FINAL REPORT

New Jersey Energy Code Compliance Study

Rutgers University

Date: June 2022

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1 EXECUTIVE SUMMARY

1.1 Study purpose and objectives

DNV and its study partner NMR (the DNV team or DNV) completed the New Jersey Energy Code Compliance study (ECC study) for Rutgers, The State University (Rutgers) and the New Jersey Board of Public Utilities (NJBPU). The ECC study was completed between February 2021 and June 2022 to assess energy code compliance for residential and commercial new construction in New Jersey. This study does not include compliance assessment of major renovation projects, only new buildings. The primary objectives of this study were:

- Assess the impacts of code compliance and the potential for enhanced savings across New Jersey residential and commercial new buildings.
  - Residential new construction was assessed against the 2015 International Energy Conservation Code (IECC 2015).
  - Commercial new construction was assessed against 2013 version of Standard 90.1 of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE 90.1-2013) energy code..
  - The analysis in this report was conducted for buildings permitted between 2018 and 2020, during the last two years of the IECC 2015 and ASHRAE 90.1-2013 code cycle. Figure 1-1 presents a graphical timeline of the ECC study in relation to New Jersey's code cycles. The timing of this study in relation to the code cycle suggests that the ECC study results represent the higher end of compliance with these codes. Typically, compliance early in a code cycle is lower and it increases as the building and enforcement communities become more familiar with the requirements; when the next code version is adopted with more stringent requirements, compliance would decrease and then repeat this cycle.

Figure 1-1. Timeline of New Jersey code adoption and compliance study

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Base Code Version	IECC 2009/ASHRAE 90.1 2007					IECC 2015/ASHRAE 90.1 2013					IECC 2018/ASHRAE 90.1-2016		
Compliance Study									ECC Study				

- Where possible, assess compliance by building size, type, code category, measure, and program participation.[1]
- Assess building department protocols and practices to identify opportunities for targeted code support activities to improve compliance.
- Identify and quantify opportunities for energy savings from increased compliance.
- Identify any differences in compliance in New Jersey compared to other jurisdictions (e.g., Massachusetts, Rhode Island) and how they can inform New Jersey practices.

1.2 Methodology overview

The DNV team conducted separate assessments of residential and commercial new construction code compliance.

- **Residential methodology**. For the residential component of the study, DNV first administered a web survey to gather demographic data and initial documentation, then requested building department records for homes of both survey respondents and non-respondents in the same communities. The DNV team reviewed the survey responses along with building department documentation to extract building details for use in code compliance analysis and building modeling. The team developed energy models to represent typical homes in New Jersey of various configurations to assess energy savings opportunities from improving code compliance for program and non-program homes in each climate zone.

[1] Participation in the New Jersey's Clean Energy Program (NJCEP) residential new construction or commercial new construction programs.

- **Commercial methodology**. For commercial buildings, DNV leveraged the Dodge Data & Analytics (the Dodge database) database to estimate the population of commercial new construction in New Jersey, then recruited a sample of buildings directly through municipal building departments. The Dodge database is a clearinghouse of construction activity and is a common source for estimating building populations in commercial new construction studies. DNV reviewed documentation received for 47 sites to gather measure-level details. DNV calculated code compliance for each site, then aggregated results to the population to develop statewide compliance estimates. The team then modeled potential savings from increasing code compliance, leveraging the U.S. Department of Energy (DOE) prototype buildings. DNV also conducted interviews with 15 code officials and design professionals to inform energy code awareness and compliance practices throughout the state.

1.3 Key findings and conclusions

The analysis completed by the DNV team supports the following key findings and conclusions:

1. **Overall compliance.** DNV assessed overall compliance levels for New Jersey residential and commercial new construction:
    a. For residential new construction, based on the consumption compliance approach, code compliance rates for non-program homes range from 86% to 90%, while program home compliance rates are slightly higher at 92% to 96%.
    b. Commercial new construction compliance, using the DNV methodology, is approximately 94%.

These compliance results do not mean that 86%-90% of non-program homes, 92%-96% of program homes, or 94% of commercial buildings in New Jersey meet the energy code. In reality, few buildings, if any, fully comply with the energy code.

- The residential scores represent the proportion of code required efficiency achieved by the investigated homes, or approximately what fraction of the existing homes' energy consumption equivalent code-built homes' would consume.
- The commercial results should be interpreted to mean that on an average basis, weighted by potential energy impact, new commercial buildings in New Jersey meet 94% of energy code requirements.. This score is related to, but not a perfect comparison to the building energy consumption because compliance does not assess provisions better than code.

2. **There are significant savings opportunities from improved compliance**. Improving energy code compliance presents opportunities to achieve additional savings in New Jersey:
    c. For residential buildings, up to 205 billion BTUs per year could be saved statewide with increased code compliance. A disproportionate amount of these savings are attributable to single-family detached homes and homes in Climate Zone 5. To put this in perspective, the 2019 Residential New Construction (RNC) program had annual savings goals of approximately 167 billion BTU per year.[2] This means that the gross technical potential savings from compliance enhancement are 123% of the 2019 RNC program goals.
    d. For commercial buildings, up to 104 billion BTUs per year could be saved statewide with increased code compliance. About 83% of the potential savings are attributable to multifamily buildings, with 77% of the savings from midrise multifamily buildings. For comparison, the 2019 Commercial New Construction program and the Commercial Pay-for-Performance program combined had annual savings goals of approximately 77.5 billion BTU per year.[3] This means that the gross technical potential savings from commercial compliance enhancement are approximately 135% of the combined 2019 commercial new construction programs goals.

[2] TRC. (June 2018). New Jersey's Clean Energy Program Fiscal Year 2019 Program Descriptions and Budget – FY19 Compliance Filing Volume 1. https://njcleanenergy.com/files/file/Library/Compliance%20Filings/fy19/TRC%20Compliance%20Filing%202019%20Vol%201%20v4%20FINAL.PDF

[3] Ibid.

3. **Opportunities exist to improve prescriptive compliance.** For both residential and commercial new construction, the ECC study identified opportunities for increased prescriptive compliance with each measure below as a good candidate to be included in a focused training session. They include the following measures:

    a. **Envelope insulation**. Both the commercial and residential analyses identified opportunities to improve compliance with prescriptive insulation requirements. For residential buildings, prescriptive code compliance is poor for ceilings, walls, and foundation walls, even among program homes. For commercial buildings, envelope opportunities exist primarily in wall, roof, and slab edge insulation construction.
    b. **Air sealing**. Residential analysis identified poor air leakage compliance. For commercial buildings, while air barriers were generally well-documented on the drawings, installation quality could not be observed and code officials identified improper installation of air barriers as a common area of noncompliance.
    c. **DCV and ERV**. Demand controlled ventilation (DCV) and Energy Recovery Ventilation (ERV) requirements are not applicable to all commercial buildings; however, for buildings where these systems are applicable, the commercial analysis identified poor compliance levels.
    d. **Lighting controls.** For commercial buildings, several lighting controls were not commonly observable on construction drawings. These include daylighting controls as well as the ability to reduce light levels for all non-emergency fixtures. The lack of observable controls on the drawings does not necessarily mean that lighting controls will not be installed, as they might be included in supporting documentation such as the lighting specifications. However, without access to this information, DNV was unable to verify if these lighting controls were part of the original design. This study cannot assess commissioning nor performance of lighting controls since the buildings assessed are mostly still under construction, but the lack of documentation on drawings suggests a potential opportunity for improvement in lighting controls design and/or documentation.

4. **The DNV team experienced limited engagement from building departments contacted during the study.** For both residential and commercial analyses, DNV experienced difficulties in obtaining the documentation necessary to assess code compliance. There were a variety of reasons for this reduced engagement, including ongoing impacts of the COVID-19 pandemic, reluctance to share documentation for buildings considered sensitive and exempt from public records requests, and difficulties in gathering documentation from municipal on-site document storage locations.

1.4 Recommendations and considerations

The DNV team identified the following recommendations and considerations for future program designs in New Jersey:

1. **Conduct targeted energy code training with code officials and building professionals to improve understanding of building science topics, key energy code provisions, and any new/updated energy code requirements**. Both code officials and building professionals expressed an interest in more frequent training sessions, with a primary focus on recent changes to the code. Furthermore, highlighting energy benefits of code-compliant construction can help the industry achieve better energy performance, potentially at lower cost. For example, in residential new construction, there are energy benefits of constructing unfinished basements as unconditioned space with insulated ductwork, hot water pipes, and frame floors, rather than as partially conditioned basements with uninsulated ductwork, piping, and floors.

    a. **Additionally, formalizing training and additional assistance through a code support initiative could enable New Jersey to claim savings from increased compliance with the energy code**. Other states have developed methods to claim savings from increased energy code compliance. This is often accomplished through a series of in-person or web-based trainings with building professionals, and is commonly complemented by ad-hoc plan review or other support services for interested projects. The approaches for claiming and evaluating savings vary by state, and several different methodologies can be employed. Given the magnitude of potential savings associated with increasing code compliance, it is something New Jersey should consider.

2. **Participate in the promulgation of code amendments as an additional mechanism to claim savings**. Other states have developed methods to participate in the code adoption process and propose code amendments that increase the stringency of the code as a means of claiming energy efficiency savings. For example, in Massachusetts, utilities and stakeholders leveraged results of prior code compliance and industry standard practice (ISP) research that found that lighting power density (LPD) significantly exceeded code requirements due to the high market penetration of LEDs, to propose commercial LPD amendments more stringent than the base code in order to improve their program design. In New Jersey, one potential amendment to consider would be to remove the IECC 2015 R402.4.1 amendment, which makes air leakage testing optional. Air leakage is an important contributor to overall home energy consumption,[4] and nominal compliance with recommended installation practices does not necessarily equate to compliance with measured leakage requirements. The amended building code in New Jersey still requires duct tightness testing for many homes. The setup for a duct leakage test overlaps with that required for testing air leakage, meaning that there is often minimal burden to also measure the air leakage of new homes.
3. **Update the baseline that is currently being used for the Residential New Construction program based on the findings in this report.** This is typically done by creating a User Defined Reference Home (UDRH), which is a customized set of model inputs that represent industry standard practice (ISP) conditions used to calculate program savings. The UDRH input assumptions are customizable and can include a wide array of variables. That said, most new construction program UDRH inputs cover a relatively limited set of measures that are significant contributors to building energy consumption.[5] The average efficiency values from this study can be used as the UDRH input assumption values.[6] Alternatively, if stakeholders wish to use different values, the team recommends that they convene a working group process to determine what the UDRH input values should be. NMR has experience facilitating these meetings and could do so through an alternative contract mechanism.
4. **Formalize engagement with state agencies/organizations and, through them, building departments to improve cooperation in future studies**. The recruitment challenges encountered in this study could be mitigated in future work through more proactive engagement of municipal building departments at the state level. This would require obtaining support and assistance from additional key agencies and organizations working throughout the state, including the Department of Community Affairs (DCA) and the state's electric and gas utilities.

[4] While the gross technical potential for achieving compliance with the 3 ACH50 blower door target among tested homes is relatively low in many categories of home, it is not possible to assess the potential of homes using the R402.4.1.1 option of the amended code. Furthermore, the savings from achieving lower levels of verified air leakage are well established. Normalizing the use of blower door testing may also lead to increased attention to this aspect of home efficiency by code officials.

[5] An example of UDRH input assumptions from Massachusetts can be found in Appendix D of the 2019 Massachusetts Residential New Construction Baseline report: https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf.

[6] The building shell values that would be used to develop a UDRH for New Jersey can be found in Section 4.3, while the mechanical equipment values can be found in APPENDIX A.

2 INTRODUCTION

Rutgers, the New Jersey Board of Public Utilities (NJBPU), and the associated sponsors of the study requested a commercial and residential energy code compliance study (ECC study) for the IECC 2015 (residential) and ASHRAE 90.1-2013 (commercial) versions of the New Jersey energy code. This study was conducted by DNV and its study partner NMR (the DNV team or DNV) from February 2021 to June 2022 and focused on buildings permitted from 2018 to 2020, during the last two years of the IECC 2015 and ASHRAE 90.1 2013 code cycle.[7] The results presented in this report likely represent the higher end of compliance with this code, as when a new code version is adopted, compliance typically decreases initially and then increases over time as the building and enforcement communities become more familiar with the new version.

Figure 2-1 presents a graphical timeline of the ECC study in relation to New Jersey's code cycles. The ECC study recruited a sample of 184 residential buildings and 47 commercial buildings to inform energy code compliance rates in the state. Other evaluation activities included a web survey, industry interviews, building-level data reviews, and energy modeling.

Figure 2-1. Timeline of New Jersey code adoption and compliance study

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Base Code Version	IECC 2009/ASHRAE 90.1 2007					IECC 2015/ASHRAE 90.1 2013					IECC 2018/ASHRAE 90.1-2016		
Compliance Study									ECC Study				

2.1 Objectives

The primary objective of this study was to assess the impacts of code compliance and the potential for enhanced savings across all building sectors in New Jersey. The team addressed the following areas:

- The compliance level in New Jersey for new residential buildings against IECC 2015 and for new commercial buildings against ASHRAE 90.1 2013.
- The differences in compliance by building size, type, code category, geographical location, utility, and program participation where possible.
- The building department protocols and practices as well as opportunities for Rutgers and NJBPU targeted code support activities to improve compliance.
- The differences in compliance in New Jersey compared to other jurisdictions (e.g., Massachusetts, Rhode Island) and how can this inform New Jersey practices.

2.2 Report structure

The remainder of this report presents the residential and commercial methodologies and results. Since the approaches necessary to assess compliance and the presentation of results differ between residential and commercial buildings, these sections are separated to facilitate easier review of the methods and results. This report includes the following sections:

- Section 3: Residential methodology
- Section 4: Residential results
- Section 5: Commercial methodology
- Section 6: Commercial results
- Appendix A: APPENDIX A

[7] It is possible that some buildings were outside of the requested window but DNV was unable to verify the permit dates for all buildings included in the study.

3 RESIDENTIAL METHODOLOGY

3.1 Residential data collection

Program home data was obtained from the implementation contractor soon after the project kick-off, followed by two phases of non-program residential data collection. The first was the administration of a bilingual web survey (English and Spanish) allowing residents to self-report demographic information and provide documentation for some of the equipment or appliances in their home (e.g., photographs of nameplates or owners' manuals). In the second phase, the team requested building department records for survey respondents' homes as well as other homes in the same communities that did not respond to the survey. Specifically, the team requested building department records for survey respondent homes plus 2–4 extra addresses in the same community to maximize the benefit of building department outreach.

The team sent letters and postcards to occupants of new homes inviting them to participate in the web survey. In total, letters and postcards were mailed to nearly 14,000 homes (Table 3-2) in July, October, November, and December of 2021. The recipient list was based on a list of new homes purchased from a third-party broker. It included many vacant, multifamily, and program homes, which the team excluded from the mailings. The survey also included soft limits on participation for high-population counties to ensure the study included a variety of homes (Figure 3-1).

Where possible, data requests and response receipts were conducted electronically to reduce the potential for the transmission of COVID-19. Nevertheless, some in-person visits to building departments by local staff were required to collect records, particularly large-format blueprints. A team of engineers and HERS raters reviewed the equipment documentation from survey responses along with responses to building department data requests to extract details pertinent to energy modeling and code compliance. This information was collated in a custom database to facilitate quality control review and analysis.

3.1.1 Composition and distribution

The Census Bureau construction permit data for single-family homes in Table 3-1 includes detached, duplex, and townhouses by climate zone (CZ).[8,9] However, the Bureau also publishes microdata at the division level, which breaks out detached homes. In the Middle Atlantic (New Jersey, New York, and Pennsylvania), detached single-family homes represented 84% of single-family permits in 2017 and 2018.[10] This value is used to estimate the mixture of permitted home configurations in comparison to those of the non-program and program homes (program models) in this study, as well as the overall program.

The division of non-program single-family detached and attached/multifamily 2–4 homes closely matches those of the permit data, although the latter has a smaller proportion of apartments. More townhouses than detached homes take part in the program, meaning it is not representative of new construction in New Jersey. On the other hand, the sample of program models analyzed appears to be comparable to the overall program, which represents 18% of permitted homes in the study period.

[8] United States Census Bureau. Building Permits Survey – ASCII files by State, MSA, County or Place. https://www2.census.gov/econ/bps/Place/Northeast%20Region (Accessed July 29, 2020).

[9] United States Census Bureau. Definitions – Building Permits Survey. https://www.census.gov/construction/bps/definitions/#one (Accessed May 23, 2022).

[10] United States Census Bureau. Characteristics of New Housing – Microdata. https://www.census.gov/construction/chars/microdata.html (Accessed March 28, 2022).

Table 3-1. Strata comparisons (permits and programs are an average of 2017 and 2018)

Data	Home Type	Percentage			Count		
		CZ4	CZ5	NJ	CZ4	CZ5	NJ
Permits	Single-Family	87%	84%	87%	12,195	3,817	16,011
Permits	Approximate Detached	–	–	73%	–	–	13,449
Program	Single-Family Detached	42%	37%	41%	1,135	189	1,324
Program Models	Single-Family Detached	30%	38%	32%	15	5	20
Non-Program	Single-Family Detached	73%	74%	73%	48	48	96
Permits	Attached/MF 2–4	–	–	27%	–	–	5,048
Program	Attached/MF 2–4	58%	63%	59%	1,598	317	1,915
Program Models	Attached/MF 2–4	70%	62%	68%	27	6	33
Non-Program	Attached/MF 2–4	27%	26%	27%	18	17	35
Permits	Approximate Attached	–	–	14%	–	–	2,562
Program	Duplex	1%	<1%	<1%	14	2	16
Program Models	Duplex	–	8%	2%	–	1	1
Non-Program	Duplex	–	14%	7%	–	9	9
Program	Townhouse	58%	62%	58%	1,576	313	1,889
Program Models	Townhouse	54%	38%	51%	27	5	32
Non-Program	Townhouse	17%	12%	15%	11	8	19
Permits	2–4 units	13%	16%	13%	1,755	732	2,780
Program	2–4 units	<1%	<1%	<1%	8	2	10
Program Models	2–4 units	–	–	–	–	–	–
Non-Program	2–4 units	11%	–	5%	7	–	7

The map of approximate non-program home locations in Figure 3-1—count per ZIP code tabulation area—shows that they are drawn from across the state. Using the National Center for Education Statistics' locale classification system,[11,12] we find that most of the sample (85%) is suburban, 11% is rural, and the remaining 5% (rounded) is urban.

[11] This rubric is finer-grained than many others, which typically use counties as the unit of analysis.

[12] National Center for Education Statistics. 2021 Locale Classifications. https://nces.ed.gov/programs/edge/Geographic/LocaleBoundaries (Accessed March 8, 2022).

Figure 3-1. Geographic distribution of non-program homes

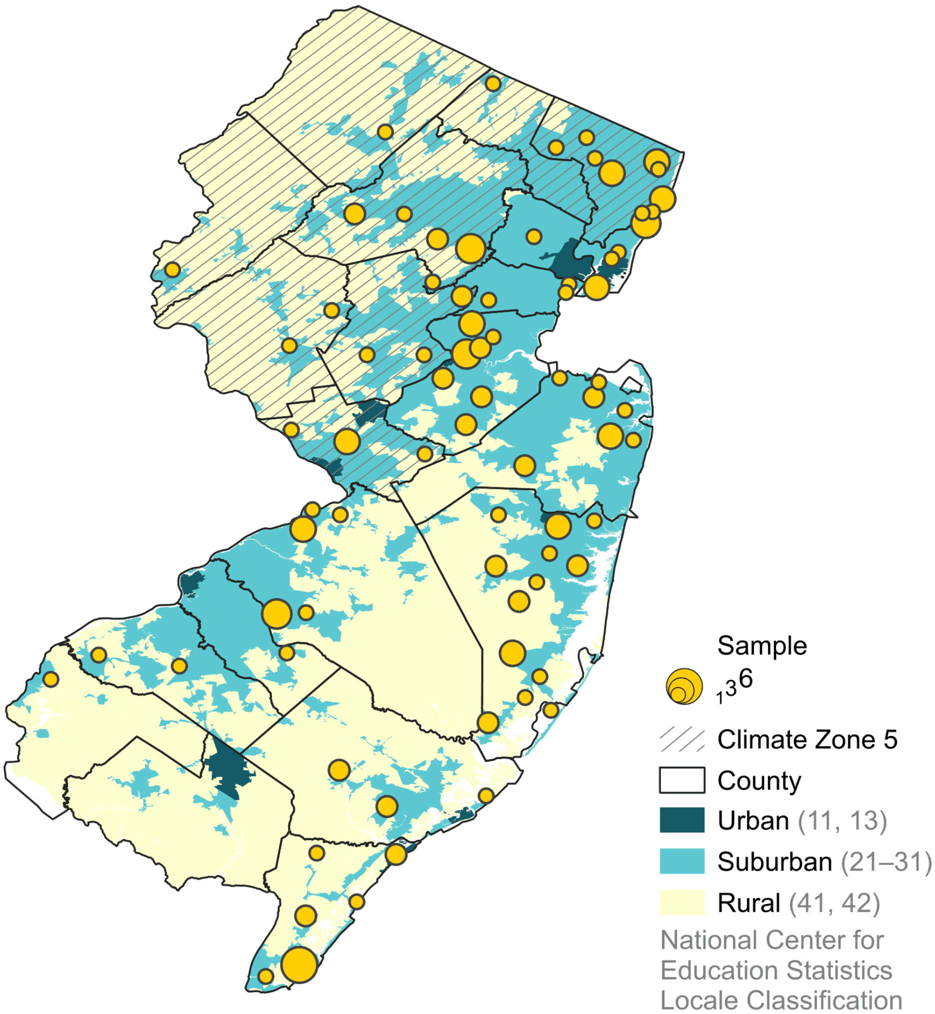


Table 3-2 shows the winnowing of potential sample sites through the data acquisition process from addresses receiving survey invitations through building department data requests to sites included in the analysis of this report.

Table 3-2. Non-program sample development

Step	Category	All Types		SF Detached		Attached/MF 2–4		Miscellaneous	
		CZ4	CZ5	CZ4	CZ5	CZ4	CZ5	CZ4	CZ5
Survey	Invitations	13,569		–	–	–	–	–	–
	Completions	55	55	38	40	15	14	2	1
	Exclusions	16	7	14	4	4	2	2	1
Building Department	Queries	131	127	55	58	26	27	51	39
	Received	104	97	54	58	26	27	24	9
	Exclusions	35	23	6	7	5	7	24	9
Data Entry	Addresses	71	71	48	51	23	20	–	–
Report	Sites	66	65	48	48	18	17	–	–

Below we provide descriptions for some of the terms used in Table 3-2:

- Miscellaneous: 5+ unit low-rise multifamily buildings, plus homes of unknown configuration associated with unresolved data requests.
- Exclusions: responses that were determined to be program participants or constructed under a different building code.
- Queries: data requests for Survey Responses plus 2–4 extra addresses in the same community to maximize the benefit of building department outreach. For the additional addresses we attempted to limit queries to one per development, and later in the project we began to emphasize addresses that were more likely to contain multiple units. Specifically, requests were made for homes in communities with significant apartment construction activity—such as Elizabeth—that were not yet represented in the data.
- Data Entry: each address with viable data. While the data was limited to square footage and equipment fuel or electrical panel capacity for approximately one third of addresses, building shell details were available for most included homes.
- Report: the number of sites represented in this report.

The Data Entry and Report rows in Table 3-2 have similar counts, but in a few cases records for multiple addresses in a single project were obtained. These addresses are recorded as unique entries in the Data Entry row, while all addresses for a project are combined into a single entry for the Report row. In these instances, the average measure values among a project's homes were used to represent the site. This prevents over-representation of a development or multi-unit building within the data, while also allowing the capture of all available information.[13] For example, if a first floor apartment was included in the sample while the information about the apartment above was available but ignored, then the ceiling insulation would be omitted and the furnace efficiency may be over-estimated, since attic furnaces are often lower-efficiency than those found in basements or conditioned space.[14]

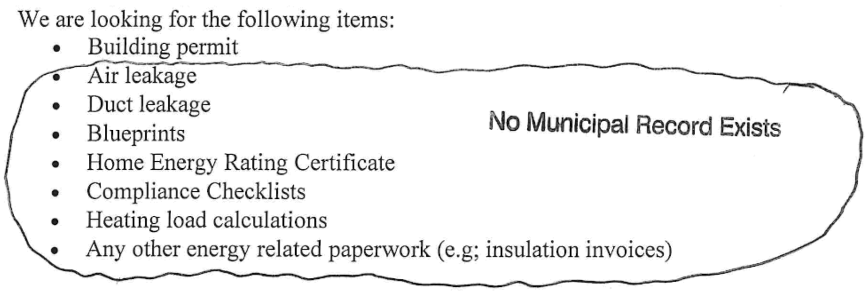
[13] This consolidation was deemed inappropriate for program home data and is discussed in Section 3.2.3.

[14] A condensing furnace requires special conditions to prevent freezing of the condensate line, which may otherwise occur if installed in a garage or vented attic.

3.1.2 Building department data quality

Building department data collection was stymied by a reluctance to furnish data through Open Public Records Access (OPRA) exemption claims, and incomplete records keeping (Figure 3-2). When municipalities did respond to requests, the extent of furnished data ranged from a simple list of permit dates to full blueprints with take-offs, equipment manuals, and test results.

Figure 3-2. A common data request response



We are looking for the following items:

- Building permit
- Air leakage
- Duct leakage
- Blueprints
- Home Energy Rating Certificate
- Compliance Checklists
- Heating load calculations
- Any other energy related paperwork (e.g; insulation invoices)

No Municipal Record Exists

The level of detail in REScheck Compliance Certificates varies greatly among builders.[15] While some certificates included enough detail to fully model the shell of a building, many others lacked key details. Some of the more common missing items are window solar heat gain coefficient (SHGC), foundation details, wall or building orientation, and buffer wall specifications (i.e., walls between the living area and attics, garages, and basements). In addition, we observed several instances where builders used REScheck for the incorrect code version compared to the building permit date.

[15] REScheck is a software product provided by the Building Energy Codes Program within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. This program is available free-of-charge, and it helps building professionals (engineers, designers, and contractors) to determine whether new homes, additions, and alterations meet the requirements of the IECC or a number of state energy codes. A REScheck report is an analysis of a project's design and includes certificates of compliance and compliance checklists. https://www.energycodes.gov/rescheck

Figure 3-3. Example REScheck compliance certificate

REScheck Software Version 4.7.1

Compliance Certificate

Project

Energy Code:	**2015 IECC**
Location:	**Toms River, New Jersey**
Construction Type:	**Single-family**
Project Type:	**New Construction**
Conditioned Floor Area:	**1,000 ft2**
Glazing Area	**12%**
Climate Zone:	**4 (5294 HDD)**
Permit Date:	
Permit Number:	

Construction Site: Owner/Agent: Designer/Contractor:

Compliance: Passes using UA trade-off

Compliance: **12.5% Better Than Code** Maximum UA: **200** Your UA: **175** Maximum SHGC: **0.40** Your SHGC: **0.40**

The % Better or Worse Than Code Index reflects how close to compliance the house is based on code trade-off rules.
It DOES NOT provide an estimate of energy use or cost relative to a minimum-code home.

