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1 EXECUTIVE SUMMARY

This executive summary provides a high-level review of the results of the 2017 Massachusetts Energy Code Compliance and Baseline Study for IECC 2012 (2017 Study). This project is part of an ongoing effort to support the adoption of energy efficiency equipment, design, and construction practices that address energy and environmental challenges in Massachusetts. The Massachusetts Commercial and Industrial Evaluation Contract (DNV GL) team collaborated with the Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) to determine the study goals and develop a research plan for the project.

1.1 Objective and Approach

The primary objectives of the 2017 Study were to assess compliance with the 2012 International Energy Conservation Code (IECC 2012) for commercial new construction in Massachusetts, as well as to leverage data collected during the compliance assessment to inform baseline market practices for commercial new construction. The 2017 Study focused on the review of construction documents for a sample of 39 buildings.

The research approach for the 2017 Study consisted of the following primary activities:

1. Revisit a sample of the 2015 Study (IECC 2009) sites to examine control/operations strategies. The DNV GL team revisited a sample of 2015 Study (IECC 2009) sites to investigate whether and how recently constructed buildings are being operated with good control strategies, primarily for lighting and mechanical systems. For the purposes of this study, good control practices were defined as controls and equipment installed, functioning and either actively managed by site personnel or controlled automatically with regular maintenance. The team visited 16 sites out of 50 in the original sample, reviewing prior data collection and conducting a facility tour and discussion with personnel at each site. A memo summarizing these results was previously shared with the PAs and EEAC for review and comment, and the revised version is included in this report as Appendix A.

2. Revise 2015 Study LPD Adjustment for Program Participation. The DNV GL team leveraged a 2015 Study (IECC 2009) observation that baseline lighting power density (LPD) was better than code, mining the 2015 Study data to estimate the magnitude of the difference between standard practice and the code requirements. After factoring in program participation impacts, the DNV GL team recommended that code-required LPDs be subject to an adjustment factor of 0.78 +/- 0.10 for any new commercial construction buildings permitted under IECC 2009. Appendix B presents the previously submitted memo, and Section 4.8.2.3 updates this analysis based on the sites recruited for the 2017 Study (IECC 2012).

3. Verify energy code compliance for commercial new construction sites permitted under IECC 2012.

   a. Sample design. The project team developed a stratified random sample based on building size, with a target population of commercial new construction buildings permitted under IECC 2012. The team recruited 39 sites for the sample.

   b. Data collection. The project team refined the compliance assessment tools from the 2015 Study (IECC 2009) and a 2016 Rhode Island Energy Code Compliance Study for use in the 2017 Study (IECC 2012). Project engineers reviewed construction documents for the sites in the sample to observe and document compliance with individual energy code provisions,
and also conducted site visits for nine sites where possible and/or appropriate to supplement the document review.

c. **Estimation of energy code compliance.** The field observations were aggregated and weighted to estimate the commercial energy code compliance for the population of buildings permitted in Massachusetts under IECC 2012. As they did in the 2015 Study (IECC 2009), the project team developed and computed two methodologies to assess overall compliance:

i. The Department of Energy and Pacific Northwest National Laboratory (DOE/PNNL) methodology was originally developed to help states demonstrate compliance with a 90% energy code compliance goal established in the American Recovery and Reinvestment Act (ARRA). This methodology has been used in the prior two Massachusetts code compliance studies and is useful for comparisons over time, but it does not recognize the energy impacts of partial compliance with code provisions, nor does it facilitate code-allowed trade-offs within the building envelope.

ii. The DNV GL team methodology was developed as an improvement over the DOE/PNNL approach by assessing both partial credit with energy code provisions and trade-offs within the building envelope. This approach is consistent with COMcheck, a tool developed by DOE that is the most commonly used approach to demonstrate compliance by building designers.

4. **Leverage code compliance data to inform baselines.** The building-level data gathered to develop the compliance estimate was also used to inform baseline practices where possible. After conducting quality control reviews of the site data, the project team normalized the results to compare observations for similar equipment, resulting in a percentage better or worse than code for each site with observed data for each code provision. The project team incorporated program participation impacts and summarized the data graphically where appropriate to present the differences compared to code and between participants and nonparticipants.

### 1.2 Key Findings and Conclusions

Figure 1-1 presents the weighted and unweighted overall statewide compliance estimates from the 2017 Study (IECC 2012) for commercial new construction buildings permitted under IECC 2012. Overall compliance, when weighted by building square footage, is estimated to be 94% using the DNV GL team methodology and 88% using the DOE/PNNL methodology. At a 90% confidence level, these results have a relative precision of 2% for the DNV GL methodology and 4% for the DOE/PNNL Methodology. While both methodologies produce overall compliance rates, the DNV GL team methodology is a better reflection of the total energy impacts associated with compliance due to its inclusion of partial compliance with individual provisions and trade-offs within the building envelope and LPD. The DOE/PNNL methodology is included for consistency with the methodologies used in Massachusetts for prior studies.

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1 The ability to inform baseline practices was largely dependent upon the availability and applicability of site data. The DNV GL team primarily leveraged construction documents to assess compliance and collect equipment data. While nearly all sites have envelope and lighting data to some extent, the sites were designed to use a wide variety of mechanical equipment for heating and cooling. Thus, observations regarding boilers, furnaces, heat pumps, and other technologies were limited by the frequency that we observed these equipment on the plans or on-site.
1.2.1 Compliance Trends over Time
The use of a consistent methodology across several code studies enables the identification of trends in compliance over time and across code versions. Figure 1-2 presents a timeline of Massachusetts energy codes along with the Stretch Code and the compliance study results over time. Compliance has been improving over time in Massachusetts, with the largest jump from IECC 2006 to IECC 2009.

1.2.2 2017 Study Baseline Observations
The DNV GL Team leveraged the data collected during the compliance assessment to inform the baselines for new construction envelope, mechanical, and lighting measures. This exercise was not designed with the rigor expected of an Industry Standard Practice (ISP) study as outlined in the ISP protocols developed by the DNV GL team (P73B). Other limitations of the data include relatively small sample sizes, potential for self-selection bias, and a wide range in site-by-site results for some measures. While acknowledging these limitations, the data collected during the compliance assessment provide valuable insights into the performance of current energy codes and the potential benefits of implementing the Stretch Code.

---

2 Compliance results in this figure reflect the unweighted DOE/PNNL methodology, as this approach was used in all three MA studies and presents the best basis for comparison over time.
concerns the 2017 Study data presents actionable evidence that standard practice is better than the code requirements for many measures. Since the energy code is by definition the minimum legal standard that buildings are required to follow, it should not be surprising that many buildings go beyond the code, particularly at the measure level. Table 1-1 summarizes the baseline observations of installed equipment efficiency relative to code for many of the measures examined; additional detail for each measure is provided in the main body of the report.

Table 1-1. Summary of 2017 Study Baseline Observations Installed Efficiency Relative to Code

<table>
<thead>
<tr>
<th>Measure</th>
<th>Number of Observations</th>
<th>Mean Observation</th>
<th>90% Confidence Interval</th>
<th>Minimum Observation</th>
<th>Median Observation</th>
<th>Maximum Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope u-factor</td>
<td>38</td>
<td>21%</td>
<td>+/- 4%</td>
<td>-17%</td>
<td>21%</td>
<td>53%</td>
</tr>
<tr>
<td>Boilers</td>
<td>14</td>
<td>16%</td>
<td>+/- 2%</td>
<td>3%</td>
<td>18%</td>
<td>20%</td>
</tr>
<tr>
<td>Furnaces</td>
<td>19</td>
<td>2%</td>
<td>+/- 1%</td>
<td>0%</td>
<td>1%</td>
<td>11%</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>14</td>
<td>16%</td>
<td>+/- 5%</td>
<td>-4%</td>
<td>17%</td>
<td>42%</td>
</tr>
<tr>
<td>Domestic Hot Water</td>
<td>19</td>
<td>94%</td>
<td>+/- 2%</td>
<td>75%</td>
<td>96%</td>
<td>99%</td>
</tr>
<tr>
<td>Interior Lighting</td>
<td>36</td>
<td>37%</td>
<td>+/- 7%</td>
<td>-8%</td>
<td>37%</td>
<td>60%</td>
</tr>
<tr>
<td>Exterior Lighting</td>
<td>33</td>
<td>24%</td>
<td>+/- 9%</td>
<td>-48%</td>
<td>19%</td>
<td>87%</td>
</tr>
</tbody>
</table>

1 The observations presented in this table show percentage better/worse than code for all measures except Domestic Hot Water, which shows the actual observed equipment efficiency. Also note that the interior lighting data presented in this table reflects the site observations and does not factor in program participation, weighting, and free ridership incorporated into the LPD adjustment presented later.

1.2.3 2017 Study Conclusions

Analysis of the 2017 Study (IECC 2012) results leads to the following conclusions about commercial energy code compliance and baseline practices in Massachusetts:

1. **The compliance of nonresidential new construction (NRNC) buildings is consistent over time, even as the energy code gets more stringent.** Using the DNV GL methodology, this study estimates a compliance rate of 94%. This should be interpreted to mean that the average new construction building meets 94% of the code requirements. Despite an increase in stringency in the code, the overall compliance rate remained high, suggesting that NRNC buildings are being built fairly well in Massachusetts.

2. **The findings of the study are a clear call to action to consider the status of standard practice across the Commonwealth and its relation to code requirements.** However, it is less clear what the actual standard practice and resulting baseline value should be for each measure. This has the potential to significantly impact program savings and future offerings. The significant deviation from code necessitates further research to corroborate these findings. Given the potential departure from
code baselines, high rigor studies aligned with the ISP framework are necessary to validate these study insights.

3. **The energy code requirement for interior lighting power is not reflective of current standard practices.** The DNV GL team’s analysis of interior LPD results, factoring in PA program participation, suggests that standard lighting practices exceed the code requirements. The increasing penetration of LEDs is a primary factor. The DNV GL team determined that on average, the installed lighting LPDs were 0.67 +/- 0.05 of the code requirements for buildings permitted under IECC 2012.

4. **The energy code does not reflect standard practices for many mechanical provisions.** The 2017 Study (IECC 2012) captured efficiency data for mechanical equipment that was on construction documents and/or installed on-site where observable. This data shows that for some mechanical provisions such as boiler efficiencies and domestic hot water efficiencies, standard practices are likely somewhat better than the code requirements.

5. **Opportunities for improving compliance remain for targeted measures.** While compliance is fairly high overall, opportunities remain to improve compliance for specific measures. These measures include relatively recent additions to the code such as daylighting, as well as measures such as air sealing that are difficult to enforce without extensive testing.

6. **Energy code determinations continue to be made at the design stage for new construction.** The decisions about equipment sizing and type, construction materials, insulation levels, and control strategies occur during the building design stage, most often by architects and engineers. This trend is consistent with the 2015 Study (IECC 2009) and was confirmed during DNV GL team interviews with design and construction teams. However, poor installation practices during construction can undermine well-designed buildings.

### 1.3 Recommendations for Program Development

The DNV GL team recommends the following based on analysis of the 2017 Study (IECC 2012) results:

1. **While this study cannot determine exact baseline values, the evidence strongly suggests that the PAs should be adjusting their program planning and implementation to account for changing standard practice.** Current projects that assume code baselines for new construction measures are at risk in an ex ante evaluation, based on these findings. PAs should pursue an orderly transition, completing the ISP research agenda as quickly as possible, negotiating their prospective and retrospective applications, and rolling out the revisions in program support documents.

2. **Focus future training on energy code changes, field verifications, and specific provisions that are not easily understood and/or complied with.** While the compliance detailed on construction documents is relatively good, opportunities remain for targeted measures, and there are many code provisions that require proper installation practices to fully capture their energy benefits. These include air sealing, insulation installation, lighting and HVAC controls, and commissioning. Training focused on these elements, including field components, will help code officials and construction teams understand and enforce best practices.

3. **Consider expanding the PA program participation data collection effort to provide more detailed information about program participation.** The existing databases provide limited information regarding the specific measures, equipment, and fixtures incentivized by PA programs.
This lack of detail is a limiting factor in participation analysis; expanding this data would improve overall understanding of program impacts.

4. **Consider engaging NRNC projects as early in the design phase as possible to improve building features.** Since code decisions are primarily made during design, early engagement can drive projects to exceed code requirements.

### 1.4 Future Research
The DNV GL team recommends the following opportunities for future research:

1. **Conduct a short-term study to corroborate the 2017 Study baseline findings in accordance with the ISP Framework.** The DNV GL team developed an ISP protocol document in 2017 outlining methods for assessing and revising baselines. The lighting end-use is currently one of the technologies in the ISP research scope for several ongoing projects, partially prompted by the findings of this study. Other measures should undergo some level of ISP research before adopting a final ISP efficiency value.

2. **Conduct a targeted compliance study focused on understanding the approach to and enforcement of buildings pursuing a performance path to demonstrate compliance with the energy code.** All of the commercial compliance studies completed in Massachusetts to date have followed the prescriptive path to compliance. However, more and more buildings are pursuing performance paths to demonstrate compliance, because that enables more expanded trade-offs and modeling, and is consistent with approaches supported by LEED and other high-performance building programs.

3. **Perform equipment- and measure-specific studies to improve understanding of energy code nuances.** Compliance studies such as the 2017 Study (IECC 2012) provide a big-picture perspective on compliance, but the combination of limited time and budget along with the need to cover the energy code from a broad perspective results in varying levels of detail on individual measures. Equipment and/or measure-specific studies would enable evaluators to explore code requirements or best practices in greater detail. Examples of these investigations could include analysis of light levels (spaces may meet the energy code but still be overlit) as well as an assessment of the appropriateness of mechanical equipment sizing.

4. **Embed code compliance assessors with building code officials to reduce any self-selection bias.** Self-selection bias is a common challenge for energy code compliance studies, as building owners and developers who are knowingly not adhering to code requirements can decline participation in compliance studies without consequence. Through collaboration with building code officials, the conductors of a compliance study would have greater access to project documentation and can conduct targeted site visits. This research could be designed as a large study with a representative sample, or be done in a more targeted manner such as a ride-along with code officials, or even a training exercise, so that evaluators can observe compliance documentation and demonstration from the perspective of the party responsible for enforcement.

5. **Include more on-site verifications in future lighting compliance and ISP studies.** The PAs recommend that future lighting verifications for compliance and ISP work ideally include more field observations to ensure that ISP recommendations reflect the lighting that is actually being installed versus what is designed in construction documents. There is concern that actual installations may not
reflect the designed lighting, and that the technologies installed, though they may meet LPD requirements, leverage inferior or unapproved lighting products that will not sustain designed performance.
2 INTRODUCTION
The 2017 Massachusetts Energy Code Compliance and Baseline Assessment for IECC 2012 (2017 Study) is part of an ongoing effort to support the adoption of energy efficient equipment, design, and construction practices that will help address energy and environmental challenges in Massachusetts. The Massachusetts Commercial and Industrial Evaluation Contract Team (DNV GL Team) collaborated with the Massachusetts Program Administrators (PAs) and the Energy Efficiency Advisory Council (EEAC) to determine the study goals and develop a research plan for the project.

2.1 Study Objectives
The overall goal of this research is to provide information to assist the PAs in the development and implementation of programs that support enhanced code-compliance rates and promote “beyond code” design and construction through the new construction programs. This study assessed compliance with the energy code for commercial buildings permitted under IECC 2012, from July 2014 through December 2016. The compliance rate is not designed to directly apply to building energy use, but rather to identify and quantify the opportunities to improve building efficiency within Massachusetts in coordination with the Massachusetts Code Compliance Support Initiative (CCSI).

The DNV GL team’s efforts addressed the following methodological approaches and/or questions:

- What is the estimated compliance level in Massachusetts with IECC 2012?
- Are commercial new construction practices keeping pace with advancements in and recent additions to the energy code?
- For what code features is the energy code appropriate to use as a baseline representing standard building practice? When is standard practice better or worse than code?
- What are the opportunities for improvement where PAs can target code support activities to improve compliance?

2.2 Study Team
The DNV GL team for this project was composed of ERS, DNV GL, and APPRISE. ERS maintained primary responsibility for the project, leading recruitment and data collection activities. DNV GL assisted with field data collection and program participation research, and APPRISE was responsible for receiving and processing the Dodge Data purchased for the study.³

2.3 Background and Context
This study assessed all sites against IECC 2012 regardless of stretch code adoption in any particular community. IECC 2012 was adopted by Massachusetts in January 2014, effective for all buildings on July 1, 2014. The 2017 Study evaluates IECC 2012 compliance for buildings permitted between July 2014 and December 2016. Since for this period, there is little difference between the stretch code and the base code, the DNV GL team did not examine compliance to stretch code, as was done in earlier years.

