I facilities. Table 8-1 lists the number of sites from the on-site data collection effort with on-site generation systems. The on-site generation was characterized as backup or emergency generation, renewable/self-generation, and co-generation (combined heat and power, CHP). There is also a fourth category we include here we classify as renewable thermal systems. This includes solar thermal, geothermal heat pumps, and biomass boilers that were noted during field data collection.

8.1 On-site generation findings

The analysis of the on-site generation data led to several high level findings:

- For campuses, education, healthcare, hospitals, lodging, and offices in Massachusetts on-site generation is fairly common. The largest share of on-site generation is for backup or emergency generation and the business types where generation is most common likely represent segments where emergency generation is frequently required by regulation.
- Backup and emergency generation is fueled 65% of the time by diesel and natural gas has a 28% share. Given that natural gas supplies can be interrupted during emergencies, generation fueled by diesel may provide a more reliable form of backup power generation.
- Internal combustion engines (ICE) account for 95% of the backup or emergency generation in Massachusetts businesses. ICE represent a well understood technology both from an engineering and maintenance perspective and provide a good backup source of power during emergencies.
- Solar accounts for 99% of the renewable generation at Massachusetts businesses.
- In Massachusetts businesses, the average size of renewable generation is 101 kW, backup or emergency generation average capacity is 129 kW and the average capacity for cogeneration is 458 kW.

The following sections provide additional information and details about the on-site generation in Massachusetts businesses.

8.2 On-site generation data

The data indicate that the largest share of on-site generation equipment was for backup or emergency generation purposes. The final column lists the number of sites with on-site generation. The sum of the previous four columns is larger than the final column because some sites have more than one type of on-site generation system. Comparing the number of sites with data collection, the number of sites with on-site generation appears to be more common at campuses, education, healthcare, hospitals, lodging, and offices. Many of the sites with on-site generation may have regulations mandating some form of emergency backup generation.

Table 8-1. Count of sites with on-site generation

<table>
<thead>
<tr>
<th>Building type</th>
<th>Total number of on-sites</th>
<th>Counts of emergency/backup generation sites</th>
<th>Counts of renewable/self-generation sites</th>
<th>Counts of cogeneration sites</th>
<th>Counts of renewable thermal systems sites</th>
<th>Counts of sites with any on-site generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campuses</td>
<td>35</td>
<td>19</td>
<td>5</td>
<td>3</td>
<td>0</td>
<td>23</td>
</tr>
<tr>
<td>Building type</td>
<td>Total number of on-sites</td>
<td>Counts of emergency / backup generation sites</td>
<td>Counts of renewable / self-generation sites</td>
<td>Counts of co-generation sites</td>
<td>Counts of renewable thermal systems sites</td>
<td>Counts of sites with any on-site generation</td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Education</td>
<td>79</td>
<td>46</td>
<td>13</td>
<td>3</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>Food sales</td>
<td>47</td>
<td>13</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Food service</td>
<td>63</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Healthcare</td>
<td>62</td>
<td>37</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>37</td>
</tr>
<tr>
<td>Hospitals</td>
<td>20</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>19</td>
</tr>
<tr>
<td>Lodging</td>
<td>60</td>
<td>27</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>31</td>
</tr>
<tr>
<td>Manufacturing or industrial</td>
<td>83</td>
<td>31</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>Office</td>
<td>117</td>
<td>59</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>62</td>
</tr>
<tr>
<td>Other</td>
<td>59</td>
<td>25</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>Public assembly</td>
<td>73</td>
<td>21</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Retail</td>
<td>72</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>800</strong></td>
<td><strong>313</strong></td>
<td><strong>42</strong></td>
<td><strong>16</strong></td>
<td><strong>7</strong></td>
<td><strong>340</strong></td>
</tr>
</tbody>
</table>

* The results presented above are un-weighted.

**The counts indicate the number sites where the technology was found. It is possible that a site may have multiple system types, or multiple systems of the same type.

### 8.3 Backup or emergency generation

Backup or emergency generation consists of systems that can be fueled by natural gas, bio gas, diesel, fuel oil, gasoline, propane, or a combination of fuels. Table 8-2 lists both the un-weighted number of systems observed onsite and the kWh-weighted share of systems by fuel type. Gasoline, biogas, propane, and mixtures of biogas and natural gas are grouped together as “other.” The kWh-weighted results indicate that the largest share (65%) of emergency or backup systems at Massachusetts businesses are fueled by diesel and the second largest share (28%) are fueled by natural gas.
Table 8-2. Fuel types for emergency and back-up generation

<table>
<thead>
<tr>
<th>Fuel types</th>
<th>Number of systems observed on-site</th>
<th>kWh-weighted share of systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>107</td>
<td>28%</td>
</tr>
<tr>
<td>Diesel</td>
<td>312</td>
<td>65%</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>17</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>19</td>
<td>3%</td>
</tr>
<tr>
<td>Unknown</td>
<td>3</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>458</td>
<td>100%</td>
</tr>
</tbody>
</table>

*The results are weighted using the kWh-level sample weight.

The fuel type for emergency and backup generation systems were also analyzed by business kWh size, and weighted by the respondent-level sample weight, shown in Table 8-3. Diesel fuel generation made up the largest share of the systems in businesses with annual energy consumption of 500,000 kWh or higher. In businesses whose annual energy consumption was below 500,000 kWh, the weighted share was dominated by the “other” fuel type, often propane. This was due to several of these sites with “other” fuels having a very large respondent weight. Drawing conclusions from the small sample of sites with backup or emergency generation and annual consumption less than 500,000 should be done with care, given the small sample size the group when it is divided across the various fuels.
Table 8-3. Fuel types for emergency and back-up generation by business kWh usage

<table>
<thead>
<tr>
<th>Business kWh usage</th>
<th>Fuel types</th>
<th>Number of systems observed onsite</th>
<th>Respondent-weighted share of systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 4,500,000 kWh</td>
<td>Natural gas</td>
<td>17</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>104</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>Fuel oil</td>
<td>3</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>2</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>126</strong></td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td>500,000 to 4,500,000 kWh</td>
<td>Natural gas</td>
<td>74</td>
<td>24%</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>138</td>
<td>72%</td>
</tr>
<tr>
<td></td>
<td>Fuel oil</td>
<td>10</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>7</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>1</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>230</strong></td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td>Less than 500,000 kWh</td>
<td>Natural gas</td>
<td>11</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
<td>12</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Fuel oil</td>
<td>1</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>8</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>32</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results are weighted using the respondent-level sample weight.

The overwhelming majority of sites with emergency and backup systems had internal combustion engines. These accounted for 95% of the population, using a kWh-level sample weight. A small percentage of backup systems were gas turbines (5%) and unknown system types (< 1%). No micro-turbines were identified in the surveyed facilities. Figure 8-1 shows that although gas turbines only make up a small percentage of the emergency and backup systems, they are most commonly found in facilities with annual energy consumption between 500,000 kWh and 4,500,000 kWh.

124 The classification of equipment into gas turbines and micro-turbines was based on the field data collected during the on-site survey and specific manufacturer definition of equipment.
Figure 8-1: Emergency and backup generation type by annual electricity usage

*The results are weighted using the kWh-level sample weight.

** These data represent 292 sites with Internal combustion engines, 22 sites with gas turbines, and 2 sites with unknown systems.

8.4 Renewable energy

The C&I Customer On-site Assessments combined on-site generation that was not used for backup or emergency generation and generation that was not CHP, into renewable energy. The types of renewable energy systems found during the on-site data collection are listed in Table 8-4. No fuel cell systems were identified in the sample.

Table 8-4: Sites with renewable and self-generation systems

<table>
<thead>
<tr>
<th>System types</th>
<th>Number of sites</th>
<th>Share of sites*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Array/PV</td>
<td>41</td>
<td>98%</td>
</tr>
<tr>
<td>Wind</td>
<td>1</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>43</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

*The results are weighted using the kWh-level sample weight.
8.5 Cogeneration

There were 16 combined heat and power facilities identified during the C&I Customer On-site Assessments. When weighted by kWh consumption, sites with natural gas and systems fueled by steam each made up 62% of the overall distribution. These findings are identified below in Table 8-5.

Table 8-5. Sites with cogeneration systems

<table>
<thead>
<tr>
<th>System Types</th>
<th>Number of Sites</th>
<th>Share of Sites*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>13</td>
<td>62%</td>
</tr>
<tr>
<td>Other[1]</td>
<td>2</td>
<td>23%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

[1] One system was determined to be fueled by biofuels, and the other fuel type was undetermined.

*The results are weighted using the kWh-level sample weight.

8.6 Generation capacity

We examined on-site generation by type and capacity as shown in Figure 8-2. The majority of sites with renewable energy systems had a total capacity less than 50 kW. Sites with backup and emergency generators also saw a large share (39%) of the systems less than 50 kW capacity while cogeneration sites generally had a total capacity between 50 to 99 kW. The overall average capacity of 458 kW for sites with cogeneration systems was higher than the average capacity of other on-site systems (except non-power systems). The overall average capacity for sites with backup/emergency systems was around 129 kW, while sites with renewable energy had much smaller capacity, with an average of just under 101 kW.

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125 Generation capacity was captured in units of kW, kBtuh, or Amps. These were converted to kW. For units reported in amps, the research team assumed a system voltage of 460V to convert to kW. For the systems where a capacity was reported but no units, the research team assumed units of kW.
Figure 8-2. On-site generation system type by system capacity

* Both the distribution of system capacity bucket and the average site capacity are weighted using the respondent-level sample weight.

** These data represent 29 sites with renewable energy systems, 248 sites with backup/emergency generator systems, 14 sites with cogeneration systems, and 2 sites with non-power systems.

***Non-power systems refer to those on-site generation sources that do not generate electricity (e.g. solar thermal, biomass, etc.).

The average generation capacity of the systems observed on-site were also analyzed by business consumption size (Table 8-6). Businesses with annual energy consumption greater than 4,500,000 kWh were found to have an average generation capacity of 876 kW for renewable systems and 1,485 kW for emergency backup generators. Cogeneration systems however were much smaller, at 180 kW. Businesses with annual energy consumption of less than 500,000 kWh saw an average generation capacity of 20 kW, 47 kW, and 70 kW for renewable systems, backup/emergency generators, and cogeneration systems respectively.

The number of systems observed in the different business kWh categories and generation type categories is also listed in Table 8-6. The sample sizes for some of these domains is small and their average capacities should not be viewed as representative of the market overall. These data, however, do support the conclusion that larger businesses generally install generation systems with larger capacity. These data also indicate that backup/emergency generators are generally larger than cogeneration and renewable systems.
for a similarly sized customers. Across all systems, renewable systems had an average capacity of 101 kW, 129 kW for backup/emergency generators, and 101 kW for cogeneration systems. While not conclusive, these finding should be considered for further investigation, particularly in light of the Commonwealth’s interest in battery storage systems and the potential use of this equipment for demand response.

### Table 8-6. Average generation capacity in kW by kWh usage

<table>
<thead>
<tr>
<th>Business kWh usage</th>
<th>Renewable energy</th>
<th>Backup/emergency generators</th>
<th>Cogeneration systems</th>
<th>Renewable thermal systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater than 4,500,000 kWh</td>
<td>876 (5)</td>
<td>1,485 (64)</td>
<td>180 (2)</td>
<td>501 (2)</td>
</tr>
<tr>
<td>500,000 to 4,500,000 kWh</td>
<td>142 (20)</td>
<td>316 (165)</td>
<td>148 (10)</td>
<td>-</td>
</tr>
<tr>
<td>Less than 500,000 kWh</td>
<td>20 (4)</td>
<td>47 (19)</td>
<td>70 (1)</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>101 (29)</td>
<td>129 (248)</td>
<td>101 (13)</td>
<td>501 (2)</td>
</tr>
</tbody>
</table>

*The results are weighted using the respondent-level sample weight.

**Numbers in parenthesis represent the quantity of sites where the total generation capacity of the facility was collected and analyzed.
9 KITCHEN EQUIPMENT AND REFRIGERATED VENDING MACHINES

The C&I Customer On-site Assessments efforts documented the baseline of existing kitchen equipment in C&I spaces. The collection of kitchen equipment information was not intended to be a fully comprehensive inventory of kitchen appliances found in C&I buildings but to provide more of an overview of the types of appliance commonly found in C&I buildings.

9.1 Kitchen equipment findings

Offices, food service sites, and lodging sites house 50% of kitchen equipment. The types of equipment found in these 3 business types differ substantially. For office and lodging, microwaves and coffee machines represent over 50% of the kitchen equipment. In food service, however, microwaves are only 10% and coffee makers are only 11% of kitchen equipment; ovens are 22%; fryers are 13%; ranges are 7%; and other kitchen equipment is 11%.