Envelope Assemblies

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	U-Factor	UA
Ceiling 1: Flat Ceiling or Scissor Truss	1,000	49.0	0.0	0.026	26
Wall 1: Wood Frame, 16" o.c.	1,200	21.0	0.0	0.057	57
Window 1: Vinyl/Fiberglass Frame:Double Pane with Low-E SHGC: 0.40	150			0.300	45
Door 1: Solid	21			0.320	7
Door 1 copy 1: Solid	21			0.320	7
Floor 1: All-Wood Joist/Truss:Over Unconditioned Space	1,000	30.0	0.0	0.033	33

The building code (Section R401.3 of IECC 2015) requires that a certificate summarizing basic efficiency information about a home be posted in a prominent location. Frequently, builders provide copies of these certificates to building departments for their records. While there were a handful of REScheck or NJ/IECC Energy Efficiency Certificates on file (Figure 3-4), they often omitted details such as window SHGC and foundation specifications. Moreover, none of the certificates the team received included mechanical equipment efficiency information.[16]

[16] REScheck only accepts mechanical equipment input when in Performance Alternative mode. Homes entered as UA Trade-off cannot include this information. This, along with the requirement to indicate orientation is an advantage of the performance path over UA for completeness of documentation. (Orientation is optional for UA and must be manually enabled.)

Figure 3-4. Example efficiency certificates

2015 IECC Energy Efficiency Certificate

Insulation Rating	R-Value	
Above-Grade Wall	21.00	
Below-Grade Wall	0.00	
Floor	30.00	
Ceiling / Roof	49.00	
Ductwork (unconditioned spaces):	_____	
Glass & Door Rating	**U-Factor**	**SHGC**
Window	0.30	0.40
Door	0.32	
Heating & Cooling Equipment	**Efficiency**	
Heating System:__________________	_____	
Cooling System:__________________	_____	
Water Heater:____________________	_____	

Name: ______________________________ Date:______________

Comments

NJ IECC/2015 Energy Efficiency Certificate for Low-rise Residential Dwellings*		
Address:	Permit #:	
Insulation Rating (batt, spray, blown, continuous, other)	*R-value*	
Ceiling/Roof		
Above Grade Wall: framed__; mass__		
Floor: over unconditioned space__; slab__		
Crawlspace Wall		
Foundation/Basement Wall		
Ductwork (unconditioned spaces)		
Fenestration Rating	*U-factor*	*SHGC*
Window		
Skylight		
Door		

Heating & Cooling Equipment	*Type* (Oil, Gas, Electric, other)	*Efficiency* (AFUE, EER/SEER, HSPF, other)
Furnace		
Heatpump		
Boiler		
Cooling System		
Water Heater		
Other		

Renewables (type of system)

Other Energy Efficiency Equipment

Builder or Design Professional Certification

Name: Date:

Registration/License Number:

Comments

** This is a generic certificate and some items listed above may not be applicable to this specific design when initially constructed; please leave those items blank.*

In contrast to energy efficiency certificates, the RESCheck Inspection checklists (Figure 3-5) were typically blank, but completed UCC-F392 Air Barrier & Insulation Checklist (Figure 3-6) were included in the building department records of many sites. Builders pursuing the R402.4.1.1 Air Barrier and Insulation Installation path of the amended code must complete this form to attest to the air tightness of a home, although several homes with blower door documentation for the R402.1.2 Testing option also supplied the checklist.

DNV

Figure 3-5. Example REScheck inspection checklist

REScheck Software Version 4.7.1

Inspection Checklist

Energy Code: 2015 IECC

Requirements: 86.0% were addressed directly in the REScheck software

Text in the "Comments/Assumptions" column is provided by the user in the REScheck Requirements screen. For each requirement, the user certifies that a code requirement will be met and how that is documented, or that an exception is being claimed. Where compliance is itemized in a separate table, a reference to that table is provided.

Section # & Req.ID	Pre-Inspection/Plan Review	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
103.1, 103.2 [PR1][1]	Construction drawings and documentation demonstrate energy code compliance for the building envelope. Thermal envelope represented on construction documents.			☐Complies ☐Does Not ☐Not Observable ☐Not Applicable	
103.1, 103.2, 403.7 [PR3][1]	Construction drawings and documentation demonstrate energy code compliance for lighting and mechanical systems. Systems serving multiple dwelling units must demonstrate compliance with the IECC Commercial Provisions.			☐Complies ☐Does Not ☐Not Observable ☐Not Applicable	
302.1, 403.7 [PR2][2]	Heating and cooling equipment is sized per ACCA Manual S based on loads calculated per ACCA Manual J or other methods approved by the code official.	Heating: Btu/hr_____ Cooling: Btu/hr_____	Heating: Btu/hr_____ Cooling: Btu/hr_____	☐Complies ☐Does Not ☐Not Observable ☐Not Applicable	Requirement will be met.

Additional Comments/Assumptions:

Figure 3-6. Example UCC-F392 air barrier and insulation checklist

PERMIT # ________ LOT: ________ BLOCK: ________

AIR BARRIER AND INSULATION CHECKLIST

In the checklist below, ***AB*** and ***I*** stand for the *air barrier* and *insulation* inspection components to be verified. The local code official will always verify the ***I*** components. In the case where the local code official is not verifying the ***AB*** components, they may be verified by a person independent of the insulation installer, or by the use of a blower door test.

If the permit holder has elected use of a blower door test, documentation of test results verifying air leakage less than 3 air changes per hour when tested per ASTM E 779 or ASTM E 1827 and reported at a pressure of 0.2 w.g. (50 Pa) shall be submitted with this checklist. A passing test demonstrates that the ***AB*** components are verified.

Component		Criteria	Y, N, or N/A	Comments	Initials	Date
Floors (including above-garage and cantilevered floors)						
General	I	Insulation is installed to maintain permanent contact with underside of subfloor decking.				
	AB	Air barrier is installed at any exposed edge of insulation.				
Rim joists	AB	Rim joists include an air barrier.				
	I	Rim joists are insulated.				
Walls						
General	I	Corners and headers are insulated.				
	AB	Junction of foundation and sill plate is sealed.				
Crawl space walls	I	Insulation is permanently attached to walls.				
	I	Exposed earth in unvented crawl spaces is covered with Class I vapor retarder with overlapping joints taped.				
Windows and doors	AB	Space between window/door jambs and framing is sealed.				
Garage separation	AB	Air sealing is provided between the garage and conditioned spaces.				
Plumbing and wiring	I	Insulation is placed between outside and pipes. Batt insulation is cut to fit around wiring and plumbing, or sprayed/blown insulation extends behind piping and wiring.				
Shower/tub on exterior wall	I	Showers and tubs on exterior walls have insulation.				
	AB	Showers and tubs on exterior walls have an air barrier separating them from the exterior wall.				
Electrical/phone box on exterior walls	AB	Air barrier extends behind boxes or air sealed-type boxes are installed.				
Ceiling/Attic						
Skylights	AB	Space between sklylight framing is sealed.				

U.C.C. F392-1 (12/15)

The team also identified a series of problems in building department data as it relates to conflicting data. Sometimes there were multiple undated documents on file that provided different accounts of a home's construction, such as R-values for a particular part of a home,[17] whether the basement was conditioned or not, and even the size of the home. Manual J equipment sizing reports,[18] when available, were a particularly egregious offender. In several instances, the Manual J

[17] R-value is a measure of a material's resistance to the flow of heat. Higher values represent more effective insulation.

[18] Manual J is a method of calculating residential HVAC equipment sizing requirements standardized by the Air Conditioning Contractors of America (ACCA). This analysis is a mandatory building code requirement (R403.7).

analysis used insulation levels that did not match the home and were far from code-compliant, which would result in the installation of over-sized equipment if these results were followed. For example, the Manual J for one home with other documentation indicating 2×6×16 R-21 walls assumed 2×4×16 R-11 walls instead.

Finally, it should be noted that in a recent study of low-rise multifamily construction, NMR uncovered evidence that although building department records often provide optimistic depictions of building construction at the measure level, the overall home performance compared to inspection data was comparable.[19, 20]

3.2 Modeling

The team developed two sets of models for non-program homes: 1) six prototype models representing the average characteristics of the homes included in the web survey and building department documentation and 2) eight individual home models of the as-built characteristics for these homes. The RNC program implementation contractor furnished the team with a sample of 53 energy models for program homes of similar styles to the non-program homes for comparison.

3.2.1 Average home models

The original intention of this study was to produce energy models for several dozen homes, like a conventional baseline study. As discussed in the previous section, the building department information for many homes was incomplete; thus, we created a set of models representing typical homes in New Jersey of various configurations.[21] These were created using averaged values derived from the information collected for this study. The primary inputs for these models are summarized in Table 3-3 through Table 3-6 and are derived from details in Section 4.3 and APPENDIX A.

Table 3-3. Key parameters of average home models – home size

	Climate Zone 4 (Toms River)			Climate Zone 5 (Morris Plains)		
Measure	**Detached**	**Town/ Duplex**	**2–4 unit**	**Detached**	**Town/ Duplex**	**2–4 unit**
Conditioned Floor Area (ft^2)	3,243	2,779	1,657	3,243	2,779	1,657
Infiltration Volume	31,828	24,718	14,738	30,464	24,718	14,738
Floors	2	2	1	2	2	1
Bedrooms	4	3	2	4	3	2

Townhouse/duplex and 2–4 unit homes share the same properties in the remaining tables of key parameters. In fact, they are combined into a single Attached/MF 2–4 category in the rest of the report. Similarly, we used our experience from other residential new construction studies to review the underlying data and pool values from non-program home categories when there was no expectation nor indication of differences in construction practices. For example, the building code requirements for Climate Zones 4 and 5 differ, but the types of windows used in low-density residential homes are similar across home types. Therefore, averaged values from the windows of all non-program homes within a climate zone were used for the models, yielding two U-factors rather than four or six.[22]

[19] NMR. (March 2022). MA20R30: Multifamily New Construction Baseline Study. https://ma-eeac.org/wp-content/uploads/MA20R30_RNCMFBaseline_Final_2022.03.02.pdf The analysis in Section 3.1 of the report compared paired data derived from building department records and energy audits conducted by HERS raters.

[20] See Table 4-20 in Section 4.5 for an exploration of the effect small differences can have on energy consumption.

[21] This is a technique similar to that employed in various studies including the Massachusetts Department of Energy Resources' building code 2022 update, and .an exploration of energy-optimized residential new construction, also in Massachusetts.

[22] U-factor is the inverse of R-value (U=1÷R), and it is the standard measure of window insulation performance. In contrast to R-values, smaller U-factors represent better insulation. Window U-factors should not be confused with SHGC, which are a measure of the window's ability to block the heat from sunlight.

Table 3-4. Key parameters of average home models – building shell

	Climate Zone 4 (Toms River)			Climate Zone 5 (Morris Plains)		
Measure	**Detached**	**Town/ Duplex**	**2–4 unit**	**Detached**	**Town/ Duplex**	**2–4 unit**
Air Leakage (ACH50)	3.22					
Shelter Class	3 4	4		4	4	4
Foundation	Mixed, see Table 3-7					
Conditioned Basement Wall R-value	9.6+3.1†			15.6		
Uncond. Basement Ceiling R-value	26.5					
Exterior Walls, % 2×4×16	34%	46%		7%	24%	
Exterior Walls, % 2×6×16	63%	29%		89%	56%	
Exterior Walls, % 2×6×24	3%	25%		4%	20%	
Exterior Walls 2×4 R-value	14.5+0.6	14.0+0		14.5+0.6	14.0+0	
Exterior Walls 2×6 R-value	18.4+0†			19.9+0†		
Window U-factor	0.305			0.301		
Window SHGC	0.265			0.272		
Window % of Floor Area	14.4%	17.1%		14.4%	17.1%	
Ceiling, % Flat	95%		47%	87%		43%
Ceiling, % Vaulted	5%		3%	13%		7%
Ceiling, % Adiabatic	0%		50%	0%		50%
Ceiling, Flat R-Value	33.9+4.2†			36.3+2.4†		
Ceiling, Vaulted R-value	33.2+0†			28.2+0.3†		

† This signifies cavity insulation plus continuous insulation. R-15+3 is equivalent to R-18 for the cavity, but superior to R-18 cavity insulation alone (R-18+0), because it supplies R-3 insulation for the framing.

Air conditioning efficiency (Table 3-5) is the only mechanical equipment property which is not shared across all models but is instead split between detached and Attached/MF 2–4 homes. Another noteworthy item here is the under-insulation of water pipes, which is modeled as not being fully insulated with R-3 or greater pipe wrap.

Table 3-5. Key parameters of average home models – mechanical equipment

	Climate Zone 4 (Toms River)			Climate Zone 5 (Morris Plains)		
Measure	**Detached**	**Town/ Duplex**	**2–4 unit**	**Detached**	**Town/ Duplex**	**2–4 unit**
Mechanical Ventilation	**Exhaust only, ASHRAE 62.2-2013, 2.9CFM/W**					
Furnace AFUE	91.0					
Central Air Conditioner SEER	13.91	13.27		13.91	13.27	
Thermostat	Programmable					
Duct Leakage, Total (CFM25 / 100 ft^2)	3.0					
Hot Water EF	0.773					
Hot Water Volume (gallons)	54					
Hot Water Insulation	NOT R-3+					
Hot Water, Low-flow Fixtures	Yes					

Lighting details were very rare in building department records. The statewide average value for IECC 2015 homes in Massachusetts (85%) was used as a proxy instead,[23] exceeding the building code requirement of 75%.

Table 3-6. Key parameters of average home models – lighting and appliances

	Climate Zone 4 (Toms River)			Climate Zone 5 (Morris Plains)		
Measure	**Detached**	**Town/ Duplex**	**2–4 unit**	**Detached**	**Town/ Duplex**	**2–4 unit**
Refrigerator & Freezer (kWh/yr)	789	698		789	698	
Dishwasher	ENERGY STAR (270 kWh/yr)					
Clothes Washer	ENERGY STAR (2.06 IMEF)					
Clothes Dryer	Non-ENERGY STAR Gas (3.30 CEF)					
Cooking	Natural Gas, Convection					
Lighting	85%					

[23] NMR Group, 2020. 2019 Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL). Table 137: Average per-home Efficient Bulb Saturation (Base Code) https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pd

The floor, wall, and ceiling area of the models were calculated with an algorithm adapted from an NREL publication.[24] The algorithm relies upon conditioned floor area, stories above grade, and the capacity of any attached garage to estimate shell areas.[25] However, NREL's approach only handles fully conditioned or unconditioned basements. The approach used for this study accounts for mixed foundations with a blend of basement conditioning and slab-on-grade, shown in Table 3-7. Finally, calculated areas are input in a symmetrical manner for homes facing north or south.[26]

Table 3-7. Foundation types of average home models by home type

	SF Detached		Town/Duplex		2–4 Units	
	CZ 4	**CZ 5**	**CZ 4**	**CZ 5**	**CZ 4**	**CZ 5**
Sites	27	22	11†	4†	–†	–†
Slab-on-grade	8%	21%	40%	50%	20%	25%
Conditioned basement	8%	23%	15%	25%	7%	13%
Partially cond. basement‡	30%	17%	–	–	–	–
Unconditioned basement	54%	39%	45%	25%	23%	13%
Another apartment	–	–	–	–	50%	50%

† Due to the small sample sizes for Attached and MF 2–4, the foundation mix was calculated for the combined Attached/ MF 2–4 category, excluding stacked apartment area, which was incorporated afterward.
‡ Partially conditioned basement spaces contribute to the infiltration volume of a home but not the conditioned floor area, and are represented as "conditioned crawlspace" within the models. Assignment to this category requires additional information, and as such was generally only possible for survey respondents.

Heating and cooling equipment capacity for the average home models was set to standard equipment capacities that satisfy REM/Rate[27] calculated peak demand and do not exceed Manual S sizing constraints, e.g., two 33 kBTUh furnaces for a home with 62 kBTUh heating load.[28] Two-story homes are modeled with an HVAC system per floor, and it is assumed that there is a return in each bedroom and one in the common area for each floor.

3.2.2 Individual home models

The team was unable to collect all the necessary information to create complete energy models for any homes, but in many cases the missing information related to less impactful aspects of the model—appliance efficiency, ceiling framing, etc.—or otherwise represented a small part of the mode inputs. Using observation- and experience-informed assumptions with averages from the previous section to fill in missing details, models for eight homes were created to supply additional context to the average home model results. Some examples of common assumptions in these models are:

[24] National Renewable energy Laboratory. December 2017. Energy Efficiency Potential in the U.S. Single-Family Housing Stock. Appendix E. https://www.nrel.gov/docs/fy18osti/68670.pdf
[25] The models in this study assume a two-car garage.
[26] REM/Rate's "Worst Orientation" tool reveals little to no change (<1%) from reorienting the models.
[27] REM/Rate is an energy modeling tool used to develop Home Energy Rating Scores (HERS) and to support residential new construction programs.
[28] 33 kBTUh output is a 36 kBTUh (a.k.a. three ton) furnace operating at 91 AFUE.

- 85% efficient lighting[29]
- Under-insulated or uninsulated hot water pipes
- Low-flow water fixtures
- Washer and dryer efficiency
- Duct location and insulation
- Code-compliant levels of exhaust-only mechanical ventilation[30]

3.2.3 Program homes

The RNC implementation contractor responded to our data request by providing energy models for 134 homes of several styles. Unfortunately, some of these homes contained errors or inconsistencies that prevented them from being analyzed with the versions of REM/Rate used in this study; see Section 0 for details. Where possible, the team made some minor modifications necessary to run these models. Other changes, such as corrections to equipment fuel or adjustments to R-value/insulation grade for 2×6 walls with R-19 batts, were not made. After non-viable and duplicate models were removed and a handful of models that had been previously provided were added, we were left with 87 valid program home models. The attrition of models is primarily due to the removal of units in buildings that were four or more floors above grade, which are subject to commercial code rather than residential code.

Not only are the home type categories available within REM/Rate different from those in this study—REM/Rate does not divide apartments into 2–4 unit and 5+ unit sub-categories—but we have learned in previous studies that the home type recorded in energy models is unreliable. Therefore, the program models were recategorized as shown in Table 4-16.[31] Homes were classified using address information (apartment numbers that indicated the presence of five or more units per building), public records data, map information and real estate listings. Since the program home models were drawn randomly from the pool of program participants, multiple records from a single site were not condensed into a single entry for analysis. Nevertheless, the number of unique sites these records would condense to is included in the table for reference.

Table 3-8. Program models by home type

	SF Detached		Attached		MF 2–4		MF 5+	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Original	15	5	21	3	–	–	69	22
Revised	15	5	27	6	–	–	32	2
Sites	12	4	20	6	–	–	13	1

29 This study did not capture detailed lighting information. The team found that 85% of light bulbs were efficient in our 2020 Massachusetts RNC baseline study and used that to inform our assumption for this study. The lighting data from Massachusetts can be found in Table 137 of the Massachusetts report: https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf.

30 Using REM/Rate's default fan efficacy of 2.9 CFM/W, while code specifies 2.8 CFM/W for flows over 90 CFM and 1.4 CFM/W for lower flow bath fans..

31 The reclassification of program homes with project start dates in 2017 and 2018 used in this report is as follows:

Original \ Reclassified	Single-Family Detached	Duplex	Townhouse	MF 2–4	MF 5+†
Single-Family	1,311	5	2	2	–
Townhouse	13	11	1,818	8	649
Multifamily	–	–	69	–	2,409

† Includes commercial code buildings of four or more storeys.

3.2.4 REM/Rate

The version of REM/Rate used to process a model can potentially have a significant impact on the results due to changes in RESNET standards, bug fixes, and the introduction of new features such as hourly simulation. The program models provided to the team for analysis were created with a variety of REM/Rate versions: one fourth with 14.6.x, more than half (53%) in an early version 15 (15.1–15.5), and another fifth (21%) with later versions (15.7.x or 15.8).

A handful of program models (four of 87) in this study were processed with version 16.3.2 when corrections were made to resolve modeling errors, but the remaining majority were analyzed with version 15.8. This version is contemporary to the study period, uses the classic seasonal modeling engine, and incorporates many improvements to the software. In contrast, the individual home and average home models that were created for this study use REM/Rate version 16.3.2.

4 RESIDENTIAL RESULTS

This section provides the results of the residential compliance analysis. The key findings are summarized below:

- Most non-program homes with a known compliance path (32 of 37, 86%) pursue prescriptive path compliance.
- Window, floor, slab, and duct leakage compliance with prescriptive code is generally good in both program and non-program homes (see Section 4.2).
- Air leakage, ceiling, wall, and foundation wall compliance with prescriptive code is poor, including in program homes.
- Less than half of program homes, and no non-program homes, satisfy ERI path requirements. However, the ERI path is known to be more demanding than other compliance paths in IECC 2015 (see Section 4.4).
- Non-program home consumption compliance ranges from 86% to 90%, while program home compliance ranges from 92% to 96% (see Section 4.5). These scores represent the proportion of code required efficiency achieved by the investigated homes, or approximately what fraction a corresponding code-built homes' energy consumption would be.).
- Up to 205 billion BTU per year could be saved statewide with increased code compliance. A disproportionate amount of these savings are attributable to single-family detached homes and homes in Climate Zone 5 (see Section 4.6). These potential savings represent 123% of the 2019 Residential New Construction program annual energy savings goals.[32]

Due to the nature and size of the collected data in this analysis, it is not possible to provide robust estimates of the statistical accuracy of the results. This also limits the statistical comparisons that may be reliably made between categories of home. However, while assessments of significant difference for measure R-values is not available, the significance of differences in compliance levels between program and non-program homes are assessed.

4.1 General characteristics

Single-family detached program homes are larger than non-program homes in Table 4-1, although the opposite is true for Attached/MF 2–4 homes. However, the non-program homes include more duplexes and apartments than the program home sample. The seven 2–4 unit apartments in the non-program data average 2.3 units per building.

Table 4-1. General home characteristics by home type and program status

Site characteristic	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	35	29	15	5	12	10	27	6
Cond. Floor Area (ft^2)	2,717	3,877	3,223	4,511	2,283	2,925	1,743	1,823
Conditioned Volume (ft^3)	24,645	24,619	30,136	41,084	20,150	23,608	14,794	15,624
Floors	2.0	2.1	1.9	2.0	2.2	2.3	2.5	1.8
Beds	4.3	4.0	3.3	3.4	3.5	2.9	2.7	2.3

[32] TRC. (June 2018). New Jersey's Clean Energy Program Fiscal Year 2019 Program Descriptions and Budget – FY19 Compliance Filing Volume 1. https://njcleanenergy.com/files/file/Library/Compliance%20Filings/fy19/TRC%20Compliance%20Filing%202019%20Vol%201%20v4%20FINAL.PDF

More details about the homes in this study can be found in APPENDIX A, but a few highlights are included here along with some observations from the data review:

- Most homes use high efficiency furnaces for heating.
- More than 90% of homes have ENERGY STAR dishwashers.
- Program homes primarily use instantaneous water heaters.
- Hot water pipe and basement duct insulation was absent or rare in non-program homes. This may be due to builders treating the basement as unfinished but conditioned space, although in some cases there was no visible foundation wall insulation (4.3.5).

4.2 Code compliance paths

Table 4-2 lists the known compliance paths of 37 non-program homes in this study, 86% of which used the prescriptive path. Specifically, these homes employed the R402.1.5 "UA trade-off" option, which is the default in REScheck. Note, however, that REScheck does not support the R402.1.2 "R-value" or R402.1.4 U-factor options,[33] and the use of these paths can be difficult to verify without thorough documentation for each home. Finally, the two "half" homes represent a site with documentation for both ENERGY STAR homes and the IECC performance path. A comparison of compliance from the perspective of different paths is discussed in Section 4.5.2.

Table 4-2. Documented code compliance paths

Compliance Path	Sites
R401–R404 Prescriptive Path	32
R402.1.2 Insulation and Fenestration Requirements	–
R402.1.4 U-factor alternative	–
R402.1.5 Total UA alternative	32
R405 Simulated Performance Alternative	3.5
R406.3 Energy Rating Index	–
ENERGY STAR Homes	1.5

4.3 Measure-level prescriptive code compliance

To assess measure-level code compliance in this section, the area-weighted center-of-cavity R-values are compared to IECC 2015 Table R402.1.2 Insulation and Fenestration Requirements by Component. This permits some level of trade-off across instances of a measure meaning that the presence of a small fraction of wall or ceiling area that does not comply with prescriptive code requirements would not automatically render the home non-compliant if other areas of the same type are insulated above code requirements. Also, recall from Section 3.1.2, the building department records used for this study may suggest that buildings are slightly better constructed than an in-person audit would reveal, particularly for walls and ceilings.

[33] It would offer little benefit for the "R-value" option, other than to explicitly document compliance via this path. On the other hand, it could be useful for the U-factor option to establish compliant combinations of cavity and continuous insulation for various framing factors.

4.3.1 Walls

Overall, framed wall insulation compliance is extremely low except for non-detached program homes in Climate Zone 5. Table 4-3 also includes compliance breakdown for 2×6 walls by general location: Ambient (outdoors) and Buffer (Garage, Basement, Attic). Ambient 2×6 wall insulation compliance is higher overall than in buffer walls, while no 2×4 walls (not shown) were compliant. The low compliance is due to the prevalence of R-15 and R-19 cavity insulation, neither of which meet code requirements without continuous insulation. Furthermore, one third of program homes include 2×6 wall area recorded as Grade I R-19 insulation. This is likely inaccurate since R-19 batts—the conventional means of obtaining this level of insulation—require 6¼ inches of space to reach this rating. A 2×6 wall only offers 5½ inches of space, which means that R-19 batts in a 2×6 wall should be recorded as Grade III or entered with an adjusted R-value of 17.1. In this analysis both program and non-program homes with R-19 walls have been adjusted to the compressed value.

Table 4-3. Wood-framed wall R-value by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	29	26	15	5	7	6	27	6
Minimum	20†	20†	13	13	15	15	13	13	13	17.1
Mean	–	–	17.3	19.3	16.7	16.7	15.4	17.4	18.4	21.0
Maximum	–	–	22	33	21	22.1	17.1	20.5	28	29.6
Comply	–	–	28%	46%*	13%	20%	0%	17%	44%	50%
Amb 2×6	–	–	38%	64%	13%	20%	0%	42%	44%	50%
Buff 2×6	–	–	25%	0%	15%	20%	0%	67%	26%	25%

† Approximate number of homes represented in average home model. Exact count varies by measure.
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.

4.3.2 Windows and skylights

Non-program homes in Climate Zone 5 have lower levels of window insulation (U-factor) compliance than other categories, although the average window U-factors in Table 4-4 are similar across all categories.

Table 4-4. Window U-factor by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	24	24	15	5	6	5	27	6
Minimum	–	–	0.277	0.270	0.270	0.250	0.280	0.270	0.270	0.250
Mean			0.308	0.301	0.296	0.292	0.292	0.303	0.298	0.280
Maximum	0.35	0.32	0.360	0.370	0.306	0.310	0.330	0.340	0.340	0.304
Comply†	–	–	96%	88%	100%	100%	100%	80%	100%	100%

† 15 ft^2 of non-compliant glazing is allowed (R402.3.3). This exemption is not factored in to these results.