The previous two compliance studies in Massachusetts, completed in 2012 and 2015, assessed compliance with IECC 2006, IECC 2009, and the Massachusetts Stretch Code, visiting fully constructed sites in 2012 and active construction sites in 2015. The IECC 2012 Code Compliance Assessment leveraged the results and

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³ The Dodge database is a commercially available listing of all construction activity in a specified jurisdiction for a given date range.
findings of these prior studies to streamline the data collection process, focusing on the code provisions that most contribute to building energy use primarily through review of construction documents, minimizing the number of field inspections. Figure 2-1 presents a graphical timeline of the code cycles in Massachusetts as well as the Stretch Code versions and compliance studies completed.

Figure 2-1. Timeline of Massachusetts Code Adoption and Compliance Studies

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</thead>
<tbody>
<tr>
<td><strong>Stretch Code</strong></td>
<td></td>
<td></td>
<td>MA Stretch Code</td>
<td>2015 MA Stretch Code</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Compliance Study</strong></td>
<td></td>
<td></td>
<td>2012 Study (P11)</td>
<td>2015 Study (P24)</td>
<td>2017 Study (P70)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IECC 2006: 82%; IECC 2009: 76%</td>
<td>IECC 2009: 85%</td>
<td>IECC 2012: 87%</td>
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</tbody>
</table>

In the 2015 study (IECC 2009), the DNV GL team assessed compliance with the Massachusetts Stretch Code for any buildings in towns that had adopted the stretch code by the building’s permitting date. The stretch code was designed to be roughly 20% more stringent than the base IECC 2009 code. However, the prescriptive requirements of the stretch code are very similar to the IECC 2012 code provisions; once Massachusetts adopted IECC 2012 as the base code, there are very few differences between the stretch code and the base code in the state. For this reason, the DNV GL team did not assess stretch code compliance during the current 2017 study; all sites were assessed against IECC 2012 regardless of stretch code adoption. Massachusetts has adopted a new stretch code that is effective in 2017 and is more stringent than the IECC 2015 base code, but the new stretch code is outside the scope of this study.

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* Compliance results in this figure reflect the unweighted DOE/PNNL methodology, as this approach was used in all three MA studies and presents the best basis for comparison over time.
3 METHODOLOGY

This section describes the methodology for the project. While the overall effort included activities to review data from the prior 2015 Study (IECC 2009), revise a prior adjustment of lighting power density (LPD) to incorporate program participation, and interview code officials and design professionals, the primary focus of this report is on the compliance assessment for new construction buildings in Massachusetts permitted under IECC 2012, and efforts to leverage the building-level data collected to inform baseline practices where possible. The prior tasks are introduced briefly below, and the final versions of previously submitted deliverables to the PAs and EEAC are included as appendices to this report.

3.1 2015 Study Revisits

The DNV GL Team revisited a sample of the 2015 Study (IECC 2009) sites to investigate how and whether recently constructed buildings are being operated with good practice control strategies, primarily for lighting and mechanical systems. For the purposes of this study, good control practices are defined as controls and equipment installed, functioning and either actively managed by site personnel or controlled automatically with regular maintenance. The team targeted 15 site revisits and recruited 16 out of the 50 sites in the study, consisting of both program participants and nonparticipants. The energy code increasingly requires initial building commissioning, but largely does not govern post-occupancy practices.

Each site visit consisted of a brief review of equipment and control strategies identified during the 2015 Study, followed by a facility tour and discussion with on-site facility personnel. The DNV GL Team developed a short data collection form to assess good practices for operation of the following equipment/systems: air handling units/rooftop units (AHUs/RTUs), boilers (heating), boilers (domestic hot water), chillers, cooling towers, pumps, exhaust fans, and lighting controls. A memo summarizing the results of this activity was shared with the PAs and EEAC previously for review and comment; the revised version is included in this report as Appendix A.

3.2 LPD Adjustment Revisions for Program Participation

As part of a separate project in the DNV GL portfolio completed prior to the start of the 2017 Study (P58), the project team leveraged its 2015 Study (IECC 2009) observation that baseline lighting power density (LPD) was generally better (lower) than code requirements to develop an initial adjustment factor to quantify the magnitude of the differential between standard practice and code requirements. The 2017 Study (IECC 2012) included a separate task to revise this initial adjustment based on the incorporation of PA program participation data.

After identifying program participation within the 2015 Study sample, the LPD adjustment was revised to account for energy efficiency program participation influence. After additional validation of program participation by the PAs in January 2018, the DNV GL team recommends that code-required LPDs be subject to an adjustment factor of 0.78 +/- 0.10 at 90% confidence for any new commercial construction buildings permitted under IECC 2009. A memo summarizing the results of this activity was previously shared with the PAs and EEAC previously for review and comment; the revised version is included in this report as Appendix B. Section 4.8.2.3 presents a similar analysis conducted for the 2017 Study, sites permitted under IECC 2012.
3.3 Energy Code Interviews

One of the early tasks of the 2017 Study (IECC 2012) was to conduct interviews with code officials and design and construction professionals to gather information on trends and common practices within the industry. The DNV GL team recruited code officials in Massachusetts towns and cities, along with design/construction professionals actively working on commercial projects in the state, leveraging the Dodge database contact information to help identify relevant firms for interview recruitment. The team prioritized recruitment targets in locations with higher concentration of commercial new construction, such as metro Boston, Springfield, and Worcester. The objective of these interviews was to collect information on awareness of the energy code, compliance and code review practices, and suggestions for improving the compliance process.

A memo summarizing the results of this activity was shared with the PAs and EEAC previously for review and comment; the revised version is included in this report as Appendix C.

3.4 Sample Design

The DNV GL team designed the sample using segmented random sampling to identify the target buildings for the 2017 Study (IECC 2012). In order to estimate the expected precision of the target variable (the compliance rate), the project team assumed a similar variability in the results across the sites to the variability observed during the 2015 Massachusetts code compliance study. The sample was designed to meet a 90/10 confidence/precision target. The compliance rate, expressed as a percentage, represents the percentage of the energy code met by the average commercial new construction building in Massachusetts. The compliance rate is not designed to directly apply to building energy use, but rather to identify and quantify the opportunities to improve building efficiency within Massachusetts in coordination with the Massachusetts Code Compliance Support Initiative (CCSI).

3.4.1 P70 Study Eligibility

The 2017 Study (IECC 2012) assessed energy code compliance for new commercial buildings governed by the 2012 International Energy Conservation Code (IECC 2012). The IECC 2012 was in place for all buildings permitted between July 1, 2014, and December 31, 2016. While the energy code applies to new construction as well as renovations and alterations, this study focused on new construction and major additions. This approach is consistent with all previous code studies completed by the DNV GL team and is also consistent with the U.S. Department of Energy (DOE) Building Energy Codes Program, which recommends that new construction and renovations be evaluated separately.

3.4.2 Population Data Set

The population frame for this study was the set of commercial new construction buildings listed in the Dodge database. The Dodge database is a commercially available listing of all construction activity in a specified jurisdiction for a given date range. Prior research for the DNV GL project portfolio found that more than 90% of the listed buildings were completed. Prior research conducted for the Census Bureau shows that Dodge covers more than 95% of new commercial building square footage.

The DNV GL team leveraged previous portfolio project work that synthesized historical Dodge data through 2015. To satisfy the eligibility range of IECC 2012 through December 31, 2016, the DNV GL team purchased

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5 While IECC 2012 was enacted effective January 1, 2014, there was a 6-month grace period during which buildings could choose to comply with either IECC 2009 or IECC 2012. Any projects permitted after July 1, 2014, must meet IECC 2012 requirements. The next code, IECC 2015, is required for all buildings permitted starting January 1, 2017.
2016 Dodge data through October 2016, as well as a subscription to the Dodge active database that contains information about current and planned projects through December 2016.

The permitting date is the primary criterion for inclusion in the sample frame, but the Dodge database does not contain this information. Instead, Dodge provides the month and year of construction start. This can be used as a reasonable proxy for the permit date, and sites were screened during recruitment to determine the actual permit date.

### 3.4.2.1 Population Data Scrubbing

The Dodge database is a clearinghouse of construction activity, and as such it contains many projects that are ineligible for this study. The DNV GL team scrubbed the Dodge data to remove blank and duplicate records as well as ineligible projects such as renovation projects, tenant fit-outs, and repairs. Table 3-1 presents a disposition table showing the original Dodge data building count and the results of the data scrubbing.

<table>
<thead>
<tr>
<th>Category</th>
<th>Building Characteristic/Disposition</th>
<th>Number of Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Dodge data set</td>
<td>Dodge historical data</td>
<td>4,333</td>
</tr>
<tr>
<td></td>
<td>Dodge active database</td>
<td>404</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>4,737</td>
</tr>
<tr>
<td>Dispositions</td>
<td>Renovation project</td>
<td>2,191</td>
</tr>
<tr>
<td></td>
<td>Tenant fit-out</td>
<td>727</td>
</tr>
<tr>
<td></td>
<td>Multifamily building less than four stories</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>Permitted prior to IECC 2012</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>Building repair</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>Exterior/unconditioned space</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>Duplicate Dodge record</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>Blank Dodge record</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Modular classroom installation</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Demolition</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Total buildings removed</td>
<td>3,857</td>
</tr>
<tr>
<td>Final sample frame</td>
<td></td>
<td>880</td>
</tr>
</tbody>
</table>

### 3.4.2.2 Multifamily Buildings

For multifamily (MF) residential buildings greater than three stories, the commercial energy code covers the building envelope and any common-area HVAC and electrical loads, while the residential code applies to any in-unit HVAC and electrical systems. Thus, using the full square footage of MF buildings is not the best proxy for the square footage governed by the commercial code. The results from the previous code studies suggest that 20%–25% of total MF building space is common-area space. However, during a project call held in March of 2017, the PAs and EEAC recommended that the full MF square footage be used for sampling so that the sample represents the full estimate of state square footage and not an estimated reduction for MF sites. The DNV GL team separated MF buildings from non-MF building in the sample design to more easily explore this in the results analysis.
3.4.3 Sample Design

The goal of the sample design was to review enough sites to estimate energy code compliance for commercial new construction across Massachusetts with reasonable precision. The precision target for the compliance rate for this study was 10% precision at the 90% confidence level.

In the previous code compliance studies, the sample was segmented by both building size and building type (office, retail, MF, etc.). However, many of the building type strata included only one or two sample points, rendering the building type results primarily anecdotal. In the last study, although overall compliance results were similar between large and small sites, there was more variability among small sites. The DNV GL team separated MF buildings from all other building types due to the volume of MF buildings within the population.

For this study, we segmented the population frame into MF and non-MF segments and then small, medium, and large buildings, based on square footage, under the hypothesis that there is a characteristic compliance performance within buildings of a certain size due to the similarity of building shell materials, mechanical systems, lighting designs, and potentially attention to compliance criteria and enforcement. We defined the segments as outlined in Table 3-2 based on our judgment of where these boundaries might be.

In order to design a sample that makes efficient use of the study resources, we did not sample buildings that are smaller than 7,000 square feet. These very small buildings account for approximately 26% of the buildings but only 2% of the total state square footage.

<table>
<thead>
<tr>
<th>Segment</th>
<th>Segment Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small non-MF buildings</td>
<td>Non-MF greater than or equal to 7,000 and less than 20,000 square feet</td>
</tr>
<tr>
<td>Medium non-MF buildings</td>
<td>Non-MF greater than or equal to 20,000 and less than 60,000 square feet</td>
</tr>
<tr>
<td>Large non-MF buildings</td>
<td>Non-MF greater than or equal to 60,000 square feet</td>
</tr>
<tr>
<td>Small MF buildings</td>
<td>MF greater than or equal to 7,000 and less than 20,000 square feet</td>
</tr>
<tr>
<td>Medium MF buildings</td>
<td>MF greater than or equal to 20,000 and less than 60,000 square feet</td>
</tr>
<tr>
<td>Large MF buildings</td>
<td>MF greater than or equal to 60,000 square feet</td>
</tr>
</tbody>
</table>

This study segmented the sample based on the size of the building, however, beyond the MF segments, we could not guarantee that the distribution of building types in the sample would be the same as that in the population. A segmented random sample of 40 sites was selected from the sample frame based on the final sample design presented in Table 3-3.
### Table 3-3. 2017 Study Initial Sample Targets

<table>
<thead>
<tr>
<th>Segment</th>
<th>Building Count</th>
<th>Building Square Footage</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small non-MF buildings</td>
<td>153</td>
<td>1,730,000</td>
<td>10</td>
</tr>
<tr>
<td>Medium non-MF buildings</td>
<td>162</td>
<td>5,817,000</td>
<td>10</td>
</tr>
<tr>
<td>Large non-MF buildings</td>
<td>149</td>
<td>23,947,000</td>
<td>10</td>
</tr>
<tr>
<td>Small MF buildings</td>
<td>22</td>
<td>299,000</td>
<td>2</td>
</tr>
<tr>
<td>Medium MF buildings</td>
<td>53</td>
<td>1,940,000</td>
<td>3</td>
</tr>
<tr>
<td>Large MF buildings</td>
<td>116</td>
<td>25,264,000</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>655</strong></td>
<td><strong>58,997,000</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>

### 3.4.4 Sample Design Summary

Table 3-4 summarizes the key parameters of the sample design.

### Table 3-4. 2017 Study Sample Design Summary

<table>
<thead>
<tr>
<th>Sampling Component</th>
<th>Sample Approach</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population data source</td>
<td>All construction projects in MA</td>
<td>Population data obtained from Dodge database for projects initiated between July 1, 2014, and December 31, 2016</td>
</tr>
<tr>
<td>Sample frame</td>
<td>Commercial new construction in MA permitted under IECC 2012, excluding buildings under 7,000 square feet.</td>
<td>Data scrubbed to remove ineligible buildings (i.e., tenant fit-outs, renovations). Excludes buildings under 7,000 square feet, corresponding to 26% of the buildings and representing 2% of total state square footage.</td>
</tr>
<tr>
<td>Sampling method</td>
<td>Segmented random sample</td>
<td>Segmentation by building size due to expected similarities in building systems and characteristics</td>
</tr>
<tr>
<td>Variable to estimate</td>
<td>Energy code compliance</td>
<td>Compliance rate, expressed as a percentage, represents the percentage of the energy code met by the average commercial new construction building in MA.</td>
</tr>
<tr>
<td>Precision target</td>
<td>10% precision at the 90% confidence level</td>
<td></td>
</tr>
</tbody>
</table>

### 3.5 Site Data Collection Methodology

This section describes the activities taken to recruit sites for the 2017 Study (IECC 2012), review construction documents for the sampled sites, and conduct field visits to validate energy code activities identified on the construction documents.
3.5.1 Recruiting

The Dodge Database contains key contact information for the sampled sites and construction documents and specifications for some of the sampled sites. After completing the sampling and screening, ERS conducted recruitment efforts by calling the primary site contacts identified during the screening to recruit sites willing to participate in the sample. A recruitment incentive of $200 was offered to each owner or their designee for participation in the study regardless of a site visit taking place. During recruitment, ERS performed an eligibility screening to confirm the permitting date and availability of construction documents. Once a site was confirmed as eligible under both criteria, ERS followed up with each site contact to answer questions about the study, inquire about additional screening questions and solicit construction documents. Following the plan review, a decision was made by the reviewer regarding a site visit. A follow-up phone call or email was then conducted by ERS to discuss the logistics of the site visit.

3.5.2 Self-Selection Bias

Due to the voluntary nature of this study, it is important to acknowledge that a degree of self-selection bias should be considered in the recruited sites and resulting compliance assessment. It is possible that site owners and contacts who were confident in the designed energy efficiency of their buildings would be more willing to participate in the study; conversely, site contacts who knew or perceived that their building presented energy efficiency challenges may have been less likely to participate. While an incentive of $200 per site visit was offered, this incentive may not have been sufficient to compensate the site contacts for their time spent on the site visits. For these reasons, it is possible that the 2017 Study evaluated buildings with energy code-related building practices that were better than state averages while underrepresenting buildings that perform worse than the code. Table 3-5 summarizes the disposition of the sample.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Target Sample Size</th>
<th>Ineligible</th>
<th>Refusals</th>
<th>No Response</th>
<th>Total contact attempts</th>
<th>Final Sample Size</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Small non-MF buildings</td>
<td>10</td>
<td>3</td>
<td>6</td>
<td>25</td>
<td>256</td>
<td>11</td>
<td>24%</td>
</tr>
<tr>
<td>2 - Medium non-MF buildings</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>14</td>
<td>156</td>
<td>10</td>
<td>34%</td>
</tr>
<tr>
<td>3 - Large non-MF buildings</td>
<td>10</td>
<td>5</td>
<td>15</td>
<td>79</td>
<td>547</td>
<td>9</td>
<td>8%</td>
</tr>
<tr>
<td>4 - Small MF buildings</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>12</td>
<td>117</td>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>5 - Medium MF buildings</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>24</td>
<td>152</td>
<td>3</td>
<td>9%</td>
</tr>
<tr>
<td>6 - Large MF buildings</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>32</td>
<td>186</td>
<td>5</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>40</strong></td>
<td><strong>18</strong></td>
<td><strong>37</strong></td>
<td><strong>186</strong></td>
<td><strong>1414</strong></td>
<td><strong>39</strong></td>
<td><strong>13%</strong></td>
</tr>
</tbody>
</table>
3.5.2.1 Mitigation of Self-Selection Bias

While self-selection bias could not be eliminated, the project team undertook the following actions to mitigate the self-selection bias and complete the sample for the 2017 Study (IECC 2012):

- **Recruiting language** – The language used in both the scripts used by ERS recruiters and the letters distributed to building owners and building officials carefully avoided terminology such as "code compliance study" and other verbiage that could have given the impression that the study was an official review with consequences for observed noncompliance. Instead, recruitment efforts highlighted that this was an energy efficiency study seeking to gather input on current building practices for new commercial construction. It was emphasized that feedback and results from the sites would be kept anonymous and that any information that could identify the individual buildings would be removed.