Energy efficiency offerings for kitchen equipment are extensive within the PA-sponsored programs in Massachusetts. As expected, these programs are not focused on microwaves and coffee makers; they offer rebates for ovens, fryers, ranges, dishwashers, and other electric- and gas-fueled appliances. These programs should consider focusing on improving the efficiency of kitchen equipment where this equipment is most commonly found: in food service, education, food sales, hospitals, and public assembly.

9.2 Kitchen equipment data

Table 9-1 lists the detailed types of kitchen equipment observed on-site, the aggregated appliance types that will be used for graphs in this section, and the un-weighted count of appliance units observed during the on-site data collection. The right-most column of Table 9-1 lists the respondent weighted distribution of cooking equipment. Microwaves, ovens, and coffee machines are the most prevalent types of kitchen appliance, together making up over half of all units.

<table>
<thead>
<tr>
<th>Detailed appliance type</th>
<th>Aggregated appliance type</th>
<th>Units observed onsite</th>
<th>Weighted share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler/cheese melter</td>
<td>Broiler</td>
<td>26</td>
<td>0%</td>
</tr>
<tr>
<td>Char broiler</td>
<td>Broiler</td>
<td>88</td>
<td>1%</td>
</tr>
<tr>
<td>Griddle, single-sided</td>
<td>Griddle</td>
<td>275</td>
<td>2%</td>
</tr>
<tr>
<td>Griddle, clam shell</td>
<td>Griddle</td>
<td>68</td>
<td>0%</td>
</tr>
<tr>
<td>Fryer, countertop</td>
<td>Fryer</td>
<td>46</td>
<td>1%</td>
</tr>
<tr>
<td>Fryer, freestanding</td>
<td>Fryer</td>
<td>478</td>
<td>2%</td>
</tr>
<tr>
<td>Fryer, pressure</td>
<td>Fryer</td>
<td>12</td>
<td>0%</td>
</tr>
<tr>
<td>Fryer, donut</td>
<td>Fryer</td>
<td>5</td>
<td>0%</td>
</tr>
<tr>
<td>Kettle, pasta cooker</td>
<td>Kettle</td>
<td>23</td>
<td>0%</td>
</tr>
<tr>
<td>Heat lamps</td>
<td>Heat</td>
<td>163</td>
<td>0%</td>
</tr>
<tr>
<td>Range top</td>
<td>Range</td>
<td>407</td>
<td>3%</td>
</tr>
<tr>
<td>Oven, pizza or bake</td>
<td>Oven</td>
<td>461</td>
<td>4%</td>
</tr>
<tr>
<td>Oven, conveyer</td>
<td>Oven</td>
<td>69</td>
<td>0%</td>
</tr>
<tr>
<td>Oven, range</td>
<td>Oven</td>
<td>611</td>
<td>7%</td>
</tr>
<tr>
<td>Oven, convection, comb, or re-therm</td>
<td>Oven</td>
<td>679</td>
<td>6%</td>
</tr>
<tr>
<td>Equipment</td>
<td>Type</td>
<td>Quantity</td>
<td>Percentage</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Food warmer</td>
<td>Warmer</td>
<td>589</td>
<td>3%</td>
</tr>
<tr>
<td>Heated display case</td>
<td>Heated</td>
<td>180</td>
<td>1%</td>
</tr>
<tr>
<td>Microwave</td>
<td>Microwave</td>
<td>4,098</td>
<td>31%</td>
</tr>
<tr>
<td>Toaster, popup</td>
<td>Toaster</td>
<td>447</td>
<td>9%</td>
</tr>
<tr>
<td>Toaster, conveyer</td>
<td>Toaster</td>
<td>108</td>
<td>1%</td>
</tr>
<tr>
<td>Coffee pot</td>
<td>Coffee</td>
<td>2,927</td>
<td>14%</td>
</tr>
<tr>
<td>Steam jacketed kettle</td>
<td>Kettle</td>
<td>130</td>
<td>1%</td>
</tr>
<tr>
<td>Braising pan/skillet</td>
<td>Braising pan</td>
<td>8</td>
<td>0%</td>
</tr>
<tr>
<td>Steam table</td>
<td>Steam table</td>
<td>232</td>
<td>1%</td>
</tr>
<tr>
<td>Dishwasher, single tank</td>
<td>Dishwasher</td>
<td>570</td>
<td>4%</td>
</tr>
<tr>
<td>Dishwasher, conveyer</td>
<td>Dishwasher</td>
<td>152</td>
<td>1%</td>
</tr>
<tr>
<td>Don't know</td>
<td>Don't know</td>
<td>4</td>
<td>0%</td>
</tr>
<tr>
<td>Other</td>
<td>Other</td>
<td>399</td>
<td>7%</td>
</tr>
</tbody>
</table>

*The results, other than the right most column are presented un-weighted. The right most column is respondent weighted.

** These data represent 595 sites.

Figure 9-1 illustrates the aggregated weighted distribution of kitchen equipment. Microwaves, ovens, and coffee machines are the most prevalent types of kitchen appliance, together making up over half of all units.
9.3 Kitchen equipment by business type

The count of kitchen equipment is disaggregated by business type in Figure 9-2. These data indicate that offices, food service, and lodging have the highest share of kitchen equipment, comprising almost half of the kitchen equipment in Massachusetts businesses.
Figure 9-2: Share of kitchen equipment by business type

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 61 food service, 83 office, 54 lodging, 62 public assembly, 40 retail, 39 other, 70 education, 20 campus, 48 healthcare, 37 food sales, 49 manufacturing/industrial, 17 warehouse, and 15 hospital sites.

Figure 9-3 illustrates the distribution of the types of kitchen equipment by business type. These data illustrate that some non-residential segments have a wide range of kitchen equipment while others have only 3 to 5 different types of equipment. Warehouses, retail, offices, and lodging businesses largely have microwaves, toasters, coffee makers, ovens, and dishwashers. Education, food sales, food service, and hospitals, however, are found to have a wide variety of kitchen equipment.

Recall that nearly 50% of kitchen equipment is found in offices, food service, and lodging. The types of equipment found in these three business types, however, differ substantially. For office and lodging, microwaves and coffee machines represent over 50% of the kitchen equipment. In food service, however, microwaves are only 10% and coffee makers are only 11% of kitchen equipment; ovens are 22%; fryers are 13%; ranges are 7%; and other kitchen equipment account for 11%. Energy efficiency offerings for kitchen equipment are extensive within the PA-sponsored programs in Massachusetts. As expected, these programs are not focused on microwaves and coffee makers; they offer rebates for ovens, fryers, ranges, dishwashers
and other electric and gas using appliances. These programs should focus on improving the efficiency of kitchen equipment where this equipment is most commonly found—in food service, education, food sales, hospitals, and public assembly.

**Figure 9-3. Distribution of types of kitchen equipment by business type**

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 20 campus, 70 education, 37 food sales, 61 food service, 48 healthcare, 15 hospital, 54 lodging, 49 manufacturing/industrial, 83 office, 39 other, 62 public assembly, 40 retail, and 17 warehouse sites.

### 9.4 Kitchen equipment by business kWh usage

Figure 9-4 illustrates the distribution of types of kitchen equipment by business kWh usage. The data indicate that businesses with annual electricity consumption in excess of 500,000 kWh have a higher concentration of microwaves and coffee machines. A larger share of the kitchen equipment incentivized by PA-sponsored programs appears to be more common in businesses with less than 4,500,000 kWh. Part of
the higher concentration of non-microwave and non-coffee maker kitchen equipment in smaller sized businesses is due to the fact that food service businesses are uncommon in the largest size grouping.

**Figure 9-4: Distribution of types of kitchen equipment by business kWh usage**

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 218 sites with usage less than 500,000 kWh, 309 sites with usage between 500,000 and 4,500,000 kWh, and 68 sites with usage greater than 4,500,000 kWh.

### 9.5 Kitchen equipment and fuel type

Some kitchen equipment, such as microwaves and coffee makers are only powered by electricity, other equipment, such as ranges and ovens, can be powered by multiple types of fuel. Figure 9-5 illustrates the different types of fuels used by various types of kitchen equipment. The most common types of kitchen equipment other than microwaves, coffee makers, and toasters are ovens (17%), dishwashers (5.6%), ranges (3.4%), and fryers (3.2%) (see Figure 9-1). Figure 9-5 illustrates that while dishwashers are nearly
all electric, the other common types of kitchen equipment have a distribution of electric and gas equipment. Ovens are nearly 50% electric and 50% gas while ranges and fryers are a majority gas with some electric and propane equipment. The PA-sponsored kitchen equipment programs offer incentives for high-efficiency electric and gas equipment.

**Figure 9-5: Kitchen equipment by fuel type**

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 595 sites.

### 9.6 Refrigerated vending machines

During the study we also collected information on the number of refrigerated vending machines at Massachusetts businesses. The weighted distribution of refrigerated vending machines by business type is presented in Figure 9-6. The majority of these machines are found in office (21%), retail (20%), and education (17%) customers in Massachusetts.
Figure 9-6: Distribution of vending machines by business type

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 117 office, 72 retail, 79 education, 73 public assembly, 83 manufacturing/industrial, 47 food sales, 59 other, 60 lodging, 35 campus, 20 hospitals, 30 warehouse, 63 food service, and 62 healthcare sites.

Figure 9-7 presents the distribution of vending machines by business electricity consumption. Almost half of refrigerated vending machines are found in businesses with annual electricity consumption between 500,000 kWh and 4,500,000 kWh.
Figure 9-7: Distribution of vending machines by kWh consumption

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 313 sites with usage less than 500,000 kWh, 382 sites with usage between 500,000 and 4,500,000 kWh, and 105 sites with usage greater than 4,500,000 kWh.
10 OFFICE EQUIPMENT

During the on-site visits the baseline distribution of computer monitors and computer power management equipment within businesses was documented. This section presents the findings of that effort. For this analysis office equipment is limited to computer monitors and computer power management systems.

10.1 Office equipment findings

Analysis of the distribution of computer monitors and power management equipment led to the following highlights:

- Over 60% of computer monitors in Massachusetts businesses were found in offices.
- Businesses with less than 500,000 annual kWh consumption have 34.8% of the computer monitors; business with 500,000 to 4,500,000 kWh have 18.7% and businesses with over 4,500,000 annual kWh have 46.5% of computer monitors.
- Businesses with less than 500,000 annual kWh consumption have 21.1% of computer power management systems; businesses with 500,000 to 4,500,000 kWh have 39.6% of systems; and businesses with over 4,500,000 annual kWh have 39.4% of power management systems.
- The different distributions of computer monitors and computer power management systems provide the PA-sponsored program with an energy efficiency opportunity. Businesses with more than 4,500,000 kWh and those with less than 500,000 kWh have a larger share of computer monitors than computer power management systems. PA-sponsored programs designed to educate and incentivized the installation of computer power management systems should focus programs on the largest and the smallest business customers.

10.2 Computer monitors

Figure 10-1 illustrates the distribution of computer monitors by business type. These data clearly indicate that the largest share of monitors (over 60%) is found in the office segment, which is consistent with expectations, since offices account for 25% of Massachusetts businesses (See Section 2 for a customer overview) and most office workers have a computer and at least one monitor. The computer monitors were divided into older cathode-ray tube (CRT) monitors and newer style LCD/LED monitors. These data from the on-sites imply that 99.3% of monitors in Massachusetts businesses are LCD/LED monitors.\textsuperscript{126} CRT monitors make up only 0.7% of monitors.

\textsuperscript{126} Laptops were not included as a type of monitor.
*The results presented above are weighted using the respondent-level sample weight.

**These data represent 67 office, 45 education, 45 retail, 51 public assembly, 49 healthcare, 35 other, 65 manufacturing/industrial, 10 hospital, 18 warehouse, 20 campus, 47 food service, 43 lodging, and 30 food sales sites.

Figure 10-2 shows the distribution of computer monitors by electricity consumption range. These data indicate that the majority of monitors are found in either businesses with annual electricity consumption in excess of 4,500,000 kWh (47%) or businesses with less than 500,000 kWh (35%) annual consumption.
Figure 10-2: Distribution of computer monitors by business kWh usage

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 185 sites with usage less than 500,000 kWh, 277 sites with usage between 500,000 and 4,500,000 kWh, and 63 sites with usage greater than 4,500,000 kWh.

Figure 10-3 shows the average number of monitors per 1,000 square feet by business type. Offices have by far the most monitors per 1,000 square feet of business space (4.11). Hospitals have almost 2 monitors per 1,000 square feet. Healthcare and public assembly business types have an average of 1.69 and 1.32 monitors per 1,000 square feet, respectively. The other business types all have an average of less than 1 monitor per 1,000 square feet.
10.3 Power management systems

Computer power management systems are mandated configurations within computer operating systems or added software to enable power management of computers (not just monitors) when they are inactive. In some cases, they involve smart plug strips but normally they just implement power saving configurations within the operating system of the computers.