All observed homes comply with window solar heat gain coefficient (SHGC) requirements (Table 4-5).

Table 4-5. Window SHGC by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	18	9	15	5	5	3	27	6
Minimum	–	–	0.179	0.202	0.200	0.201	0.180	0.280	0.206	0.211
Mean	–	–	0.266	0.268	0.250	0.234	0.262	0.283	0.245	0.270
Maximum	0.40	–	0.387	0.330	0.310	0.270	0.310	0.290	0.313	0.340
Comply	–	–	100%	–	100%	–	100%	–	100%	–

While the IECC removed hard window area ratio requirements in the early 2000's, 15% of conditioned floor area is used for the reference design in the Total UA alternative compliance path. Because windows are typically the least-insulated measure in a home, the amount of window area can significantly impact home performance and this ratio therefore serves as an important metric of home efficiency. Non-program and program detached homes have similarly low levels of adherence to this guideline (Table 4-6).

Table 4-6. Window-to-floor ratio by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	20	21	27	5	4	5	27	6
Minimum	–	–	8%	7%	6%	7%	16%	10%	6%	7%
Mean	–	–	14%	14%	11%	10%	22%	13%	11%	10%
Maximum	15%	15%	28%	31%	15%	18%	29%	15%	15%	18%
Meets Target	–	–	65%	67%	67%	67%	0%	100%	96%	83%

Two skylights, both code complaint, were recorded in non-program homes. There were no skylights recorded in program home models.

Table 4-7. Skylight U-factor by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	–	2	–	–	–	1	–	–
Minimum	–	–	–	0.28	–	–	–	–	–	–
Mean			–	0.40	–	–	–	–	–	–
Maximum	0.55	0.55	–	0.52	–	–	–	–	–	–
Comply	–	–	–	100%	–	–	–	–	–	–

4.3.3 Ceilings

IECC specifies a single requirement for ceilings, which is R-49 in both climate zones 4 and 5; however, there are two exceptions. The first allows for up to 500 square feet of R-30 ceiling area if the cavity depth is inadequate to install R-49. This has the effect of allowing R-30 vaulted ceilings where non-spray foam insulation is used, therefore vaulted ceilings and vented attics are reported separately.[34] The second exception permits the substitution of R-38 if the uncompressed insulation covers the wall top plate—as in a raised-heel or energy truss roof—when using the R-value table (R402.1.2) form of prescriptive compliance. This exception does not apply to other variants of the prescriptive path such as U-factor alternative (R402.1.4) and Total UA Alternative (R402.1.5, also known as UA trade-off).

[34] Twelve of thirteen homes (92%) with verified ceiling insulation material used a form of fiberglass, and at least 68% of the ceiling area in another 46 homes is likely to be fiberglass batt based on inferences from building department files.

Compliance with the R-49 prescriptive requirement for vented attic insulation in Table 4-8 is low among non-program homes due to the prevalence of R-38 fiberglass batt insulation. While it is difficult to determine whether a home satisfies the numerous requirements for the R-38 exemption from plans, trusses make up half of all verified vented attic framing, and there was evidence of energy trusses specifically in at least six of 33 detached homes with R-38 insulation. On the other hand, none of the 20 non-program homes we recorded a compliance path for used the R-value form of prescriptive compliance; 18 were UA trade-off and the others were performance (R405).

Program home vented attic R-value compliance improves when comparing the models to the R402.1.4 U-factor alternative option of the prescriptive compliance.[35] This is due do the impact of a range of factors such as ceiling framing spacing and construction type, continuous insulation, etc. For example, a 24-inch center ceiling truss with R-13+25 Grade I insulation—which is nominally equivalent to an R-38 batt insulation—complies with R402.1.4.

Table 4-8. Ceiling R-value, vented attic by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	25	23	15	5	7	6	25	4
Minimum	49†	49†	30	30	38	48.9	30	30	37.8	38
Mean	–	–	39	38.6	45.5	49.4	34.6	39	45.4	46.5
Maximum	–	–	49	49	49	51	38	49	49	50
Comply	–	–	20%	17%*	33%	60%	0%	17%	28%	50%
R402.1.4	–	–	–	–	73%	100%	–	–	84%	100%

† Or R-30 if cavity-depth prevents R-49, for up to 500 ft², or R-38 if insulation covers wall top-plate.
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.

Vaulted ceiling compliance can be difficult to assess due to the inclusion of sealed attics within the same model result category, which do not qualify for the R-30 exemption since they are not space-constrained. These ceilings are typically insulated with spray foam insulation and should therefore satisfy the R-30 requirement for true vaulted ceilings. Nevertheless—as shown in Table 4-9—overall compliance for vaulted ceilings remains low, especially among non-program homes.[36]

[35] Not to be confused with R402.1.5 Total UA alternative.

[36] Three non-program homes are non-compliant due to excessive vaulted area rather than insufficient insulation.

Table 4-9. Ceiling R-value, vaulted / sealed attic by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	5	11	6	1	–	3	1	1
Minimum	30†	30†	30	19	38	38	–	30	32	30
Mean	–	–	33.2	26.6	39.8	38	–	35.4	32	30
Maximum	–	–	38	38	49	38	–	38.3	32	30
Comply	–	–	60%*	45%*	100%	100%	–	33%	0%	100%

† If cavity-depth prevents R-49, for up to 500 ft².
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.

4.3.4 Floors

Floor insulation compliance is relatively high overall, but may be higher than shown in Table 4-10 for non-program homes due to a cavity exemption permitting R-19. While this exemption is difficult to verify due to frequent gaps in floor framing information within building department records, no program or non-program homes with R-19 floors and known framing were constrained by the depth of the cavity.

Table 4-10. Floor R-value by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	24	18	10	3	5	4	18	5
Minimum	19†	30†	19	13	30	30	30	30	19	0
Mean	–	–	27.0	29.7	32.7	31.7	31.6	30.5	30.2	27.4
Maximum	–	–	38	44	49	35	38	31.8	38	38
Comply	–	–	100%	83%	100%	100%	100%	100%	100%	80%

† Or R-19 if cavity-depth prevents R-30.

4.3.5 Foundations

Despite substantial average R-values, Table 4-11 reveals that basement wall compliance is low across all home categories. However, it is possible that the average R-value and especially compliance levels are higher in Climate Zone 4. Many of these homes use the Superior Walls pre-cast insulated foundation system; however—as confirmed by the manufacturer—there are no clear visible indications on these products to distinguish the Xi Wall from the Xi-15 wall. Instead, one requires a measurement of cavity depth to determine if an installation uses the Xi-15 product, which is fully code compliant, or the Xi version, which requires supplementary insulation to comply with conditioned basement wall code requirements.

Table 4-11. Conditioned basement wall R-value by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	8	7	7	4	2	1	2	2
Minimum	10/13†	15/19†	4.2	11.0	10.2	11	11.0	19	11	13
Mean	–	–	8.2	15.1	13.5	13	15.5	19	11	13
Maximum	–	–	18.5	21	19	15	20	19	11	13
Comply	–	–	50%	29%	14%	50%	50%	100%	0%	0%

† Continuous insulation of first value (e.g., R-10) or cavity insulation of second (e.g., R-13)

Counts across most categories in Table 4-12 are small, but compliance levels for on-grade slab insulation are high in the observed homes apart from Attached/MF 2–4 homes in Climate Zone 5. Also, the non-program single-family detached home in Climate Zone 4 is known to have insulation of compliant depth/width, but the R-value could not be found.

Table 4-12. On-grade slab R-value by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	1	5	2	1	3	2	24	1
Minimum	10	10	–	0	10	11	10	0	10	10
Mean	–	–	–	8.1	10	11	10	5	10	10
Maximum	–	–	–	14	10	11	3	10	10	10
Comply	–	–	–	80%	100%	100%	100%	50%	100%	100%

4.3.6 Air leakage

Amendments to the code in New Jersey allow air leakage compliance to be displayed in two ways: 1) through an air leakage test (R402.4.1.2) and 2) through visual inspection and populating the UCC-F392 Air Barriers and insulation checklist option (R402.4.1.1).[37] Air leakage compliance rates for blower door tested homes (R402.4.1.2) in Table 4-13 are low across the board, but counter-intuitively may be higher in some non-program categories. However, overall compliance rates (86%) for non-program homes using either the UCC-F392 Air Barrier and Insulation checklist option (R402.4.1.1) or testing are higher than for tested homes alone. Because no building department records were collected for program homes, it was not possible to verify that UCC-F392 forms had been filed. Program home compliance rates are therefore the same in both rows, and the combined compliance values should be considered conservative estimates. Finally, as previously mentioned, some builders

[37] https://www.state.nj.us/dca/divisions/codes/publications/pdf_bulletins/b.15_4.pdf

provided both blower door results and UCC-F392;; four of the five sites with documentation for both options met the 3 ACH50 testing threshold.

Table 4-13. Air leakage (ACH50) by home type and program status

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	8	8	15	5	3	3	27	6
Tested	–	–	6	5	15	5	2	3	27	6
Minimum	–	–	2.6	2.8	1.5	2.4	2.9	2.8	2.8	2.6
Mean	–	–	2.9	3.7	3.4	2.9	3.7	2.9	4.4	4.8
Maximum	3	3	3.3	6.3	5.7	3.9	4.4	3.0	8.3	8.0
Comply	–	–	100%	75%	53%	80%	67%	100%	37%	33%
Tested	–	–	83%	60%	53%	80%	50%	100%	37%	33%

4.3.7 Duct leakage

In Table 4-14, duct leakage compliance is high for all strata, although five townhouses in the Attached/MF 2–4 program-home category included tested values of exactly 4.00% total duct leakage, which seems unlikely. Two homes not included in the table—an Attached/MF 2–4 program home in Climate Zone 4 and a detached non-program home in Climate Zone 5—are conditioned with ductless heat pumps and are not included in the table.

Table 4-14. Percent total duct leakage by home type and program status (CFM25 ÷ 100 ft2 CFA)

	IECC		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	8	5	15	5	1	3	26	6
Minimum	–	–	2.6	2.8	1.5	2.4	2.9	2.8	2.8	2.6
Mean	–	–	3.1	3.4	1.7	1.0	3.5	1.9	2.6	2.8
Maximum	4	4	5.4	6.3	3.5	2.2	3.5	2.4	5.7	4.1
Comply	–	–	88%	80%	100%	100%	100%	100%	92%	83%

† One townhome included duct leakage results entered as CFM50. This a very unusual option and was assumed to be a data entry error since 1) the more conventional CFM25 was previously placed next to CFM50 in REM/Rate's user interface and 2) the value was not unusual for a CFM25 reading; equivalent to 4.1 CFM25 ÷ 100 ft2 CFA.

4.4 HERS and ERI

HERS and ERI are closely related but differing methods for rating a home's efficiency based on projected energy consumption.[38] While RESNET controls the HERS standard, the IECC specifies the latter as a compliance option in section R406. Since HERS and ERI scores are generally well correlated (see Table 4-16 for examples) and there is significant confusion surrounding the distinctiveness of these systems, some states accept HERS as an alternative to the ERI, while others amend the code to replace the ERI with HERS.[39,40] In addition, REM/Rate affords no mechanism for bulk export of model ERIs, and Table 4-15 therefore includes the HERS ratings for program homes. If one treats the energy rating as the sole measure of code compliance—assuming various path-independent mandatory requirements such as duct insulation levels and permissible levels of air leakage are satisfied—and accepts HERS as equivalent to ERI, two-fifths (43%) of program homes are ERI path compliant. In contrast, none of the non-program individual home models comply with the ERI path maximum rating.[41]

Table 4-15. HERS index score by home type and program status

	IECC ERI		Single-Family Detached				Attached/MF 2–4			
			Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	–	3	2	15	5	1	2	27	6
Minimum	–	–	61	62	49	22‡	63	68	42	47
Mean	–	–	63	62.5	54.2	49.0	63	70	55.6	54.5
Maximum	54	55	65	63	59	57	63	72	65	60
Comply‡	–	–	0%	0%	47%	60%	0%	0%	37%	50%

† Without PV, this home's rating is 44 and the CZ5 detached program home average rating is 53.4.
‡ Treating HERS as equivalent to ERI.

Table 4-16 lists the ratings of the models synthesized from average home data as outlined in Section 3.2.1. Although 2–4 unit multifamily, duplexes, and townhouses use most of the same inputs, separate models were created to account for different home sizes and geometries such as amounts of floor, wall, and ceiling area shared with other units. While RESNET includes score adjustments to account for home size in the HERS score, changes to the type of home also alter the behavior of modeling software. For example, the table includes ratings of apartments with explicit foundation details to match the findings from our building department research. However, if the foundation type of these models is changed to a generic "Apartment over enclosed space" as recommended by REM/Rate, the MF 2–4 HERS scores are noticeably higher (73 for Climate Zone 4 and 81 for Climate Zone 5) despite virtually unchanged ERIs (70 and 76, respectively).

[38] Differences include the treatment of mechanical ventilation and RESNET's Index Adjustment Factor, which is a multiplier used in calculation of the HERS score that is intended to account for differences in home size.

[39] Massachusetts Board of Building Regulation and Standards. (Oct. 2020). BBRS Energy Code Advisory to the 2018 International Energy Conservation Code with the Massachusetts Amendments, Effective October 13, 2020. https://www.mass.gov/doc/780-cmr-ninth-edition-residential-chapter-11-energy-efficiency-bbrs-advisory-as-of-10132020-0/download (Accessed March 3, 2021)

[40] Vermont Department of Public Works. (2020). 2020 Vermont Residential Building Energy Standards R407/2/2 ERI-based compliance for Stretch Code. https://codes.iccsafe.org/s/VTRES2020P1/chapter-4-re-residential-energy-efficiency/VTRES2020P1-RE-Ch04-SecR407.2.2 (Accessed April 29, 2022)

[41] The building department record review yielded ratings (57 and 58) for two non-program homes in Climate Zone 4, which also do not satisfy the ERI path rating requirement.

Table 4-16. HERS and ERI of average non-program home models by home type

	IECC		SF Detached		Attached		MF 2–4	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
HERS	–	–	66	72	68	73	66	72
ERI	54	55	65	71	68	73	69	75

The average model HERS scores in Table 4-16 are similar to but higher than those for the small sample of individual homes in Table 4-15. See the NMR compliance analysis in Section 4.5.2 for more information on how the individual home models differ from the average home models at the building component level.

4.5 Consumption compliance analysis

The consumption compliance approach uses energy modeling to develop a code compliance scoring system that is more calibrated to calculated energy consumption than other code compliance assessments. This method compares homes to the IECC prescriptive requirements that apply to each sample and does not account for trade-offs that may take place under the UA trade-off and performance paths for compliance. Therefore, it is possible that the consumption compliance approach overstates the level of non-compliance and potential savings associated with homes that use these code compliance paths. The consumption compliance approach does not address these complicating factors, and this should be considered when reviewing the results in this section.

This method assesses compliance for the following building components:

- Above-grade wall insulation and installation quality
- Air leakage
- Duct leakage and insulation
- Foundation wall insulation and installation quality
- Frame floor insulation and installation quality
- Lighting efficiency
- Mechanical ventilation rates, fan efficacy and energy recovery
- Roof insulation and installation quality
- Slab insulation and installation quality
- Window efficiency

Two models are used to calculate compliance for each home. One is an as-built model, or a model that represents the home as it exists, and the other is a code-built model that is a version of the home built to prescriptive code requirements. The difference in consumption of the as-built model from the code-built model is used to calculate the compliance level for each measure. If the as-built model consumes the same amount of energy or less than the code-built model, it is considered 100% compliant.[42] If the as-built model is less efficient than code, the measure is scored as partially compliant proportionate to the percentage change in consumption.

After the measure-level compliances are computed, they are weighted and combined to create an overall home compliance score. Measure weights are calculated using the fraction of total consumption each measure contributes to a home, averaged across the sample of homes used for weighting. By developing a distinct point system for both IECC 2015 Climate

[42] By providing only the maximum possible points this method does not apply extra credit for exceeding the prescriptive code requirements.

Zone 4 and Climate Zone 5, this approach accounts for variations among code requirements. For example, only Climate Zone 4 has fenestration solar heat gain coefficient (SHGC) requirements in New Jersey.

The following formulas are used for the calculations described above:

$$\Delta AB_{Home\ i,Measure\ j} = \frac{(CB_{Home\ i,Measure\ j} - AB_{,Home\ i,Measure\ \mathrm{j}})}{AB_{Home\ i,,\mathrm{Measure\ j}}}$$

$$Compliance_{Measure\ j} = \begin{cases} 1 + \Delta AB_{Home\ i,Measure\ j}\ if\ \Delta AB_{Home\ i,Measure\ j} < 0 \\ 100\%\ if\ \Delta AB_{Home\ i,Measure\ j} \geq 0 \end{cases}$$

$$Weight_{Measure\ j} = \mathrm{Average}\left(\frac{AB_{Home\ 1,Measure\ j}}{AB_{Home1}}, \frac{AB_{Home\ 2,Measure\ j}}{AB_{Home2}}, \ldots\right)$$

$$Compliance_{Home\ i} = \sum_{j=1}^{n} Weight_{Measure\ j} \times Compliance_{Measure\ j}$$

Where:

$$AB_{Home\ i} = As - built\ consumption\ of\ home\ \mathrm{i}$$

$$CB_{Home\ i} = Code - built\ consumption\ of\ home\ \mathrm{i}$$

$$\Delta AB_{Home\ i,Measure\ j} = Difference\ between\ code - built\ and\ as - built\ models$$

$$Compliance_{Measure\ \mathrm{j}} = Measure\ compliance\ with\ prescriptive\ code$$

$$Weight_{Measure\ j} = Fraction\ of\ a\ home's\ consumption\ attributable\ to\ measure\ \mathrm{j}$$

$$Compliance_{Home\ i} = Home\ compliance\ with\ prescriptive\ code$$

Below is an example of how these calculations would work for a home that does not meet the lighting code requirement. In this scenario, the as-built model has a higher consumption than the code-built model because the code-built home is more efficient.

$$\Delta AB = \frac{(3\ \mathrm{MMBtu} - 5\ \mathrm{MMBtu})}{5\ \mathrm{MMBtu}} = -0.4$$

$$Compliance_{Lighting} = 1 - 0.4 = 60\%$$

If lighting accounts for 10% of as-built home energy consumption in the sample, the example home's total home compliance would be credited 6% (10% × 60%) for the underperforming lighting.

The weight of individual components varies depending on the sample of homes and the home under consideration. The total possible points per measure varies between the samples because the relative impact of the measures shifts between different codes and between different samples of homes; hence, it is important for the sample to represent the market as well as possible. However, the relative weights of measures across strata is not a critical comparison because the goal of this system is to assess compliance percentages. This approach is akin to the PNNL scoring system, in which the total possible points vary across different codes due to the number and importance of various code requirements and scores are normalized from 0% to 100% to simplify cross code comparisons.

4.5.1 Measure rank

The relative importance of each measure to a home's overall energy consumption is presented in Table 4-17, which is sorted by the average weight of all four strata. The remaining tables in this section are sorted in the same manner. Although the exact weights vary by climate zone and program status, foundations are universally low-ranked, whereas walls, windows, and ventilation are virtually tied for first place.

Table 4-17. Compliance measure weights by climate and program status

Measure	Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~31†	~28†	20	33
Exterior Walls	22%	21%	18%	16%
Windows & Skylights	17%	18%	21%	21%
Mechanical Ventilation	14%	15%	21%	19%
Ducts	15%	15%	6%	7%
Ceilings	8%	9%	7%	6%
Air Leakage	5%	4%	10%	11%
Lighting	5%	5%	9%	9%
Framed Floors	9%	8%	1%	3%
Conditioned Basement Walls	3%	3%	2%	5%
Slabs	2%	2%	4%	3%

† Approximate number of homes represented in average home models. Exact count varies by measure.

4.5.2 Non-program home compliance

The compliance levels of individual home models in Table 4-17 are comparable to those of the average home models, with some exceptions such as duct leakage, air leakage, ceiling insulation, and mechanical ventilation. However, the latter is likely conservative for average home models—as is the lighting compliance value—due to various assumptions made for the models (Section 3.2). Overall, non-program homes would receive a B+ or A- for code compliance.

Table 4-18. Non-program consumption compliance by model and home type

Measure	Single-Family Detached				Attached/MF 2–4			
	Average		Individual		Average		Individual	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~25†	~23†	6	–	~6†	~5†	–	2
Exterior Walls	81%	89%	77%	–	77%	86%	–	88%
Windows & Skylights	100%	100%	100%	–	100%	100%	–	100%
Mechanical Ventilation	95%	99%	90%		94%	99%		99%
Ducts	79%	81%	92%	–	100%	100%	–	100%
Ceilings	63%	59%	72%	–	63%	59%	–	88%
Air Leakage	85%	88%	95%	–	85%	89%	–	100%
Lighting	100%	100%	100%	–	100%	100%	–	100%
Framed Floors	93%	77%	93%	–	87%	78%	–	80%
Conditioned Basement Walls	60%	58%	75%	–	67%	56%	–	100%
Slabs	97%	100%	93%	–	100%	100%	–	97%
TOTAL	86%	87%	88%	–	88%	90%	–	95%

† Approximate number of homes represented in average home model. Exact count varies by measure.

4.5.3 Program home compliance

Overall, program home compliance is an A or A-, akin to that of the average non-program models. However, this does not account for misstated Grade I R-19 wall entries, which increase the level of compliance for exterior walls compared to the Grade III or R-17.1, which would be more accurate (Section 4.3.1). On the other hand, there are indications of notably higher levels of compliance in program homes for some measures, particularly ceiling insulation.

Table 4-19. Consumption compliance by home type and program status

Measure	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~25†	~23†	15	5	~6†	~5†	27	6
Exterior Walls	81%	89%	85%	86%	77%	86%	85%	98%
Windows & Skylights	100%	100%	100%	100%	100%	100%	100%	100%
Mechanical Ventilation	95%	99%	95%	100%	94%	99%	94%	98%
Ducts	79%*	81%	100%	100%	100%	100%	98%	100%
Ceilings	63%*	59%*	94%	100%	63%*	59%	95%	97%
Air Leakage	85%	88%	77%	97%	85%	89%	64%	62%
Lighting	100%	100%	100%	100%	100%	100%	100%	100%
Framed Floors	93%	77%	100%	99%	87%	78%	100%	95%
Conditioned Basement Walls	60%*	58%	87%	78%	67%	56%	98%	89%
Slabs	97%	100%	97%	99%	100%	100%	99%	99%
TOTAL	85%	85%	92%	96%	87%	88%	92%	94%

† Approximate number of homes represented in average home model. Exact count varies by measure.
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.

Table 4-20 provides a side-by-side comparison of the measure-level prescriptive code compliance from Section 4.3 and the energy-consumption based consumption compliance in Table 4-19. The latter supplies partial credit for non-compliant measures, while the former does not.

Table 4-20. Prescriptive code and consumption compliance by home type and program status

Measure		Single-Family Detached				Attached/MF 2–4			
		Non-Program		Program		Non-Program		Program	
		CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites		~26†	~23†	15	5	~6†	~5†	27	6
Exterior Walls	Cons.	81%	89%	85%	86%	77%	86%	85%	98%
	Presc.	28%	46%	13%	20%	0%	17%	44%	50%
Windows & Skylight	Cons.	100%	100%	100%	100%	100%	100%	100%	100%
U-factor	Presc.	96%	88%	100%	100%	100%	80%	100%	100%
Mechanical Vent.	Cons.	95%	99%	95%	100%	94%	99%	94%	98%
	Presc.	0%	0%	7%	25%	–	0%	19%	0%
Ducts	Cons.	79%	81%	100%	100%	100%	100%	98%	100%
	Presc.	88%	80%	100%	100%	100%	100%	92%	83%
Ceilings	Cons.	63%	59%	94%	100%	63%	59%	95%	97%
Flat	Presc.	20%	17%	33%	60%	0%	17%	28%	50%
Air Leakage	Cons.	85%	88%	77%	97%	85%	89%	64%	62%
Tested	Presc.	83%	60%	53%	80%	50%	100%	37%	33%
Framed Floors	Cons.	93%	77%	100%	99%	87%	78%	100%	95%
	Presc.	100%	83%	100%	100%	100%	100%	100%	80%
Cond. Bsmnt. Walls	Cons.	60%	58%	87%	78%	67%	56%	98%	89%
	Presc.	50%	29%	14%	50%	50%	100%	0%	0%
Slabs	Cons.	97%	100%	97%	99%	100%	100%	99%	99%
	Presc.	80%	100%	100%	100%	50%	100%	100%	80%

† Approximate number of homes represented in average home model. Exact count varies by measure.

4.6 Gross technical potential savings

Multiple approaches to calculating gross technical potential (GTP) savings are included this section, all of which use the consumption compliance modeling results to calculate the average amount of energy consumption that could be saved through universal prescriptive code compliance of as-built homes. The various forms offer context for interpreting the results from one another, and those which are analogous to selected code compliance paths are collected in Table 4-23. Some caveats to these savings estimates include:

- Potential savings from ceilings may be over-estimated if the R-38 energy-truss exemption is common, particularly in non-program homes.
- Program home exterior walls include some questionable cavity insulation values (Section 4.3.1), so the potential savings are likely an underestimate.
- Measures with 100% compliance (lighting and windows) are omitted as there are no potential savings from increased compliance.

The natural extension to the prescriptive code-based consumption compliance of the previous section are the prescriptive potential savings in Table 4-21. In this analysis, non-program Single-Family Detached savings are between two-and-three-fold those of program homes, while the ratio is closer to 1.5 to 1 for Attached/MF 2–4.

Table 4-21. Average measure-level prescriptive potential savings

Measure	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~26†	~23†	15	5	~6†	~5†	27	6
Exterior Walls	19%	11%	15%	14%	23%	14%	15%	2%
Mechanical Ventilation	5%	1%	5%	<1%	6%	1%	6%	2%
Ducts	21%	19%	0%	0%	0%	0%	2%	0%
Ceilings	37%	41%	6%	0%	37%	41%	5%	3%
Air Leakage	15%	21%	23%	3%	15%	11%	36%	38%
Framed Floors	7%	23%	0%	1%	13%	22%	<1%	5%
Conditioned Basement Walls	40%	42%	13%	22%	33%	34%	2%	11%
Slabs	3%	0%	3%	1%	0%	0%	1%	1%
Weighted TOTAL	14%	13%	7%	4%	12%	10%	8%	6%

† Approximate number of homes represented in average home model. Exact count varies by measure.

The site-level savings (weighted total) in Table 4-21 are the sum of measure-level savings weighted by the measure impacts from Table 4-17. In contrast, Table 4-22 presents the part of each home's energy use intensity (EUI)[43] that could be reduced by increasing prescriptive-code compliance.[44] In both analyses, there are significant potential savings from increased wall insulation in both program and non-program homes, and the latter would also benefit from more ceiling insulation.

43 EUI is defined as consumption divided by square footage.

44 The total in Table 4-22 is not weighted since the measure-level savings are normalized by home size, but rather the total is a sum of the change in EUI per measure divided by the change in total EUI. The measure-level percentages themselves are the change in EUI divided by the whole home change in EUI.