- **Primarily targeting building owners** – Recruitment efforts targeted building owners as the initial and primary site contacts. This strategy sought to mitigate site representatives’ reluctance to participate, as building owners have a vested interest in participating in a study that reviews the energy efficiency of their building. If the recruiter was unable to contact the building owner, efforts were then directed to the design teams and/or any additional contacts provided by the Dodge Data.

- **Additional recruitment efforts** – The success rate for recruiting all sites was lower than anticipated during the study design. To improve recruitment success, emails were sent to site contacts with direct letters explaining the purpose of the study. The success rate improved slightly after this process was added. The DNV GL team took additional actions to recruit sites in difficult strata, including:
  - Direct outreach to municipal building departments by phone and in person to obtain construction documents directly
  - Engagement of PAs for hard-to-reach strata to leverage any account relationships (regardless of program participation) to identify primary contacts for recruitment
  - Direct outreach to design and construction professionals interviewed previously by the project team to recruit projects associated with these contacts in the Dodge Database.
  - Submission of bulk requests to architects and developers with multiple projects in the selected recruitment sample.

3.5.3 Data Collection Procedures

This section outlines the data collection procedures used to collect site-level code compliance data for the 2017 Study (IECC 2012).

3.5.3.1 Data Collection Tool

The DNV GL team modified the data collection tool that was most recently used in the 2016 Rhode Island code compliance study, customizing it for Massachusetts-specific requirements, to streamline the data collection and analysis of the 2017 Study (IECC 2012). The DNV GL team built this tool using Microsoft Excel to facilitate the data collection and subsequent analysis for individual sites as well as aggregated site data across all sites in the study.

3.5.3.2 Construction Documentation Review

The primary means of verification of energy code compliance was a review of the construction documents for each site. For all 39 sites, field engineers conducted detailed reviews of construction documents, recording general site information as well as specific details for the building envelope, mechanical systems, lighting, and swimming pools where applicable.
3.5.3.3 Site Visit
During the 2017 Study (IECC 2012), site visits were used strategically, where possible, to supplement the information collected during the review of construction documents. This approach was developed based on a primary finding of the 2015 Study (IECC 2009) that in terms of demonstration of energy code compliance, few deviations were observed between construction documents and field observations. Thus, for the 2017 Study, site visits were used to gather information that was not obtainable from the review of the construction documents. Examples include sites without fully developed lighting fixture inventories in the set of documents received, as well as observations of the quality of installation of various code features such as insulation, sealing, and controls. The DNV GL team conducted site visits for nine out of the 39 sites in the study.

3.5.3.4 Code Compliance Analysis and Quality Control
Following the data collection activities, the field engineer assigned to each site finalized the site data in the data collection tool and submitted the site for analysis and quality control. The analysis was largely automated using Microsoft Excel. The QC reviewer conducted a detailed review of each site, examining the data collection instrument as well as the analysis output. Several manual compliance determinations were made for each site; these were all completed by the same QC reviewer for consistency and quality control. Where necessary, the QC reviewer consulted with the field engineers, construction documents, and site photos to resolve any questions and provide feedback to improve the accuracy of future sites completed by each engineer.

3.6 Estimation of Energy Code Compliance for Massachusetts Commercial New Construction under IECC 2012
The 2017 Code Compliance Study assessed compliance with the 2012 International Energy Conservation Code (IECC 2012) based on a review of observable prescriptive energy code requirements for each study site. This is consistent with the approach taken in the previous 2012 and 2015 studies. While IECC 2012 offers prescriptive and performance compliance options, the DNV GL team assessed compliance based on the prescriptive approach for the following reasons:

- **The majority of design teams choose the prescriptive path for compliance.** The performance path requires two complete energy performance models: one for the building as designed and one for a similar building that meets all of the prescriptive requirements. DNV GL team interviews with design professionals and building officials indicated that the primary reason for buildings pursuing the performance path is either that the designed building has more than 30% glazing—which is generally only triggered for large high-rise developments with primary curtain wall envelope assemblies—or that the project is pursuing LEED® or another high-performance building program.

- **Buildings whose owners elect to comply with the performance path must still meet many of the code requirements** (termed “mandatory” in the code language) on a prescriptive basis. This includes the air leakage requirements for the building envelope, most mechanical system requirements, and all service-water heating and electrical power and lighting system requirements.

- **It is difficult for code officials and compliance studies to assess compliance using the performance-based approach.** Often, officials and compliance evaluators have no access to documentation of the modeling procedures and assumptions used to comply with this approach. When the documentation is available, the procedure for verifying the model results is onerous and beyond the budget capabilities of either code enforcement offices or compliance studies. As a result, our interviews...
with code officials reveal that most accept a design professional’s signed statement that the project meets code. This is an acceptable compliance path. Future proposed versions of the energy code include provisions requiring post-construction building performance monitoring to verify that the actual performance is consistent with the model results. Post-construction monitoring could make future assessment of performance methodologies more easily achievable.

Consistent with the 2015 Study (IECC 2009) and 2016 Rhode Island compliance study (IECC 2012 with RI amendments), compliance was evaluated using two different methodologies: one developed originally by the Department of Energy (DOE) in conjunction with the Pacific Northwest National Laboratory (PNNL) (the DOE/PNNL method) and an enhanced methodology developed by the project team to more accurately capture the energy impact of observed building practices (the DNV GL method). Both methods were used during the 2015 Study and can provide a reasonable basis for comparing the compliance rates over time, factoring the increase in stringency of IECC 2012.

3.6.1 **DOE/PNNL Methodology**

The DOE/PNNL method was originally developed as a tool to assess state compliance rates and develop plans to reach 90% compliance with IECC 2009; this goal was established in the American Recovery and Reinvestment Act (ARRA). The DOE/PNNL method weights each provision of the energy code according to the relative energy impact of its compliance or noncompliance. Each provision is assigned to one of three tiers: tier 1 provisions have the lowest impact; tier 2 has twice the impact of tier 1; and tier 3 has three times the energy impact of tier 1.

The DOE/PNNL method, however, has limitations. The IECC and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 both allow for compliance trade-offs within the building envelope category. The DOE/PNNL method evaluates each individual provision as either “compliant” or “not compliant,” generating a result inconsistent with code protocols. Also, the DOE/PNNL method does not consider the energy impacts for partial compliance of a provision. For example, if the above-grade wall insulation requirements were met by 75% of the above-grade walls at a building, this site would be evaluated as “not compliant” for this provision under the DOE/PNNL method, since 25% of the walls did not meet the code. The DOE/PNNL method has no way of taking this level of partial compliance in to account when evaluating energy impacts, which is a significant drawback.

PNNL, with feedback from this evaluation team and several others around the country, recognizes these limitations and is currently working on revisions to their recommended methodology.

3.6.1.1 **Modifications to DOE/PNNL Method**

The DNV GL team identified a number of instances where the DOE/PNNL method does not accurately assess the impacts of energy code provisions. Many of these changes were identified and modified by ERS and DNV GL during the development of the 2015 Study (IECC 2009). Adjusted weighting was applied for the following provisions:

- **Documentation and labeling** – Many code provisions under the DOE/PNNL method award compliance points for providing documentation such as fenestration performance certification labels, insulation R-value labels, etc. While these are important components to demonstrating compliance, the DNV GL team method assesses the actual performance of these features rather than just awarding points for the labels themselves. Where labels were absent, our field engineers used construction documents, product
specification sheets, discussions with on-site contractors, and industry standard references such as the R-value per inch of insulation to determine the actual performance of the installed features.

- **Internal consistency** – In each broad energy code category (envelope, mechanical, and lighting), we evaluated code measures against each other to ensure that their relative weighting reflected the local climate conditions and impacts on building energy use. These modifications allowed for a more granular assessment of the actual impact of the energy code provisions.

- **Windows versus skylights** – Windows and skylights are assigned the same weight in the DOE/PNNL method; however, buildings with both windows and skylights generally have much larger square footage of vertical fenestration (windows) than horizontal (skylights). Thus, the relative weight of windows should be higher than that of skylights.

- **Solar heat gain coefficient** – The DOE/PNNL method scores the impact of solar heat gain coefficient (SHGC) as greater than the impact of fenestration air leakage. In Massachusetts’ climate zone, the impact of SHGC is lower than the impact of fenestration air leakage, and the relative weights should reflect this.

- **Bi-level switching versus automatic controls** – The DOE/PNNL method assigns a higher weight to bi-level switching than the ability to turn lights fully off manually or automatically. The relative impacts are likely the opposite, and so we have reversed the weights.

- **Interior versus exterior lighting** – Similar to windows and skylights, the DNV GL team determined that interior lighting should be weighted more than exterior lighting, as it is generally a larger contributor to the overall energy use. We have reassessed interior lighting as tier 3 and exterior lighting as tier 2.

### 3.6.2 2017 DNV GL Team Methodology

The current DNV GL team method incorporates all of the modifications to the DOE/PNNL method, while also gaining the functionality to award partial compliance with energy code measures, and to assess trade-offs within the building envelope that are allowed by IECC. This allows energy impacts resulting from practices related to the code, rather than simply measuring compliance. We thus recommend it as the preferred approach for estimating the energy impacts of code compliance.

#### 3.6.2.1 Partial Compliance

To assess partial compliance, the energy code provisions were divided into the following two categories:

- **Yes/no questions** – Many code provisions are assessed as either compliant or noncompliant under the DOE/PNNL method. The DNV GL team modified these questions to allow partial compliance values of one-third (recording a value of "somewhat" on the data collection form) or two-thirds (a value of "mostly" on the data collection form).

- **Performance and efficiency requirements** – Where specific efficiency or performance levels were required by code, the DNV GL team calculated the ratio of actual performance to the code level and used this ratio to weight the score. This was commonly used for mechanical equipment efficiencies and lighting power density (LPD). Any values that exceeded the energy code were given full credit for compliance but were not awarded more compliance points for exceeding the code.

#### 3.6.2.2 Trade-offs within the Building Envelope

The IECC 2012 code allows trade-offs within the building envelope provisions, yet a manual checklist-type of prescriptive compliance assessment evaluates each code provision and cannot easily incorporate interactive effects and trade-offs. In the field, a DOE-developed tool called COMcheck is commonly used to demonstrate
energy code compliance. COMcheck automatically calculates trade-offs within the building envelope, a key feature missing from the DOE/PNNL methodology. In order to assess these trade-offs, the building envelope components observed by the field engineers were converted to u-factor equivalent and weighted by square footage, resulting in data points for the code-allowed weighted u-factor as well as an installed weighted u-factor. We compared these numbers to assess compliance across the relevant envelope provisions, applying this score to all the envelope features subject to the u-factor analysis for which we collected data. For all of the compliance analyses completed in the study, the maximum allowable compliance was 100%. Trade-offs are not allowed between the code categories (e.g., envelope and lighting); awarding compliance scores greater than 100% would suggest that a building envelope modeled to perform better than code could offset other areas that may be worse than code. This is not allowed in the prescriptive path to energy code compliance.

During the course of conducting plan reviews and site visits for this study, there were cases in which data was missing from the plans and unavailable to field staff during the site visits. The most common example of this is fenestration performance data for windows and doors. Often, the plans provided some characteristics of the glazing performance (e.g., low-e, insulated glass, etc.) but did not provide specific performance characteristics such as the u-factor and SHGC. Where possible, using product specifications and conversations with on-site staff, the project team made efforts to gather descriptive information about the equipment and used that information for trade-off assessments in the analysis tool.

### 3.6.3 Aggregating Compliance Results

For both methodologies presented above, the DNV GL team aggregated the individual site results based on the sample design to estimate compliance with the energy code for all commercial construction activity in Massachusetts. The results for each site were aggregated using the proportional weights for each building stratum; these weights were calculated by dividing each stratum population by the corresponding stratum sample size. Table 3-6 shows the weights for each stratum.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Description</th>
<th>Population Building Count</th>
<th>Target Sample</th>
<th>Sampled Sites</th>
<th>Stratum Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small buildings (7,000–20,000 sq ft)</td>
<td>150</td>
<td>10</td>
<td>11</td>
<td>13.6</td>
</tr>
<tr>
<td>2</td>
<td>Medium buildings (20,000–60,000 sq ft)</td>
<td>159</td>
<td>10</td>
<td>10</td>
<td>15.9</td>
</tr>
<tr>
<td>3</td>
<td>Large buildings (&gt;60,000 sq ft)</td>
<td>144</td>
<td>10</td>
<td>9</td>
<td>16.0</td>
</tr>
<tr>
<td>4</td>
<td>Small multifamily (7,000–20,000 sq ft)</td>
<td>19</td>
<td>2</td>
<td>1</td>
<td>19.0</td>
</tr>
<tr>
<td>5</td>
<td>Medium multifamily (20,000–60,000 sq ft)</td>
<td>50</td>
<td>3</td>
<td>3</td>
<td>16.7</td>
</tr>
<tr>
<td>6</td>
<td>Large multifamily (&gt;60,000 sq ft)</td>
<td>115</td>
<td>5</td>
<td>5</td>
<td>23.0</td>
</tr>
</tbody>
</table>

The approach used to calculate the compliance score is consistent with the approach used in the 2015 study (IECC 2009) and was adapted from the California Evaluation Framework methodology (TecMarket Works, et. al, 2004) for stratified sample design. The overall compliance score (c) was calculated based on the following formula:
\[ c = \frac{\sum_{i=1}^{n} w_i s_i y_i}{\sum_{i=1}^{n} w_i s_i} \]

where,

- \( w_i \) = Stratum site weight
- \( s_i \) = Site square feet
- \( y_i \) = Site compliance rate

The statistical precision of \( c \) can be determined by calculating the standard error (\( se \)) using the following equation:

\[ se(c) = \frac{1}{\bar{x}} \sqrt{\sum_{i=1}^{n} w_i (w_i - 1) e_i^2} \]

where,

\[ \bar{x} = \sum_{i=1}^{n} w_i s_i \]
\[ e_i = y_i - cx_i \]

The error bound (\( eb \)) is calculated as \( eb(c) = 1.645 \, se(c) \)

The relative precision (\( rp \)) as \( r_p = \frac{eb(c)}{c} \)

### 3.6.4 Control for Site Consistency

Since some of the strata in the sample contained one or a few sites, the team was concerned that individual sites could have undue influence on the weighted results. The project team examined the results for consistency and soundness, aggregating the results by square footage to understand the influence of any sites on the overall results. This analysis showed that none of the sites had undue influence on the results; the compliance results did not vary substantially regardless of the aggregation method applied. The project team feels comfortable that the aggregation method is reflective of the sample design and the energy code measures observed on the construction documents and in the field.

### 3.7 Informing Baseline Practices

In addition to developing estimates of energy code compliance for Massachusetts commercial nonresidential new construction, an objective of the 2017 Study (IECC 2012) was to gather site-level construction data that can be used to inform baseline practices. As discussed above in Section 3.2, this approach has been used previously to adjust code LPD values based on field observations.

The DNV GL team completed the following activities to review and analyze building data for baseline applications:

- **Review and quality control of raw site data.** The team reviewed the raw data gathered during the site data collection, removing any incomplete data. In some cases, analysts researched equipment specification data or consulted field engineers and/or construction documents to resolve discrepancies.

- **Normalize data where necessary.** Many sections of the energy code, particularly for mechanical equipment, specify varying efficiency requirements based on fuel, size, and equipment type. In order to
compare data for similar equipment (i.e., all boilers, all heat pumps, etc.), the data was normalized, resulting in a percentage better or worse than code for each site with observed data for each provision.

- **Incorporate program participation where applicable.** The project team cross-referenced the 39 sampled sites with DNV GL’s master PA program participation data set to identify the sites that participated in any PA programs. This data was incorporated into the normalized results so that comparisons between participants and nonparticipants can be made.

- **Summarize and present graphically where appropriate.** The resulting analysis is presented in the section below. Where possible, this data is presented graphically to show differences to code and between participants and nonparticipants.
4 ANALYSIS AND RESULTS

This section contains the results from the 2017 Massachusetts Commercial Energy Code Compliance and Baseline Practice Assessment for IECC 2012 (2017 Study).