The on-site assessment efforts found that 10% of businesses have computer power management systems. These systems however are not equally distributed across business types or business size. Figure 10-4 illustrates the distribution of power management systems by business type.
Figure 10-4: Share of businesses with power management systems

*The results presented above are weighted by the respondent-level sample weight.

**These data represent 62 healthcare, 83 manufacturing/industrial, 20 hospital, 73 public assembly, 79 education, 117 office, 72 retail, 47 food sales, 35 campus, 63 food service, 59 other, 60 lodging, and 30 warehouse sites.

Figure 10-5 illustrates the distribution of power management systems by business annual electricity consumption. The distribution of computer power management systems indicates that businesses with 500,000 to 4,500,000 annual kWh have approximately the same share of systems as businesses with greater than 4,500,000 kWh. The distribution of computer power management systems differs substantially from the distribution of computer monitors illustrated in Figure 10-2. Businesses with greater than 4,500,000 kWh account for 46.5% of computer monitors, indicating that they have a larger share of monitors than power management systems. Businesses with 500,000 to 4,500,000 annual kWh have 18.7% of monitors but 39.6% of power management systems. The differences in the distribution of computer monitors and computer power management systems indicates that educating large businesses on the benefits of computer power management systems may be a PA-sponsored EE program opportunity.
Figure 10-5: Share of businesses with power management systems by business kWh usage

*The results presented above are weighted with the respondent-level sample weight.

**These data represent 34 sites with usage less than 500,000 kWh, 60 sites with usage between 500,000 and 4,500,000 kWh, and 21 sites with usage greater than 4,500,000 kWh.
11 PROCESS EQUIPMENT

In planning the C&I On-Site Assessments Study, we were interested in collecting market characterization information from manufacturing- and industrial-type customers, but because it is challenging to administer end-use market characterization surveys on-site at industrial facilities, they were not initially chosen for the 2014 data collection sample. However, due to concurrent technical potential study efforts, the on-site team began visiting industrial sites early in the fall of 2014. The DNV GL team worked quickly in collaboration with the PAs to develop a data-collection module that would be used to collect data pertaining to process loads at customer sites.

We designed this module to collect high-level information to provide a broad overview of the types of process equipment that exist at customer sites. We understood that industrial and manufacturing customers’ sole focus is to make and sell product and that it would not be possible to get detailed process information for all process equipment types. Therefore, we focused on capturing a general picture of the type of industrial customers visited during the on-site assessments, the types of equipment found at these facilities, and variables such as average age, quantities, and size of the energy consuming equipment found. Of the 85 manufacturing on-site visits completed for this study, thirty-seven (44%) were identified as a recent program participant based on tracking data from 2011-2014.

11.1 Process equipment findings

The analysis of the process equipment data revealed a mix of findings. The findings presented in the sub-section below are limited to high-level details of process equipment across all facilities. Equipment specific findings on the different process equipment types covered in this report are located at the start of each equipment sub-section.

Consistent with the data presented in other sections of the report the majority of the figures and tables presented in the process equipment section have the appropriate site-level sample, respondent or kWh weights applied to the results. PA provided tracking data indicates the population of manufacturing and industrial sites to be slightly over nineteen thousand. Over eighteen-thousand of those manufacturing facilities (94%) fall in the annual electric usage category of 500,000 kWh or less. Less than 230 sites (1.2%) showed annual electricity usage over 4,500,000 kWh and less than one thousand sites (5%) showed annual electricity usage between 500,000 and 4,500,000 kWh. As a result, the sample and respondent weights place a high influence on data captured at sites consuming less than 500,000 kWh per year.

The next sub-section covers characteristics specific to the facilities as a whole. All of the figures in the facility information are presented either using the site-level or kWh-level weighting. Often the kWh weighted figures more closely match the un-weighted results of the data findings. While the kWh weighted data is helpful it should be noted that it is limited to electrical energy consumption. It was not possible to develop a combined electrical, gas, and other energy source consumed at the facilities. For certain figures where the site-level sample weighted results were overshadowed by the results of one or two low electricity consuming sites the kWh weighted results are displayed side-by-side with the site weighted results as a point of reference.

The equipment observed across the eighty-five process facilities varied significantly with some equipment types found at most sites and other equipment types only found at a handful of sites. Process compressors were the most commonly seen process specific equipment observed. Approximately 90% of process sites
visited had a compressor in operation. Some significant findings from the process compressor section include:

- 82% of facility level reported uses of compressed air is for pneumatics
- 95% of facilities report having adequate compressed air storage
- 41% of all compressor systems observed are between 10-25 HP
- 21% of all compressors are over 100 HP

Miscellaneous process motors, specifically motors that do not serve a process usage category covered by one of the other specific process equipment end use categories, were observed at just over half of the process facilities visited. More miscellaneous motors were observed than any other process specific end use equipment. Some significant findings from the miscellaneous process motors included:

- A total of 1,218 general miscellaneous motors were observed at 46 different facilities.
- 222 miscellaneous process motors observed were manufactured prior to 1990 which represented 45% of all miscellaneous motors based on respondent weighting.
- Respondent weighting indicates that 45% of miscellaneous motors are 1 HP or less.

Process ventilation, compressed air dryers, and process cooling equipment were all observed at over half of the process facilities visited. Of the 61 facilities with process dedicated ventilation an average 11 fans or motors were in operation. The un-weighted average HP for process ventilation equipment was 5.7 HP but only 3% of those motors were clearly determined to operate under VFD control.

### 11.2 Facility information

It is very difficult to categorize industrial facilities and the equipment that is used. Many of the processes we observed were unique and depended on custom-built equipment. We have grouped the types of facilities visited during the on-sites based on NAICS codes. Table 11-1 provides a summary of the types of facilities visited during the on-site data collection effort.

#### Table 11-1. Types of process facilities visited

<table>
<thead>
<tr>
<th>Abbreviated NAICS Code</th>
<th>Quantity</th>
<th>Percent of process sites visited</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>Biological/pharmaceutical manufacturing</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>Grocery and related product wholesaler</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>Non-metallic mineral product manufacturing</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>Showcase, partition, shelving, and locker manufacturing</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>All other support services</td>
<td>2</td>
<td>2.4%</td>
</tr>
<tr>
<td>Beverage manufacturing</td>
<td>2</td>
<td>2.4%</td>
</tr>
<tr>
<td>Durable goods wholesaler</td>
<td>2</td>
<td>2.4%</td>
</tr>
<tr>
<td>Electrical equipment production</td>
<td>2</td>
<td>2.4%</td>
</tr>
<tr>
<td>Newspaper publishers</td>
<td>2</td>
<td>2.4%</td>
</tr>
<tr>
<td>General printing</td>
<td>3</td>
<td>3.5%</td>
</tr>
<tr>
<td>Abbreviated NAICS Code</td>
<td>Quantity</td>
<td>Percent of process sites visited</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Iron, steel, aluminum production</td>
<td>5</td>
<td>5.9%</td>
</tr>
<tr>
<td>Paper manufacturing</td>
<td>5</td>
<td>5.9%</td>
</tr>
<tr>
<td>Fabricated metal product manufacturing</td>
<td>6</td>
<td>7.1%</td>
</tr>
<tr>
<td>General electronic component/instrument</td>
<td>6</td>
<td>7.1%</td>
</tr>
<tr>
<td>Miscellaneous manufacturing</td>
<td>6</td>
<td>7.1%</td>
</tr>
<tr>
<td>Food processing</td>
<td>7</td>
<td>8.2%</td>
</tr>
<tr>
<td>Plastics and Rubber manufacturing</td>
<td>8</td>
<td>9.4%</td>
</tr>
<tr>
<td>General purpose machinery manufacturing</td>
<td>9</td>
<td>10.6%</td>
</tr>
<tr>
<td>Utilities</td>
<td>15</td>
<td>17.6%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>85</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Results shown here are unweighted.

**The abbreviated NAICS codes listed above represents the level of Industry distinction associated with the first three digits of the North American Industry Classification System’s code for the eighty-five manufacturing or industrial facilities visited.

While on-site, field staff asked a series of background questions about the facility operations and discussed with the facility contact general practices. Field staff were instructed to ask about what was produced at the facility, production schedules, average age of equipment, maintenance costs and number of shifts. Figure 11-1 shows the fraction of facilities with seasonal fluctuations using both site and kWh weighting factors. We see that 22% of these types of facilities in Massachusetts have a seasonal fluctuation in operations. Many of these are food processing and water or wastewater treatment plants.

**Figure 11-1. Seasonal fluctuation of production**

*The results presented above are weighted using the site-level sample weight.

**These data represent 88 sites, 13 sites reporting yes, 66 sites reporting no, and 9 sites for which seasonality was unknown.

Figure 11-2 shows the average age of all process equipment at the facility as reported by facility representatives during on-site interviews.
In later sections of this chapter, specific process equipment ages are presented based on manufacture dates listed on nameplates or, if manufacture dates were unavailable, through site contact knowledge. In cases where equipment manufacture dates were not available site contacts were asked if they could provide the exact year of installation for the equipment. If an exact year was known the year was entered. If the exact year was unknown, the site contact was asked to approximate whether or not the equipment was installed before or after January 2009. As a result, the age categories provided for specific end use equipment will show some overlap, since all equipment approximated as installed prior to 2009 by site contacts will appear in a separate category from equipment with known manufacture dates prior to 2009.

The average age of equipment varied across the industrial facilities visited, but nearly 50% of customers site weighted and 58% of customer kWh weighted indicated that the average age of equipment at their facilities is between 8-15 years old. Industrial type customers tend to keep their process equipment longer due to higher costs to replace and difficulty replacing custom designed equipment. This is likely why we also see the large majority of customers (84% site weighted and 73% kWh weighted) indicate the average age of equipment is at least eight years old.

Figure 11-3 shows the average maintenance costs for process equipment using both site and kWh weighting factors. This data indicates that over 58% of sites weighted by electric consumption indicate that they consider their facilities to have medium to high maintenance costs. We also see a drastic difference between the site weighted and kWh weighted values for customers who indicate that they generally have low maintenance costs. What this may indicate is that the customers who use more electricity tend to have higher maintenance costs. Due to the effects of the sample weighting, smaller customers make up a larger
population and therefore are more heavily weighted on a site basis. When comparing the site-weighted results to the kWh-weighted results, the proportion of low-cost maintenance facilities is dramatically reduced. This indicates that low cost maintenance facilities are generally more associated with smaller customers and therefore the larger energy-consuming customers tend to have average-high maintenance costs. These higher costs can be associated with the need to guarantee the performance of large high-energy consuming, high value, custom equipment and ensure the equipment remains operational. These maintenance practices may also be part of the reason why the average age of equipment is often 8 years or older.

**Figure 11-3. Maintenance cost levels for process equipment**

![Maintenance Cost Levels](image)

*These data represent 89 facilities, 16 indicated high maintenance costs, 32 average, 16 low, 2 would not disclose, and 23 said they didn't know.

Figure 11-4 shows the average number of shifts weighted by consumption (kWh). We found there to be one site in our sample that indicated they only have shifts on an as-needed basis. This was a part time repair facility. The data indicates that most facilities (56%) operate three shifts per day. Three facilities reported operating on a 4-shift schedule. Four shift schedules include four 6-hour shifts per day. Employees on a 4-shift schedule work 6-hour shifts some days and back-to-back 6-hour (12-hour) shifts on other days.
**Figure 11-4. Summary of production shifts**

![Pie chart showing production shifts](image)

*The results presented above are weighted using the kWh-level sample weight.*

**These data represent 87 sites, 1 reporting 0 shifts or as-needed, 31 reporting 1 shift, 19 reporting 2 shifts, 32 reporting 3 shifts, 3 reporting 4 shifts, and 1 site for which that data was not known.*

### 11.3 Compressed air systems

Compressed air is used across a wide array of industrial facilities and industrial processes. Air compressors are also found in non-industrial sites including hospitals, college campuses, and other facilities. These systems have multiple uses and can be used directly in the manufacturing process (e.g., ejecting product from forming molds, driving pneumatic tools such as air mixers, providing blow off - shaving removal from cutting tools, and for conveying systems). Compressed air can also be used to provide breathable air in hazardous spaces.

Compressed air configurations can consist of single or multiple compressors that are part of a central distribution system and can be centrifugal, scroll, reciprocating, or rotary screw units. Central compressed air systems consist of the compressor[s], storage tanks, air dryers, filters and drains.

Air dryers remove moisture from the compressed air before it if fed through the system. Dryers can be either constant speed (on continuously) or cycling (incremental operation) with refrigeration system or consist of regenerative system using desiccants. Drains remove the moisture from the system. The water can be purged using compressed air or by no-loss drains that utilize a float and pump system in place of blown compressed air. Filters remove dust, dirt, and other contaminants from the compressed air flow.