Table 4-22. EUI-normalized prescriptive potential savings

Measure	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~26†	~23†	15	5	~6†	~5†	27	6
Exterior Walls	4%	2%	4%	3%	5%	3%	4%	<1%
Mechanical Ventilation	<1%	<1%	1%	<1%	1%	<1%	1%	<1%
Ducts	4%	3%	0%	0%	0%	0%	<1%	0%
Ceilings	3%	4%	<1%	0%	3%	4%	1%	<1%
Air Leakage	1%	1%	3%	1%	<1%	<1%	6%	5%
Framed Floors	1%	2%	0%	<1%	1%	2%	<1%	1%
Conditioned Basement Walls	2%	2%	1%	3%	1%	1%	<1%	1%
Slabs	<1%	0%	<1%	<1%	0%	0%	0%	0%
TOTAL	15%	14%	10%	6%	12%	10%	11%	8%

† Approximate number of homes represented in average home model. Exact count varies by measure.

As previously discussed, the measure-level consumption compliance results in the last section, as well as the related potential savings in this section, thus far compare homes to the prescriptive code R402.1.2 Insulation and Fenestration Criteria Requirements option, whether they pursued this compliance path or another. In Table 4-23, comparisons which are analogous to other compliance paths are presented. The average amount the as-built homes' heating and cooling loading exceeds that of code-compliant homes is comparable to R402.1.5 Total UA alternative,[45] while the average amount as-built homes' total energy consumption exceeds that of a compliant home is similar to R405.3 Performance-based compliance.[46] One reason that the analog values can differ for the same strata is that the UA trade-off path treats all aspects of the shell as equivalent. For example, foundations are exposed to less-extreme temperatures than ceilings, windows, or walls. While foundations have low compliance levels in Table 4-20 and would therefore contribute to a significant portion of prescriptive code or UA-analog savings potential, they also receive a low weight in Table 4-17, resulting in a smaller contribution to performance-based analog.

[45] However, one difference between the two is that the Total UA-analog is not limited to shell insulation. It also includes lighting and air leakage and is based on load rather than UA alone. This accounts for the conditions different portions of the home are exposed to, which emphasizes ceilings, windows and walls over foundations.

[46] However, the performance-based analog includes lighting while the Performance-based compliance path does not. Finally, the performance path includes a cap on window to floor area ratio of 3 to 20 (15%), while this analysis does not.

Table 4-23. Alternate path potential site savings

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	~26†	~23†	15	5	~6†	~5†	27	6
R-value (Table 4-21)	14%	13%	7%	4%	12%	10%	8%	6%
EUI (Table 4-22)	15%	14%	10%	6%	12%	10%	11%	8%
Total UA Alternative analog‡	12%	13%	1%	<1%	8%	8%	4%	2%
Performance-based analog‡	15%	16%	2%	0%	10%	9%	5%	4%

† Approximate number of homes represented in average home model. Exact count varies by measure.
‡ Both analogs include lighting, which the code compliance paths do not. The UA analog also includes air leakage, which is not currently a tradeable measure.

4.6.1 Statewide GTP

The total statewide gross technical potential savings (BTU/home/yr [EUI × CFA] × EUI savings × number of homes) across all strata in Table 4-22 are 205 billion BTU per year. To put this in perspective, the 2019 Residential New Construction (RNC) program had annual savings goals of approximately 167 billion BTU per year.[47] This means that the gross technical potential savings from compliance enhancement are 123% of the 2019 RNC program goals. However, there are some caveats to these results:

- Per Section 3.1.1, the detached/attached breakdown is based on Census division-level data and is therefore approximate.
- These savings are based on prescriptive code and subject to the caveats about ceiling and wall savings presented at the beginning of Section 4.6.

[47] TRC. (June 2018). New Jersey's Clean Energy Program Fiscal Year 2019 Program Descriptions and Budget – FY19 Compliance Filing Volume 1. https://njcleanenergy.com/files/file/Library/Compliance%20Filings/fy19/TRC%20Compliance%20Filing%202019%20Vol%201%20v4%20FINAL.PDF

Table 4-24. Statewide potential savings

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
EUI (kBTU/ft^2/yr)	28.7	28.3	21.1	15.5	32.5	32.3	17.6	17.0
Conditioned Floor Area	2,717	3,877	3,223	4,511	2,283	2,925	1,743	1,823
Million BTU/home/yr (EUI×CFA)	78.0	109.7	68.0	69.9	74.2	94.5	30.7	31.0
EUI Savings (Table 4-22)	15%	14%	10%	6%	12%	10%	11%	8%
Homes	9,679	3,111	568	95	2,624	1,151	799	159
Billion BTU/yr Savings	113.2	47.8	3.9	0.4	25.4	11.2	2.7	0.4

Table 4-25 compares the fraction of statewide savings represented for each category of homes (header rows in Table 4-24) to the fraction of new homes the category represents. For example, non-program homes (unsurprisingly) represent a larger proportion of savings per home relative to their population. Note, this table does not highlight all possible subgroups but it shows how potential savings are not necessarily proportional to any particular group's share of the population.

Table 4-25. Potential savings proportionality

	Savings	Homes	Ratio
Climate Zone 5	29%	25%	1.18 : 1.00
Detached Homes	80%	73%	1.11 : 1.00
Non-Program	96%	91%	1.06 : 1.00

4.7 Regional compliance context

Table 4-26 provides a summary of a dozen studies located as potential comparisons for this review of residential new construction code compliance under IECC 2015 in New Jersey. (Locations are linked to the report if publicly available at time of writing.) None of these studies precisely match the same time-frame, building code, climate, and home types as this analysis. However, the 2019 Massachusetts and 2018 New York studies are serviceable references, with some caveats: 1) The data were collected in site visits, and 2) While the single-family categories of both are primarily based on detached housing, they include other home types; detached housing represents 96% and 93% of the respective samples. Also note that studies of residential new construction in Connecticut (IECC 2015) and Rhode Island (IECC 2015) are planned for the summer of 2022.

Table 4-26. Residential construction studies

Location	Conducted	Code(s)	CZ	Home type(s)
Vermont	2021	RBES 2015†	5 & 6	1–3 units
Massachusetts	2021	IECC 2015+	5	5+ units
Maine	2020	IECC 2009	6 & 7	"Single-family," Manufactured, "Multi-family"
US (RESNET)	2019	Varies	1–7	"Single-family," "Multi-family"
Massachusetts	2019	IECC 2015+	5	1–4 units
New York	2018	IECC 2012 & IECC 2015‡	4–6	1–4 units, 5+ units
Pennsylvania	2018	Varies	4–6	Detached, Attached, Manufactured, 2+ units
Rhode Island	2017	IECC 2012♦	5	1–2 units
Connecticut	2017	IECC 2012♦	5	Detached, Attached, Townhouse
Maryland	2016	IECC 2012	4	"Single-family"
Illinois	2014	IECC 2012	5	3 floors or less
Delaware	2012	–	4	"Single-family"

† RBES is a derivative of IECC with multiple local prescriptive path options.
+ Massachusetts includes a "base code" and an opt-in "stretch code." These are lightly amended versions of the 2015 code, with the latter requiring ERI path compliance.
‡ New York includes a stretch code requiring ERI path compliance which municipalities may voluntarily adopt like Massachusetts. However, the New York stretch code also requires several mechanical system improvements from a menu of predetermined options.
♦ Connecticut and Rhode Island building codes include amendments to significantly loosen duct leakage requirements for all homes. In addition, Rhode Island eliminates the air leakage threshold requirement for all homes—only requiring that testing be performed—while Connecticut relaxes the air leakage requirements for non-detached homes.

4.7.1 Consumption compliance comparison

Table 4-27 compares the consumption compliance of non-program homes in New Jersey to those for the 2019 residential baseline in Massachusetts. In addition to different home-size categories between the two studies, the Massachusetts values of two code variants have been weighted to represent the entire state. Massachusetts is predominantly stretch code, which is equivalent to the IECC ERI compliance path with some amendments. With those caveats in mind, there are some potential differences in compliance between the two jurisdictions:

- Window and skylight compliance appears to be higher in New Jersey. However, window details are frequently unavailable in the post-construction audits used to collect for the Massachusetts study, which required the frequent use of conservative defaults in home models.
- Ceiling insulation compliance is lower in New Jersey due to the prevalence of R-38 insulation. As previously noted, the building code permits R-38 under certain conditions and so these homes may comply with prescriptive code. In addition, REM/Rate cannot handle such nuances, and therefore R-49 ceilings are used for the consumption compliance reference home. For context, flat ceilings in Massachusetts averaged R-44 versus R-38 in New Jersey. At least two thirds of flat ceilings in Massachusetts include continuous insulation compared to 43% of those in New Jersey (n=21).
- Conditioned basement wall compliance is lower in New Jersey. Conditioned basements in Massachusetts are typically finished spaces with insulated framing or insulated with spray-foam. In contrast, many basements in New Jersey are

better described as partially conditioned space (Table 3-7), and these uninhabited portions of the home may receive less attention than finished basements.[48]

Table 4-27. Consumption compliance of non-program homes in Climate Zone 5 by home type

Measure	Single-Family Detached	Attached/ MF 2–4	Massachusetts 1–4 units[49]
Sites	~23†	~5†	100
Exterior Walls	89%	86%	95%
Windows & Skylights	100%*	100%	89%
Ducts	81%	100%	72%
Ceilings	59%*	59%*	87%
Air Leakage	88%	89%	85%
Framed Floors	77%	78%	82%
Conditioned Basement Walls	58%*	56%*	91%
Slabs	100%	100%	93%

† Approximate number of homes represented in average home model. Exact count varies by measure.
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of homes in Massachusetts at the 90% confidence level.

4.7.2 HERS Index Score comparison

The small sample sizes in New York Climate Zone 4 and throughout New Jersey prevent robust comparisons between studies. Nevertheless, it appears that the HERS Index Scores of individual (Table 4-28) and average (Table 4-29) homes in New Jersey are overall higher than those in New York or Massachusetts.

[48] For reference, one fourth (19 of 73) new homes in 2018 New York study possessed partially conditioned basements. These homes are all located in Climate Zone 5 and are predominantly insulated with non-compliant fiberglass batts in a 2×4 wall cavity.

[49] NMR Group, 2020. 2019 Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL). Table 16: MA-REC Statewide Measure-level Compliance) https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf

Table 4-28. Non-program home HERS Index Scores by home type and jurisdiction

	New Jersey						MA 2019 (1–4 units[50])		NY 2019 (1–4 units)[51,52]	
	IECC ERI		Single-Family Detached		Attached/ MF 2–4		Base Code	Statewide	IECC 2012 & IECC 2015	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 5	CZ 5	CZ 4	CZ 5
Sites	–	–	3	2	1	2	51	100	5	68
Minimum	–	–	61	62	63	68	5	-10	–	–
Mean	–	–	63	62.5	63	70	59.6	59.3	67.6	53.9
Maximum	54	55	65	63	63	72	95	95	–	–

Table 4-29. HERS of average non-program home models by home type

	SF Detached		Attached		MF 2–4	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
HERS	66	72	68	73	66	72

50 NMR Group, 2020. 2019 Residential New Construction Baseline/Compliance Study (MA19X02-B-RNCBL). Table 29: Average REM/Rate HERS Index Scores https://ma-eeac.org/wp-content/uploads/MA19X02-B-RNCBL_ResBaselineOverallReport_Final_2020.04.01_v2.pdf

51 Cadmus. October 2019. 2019 Single-Family Building Assessment, Appendix A, Table 13: New Homes – Typical Home Profile https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/2019-RBSA-appendix-a.pdf (Accessed February 7, 2020),

52 This study does not appear to explicitly exclude program homes.

5 COMMERCIAL METHODOLOGY

5.1 Sample design

5.1.1 Population

The population frame for this study consisted of New Jersey commercial new construction buildings permitted under ASHRAE 90.1-2013 from January 1, 2018, until March 1, 2020. To estimate this population, DNV purchased a subscription to Dodge Data & Analytics (the Dodge database). This resource has been used in prior studies by DNV and is a common source for estimating building populations in commercial new construction studies.

The Dodge database is a clearinghouse of construction activity with a primary use in the industry as a construction bid management platform; as such, the Dodge database contains many projects that are not new commercial construction and thus ineligible for the study. These ineligible projects are wide ranging, but some examples include municipal paving projects, renewable energy generation, minor renovations, and tenant fit-outs. DNV conducted extensive data scrubbing to flag the ineligible buildings and estimate the population frame for this study. Table 5-1 shows the disposition summary table from the Dodge database.

Table 5-1. Dodge database disposition summary

Disposition	Count of records
Total records in Dodge database in New Jersey	22,357
Duplicate records	22
Excluded project type	14,578
Building repairs, improvements, and renovations	5,189
Multifamily less than four stories	1,234
Exterior or unconditioned space	8
Total records removed	21,031
RECORDS ESTIMATED IN NEW JERSEY POPULATION	**1,326**

5.1.2 Participant tracking data

In addition to its review and scrubbing of the Dodge data, the team reviewed the New Jersey's Clean Energy Program (NJCEP) participant tracking data to identify program participants for stratification in the sample design. This dataset included 196 new construction projects completed from 2018-2021. 109 out of the 196 tracking projects matched to the full Dodge frame, while only 25 of these NJCEP tracking projects matched to the eligible projects in the Dodge frame. The team attributes the low number of matches between the eligible projects and tracking data to the inclusion of projects which were major renovations instead of ground up new construction in the NJCEP tracking data. NJCEP does not distinguish between major renovations and new construction, and therefore many of the projects categorized as new construction in the tracking system were not eligible for the study.

5.1.3 Target sample and design effects

After preliminary analysis, the team determined that a sample size of 55 sites in 18 municipalities, drawn using a clustered systematic sampling approach, would meet a target relative precision of level of ± 12% at the 90% confidence level, assuming a CV of .5 and modest clustering design effects.

The design effect of a cluster sample represents the expected increase in variance of analysis estimates caused by the members of each cluster being like one another for any metric. The greater the correlation among cluster members, the greater the increase in variance. The cluster is the first stage of sampling, in this case the municipality. We assume that, within a municipality stratum defined by size, there is relatively little “town effect.” That is, we don’t expect sites within the same municipality to be a lot more similar than sites from different municipalities, in terms of the compliance metrics of interest. Put another way, we expect that differences from one municipality to another are mostly the effects of random groups of buildings being built in one town rather than another, and only slightly the effect of municipalities within a stratum being inherently different in code enforcement or compliance. Specifically, we assumed that the cross-municipality variability was 5% due to inherent differences, and the remainder due to different random groups of buildings in each municipality.

5.1.4 Stratification

For the sample design, the team used the following stratification attributes:

- Building level: Size (based on the square footage of the project), Participation, Multifamily/Non-Multifamily
- Municipality level: Size (based on the total new construction square footage in the municipality)
  - While Urban/Less Urban and primary Electric Utility were desired stratification attributes to ensure some geographic distribution of the sample, including these as explicit stratification variables was not possible due to the relatively small sample size. Instead, the team used these variables to control the sorting of the sample frame prior to systematic random sampling so that any selected sample would be spread across these attributes and serve as an implicit stratification.

For the first stage of the design, the team allocated the sample to municipality sampling cells approximately proportional to size (total estimated eligible floorspace). With an overall target of 18 municipalities, any one municipality accounting for over 5% of total estimated floorspace was targeted for selection with certainty. Three municipalities—Linden, Piscataway, and Jersey City—met this criterion. Other municipalities were placed into small, medium, and large strata depending on the floorspace they represented in the Dodge data such that each represents 33% of the new construction square footage:

- 11 Large municipalities (750,000 – 2,000,000 square feet)
- 32 Medium municipalities (230,000 – 750,000 square feet)
- 313 Small municipalities (< 230,000 square feet)

From each of these municipality size strata, we selected five municipalities into the primary sample.

For the second stage of the design, the team stratified projects by building size, participant, or non-participant and by multifamily or non-multifamily. The sample of projects was allocated to the combination of municipality stratum and project stratum proportional to size.

The team designed the sample selection to allow for a proportion of the first-stage selections to decline to cooperate, as well as a proportion of second-stage selected projects to be ineligible. Ineligible projects were primarily those that were not completed within the target study window, including projects that were entered into the Dodge data but never permitted or built.

5.1.5 Sample draw

To implement the clustered systematic random selection strategy, all municipalities within a first stage stratum were arranged in random order, and then sorted by the urban/less urban and electric utility control variables. Then, a random start point was selected, with each subsequent sample point selected at a fixed interval based on the size of the stratum population and the target number of completes. For example, if a stratum contained 10 municipalities with a target of 5, municipalities would be selected at a fixed interval of two observations after the random starting point. Table 5-2 shows an example of this process, where the initial random selection point is highlighted.

Table 5-2. Systematic random sampling example

Urban/Less Urban	Utility	Municipality	Selection Priority	Primary/Backup
UR	PSEG	A	3	Primary
UR	PSEG	B	8	Backup
UR	JCP&L	C	4	Primary
UR	JCP&L	D	9	Backup
UR	Rockland	E	5	Primary
LR	PSEG	F	10	Backup
LR	JCP&L	G	1	Primary
LR	Rockland	H	6	Backup
LR	Rockland	I	2	Primary
LR	ACE	J	7	Backup

Based on the above process, municipalities are assigned a contact order for recruitment. If a targeted municipality declines or is determined not to be worth continuing to pursue, the first backup municipality in the randomized list may be recruited.

To select specific projects for analysis, the team arranged all projects within a second-stage sampling stratum in random order. Within each stratum, projects were requested for review in the random project selection order, within the recruited municipalities. Initially, when a municipality with more than 10 projects was recruited, only the 10 highest priority projects were requested to reduce burden on both the municipality and project team. This approach allowed for the selection of substitute projects as needed, under the assumption that some projects would be screened out as ineligible; however, as discussed in Section 5.2.2, municipalities were often unable or unwilling to provide documents for several of projects among the initial 10 requested, leading the team to request more additional backup projects than originally anticipated.

Table 5-3 shows the planned project-level stratification and sample targets.

Table 5-3. Second-stage project stratification and allocation

Building Type	Participation Status	Size Group	# Projects	Estimated SF	% Projects	% SF	Adjusted Allocation	CL 90 Precisions (FPC)	CL 80 Precisions (FPC)
Multifamily	Non-Participant	≤ 25,000	113	1,118,548	8.60%	2.30%	7	30.20%	23.50%
		> 25,000	85	10,659,662	6.40%	22.20%	10	24.60%	19.10%
Non-Multifamily	Non-Participant	≤ 25,000	902	6,949,225	68.40%	14.40%	7	31.00%	24.10%
		25,000 - 100,000	113	6,159,760	8.60%	12.80%	8	28.20%	21.90%
		≥ 100,000	74	21,984,532	5.60%	45.70%	14	19.90%	15.50%
Mixed	Participant	≤ 25,000	19	127,281	1.90%	0.40%	6	28.50%	22.20%
		> 25,000	6	1,049,331	0.50%	2.20%	3	36.80%	28.60%
	Total		1,312	48,048,339	100.00%	100.00%	55	10.90%	8.50%

5.2 Data collection

This section outlines the data collection procedures used to collect site-level commercial code compliance data for ASHRAE 90.1-2013.

5.2.1 Data collection tool

The DNV team modified the data collection tool that was most recently used in the Massachusetts Non-Residential New Construction (NRNC) Market Characterization Study (NRNC Study).[53] customizing it for New Jersey-specific requirements to streamline the data collection and analysis of the Rutgers evaluation (ASHRAE 90.1-2013). The DNV team built this tool using Microsoft Excel to facilitate the data collection and subsequent analysis for both individual sites and aggregated site data across all sites in the study. The data collection instrument captures building envelope, mechanical system (HVAC), and electrical system (lighting) components as detailed in Table 5-4:

Table 5-4. Data collection approach

Building category	Key building practices included in data collection
Building envelope	• Building envelope insulation assessment, including wall, roof, and slab insulation • Window details, including u-factor and solar heat gain coefficient (SHGC) where available • Information on how the continuous air barriers are documented on construction documents. • Estimate of building glazing percentage.
Mechanical systems (HVAC)	• Full equipment inventory based on equipment schedules including efficiency levels and control strategies. • HVAC controls characterization – assessment of control strategies specified on construction drawings for equipment and spaces/zones.
Electrical systems (lighting)	• Interior and exterior lighting power density (LPD). • Inventory of lighting control strategies, including daylighting and space-level controls.

5.2.2 Site recruitment

Following the sampling methodology, DNV recruited sites for the study by directly engaging municipal building departments. This was an approach used in previous code compliance studies by DNV. This approach was also designed to mitigate self-selection bias. Selection bias is a common challenge for energy code compliance studies and building practice assessments, as building owners and designers who are knowingly not adhering to code requirements can decline participation without consequence. By engaging municipal departments directly, this bias was mitigated, as individual site owners were not contacted directly and the documents reviewed were those filed with each building's municipal authority having jurisdiction (AHJ).

The recruitment approach required a mix of methods to acquire construction documents, including direct communication with municipal building department staff. In many cases, the team had to submit a Public Records Request and/or conduct visits to municipal building departments to identify and acquire additional documentation. The team requested construction

[53] https://ma-eeac.org/wp-content/uploads/MA-CIEC-stage-5-report-P70-Code-Compliance-and-Baseline-FINAL.pdf

drawings along with supporting materials, which included commissioning plans, sequence of operations documents, COMcheck assessments, and specifications. For most sites, however, municipal building departments could only provide construction drawings.

Figure 5-1 shows a map of the recruited sites, and Table 5-5 shows the distribution of recruited sites by stratum and municipality.

Figure 5-1. ECC study recruited sites

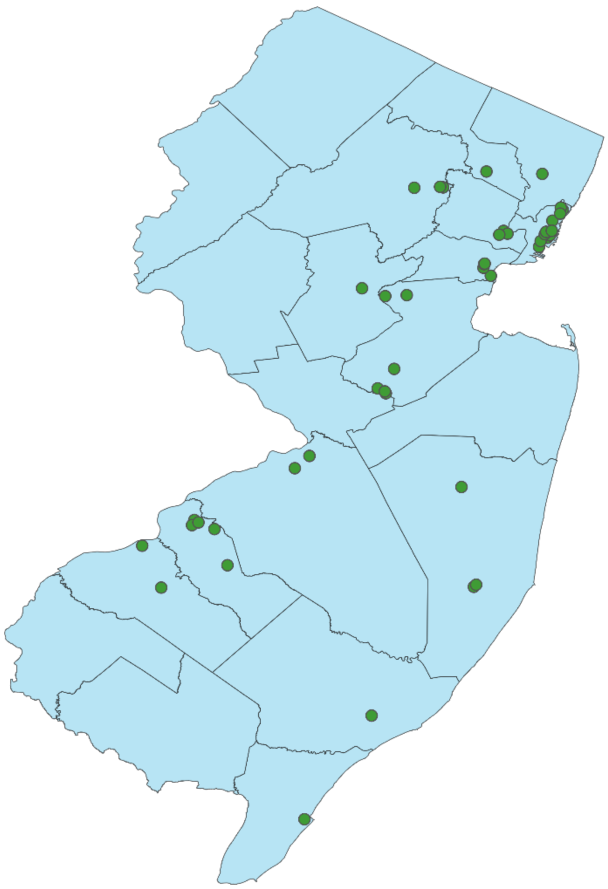


Table 5-5. ECC Study commercial recruitment results by municipality and stratum

Stratum	Municipalities recruited	Count of sites recruited
1. Non-Multifamily - Non-Participant - <= 25,000	6	10
2. Non-Multifamily - Non-Participant - 25,000 - 100,000	5	6
3. Non-Multifamily - Non-Participant - >= 100,000	2	3
3. Non-Multifamily - Non-Participant - >=100,000	6	8
4. Multifamily - Non-Participant - <= 25,000	2	4
5. Multifamily - Non-Participant - > 25,000	4	10
6. Participant - <= 25,000	4	4
7. Participant - > 25,000	2	2
Totals	**21**	**47**

The DNV team encountered several challenges during site recruitment, as detailed below:

- **OPRA (Open Public Records Act) exemptions.** Throughout the recruitment phase, approximately one third of the cities and towns contacted by DNV in New Jersey cited the security concerns and OPRA exemption and thus declined to provide DNV with the full requested documentation. DNV did not anticipate the extent that towns would cite this OPRA exemption, as this has not been observed in prior studies.
- **CLRA (Common Law Right of Access) requests.** DNV shared the recruitment challenges due to OPRA exemptions with Rutgers, and in doing so both the DNV and Rutgers teams learned about New Jersey DCA Bulletin 03-3, a guidance document that sought to provide clarity around OPRA requirements, explicitly specifying that the common law right of access (CLRA) enables individuals to request information, including building plans, with a written request stating a reasonable reason for obtaining the documents.[54] DNV used the CLRA process to re-request documentation from 12 towns previously contacted under OPRA who refused, citing the security exemption, and as a result received documentation from 2 of these towns. DNV used the CLRA process for all additional recruitment attempts to new towns, resulting in 32 total CLRA requests. Several towns cited the same OPRA security exemptions in response to the CLRA requests and declined to provide DNV with the requested documentation.
- **Municipal file storage and organization impacts.** The lack of proper storage and organization methods at municipal building departments across the state negatively impacted our recruitment efforts. DNV requested documentation for many sites where municipal building departments were unable to locate all or some of the construction drawings. This issue occurred while requesting sites via email and phone and during in-person visits. Many sites with paper plans were not found where initially thought to be stored at several different municipal offices. Many building departments also had off-site storage locations that required extra time and effort to travel to and search for files in, which also contributed to the difficulty of locating documentation in a timely manner.
- **COVID-19 pandemic recruitment impacts.** The ongoing COVID-19 pandemic affected this study recruitment due to multiple municipalities having limited staff available to assist DNV in confirming building permitting dates, identifying eligible buildings, responding to OPRA requests and follow-up questions in a timely manner, and physically obtaining construction drawing documentation.

[54] New Jersey DCA Bulletin 03-3. July 2003. https://www.nj.gov/dca/divisions/codes/publications/pdf_bulletins/b_03_3.pdf.

5.2.3 Construction documentation review

The primary means of verification of energy code compliance was a review of the construction documents received for each site during recruitment. For all 47 sites, field engineers conducted detailed reviews of construction documents, recording general site information as well as specific details for the building envelope, mechanical systems, and lighting in the data collection instrument.

Site interviews. DNV attempted to conduct telephone interviews with sampled sites to augment the construction documentation review. This approach was taken in lieu of on-site field visits as a response to the COVID-19 pandemic. DNV contacted building owners and/or design teams for all recruited sites, using email and telephone, but were unable to complete any site interviews. This was likely partially a result of poor contact information in the Dodge data and on construction drawings, where general corporate contact information was provided in lieu of individual site contacts, but it also aligned with response and recruitment challenges observed with both municipal building department recruiting and with residential homeowners.

5.2.4 Code compliance analysis and quality control

Following the data collection activities, the field engineer(s) assigned to each site finalized the data collection instrument and submitted the site for analysis and quality control (QC). The analysis and data aggregation was largely automated using Microsoft Excel. Senior DNV staff performed QC, conducting a detailed review of each site, examining the data collection instrument and the analysis output. Several manual compliance determinations were made for each site; these were all completed by the same QC reviewer for each category (envelope, HVAC, or lighting) for consistency. Where necessary, the QC reviewer consulted with the field engineers and construction documents to resolve any questions and provide feedback to improve the accuracy of future sites completed by each engineer.