4.1 Energy Code Compliance Results for IECC 2012

This section contains the results from the 2017 Study. The initial results presented are the weighted compliance scores aggregated for Massachusetts using both the Department of Energy/Pacific Northwest National Laboratory (DOE/PNNL) and enhanced DNV GL methodologies. Following this discussion, this section includes breakouts of the sample results by different stratifications such as building type and code component. The stratified results are presented without site-level weighting because the small sample sizes in some of the strata.

4.2 Overall Compliance for 2017 Study

Figure 4-1 presents the overall statewide compliance rates for Massachusetts commercial new construction under IECC 2012 using both the DOE/PNNL and DNV GL methodologies. As discussed in the methodology section, compliance was weighted by building square footage for each of the strata. The overall compliance rate is estimated to be 88% using the DOE/PNNL methodology and 94% using the DNV GL team methodology. At a 90% confidence interval, these results have a relative precision of 4% for the DOE/PNNL methodology and 2% for the DNV GL methodology.

![Figure 4-1. Overall Compliance for 2017 Study](image)

4.2.1 Interpretation of Compliance Scores

For the purposes of this study, it is important to define what is meant by compliance. The compliance rates presented throughout this report do not represent the percentage of commercial buildings that fully comply
with the energy code. The project team was only able to observe a subset of the code provisions for each building and was limited by the timing of construction, available documentation, and other factors. Even with this caveat, very few buildings, if any, fully comply with the energy code. Rather, the compliance scores presented should be interpreted to mean that commercial buildings in Massachusetts meet 94% of the energy code requirements per the DNV GL methodology. This interpretation of compliance is consistent with the results of the 2012 and 2015 studies in Massachusetts and other studies throughout the country.

While the results suggest a code compliance rate of 94%, it is important to acknowledge that the actual code compliance rate for Massachusetts may differ due to any of the following factors:

- **Self-selection bias** – As described in the methodology section of this report, building owners, designers, and contractors who are constructing buildings in close accordance with codes are more likely to agree to participate in a self-selecting compliance study. Conversely, owners and building staff who know that their buildings may not meet the code, or are simply unaware of that status, are less likely to participate. The DNV GL team made significant efforts to minimize this bias, but there is still likely to be some self-selection bias among the participants.

- **Observable provisions** – The estimated compliance rate is based on the suite of observable code provisions during construction document reviews and field visits. Some code provisions, such as the proper sizing of mechanical equipment and fenestration specifications, are extremely difficult to observe in this fashion; thus, the compliance estimate does not account for all code provisions. Provisions that could not be observed did not factor in to the compliance assessments; it is possible that the compliance scores could shift either way if observations regarding compliance or noncompliance were possible for these unobservable provisions.

- **Installation quality** – The quality of equipment and systems installation is an important factor in assessing the energy impact of code compliance. The energy code specifically addresses the quality of installation, especially for insulation and air sealing. When poor quality installations were observed during the study it was recorded, but for most sites it was not possible to assess installation quality and quantify its impacts.

- **High-performance buildings** – Many sites evaluated during the study were high-performance buildings seeking LEED or other green building certifications. While the project team evaluated the compliance of these sites prescriptively, many of these programs require performance modeling to demonstrate compliance and/or achieve certifications, and sites may leverage trade-offs in the performance modeling that could result in failing to meet individual prescriptive requirements.

The 2017 Study (IECC 2012) compliance rate (DNV GL methodology) of 94% based on provisions observed at the study sites suggests that the commercial new construction industry has adapted well to the change in energy code from IECC 2009 to IECC 2012, as compliance rates are similar despite the change in code stringency. Some of this is likely due to the Massachusetts Stretch Energy Code, which was voluntarily adopted by more than 50% of the municipalities in Massachusetts prior to the state’s adoption of IECC 2012. When it was originally adopted, the Stretch Code was based on IECC 2009 and designed to be roughly 20% more stringent than the base code. However, the prescriptive requirements of the Stretch Code are very similar to the IECC 2012 base code provisions. Since many towns had already adopted the Stretch Code, including most of the MA cities where the majority of commercial new construction is occurring, the

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6 Both of the methodologies used in this study were designed to assess compliance with the energy code on a prescriptive basis. The actual determination of compliance for each site for the purposes of issuing a certificate of occupancy is outside of the scope of this project, as the assessment is made by the local code enforcement official in each site’s jurisdiction.
requirements of IECC 2012 were likely already familiar to many in the design, construction, and enforcement industries.

**4.2.2 Comparison of Methodologies**

The two methodologies used to evaluate compliance result in different estimates for commercial new construction. The project team expected that the DNV GL methodology would result in a higher compliance score than the DOE/PNNL methodology because the DNV GL methodology awards partial credit for partial compliance, while the DOE/PNNL methodology does not. This partial compliance is most applicable to the building envelope, whereas the DNV GL methodology facilitated trade-offs, consistent with the COMcheck software commonly used to demonstrate compliance with the energy code in the field. Under the DOE/PNNL methodology, each provision was evaluated independently on a prescriptive basis; thus, individual provisions that fail to meet the prescriptive requirement could still receive partial or full compliance based on the trade-off results. Conversely, in some cases individual prescriptive requirements were met while the trade-off model determined the overall envelope to be worse than the code. Since the DNV GL methodology incorporates partial credit and trade-offs in the building envelope, the project team feels that this methodology is a better reflection of the compliance rate than the DOE/PNNL methodology. However, the DOE/PNNL methodology is more consistent with methodologies in previous studies both in Massachusetts and in other states and is useful in identifying trends over time or across jurisdictions.

The project team imposed a maximum envelope score of full (100%) compliance with the energy code because trade-offs are not allowed across the energy code sections. The modeled building envelopes for 35 sites were better than code; however, scoring these sites as better than code would result in strong envelope performance potentially offsetting underperformance in other areas of the building. IECC 2012 does not allow trade-offs between building envelope, mechanical, and lighting provisions; the project team’s use of the building envelope modeling is consistent with this approach.

Figure 4-2 compares the compliance scores for each site across the two methodologies. Any point along the green dotted line (y=x) indicates that compliance scores are consistent across methodologies. Points above the line indicate that DNV GL compliance score is greater than DOE/PNNL, with the vertical distance between any point and the line representing the magnitude of this difference. The project team explored the removal of any outliers in this data, but that did not have significant impact on the overall weighted results.
4.2.3 Data Availability and Variability

The primary data collection method used by the DNV GL team to assess compliance for the 2017 Study (IECC 2012) was review of construction documentation, supplemented by site visits where feasible to gather data not available on plans. While the team received plans for all 39 sites in the sample, the number of measures assessed for each site varied based on the building characteristics specific to each building, as well as the availability of complete documentation on plans and/or on-site. This variability is inherent in all field-based compliance assessments, and the discussion and figures below provide additional insight into the composition of the compliance scores.

4.2.3.1 Code Applicability

Some of the variation in applicability was due to provisions that apply to some sites but not to others. For example, buildings that are completely slab-on-grade construction do not have below-grade walls and are thus not evaluated for the below-grade wall provision. Sites that have some slab-on-grade and some below-grade would be assessed for both requirements in the code, while sites without slab-on-grade construction would only be evaluated for the below-grade wall provision.

The variation in site composition is best shown graphically when comparing the contributions of each major code category – envelope, mechanical, and lighting provisions – to the total score. The figures below show the contributions using the DNV GL compliance methodology; while the compliance scores were generally lower for the DOE/PNNL methodology, the variation of applicable provisions did not differ significantly enough to necessitate the presentation of both methodologies. While the contributions range across sites, they are generally consistent across methodologies. On average, approximately 35% of the compliance scores result from building envelope provisions, about 39% from mechanical systems, and approximately 25% from lighting. Figure 4-3 shows the total potential scoring variability.
While Figure 4-3, above, shows the distribution of available scores across the energy code categories, it is important to recognize that the number of observable and applicable code provisions at each site ranged greatly based on factors that include the information available to the field engineers and the building size, type, and specific features of each site. Figure 4-4 shows the total number of compliance points possible at each of the 39 project sites; while each site could receive a maximum compliance score of 100%, the total possible points that could be obtained varied across the sites based on observable features.
4.3 Compliance Stratifications
This section provides the estimated compliance rates for selected stratifications of the sampled sites. With the exception of building size, these results are presented unweighted but they provide insights into how construction practices in Massachusetts comply with the energy code.

4.3.1 Compliance by Stratum
Table 4-1 shows compliance by stratum. The DNV GL method consistently results in higher compliance than the DOE/PNNL methodology, but the difference between the two approaches varies across the strata. There do not appear to be significant differences in compliance based on building size. This finding is consistent with the 2015 Study (IECC 2009).

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Description</th>
<th>Sampled Sites</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small buildings (7,000–20,000 sq ft)</td>
<td>11</td>
<td>94%</td>
<td>87%</td>
</tr>
<tr>
<td>2</td>
<td>Medium buildings (20,000–60,000 sq ft)</td>
<td>10</td>
<td>92%</td>
<td>86%</td>
</tr>
<tr>
<td>3</td>
<td>Large buildings (&gt;60,000 sq ft)</td>
<td>9</td>
<td>95%</td>
<td>91%</td>
</tr>
<tr>
<td>4</td>
<td>Small multifamily (7,000–20,000 sq ft)</td>
<td>1</td>
<td>95%</td>
<td>87%</td>
</tr>
<tr>
<td>5</td>
<td>Medium multifamily (20,000–60,000 sq ft)</td>
<td>3</td>
<td>90%</td>
<td>85%</td>
</tr>
<tr>
<td>6</td>
<td>Large multifamily (&gt;60,000 sq ft)</td>
<td>5</td>
<td>93%</td>
<td>83%</td>
</tr>
</tbody>
</table>

4.3.2 Compliance by Building Type
Table 4-2 shows the unweighted compliance by building type for the 2017 Study (IECC 2012). As discussed in the sampling methodology, due to the large volume of multifamily (MF) construction in the population, separate strata were created explicitly for MF buildings. However, no further stratification by building type was made during the sampling. This was a deviation from the prior study, which stratified by size and building type, resulting in several strata containing only one or two buildings.

<table>
<thead>
<tr>
<th>Building Type</th>
<th>Building Count</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education</td>
<td>11</td>
<td>94%</td>
<td>90%</td>
</tr>
<tr>
<td>Office</td>
<td>9</td>
<td>95%</td>
<td>89%</td>
</tr>
<tr>
<td>Retail</td>
<td>4</td>
<td>93%</td>
<td>89%</td>
</tr>
<tr>
<td>Service/Warehouse</td>
<td>6</td>
<td>91%</td>
<td>85%</td>
</tr>
<tr>
<td>Multifamily</td>
<td>9</td>
<td>92%</td>
<td>84%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>39</strong></td>
<td><strong>93%</strong></td>
<td><strong>87%</strong></td>
</tr>
</tbody>
</table>

Overall, there was little difference in compliance between Multifamily and non-Multifamily sites, though some differences were observed across code categories, as presented in Figure 4-5. For Multifamily sites,
commercial energy code applies to the building envelope and common area mechanical and lighting loads; residential unit HVAC and lighting are covered by the residential code.

**Figure 4-5. Comparison of Multifamily and Non-Multifamily Compliance, DNV GL Method**

4.3.3 Compliance by Code Area

Figure 4-6 shows the estimated compliance for the primary energy code categories: envelope, mechanical systems (HVAC), and lighting systems. All code areas typically saw a high compliance rate, with lighting having the highest compliance percentage. Due to the partial credit and envelope trade-offs discussed in the methodology section, the building envelope had the largest difference in compliance between the DNV GL method and the DOE/PNNL method.

**Figure 4-6. 2017 Study Compliance by Energy Code Category**
4.4 Compliance Trends over Time

Employing a consistent compliance assessment methodology across several Massachusetts code studies enables the identification of trends in compliance over time and across code versions. The 2017 Study (IECC 2012) results provide an additional data point for IECC 2012. The results of the 2017 Study, as well as two prior studies conducted in Massachusetts, are presented in Table 4-3.

Table 4-3. Massachusetts Code Compliance Results over Time

<table>
<thead>
<tr>
<th>Code Version</th>
<th>Code Cycle Timing</th>
<th>Number of Data Points</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
<th>DNV GL Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC 2006</td>
<td>End of cycle</td>
<td>48</td>
<td>N/A</td>
<td>82%</td>
<td>2012 Study</td>
</tr>
<tr>
<td>IECC 2009</td>
<td>Beginning</td>
<td>27</td>
<td>N/A</td>
<td>76%</td>
<td>2012 Study</td>
</tr>
<tr>
<td>IECC 2009</td>
<td>End</td>
<td>50</td>
<td>94%</td>
<td>85%</td>
<td>2015 Study</td>
</tr>
<tr>
<td>IECC 2012</td>
<td>All</td>
<td>39</td>
<td>94%</td>
<td>88%</td>
<td>2017 Study</td>
</tr>
</tbody>
</table>

Figure 4-7 presents this data graphically. While this graph is not entirely to scale, the dotted line imposed on the graph shows the expected trends in compliance across code versions. When a new code is adopted the expectation is that compliance sharply declines because the new code is more stringent than the previous and the design/construction community is likely unfamiliar with the new provisions. As these communities become more familiar with the code changes and new requirements, compliance increases until the next version is adopted and the cycle repeats. This trend was observed during the 2012 and 2015 studies; while the 2017 Study only supplies one data point for the entire IECC 2012 period, it is likely that this pattern continued. It is worth noting, however, that the Massachusetts Stretch Code and Code Compliance Support Initiative (CCSI) may also have influenced this trend in the IECC 2012 and to some extent IECC 2009 code cycles.

Figure 4-7. Graphical Representation of Compliance Rate Changes with New Code Adoption
4.5 Program Participation
The DNV GL team examined the program participation data to identify which of the 39 sampled sites participated in PA programs. Generally, participation was categorical; for example, for lighting, the PA data indicated whether a site received upstream and/or downstream lighting incentives, but it did not specify an inventory of incentivized fixtures or controls. Given this data, each site was evaluated for program participation for each of the three primary categories of the energy code: envelope, mechanical, and lighting. If a site received any incentive for any measure within each category, it was considered a participant for that entire code area. The assumption here is that since the site received some incentive for the category, their decisions reflect a more informed perspective than a site that did not receive any incentives. There was one site that participated in the Comprehensive Design Approach (CDA) whole building performance program; this site was considered a participant in all PA programs. Table 4-4 shows the participation counts by code category.

<table>
<thead>
<tr>
<th>Code Category</th>
<th>Participants</th>
<th>Nonparticipants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Envelope</td>
<td>1</td>
<td>38</td>
</tr>
<tr>
<td>HVAC</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Lighting</td>
<td>21</td>
<td>15</td>
</tr>
</tbody>
</table>

4.6 Building Envelope
This section explores the compliance scores and baseline implications for selected individual envelope code provisions.

4.6.1 Individual Code Provisions
Table 4-5 displays the unweighted compliance for select building envelope provisions and the percentage of sites where each provision was verifiable on construction documentation and/or during field visits.

<table>
<thead>
<tr>
<th>Provision Description</th>
<th>Percentage Verifiable</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous air barrier installed to control air leakage into or out of the conditioned space. Air barrier assembly must connect and seal all envelope materials and penetrations.</td>
<td>87%</td>
<td>95%</td>
<td>82%</td>
</tr>
<tr>
<td>Below-grade wall insulation R-value</td>
<td>38%</td>
<td>93%</td>
<td>93%</td>
</tr>
<tr>
<td>Slab edge insulation R-value</td>
<td>92%</td>
<td>81%</td>
<td>81%</td>
</tr>
<tr>
<td>Slab edge insulation depth</td>
<td>92%</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td>Roof insulation R-value</td>
<td>97%</td>
<td>99%</td>
<td>89%</td>
</tr>
<tr>
<td>Above-grade wall insulation R-value</td>
<td>97%</td>
<td>95%</td>
<td>68%</td>
</tr>
<tr>
<td>Vestibules installed where required</td>
<td>90%</td>
<td>82%</td>
<td>74%</td>
</tr>
</tbody>
</table>

1Percentage verifiable indicates the percentage of the 2017 Study sites where it was possible for the project team to assess compliance for each code provision either from construction documents or during field visits.
This table suggests the following observations about specific envelope building practices:

- **Prescriptive insulation requirements** – For the prescriptive insulation requirements, the DNV GL methodology calculates trade-offs within the building envelope while the DOE/PNNL methodology results are most reflective of the actual observations on construction plans and field visits. Further, buildings pursuing the performance path to demonstrate code compliance may not be subject to, and may not meet, all of the individual prescriptive envelope requirements.
  - **Slab insulation** – Slab insulation was assessed based on required R-value (81% compliance) and insulation depth (75% compliance). While there is some opportunity for improvement, a common observation on many sets of construction documents was that the slab edge insulation did not create the required thermal break between the slab and exterior ground. Often, slab insulation did not extend far enough along the inside or outside of the footing, nor did it wrap around and under the slab for the code-required depth.
  - **Above-grade wall insulation** – There was a large difference observed between DNV GL and DOE/PNNL methodologies for above-grade wall insulation. Overall, this was due to individual wall assemblies not meeting code. The DOE/PNNL method does not allow for partial credit, while the DNV GL method reflects a more accurate portrayal of above-grade envelope construction.
  - **Roof insulation** – Roof insulation was consistently documented at levels that meet the energy code requirements, regardless of roof type.