The following figures reflect the information gathered through facility contact interviews and data gathered during the equipment inventories at all process facilities with compressed air systems. The findings in Figure 11-5 through Figure 11-11 reflect facility-wide practices and characteristics and are. Figure 11-12 through Figure 11-15 results are based on unit-level characteristics for all compressed air and air drying systems observed.
Figure 11-5 illustrates the distribution of facility reported main compressed air usage type based on site-level weights. Across all business energy usage categories pneumatics was the most common reported compressed air usage type at 82%. Pneumatics covers a wide range of equipment ranging from hand tools to large devices. Pneumatic equipment can be found in different size facilities and across varied manufacturing processes. Process and conveying are the next largest compressed air end users respectively. Compressed air fed directly to process machines like injection molding machines (IMMs) is considered a process use. Compressed air transporting plastic shot directly to the IMM hoppers is an example of conveying.

Sites with annual energy usage below 500,000 kWh only reported pneumatics as the main compressed air usage which drives the overall pneumatics percentage up to 82%. At facilities with energy usage between 500,000 and 4.5M kWh the process usage category accounted for 51% of reported main compressed air usage type with pneumatics only accounting for 19%. At facilities with annual energy usage above 4.5M kWh the distribution was more evenly spread out with conveying accounting for 23%, pneumatics accounting for 31%, and process accounting for 38%.

The average reported age for facility level compressed air systems based upon business-level weights is shown in Figure 11-6. The site evaluations found that 81% of the industrial air compressors were built between 1990 and 1999. Seven percent of air compressors are of 2000-2008 vintage. Air compressors are costly to replace thus it is more likely that a facility will operate and maintain existing equipment over costly replacements.

Industrial customers are willing to spend the money if the payback is there. Compressed air is often a crucial part of the manufacturing process and the loss of process air can stop production cold. Reliability is an important factor in deciding to replace or repair a system. Simply replacing a working air compressor with a
more efficient compressor just for the efficiency savings can be a hard sell. If this is a replacement for a failing unit, a compressor with high maintenance costs, or expansion of capacity to meet increased future demand then the project will more likely be implemented.

The site personnel are also aware that distribution system losses and floor conditions that now exceed initial design criteria are equally important. The payback for a compressor at these conditions is driven by the waste and not the required operation. The best compressor project for the large end-user is one that addresses the distribution inefficiencies (if any), considers the maintenance costs, and provides an honest cost/savings analysis in relation to production.

Figure 11-6. Facility reported process process-compressor average age

The results presented above are weighted using the site-level sample weight.

These 46 sites reporting on the average age for compressed air systems, 1 reporting prior to 1990, 8 reporting between 1990 and 1999, 15 reporting between 2000 and 2008, 13 reporting 2009 and later, and 9 that could not say with certainty.

Based upon the respondent-level sample weight, 52.0% of the air compressors were manufactured in 2008 or earlier (Figure 11-7). The exact age is not known in this group and may extend to before 2000. An additional 6% of units were manufactured from 2000 to 2008. The weighted respondent data also shows that 40% of the units were manufactured in 2009 or later.
The results presented above are weighted using the respondent-level sample weight.

These data represent 408 compressor ages, 5 manufactured prior to 1990, 15 manufactured between 1990 and 1999, 65 manufactured between 2000 and 2008, 125 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, and 198 manufactured in 2009 or later.

Facility-level reported compressor system control strategy is illustrated in Figure 11-8. Load/unload control is used to control 80.0% of air compressors in the industrial sites. Compressed air usage is seldom continuous even in manufacturing applications. Load/unload refers to a compressor cycling between two pre-determined pressure set points. The compressor operates at full capacity when compressed air (load) is required and then drops to a lower level of operation (or possibly turn off) when compressed air requirements are reduced (unload). Load/unload is a common strategy for smaller units and this finding is consistent with the finding that reciprocating compressors are the most common compressor type shown in Figure 11-11 below.

"Don't know" is the second most common compressor control at 9.0%. This finding may be caused by facility staff being uninformed about compressor operations or hesitant to classify a general site control strategy when multiple control strategies exist. Other types of strategies can include on/off loading and multistage operation. On/off and load/unload are two stage operations (there are two operating conditions that must be met). Multistage operating can implement 3 or 5 different pressure set points and stage compressor or compressors operation accordingly. Defining the difference between two stage and multistage operation is often the reason for a "don't know" response. Variable speed drives account for 6.0% of controls. These are associated with larger systems (centrifugal and screw compressors) and the response is again compatible with the equipment provided in Figure 11-8.

Air compressors operating with poppet valves are typically comprised of four poppet valves. These valves are mounted in the air end rotor housing and again open and close as needed. These are generally spring loaded 2-way normally closed valves. Poppet size and composition is based upon design system pressures. Air pressure is sensed at a part of the value called the pilot port. This pressure forces a piston down opening the seal and allowing the value to open. When the pilot port pressure is reduced, the spring actuator pushes the piston up and seal the port. The poppets open and close in response to compressed air requirements. When poppets are open, compressed air flows through the system. When the poppets are closed, they
represent a pressure against the air compressor, which uses more energy when compared with variable flow air compressors. Poppet valves account for 2% of controls.

**Figure 11-8. Compressor control type**

* The results presented above are weighted using the site-level sample weight.

** These data represent 48 sites reporting on the control strategy for their compressed air systems, 10 reporting load/unload, 4 reporting on/off, 2 reporting poppet valves, 19 reporting variable speed drives, and 13 that didn’t know.

The reported facility level compressed air storage adequacy status is illustrated in Figure 11-9. Compressed air is not used continuously in most industrial facilities. A storage tank(s) is installed to minimize compressed air surges and regulate required pressure. The cylinder tank on small self-contained systems provides the storage capacity. In central plant compressed air systems, multiple tanks can be located in the compressor room or across the facility. 95.0% of the facilities thought they had adequate compressed air storage capacity. Two sites (1.0%) indicated that storage capacity was an issue in at least part of their system.
Moisture is a maintenance problem in compressed air systems. Water condenses from the water vapor in the air during the compression process. This moisture must be removed. In the past, a portion of the compressed air flow was used to blow the water from the system. Zero-loss drains use floats and pumps for that task and do not waste compressed air. They are offered as an option on new systems. They can also be added to existing systems as a retrofit. Retrofit costs, and relatively low savings compared with other process related options, can make zero-loss drains a less popular efficiency upgrade option. Figure 11-10 shows that 83.0% of the compressed air systems do not have zero-loss drains installed.

**Figure 11-10. Facilities with zero-loss drains**

* The results presented above are weighted using the site-level sample weight.
** These data represent 48 sites reporting on the presence of zero-loss drains in their compressed air systems, 18 that have zero-loss drains, 9 that do not have zero-loss drains, and 21 that did not know.
Room air or outdoor air is drawn into the compressor for compression. This air contains dust, dirt, and other contaminants. The compressed air system can contain rust, pipe scale, compressor lubricants, and other contaminants. These contaminants must be removed from the system. Excessive pressure pressure drop from filters used to capture these contaminants results in poor system performance and increased energy costs. Low pressure filters provide less resistance for the air movement while maintaining filtering requirements.

Facility level reported presence of low pressure drop filters on compressed air systems is shown in Figure 11-11. “Don’t know” was the response at 81.0% of sites based on the site-level sample weight. For the twenty facilities where this characteristic was not known a number of scenarios were present. For smaller sites with one or two compressed air systems, the site contact may not have been that knowledgeable on all the parameters of the compressed air system, so the value for this questions was left at “don’t know.” Additionally, filters can be provided through a maintenance contract and site contacts may not be knowledgeable of the exact filter type installed at the facility. Low pressure drop filters are not cost prohibitive in that they are just a filter replacement involving a more expensive filter. The problem associated with the measure is accurately quantifying the savings attributed to the change in the system operation due to a low loss filter outside of outside factors. Site-level sample weighting shows 14.0% of site level compressed air systems are operating with low pressure drop filters, or 19 of 48 sites in raw values.

**Figure 11-11. Facilities with low-pressure drop filters**

* The results presented above are weighted using the site-level sample weight.

** These data represent 48 sites reporting on the presence of low-pressure drop filters in their compressed air systems, 19 that have the filters, 9 that do not, and 20 that did not know.

The distribution of compressor system types is shown in Figure 11-12. Reciprocating air compressors account for 64.0% of the equipment with 30.0% of compressors identified as scroll units. Reciprocating compressors are most commonly found as smaller self-contained units with built-in storage tank. These are used for smaller site applications. Rotary screw and centrifugal compressors are often located in larger facilities. They can be single compressor systems or be a part of a multi-compressor central plant. Screw and centrifugal compressors are compatible with variable speed drive applications.
As shown in Figure 11-13, the most common air-compressor size is 10-HP to 24.9-HP at 41% of all process compressors. Process compressors less than 5.0-HP in size account for another 19.0% of all units. This is, again, consistent with smaller reciprocating units. There are no centrifugal or rotary screw units in the <25.0-HP range. 20% of the compressors are in the 100-199 HP category. This is the type of equipment most commonly serving larger process loads, central plants, and coincide with the rotary screw and centrifugal units. For 6% of compressors the HP was not determinable. Part of this may be attributed to not being able to determine if a unit is a screw or centrifugal system and may be associated with larger equipment.

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 409 compressors, 3 centrifugal, 95 reciprocating, 301 rotary screw, 7 scroll, and 3 that were not identifiable.

Figure 11-13. Process compressor sizes in horsepower

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 408 process compressors’ rated horsepower, 16 between 0-4.9, 38 between 5-9.9, 50 between 10-24.9, 41 between 25-49.9, 39 between 50-99.9, 182 between 100-199, 25 at or above 200 horsepower, and 17 for which the horsepower was not known.
Figure 11-14 provides air-compressor quantities according to annual energy usage of the industrial facility. 64.0% (25 units) of the industrial air-compressors are located in facilities that consume less than 500,000 kWh of electricity per year. The 31.0% represents 270 units in the 500,000 – 4,500,000 kWh range, and 114 units at facilities consuming more than 4,500,000 kWh per year. These are quantities only and make no reference to compressor type, size or horsepower. While smaller compressors may be installed in less energy intensive facilities, there may not be a direct correlation between compressor size and energy intensity. Small units may be dedicated low-use systems in large facilities and a large screw or centrifugal system may be found in a facility that is currently experiencing a reduction or lull in business or has few other end-uses.

Figure 11-14: Process compressor quantities by business energy-usage category

![Diagram showing air-compressor quantities by business energy-usage category](image)

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 409 compressors, 25 observed at sites with an annual energy usage less than 500,000 kWh, 270 at sites with an annual energy usage between 500,000 and 4.5 million kWh, and 114 at sites with an annual energy usage greater than 4.5 million kWh.

As shown in Figure 11-15, 37.0% of the systems observed were operating at the 100 psi to the <150 psi pressure range. Another 13.0% of the systems operate at less than 100 psi. These values are based on either pressure readout on the compressor or from site contact input. We did not refer to the maximum operating pressure listed on the compressor nameplate. “Don’t know” is mostly on smaller reciprocating systems where pressure gauges were malfunctioning or non-existent. Using the respondent-level sample weight, the 48.0% "don’t know" response corresponds with 37 of the units. Without the weighting, 62.0% of the air compressors operate in the 100 – 150 psi pressure range which is common for smaller the systems that are predominant in this population.
Air dryers remove moisture from the air after it is compressed and before it is sent to distribution. Figure 11-16 provides information on the type of dryers. Even though data was reported on 175 compressors there were only data reported on 79 dryers. The contrast in the number of air dryers compared to compressors can partially be explained by the high presence of smaller compressors that did not have a dedicated air dryer. Some air-dryers are also serving multiple compressors.

The most common air dryer is a refrigerated system that removes the moisture through a refrigeration cycle. Refrigerated dryers that operate continuously are non-cycling dryers. A by-pass valve redirects the refrigerant to meet required dew point settings. As shown in in the figure, 34.0% of the dryers are non-cycling.

The cycling air dryer consists of heat exchangers and a cooling medium. A refrigerated fluid cools the medium and the medium removes the moisture. This requires less energy than the by-pass method. When not needed, the unit cycles off saving energy compared to the non-cycling type. The data collected also indicates that 34.0% of the units are cycling air dryers.

Desiccants are materials which extract moisture from air upon contact. The desiccant must be heated to complete the drying process. 9.0% of the dryers are desiccant systems according to the data. A heatless desiccant system uses dry compressed air to regenerate the desiccant in place of heat. Heatless desiccant systems account for 2.0% of the units.

The “don’t know” designation primarily signifies not being able to verify if refrigerated dryers are cycling or non-cycling.
According to the data collected as showed in Figure 11-17 below, nearly 75% of air dryers were installed before 2009. Based on observation from the field, many of the older compressed air dryers don’t get replaced on the same interval as the compressors themselves. Assuming new compressors replace identically sized older compressors, the new compressors do not always require replacing the air dryer.