5.3 Process evaluation

The DNV team initially planned to conduct a Delphi panel with code officials and the construction and design community, consisting of 15 code officials and design professionals, with three rounds of interviews. In November 2021, the DNV team and Rutgers discussed the recruitment challenges and agreed to replace the Delphi Panel with a single interview.

The DNV team recruited code officials in New Jersey 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 this study to help identify relevant firms for interview recruitment, prioritizing targets in locations with higher concentration of commercial new construction, such as metro New York and Philadelphia. Table 5-6 summarizes the interview targets and completed activities. DNV completed 15 individual interviews, and several interviewees had expertise in multiple engineering and architectural disciplines.

Table 5-6. Disposition summary of process evaluation interviews

Interviewee Type	Interview Completions	Number of individuals contacted
Code officials	7	42
Design professionals – Architect	1	20
Design professionals – Mechanical engineer	1	15
Design professionals – Electrical engineer	1	10
Construction professionals – General contractor	4	18
Construction professionals – Specialized trades	1	1
Total	**15**	**106**

The objective of the interviews was to collect the following information, and the key findings and results from the interviews are included in Section 6.4:

- 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

5.4 Estimation of energy code compliance for New Jersey commercial new construction under ASHRAE 90.1-2013

The ECC study assessed compliance with ASHRAE 90.1-2013 based on a review of observable prescriptive energy code requirements for each study site. DNV has used this approach in many prior compliance studies in other jurisdictions. While ASHRAE 90.1-2013 offers both prescriptive and performance compliance options, DNV assessed compliance based on the prescriptive approach for the following reasons:

- **Most 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.
- **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.

Assessing buildings using the prescriptive path may underestimate compliance, as buildings choosing the performance path may purposely elect to design/install worse-than-code components in one area and make up the difference in another. This is discussed further in the limitations of the compliance analysis, Section 5.4.4.

DNV evaluated compliance using two different methodologies: one developed originally by the Department of Energy (DOE) in conjunction with the Pacific Northwest National Laboratory (PNNL) (the PNNL method), and an enhanced methodology developed by DNV to more accurately capture the energy impact of observed building practices (the DNV method).

5.4.1 PNNL methodology

The 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). DNV adapted this methodology to ASHRAE 90.1-2013, incorporating any new and/or revised measures in the code. The 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 PNNL method, however, has limitations. ASHRAE 90.1-2013 allows for compliance trade-offs within the building envelope category. The PNNL method evaluates each individual provision as either "compliant" or "not compliant," generating a result inconsistent with code protocols. Also, the 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 PNNL method, since 25% of the walls did not meet the code. The PNNL method has no way of distinguishing between varying levels of non-compliance to assess partial compliance when evaluating energy impacts, which is a significant drawback.

5.4.2 DNV methodology

The DNV method leverages the same measures used in the PNNL method, with the key difference that it allows partial compliance for measures that do not fully meet the code. In the above grade wall insulation example, if insulation requirements were met by 75% of the walls at a building, this site would receive a compliance score of 75% for this measure. Due to partial compliance, the DNV method typically results in higher compliance scores than the PNNL method, but they are a better representation of how the building design aligns with code requirements.

5.4.2.1 Partial compliance

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

1. **Yes/no questions**. Many code provisions are assessed as either compliant or noncompliant under the PNNL method. The DNV team modified these questions to allow partial compliance values of one-third (recording a value of "somewhat compliant" on the data collection form) or two-thirds (a value of "mostly compliant" on the data collection form).
2. **Performance and efficiency requirements**. Where specific efficiency or performance levels were required by code, the DNV team calculated the ratio of actual performance to the code level and used this ratio to weight the score. This was commonly used for building envelope insulation levels, 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.

5.4.3 Weighting and estimation

DNV calculated weights for each project in the final sample by regarding the Stage 1 and Stage 2 inclusion probabilities as random, and accounting also for the eligibility rate. Projects were deemed ineligible due to several factors, though primarily this was due to projects permitted under a code not applicable to this study – either permitted too early (under the prior code) or too late (project had not yet filed for permit and was thus not known to the municipality). Overall, the study found that 9% sites in the Dodge data representing 7% of floorspace were ineligible for analysis, varying by building size stratum and multifamily designation, as shown in Table 5-7. 49% of requested sites representing 34% of floorspace had indeterminate eligibility, primarily based on municipality non-response and claimed OPRA exemptions. During weighting to adjust the population to account for ineligible sites, we assumed that the rate of ineligibility seen in our sample for a particular stratum would apply to all other buildings in that stratum.

Table 5-7. Site eligibility results

Stratum	Target	Total Sites Requested	Total Eligible	Total Ineligible	Total Indeterminate	Total QC	Eligibility Rate (all sites)	Eligibility Rate (w/o indeterminates)
1. Non-Multifamily - Non-Participant - ≤ 25,000	7	164	68	8	88	164	41%	89%

2. Non-Multifamily - Non-Participant - 25,000 - 100,000	8	37	16	2	19	37	43%	89%
3. Non-Multifamily - Non-Participant - ≥ 100,000	14	48	32	2	14	48	67%	94%
4. Multifamily - Non-Participant - ≤ 25,000	7	24	15	1	8	24	63%	94%
5. Multifamily - Non-Participant - > 25,000	10	53	22	2	29	53	42%	92%
6. Participant - ≤ 25,000	6	25	9	0	16	25	36%	100%
7. Participant - > 25,000	3	6	3	1	2	6	50%	75%
TOTALS:	**55**	**357**	**165**	**16**	**176**	**357**	**46%**	**91%**

First, the team estimated the number of eligible projects in project stratum j as follows:

$M_{Tj} = \Sigma_k \, r_{kj} M_{kj}^*$

where,

M_{Tj} = estimated total eligible projects in project stratum j
M_{kj}^*= total projects in project stratum j, municipality stratum k in the sampling frame
r_{kj} = fraction of screened projects from project stratum j, municipality stratum k that were eligible (excluding indeterminate)

For a project in project stratum j and municipality stratum k, the following calculations apply:

The Stage 1 inclusion probability is:

$p_{1k} = n_k/N_k$

where n_k and N_k, respectively, are the number of cooperating municipalities and the total number of municipalities in the sample frame, from municipality stratum k.

The Stage 2 inclusion probability, conditional on the municipality being in the cooperating sample, is:

$p_{2j} = m_{Tj}/M_{Tj}$

where m_{Tj} is the total number of projects in the sample and M_{Tj} is the total estimated number of eligible projects in the population from project stratum j, as calculated above.

The overall inclusion probability is the product of the Stage 1 and Stage 2 inclusion probabilities:

$p_{kj} = p1_k \, p2_j$

The sample expansion weight is the multiplicative inverse of the overall inclusion probability:

$w_{kj} = 1/p_{kj}$.

Weighted average compliance

Once the case weights were calculated as indicated, the team calculated various weighted average compliance metrics in terms of weighted relevant square footage – that is, weighting each site's observed value by the product of the case weight and the relevant square footage.

$$y_{POP} = \Sigma_j (w_j\, RSF_j\, y_j) / \Sigma_j (w_j\, RSF_j)$$

where,

w_j = case weight for site j
y_j = value observed for site j
RSF_j = relevant square footage for quantity y at site j

The resulting population estimate y_{POP} represents the average value of y across all relevant square footage in the new construction population.

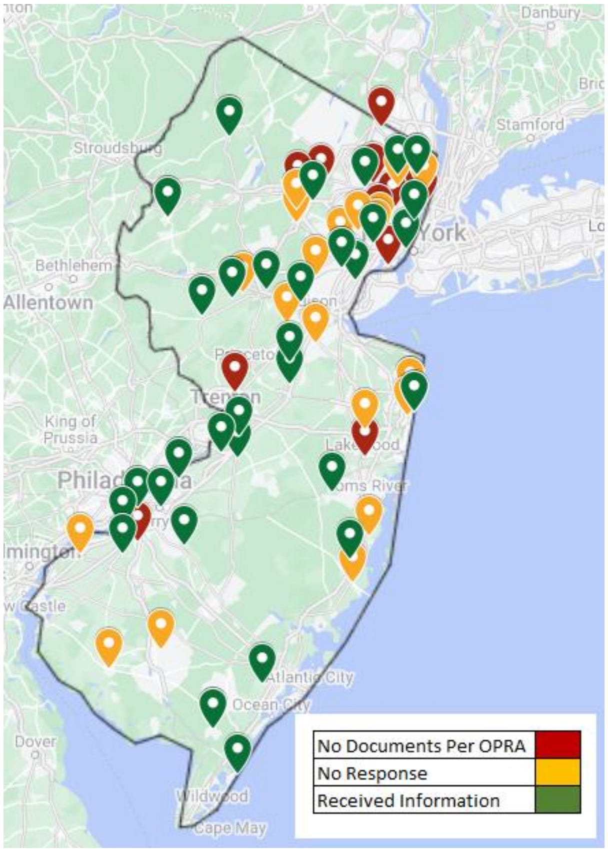
The relevant square footage depends on the parameter y. For interior lighting, it is all interior floorspace. For HVAC, it is heated or cooled floorspace. For envelope characteristics, it is the wall, roof, or window area.

5.4.4 Limitations of the compliance analysis

While this analysis produces statewide compliance estimates for New Jersey commercial new construction, it is important to acknowledge several potential limitations to the methodology and their potential implications:

- **Non-response bias**. Non-response bias is a common challenge in code compliance studies. Municipalities may decline to provide documentation for some or all of the buildings requested in their jurisdiction, and the resulting sample may not reflect the actual distribution of building types in the recruited jurisdictions and/or state. Specifically, in the ECC study, municipalities did not provide requested documentation for several reasons, including OPRA exemptions, inability to locate requested documents in their files, and not responding at all to DNV requests. This non-response may affect the distribution of building types and sizes reflected in the population. DNV examined the municipalities that provided documentation, those that did not respond, and those that cited OPRA or other exemptions but did not identify any distinct trends that may have influenced municipality responses. Figure 5-2 shows a map of all the municipalities where DNV requested data and the color-coded results; municipalities where DNV received documentation are shown in green, municipalities with no response in yellow, and municipalities refused citing OPRA exemptions in red.

Figure 5-2. ECC study requested municipalities



- **Prescriptive compliance does not assess code tradeoffs**. While the majority of design teams choose the prescriptive path for code compliance, and most prescriptive requirements apply even to buildings pursuing the performance path, for performance path compliance the code does allow tradeoffs where worse-than-code performance for one measure or category is offset by better-than-code performance in another. Thus, if buildings pursued the performance path, it's possible that the prescriptive assessment may underestimate compliance. However, given the high compliance results, this is not likely a significant issue. The ECC study evaluated prescriptive compliance for each code measure, so while it may not reflect the actual energy impact of design choices for buildings pursuing the performance path, it does provide insight into how well each measure is met by design teams and identifies opportunities for measure-specific improvements.
- **The ECC study does not assess measure installation or building operations**. By design, this analysis reviewed construction documentation to assess how well the building design and documentation meet the requirements of the energy code. The study does not assess installation of equipment or building components and it does not assess building operations. Many requirements, in particular lighting and mechanical controls, require proper setup and commissioning to recognize the energy performance benefits of the design. For example, the code requires that exterior lighting systems be equipped with either an astronomical timeclock or a photocell (or both) to control operations, but if these are not configured properly, they will not effectively control the exterior lighting. This study assesses the presence of these requirements in the design documentation provided, but cannot assess how well buildings and systems are commissioned and thus operated

5.5 Energy modeling

The DNV team assessed energy savings from improved code compliance by leveraging the commercial prototype building models developed by the United States Department of Energy (DOE). These prototype building models were developed to estimate energy impacts from proposed code changes and give a detailed picture of the energy usage of typical buildings built to multiple model energy codes, including New Jersey's commercial energy code assessed in the ECC study, ASHRAE Standard 90.1-2013. DNV ran these models with the EnergyPlus whole building energy simulation program using New Jersey climate data to estimate the energy usage of fully code-compliant commercial buildings. Next, we adjusted the inputs of the prototypes to match the actual, representative construction characteristics of non-code-compliant buildings in New Jersey found from the data collection. The difference in usage between the code-compliant prototype buildings and the adjusted buildings represents the available savings from code compliance.

5.5.1 Building prototype selection

The DOE developed prototype models for 17 different commercial building types. Table 5-8 summarizes the building prototype models available.

Table 5-8. DOE prototype building models

DOE prototype models		
Large office	Primary school	Outpatient health care
Medium office	Secondary school	Small hotel
Small office	Supermarket	Large hotel
Warehouse	Quick-service restaurant	Midrise apartment
Stand-alone retail	Full-service restaurant	Highrise apartment
Strip mall	Hospital	

DNV selected the building types to model based on the best available data among the sample population collected during data collection. A DOE prototype was assigned to each site in our sample based on the building type that best matched the occupancy and construction characteristics.

Table 5-9. DOE prototype model selection

Building Type	Site Count	SF	%SF	DOE Prototype Model
Warehouse	10	3,015,752	57.90%	Warehouse
Multifamily (midrise)	13	1,184,622	22.74%	Midrise apartment
Multifamily (highrise)	3	193,312	3.71%	Highrise apartment
Food Service	4	21,196	0.41%	Full-service restaurant
Retail	9	343,601	6.60%	Stand-alone retail
Health Care	4	152,832	2.93%	Outpatient health care
Other	4	297,095	5.70%	N/A
TOTAL	**47**	**5,208,410**	**100%**	

5.5.2 Non-compliant building characteristics

DNV developed non-compliant building characteristics for each of the six building types included in this modeling exercise. To do this, DNV calculated the percent better or worse than code for the measures with the largest expected energy impact. The measures assessed for the model adjustments included envelope wall insulation, roof insulation, slap edge/foundation insulation, window U-value, lighting LPD, solar heat gain coefficient, mechanical cooling efficiency, and mechanical equipment heating efficiency. These characteristics were averaged for each building type and weighted by individual site square footage. Each characteristic is a percentage of a code compliance value in the code compliant prototype model, with 100% equal to code, greater than 100% better than code, and less than 100% worse than the code value.

Table 5-10. Non-compliant model parameter characteristics

DOE Prototype Model	Exterior walls	Roof	Window thermal property	Window SHGC	Skylight U-factor	Foundation	Heating equipment efficiency	Cooling equipment efficiency	Interior LPD
Warehouse	115%	88%	107%	95%	n.d.	41%	122%	104%	159%
Stand-alone Retail	69%	46%	n.d.	n.d.	n.d.	66%	102%	100%	166%
Full-service restaurant	107%	82%	62%	46%	n.d.	85%	107%	100%	127%
Outpatient health care	109%	100%	n.d.	n.d.	n.d.	67%	115%	101%	136%
Midrise apartment	83%	82%	39%	n.d.	n.d.	62%	118%	103%	143%
Highrise apartment	94%	82%	97%	101%	n.d.	0%	124%	100%	121%

DNV used these characteristics to adjust the prototype code-compliant building models. We calculated non-compliant characteristics by multiplying or dividing, depending on the parameter, an existing model input by the percentage better or worse than code. Examples include multiplying code-compliant insulation thermal resistance inputs in the model by the non-compliant parameter characteristics to get the existing building value. Similarly, for inputs rated using conductivity in the model, the value would be divided by the non-compliant characteristic percentages. The non-compliant adjusted models only modeled parameters that were found to be worse than code to assess the potential savings associated with bringing these up to code. Our building characteristic analysis showed several parameters with better than code values. Including these in the non-compliant model would limit our ability to assess non-compliant energy impacts.

5.5.3 Estimating new construction square footage

The DNV team estimated an average annual new construction square footage based on three years of historical data from the New Jersey Department of Community Affairs (DCA) new construction permitting data.[55] We averaged the new construction square footage for various building types for the years starting in 2018 through 2020 to match the compliance study period. This data was then aligned to the DOE prototype building types.[56] The three-year average annual new construction square footage is 57,002,111, while the modeled building types account for 82% of this area. Table 5-11 shows the projected annual new construction square footage by building type.

[55] https://www.nj.gov/dca/divisions/codes/reporter/building_permits.html#6

[56] The new construction data included a single multifamily value and did not differentiate between midrise and highrise buildings. DNV estimated the distribution of square footage between midrise and highrise multifamily buildings by reviewing the New Jersey Multifamily Baseline Study (https://njcleanenergy.com/files/file/Library/NJ_Multifamily_EE_Baseline_Final%20Report_20190926_docx.pdf) along with the weighted population numbers from this ECC study. The resulting distribution for multifamily square footage used in this analysis was 51% of total multifamily square footage for midrise and 49% of total multifamily square footage for highrise.

Table 5-11. Average annual new construction area for modeling

Building Type	3-year Average New Construction Square Footage	% of Total SF
Warehouse	19,014,677	33%
Retail	1,691,495	3%
Food Service	623,268	1%
Health Care	1,768,068	3%
Midrise Multifamily	12,177,192	21%
Highrise Multifamily	11,699,655	21%
TOTAL	**35,274,701**	**82%**

All modeling was done using Climate Zone 4A. Initially, we modeled all baseline code-compliant models using both climate zones, 4A and 5A. However, new construction square footage data was not separated by climate zone, we modeled all non-compliant buildings and calculated energy savings based on Climate Zone 4A. Based on the baseline code-compliant models run in both climate zones, building energy consumption in Climate Zone 4A is consistently lower than Climate Zone 5A by about 9% on average across the building types modeled. DNV chose to use this simplification to produce a conservative estimate and not overstate the potential savings.

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6 COMMERCIAL RESULTS

This section provides the commercial code compliance results for the ECC study. This includes a discussion of overall compliance results, examination of compliance across several stratifications, and measure-level observations for each of the three primary code categories: envelope, mechanical systems (HVAC), and lighting.

6.1 Overall compliance assessment for ASHRAE 90.1-2013

This section contains the results from the ECC study. The initial results presented are the weighted compliance scores aggregated for New Jersey using both the PNNL methodology as well as the DNV method (see Section 5.4 for discussion of methodologies). Following overall results, this section examines compliance across several stratifications, including building size, building type, NJ ECB program participation, and energy code category.

Table 6-1 presents the overall statewide compliance rates for New Jersey commercial new construction under ASHRAE 90.1-2013 using both the PNNL and the DNV methodologies, along with upper and lower bounds at 90% confidence. The overall compliance rate is estimated to be 87% using the PNNL methodology and 94% using the DNV methodology.

Table 6-1. Overall commercial compliance results

Compliance Method	Compliance %	Lower bound @ 90% confidence	Upper bound @ 90% confidence
DNV	94%	92%	96%
PNNL	87%	84%	90%

6.1.1 Benchmarking ECC study compliance results

DNV conducted a literature review of prior commercial compliance studies to benchmark the ECC study compliance results. While these other studies can provide some reference and context for the ECC study, it is important to recognize that these studies leveraged a variety of different methodologies and code versions to develop compliance estimates. Some key considerations when reviewing this benchmarking are:

- **Code basis**. Prior commercial compliance studies conducted by DNV and others have generally been based on the IECC code, which while similar, is a different code from ASHRAE 90.1, the code in effect in New Jersey.
- **Code version**. Typically, commercial compliance studies assess compliance with the code in effect during the study period. Different states adopt codes at different times, and many states also amend the model codes to either increase or decrease stringency of specific measures. While the code has generally become more stringent over time, the increases have not been linear. Thus, it is difficult to directly compare compliance results across states and across code versions.
- **Study timing in the context of code cycles.** The timing of when in a code cycle a compliance study was conducted can affect the compliance results. Since new versions of the code typically are more stringent than the prior version, it is common to see lower compliance early in a code cycle, and then higher compliance throughout the cycle as the building and enforcement communities become more familiar with the requirements of the new code version. While some of the benchmark studies have been able to identify the timing of the study within the code cycle, others do not provide this detail.
- **Different compliance methods and definitions**. The studies in Table 6-2 leverage a variety of different compliance methods and definitions. This table includes several studies conducted by the DNV team that have similar methods to the ECC study, but other study methodologies such as COMcheck analysis and Delphi panels have also been

employed and are more difficult to directly compare. The DNV method is included where the methodology is similar, and PNNL and other compliance results are included together.

- **Shift away from compliance percentage and toward savings opportunity and Industry Standard Practice**. Several states and the Department of Energy (DOE) have shifted their focus away from developing an overall statewide compliance estimate and focused more on a subset of code measures to assess industry standard practices (ISP) and lost savings opportunities at the measure level. While some states continue to pursue statewide compliance results, future studies are more likely to focus on specific measures and ISP. It's important to note that Rutgers and the NJBPU have added an ISP analysis that leverages the ECC study data and will be delivered separately from this ECC study report.

Table 6-2 presents a comparison of the ECC study results to compliance studies completed in other jurisdictions. With the caveats listed above, compliance in New Jersey is similar to many of the other jurisdictions. Most of the other studies are several years old and most reflect prior code versions, but when thinking of compliance in the context of the code in place at the time of the study, results are similar to other jurisdictions. Future efforts to assess ISP and measure-specific analysis could be an opportunity for further future benchmarking.

Table 6-2. Benchmarking ECC study commercial compliance results with other jurisdictions

Jurisdiction	Year published	Applicable code(s)	DNV compliance	PNNL or other compliance result	Compliance approach
New Jersey (ECC study)	2022	ASHRAE 90.1-2013	94%	87%	Plan review
Connecticut	2022	IECC 2015	n/a	in progress	Plan review, COMcheck analysis, results expected in 2022
Massachusetts	2021	IECC 2015	n/a	n/a	No overall compliance, focus on Industry Standard Practice and select measure compliance
DOE - various	2021	various	n/a	n/a	No overall compliance, DOE code study focused on lost energy savings by measure,
New York	2020	2016 ECCNYS (based on IECC 2015 and ASHRAE 90.1-2013)	n/a	83%	Delphi panel to assess compliance
Massachusetts	2018	IECC 2012	94%	88%	Plan review, targeted site visits
Rhode Island	2016	IECC 2012	90%	86%	Plan review, targeted site visits
Connecticut	2015	IECC 2006 & IECC 2009	n/a	75%	Plan review, COMcheck analysis
New York	2015	2010 ECCNYS (based on IECC 2009)	n/a	74%	Delphi panel to assess compliance
Massachusetts	2015	IECC 2009	94%	85%	Plan review, some site visits
Rhode Island	2013	IECC 2009	n/a	70%	Plan review, some site visits
Massachusetts	2012	IECC 2009	n/a	76%	Plan review, some site visits
Massachusetts	2012	IECC 2006	n/a	82%	Plan review, some site visits
New York	2012	ASHRAE 90.1-2004/2007	n/a	85%	Plan review, some site visits

6.1.2 Interpretation of compliance scores

For context regarding these reports, it is important to define what is meant by compliance levels. 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 on an average basis, commercial buildings in New Jersey meet 94% of the energy code requirements when weighted by potential energy impact as outlined in the DNV methodology (Section 5.4.2). This score is related to, but not a perfect comparison to the building energy consumption because it does not reflect performance modeling and compliance does not assess provisions better than code This interpretation of compliance is consistent with the results of the prior compliance studies throughout the country.

Additionally, since the ECC study was conducted by analyzing buildings permitted during the last two years of the ASHRAE 90.1-2013 code cycle, these results likely reflect the high end of compliance with this code. Typically, when a new code version is adopted, compliance drops initially and then increases over time as the building and enforcement communities become more familiar with the code changes.

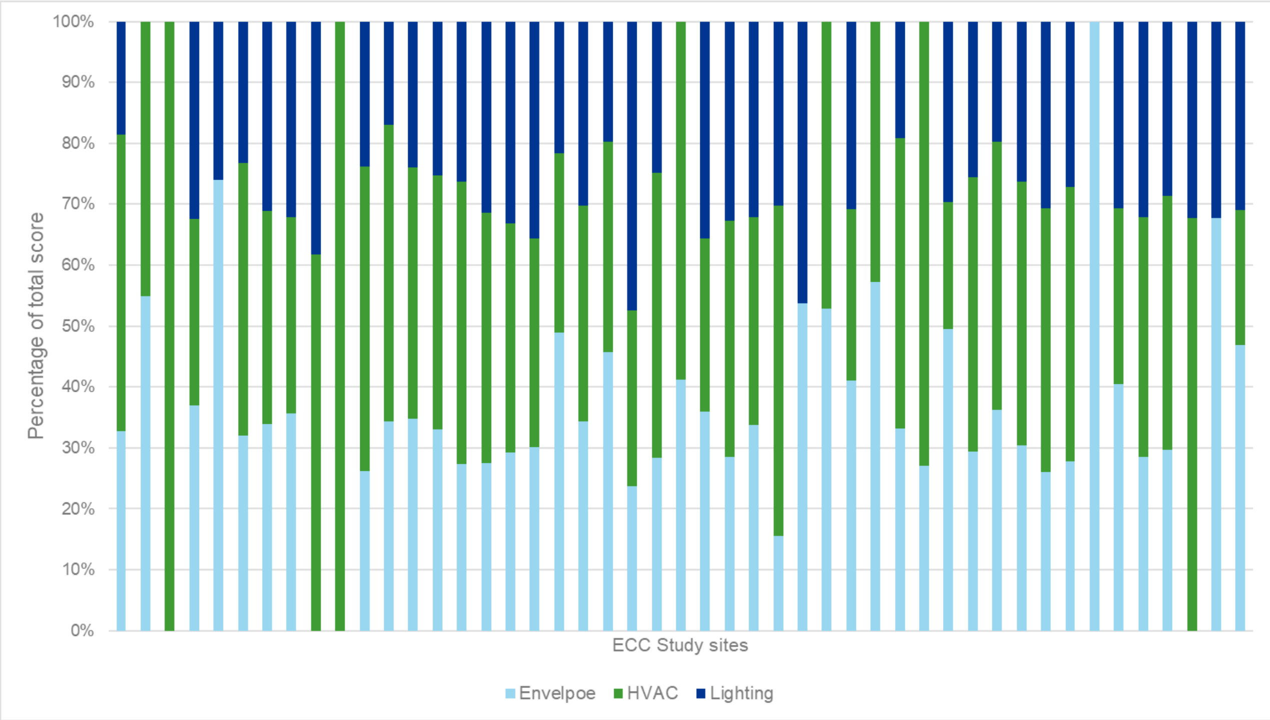
6.1.2.1 Site variability

The primary data collection method used by DNV to assess compliance for the ECC study was review of construction documentation. While the team received at least partial construction documents for all 47 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 completeness and detail of the documentation provided. This variability is inherent in all document review-based compliance assessments, and the discussion and figures below provide additional insight into the composition of the compliance scores.

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.