- **Air barriers** – The air barrier was a Massachusetts-specific amendment to the IECC 2009, and was added to the base code in IECC 2012. Thus, designers and builders in MA have been required to comply with this requirement for several years; the compliance results of 95% for the DNV GL methodology suggest that this requirement is fairly well understood by the design community. The field engineers did not conduct blower door testing to verify the installation quality of the air barrier, but the score here primarily reflects the consistently thorough documentation of the air barrier on construction documents. It should be noted here that poor quality installation and the failure to seal penetrations and gaps in the air barrier such that it is not fully continuous would likely have significant impacts on air barrier performance.

- **Vestibules** – The compliance for vestibules was 82% for the DNV GL method and 74% for the DOE/PNNL method. Field engineers evaluated all main entrances to the sampled sites; however, the code specifies that entrances not intended for public use may be exempted from the requirement. The intended purpose of entrance doors is often difficult to decipher from plan reviews and field visits.

### 4.6.2 Informing Baselines

The building envelope data captured during the 2017 Study (IECC 2012) enables some initial insights into baseline practices in Massachusetts, as discussed below.

#### 4.6.2.1 Envelope U-Factor

The DNV GL team used the individual envelope shell components observed at each site to estimate a code-allowed u-factor and an observed u-factor, incorporating trade-offs across envelope shell components as allowed by the code. Envelope data was available for 38 (97%) of the 2017 Study sites. Figure 4-8 compares the observed u-factors to the code; the code-allowed value is shown as 0% and any values above zero on the y-axis represent the percentage better than the code and below zero represent worse than code. Across the 38 sites, the average result was a building envelope 21% better than the code.
Table 4-6. Summary Statistics for Envelope Observations

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Envelope</th>
<th>Five Number Summary</th>
<th>Envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>38</td>
<td>Minimum</td>
<td>-17%</td>
</tr>
<tr>
<td>Mean</td>
<td>21%</td>
<td>1st Quartile</td>
<td>11%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>15%</td>
<td>Median</td>
<td>21%</td>
</tr>
<tr>
<td>90% Confidence Interval</td>
<td>4%</td>
<td>3rd Quartile</td>
<td>31%</td>
</tr>
<tr>
<td>Maximum</td>
<td></td>
<td>Maximum</td>
<td>53%</td>
</tr>
</tbody>
</table>

Figure 4-8. Envelope U-Factor Site Results Relative to Code

4.7 Mechanical Systems (HVAC)

This section explores the compliance scores and baseline implications for selected individual mechanical code provisions.
4.7.1 Individual Code Provisions

Table 4-7 displays the unweighted compliance for select mechanical provisions and the percentage of sites where each provision was verifiable on construction documentation and/or during field visits.

<table>
<thead>
<tr>
<th>Provision Description</th>
<th>Percentage Verifiable</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical equipment meets efficiency requirements</td>
<td>94%</td>
<td>99%</td>
<td>94%</td>
</tr>
<tr>
<td>Air economizers are provided where required and meet the requirements for design capacity and control.</td>
<td>56%</td>
<td>92%</td>
<td>86%</td>
</tr>
<tr>
<td>Zone controls can limit simultaneous heating and cooling and sequence heating and cooling to each zone.</td>
<td>56%</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Motors have the capability to operate below full speed where required by motor size (≥7.5 hp for VAV fan motors and heat rejection fan systems).</td>
<td>41%</td>
<td>94%</td>
<td>94%</td>
</tr>
<tr>
<td>Energy recovery installed where required</td>
<td>69%</td>
<td>91%</td>
<td>81%</td>
</tr>
<tr>
<td>Domestic hot water heater meets efficiency requirements</td>
<td>49%</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Motorized dampers installed on outdoor air supply and exhaust ducts</td>
<td>90%</td>
<td>98%</td>
<td>94%</td>
</tr>
<tr>
<td>Demand-controlled ventilation installed where required</td>
<td>62%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The project team made the following observations regarding these mechanical code provisions:

- **Mechanical equipment efficiency** – The code requires mechanical equipment to meet specified efficiency levels that vary based on the size and type of equipment. Consistent with the 2015 Study (IECC 2009), high compliance was observed for this provision, as the overwhelming majority of equipment evaluated met the code requirements. This is likely due to manufacturers and distributors supplying products to the code requirements.
- **Variable speed drives** – The code requires that variable air volume (VAV) fan motors and heat rejection equipment with motors greater than 7.5 hp have controls to reduce fan speeds when operated below design conditions. These requirements were met at almost every site where observable, in nearly all cases by variable speed drives (VSDs).
- **Motorized dampers** – The code requires that motorized dampers be installed on outdoor air supply and exhaust ducts; this requirement was observable in 90% of sites and compliant in nearly all of them.
Figure 4-9 compares the mechanical compliance for participants and nonparticipants.

![Figure 4-9. Mechanical Compliance by PA Program Participation](image)

4.7.2 Informing Baselines

The DNV GL team captured equipment-level data on equipment efficiencies, as well as some categorical data assessing compliance with various mechanical controls requirements, as discussed below. Note that data is presented at the site level; for sites with multiple equipment units, a weighted average was calculated for the entire site.

4.7.2.1 Boilers and Furnaces

The code requirements for boilers and furnaces vary based on fuel type, equipment type, and boiler/furnace size. Given the range of different sizes and code-required efficiency levels, the data was normalized such that it can be displayed as a percentage better or worse than code. Figure 4-10 presents the comparison of observed boilers to code and Figure 4-11 compares observed furnaces to code (color coded for PA mechanical program participation). All boilers were observed to be more efficient than the code. The average across all observations was 16% better than code. The observations for furnaces were closer to the code value, which although it varies slightly depending on fuel and size is about 80%. The average across all furnace observations was 2% better than code.

---

7 The Massachusetts PAs adopted an above code baseline for boilers in Spring 2017 following the March 2017 publication of a dedicated boiler study by the DNV GL team (http://ma-eeac.org/wordpress/wp-content/uploads/Gas-Boiler-Market-Characterization-Study-Phase-II-Final-Report.pdf). The revised baselines adopted per the study are 85% efficiency for boilers less than 2,000 MBH and a case-by-case baseline for larger and custom projects. However, for the buildings in this 2017 Study, the relevant baseline is the IECC 2012 code boiler efficiency levels, since all the buildings in this study were permitted prior to the boiler study publication and subsequent adoption by the PAs.
Table 4-8. Summary Statistics for Boiler Observations

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Boilers</th>
<th>Five Number Summary</th>
<th>Boilers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of observations (n)</strong></td>
<td>14</td>
<td>Minimum</td>
<td>3%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>16%</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Quartile</td>
<td>15%</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>5%</td>
<td>Median</td>
<td>18%</td>
</tr>
<tr>
<td><strong>90% Confidence Interval</strong></td>
<td>2%</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Quartile</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>20%</td>
</tr>
</tbody>
</table>

Figure 4-10. Boiler Observations Relative to Code Requirements

- Participants
- Nonparticipants
- Code Value

Site observations (n=15 sites)
### Table 4-9. Summary Statistics for Furnace Observations

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Furnaces</th>
<th>Five Number Summary</th>
<th>Furnaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>19</td>
<td>Minimum</td>
<td>0%</td>
</tr>
<tr>
<td>Mean</td>
<td>2%</td>
<td>1st Quartile</td>
<td>0%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>3%</td>
<td>Median</td>
<td>1%</td>
</tr>
<tr>
<td>90% Confidence Interval</td>
<td>1%</td>
<td>3rd Quartile</td>
<td>3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>11%</td>
</tr>
</tbody>
</table>

### Figure 4-11. Furnace Observations Relative to Code Requirements

![Graph showing furnace observations relative to code requirements]
4.7.2.2 Heat Pumps

The DNV GL team observed heat pumps in 14 of the 39 sites. Figure 4-12 shows the heat pump observations compared to the code requirements; all sites except for one averaged heat pump efficiencies better than code. Across all observations, the average heat pump was 16% better than code.

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Heat Pumps</th>
<th>Five Number Summary</th>
<th>Heat Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>14</td>
<td>Minimum</td>
<td>-4%</td>
</tr>
<tr>
<td>Mean</td>
<td>16%</td>
<td>1\text{st} Quartile</td>
<td>8%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>12%</td>
<td>Median</td>
<td>17%</td>
</tr>
<tr>
<td>90% Confidence Interval</td>
<td>5%</td>
<td>3\text{rd} Quartile</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>42%</td>
</tr>
</tbody>
</table>

Figure 4-12. Heat Pump Observations Relative to Code Requirements

-10% - 0% - 10% - 20% - 30% - 40% - 50%

0 2 4 6 8 10 12 14 16

Site observations (n=14 sites)

 Participants  Nonparticipants  Code Value
4.7.2.3 Domestic Hot Water

The results for domestic hot water (DHW) present a clear picture despite one likely outlier. Although the code value fluctuates slightly by technology, it is roughly 80% efficiency for DHW. All observations except for one were well above 90% efficient, regardless of program participation. This suggests that the market is likely in the 90% range; the average across all DHW observations was 94% efficient.

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>DHW</th>
<th>Five Number Summary</th>
<th>DHW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>19</td>
<td>Minimum</td>
<td>75%</td>
</tr>
<tr>
<td>Mean</td>
<td>94%</td>
<td>1st Quartile</td>
<td>95%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>5%</td>
<td>Median</td>
<td>96%</td>
</tr>
<tr>
<td>90% Confidence Interval</td>
<td>2%</td>
<td>3rd Quartile</td>
<td>96%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>99%</td>
</tr>
</tbody>
</table>

4.8 Lighting

This section presents the analysis of observed lighting provisions of the energy code for the 2017 Study (IECC 2012).


Table 4-12 displays the unweighted compliance for select lighting provisions and the percentage of sites where each provision was verifiable on construction documentation and/or during field visits.
Table 4-12. Select Lighting Energy Code Provisions

<table>
<thead>
<tr>
<th>Provision Description</th>
<th>Percentage Verifiable</th>
<th>DNV GL Compliance</th>
<th>DOE/PNNL Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic lighting control to shut off all non-emergency building lighting (required in buildings &gt;5,000 sq ft)</td>
<td>64%</td>
<td>95%</td>
<td>92%</td>
</tr>
<tr>
<td>Lighting controls allow occupants to reduce lighting load by at least 50% (commonly bi-level switching).</td>
<td>100%</td>
<td>96%</td>
<td>92%</td>
</tr>
<tr>
<td>Daylight zones are provided with individual controls that control the lights independent of the general area lighting.</td>
<td>92%</td>
<td>81%</td>
<td>81%</td>
</tr>
<tr>
<td>Each area enclosed by walls or partitions has required manual lighting controls.</td>
<td>100%</td>
<td>97%</td>
<td>92%</td>
</tr>
<tr>
<td>Exterior lighting controlled by photocell or timer</td>
<td>72%</td>
<td>98%</td>
<td>96%</td>
</tr>
<tr>
<td>Lighting power density (LPD) in interior spaces is at or below code-required levels.</td>
<td>95%</td>
<td>100%</td>
<td>97%</td>
</tr>
<tr>
<td>LPD in exterior spaces is at or below code-required levels.</td>
<td>87%</td>
<td>97%</td>
<td>88%</td>
</tr>
</tbody>
</table>

A few observations can be made from analysis of the individual lighting provisions:

- **Daylighting compliance** – The energy code requires that daylight zones be provided with individual controls independent of general lighting controls. This was observed to have low compliance (~50%) during the 2015 Study (IECC 2009), but the 2017 Study (IECC 2012) results suggest that compliance with this requirement has increased (81%). Daylighting was new to IECC 2009 and this improvement likely represents the increasing familiarity that design professionals have with this requirement.

- **LPD** – There was only one site that did not meet the required lighting power allowance in the 2017 Study. The majority of sites evaluated were substantially better than the code requirements, as discussed in the baseline section below.

- **Other lighting controls** – The code contains several other lighting controls, including manual switching, lighting load reductions, and exterior control requirements. These requirements all had compliance rates over 90%, suggesting that these are well understood and commonly implemented.

### 4.8.2 Informing Baselines

The lighting data gathered for the 2017 Study (IECC 2012) can inform Massachusetts new construction baseline lighting practices.

#### 4.8.2.1 Lighting Fixture Distribution

As part of the lighting data collection, the DNV GL team conducted lighting fixture inventories for all surveyed interior and exterior spaces. Figure 4-14 and Figure 4-15 present the distribution of interior and exterior fixtures by lighting technology for the 2017 Study (IECC 2012) and the prior 2015 study (IECC 2009). The primary observation here is the growth of LEDs in the last 3 years.
Figure 4-14. Comparison of Interior Lighting Technologies between the 2015 and 2017 Studies

<table>
<thead>
<tr>
<th>Technology</th>
<th>2015 Study (n=14,300 fixtures)</th>
<th>2017 Study (n=15,085 fixtures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>33%</td>
<td>84%</td>
</tr>
<tr>
<td>T8</td>
<td>13%</td>
<td>7%</td>
</tr>
<tr>
<td>T5</td>
<td>22%</td>
<td>7%</td>
</tr>
<tr>
<td>CFL</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Other</td>
<td>30%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Figure 4-15. Comparison of Exterior Lighting Technologies between 2015 and 2017 Studies

<table>
<thead>
<tr>
<th>Technology</th>
<th>2015 Study (n=1,968 fixtures)</th>
<th>2017 Study (n=1,418 fixtures)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED</td>
<td>85%</td>
<td>77%</td>
</tr>
<tr>
<td>HID</td>
<td>4%</td>
<td>20%</td>
</tr>
<tr>
<td>CFL</td>
<td>9%</td>
<td>7%</td>
</tr>
<tr>
<td>Other</td>
<td>2%</td>
<td>0%</td>
</tr>
</tbody>
</table>
**Program Participation Impacts**

Figure 4-16 compares the interior lighting fixture distribution for the 2017 Study for participants and nonparticipants. While both populations show high penetration of LED lighting, the trend is more pronounced for participants (94% of fixtures). Exterior lighting is not displayed due to small sample sizes when split by participation.

![Figure 4-16. 2017 Study Interior Lighting Technologies by PA Program Participation](image)

### 4.8.2.2 Lighting Power Density

Figure 4-17 presents the observed interior LPD observations compared to the code requirements. Data was observed for 36 out of the 39 study sites; all except for one site was observed to have LPD better than code. The average across all observations was 37% better than the code.

**Table 4-13. Summary Statistics for Interior Lighting Observations**

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>LPD</th>
<th>Five Number Summary</th>
<th>LPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>36</td>
<td>Minimum</td>
<td>-8%</td>
</tr>
<tr>
<td>Mean</td>
<td>37%</td>
<td>1st Quartile</td>
<td>24%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>16%</td>
<td>Median</td>
<td>37%</td>
</tr>
<tr>
<td>Precision at 90% Confidence</td>
<td>7%</td>
<td>3rd Quartile</td>
<td>49%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>60%</td>
</tr>
</tbody>
</table>
Figure 4-17 shows the interior LPD observations relative to code requirements. Data was observed for 33 of the 39 sites, and across all observations the average result was 24% better than the code.

Figure 4-18 shows the exterior LPD observations compared to code requirements. Data was observed for 33 of the 39 sites, and across all observations the average result was 24% better than the code.

Table 4-14. Summary Statistics for Exterior Lighting Observations

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>Exterior Lighting</th>
<th>Five Number Summary</th>
<th>Exterior Lighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations (n)</td>
<td>33</td>
<td>Minimum</td>
<td>-48%</td>
</tr>
<tr>
<td>Mean</td>
<td>24%</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Quartile</td>
<td>8%</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>23%</td>
<td>Median</td>
<td>19%</td>
</tr>
<tr>
<td>90% Confidence Interval</td>
<td>9%</td>
<td>3&lt;sup&gt;rd&lt;/sup&gt; Quartile</td>
<td>40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>87%</td>
</tr>
</tbody>
</table>
4.8.2.3  Interior LPD adjustment for IECC 2012

As discussed in Section 3.2, the DNV GL team used the results of the 2015 Study (IECC 2009), incorporating program participation, to estimate and recommend an adjustment to IECC 2009 code LPD ratios so that they better reflect observed market practices. The data captured for the 2017 Study (IECC 2012) enables a similar exercise to develop an estimate for IECC 2012. The methodology used to develop this estimate is consistent with the previous exercise and is summarized as follows:

1. **Aggregate 2017 Study data by site** – This initial step calculated a code-allowed wattage and an installed wattage for each of the 37 sites where LPD data was observable. For some sites, a census fixture inventory was completed, while for others a representative sample was used, capturing the square footage assessed.