**Figure 11-17: Air dryer ages**
As shown in Figure 11-18, based upon the respondent-level weighted data, 44 air dryers are located in facilities consuming less than 4,500,000 annual kWh and 37 dryers are located in facilities with greater than 4,500,000 annual kWh usage.

**Figure 11-18: Air dryer quantities by business energy usage category**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 81 air dryers, 44 at sites with an annual energy usage between 500,000 and 4.5 million kWh, and 37 at sites with an annual energy usage greater than 4.5 million kWh.

### 11.4 Process heating

A process heating load pertains to manufacturing operations, where heat from steam or hot water is used in the manufacturing of a final product. A process heating load can be either a continuous load or batch. In a continuous load, the demand is fairly constant over long durations of time. The batch load is characterized by shorter demand periods and often variable temperatures. Across the eighty-five industrial sites visited only twenty-one indicated the presence of dedicated process heating equipment and operation. In an effort to account for this relatively small sample all of the figures presented in the process heating section will be accompanied by the un-weighted results. As shown in Figure 11-19, based upon weighted site-level samples, annealing accounts for 89% of process heating. Annealing is the heating of the workable material to a specific temperature and allowing it to cool slowly. Curing and drying, injection molding, and food processing are the next most common process heating end uses. It should be noted that these sample are very small with on 21 customers indicating some kind of process heating. Figure 11-20 provides the unweighted results.
The results presented above are weighted using the site-level sample weight. **These data represent 21 sites process heating operations, 2 reporting annealing, 1 reporting chemical mixing, 6 reporting curing and drying, 4 reporting food process, 1 reporting heating and drying, 2 reporting injection molding, 2 reporting metal heat treating, 1 reporting plastics extrusion, and 2 that were categorized as other.

A boiler can provide the steam or hot water for the process load. These boilers are critical parts of the manufacturing process. The boilers need to reliably work with the process lines. Servicing the boilers is an
important part of assuring production reliability. According to the data collected shown in Figure 11-21, 79% of the sites service their boilers at least annually according to the weighted site-level sample data, while 10% of the sites do not have annual service contracts. Figure 11-22 shows the same information un-weighted. The one site that reported not servicing its boilers annually has just one process boiler with an input less than 200 MBTU and serviced the boiler was performed on an as needed basis.

**Figure 11-21. Site-level process boiler serviced annually**

![Pie chart showing 79% serviced, 10% not serviced, and 11% don't know.]

*The results presented above are weighted using the site-level sample weight.

**These data represent 17 sites process boiler servicing practices, 14 reporting boilers are serviced annually, 1 reporting they are not serviced annually, and 2 that did not know.

**Figure 11-22: Site-level process boiler serviced annually (un-weighted)**

![Pie chart showing 82% serviced, 6% not serviced, and 12% don't know.]

*The results presented above are un-weighted.

**These data represent 17 sites process boiler servicing practices, 14 reporting boilers are serviced annually, 1 reporting they are not serviced annually, and 2 that did not know.
Burners atomize the fuel with air for combustion in the boiler. Excess combustion air is often provided to assure safe operation but can lower efficiency. The excess air can be 15%-20% greater than what is actually required by code for safe combustion. CO or O₂ trim controls are designed to reduce the quantity of excess combustion air and still assure safe operation. Trim controls are effective on boilers that are 300-HP or greater in size but controls can be installed on units as small as 100-HP depending upon operation. As shown in Figure 11-23, the weighted data finds that 78% of the sites do not operate with any trim controls. This may also include existing trim systems that are no longer functional. Trim controls were not standard equipment on older boilers and must be installed as part of a custom retrofit. While anything done to optimize the operation of existing systems is more cost effective than total system change-outs the installation costs and projected savings of trim control retrofits may be a factor in the low saturation rate.

**Figure 11-23. Site-level process boilers with CO or O₂ trim controls**

![Pie chart showing 78% no trim controls, 21% with trim controls, and 1% don't know]

*The results presented above are weighted using the site-level sample weight.

**These data represent 17 sites process boiler servicing practices, 5 reporting yes to CO or O₂ Trim Controls, 11 reporting no to CO or O₂ Trim Controls, and 1 that didn't know.

The same information, presented un-weighted, is shown in Figure 11-24.

**Figure 11-24. Site-level process boilers with CO or O₂ trim controls (un-weighted)**

![Pie chart showing 65% no trim controls, 29% with trim controls, and 6% don't know]

*The results presented above are un-weighted.

Waste heat is generated in a boiler that can be captured. The most common heat recovery systems are heat recovery from the exhaust stack heat and heat recovery from boiler blowdown. A stack economizer captures
a portion of the heat being exhausted from the boiler. This waste heat can be used to pre-heat the combustion air drawn into the burner. Steam boilers require a blowdown to remove destructive solids from the system. The heat from the blowdown can be used to increase makeup water temperatures. The data shown in Figure 11-25 indicate that 74% of the sites do not have operating heat recovery equipment. Heat recovery is not installed as standard equipment and must be considered on a case-by-case basis. In addition to the retrofit installation costs heat recovery equipment also adds to annual maintenance costs. Three sites in the weighted sample have some form of heat recovery.

**Figure 11-25. Site-level process boiler heat recovery systems**

*The results presented above are weighted using the site-level sample weight.

**These data represent 16 sites heat recovery operations for process boilers, 3 reporting yes to having heat recovery, 11 reporting no to having heat recovery, and 2 that didn’t know.

The same information, presented un-weighted, is shown in Figure 11-26.
Figure 11-26. Site-level process boiler heat recovery systems (un-weighted)

*The results presented above are un-weighted.

**These data represent 16 sites heat recovery operations for process boilers, 3 reporting yes to having heat recovery, 11 reporting no to having heat recovery, and 2 that didn't know.

Figure 11-27 below shows the types of process boilers found. Fire tube boilers are available for low- or high-pressure steam, or for hot water applications. Typically used for applications ranging from 15 to 2,200 horsepower, a fire tube boiler uses a cylindrical vessel, with the flame in the furnace box and the combustion gases inside the tubes. In the water tube boilers, tubes contain steam and/or water, and the products of combustion pass around the tubes. As shown in Figure 11-27, 74% of the boilers are water tube boilers.
The results presented above are weighted using the respondent-level sample weight.

**These data represent 39 process boilers, 16 fire tube, 19 water tube, and 4 that were not identifiable.

The same information, presented un-weighted is shown in Figure 11-28.

**Figure 11-28. Process boiler types (un-weighted)**

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Figure 11-29 shows that 49% of the process boilers were manufactured in 2009 or later. Sixteen percent of the process boilers are pre 1990 vintage. The trim controls and heat recovery systems described previously were not available as options in 2009 suggesting that those technologies are not likely incorporated into some of the new boiler systems.
The results presented above are weighted using the respondent-level sample weight.

These data represent 37 process boilers for which an age was determined, 6 manufactured prior to 1990, 4 manufactured between 1990 and 1999, 3 manufactured between 2000 and 2008, 6 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, and 18 manufactured in 2009 or later.

The same information, presented un-weighted, is shown in Figure 11-30.

The results presented above are un-weighted.

These data represent 37 process boilers for which an age was determined, 6 manufactured prior to 1990, 4 manufactured between 1990 and 1999, 3 manufactured between 2000 and 2008, 6 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, and 18 manufactured in 2009 or later.
Field staff collected information on the boiler capacities during the on-site assessments. Sixty-nine percent of the process boilers were found to be between 1,000 and 5,000 MBTUH in capacity according to the weighted respondent-level sample data shown in Figure 11-31. Thirteen percent of the boilers were in the 500-1,000 MBTUH size category and 9% were < 500 MBTUH in capacity.

**Figure 11-31: Process boiler capacity in MBTUH**

*The results presented above are weighted using the respondent-level sample weight.*

**These data represent 38 process boilers capacity in MBTUH, 14 between 0-499, 8 between 500-999, 7 between 1,000-4,999, 2 between 5,000-9,999, 5 at or above 10,000 MBTU, and 2 for which the capacity was not known.*

The same information, presented un-weighted, is shown in Figure 11-32.

**Figure 11-32: Process boiler capacity in MBTUH (un-weighted)**

*The results presented above are un-weighted.*

**These data represent 38 process boilers capacity in MBTUH, 14 between 0-499, 8 between 500-999, 7 between 1,000-4,999, 2 between 5,000-9,999, 5 at or above 10,000 MBTU, and 2 for which the capacity was not known.*
Figure 11-33 presents the boiler quantities found at industrial facilities according to their kWh usage classification. Overall, 64.0% of the boilers were found in facilities that consume between 500,000 and 4,500,000 kWh annually. Only two sites (7.0%) with less than 500,000 kWh of annual electrical consumption were found to require process heating.

**Figure 11-33: Process boiler quantity by business energy-usage category**

![Pie chart showing boiler quantities by energy usage category]

*The results presented above are weighted using the respondent-level sample weight.

**These data represent 39 process boilers, 2 at sites with annual usage below 500,000 kWh, 21 at sites with an annual usage between 500,000 and 4.5 million kWh, and 16 at sites with an annual usage greater than 4.5 million kWh.

The same information, presented un-weighted, is shown in Figure 11-34.

**Figure 11-34: Process boiler quantity by business energy-usage category (un-weighted)**

![Pie chart showing boiler quantities by energy usage category (un-weighted)]

*The results presented above are un-weighted.

**These data represent 39 process boilers, 2 at sites with annual usage below 500,000 kWh, 21 at sites with an annual usage between 500,000 and 4.5 million kWh, and 16 at sites with an annual usage greater than 4.5 million kWh.
A direct fired process is one that does not depend on a central steam or hot water boiler and distribution systems covered in the process boiler section above. The heating elements or burner is located at and is part of the process units. An example of this would be a drying oven where air is heated by electric resistance elements or gas fired burners. Heated barrels in injection molding machines are also direct fired systems. In total, 346 direct fired units were observed in the field. As shown in Figure 11-35, the weighted respondent-level sample data finds that 53% of direct fired units are 100 – 200 MBTUH in size. Direct fired units may also be electric-fueled or gas-fueled. During the on-sites assessments, field staff found that of the 346 units, 178 were confirmed as gas-based and 64 were confirmed as electric-based.

Direct fired equipment may also be custom built and sized for a particular function or task. Heating capacities are not always provided on equipment nameplates. Field staff was not able to determine the capacities of 18.0% of the equipment. The electrically fueled process heating units input was converted to MBTUH to allow for consistent reporting across all fuel types in Figure 11-35 and Figure 11-36 below.

**Figure 11-35. Direct-fired equipment input capacity in MBTUH**

![Diagram showing distribution of direct fired equipment input capacity in MBTUH]

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 346 direct fired process equipment with input capacities listed in MBTU, 67 between 0-4.9, 28 between 5-9.99, 67 between 10-99.9, 41 between 100-199.9, 12 between 200-499.9, 18 at or above 500, and 113 for which the input capacity was not known.
Figure 11-36: Direct-fired equipment input capacity in MBTUH (un-weighted)

*The results presented above are un-weighted.
** These data represent 346 direct fired process equipment with input capacities listed in MBTU, 67 between 0-4.9, 28 between 5-9.99, 67 between 10-99.9, 41 between 100-199.9, 12 between 200-499.9, 18 at or above 500, and 113 for which the input capacity was not known.

While collecting information on these systems, field staff collected information on the estimate annual operating hours. As shown in Figure 11-37, 21 of the direct fired process equipment had variable operation and are used “as needed” in the manufacturing process. This means that there is no set scheduled operation in place for these units. Heater operation is based upon sales and the business cycle and the specification of the product being produced. We found that 67 direct fired units operate continuously (8,760 hours per year). The wide range of operating hours is consistent with varied manufacturing processes across multiple industries.
Figure 11-37: Direct-fired equipment annual operating hours

*The results presented above are weighted using the respondent-level sample weight.

**These data represent reported annual hours of operation for 346 direct fired units, 21 units reported minimal operation on an as-needed basis, 4 reported annual operation of 0-999 hours, 20 reported annual operation of 1,000-1,999 hours, 4 reported annual operation of 2,000-2,999 hours, 7 reported annual operation of 3,000-3,999 hours, 2 reported annual operation of 5,000-5,999 hours, 67 reported non-stop operation of 8,760 hours, and for 221 units the annual hours of operation was not known.
Figure 11-38. Direct-fired equipment annual operating hours (un-weighted)

*The results presented above are un-weighted.
11.5 Process refrigeration/cooling

Process cooling equipment consists of chillers and refrigeration systems that provide cooling of product during and after manufacturing. Chilled water or refrigerant is pumped to the process line or equipment. The equipment type is similar to equipment providing space cooling or serving refrigerated cases in retail markets.