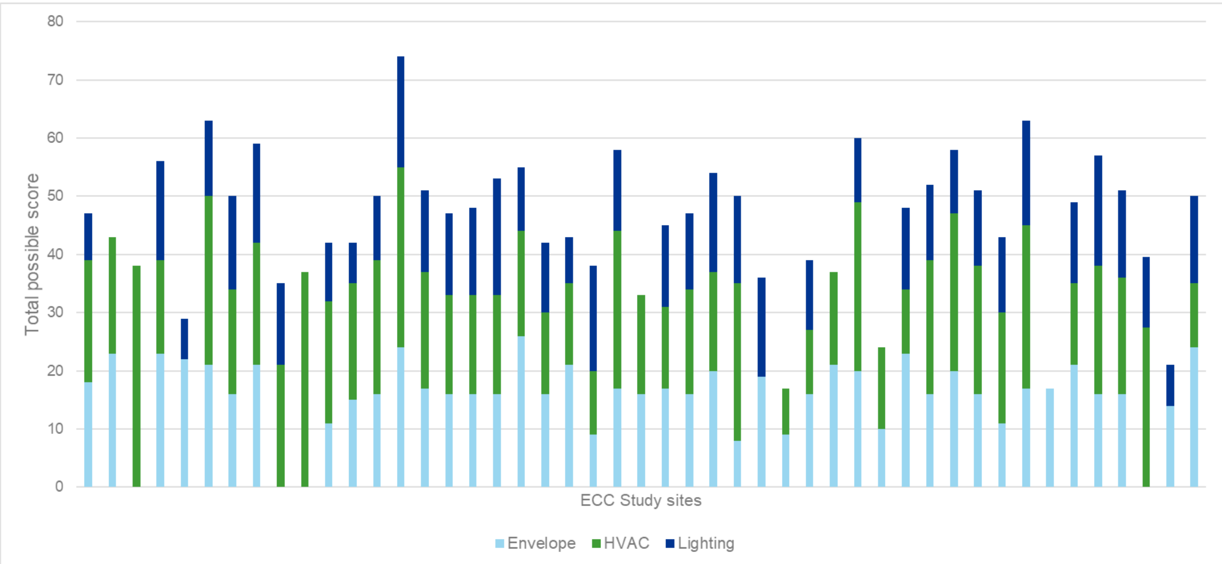
The variation in site composition is best shown graphically when comparing the contributions of each major code category—envelope, mechanical (HVAC), and lighting provisions—to the total score. The figures below show the contributions using the DNV compliance methodology; while the compliance scores 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 39% of the compliance scores result from envelope provisions, 44% from HVAC provisions, and 29% from lighting. Figure 6-1 shows the variability of compliance scores across the three code components.

Figure 6-1. DNV method compliance score variability



While Figure 6-1 shows the distribution of available scores across the energy code categories, the number of observable and applicable code provisions at each site ranged greatly based on the specific features of each site and the information available to the field engineers. Figure 6-2 shows the total number of compliance points possible at each of the 47 ECC study sites; while each site could receive a maximum compliance score of 100%, the total possible points varied based on the observable provisions.

Figure 6-2. DNV method total possible compliance score by site



6.2 Compliance stratifications

This section provides the estimated compliance rates for select stratifications of the sampled sites.

6.2.1 Compliance by size

Table 6-3 shows the compliance results across the sample strata. Overall compliance was fairly consistent across strata, though the highest compliance was observed for small Multifamily non-participants (Stratum 4).

Table 6-3. Commercial compliance results by stratum (DNV method)

Stratum	Site count	DNV Compliance	Lower bound @ 90% confidence	Upper bound @ 90% confidence
1. Non-Multifamily - Non-Participant - ≤ 25,000	10	94%	93%	95%
2. Non-Multifamily - Non-Participant - 25,000 - 100,000	6	94%	91%	97%
3. Non-Multifamily - Non-Participant - ≥ 100,000	11	93%	90%	96%
4. Multifamily - Non-Participant - ≤ 25,000	4	97%	94%	99%
5. Multifamily - Non-Participant - > 25,000	10	93%	89%	98%
6. Participant - ≤ 25,000	4	93%	87%	100%
7. Participant - > 25,000	2	93%	93%	94%

6.2.2 Compliance by program participation

Table 6-4 shows the compliance results stratified by participation. Overall program participation in commercial new construction programs in New Jersey is limited, and as such, only six participant sites were recruited for the study. Compliance was not statistically different between participants and non-participants. One potential explanation is that the participating sites were not full building participants receiving program support for the entire building design, but rather the participants received measure-specific program support. For the participants, three sites received performance lighting incentives, two received HVAC incentives, and three received incentives for food service equipment, which were not evaluated as part of the study. Several of the six sites received incentives for multiple measures.

Table 6-4. Commercial compliance by participation (DNV method)

Participation	Site count	DNV Compliance	Lower bound @ 90% confidence	Upper bound @ 90% confidence
Participants	6	94%	88%	98%
Non-participants	41	93%	92%	96%

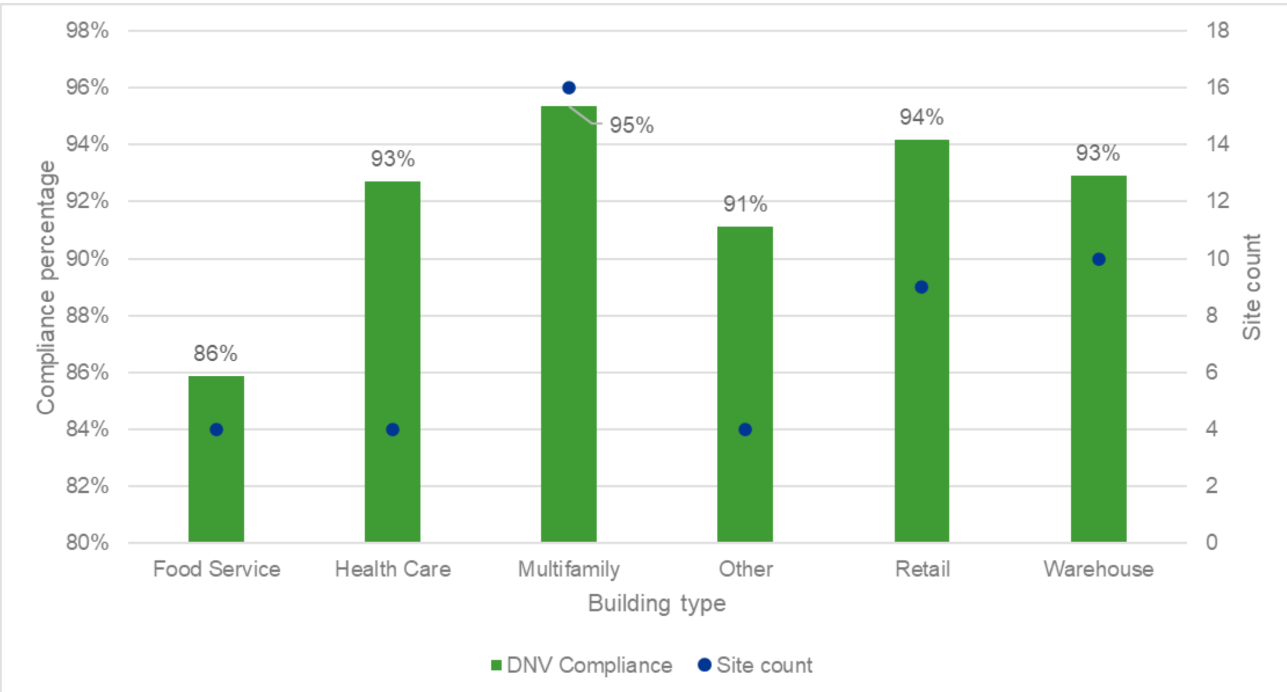
6.2.3 Compliance by building type

Table 6-5 and Figure 6-3 provide compliance results by building type. As discussed in the sampling methodology (Section 5.1), due to the large volume of multifamily construction in the population, separate strata were created explicitly for Multifamily buildings. While no additional stratification by building type was included in the sample, these results reflect the consolidated building types represented by the sample. Note that “Other” includes four building types with one building each (school, hospital, hotel, and industrial). These results show that Multifamily sites had the highest compliance, while food service buildings (dine-in and fast-food restaurants) had the lowest compliance.

Table 6-5. Commercial compliance by building type (DNV method)

Building category	Site count	DNV Compliance	Lower bound @ 90% confidence	Upper bound @ 90% confidence
Envelope	43	91%	90%	93%
HVAC	43	95%	91%	98%
Lighting	39	96%	92%	99%

Figure 6-3. Commercial compliance by building type (DNV method)



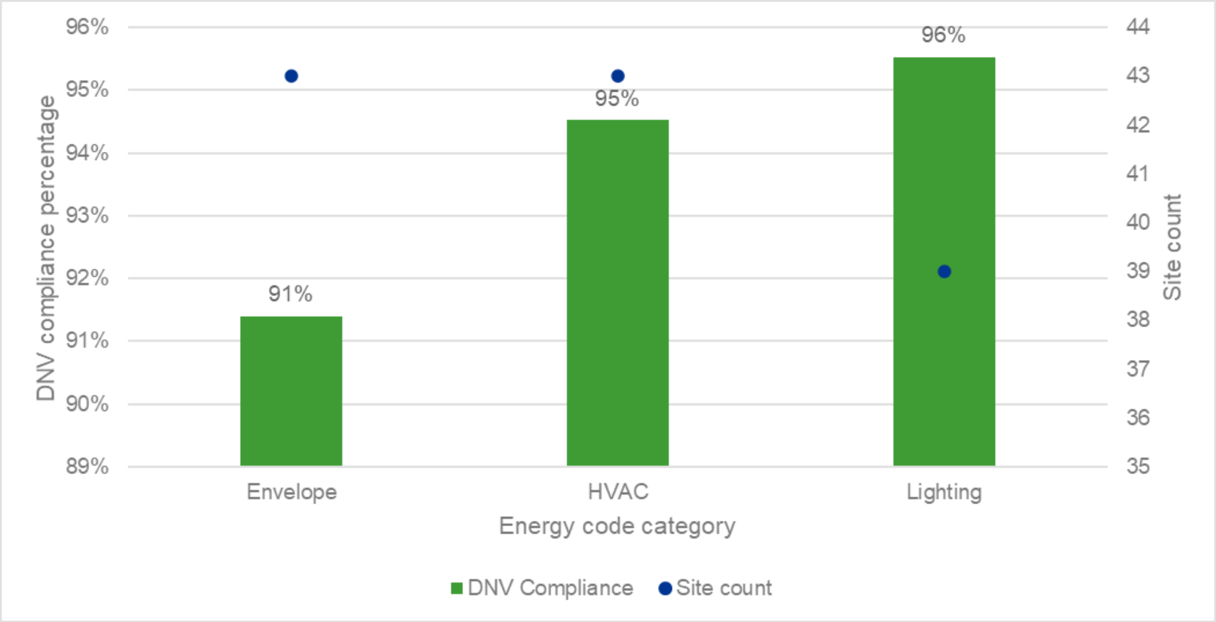
6.2.4 Compliance by energy code category

Table 6-6 contains the compliance results for the primary energy code categories: envelope, mechanical systems (HVAC), and lighting systems, along with upper and lower bounds at 90% confidence. These results are also shown graphically in Figure 6-4. Overall, the building envelope had the lowest compliance, while compliance for HVAC and lighting was similar.

Table 6-6. Commercial compliance by energy code category (DNV method)

Building category	Site count	DNV Compliance	Lower bound @ 90% confidence	Upper bound @ 90% confidence
Building envelope	43	91%	90%	93%
HVAC	43	95%	91%	98%
Lighting	39	96%	92%	99%

Figure 6-4. Commercial compliance by energy code category (DNV method)



The following sections contain additional measure-level observations for each of the three code categories.

6.2.4.1 Building envelope

This section provides additional details on the code compliance results for building envelope measures reviewed during the ECC study. Table 6-7 shows select envelope measures, identifying for each measure the number of sites where details were verifiable, the percentage of square footage that this represents, and the unweighted compliance value (DNV method).

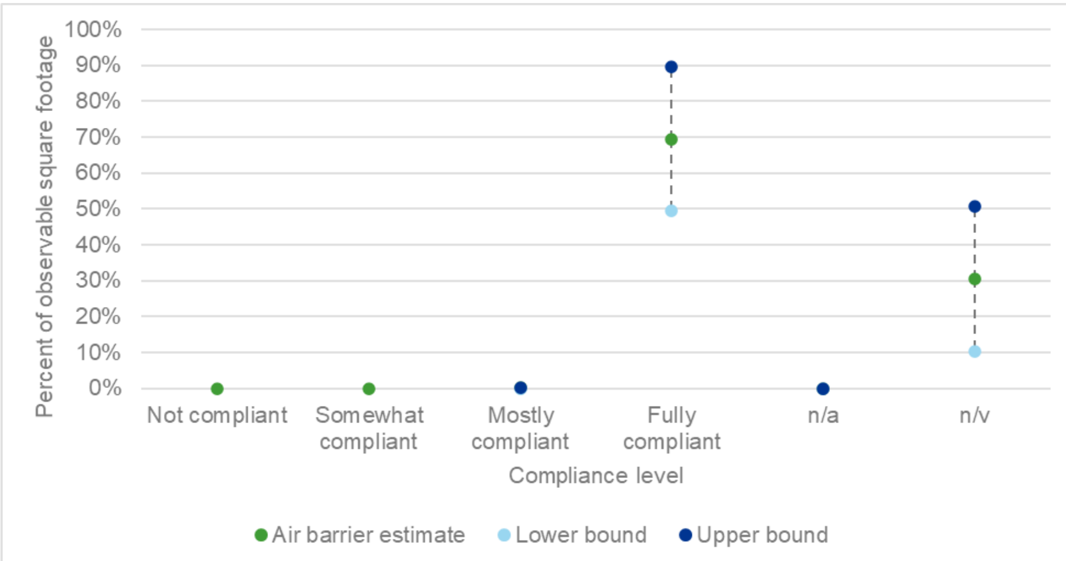
Table 6-7. Commercial building envelope measure-level compliance

Code measure	Number of sites verifiable (includes not applicable)	Estimated % of new construction represented*	DNV average compliance (unweighted)
Air barrier	37	70%	99%
Slab-edge insulation	39	84%	69%
Above grade wall insulation	43	100%	87%
Roof insulation	43	100%	81%
Window u-factor	17	59%	97%
Vestibules	36	81%	96%

The bullets and figures below provide additional insights into compliance for each of these measures. In the figures, the green circle shows the estimate of observable square footage that meets each compliance level, and the light and dark blue circles represent the lower and upper bounds at 90% confidence.

- **Air barrier compliance**. Air barriers were verifiable for 37 of the 43 sites, representing approximately 70% of commercial new construction. Where verifiable, the air barrier details were found to be well-defined on the construction documents, identifying barrier locations and its continuity throughout any joints and penetrations in the building envelope. However, as discussed in Section 5.4.4, this study cannot assess the quality of installation, which is particularly important for air barriers. Rather, this identifies that the air barrier is commonly explicitly called out on the construction drawings.

Figure 6-5. Air barrier compliance estimate



- **Slab-edge insulation**. The code requires that for slab-on-grade construction, insulation is provided along the perimeter of the slab. While the amount (R-value) of insulation and the depth varies by climate zone and building type, in all cases the code requires a thermal break between the slab and the exterior. Figure 6-6 shows the compliance distribution for slab edge insulation R-value and Figure 6-7 shows insulation depth. In many instances, the R-value of installed insulation was below the code requirements, with only 16% of observable square footage fully compliant. There was usually some insulation, but not as much as required. Conversely, compliance was high for slab edge insulation depth. This may represent an opportunity for code training targeting changes in recent code versions that may have increased the insulation requirements.

Figure 6-6. Slab-edge insulation R-value compliance estimate

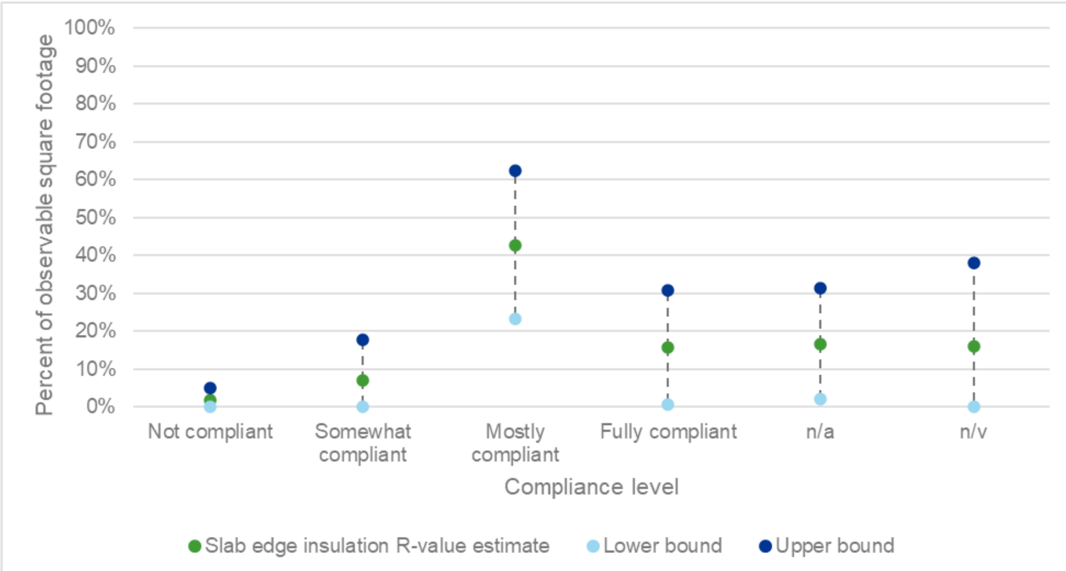
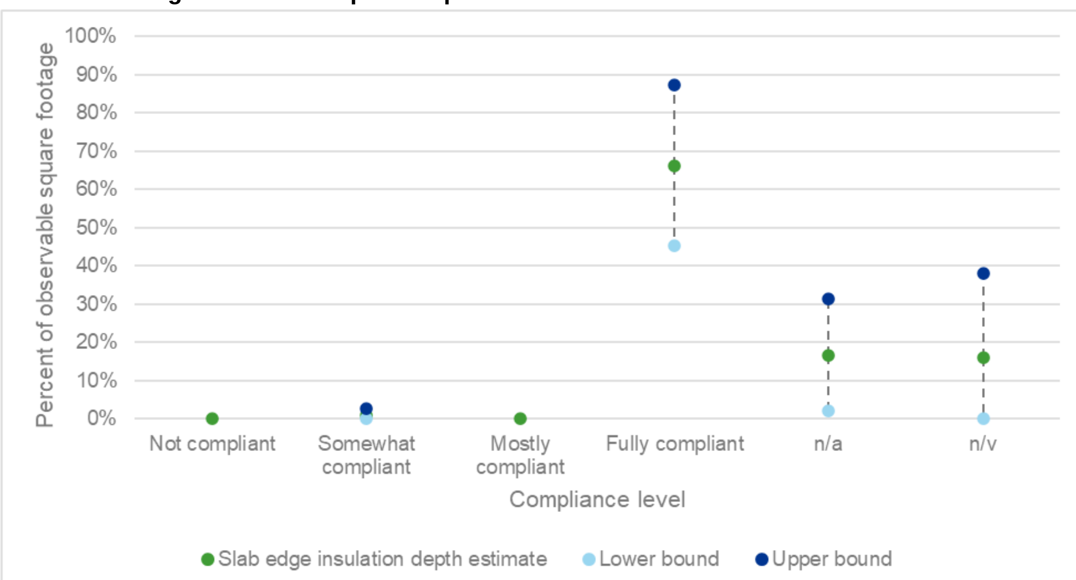
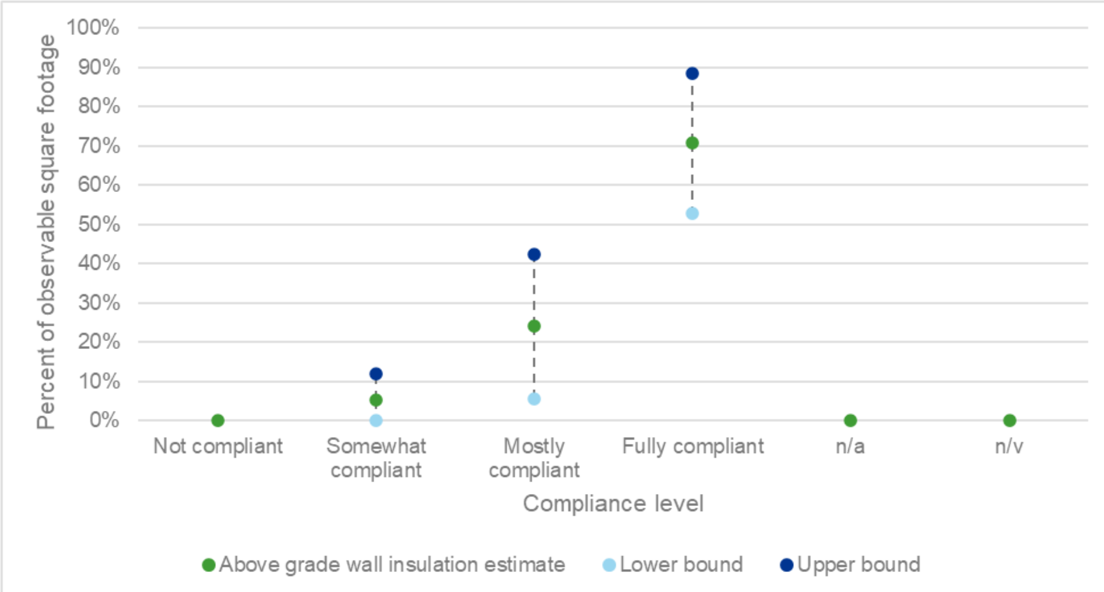


Figure 6-7. Slab-edge insulation depth compliance estimate



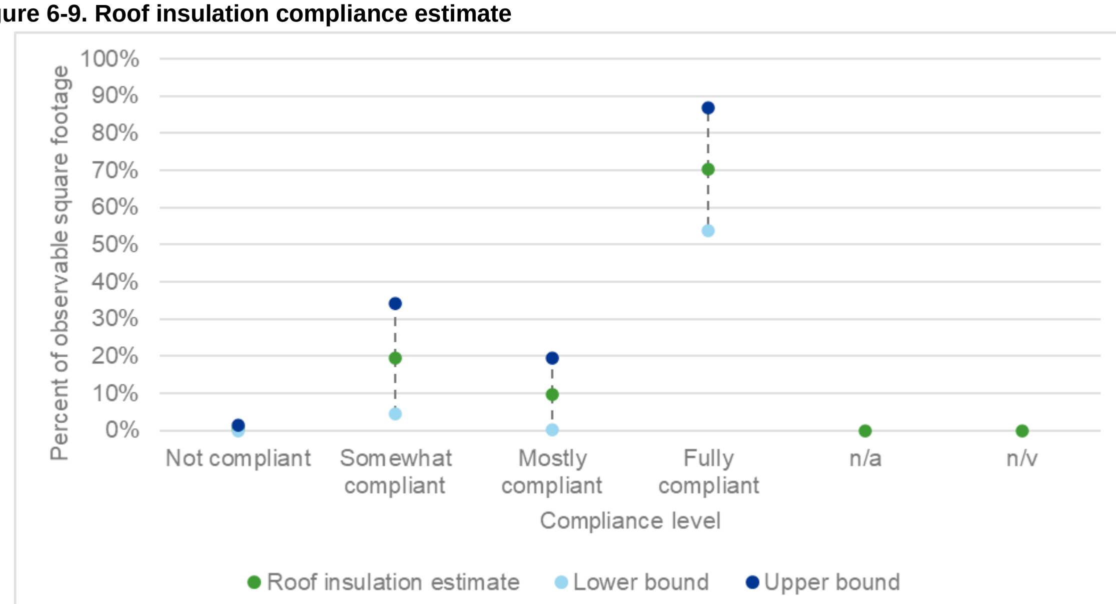
- **Above grade wall insulation**. Above grade wall details were observable for all ECC study sites where envelope details were received. Figure 6-8 shows the distribution of compliance. About 70% of observable square footage was fully compliant, but there were many sites where insulation levels were lower than code requirements. These commonly included mass walls and steel-framed walls that did not meet code-required levels for continuous insulation.

Figure 6-8. Above grade wall insulation compliance estimate



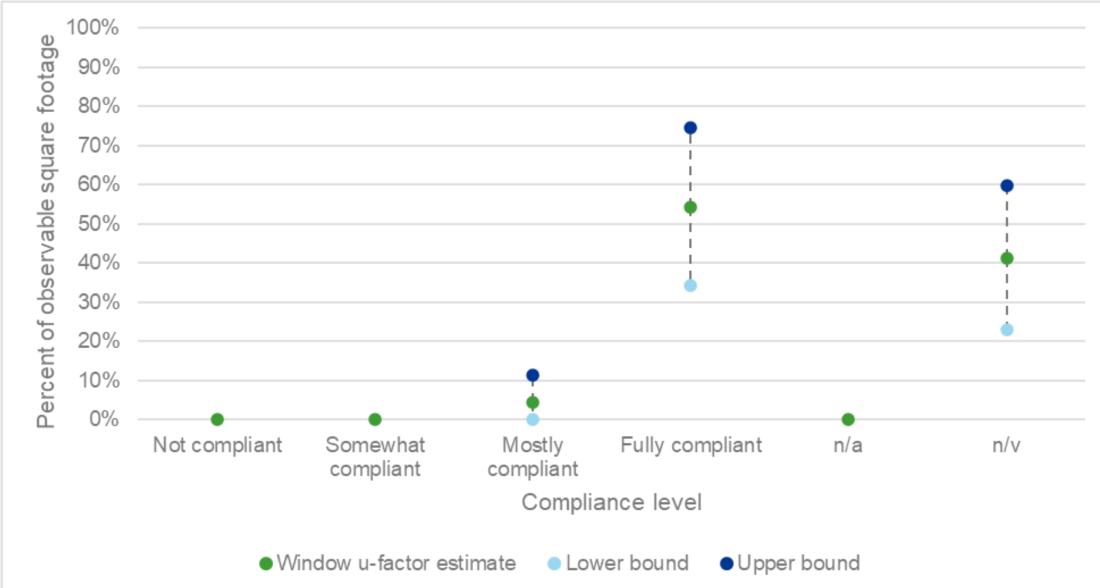
- **Roof insulation** details were provided for all ECC study sites where envelope details were received. Similar to above grade walls, compliance was mixed; all sites have some roof insulation, but in some cases the amount (R-value) included on the construction drawings did not meet the code required levels. Figure 6-9 shows the compliance distribution: about 70% fully compliant, with 20% somewhat compliant and 10% mostly compliant.