2. **Weight data by square footage and 2017 Study site weight** – The site weighting is consistent with the overall compliance methodology used for the 2017 Study. First, where a census was not completed, the observed spaces were aggregated to represent the total installed and allowed wattage for each building. One exception to note here is for MF buildings; since only common areas are subject to the commercial LPD requirements, the team used the sampled areas as a better approximation of the common-area wattage than the overall building square footage. The 2017 Study site weights were then applied, resulting in a statewide ratio of estimated actual installed wattage to estimated code-allowed wattage.

3. **Review data for outliers or additional stratifications** – We reviewed the resulting data to identify outliers and determine whether sample sizes support additional stratification by building type or building size. This review showed that no individual site unduly influenced the outcome, and that values from potential subsectors were not significantly different from the statewide value.
4. **Adjust for program participation** – The DNV GL team adjusted for program participation in a three-step process.

   a. **Identify program participation within the sample** – The DNV GL team cross-referenced the sampled sites with PA participation databases and supplemental comparisons in conjunction with the PAs and found that 21 sites (58%) received lighting incentives and can be classified as participants, as shown in Table 4-15.

<table>
<thead>
<tr>
<th>2017 Study Site Type</th>
<th>Number of Sites</th>
<th>Ratio of installed wattage to Code Maximum allowed wattage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (P)</td>
<td>21</td>
<td>0.53</td>
</tr>
<tr>
<td>Nonparticipants (Np)</td>
<td>15</td>
<td>0.68</td>
</tr>
</tbody>
</table>

b. **Adjust the participant compliance ratio to account for program influence.** – The compliance ratio for participants was adjusted to account for (i.e., remove) the influence of the programs using the free ridership (FR) rate. The team utilized FR values from the Massachusetts Three-Year Plan 2016–2018 for the various lighting programs, evaluated each participating site’s program and corresponding FR estimate, and averaged the FR for all sampled participants. The resulting FR estimate was 0.16, which approximates the proportion of the difference between the nonparticipant and participant compliance ratios that is not attributable to program influence.

c. To reflect the market compliance ratio from the perspective of participants, we calculated the participant-adjusted value (Padj), by accounting for program influence (1-FR) from the difference between Np and the P values, as shown in the following equation:

\[
Padj = P + [(Np - P) \times (1 - FR)] = 0.53 + [(0.68 - 0.53) \times (1 - 0.16)] = 0.65
\]

As shown above, 84% (1 – 0.16) of the difference between the nonparticipant and participant compliance ratios is used to approximate program influence, and we estimate an adjusted compliance ratio (Padj) of 0.65 for program participants without program influence.

5. **Apply to population** – The DNV GL team analyzed Dodge records and program tracking data to estimate a population participation rate of 40%. This participation rate was used to compute a weighted average compliance ratio for the adjusted participants and the nonparticipants.
<table>
<thead>
<tr>
<th>2017 Study Site Type</th>
<th>Number of Sites</th>
<th>Unweighted Compliance Ratio</th>
<th>Adjusted Compliance Ratio</th>
<th>Population Participation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants (P)</td>
<td>14</td>
<td>0.53</td>
<td>0.65</td>
<td>0.4</td>
</tr>
<tr>
<td>Nonparticipants (Np)</td>
<td>23</td>
<td>0.68</td>
<td>N/A</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Weighted average adjustment factor at 90% confidence</strong></td>
<td></td>
<td></td>
<td><strong>0.67 +/- 0.05</strong></td>
<td></td>
</tr>
</tbody>
</table>

As shown in
Table 4-16, the DNV GL team recommends that an adjustment factor of 0.67 +/- .05 be used to “de-rate” code-required LPDs for any new commercial construction buildings in the project sample.

4.8.2.4 Lighting Controls

As part of the fixture inventory, the DNV GL team identified lighting controls for each fixture wherever possible. Figure 4-19 shows the distribution of fixtures by control type. Occupancy controls were observed for 74% of all fixtures where control observations were made, most often as the only control, but also in conjunction with manual controls. While this data was not captured during the 2015 Study (IECC 2009), the prevalence of occupancy sensors suggests that this is becoming a standard practice, as many sensors were fixture-mounted.

Figure 4-19. Interior Lighting Controls Identified during 2017 Study

- Occupancy sensor only
- Occupancy and manual control
- Manual control only
- Central control system
5 CONCLUSIONS AND RECOMMENDATIONS

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

5.1 Conclusions

The following conclusions can be drawn from the analysis presented above.

1. **The compliance of nonresidential new construction (NRNC) buildings is consistent over time, even as the energy code gets more stringent.** Using the DNV GL methodology, this study estimates a compliance rate of 94%. This should be interpreted to mean that the average new construction building meets 94% of the code requirements. Despite an increase in stringency in the code, the overall compliance rate remained high, suggesting that NRNC buildings are being built fairly well in Massachusetts.

2. **The findings of the study are a clear call to action to consider the status of standard practice across the Commonwealth and its relation to code requirements.** However, it is less clear what the actual standard practice and resulting baseline value should be for each measure. This has the potential to significantly impact program savings and future offerings. The significant deviation from code necessitates further research to corroborate these findings. Given the potential departure from code baselines, high rigor studies aligned with the ISP framework are necessary to validate these study insights.

3. **The energy code requirement for interior lighting power is not reflective of current standard practices.** The DNV GL team’s analysis of interior LPD results, factoring in PA program participation, suggests that standard lighting practices exceed the code requirements. The increasing penetration of LEDs is a primary factor. The DNV GL team determined that on average, the installed lighting LPDs were 0.67 +/- 0.04 of the code requirements for buildings permitted under IECC 2012.

4. **The energy code does not reflect standard practices for many mechanical provisions.** The 2017 Study (IECC 2012) captured efficiency data for mechanical equipment that was on construction documents and/or installed on-site where observable. This data shows that for some mechanical provisions such as boiler efficiencies and domestic hot water efficiencies, standard practices are likely somewhat better than the code requirements.

5. **Opportunities for improving compliance remain for targeted measures.** While compliance is overall fairly high, opportunities remain to improve compliance for specific measures. These measures include relatively recent additions to the code such as daylighting, as well as measures such as air sealing that are difficult to enforce without extensive testing.

6. **Energy code determinations continue to be made at the design stage for new construction.** The decisions about equipment sizing and type, construction materials, insulation levels, and control strategies occur during the building design, most often by architects and engineers. This trend is consistent with the 2015 Study (IECC 2009) and was confirmed during DNV GL team interviews with design and construction teams. However, during construction, poor installation practices can undermine well-designed buildings.
5.2 Recommendations
The DNV GL team recommends the following based on analysis of the 2017 Study (IECC 2012) results:

1. **While this study cannot determine exact baseline values, the evidence strongly suggests that the PAs should be adjusting their program planning and implementation to account for changing standard practice.** Current projects that assume code baselines for new construction measures are at risk in an ex ante evaluation, based on these findings. PAs should pursue an orderly transition, completing the ISP research agenda as quickly as possible, negotiating their prospective and retrospective applications, and rolling out the revisions in program support documents.

2. **Focus future training on energy code changes, field verifications, and specific provisions that are not easily understood and/or complied with.** While the compliance detailed on construction documents is relatively good, opportunities remain for targeted measures, and there are many code provisions that require proper installation practices to fully capture their energy benefits. These include air sealing, insulation installation, lighting and HVAC controls, and commissioning. Training focused on these elements, including field components, will help code officials and construction teams understand and enforce best practices.

5.3 Considerations
DNV GL makes the following two considerations based on analysis of the 2017 Study (IECC 2012):

1. **Consider expanding the PA program participation data collection effort to provide more detailed information about program participation.** The PA program participation database provides relatively limited information on the specific measures incentivized by the programs. This data is used to identify participants and nonparticipants in the calculation of baseline practices; however, the lack of detail on the specific participation is a limiting factor in this analysis. More detailed participation data would improve our understanding of program impacts.

2. **Consider engaging NRNC projects as early in the design phase as possible to improve building features.** The design team is primarily responsible for selection of equipment, lighting design, control strategies, and building materials. Early engagement of projects helps ensure that they exceed code requirements.

5.4 Future Research
The DNV GL team recommends the following four opportunities for future research to improve the quality of NRNC market data and overall evaluation activities.

1. **Conduct a short-term study to corroborate the 2017 Study baseline findings in accordance with the ISP Framework.** The DNV GL team developed an ISP protocol document in 2017 outlining methods for assessing and revising baselines. The lighting end-use study is currently one of the technologies in the scope of ISP research, partially prompted by the findings of this study. Other measures should undergo some level of ISP research before adopting a final ISP efficiency value.

2. **Conduct a targeted compliance study focused on understanding the approach to and enforcement of buildings pursuing a performance path to demonstrate compliance with the energy code.** All of the commercial compliance studies completed in Massachusetts to date have followed the prescriptive path to compliance. However, more and more buildings are pursuing
performance paths to demonstrate compliance, because that enables more expanded trade-offs and modeling, and is consistent with approaches supported by LEED and other high-performance building programs. Design professional interviews suggest that code officials are less familiar with performance modeling and commonly accept a design team statement, COMcheck report, or look for a few key provisions to demonstrate compliance. A targeted study focused on the performance path would improve understanding of the approach to identify a method that facilitates effective code official review.

3. **Perform equipment- and measure-specific studies to improve understanding of energy code nuances.** Compliance studies such as the 2017 Study (IECC 2012) provide a big-picture perspective on compliance, but the combination of limited time and budget along with the need to cover the energy code from a broad perspective results in varying levels of detail on individual measures. Equipment and/or measure-specific studies would enable evaluators to explore code requirements or best practices in greater detail. Examples of these investigations could include analysis of light levels (spaces may meet the energy code but still be overlit) as well as an assessment of the appropriateness of mechanical equipment sizing.

4. **Embed code compliance assessors with building code officials to reduce any self-selection bias.** Self-selection bias is a common challenge for energy code compliance studies, as building owners and developers who are knowingly not adhering to code requirements can decline participation in compliance studies without consequence. Through collaboration with building code officials, the conductors of a compliance study would have greater access to project documentation and can conduct targeted site visits. This research could be designed as a large study with a representative sample, or be done in a more targeted manner such as a ride-along with code officials, or even a training exercise, so that evaluators can observe compliance documentation and demonstration from the perspective of the party responsible for enforcement.

5. **Include more on-site verifications in future lighting compliance and ISP studies.** The PAs recommend that future lighting verifications for compliance and ISP work ideally include more field observations to ensure that ISP recommendations reflect the lighting that is actually being installed versus what is designed in construction documents. There is concern that actual installations may not reflect the designed lighting, and that the technologies installed, though they may meet LPD requirements, leverage inferior or unapproved lighting products that will not sustain designed performance.
APPENDIX A. P70 MILESTONE 2-1: SUMMARY OF P24 CONTROLS/OPERATIONS SITE REVISITS

Memo to: Ari Michelson, ERS
From: Massachusetts Program Administrators Research Team and Energy Efficiency Advisory Council EM&V Consultants
Date: May 19, 2017

P70 Milestone 2-1. Summary of P24 Controls/Operations Site Revisits

Overview
This memo presents a summary of results from the DNV GL Team’s revisit of 16 sites included in the 2015 Massachusetts Commercial New Construction Energy Code Compliance Follow-up Study (P24). Note that while the planned sample was 15 sites, we were able to recruit an additional site for revisit. This memo satisfies Milestone 2-1 for P70. The purpose of this study is to qualitatively explore control practices in newly constructed buildings.

During this task, field engineers from the DNV GL Team interviewed on-site facility staff to understand general building control strategies, reviewed energy management system (EMS) scheduling where possible, and conducted facility tours to observe specific building control features, such as setpoints and schedules. The energy code itself does not explicitly govern building operations, but rather specifies that building systems have control capabilities; therefore, this exercise sought to assess the operations of recently constructed commercial buildings in the context of good control and management practices for the primary building systems and equipment installed. For the purposes of this study, good control practices are defined as controls and equipment installed, functioning and either actively managed by site personnel or controlled automatically with regular maintenance.

The overall results of the P24 Revisits, including the number of sites where each building system was observable, as well as the average good practice assessment, is presented in Table 1.1. The DNV GL Team’s field engineers assessed building operations according to a scale from 1 to 5, with 1 representing no active management/control and 5 representing alignment with system good practices. Overall, the majority of building systems function fairly well; the average values across all systems and sites were above 4 on this scale. Section 2 describes the methodology and approach in greater detail, and Section 3 presents our observations from the revisits regarding general control approaches and specific building systems.

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Table 1.1. Assessed Quality of Building System Control Operation for C&I New Construction Post-Occupancy

<table>
<thead>
<tr>
<th>Control of Building System/Equipment</th>
<th>Count of Site Observations</th>
<th>Average Overall Building System Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler - heating</td>
<td>10</td>
<td>4.1</td>
</tr>
<tr>
<td>Boiler - DHW</td>
<td>10</td>
<td>4.8</td>
</tr>
<tr>
<td>Lighting</td>
<td>16</td>
<td>4.4</td>
</tr>
<tr>
<td>Pumps</td>
<td>12</td>
<td>4.8</td>
</tr>
<tr>
<td>Exhaust fans</td>
<td>16</td>
<td>4.2</td>
</tr>
<tr>
<td>AHU/RTU</td>
<td>16</td>
<td>4.3</td>
</tr>
<tr>
<td>Chiller</td>
<td>3</td>
<td>4.7</td>
</tr>
<tr>
<td>Cooling tower</td>
<td>1</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Methodology

The DNV GL Team revisited a sample of the 2015 Study (IECC 2009) sites to investigate how recently constructed buildings are being operated with respect to good-practice control strategies, primarily for lighting and mechanical systems. The team targeted 15 but recruited 16 sites consisting of both program participants and non-participants; the distribution of sites is presented in Table 2.1. This sample is not meant to be statistically representative of the new construction population, but rather to provide insights into post-construction building operations. The energy code increasingly requires initial building commissioning but largely does not govern post-occupancy practices. These insights, in conjunction with the site data that will be gathered during Task 5 of P70, can be used to inform baseline practices in terms of installed equipment as well as building operations.

Table 2.1. Summary of NC Post-Occupancy Recruitment

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Population</th>
<th>Target</th>
<th>Completes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Site Program Participants (P1)</td>
<td>13</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Large Site Program Non-Participants (NP1)</td>
<td>11</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Small Site Program Participants (P2)</td>
<td>8</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Small Site Program Non-Participants (NP2)</td>
<td>18</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>15</td>
<td>16</td>
</tr>
</tbody>
</table>

These site visits consisted of a brief review of equipment and control strategies identified during the 2015 Study (IECC 2009), followed by a facility tour and discussion with on-site facility personnel. The DNV GL Team developed a short data collection form to assess good practices for operation of the following

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9 Note that for this activity, participants were considered to be any site that received PA incentives as part of the new construction effort, based on analysis performed by the DNV GL Team for the P24 sites. Participation was considered by category: lighting, lighting controls, HVAC, envelope, or comprehensive design assistance (CDA) program participation.

10 Large and small sites are designated by square footage and are consistent with P24. Small sites are less than 50,000 square feet, and large sites are greater than or equal to 50,000 square feet. This table includes participants (P) and nonparticipants (NP)
equipment/systems: air handling units/rooftop units (AHUs/RTUs), boilers (heating), boilers (domestic hot water), chillers, cooling towers, pumps, exhaust fans, and lighting controls.

For each category, field engineers analyzed the operations of relevant equipment, assessing a series of control/operations features and requirements and then rating the operations of each applicable equipment category at the site on a scale of 1 to 5, where 1 represents equipment that is not actively managed and 5 represents equipment that is operating according to good practices. Table 2.2 shows the general rating rubric used during the assessments.

<table>
<thead>
<tr>
<th>Qualitative Assessment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Controls and equipment not installed; clear evidence that system(s) are not actively managed and/or adjusted manually</td>
</tr>
<tr>
<td>2</td>
<td>Some controls and equipment not installed; some evidence that system(s) are not actively managed.</td>
</tr>
<tr>
<td>3</td>
<td>Controls and equipment mostly installed. Some system(s) not actively managed or have been bypassed</td>
</tr>
<tr>
<td>4</td>
<td>Controls and equipment installed and mostly actively managed. Some systems/controls may have bypasses.</td>
</tr>
<tr>
<td>5</td>
<td>Controls/Equipment installed and actively managed/automated by facility staff or third party</td>
</tr>
</tbody>
</table>

Following the site visits, the DNV GL Team calibrated results through in-person discussions of assessments to ensure consistency across sites and site engineers. It is worth noting that the DNV GL team did not perform independent commissioning of the sites, which is the best way to assess if controls are working correctly. This was an exploratory exercise designed as a qualitative assessment to better understand the controls in operation at recently constructed buildings.