During the on-site assessments field staff collected information on the different types of process cooling equipment they found. As shown in Figure 11-39, screw chillers accounted for 27% of process cooling equipment according to the weighted respondent-level sample data. 6% of process cooling loads are met by centrifugal chillers. Reciprocating and scroll chillers account for 16% and 12% of equipment respectively. Cooling tower only suggests that ambient air is sufficient to meet cooling loads without mechanical compressors during portions of the year.

Figure 11-39: Process cooling equipment types

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 136 process cooling system types, 11 centrifugal compressors, 22 cooling tower only systems, 18 reciprocating compressors, 27 screw compressors, 23 scroll compressors, and 35 for which the type was not identifiable.

The weighted the respondent-level sample data was reviewed according to facility energy usage. As shown in Figure 11-40, 54.0% with annual energy usage less than 4,500,000 and greater than 500,000 kWh required process cooling.
Figure 11-40. Process cooling equipment quantities by business energy-usage classification

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 136 process cooling units, 46 at sites with an annual energy usage between 500,000 and 4.5 million kWh, and 90 at sites with an annual energy usage greater than 4.5 million kWh.

Figure 11-41 presents the average age of cooling equipment observed in the field. The data collected indicates that 33% of the process cooling units were manufactured before 1990 and another 8 process cooling units were manufactured before 2000. Sixteen units were manufactured in 2009 or later. Process cooling systems consist of the chillers, pumps, and towers. These systems are expensive to install and maintain. There is certainly energy and some dollar savings present here with the high stock of older equipment. The high replacement costs may make system and equipment changes less cost effective.

Figure 11-41: Process cooling-equipment average age

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 136 process cooling manufacture date, 4 manufactured prior to 1990, 24 manufactured between 1990 and 1999, 19 manufactured between 2000 and 2008, 48 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, 23 manufactured in 2009 or later, and 18 for which the manufacture date was not determined.
Process cooling equipment ranges from 10-tons and less to chillers greater than 500-tons. The small process cooling units tend to be self-contained packages that contain scroll compressors. These provide spot cooling for specific cooling loads. The large equipment is primarily centrifugal and rotary screw systems in a central plant that provide chilled water or refrigerant across multiple devices in the plant. Figure 11-42 indicates the capacity of the systems observed in the field. Based upon the weighted sample data small systems account for 8% of process cooling equipment and the largest equipment accounts for just 2%. For a significant portion of the process cooling equipment the capacity was not determinable on-site (59%). Frequently the rated cooling capacity of the process cooling equipment types captured in this section is not listed on equipment nameplates. For over half of the units with an unknown capacity a valid manufacture and model number was captured for the unit however the capacity was not listed and could not be easily found online.

![Figure 11-42: Process Cooling-equipment capacity in tons](image)

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 136 process cooling units, 7 with a rated capacity of 0-9.9 tons, 6 with a rated capacity of 10-19.9 tons, 3 with a rated capacity of 20-49.9 tons, 10 with a rated capacity of 50-99.9 tons, 8 with a rated capacity of 100-199 tons, 9 with a rated capacity of 200-499 tons, 6 with a rated capacity at or above 500 tons, and 87 for which the rated capacity was not known.

Chilled water pumps provide chilled to the required process equipment and loads. Smaller pumps are associated with smaller reciprocating and scroll systems that are dedicated to specific process loads. The larger pumps are generally linked with large chillers and central chilled water plants.

The rated horsepower of the chilled and condenser water pumps is shown in Figure 11-43. Over two-thirds of all pumps were rated between 0 and 19 HP. At sites with annual energy usage between 500,000 and 4.5M kWh 98% of pumps were between 1 and 49 HP. Across all sites the most common HP range was between 10-19 HP. For the 19 pumps above 50 HP the efficiency was available and captured for 12 of the 19 pumps. The rated efficiency for those 12 pumps fell between 93% and 95% or an average of 93.7%. For the 106 pumps with rated HP between 0-49 the efficiency was available and captured for 42 pumps. The efficiency for those pumps ranged from 84%-94.7% or an average of 89.2%.
The results presented above are weighted using the respondent-level sample weight.

These data represent 137 chilled or condenser water pumps, 10 with a HP less than 1, 30 with a HP between 1 and 4.9, 13 with a HP between 5-9.9, 34 with a HP between 10-19.9, 19 with a HP between 20-49.9, 10 with a HP between 50-99.9, 6 with a HP between 100-199, 6 with a HP at or above 200, and 9 for which the HP was not known.

The 137 chilled and condenser water pumps observed in the field were located at twenty-four different businesses, all with annual energy usage at or above 500,000 kWh. The 19 pumps located at sites with an annual energy usage between 500,000 and 4.5 million kWh were observed at eight different sites or an average of 2.375 pumps per site. The 118 pumps located at sites with an annual energy usage greater than 4.5 million kWh were observed at sixteen sites or an average of 7.4 pumps per site. Figure 11-44 illustrates the distribution of chiller or condenser water pumps by business energy-usage category.
The observed or site contact reported chilled or condenser water pump control strategy by pump motor is illustrated in Figure 11-45. The responses captured in the field were open ended and either came directly from the site contact or were physical observations made by field staff. Four of the responses were “EMS;” however, EMS is not necessarily a control strategy. A pump controlled by an EMS system could be a fixed speed, controlled by VSD, or a run on demand pump. In raw numbers 90 of the 137 pumps have a control strategy defined as fixed speed, demand, or VFD. Of the 54 fixed speed pumps the rated HP ranges from .5 to 20 HP with an average of 7.5 HP. All pumps over 50 HP were either controlled by VFD, “EMS,” or the control strategy was not known.

**Figure 11-45: Chilled water-pump controls**

*The results presented above are weighted using the respondent-level sample weight.*

**These data represent the control strategy for 137 chiller or condenser water pumps, 9 on demand, 9 controlled by EMS, 54 fixed speed, 27 controlled by VFDs, and 38 for which the control is not known.*

The distribution of chilled or condenser water pumps’ age is shown in Figure 11-46. For Chilled water pump age, the high percentage of pumps manufactured in 2008 or prior is attributable to field staff or site contact age estimates in the absence of a known exact age of equipment.

In looking at estimated and known age by equipment size, no meaningful correlations were made between the distribution across all ages and sizes. When looking at known pump efficiencies by age the results are as expected. Four of the five pumps manufactured after 2008 had a known efficiency of 95% and for the other the efficiency was unknown. Eighteen pumps with known efficiencies had a rated efficiency below 90%. One of those eighteen was manufactured in 2000 and for the other seventeen the age was estimated to be sometime prior to 2009.
*The results presented above are weighted using the respondent-level sample weight.

*These data represent the age for 137 chiller or condenser water pumps, 3 manufactured between 1990 and 1999, 7 manufactured between 2000 and 2008, 107 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, 5 manufactured in 2009 or later, and 15 for which the age was not known.

### 11.6 Injection Extrusion and Forming

Several types of forming processes were encountered in the field. The injection molding processes inject material (metal, glass, and most commonly plastic) into a mold which provides shape for the item. An example is producing plastic lids. Air can be forced into the molds to create hollow items. This process is called blow molding. In extrusion molding, material (metal or plastic) is forced through a die. The run can be continuous or semi-continuous. Extruded product examples are film and wire. Thermoforming is heating plastic sheets and then shaping and trimming the final product. Common elements to all these processes are transporting and heating the raw material, implementing a forming process, and handling the final product. Electric heat is the most common process heating source. Process cooling and compressed air systems may support these processes.

Figure 11-47 shows the various product molding, extrusion, and forming systems identified in the industrial sites. Systems were identified according to broad system types and are not broken out by material type (plastic, metal, glass). Injection molding machines were the most prevalent at 56.0% of the equipment. Extrusion machines were the second most common (30.0%) followed by blow molding machines at 12.0%. Thermoforming machines comprised just 1.0% of the units.
The results presented above are weighted using the respondent-level sample weight.

These data represent 127 units, 30 blow molding, 17 extrusion units, 75 injection molding units, 4 thermoforming units, and 1 units for which the type was not identifiable.

The various forming, molding, and extrusion systems technology types are detailed in Figure 11-48. Injection molding machines had the widest variation in technology types with 29 hydraulic units, 15 hybrid, 11 electric, and 20 for which the equipment type was not identifiable. Blow molding units were mostly hydraulic machines (20) with two electric, one hybrid and seven for which the operational type was not identifiable. All but one of the extrusion systems observed were single screw operation.
Equipment is sized in tons in the forming industry. In molding machines, the tons refers to the clamping force required to seal the molds. In extrusion, tons refers to the ram pressure forcing malleable material through a die. The larger the component made or the denser the material, the larger the equipment must be. The molding forming, and extrusion equipment tonnage ratings are illustrated in Figure 11-49. The tonnage is fixed by design at the machine so it is not possible to have a 100 ton machine operate as a 250 ton machine in the future. The tonnage rating of injection molding units was most readily identifiable relative to the extrusion, blow molding and forming equipment. Of the seventy-five observed injection molding units there was an equal distribution across all tonnage categories ranging from 28 to 720 tons. Only four of the thirty blow molding units observed in the field had a tonnage rating listed on the unit or known by the site contact and all four were rated at five tons. Of the seventeen extrusion units observed only seven had an identifiable tonnage rating. Of the ten extrusion units with an unknown tonnage nine of them had a known horsepower. The extrusion equipment’s rated horsepower ranged from 75 HP with 3” barrels to 500 HP with 6” barrels. Unfortunately, it is not possible to accurately convert the known HP of the extrusion units to

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* The results presented above are weighted using the respondent-level sample weight.

** These data represent 127 units, 30 blow molding, 17 extrusion units, 75 injection molding units, 4 thermoforming units, and 1 units for which the type was not identifiable.
tonnage given the information gathered. None of the four thermoforming units had an identifiable tonnage but all operated 8,000 to 8,760 annual hours.

**Figure 11-49: Injection/forming/extrusion/molding equipment sizes in tons**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 127 units, 30 blow molding, 17 extrusion units, 75 injection molding units, 4 thermoforming units, and 1 units for which the type was not identifiable.

Figure 11-50 indicates the annual operating hours of these machines. Annual operating hours are reported using the respondent-level sample weights. Annual operation refers to the hours the machines are used for the process. Operating hours can vary significantly even between machines in the same facility. Some machines are dedicated to a certain process line or product run. These are used only for that contract run. Machine operation can also be impacted by seasonal demands and by business cycles. Thirty eight percent of molding machines continuously operate day and night year-round. Twenty five percent of molding machines operate between 3,000 and 4,000 hours. The “don’t know” category accounts for 8% of the units. Some of these units contributing to “don’t know” are idle units waiting for new contract runs or are idle because product type and specifications have changed moving production to other process lines. Machines that operated on annual run times will vary over time for each machine due to changes in product and contracted quantities.
As shown in Figure 11-51, nearly 75% of the thermoforming machines were manufactured before 2008. All forming machines are expensive to replace so existing units are well maintained and retained as long as possible. New equipment may be more efficient, but reduction in cost-per-unit production or increases in throughput need to be significant for a machine to be replaced and whole machine are rarely replaced just for energy savings. It is not uncommon to see older equipment operating on plant floors for those reasons.
**Wastewater treatment plants**

While visiting process facilities field engineers sought to obtain relevant data on both wastewater treatment plants (WWTx) and water treatment plants. While visiting the treatment plants field staff asked the site contact a series of questions to gain a better understanding of the plant operations while also collecting specific equipment information. The information they gathered included plant capacity (gallons of water treated per day), peak periods or seasonal fluctuations, daily peak periods as well as whether or not a SCADA system was in place, whether or not biogas was used for cogeneration, what sort of aeration system was used and how was sludge dried. This section provides a summary of the information collected on-site from these types of facilities. Due to the small sample size of treatment plants, this information is not necessarily representative of all treatment plants in Massachusetts. Un-weighted figures and charts are provided below each weighted figure to provide a point of reference.

Figure 11-52 shows the various sizes of the treatment plants that were visited during the study. We surveyed eight plants in total. Almost 75% of the plants visited had a treatment capacity between 1 and 5 million gallons per day (MGD). Only 1 plant was visited was between 5 and 10 MGD and 2 plants were more than 10 MGD facilities. Figure 11-53 provides the same results un-weighted.
Figure 11-52. Wastewater treatment plant daily capacity

- 74% of facilities have daily capacity of 10 Million Gallons/Day and above
- 13% have daily capacity of 5-9.9 Million Gallons/Day
- 13% have daily capacity of 1-4.9 Million Gallons/Day

*The results presented above are weighted using the site-level sample weight.

**These data represent 8 wastewater treatment facilities’ daily capacity in gallons per day, 5 between 1-4.9 million, 1 between 5-9.9 million, 2 at or above 10 million.