Figure 6-9. Roof insulation compliance estimate



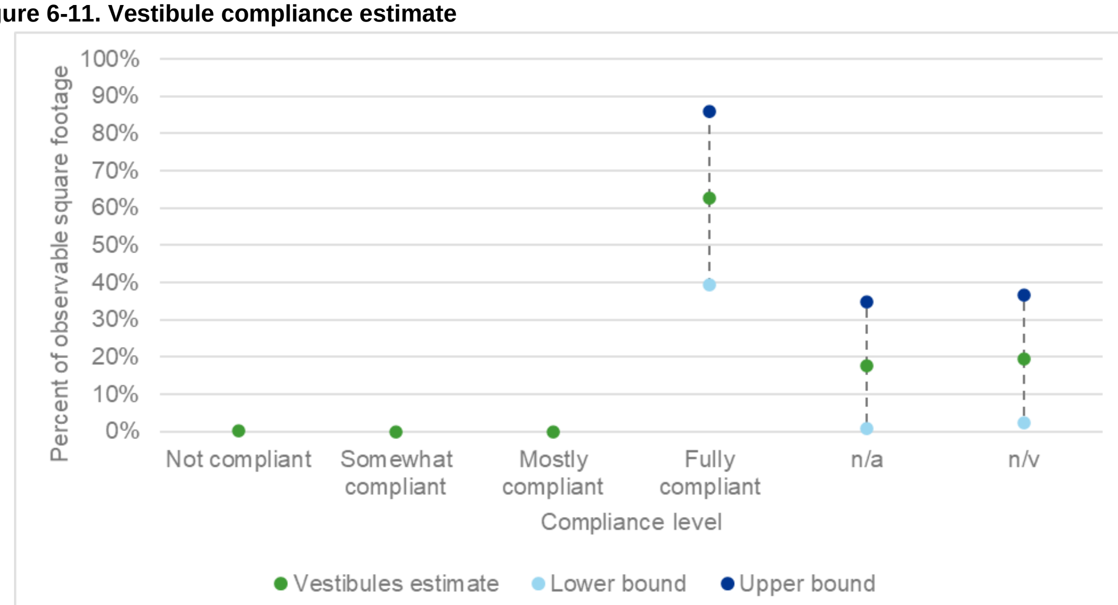
- **Window U-factor.** Figure 6-10 shows the window U-factor compliance results. While most observable windows were found to be compliant, windows were not well-documented on drawings, with details observable at only 17 sites representing 59% of square footage.

Figure 6-10. Window U-factor compliance estimate



- **Vestibules.** Vestibules are required for the primary entrances in most spaces in commercial buildings. Overall, vestibules were found to be in compliance where observable. Figure 6-11 displays the compliance for this measure; this could not be observed for 19% of the square footage, and was determined to not be applicable for 18% of square footage, primarily due to small entry spaces not requiring vestibules.

Figure 6-11. Vestibule compliance estimate



6.2.4.2 Mechanical Systems (HVAC)

This section provides additional details on the compliance results for the mechanical system (HVAC) measures reviewed during the ECC study. Table 6-8 shows select envelope measures, identifying for each measure the number of sites where details were verifiable, the percentage of square footage that this represents, and the unweighted compliance value (DNV method).

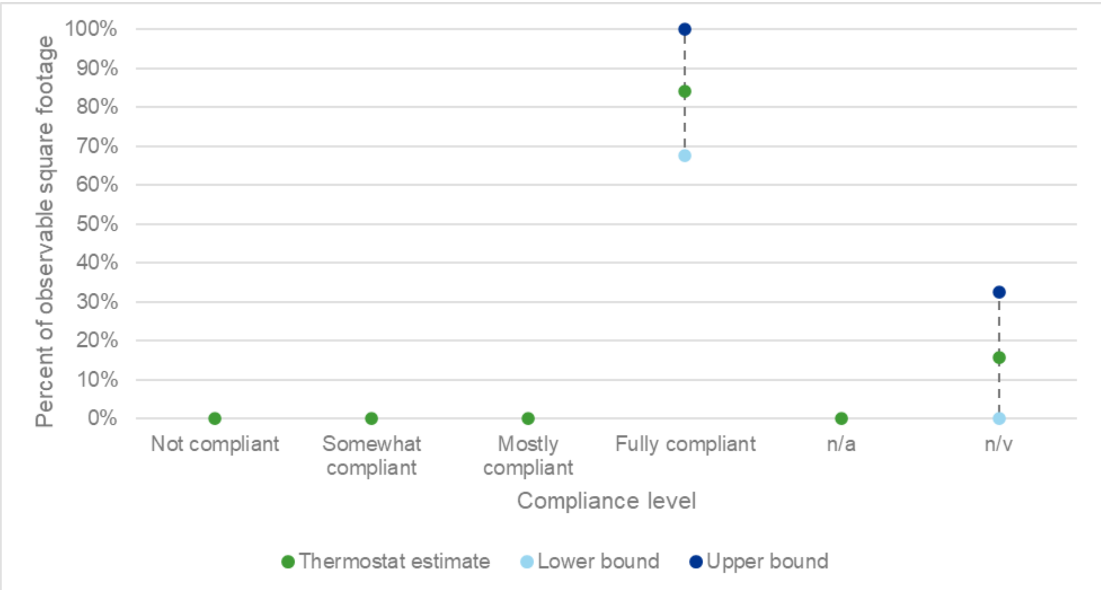
Table 6-8. Commercial HVAC measure-level compliance

Code measure	Number of sites verifiable	Estimated % of new construction represented*	DNV average compliance (unweighted)
Thermostats	39	84%	100%
Heating equipment efficiency	43	100%	99%
Cooling equipment efficiency	43	100%	95%
Variable frequency drives (VFDs)	31	75%	71%
Duct insulation	34	77%	100%
Pipe insulation	24	32%	100%
Economizers	36	96%	96%
Motorized dampers for outdoor air ducts	24	60%	91%
Energy recovery ventilation (ERV)	39	92%	29%
Demand control ventilation (DCV)	29	64%	13%

The bullets and figures below provide additional insights into compliance for the HVAC measures. In the figures, the green circles show the estimate of observable square footage that meets each compliance level, and the light and dark blue circles represent the lower and upper bounds at 90% confidence.

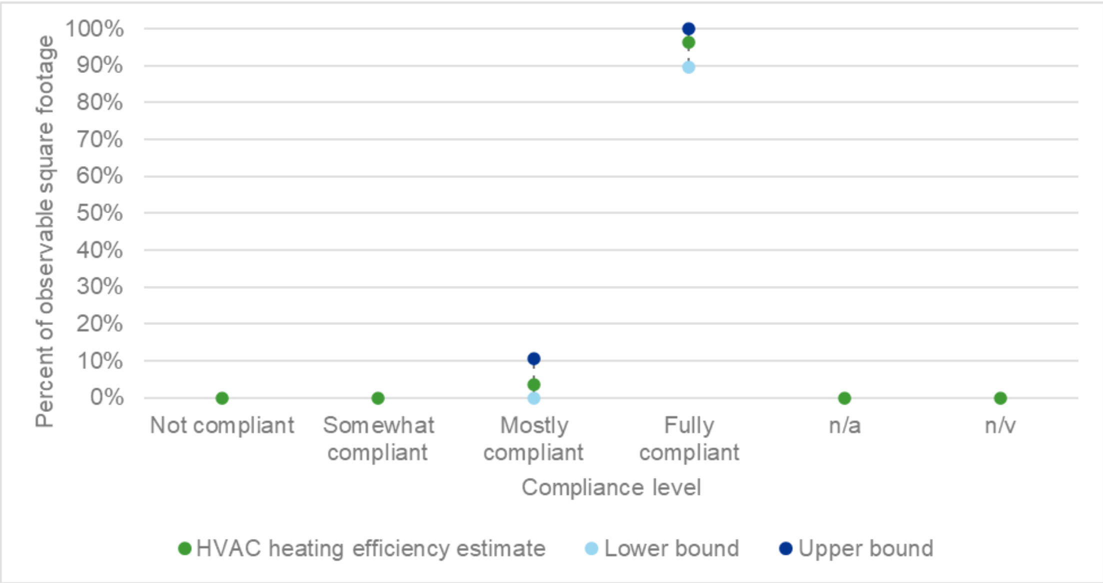
- **Thermostats**. The code requires manual thermostats in all spaces to enable temperature control. This was observable at 84% of the square footage but was found to be universally compliant. This suggests that thermostats are a standard practice in HVAC design.

Figure 6-12. Thermostat compliance estimate



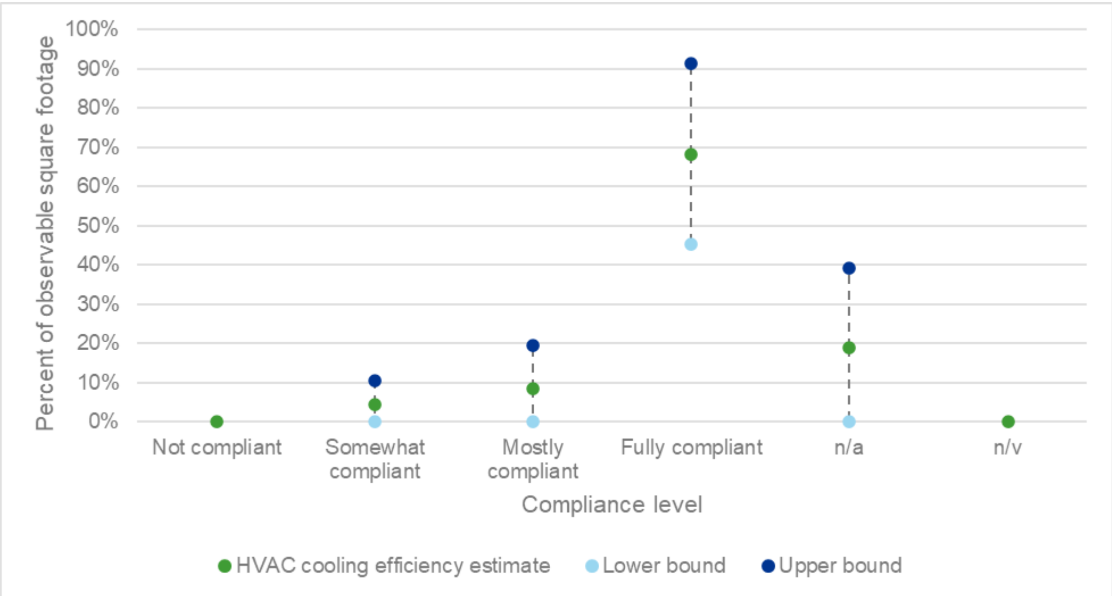
- **Heating equipment efficiency**. The efficiency of heating equipment was observable at all sites where HVAC details were provided. Overall, compliance was high, with only a few individual pieces of equipment not in compliance with the code requirements. This is consistent with prior studies, which have found that equipment manufacturers do not typically make equipment that does not comply with the code. Any non-compliance is more likely due to unique configurations or improperly sized equipment.

Figure 6-13. HVAC heating equipment efficiency compliance estimate



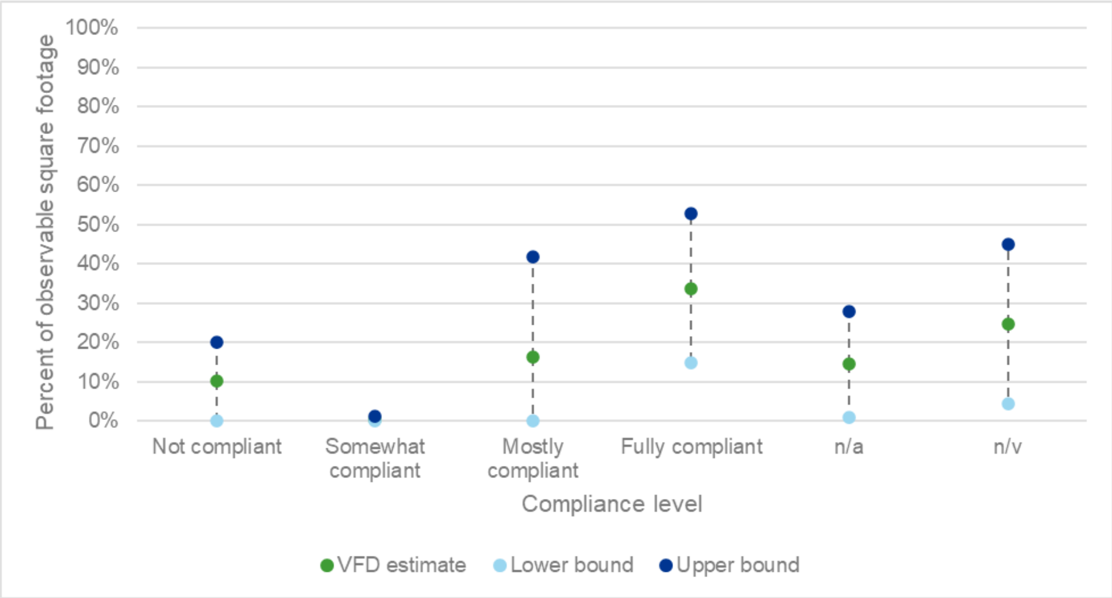
- **Cooling equipment efficiency**. The efficiency of cooling equipment was observable at 81% of square footage. Most equipment was found to be compliant, but some equipment on the construction drawings had efficiency values worse than code. The equipment with efficiency values worse than code were generally small-capacity units with a weighted average cooling capacity of 15,646 Btu/h. Figure 6-14 shows the distribution of compliance for this measure.

Figure 6-14. HVAC cooling equipment efficiency compliance estimate.



- **Variable frequency drives (VFDs)**. The code requires that VFDs or another air flow control are provided on all applicable cooling systems to vary the indoor fan airflow. Figure 6-15 shows the compliance distribution for VFDs. They were observable at 61% of new construction square footage, but compliance was mixed.

Figure 6-15. VFD compliance estimate



- **Duct and pipe insulation.** Duct and pipe insulation is observable at 77% and 32%, respectively. Building plans often did not provide details on duct or pipe insulation levels, and if the plans provided are incomplete, assessing this measure becomes difficult. This lack of detail led to many cases where we were unable to observe compliance. However, when we did have information on duct and pipe insulation, compliance was high.

Figure 6-16. Pipe insulation compliance estimate

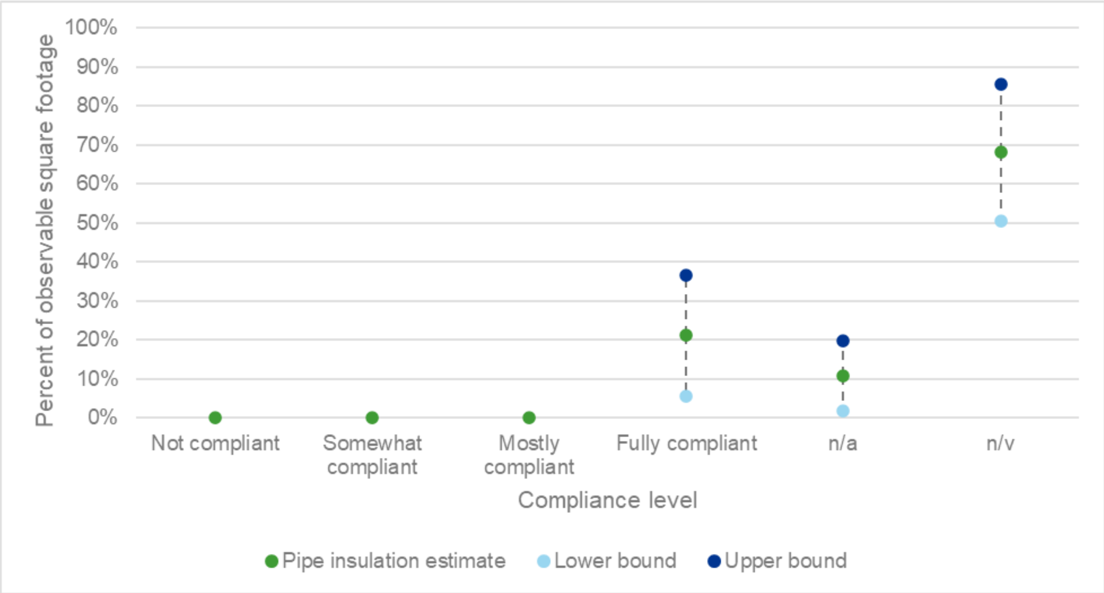
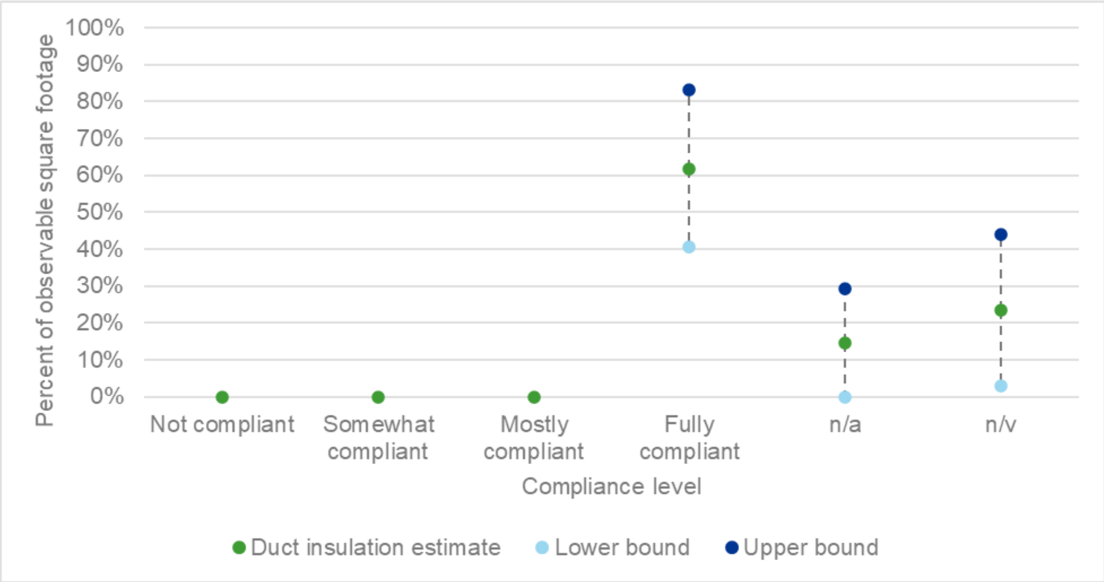
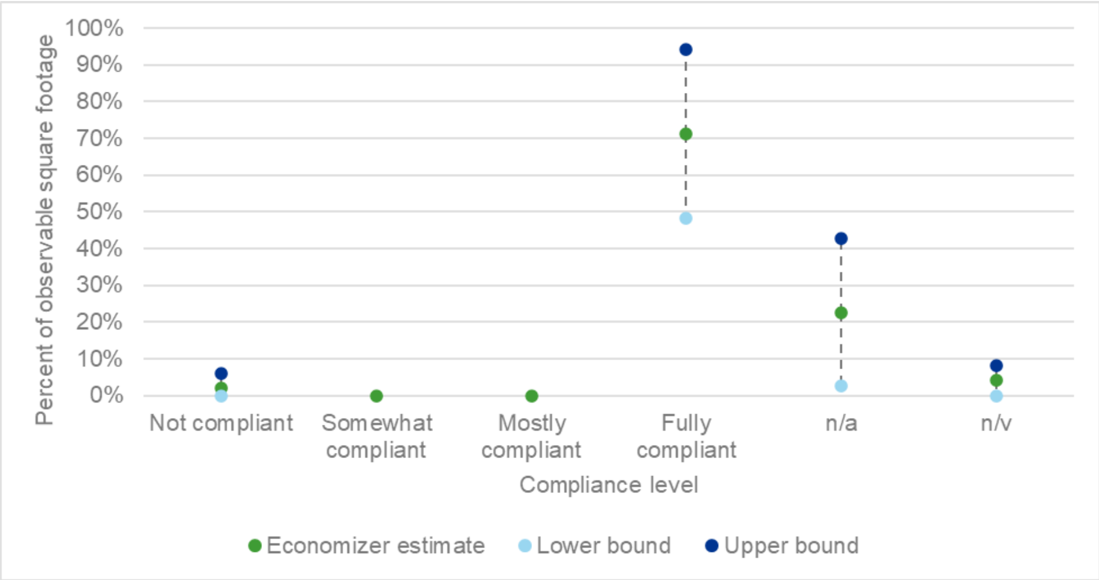


Figure 6-17. Duct insulation compliance estimate



- **Economizers.** Economizer controls is observable at 96% of square footage and compliance is high. We found that economizing controls is often well documented, and is frequently called out on plans.

Figure 6-18. Economizers compliance estimate



- **Demand control ventilation (DCV) and Energy Recovery Ventilation (ERV).** DCV is observable at 64% of square footage, while ERV is observable at 92% of square footage. Of the observable square footage, DCV is found to be not applicable or not required by code in 55% of square footage, while ERV is found to be not applicable or not required by code in 78% of square footage. Of the applicable square footage, compliance for DCV and ERV is low.

Figure 6-19. Demand control ventilation (DCV) compliance estimate

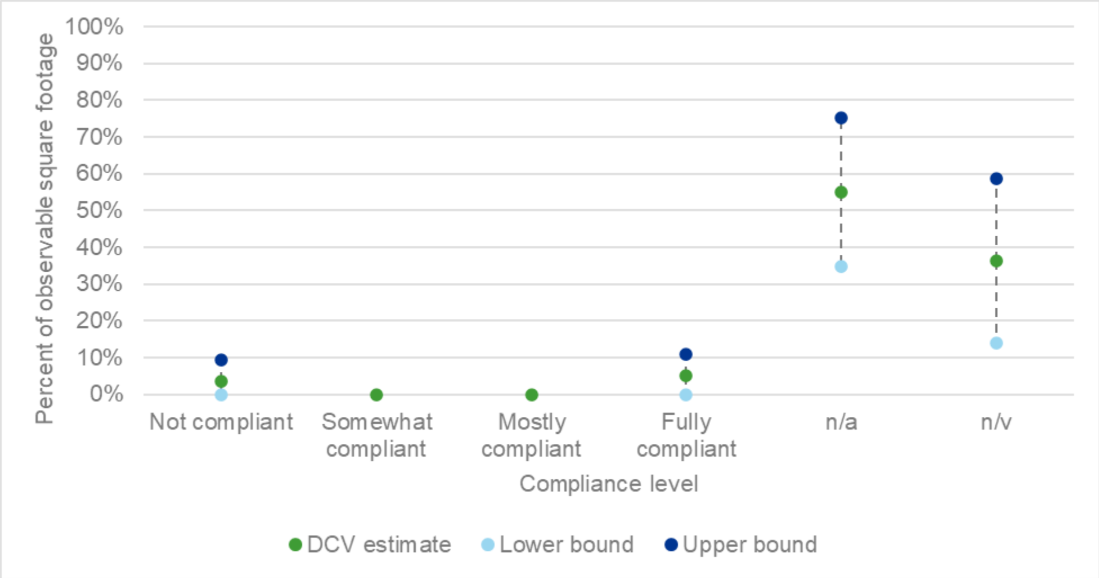
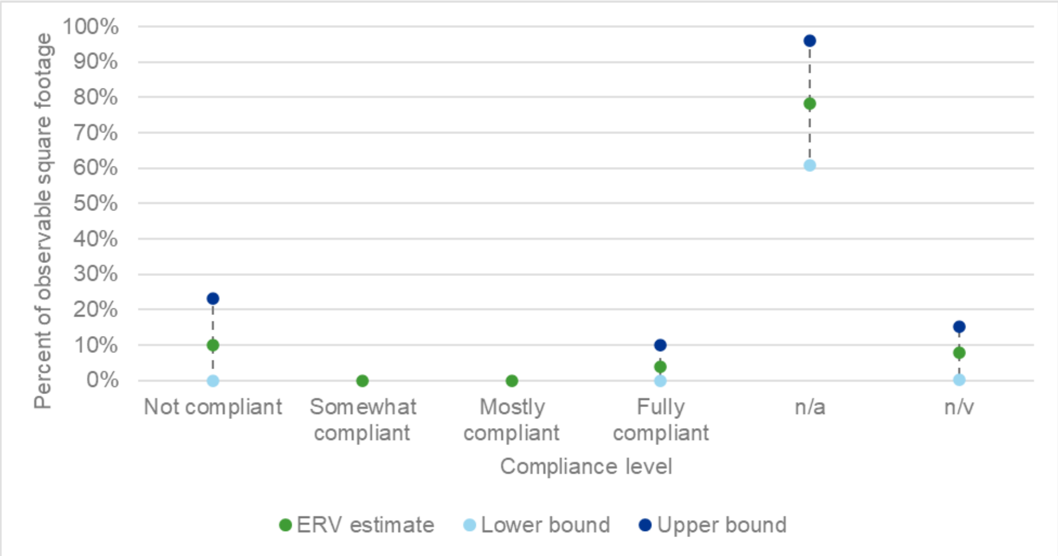


Figure 6-20. Energy recovery ventilation (ERV) compliance estimate



6.2.4.3 Lighting

This section presents the analysis of observed lighting provisions of the energy code for ASHRAE 90.1 2013. Table 6-9 shows select envelope measures, identifying for each measure the number of sites where details were verifiable, the percentage of square footage that this represents, and the unweighted compliance value (DNV method).

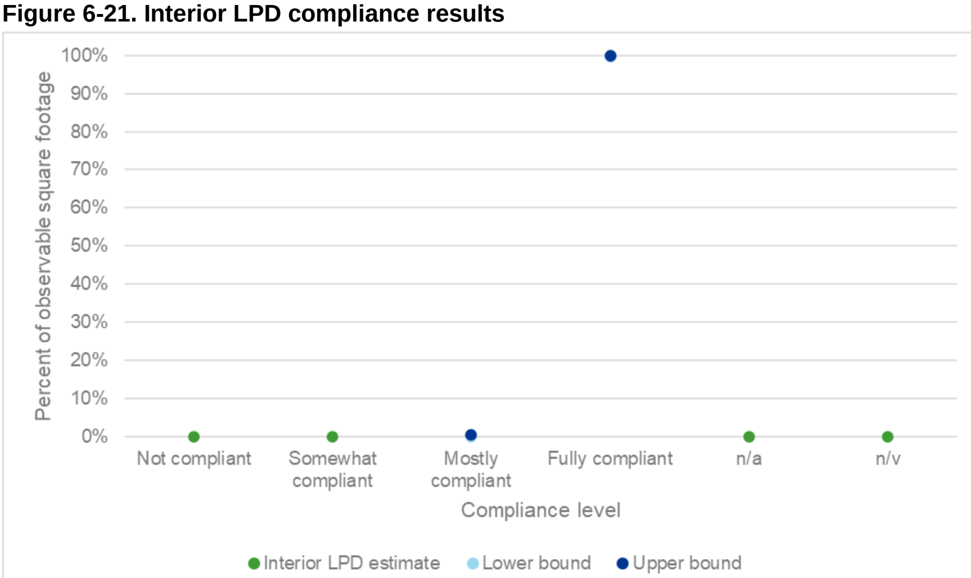
Table 6-9. Commercial lighting measure-level compliance

Code Measure Description	Number of sites verifiable*	Estimated % of new construction represented*	DNV average compliance (unweighted)
Manual light switch for each enclosed space	38	91%	100%
Lighting power density (LPD) in interior spaces	39	100%	100%
LPD in exterior spaces	31	71%	98%
Lighting controls allow occupants to reduce lighting load by at least 50% (commonly bi-level switching).	30	84%	67%
Reduced lighting load by 50% within 20 minutes	25	71%	84%
Daylight zones are provided with individual controls that control the lights independent of the general area lighting	24	43%	79%
Exterior lighting controls	27	57%	100%

This table, along with other lighting data, suggests the following observations from the analysis of the individual lighting measures:

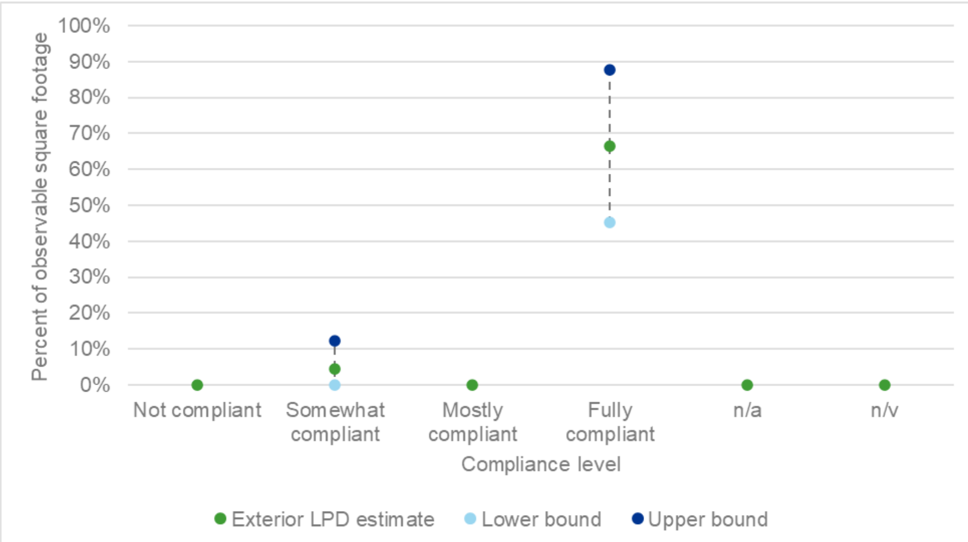
- **Interior LPD** – The DNV team assessed interior LPD using the space-by-space method. In this method, DNV engineers estimated the square footage for each individual space within the sample buildings to compute the total allowed wattage for the building (trade-offs are allowed within spaces provided that the overall wattage is less than the allowed wattage). Engineers then inventoried all interior fixtures to determine the assessed wattage and compared that to the code allowed values. Figure 6-21 presents the interior LPD compliance results; 99.87% of the observed square footage was compliant with the code. This is consistent with prior studies and reflects the continued increasing penetration of LEDs in Massachusetts and other states that outpace the code LPD requirements.