**Site Observations**

This section presents a summary of the observations captured during the site revisits. A summary of the general building control approach is presented first, followed by insights for the primary building systems observed during the site visits.

**Building Control General Approach**

The site visits included a brief interview with facility staff to understand the building’s overall approach to building operations and control. This interview discussed EMSs, central lighting controls, operations and maintenance (O&M) manuals, and site commissioning. Table 3.1 presents the results of these interviews, followed by a summary of observations.
Table 3.1. Overall Building Control Summary

<table>
<thead>
<tr>
<th>Site Response</th>
<th>EMS</th>
<th>Central Lighting Controls</th>
<th>Commissioning</th>
<th>O&amp;M Manuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed/ provided to site</td>
<td>13</td>
<td>10</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Not installed/ provided to site</td>
<td>3</td>
<td>6</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Site contact did not know</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16</strong></td>
<td><strong>16</strong></td>
<td><strong>16</strong></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

- **EMS Control** – Out of the 16 sites visited, 13 had installed EMSs. EMS operations varied across the sites, with 9 sites managing the system internally and 4 sites contracting out EMS operations to a third-party vendor. Many of the sites that manage their EMS internally on a day-to-day basis leverage vendor support when problems arise.

- **Central Lighting Control System** – Of the 16 sites, 10 had installed a central lighting control system capable of controlling some or all lighting at the site. While some of these lighting systems have the functionality to interface with the EMS, site contacts indicated in nearly every case that they are controlled independently of their EMS and are managed internally at the site.

- **Commissioning** – We discovered that 57% of the sites (9 of 16) visited were commissioned. The DNV GL Team asked for a copy of the commissioning report and were able to see it for several sites.

- **Operations & Maintenance Manuals** – The energy code requires that O&M manuals are provided for the mechanical equipment on-site. While these weren't available to the field engineers for the majority of the visits, the site contacts for 15 of the sites indicated that these were provided by the construction team during or soon after construction.

**Boilers**

Field engineers assessed the boiler operations for both heating and domestic hot water (DHW) applications. The primary descriptive data points included the boiler type and distribution method, as well as operational controls, which included examining the return water temperature, checking the hot water reset schedule, and verifying that the boiler pumps only cycle when the boiler is firing. For boilers used for heating, field engineers also attempted to verify that the boiler system is disabled above certain outside air temperatures. For DHW boilers, the team identified the boiler type and reviewed the hot water setpoint.

**Boiler Observations – Space Heating**

Boiler observations were made for 10 of the 16 sites, all of which were equipped with condensing boilers. Figure 3.1 shows the overall assessment for boiler heating operations. The primary areas where good practices were not observed were in relation to hot water reset schedules. There were several sites where schedules were not optimized, limiting the condensing benefits. Some boilers were equipped with pumps with variable frequency drives (VFDs), but in several instances the VFDs were manually bypassed, limiting the operational savings. These sites were assessed scores of 3 or 4 depending on what was bypassed.
Boiler Observations – Domestic Hot Water

Boilers for DHW were observed in 10 of the 16 sites and were all condensing boilers. The hot water setpoint was the primary observation point for DHW operations; this setpoint ranged from 125°F to 150°F. As shown in Figure 3.2, most sites are operated within good practice expectations. The sites with the higher setpoints could likely be lowered for increased boiler efficiency.
Lighting Systems

The field engineers’ review of operations and controls of site lighting focused on examining the centrally controlled lighting systems where installed or possible, as well as a building tour to observe space and fixture-level controls. The field team documented the presence of occupancy sensors, daylight sensors for daylit areas, and timer/photocell controls on the exterior lighting.

Lighting Observations

Lighting system observations were made for all 16 of the revisit sites. The field engineers found that lighting systems for the 16 sites were for the most part operating according to good practices, as shown in Figure 3.3.

![Figure 3.3. Overall Site Assessments of Lighting System Control Operations](image)

The sites with central lighting systems (10 out of 16 sites) typically had space-level scheduling in place to govern occupied and unoccupied periods. Occupancy sensors were found throughout all but one site, and field engineers observed more ceiling- and fixture-mounted sensors than wall-mounted. This suggests that occupancy sensors are likely standard practice in new construction; the P70 Task 5 data collection is explicitly looking at lighting control types and should provide additional insight into this observation.

Daylighting was only observed in 4 out of the 16 sites. While some sites only had small daylit areas and 2 sites did not have spaces required by code to have daylight sensors, the lack of independent daylighting controls is consistent with the P24 Study finding that daylight controls were not installed where required (daylighting controls were found in only 50% of verifiable sites during P24). Exterior lighting controls were also reviewed during these revisits to ensure that they are controlled by a photocell or astronomical time clock. The field engineers observed full compliance for all 16 sites. Table 3.2 summarizes the primary lighting system observations.
### Exhaust Fans

To assess exhaust fan controls, field engineers examined whether the fans are operated on a programmed schedule. For sites with an EMS, the schedule can usually be observed on the fan status screen; for sites without an EMS, field engineers inspected the fans and discussed operations with on-site facility staff.

#### Exhaust Fan Observations

Exhaust fan operations were observed at all 16 sites; the overall assessment of exhaust fan operations is presented in Figure 3.4. This assessment was primarily driven by observed exhaust fan scheduling. While most sites are functioning well, for several sites the DNV GL Team observed that exhaust fans run constantly, even when the building is unoccupied. Opportunities for improvement include building scheduling for occupied/unoccupied times, as well as connecting the exhaust fan operations to occupancy sensors, particularly in restrooms and other smaller spaces.

![Figure 3.4. Overall Site Assessments of Exhaust Fan Operations](image)

### Pumps

To assess pump operations, field engineers looked primarily at hot water and chilled water circulation pumps to confirm that they have controls to disable operations above/below programmed outside air temperatures. They also verified that variable speed controls are in place where required by code. For chillers, field
engineers also looked at the condenser water pump for variable speed controls to ensure that it is set up to only operate when the chiller is on.

**Pump Observations**

Overall, the field engineers found that pump operations aligned with good practices where observable. Figure 3.5 shows the overall site assessment for the 12 sites where pump observations were made. The lower overall assessments for 3 sites in Figure 3.5 resulted from observed opportunities to adjust and tune the temperature setpoints.

![Figure 3.5. Overall Site Assessments of Pump Operations](image)

Table 3.3 presents the observations by type of pump. Notably, all observed pumps were controlled by VFDs, suggesting that this may be standard practice.

<table>
<thead>
<tr>
<th>Observation</th>
<th>Hot Water Circulation Pump</th>
<th>Chilled Water Circulation Pump</th>
<th>Condenser Water Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of sites observed</td>
<td>10</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Controls to disable based on outside air temperature</td>
<td>10</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>VFD to control pump operations</td>
<td>10</td>
<td>5</td>
<td>1</td>
</tr>
</tbody>
</table>

**Air Handling Units / Rooftop Units**

For AHUs and RTUs, the field engineers confirmed whether or not an occupied/unoccupied schedule was set up for each zone controlled by this equipment. They also reviewed the supply fan operations, heating and
cooling setpoints, and outside air dampers. Additionally, as applicable, the team reviewed economizer functionality, demand controlled ventilation (DCV) controls, variable air volume (VAV) static pressure reset controls, and variable speed controls on motors as required by the energy code (for IECC 2009 greater than 10 hp).

**AHU/RTU Observations**

Observations on AHUs and RTUs were made for all 16 sites. Figure 3.6 displays the overall assessment for each site. In general, temperature setpoints were established for nearly all sites in the sample; however, in several cases the facility staff regularly manually overrides these setpoints, resulting in an assessed score of “3.” In one case, the facility staff member giving the tour was correcting thermostat adjustments in real-time during the field engineer’s visit; this site was assessed as score of “1.” The following additional AHU/RTU observations were made:

- **Variable speed control** – Consistent with the pump observations, it was noted that all motors greater than 10 hp requiring variable speed control on AHU/RTUs had VFDs installed.
- **Economizers** – The field engineers observed properly functioning economizers for 10 sites. Since these visits were conducted during the winter, however, the engineers were not able to witness the controls beyond a review of the EMS or discussions with facility personnel.
- **DCV** – Spaces requiring DCV were observed in 13 out of the 16 sites, with 10 sites having operational DCV systems.
- **Outside air dampers** – The field engineers indicated for several sites that there appeared to be too much ventilation air. One site had outside air dampers wide open on a 20°F day, and for other sites, incorporating occupancy sensing into the damper control could help reduce overventilation.

![Figure 3.6. Overall Site Assessments of AHU/RTU Operations](image)

**Standard Practice Implications and Next Steps**

This data collection activity was designed to gather anecdotal insights into the operations of recently constructed commercial buildings in Massachusetts. While it is not statistically representative of the MA new
construction population or the P24 Study, we can discern several likely standard practices from the site observations:

1. **Controls installed and actively operated.** In general, controls are installed and operated to reduce energy usage in both participant and non-participant buildings. Both participant and non-participant buildings were observed operating at both the lowest and highest rating points. This study was meant to be a qualitative first foray into how we observe building operations and controls strategies in place. At first glance, there does not appear to be strong differences between participants and non-participants. However, this is not quantitative and should be explored further before any definitive conclusions are made.

2. **Additional control optimization opportunities likely remain.** The methodology was designed to observe whether control strategies were in place at all, but not whether they were optimized. For example, lighting controls were assumed to follow good practices if schedules reflecting business hours were programmed in the controllers; however, it may have been possible to reduce the hours of operation even more through more aggressive scheduling.

3. **VFDs are used to satisfy variable speed control requirement.** In all cases where variable speed control was required by the energy code, VFDs were installed to meet this requirement. While in several cases the VFDs were bypassed or not functioning optimally, they seem to be the standard construction practice.

4. **Occupancy sensors are widely implemented.** The IECC 2009 requires, at a minimum, manual lighting controls in all spaces and the capacity to reduce space lighting load by 50%. Based on the observations completed in this task, occupancy sensors appear to be the standard practice employed to satisfy this requirement. Sensors are often installed in conjunction with manual switches, but the team observed more fixture- and ceiling-mounted sensors than wall mounts.

5. **Exterior lighting controls are widespread.** All sites visited during this task had exterior lighting controlled by photocells or an astronomical time clock, suggesting that this is a standard practice.

**Next Steps**

The DNV GL Team is concurrently working on Task 5 of P70, an assessment of energy code compliance and baseline implications of buildings constructed under the subsequent version of the energy code, IECC 2012. This additional data can be combined with both the revisit and original data from P24 to observe building practices over time.

This was the DNV GL Team’s first attempt at assessing operations and controls practices in this manner. Overall, the data collection instrument and scoring algorithms worked well. The on-site engineers were generally able to observe control indicators (such as setpoints and schedules) that allowed for an objective assessment of the controls. While some minor improvements in the data collection would improve the depth of data collection and streamline the analysis, we do not foresee that a major revamp of the tool is necessary prior to its future use for Task 5 sites or in other future applications.
APPENDIX B. REVISED BASELINE ADJUSTMENT FOR NEW COMMERCIAL CONSTRUCTION LIGHTING POWER DENSITY

Memo to: Ari Michelson, ERS
From: Sue Haselhorst, ERS
Massachusetts Program Administrators Research Team and Energy Efficiency Advisory Council EM&V Consultants
Date: January 13, 2017

Copy to: Chad Telarico, DNV GL

Revised Baseline Adjustment for New Commercial Construction Lighting Power Density (LPD)

Overview

This updated memo presents a revised adjustment factor for lighting power density (LPD) that can be applied to analyses of new commercial construction buildings permitted under the 2009 International Energy Conservation Code (IECC 2009). The Massachusetts Energy Efficiency Programs Commercial & Industrial Evaluation Contractor team, DNV GL, prepared the original memo as part of the Impact Evaluation of the Massachusetts Commercial and Industrial Upstream Lighting Program (P58). The adjustment factor reflects the LPD standard practice we observed during the 2015 Massachusetts Commercial New Construction Energy Code Compliance Follow-Up Study (2015 Code Study). The original memo did not address program administrator (PA) program participation; this revision builds upon the original memo, adding step 5 in the methodology below to incorporate PA program participation into the LPD adjustment. This revised memo was developed primarily for use in the DNV GL team’s analysis of the CDA Impact Evaluation (P56).

Following a series of conversations in Fall 2017 regarding the LPD adjustment approach, the DNV GL Team, the PAs, and the EEAC agreed in January 2018 to make the following changes to the LPD Adjustment approach:

1. Remove sites with less than ten percent (10%) of square footage observed during 2015 Study.
2. Reclassify program participation for several sites per additional information provided by the PAs.

Based on our observations presented in the 2015 Code Study, and these subsequent revisions, the DNV GL team recommends that an adjustment factor of 0.78 +/- 0.10 be used to “de-rate” code-required LPD for analyses of new commercial construction buildings. The following savings calculation used for these sites would be:

\[ \text{Savings } kW = \text{LPD Code} \times 0.78 - \text{Installed LPD} \]

There have been some code changes since the 2015 Code Study, as Massachusetts adopted IECC 2012 in July 2014 and recently adopted IECC 2015, effective January 2017. The new codes include optional enhanced lighting efficiency provisions, and the IECC 2015 contains more stringent LPD requirements for most space types. While the approach outlined in this memo is reasonable for the few new construction sites

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11 The original memo was titled “P58 Baseline Adjustment Memo for NC from 2015 Code Study” and was distributed via email to the PAs and EEAC on 7/15/16 by Jessi Baldic of DNV GL.
likely impacted by the Upstream Lighting Evaluation (P58) and the sites under review for the CDA Evaluation (P56), further discussions should occur between the DNV GL team and the Energy Efficiency Advisory Council before applying this method or the adjustment factor more broadly. To use this adjustment factor prospectively, the DNV GL team recommends additional analyses in order to better understand both changes in LED market adoption and in code stringency. Since LPD requirements did not change significantly in IECC 2012 (aside from the optional enhanced lighting efficiency package) and LED adoption has likely increased, we expect that LPD standard practice may be even better than the base code for buildings constructed during this time period. Data from the IECC 2012 portion of P70 (Task 5) can be used to assess this. For prospective application with IECC 2015, the change in LPD stringency could be compared to an estimate of future changes in LED market adoption to estimate any changes in the LPD adjustment factor.

Background

The 2015 Code Study assessed energy code compliance in the state of Massachusetts for buildings permitted under IECC 2009. There were 50 building sites included in the study. The DNV GL team assessed code compliance for each of these buildings as a whole by collecting the building-envelope, mechanical, and lighting data from construction documents and conducting on-site inspections. In 45 of the 50 building sites, we examined the lighting fixtures that were either installed or planned (where construction was not complete) in representative spaces to determine whether or not each site met the applicable LPD requirements of the code. Notably, we observed that the standard practice LPD for commercial new construction was better (i.e., lower LPDs) than the energy code requirements. However, because the focus of the study was on building compliance and not measure compliance, it did not quantify the differences between the observed standard practice and the code for LPD.

In conjunction with the PAs and EEAC, the DNV GL team leveraged the 2015 Code Study data to develop an adjustment factor for LPD that could be applied to new commercial construction buildings affected by other projects within the DNV GL team portfolio to better reflect standard practices observed in Massachusetts. The initial adjustment was developed for P58, the Upstream Lighting Project, and this revised estimate, incorporating program participation, was primarily developed for use in the P56 CDA project modeling of LPD.

Methodology and Results

This section presents the methodology we used to develop the LPD adjustment factor, using the 2015 Code Study data. Steps 1 through 4 were completed as part of the original memo; Step 5 below is the new item for this revised memo.

1. **Aggregate 2015 Code Study data by site.** The objective of the 2015 Code Study was to assess LPD by performing fixture counts in representative spaces at the project sites. While the evaluators were able to complete a census LPD assessment at some of the small sites, spaces were sampled at larger sites. The team used a data collection tool that captured space type, space square footage, and a fixture inventory for multiple spaces at each site, and then they calculated both the code-allowed wattage and the actual wattage for each space. These individual sampled wattages and areas were summed to

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12 The DNV GL team held several discussions during its biweekly calls regarding this adjustment and its impact on net-to-gross (NTG) estimation, which is performed by the Massachusetts cross-cutting evaluation team. We have identified a need for greater communication and clarity in using consistent baselines across the evaluations and NTG studies, and while this is on the agenda of the baseline framework project that DNV GL is working on, this is a broader discussion and is out of scope for this specific LPD adjustment.

determine an overall code-allowed wattage and LPD and an actual wattage and LPD for each project site. This data reflects only the sampled spaces at each site.

2. **Weight 2015 Code Study data by building square footage.** For the next step, the team applied each building’s allowed and actual LPDs to the building’s total square footage to calculate building-level allowed and actual wattage. One exception to note here is for multifamily buildings; since only common areas are subject to the commercial LPD requirements, the team used the sampled areas as a better approximation of the common-area wattage than the overall building square footage.