Figure 11-53: Wastewater treatment plant daily capacity (un-weighted)

- 62% of facilities have daily capacity of 10 Million Gallons/Day and above
- 25% have daily capacity of 5-9.9 Million Gallons/Day
- 13% have daily capacity of 1-4.9 Million Gallons/Day

*The results presented above are un-weighted.

**These data represent 8 wastewater treatment facilities’ daily capacity in gallons per day, 5 between 1-4.9 million, 1 between 5-9.9 million, 2 at or above 10 million.

Of these facilities, 39% of the treatment plants had a SCADA system in place as shown in Figure 11-54. SCADA (Supervisory Control and Data Acquisition) systems are computer-based control systems used to monitor the facilities equipment, much like a building energy management system (EMS) would. SCADA systems collect and store information on equipment operations that may be used for reporting, maintenance tracking, and understanding whether or not equipment is functioning properly. Similar to EMS, SCADA can
help reduce operating costs and improve operational performance. Figure 11-55 provides the same results un-weighted.

**Figure 11-54: Wastewater treatment facilities with SCADA systems**

![Pie chart showing percentages of facilities with SCADA systems](image)

*The results presented above are weighted using the site-level sample weight.

* These data represent 8 wastewater/water treatment use of SCADA Systems, 4 with SCADA systems, 2 without SCADA systems, and 2 for which it was not known.

**Figure 11-55: Wastewater treatment facilities with SCADA systems (un-weighted)**

![Pie chart showing percentages of facilities with SCADA systems (un-weighted)](image)

*The results presented above are un-weighted.

* These data represent 8 wastewater/water treatment use of SCADA Systems, 4 with SCADA systems, 2 without SCADA systems, and 2 for which it was not known.
A bi-product of the wastewater treatment plant process is bio-gas. Bio-gas produced in anaerobic condition produces methane which can be used as a fuel generator to produce electricity or heat. According to the Massachusetts Department of Environmental Protection (MA DEP) of the 133 WWTx’s in the state, only 5 use anaerobic digestion for treating sludge and collect the bio-gas bi-product for use. Of the 8 treatment plants visited for the C&I On-site Assessments, field staff did not observe that any of them produced and collected bio-gas to use as a fuel.

Treatment plants often use aeration systems to treat municipal wastewater, maximize aerobic digestion and control odors. Aeration systems are designed to maintain oxygen levels in the wastewater flow during the treatment process. Maintaining oxygen levels is essential for keeping the microorganisms that turn organic wastes into inorganic bi-products alive. Energy costs associated with the operation of aeration systems are generally 30%-60% of a WWTx facility’s electric bill. To be conservative, many facilities provide more oxygen than is needed to support the activity of the microorganisms. Modulating aeration based on dissolved oxygen levels, so that aerators only provide the amount of oxygen needed to adequately treat the wastewater, can help reduce energy costs and improve efficiencies. As Figure 11-56 indicates, over 50% of the treatment plants visited during the on-site assessments staged aeration so that only the oxygen that was needed for treatment is provided. Field staff were unable to confirm staged aeration at 33% of the facilities. Figure 11-57 provides the same results un-weighted.

**Figure 11-56: Wastewater system aerators staged to match dissolved oxygen levels**

*The results presented above are weighted using the site-level sample weight.

** These data represent 8 wastewater/water treatment facilities ability to stage aerator operation to match dissolved oxygen levels, 5 that do, 1 that does not, and 2 for which it was not known.

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Figure 11-57. Wastewater system aerators staged to match dissolved oxygen levels (un-weighted)

![Pie chart showing the results of staged aerator operation.]

*The results presented above are un-weighted.

** These data represent 8 wastewater/water treatment facilities ability to stage aerator operation to match dissolved oxygen levels, 5 that do, 1 that does not, and 2 for which it was not known.

Aeration systems can also vary in efficiency depending on the type of blower used and whether or not the aeration diffuser is a coarse-bubble or fine-bubble system. Coarse-bubble diffusers tend to use more energy while fine-bubble diffusers have a higher aeration efficiency and therefore tend to require less energy to run. Of the 8 systems observed in the field, 4 of them were identified as fine-bubble membrane systems. The remaining were unable to be determined. One of the 8 systems observed, were operated with a turbo-blower; these are considered to be the most efficient blowers in the market with a 70%-80% efficiency rating according to industry sources.
Sludge drying could represent another area for potential energy savings opportunities. Six sites of the eight waste water treatment plants were identified as having a sludge drying systems. Of these sites the drying processes were identified as on-site composting, use of a gravity belt, use of a hot-fluid system and use of emulsion polymers.

Figure 11-59 presents the various types of equipment that field staff did collect information on during the site visits. Of the 8 waste water treatment plants visited, field staff collected information on over 450 pieces of equipment. Additionally, some of the equipment in this section was observed at a handful of water treatment, manufacturing and one warehouse facility. The quantities are listed by units of equipment, which refers to equipment that serves a role in the wastewater or water treatment function but is a separate piece of equipment with a dedicated nameplate. The most commonly observed equipment were mixers and water pumps. The "other" category consists of equipment such as UV disinfection systems, sludge grinders, and grit removal systems.
Figure 11-59: Wastewater treatment equipment types present

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 453 wastewater treatment equipment units - 47 aerators, 16 blowers, 8 centrifuges, 10 clarifiers, 64 mixers, 37 odor control fans, 9 polymer pumps, 53 sludge pumps, 11 thickeners, 122 water pumps, and 76 systems dedicated to the process of wastewater treatment but do not fall into one of the above categories.

Figure 11-60 represents the wastewater equipment distribution by site for all sites with equipment that serve wastewater or water treatment processes. Wastewater treatment sites are labeled as WWTx, water treatment facilities are labeled as H20Tx, other manufacturing sites are labeled as OthManf, and the one warehouse with water treatment equipment is labeled as warehouse. The facility type labels are followed by a number representing the annual kWh usage category for the site with a “2” representing annual usage between 500,000 kWh and a “3” representing annual usage over 4,500,000 kWh.
Figure 11-60. Wastewater treatment equipment type counts present by site (un-weighted)

*The results presented above are un-weighted.

**The equipment represented above was present at 8 Wastewater Treatment Facilities, 2 Water Treatment Facilities, 3 manufacturing facilities, and one warehouse.

Figure 11-61 shows the distribution of various sizes (HP) of equipment found in the field. The data indicates that the majority of centrifuges, clarifiers, control fans and thickeners sizes are below 5 HP, while aerators, blowers, and sludge pump tend to be larger in size (greater than 10 HP).
While on-site, field staff asked the facility contact what the approximate operating hours per year were for each piece of equipment we collected information on (Figure 11-62). About 1/3 of the responses were "Don’t Know"; however, we did determine that 25% of the equipment was in use for 11 - 15 hours per day, while 17% of equipment is in operation 24 hours per day, 365 days of the year. The equipment most often found to be in operation 24 hours/day, 365 days/year were: water pumps, sludge pumps, mixers, and exhaust fans. Water pumps and sludge pumps were also often noted to be in operation for less than 4,000 hours per year along with blowers, chemical pumps, and mixers. The amount of time pumps (of any type) operate in general is greatly dependent on the process they support. We did not find any immediate correlation between the size of the pumps and their annual operation hours. Large pumps may be found to operate for 8760 hours per year for processes like secondary treatment, and they may operate for less than 200 hours per year to support processes like backwashing.
*The results presented above are weighted using the respondent-level sample weight.

** These data represent the annual operating hours of 453 units, 39 that operate 0-999, 15 which operate 1,000-1,999, 54 that operate between 2,000-2,999 hours, 5 that operate between 3,000-3,999 hours, 32 that operate between 4,000-4,999 hours, 58 that operate between 5,000-5,999 hours, 3 that operate between 6,000-6,999 hours, 65 that operate between 7,000-8,759 hours, 57 in constant operation for 8,760 hours, and 125 units for which the annual operation was not known.

Figure 11-63 presents the same information unweighted.
*The results presented above are un-weighted and represent equipment units observed in the field.

** These data represent the annual operating hours of 453 units, 39 that operate 0-999, 15 which operate 1,000-1,999, 54 that operate between 2,000-2,999 hours, 5 that operate between 3,000-3,999 hours, 32 that operate between 4,000-4,999 hours, 58 that operate between 5,000-5,999 hours, 3 that operate between 6,000-6,999 hours, 65 that operate between 7,000-8,759 hours, 57 in constant operation for 8,760 hours, and 125 units for which the annual operation was not known.

Figure 11-64 presents the age of the various type of equipment observed on-site. The data indicate that the greatest prevalence of new equipment was found with centrifuges, blowers and thickeners, while aerators, clarifiers, mixers and pumps tend to have the highest percentages of older equipment. Polymer pumps and aerators had a particularly high number of equipment that has been in operation since before 1990. For aeration systems, this may represent an opportunity for energy efficiency programs based on the finding that only about half of aeration systems observed, were confirmed to be the more efficient fine bubble systems, and that only about half were confirmed to be staged to match dissolve oxygen levels.
Figure 11-64. Wastewater/water treatment average age of equipment

*The results presented above are weighted using the respondent-level sample weight.

** These data represent 453 wastewater treatment units’ age, 47 aerators, 16 blowers, 8 centrifuges, 10 clarifiers, 64 mixers, 37 odor control fans, 9 polymer pumps, 53 sludge pumps, 11 thickeners, 122 water pumps, and 76 systems dedicated to the process of wastewater treatment but do not fall into one of the above categories.

During the on-site assessments, field staff also gathered information on the types of controls for the different types of equipment observed at the facilities (Figure 11-65). The data indicate that for 60% of the units observed the control method could not be determined, none were found to be manually operated, 19% were found to be fixed operationally so they run at constant speed, and another 21% were found to vary operation based on flow or operated with a VSD. Many exhaust fans tend to be operating at a fixed speed along with primary, secondary and tertiary treatment pumps.
**Figure 11-65. Wastewater treatment equipment controls**

![Diagram showing wastewater treatment equipment controls]

*The results presented above are weighted using the respondent-level sample weight.*

**These data represent the control strategy for 453 wastewater treatment units, 79 fixed, 1 manual, 75 VSD, 19 which variable by flow, and 279 for which the control type was not identifiable.*

Figure 11-66 shows the unweighted distribution of wastewater and water treatment equipment control types when the motor control type was identifiable. Because of the location and positioning of the wastewater treatment equipment, a large portion of the equipment had controls that were not identifiable. While Figure 11-66 attempts to clearly illustrate the distribution of known controls, it should be noted that an additional 279 units were observed for which the control type was not identified.
The miscellaneous process motors section of the data collection effort was a catch-all for any process motor present not captured by one of the other process equipment sections. These motors are in large part devoted to a single task; pumping, moving product (conveyor), moving air (blower fans), mixing product, among others. Some motors are classified as direct drive meaning they deliver power directly to mechanism with no gear reductions or friction from a gearbox, belt, pulley, or chain. The data collection staff were instructed to capture motors defined by these characteristics.

There were times when a description from a site contact or details found in a process flow chart caused field staff to inventory process motors in other process equipment sections above where on the surface they would normally be found in the miscellaneous process motors section. The reverse occurred to some degree where motors were recorded in other process sections that are more characteristic of what is being defined as miscellaneous process motors for this report. This inability to consistently classify every piece of end use equipment found in a process facility is a known uncertainty. In reviewing process equipment data hundreds of end use equipment records were moved across end use sections to maintain the highest achievable level of consistency.

Motor types, motor uses, motor control types, motor sizes and motor ages were of significant focus for observed miscellaneous motors. The average age of motors based on respondent weighting showed a significantly high portion of motors still in operation were manufactured prior to 1990 (45%) and only 2% were manufactured after 2008.

The distribution of stand-alone vs. integrated miscellaneous process motors is shown in Figure 11-67. Stand-alone motors were isolated from other motors and not part of an assembly line or process activity that included simultaneous operation of additional motors. For over half of the total motors observed, field
staff were not able to confidently determine if the individual motors should be classified as stand-alone or integrated. The two biggest factors that contributed to the high incidence of uncertainty surrounding this characteristic were limited time and access on the plant floors. The motors collected in the process motor category were observed at 46 different facilities with an average of 26 motors per site. Often site level interviews with facility staff knowledgeable about these motors took several hours and in some cases the actual tour of facilities where equipment inventories primarily were conducted were done in haste or in the absence of a knowledgable site contact. Simple line diagrams or detailed information on motor operation and load design were rarely available.

For miscellaneous process motors where the operation load type was identified, approximately 44% were integrated and 56% were stand alone. For the sites with annual energy usage below 500,000 kWh the uncertainty level was the highest with 82.5% of motor load types being unknown. For the mid–level and high energy usage sites the unknown were around 10%. For the mid-level energy usage sites, a higher percentage of stand-alone motors were observed at 58% versus 30% integrated. For the sites with annual energy usage over 4.5M kWh, 61% of motors were integrated and 29% were stand-alone.

**Figure 11-67. Process motors - stand-alone vs. integrated**

![Pie chart showing distribution of motors](image)

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1218 miscellaneous process motors operational load type in terms of operating in isolation or in an integrated system, 473 were stand-alone, 402 were integrated, and for 343 where the operational load type was not identifiable.

The distribution of miscellaneous process motors recorded primary load type is shown in Figure 11-68. The categories shown were post-coded by senior DNV GL engineers following site visits. The post coding effort was based on the open ended entries capturing equipment served, comments about the motor, and in some cases images of the motor and or motor nameplate.

Figure 11-69 illustrates the distribution of miscellaneous process motor load types across the three different business annual kWh usage categories. The first bar for each motor load type presents the average representation that load type has across all business usage categories. For the other three usage categories the bars represent the motor load type’s share of the overall motor load types within the three respective business kWh size usage categories.
The “other” miscellaneous process motor load category represented 41% of overall motors and were most prevalent in business that fell into the lowest annual energy usage category with 50% of those business’ process motors. Direct drive load type motors had the second highest representation across all process motor load types at 25%. The mixer load type category represented 5% of the overall process motor population and were most prevalent at the lowest level annual energy usage category businesses at 6.6%.

The pump load type category captured all pump motors not represented at industrial facilities as chiller/condenser water pumps, process heating pumps, and wastewater treatment categories discussed above. Any motor tasked with moving some liquid media not categorized in one of the other process pumping categories were captured here. The pump load category represented 16% of all process motors and were most prevalent in the business with annual energy usage below 500,000 kWh.

The blower fan load type category defines any motor that moves air or gas mixture as part of a manufacturing process. Blower fans represent 3% of the overall miscellaneous process motors and saw the highest representation in the high energy usage businesses at 13% of those process motors. The blower fan motors are not however exhaust or make-up air fans, designed to remove particulate and maintain healthy habitable air quality. Those fan motors are captured in Section 11.8 plant ventilation below.

Conveyor load type motors are dedicated to the task of moving product via belts, pulleys, chains, or some other similar means as part of the production process. Conveyors represented 5% of all miscellaneous process motors. They were not present at process facilities with energy usage below 500,000 kWh and most prevalent at facilities with annual energy usage between 500,000-4.5M kWh at 15% of this sector.

Figure 11-68. Miscellaneous process motor equipment load type

* The results presented above are weighted using the respondent-level sample weight.

** These data represent the primary load type of 1218 miscellaneous process motors, 125 Blower Fans, 269 Conveyor, 271 Direct Drive, 20 Mixer, 302 Other Process, 145 Pump, and for 86 the primary load type was not identifiable.
The results presented above are weighted using the respondent-level sample weight.

** These data represent the primary load type of 1218 miscellaneous process motors, 125 Blower Fans, 269 Conveyor, 271 Direct Drive, 20 Mixer, 302 Other Process, 145 Pump, and for 86 the primary load type was not identifiable.

The distribution of miscellaneous process motor types is shown in (Figure 11-70). 71% of the motor types could not be identified. In many cases motors were located in restricted areas and confirming the motor type was not possible. Site level weighting shows AC Induction motors were the most prevalent motor type observed in the field. AC Induction motors were the only motor types observed at sites with kWh usage below 500,000. At sites with annual energy usage of 500,000-4.5M kWh DC Brushed and Brushless motors accounted for only 12% of motors. At sites with annual energy consumption over 4.5M kWh DC motor types jumped up to 27% combined with AC Induction accounting for 43%.
The distribution of miscellaneous process motor units by rated horsepower is shown in Figure 11-71. Close to half of the motors inventoried were less than one horsepower and 74% were under 5 horsepower. As the horsepower categories increase the percent of the total motor population continually diminishes with motors over 500 horsepower accounting for only .25% of the motor population units inventoried. For the business with annual energy usage below 500,000 kWh the only process motor sizes observed were below 5 horsepower. At facilities with the annual electricity usage over 4.5M kWh motors over 10 HP accounted for over 50% of the observed motors with 0 motors observed below 1 HP.
Figure 11-71. Miscellaneous process motor horsepower

* The results presented above are weighted using the respondent-level sample weight.

** These data represent the horsepower of 1218 miscellaneous process motors, 199 between 0-.99, 341 between 1-4.9, 189 between 5-9.9, 143 between 10-19.9, 98 between 20-49, 88 between 50-99, 42 between 100-199, 45 between 200-499, 14 at or above 500 horsepower, and 59 for which the horsepower was not known.

Miscellaneous process motor distribution across business annual energy usage size categories is shown in Figure 11-72. The site-level weighting places a significant emphasis on the 61 process motors observed at businesses with annual usage below 500,000 kWh. In terms of raw numbers over two-thirds of the total 1,218 process motors observed in the field were found at businesses with annual energy usage between 500,000 and 4.5M kWh.

Figure 11-72. Miscellaneous process motor distribution by kWh usage

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 1218 miscellaneous process motors, 61 at sites with an annual energy usage under 500,000 kWh, 810 at sites with an annual energy usage between 500,000 and 4.5 million kWh, and 347 at sites with an annual energy usage greater than 4.5 million kWh.
The distribution of process motors age is shown in Figure 11-73. Respondent-level sample weighting shows the 224 observed motors with ages prior to 1990 represent 45% of the population of motors. Of the 61 motors observed at sites with annual energy usage below 500,000 kWh, 43 were manufactured prior to 1990. Based on respondent-level weighting 2.2% motors were manufactured after 2008 or 41 of the 1,218 observed process motors.

**Figure 11-73. Miscellaneous process motor age**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent the age of 1218 process motors, 224 manufactured prior to 1990, 132 manufactured between 1990 and 1999, 180 manufactured between 2000 and 2008, 538 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, 41 manufactured in 2009 or later, and 83 for which the date was not determined.

Figure 11-74 shows the distribution of VFD control for miscellaneous process motors. There were only a small percentage of process motors for which field staff was able to identify VFD control. In terms of respondent-level sample weighting 65% of the process motors control type is unknown and slightly less than half of the raw observed process motors control strategy was not determined. One of the biggest limitations field staff had in identifying VFD control is that motors and their controllers are often located in areas not easily accessible, so nameplate and control method characteristics data is captured from afar or second hand from site contact or equipment inventory logs. Even when access to the motor nameplate is permitted, the nameplate does not indicate the presence of a VFD. In many cases VFDs are not cost effective if a motor is less than 5 HP or does not run for significant portions of time. For all miscellaneous process motors at or above 25 HP 64% of those with known control types had a VFD in terms of raw units observed. That same number drops to 23% for all miscellaneous motors between 5 and 24.9 HP with known control types in terms of raw units observed.
**Figure 11-74. Process motor controlled by VFDs**

![Pie chart showing the distribution of VFD control for process motors.](image)

* The results presented above are weighted using the respondent-level sample weight.

** These data represent the control strategy for 1218 process motors, 110 controlled by VFD, 540 not controlled by VFD, and 568 for which the control is not known.

### 11.9 Plant ventilation

While visiting process facilities field engineers sought to obtain relevant data on the fan and ventilation systems that served specific areas and their functions in a plant. These include general ventilation, process ventilation, dust and fume removal, bag-house operation, and some environmental controls. These areas are not treated as space conditioning type HVAC exhaust/ventilation system as they have different equipment and operational specifications.

The distribution of process ventilation units by rated horsepower is shown in Figure 11-75. Close to half of all process ventilation motors are under 5 horsepower and over 65% of the units are less than 10 horsepower. That majority of the ventilation equipment for which a horsepower was not obtained were located in areas the field surveyor was not able to access or was not allowed to approach for safety concerns.
**Figure 11-75. Ventilation motor horsepower**

* The results presented above are weighted using the respondent-level sample weight.
** These data represent the horsepower of 572 units, 29 between 0-.9, 277 between 1-4.9, 86 between 5-9.9, 27 between 10-19.9, 8 between 20-49, 4 between 50-99, 4 between 100-199, 1 at or above 200 horsepower, and 136 for which the horsepower was not known.

As shown in Figure 11-76, the majority of all process ventilation units where the control method was determined were not controlled by VFDs. Five of the nine units controlled by VFDs were manufactured in 2012. Of the 44 ventilation motor units rated at or above 10 HP, only one was determined to be controlled by a VFD. As was the case with all process ventilation equipment, access to unit nameplates and knowledgeable facility staff prevented field staff from being able to determine control strategies for all ventilation equipment.

**Figure 11-76. Ventilation equipment controlled by VFDs**

* The results presented above are weighted using the respondent-level sample weight.
** These data represent the control strategy for 572 plant ventilation units, 9 controlled by VFD, 413 not controlled by VFD, and 130 for which the control is not known.
Of the 572 total observed process ventilation units nearly 500 were estimated to be manufactured prior to 2009 as shown in Figure 11-77. In many cases process ventilation equipment is located above the factory floor and does not always have a nameplate legible from the floor or roof. Field staff relied on information provided by site contacts to determine ages for units where nameplate data was inaccessible or nameplate data did not contain a manufacture date. All of the units with known manufacture dates prior to 2000 were located at businesses with annual energy usage of 500,000 kWh or higher.

**Figure 11-77. Process ventilation equipment average age**

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 554 process ventilation units’ age, 20 manufactured prior to 1990, 43 manufactured between 1990 and 1999, 112 manufactured between 2000 and 2008, 325 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, and 34 manufactured in 2009 or later.

### 11.10 CNC, product packaging, and modular precision manufacturing machines

The majority of the computer numerical controlled (CNC) or modular precision manufacturing (MPM) machines is composed of multiple custom built motors. This equipment is primarily manufactured in China, Germany or Italy and replacement parts have to be ordered directly from the supplier or the whole machine needs to be replaced. The total capacity of the machine is the clearest way to quantify the energy consumption.

Figure 11-78 shows CNC equipment quantities across business sizes. Over half the estimated population of CNC or MPM equipment is found at sites with annual energy usage between 500,000 and 4,500,000 kWh (273 of 444 observed machines) based on the respondent-level sample weights. While CNC or MPM machines were found at thirty-five sites, the top seven sites accounted for 70% of the 444 total units, while 40% of the thirty-five sites had just one unit.
**Figure 11-78. CNC equipment quantities across business sizes**

- 56% of sites use less than 500,000 kWh.
- 34% of sites use between 500,000 and 4,500,000 kWh.
- 10% of sites use more than 4,500,000 kWh.

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 444 CNC machines, 14 at sites with an annual energy usage under 500,000 kWh, 273 at sites with an annual energy usage between 500,000 and 4.5 million kWh, and 157 at sites with an annual energy usage greater than 4.5 million kWh.

The distribution of CNC or modular precision manufacturing machines’ age is shown in Figure 11-79. Based on the respondent-level site weights, over 85% of CNC or modular precision manufacturing machines were produced prior to 2009. For the sites with the highest quantities of CNC machines the manufacturing dates do not reveal any meaningful patterns and ages are evenly dispersed across all age categories. The eighteen of the twenty machines manufactured prior to 1990 were located at one business. The same business also had fifteen units manufactured after 2008.

**Figure 11-79. CNC equipment average age**

- 48% were manufactured in 2008 or earlier (estimated).
- 22% were manufactured in 1990-1999.
- 12% were manufactured in 2000-2008.
- 6% were manufactured prior to 1990.
- 3% are Don't Know.

* The results presented above are weighted using the respondent-level sample weight.

** These data represent 444 CNC machines’ age, 28 manufactured prior to 1990, 59 manufactured between 1990 and 1999, 48 manufactured between 2000 and 2008, 231 for which the age was not clearly identifiable but were estimated to be manufactured in 2008 or prior, 50 manufactured in 2009 or later, and 28 for which the manufacture date was not determined.
The kW input capacity distribution for CNC or modular precision manufacturing machines is illustrated in Figure 11-80. Site level weighting shows the kW input was not determinable for 58% of units however the raw data is significantly more revealing. In some cases the unit’s input is not quantified in kW but in tonnage. In others the nameplate was not legible. For the 247 units with a known kW input over 70% were less than 20 kW. The exception was at businesses with annual energy usage over 4.5M kWh where 64% of units with a known kW input were at or above 40 kW.

**Figure 11-80. CNC machine capacity (kW)**

*The results presented above are weighted using the respondent-level weight.

** These data represent the kW input of 444 CNC or modular precision manufacturing units, 24 with an input between 0-1.9 kW, 35 with an input between 2-4.9 kW, 26 with an input between 5-9.9 kW, 44 with an input between 10-19.9 kW, 24 with an input between 20-29.9 kW, 21 with an input between 30-39.9 kW, 22 with an input between 40-49.9 kW, 22 with an input between 50-99.9 kW, 29 with an input between at or above 100kW, and 197 for which the kW input was not known.*
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