3. **Weight 2015 Code Study data by project site weight.** The building-level wattage was then weighted by the 2015 Code Study project site weights to estimate LPD standard practice in Massachusetts. This approach was consistent with the 2015 Code Study’s sample design and compliance results aggregation. The resulting LPD adjustment factor is the statewide ratio of estimated actual wattage to estimated code-allowed wattage (herein referred to as the “compliance ratio”).

4. **Review data for outliers and potential for additional stratifications by building type and/or building size.** We reviewed the resulting data to identify outliers and determine whether sample sizes support additional stratification by building type or building size. This review showed that no individual site unduly influenced the outcome, and that values from potential subsectors were not significantly different from the statewide value. Table 1 shows summary statistics of the LPD observations.

<table>
<thead>
<tr>
<th>Summary Statistics</th>
<th>LPD</th>
<th>Five Number Summary</th>
<th>LPD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of observations (n)</strong></td>
<td>38</td>
<td>Minimum</td>
<td>-68%</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>22%</td>
<td>1st Quartile</td>
<td>6%</td>
</tr>
<tr>
<td><strong>Precision at 90% Confidence</strong></td>
<td>13%</td>
<td>Median</td>
<td>31%</td>
</tr>
<tr>
<td>3rd Quartile</td>
<td>38%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>63%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. **Adjust for program participation.** The DNV GL team accounted for program participation among the 2015 Study (IECC 2009) sites. This was a three-step process:

   a. **Identify program participation within the sample.** The DNV GL team cross-referenced the 2015 Study sites with the aggregated program database to identify the participants in lighting programs. Of the 38 sites included in the final analysis, 26 (68%) participated in a PA lighting program (upstream, performance, prescriptive, customer, and/or CDA). Table 2 shows the participation rate and corresponding compliance ratios (actual / code-allowed wattage) for participants (P) and non-participants (Np). Rather than just relying solely on the Np compliance ratio to represent standard practice LPD, we also need to take into account what the standard practice LPD would have been from the perspective of the participants. In the next step, we adjust the participant compliance ratio (0.779) to
estimate this value as a way to characterize a more comprehensive, unbiased view of the baseline or standard practice LPD under this code.

<table>
<thead>
<tr>
<th>2015 Study Site Type</th>
<th>Number of Sites</th>
<th>2015 Study Participation Rate</th>
<th>Compliance Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA program participants (P)</td>
<td>26</td>
<td>68%</td>
<td>0.779</td>
</tr>
<tr>
<td>Non-participants (Np)</td>
<td>12</td>
<td>32%</td>
<td>0.782</td>
</tr>
</tbody>
</table>

b. **Adjust the participant compliance ratio to account for program influence.** We adjusted the participant compliance ratio (0.63) to account for (i.e., remove) the influence of the programs using the free ridership (FR) rate.

i. **Calculate rate of free ridership of program participants** - The team utilized free ridership (FR) values from the Massachusetts 2014 Technical Resource Manual for the various lighting programs, evaluated each participating site’s program and corresponding FR estimate, and averaged the FR for all sampled participants. The resulting FR estimate was 0.17, which we use to approximate the proportion of the difference between the nonparticipant and participant compliance ratios that is not attributable to program influence.

ii. **Adjust participant compliance ratio to account for free ridership** - To reflect the market compliance ratio from the perspective of participants, we calculate the participant-adjusted value (Padj), by accounting for program influence (1-FR) from the difference between Np and the P values, as shown in the following equation:

\[
Padj = P + [(Np - P) \times (1 - FR)] = 0.779 + [(0.782 - 0.779) \times (1 - 0.17)] = 0.782
\]

As shown above, 83% (1-0.17) of the difference between the nonparticipant and participant compliance ratios is used to approximate program influence, and we estimate an adjusted compliance ratio (Padj) of 0.782 for program participants without program influence.

c. **Apply to population.** The DNV GL team analyzed Dodge records and program tracking data to estimate a population participation rate of 40%. This participation rate was used to compute a weighted average compliance ratio for the adjusted participants and the non-participants. These results are presented in Table 2.
Table 2. Compliance Ratio for LPD Adjustment

<table>
<thead>
<tr>
<th>2015 Study Site Type</th>
<th>Number of Sites</th>
<th>Sample Participation Rate</th>
<th>Unweighted Compliance Ratio</th>
<th>Adjusted Compliance Ratio</th>
<th>Population Participation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA program participants (P)</td>
<td>26</td>
<td>68%</td>
<td>0.779</td>
<td>0.7820</td>
<td>40%</td>
</tr>
<tr>
<td>Non-participants (Np)</td>
<td>12</td>
<td>32%</td>
<td>0.782</td>
<td>0.7826</td>
<td>60%</td>
</tr>
</tbody>
</table>

**Weighted average adjustment factor at 90% confidence**

0.78 +/- 0.10

The DNV GL team recommends that an adjustment factor of 0.78 +/- 0.10 be used to “de-rate” code-required LPDs for any new commercial construction buildings in the project sample. We explored developing additional adjustment factors by building type and building size but determined that sample sizes were not large enough to support this analysis. Figure 1 presents the LPD observations compared to code and Figure 2 presents a graphical representation of the LPD adjustment method (not to-scale).

**Figure 1. Interior LPD Observations Relative to Code Requirements**
Figure 2. Graphical Representation of LPD Adjustment Calculations*

* Figure not to-scale, presented to illustrate methodology
APPENDIX C. INTERVIEW SUMMARY MEMO FOR P70

Memo to: Ari Michelson, ERS
Massachusetts Program Administrators Research
Team and Energy Efficiency Advisory Council EM&V Consultants

From: Ari Michelson, ERS
Date: 7/27/17

Milestone 3.2 Deliverable: Interview Summary Memo for P70 – MA Energy Code Compliance and Baseline Assessment for IECC 2012

Executive Summary
This memo summarizes the findings and insights gathered from the market actor interviews completed as part of Project 70: MA Energy Code Compliance and Baseline Assessment for IECC 2012. Market actors fell into two groups: 1) Massachusetts code officials and 2) design/construction team members, including architects, design engineers, general contractors, and other building professionals. The DNV GL team asked interviewees to provide their perspectives on:

- Sections of the energy code where new construction buildings are commonly not compliant
- The compliance tools and methods employed during planning and construction
- Interviewee recommendations to improve energy code training and other activities to better support the industry

Overall, common areas of lower compliance include air sealing, particularly in ductwork and the air barrier, as well as insulation installation quality and the more complex control requirements of the code. The air barrier and sealing requirements are particularly important, as these findings suggest that the code requirements and their impacts on building energy performance are not well understood within the construction community.

- Interviewees were eager to provide recommendations that could improve code support programs. Common themes that emerged included:
  - More specialized training sessions focusing on specific code provisions where knowledge gaps exist (sealing, daylighting, controls)
  - More hands-on and field trainings to demonstrate requirements and their benefits at job sites
  - A stronger focus on new and/or updated requirements in new versions of the code, and the rationale for implementing these changes.

The remainder of this memo briefly outlines the methodology used to recruit interviewees and conduct the interviews, followed by more detailed results from the code official and design and construction professional interviews.

Methodology
The DNV GL team recruited code officials in Massachusetts towns and cities, along with design/construction professionals actively working on commercial projects in the state. We leveraged the Dodge database contact information acquired for Task 5 of this study to help identify relevant firms for interview recruitment,
prioritizing targets in locations with higher concentration of commercial new construction, such as metro Boston, Springfield, and Worcester. Table C-1 summarizes the interview targets and completed activities. We completed 23 individual interviews, and several interviewees had expertise in multiple engineering and architectural disciplines.

<table>
<thead>
<tr>
<th>Interviewee Type</th>
<th>Interview Target</th>
<th>Interview Completions</th>
<th>Areas of Expertise</th>
<th>Contact Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code officials</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>31</td>
</tr>
<tr>
<td>Design professionals – architect</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Design professionals – mechanical engineer</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Design professionals – electrical engineer</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Construction professionals – general contractor</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Construction professionals – specialized trades</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>25</strong></td>
<td><strong>23</strong></td>
<td><strong>26</strong></td>
<td><strong>107</strong></td>
</tr>
</tbody>
</table>

The objective of the market actor interviews was to collect the following information from interviewees:

- Awareness of the energy code
- Activities performed to design and build commercial buildings incorporating the energy code requirements
- Compliance and code review practices
- Awareness and usefulness of existing energy code training and other support services
- Suggestions for improving the compliance process

**Results**

This section presents the results and observations from the interviews completed by the DNV GL team. We will consider these results in conjunction with the site reviews completed for Task 5 of this study.

**Code Officials**

The DNV GL team interviewed 10 code officials representing cities and towns across Massachusetts, as shown in Figure C-1.
Experience and review processes

The number of staff members employed by the building departments interviewed ranged from five to 20. The number of commercial permits issued in the past year ranged from five in a rural town to hundreds in major cities. Across all code officials interviewed, the average experience reported was 18 years, and the median was 15 years. Code officials were asked about their familiarity with IECC and ASHRAE 90.1, and all except one reported much more familiarity with IECC, often in conjunction with the MA stretch code where it has been adopted.

We asked code officials to estimate the average distribution of their code review among the various codes they are responsible for enforcing. The results in Figure C-2 show that most review time is spent collectively on building, mechanical, and fire codes and only about 18% of review time is spent on the energy code. The median number of hours reported to review plans for energy code compliance was 3.5. The code officials noted they generally have heavy workloads; they focus their reviews primarily on the enforcement of health and life safety codes, with limited time available for the remaining codes, including the energy code.
Perspectives on energy code compliance

Code officials reported familiarity with the IECC energy code books, software programs – primarily COMcheck – and custom checklists as the most common tools referenced to demonstrate compliance and enforce the code. While COMcheck reports are commonly provided, the building departments interviewed do not consistently require these reports for energy code compliance.

Additionally, we asked code officials several questions about how they review plans for energy code compliance, what information is regularly absent from plans, and what specific areas are commonly out of compliance with the energy code. Code officials consistently identified fenestration details, air barrier documentation, and wall insulation as building components that are often missing from the plans they review. This observation is mostly consistent with the DNV GL team’s review of plans during the Massachusetts Commercial New Construction Energy Code Compliance Follow-up Study completed in 2015, particularly for fenestration and air barriers.

The primary areas of noncompliance as observed by the code officials include:

- Insulation levels, particularly in ductwork and to establish a thermal break where required by code
- Quality of insulation installation and general contractor work. Code officials felt that contractors often focus on speed and efficiency and can cut corners on some energy and non-energy code related building components, negatively affecting their energy performance.
- Air barriers and sealing of penetrations and openings within the building envelope

We also asked the code officials to rate how often they observe a series of common commercial energy code provisions in compliance with the code requirements, using a scale of 1 to 5, with 1 representing never in compliance and 5 representing always in compliance. Figure C-3 shows the average responses across the 7 of 10 code officials who responded to these questions. The code requirements with the lowest scores were for piping insulation, duct sealing, and air barrier continuity across penetrations and joints. The requirements with the highest scores include envelope R-values, lighting controls, HVAC controls, and fenestration u-factors. It’s worth noting that not one area had universal reporting of full compliance (score of 5) by the code officials.
Suggestions for future training

The code officials interviewed unanimously indicated that they have received energy code training in some form in recent years. They primarily received such training via the Code Compliance Support Initiative (CCSI) or the PAs through Mass Save®. While they collectively felt that they were well prepared to review and enforce the energy code for commercial projects, the code officials made several recommendations for future training sessions’ structure and scope:

- There should be more hands-on training sessions with live demonstrations, site visits, and other methods to see what’s required in person rather than having an instructor repeat the code language or show photographs.
- Future training topics should include code changes, more in-depth training on compliance software such as COMcheck and performance modeling software, lighting systems, and new technologies and their applications to the energy code.
- Generally, code officials were more interested in in-person trainings and less interested in webinars or other online training sessions.
- Training sessions should include more information on the intent behind updates and modifications to the energy code.
- Some code officials indicated that more accessible and simpler education resources, particularly checklists to ensure that their plan reviews cover all necessary provisions, would make their jobs easier.
Design and Construction Professionals

The DNV GL team interviewed a mix of design, engineering, and construction professionals to learn about their expertise with the energy code, their interactions with code officials, and their perspectives on improving energy code support.

Energy code expertise

Consistently across the organizations interviewed, the respondents indicated that energy code expertise is most often concentrated with a discreet in-house individual or team within their organizations. While engineers, architects, and others involved in the design phase commonly have a working knowledge of the code, many organizations designate an in-house resource to review all projects and/or provide guidance to project teams. For general contractors and specialized trades, while there was some variability, the interviewees indicated that field staff commonly have limited knowledge of the energy code; they learn the components needed to do their jobs but not necessarily the entire energy code.

The design and construction professionals reported regular interactions with code officials, both in the design stage related to the issuance of construction permits, and for inspections throughout the construction timeline. Interviewee perspectives on code official knowledge varied, with many design and construction professionals indicating that code officials do not commonly address the energy code with them beyond requesting COMcheck documentation. Interviewees also noted that code official knowledge and enforcement rigor differed widely across jurisdictions.

Perspectives on energy code compliance

The design and construction professionals consistently indicated that decisions about how to comply with the energy code are most often made during the design phase of a project. This process usually involves discussions between the site owner and the design team to review project goals and objectives. General contractors and specialized trade interviewees indicated that they had less involvement in this process and that often when projects come to them the code decisions have already been made. Over 75% of the interviewees indicated that they do work with owners seeking beyond-code performance. This is done most often through LEED, but this decision lies with the owner and their project objectives. Without a committed owner, design and construction interviewees indicated that projects are more likely to just meet the code requirements. When asked about the frequency with which their buildings exceed the code requirements, the average response among interviewees was approximately 33% of their projects.

Energy code familiarity was split between IECC and ASHRAE 90.1. Engineers were found to be more familiar with ASHRAE 90.1 and architects and specialized trades more familiar with IECC. We asked these interviewees their opinions on the most common energy code features that typically are designed/installed better and worse than code; their responses are summarized in Table C-2. The common challenges identified by the design and construction professionals are consistent with those identified by code officials, suggesting that these should be focus areas for compliance improvement.
Table C-2. Design and construction professional energy code features

<table>
<thead>
<tr>
<th>Typically more efficient than energy code</th>
<th>Common energy code compliance challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Lighting – easy to meet code requirements, especially with LEDs</td>
<td>• Air barrier requirements can be challenging and difficult to achieve</td>
</tr>
<tr>
<td>• HVAC systems commonly meet or exceed code requirements, specifically boilers and chillers</td>
<td>• Building envelope requirements, especially buildings with significant glazing percentages and air sealing</td>
</tr>
<tr>
<td></td>
<td>• Duct leakage</td>
</tr>
<tr>
<td></td>
<td>• HVAC controls and complex systems such as heat recovery; gap in commissioning implementation and oversizing some systems</td>
</tr>
</tbody>
</table>

**Improving code support**

While 90% of design and construction professionals interviewed said they have sufficient understanding of the commercial energy code requirements, 69% said they would like to receive additional training.

Design and construction professionals made several recommendations to improve energy code training:

- A mix of web-based and in-person trainings would help improve reach within the design and construction industry. This contrasts with code officials who preferred in-person training over web-based offerings.
- Focus training on duct work, ventilation, and new code requirements.
- Add a component of training sessions to discuss the balance of first-cost implications with operating and lifetime costs of efficiency options. This could help design teams market beyond code products and approaches to building owners.
- Conduct additional training for code officials on the performance compliance path. There is a gap in code official understanding of energy performance modeling. As more and more projects are required or elect to demonstrate compliance through energy modeling, it is becoming more important for the enforcement community to understand modeling processes to hold building designers and builders accountable to the energy code.

The design and construction professionals also offered several opportunities to improve the PA code programs, including:

- Engage industry organizations to provide more support and training to contractor groups.
- Incorporate more incentives based on actual building performance with respect to the energy code.
- Expand and promote incentive programs, particularly for renovations, to encourage building owners to bring older buildings up to code.
- Develop compliance checklists that can be used for design, construction, and code enforcement.
- Promote training to younger staff members at design and construction firms. Often the senior engineers understand the code, while younger staff members have not had enough exposure to grasp the intricacies of code.
- Build code compliance verification checklists and verifications directly into energy modeling software.
• Align the requirements of the energy code and LEED to streamline review and enforcement processes across high-performance building programs.

**Next Steps**

These interviews were conducted to provide perspectives on energy code methods and qualitative compliance observations from code officials and the design and construction community. While the interviewees do not constitute a statistically representative sample across Massachusetts, this data is a helpful gauge of common methods and enforcement challenges. These interview results will be incorporated into the final project report and compared with the findings from the Task 5 site work underway for this study.
About DNV GL

Driven by our purpose of safeguarding life, property, and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter, and greener.