Figure 6-21. Interior LPD compliance results



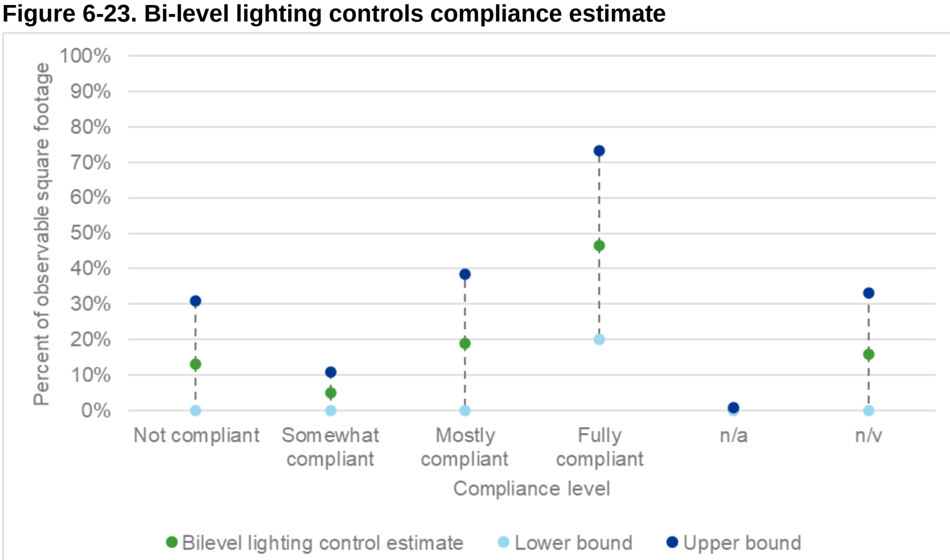
- **Exterior LPD –** For exterior lighting, the code provides a base allowance of wattage based on the building zone in addition to specific wattage requirements for individual spaces (walkways, parking lots, etc.); some of these spaces are tradeable and some are not. Site engineers inventoried all available exterior fixtures can compared them to the allowed wattage to determine compliance, shown in Figure 6-22. 98% of observable square footage was compliant.

Figure 6-22. Exterior LPD compliance results



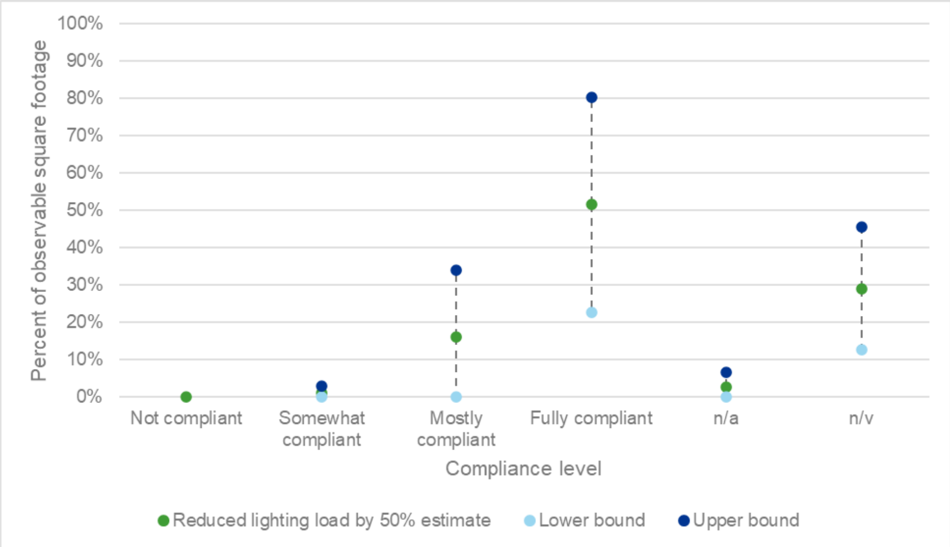
- **Bi-level switching –** The energy code requires at least one intermediate step in lighting power or continuous dimming in addition to full "ON" and full "OFF." Figure 6-23 shows the weighted percentage of observed floorspace distributed across compliance levels: 67% of the sites reviewed were fully compliant. The DNV team found that inconsistent or incomplete documentation likely played a role in the partial compliance values.

Figure 6-23. Bi-level lighting controls compliance estimate



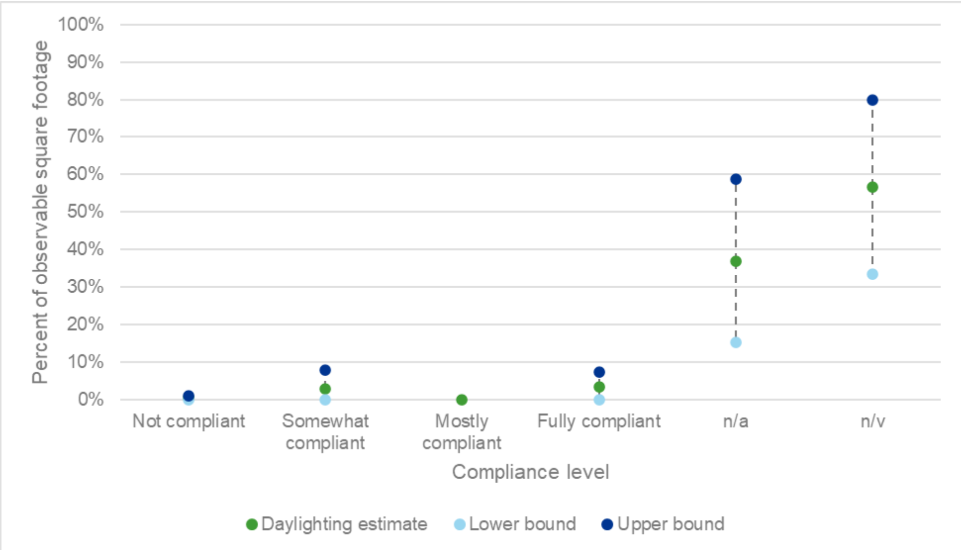
- **Reduced lighting load by 50% within 20 minutes –** The energy code requires that all lighting in a space should automatically be reduced by at least 50% within 20 minutes of all occupants leaving the space. Certain exceptions to this code provision include general lighting in shop or laboratory classrooms, general lighting in spaces where automatic lighting shutoff would endanger the safety of any occupants, or lighting that is required for 24/7 operation. Figure 6-24 shows the weighted percentage of observed floorspace distributed across compliance levels: 84% of the sites reviewed were fully compliant. The DNV team found that inconsistent or incomplete documentation also likely played a role in the partial compliance values.

Figure 6-24. Reduced lighting load by 50% within 20 minutes compliance estimate



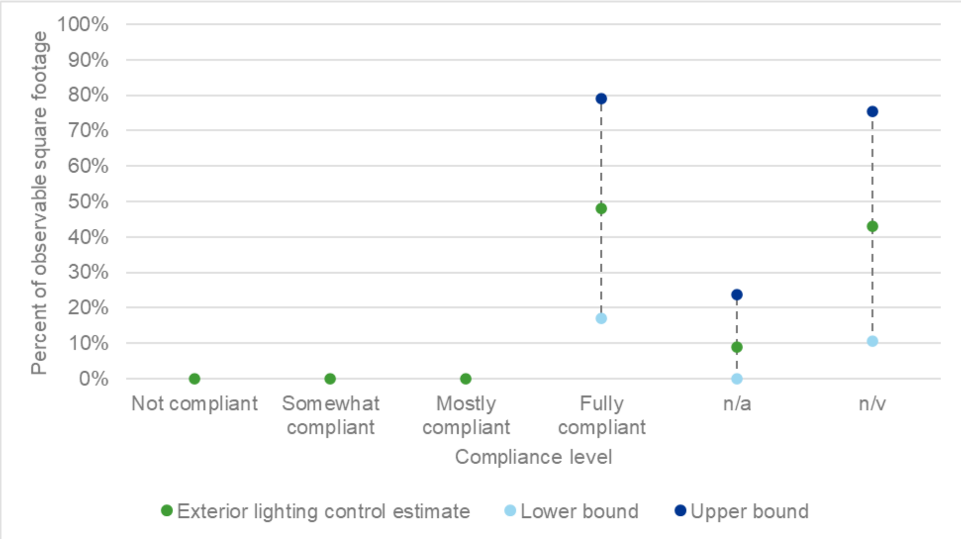
- **Daylighting** – The energy code requires that daylight zones are provided with individual controls independent of general lighting controls. Recent versions of ASHRAE 90.1 have expanded the focus on daylighting, highlighting the increased interest in ensuring that daylight zones are able to incorporate natural light whenever possible. Figure 6-25 shows the compliance results for daylighting. This measure was not well detailed on construction documents, contributing to a high percentage of square footage that could not be verified. There were also many buildings where this provision did not apply (n/a). Where daylighting was verifiable, DNV found this measure to be 79% compliant. This highlights a need for continued focus on daylighting control as a strategy to manage lighting loads.

Figure 6-25. Daylighting compliance estimate



- **Exterior controls –** The code requires that external lighting is provided with controls that automatically turn off lighting as a function of available daylight, either by photocell control, astronomical timers with seasonal daylight adjustment, or some combination of the two. Figure 6-26 shows the compliance results. This was well-documented in only 55% of the sites evaluated, however, it was 100% compliant when available. Many sites reviewed, however, did not provide sufficient data to verify exterior controls.

Figure 6-26. Exterior lighting controls compliance results



6.3 Modeling energy savings

This section summarizes the modeled code compliant energy consumption and non-code compliant energy for the six building types representing 82% of the projected new construction square footage. Table 6-10 shows the summary of the modeling results, and annual savings potential to bring new construction up to code.

Table 6-10. Energy modeling potential savings due to compliance

Building Type	Code Compliant Energy (kBtu)	Code Compliant EUI (kBtu/ft^2)	Non-Compliant Energy (kBtu)	Non-Compliant EUI (kBtu/ ft^2)	EUI Savings (kBtu/ ft^2)	3-year Average New Construction SF	% of Total SF	Potential Savings (MMBtu)
Warehouse	991,833	19.06	999,965	19.21	0.16	19,014,677	33%	2,971
Retail	1,105,535	44.77	1,239,053	50.18	5.41	1,691,495	3%	9,146
Food Service	2,216,411	402.84	2,226,062	404.59	1.75	623,268	1%	1,093
Health Care	4,585,406	111.99	4,687,182	114.47	2.49	1,768,068	3%	4,395
Midrise Multifamily	1,596,921	47.33	1,820,341	53.95	6.62	12,177,192	21%	80,635
Highrise Multifamily	3,977,760	47.16	4,023,730	47.70	0.54	11,699,655	21%	6,376
TOTAL						**35,274,701**	**82%**	**104,617**

The difference in EUI, energy consumption per square foot, between a code-compliant and non-code compliant building varies from 0.16 kBtu/ft^2 for warehouse buildings to 6.62 kBtu/ft^2 for midrise multifamily buildings. The majority of projected annual new construction square footage is multifamily buildings, including both highrise and midrise multifamily. Additionally, midrise multifamily buildings account for the greatest savings potential for both EUI per square foot (6.62 kBtu/ft^2) and total savings potential (80,635 MMBtu); this represents 77% of the total savings potential.

In total, up to 104 billion BTUs per year could be saved statewide with increased code compliance. For comparison, the 2019 Commercial New Construction program and the Commercial Pay-for-Performance program combined had annual savings goals of approximately 77.5 billion BTU per year.[57] This means that the gross technical potential savings from commercial compliance enhancement are 135% of the combined 2019 commercial new construction programs' goals.

6.4 Process evaluation

This section summarizes the findings and insights gathered from the in-depth interviews completed as part of the process evaluation. The interviewees fell into two groups: 1) New Jersey code officials and 2) Design/construction professionals, including architects, design engineers, general contractors, and other building professionals. The DNV team asked interviewees to provide their perspectives on the following:

- 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
- Interviewee perspectives on the future of energy code and energy goals

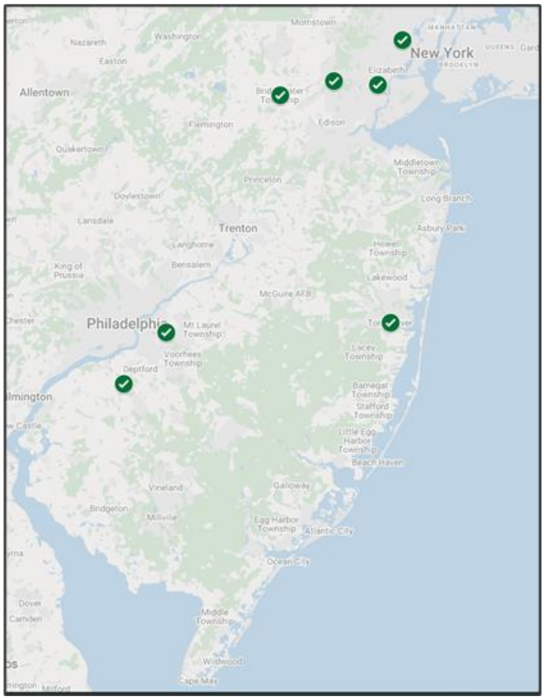
The remainder of this section contains detailed results from the code official and design and construction professional interviews.

6.4.1 Code officials

The DNV team interviewed seven code officials representing cities and towns across New Jersey shown in Figure 6-27, working with both residential and commercial projects. Many of the offices have staff ranging from two to fifteen people, with employees' experience ranging from 5 to 20 years.

[57] TRC. (June 2018). New Jersey's Clean Energy Program Fiscal Year 2019 Program Descriptions and Budget – FY19 Compliance Filing Volume 1. https://njcleanenergy.com/files/file/Library/Compliance%20Filings/fy19/TRC%20Compliance%20Filing%202019%20Vol%201%20v4%20FINAL.PDF

Figure 6-27. Interviewed code official by location



6.4.1.1 Perspectives on energy code compliance

We asked code officials several questions about what information is regularly absent from plans, and what specific areas are commonly out of compliance with the energy code. The team asked them 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. The primary areas of noncompliance as observed by the code officials include the following, and are commonly seeing in residential construction as well:

- **Air barrier and air barrier continuity** – 50% of the code officials interviewed mentioned the low compliance rate with the air barrier and air barrier continuity (across assemblies, joints etc.) due to installation staff not having proper training on installation techniques because the air barrier is not represented accurately on construction documents. The interviews also noted that those inspecting these measures may not have a complete understanding of what code requires and how it should be installed.
- **Installation of envelope insulation** – 5 out of the 7 code officials interviewed commented on the lack of compliance in insulation of envelope insulation due to lack of training provided on installation methods for those in the field. There were also themes noted in the interviews of lack of knowledge of specific code requirements for this measure.
- **Piping and duct insulation and sealing** – 5 out of the 7 code officials interviewed also stated that piping and duct insulation is a relatively new feature in the energy code, and often doesn't comply with the energy code in the field due to the lack of awareness of installers as code changes and new measures are added to code. This noncompliance was also a consistent finding in our plan reviews.

6.4.1.2 Future training on energy code

The code officials interviewed unanimously indicated they currently participate in regular trainings and continued education seminars, mostly to maintain licensure. They primarily receive training held by Rutgers University and the New Jersey Department of Community Affairs (DCA). While most code officials interviewed collectively felt that they were well prepared to review and enforce the energy code for commercial projects, they all supported having more education and trainings on code activities in the state to ensure those in the industry have the proper education and tools to be successful. Common training themes included:

- Code officials have a basic understanding of the energy code, but the code changes over time as new versions are adopted. Code officials were interested in more frequent training or education to ensure there is a comprehensive understanding of energy code changes.
- Many code officials specifically asked for more training on different energy technologies in addition to general code training, specifically asking for more training on air sealing and the air barrier.
- Most code officials interviewed prefer to receive more training in webinar or online format, due to the increased accessibility of online training in a large state and the wider audiences it can reach. However, some code officials did note that in-person formatting is also helpful to ensure engagement in the training.

6.4.2 Design and construction professionals

The DNV team interviewed eight 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. We asked design professionals questions to better understand their typical firm operations and experience in the field, and to gather their perspectives on building electrification and both current and anticipated future challenges in meeting energy goals.

6.4.2.1 Energy code expertise

Consistently across the organizations interviewed, the respondents indicated that energy code expertise is most often concentrated with a specific 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, most organizations interviewed designate an in-house resource to review all projects and/or provide code-specific guidance to project teams. The design professionals interviewed also all work nationwide across many state and local jurisdictions, but have a dedicated team of in-house resources to review New Jersey projects.

6.4.2.2 Building construction beyond code compliance

DNV asked design and construction professionals to offer perspectives on why and when buildings pursue design criteria that exceed code requirements. The interviews with design professionals indicated that the primary reason for buildings pursuing beyond code compliance design is mainly due to the projects pursuing LEED® or other high-performance building programs. Other comments from design teams highlighted that project costs are a key barrier to pursuing beyond code design. Many design professionals commented on the high costs involved to construct buildings that go beyond code, and one professional mentioned that energy efficient products and equipment are specially made for specific customers, and thus can cost more to obtain. When asked for specific building components and designs that are more frequent to be installed above code, the responses primarily included lighting due to the rise in LEDs.

6.4.2.3 Improving energy code support

While 50% of design and construction professionals interviewed said they have sufficient understanding of the commercial energy code requirements, 75% said they would like to receive additional training. Design and construction professionals made several recommendations to improve energy code training:

- Expand online webinars or virtual trainings to help improve reach within the design and construction industry. More than half of the interviewed design professionals agreed this would be beneficial.

- Conduct trainings more frequently based on updates and changes to energy code. More than half of the professionals interviewed supported more frequent guidance and education supporting the code changes from the state, to ensure those in the industry are up to date with the most recent iterations. Several professionals suggested a dedicated state resource for energy code, such as an email, website, or hotline, that would become a location for the most correct and up to date source of information for code officials, installers, contractors, designers, and building/homeowners to ask questions about code.

- Focus training topics on building science topics such as envelope building shell design strategies and the design intent of each code requirement to improve overall knowledge. Include training on new and emerging energy efficient and/or renewable technologies.
- Promote collaboration between code officials and design professionals throughout the plan design and review process for a consistent understanding of the building design.

APPENDIX A. SINGLE-FAMILY & ATTACHED/MF 2-4 DETAILS

Demographics

Survey respondents are primarily high-earning homeowners with a college education.

Tenure

Almost all survey-responses in Table A-1 were from homeowners about their primary residence.

Table A-1. Tenure by home type

	Single-Family Detached	Attached/MF 2–4
Surveys	64	23
Homeowner	98%	96%
Primary residence	97%	100%

Occupancy

The average occupancy of survey respondents of both Single-Family Detached and Attached/MF 2–4 home in Table A-2 is slightly more than three persons per home. Attached/MF 2–4 households are slightly smaller and younger than those in detached homes, but are less likely to have children.

Table A-2. Average occupancy by home type

	Single-Family Detached	Attached/MF 2–4
Surveys	64	23
5 and under	0.5	0.4
6 to 18	0.7	0.3
19 to 34	0.5	1.0
35 to 54	1.1	0.9
55 to 64	0.4	0.3
65 and over	0.3	0.3
TOTAL	3.4	3.1

Education

More than 80% of survey respondents have four or more years of college (Table A-3).

Table A-3. Educational attainment by home type

	Single-Family Detached	Attached/MF 2–4
Surveys	64	23
High school/GED	2%	0%
Some college	8%	17%
Associate's	5%	4%
Bachelor's	39%	9%
Graduate or Professional	31%	61%
Doctorate	16%	9%

Income

Respondent incomes (Figure A-1 and Table A-4) appear disproportionately skewed toward the highest income brackets compared to recent Census data. However, respondents are primarily purchasers (Table A-1) of new homes, more than half of whom possess advanced degrees as shown in Table A-3.

Figure A-1. Self-reported income by home type

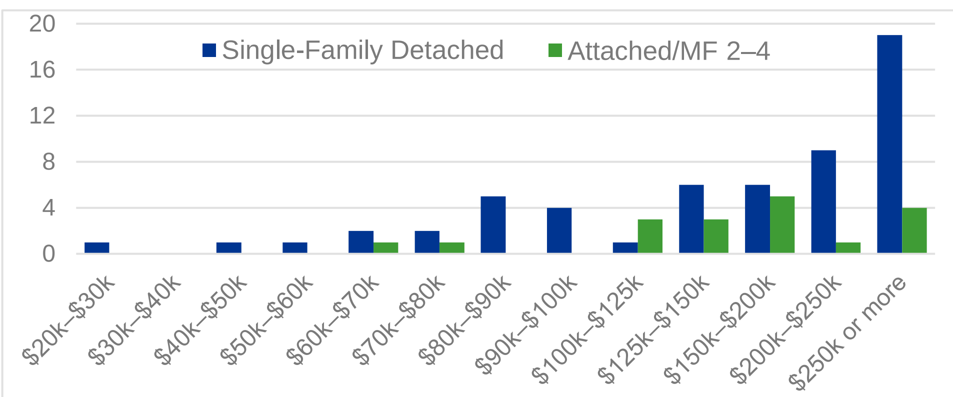


Table A-4. Self-reported income by home type

	Single-Family Detached	Attached/MF 2–4
Surveys	57	18
$20,000 to $29,999	1	–
$30,000 to $39,999	–	–
$40,000 to $49,999	1	–
$50,000 to $59,999	1	–
$60,000 to $69,999	2	1
$70,000 to $79,999	2	1
$80,000 to $89,999	5	
$90,000 to $99,999	4	–
$100,000 to $124,999	1	3
$125,000 to $149,999	6	3
$150,000 to $199,999	6	5
$200,000 to $249,999	9	1
$250,000 or more	19	4
Low-income	4%	6%

The proportion of low-income survey respondents in Table A-4 is slightly lower than the fraction of families below the poverty line in Table A-5.

Table A-5. 2019 household income (2020$)[58,59]

	Census
Less than $15,000	7.8%
$15,000 to $24,999	6.7%
$25,000 to $34,999	6.6%
$35,000 to $49,999	19.0%
$50,000 to $74,999	14.5%
$75,000 to $99,999	12.3%
$100,000 to $149,999	17.8%
$150,000 to $199,999	10.4%
$200,000 to $249,999	14.8%
Below poverty level	7.0%

General

Home type

Table A-6 shows that occupants may have some difficulty in classifying non-detached housing, although the precise options available in the survey listed below may have been perceived as ambiguous. For example, duplexes have walls adjacent to another home. However, there was no townhouse-duplex confusion seen in the responses.

- Single-family home
- Duplex or two-family home
- Townhouse or row house (adjacent walls to another house)
- 2-4-unit apartment or condo
- 5+ unit apartment or condo

[58] United States Census Bureau. 2020. American Community Survey –Income in the Past 12 Months (S1901). https://data.census.gov/cedsci/table?q=Income%20%28Households,%20Families,%20Individuals%29&g=0400000US34&tid=ACSST5Y2020.S1901 (Accessed May 5, 2022)

[59] United States Census Bureau. 2020. American Community Survey –Ratio of income to Poverty Level of Families in the Past 12 Months (B17026). https://data.census.gov/cedsci/table?q=Income%20%28Households,%20Families,%20Individuals%29&g=0400000US34&tid=ACSDT5Y2020.B17026 (Accessed May 5, 2022)

Table A-6. Self-assessed home type by home type (includes some omitted homes)

	Single-Family Detached	Duplex	Townhouse	MF 2–4	MF 5+
Single-Family Detached	82	–	1	–	–
Duplex	–	5	–	1	–
Townhouse	–	–	23	–	–
MF 2–4	–	–	–	1	1
MF 5+	–	–	–	–	2

Conditioned floor area

Table A-7 compares the average home size reported by survey respondents with the average home size for homes in this study. Given that the survey accepts sizes in increments of one hundred square feet, the averages appear consistent.

Table A-7. Average home size by home type

	Single-Family Detached		Attached/MF 2–4	
	Self-Assessed	Records Review	Self-Assessed	Records Review
Surveys	61	36	23	12
Mean	2,726	3,045	2,335	2,223

The average home sizes in Table A-7 mask considerable variation in respondent accuracy. Table A-8 shows the proportion of the survey home size response to the area obtained from our records review, where both values are available. A possible cause of error for Attached/MF 2–4 housing are responses that include more than one unit. Differences in the inclusion or exclusion of basements are a likely source of variation in Single-Family Detached home size accuracy.

Table A-8. Self-assessed home size accuracy by home type

	Single-Family Detached	Attached/MF 2–4
Surveys	34	12
Minimum	50%	77%
Mean	100%	126%
Maximum	228%	300%

Utility territories

The proportion of homes per gas provider differs between groups in Table A-9. For example, New Jersey Natural Gas is over-represented in Single-Family Detached homes however, the rank of utilities (PSE&G as largest, Elizabethtown as smallest) is correct for these homes.

Table A-9. Non-program gas utility by home type

	Single Family Detached	Attached/MF 2–4	Homes with Gas Service[60]
Sites	96	35	2,927,324
Elizabethtown Gas	6%	11%	9%
New Jersey Natural Gas	32%	9%	17%
PSE&G	39%	74%	58%
South Jersey Gas	21%	6%	13%
N/A	2%	0%	3%

Among Single-Family Detached homes in Table A-10, Atlantic City Electric is over-represented while Public Service Electric & Gas is under-represented. The utility rank for Attached/MF 2–4 is correct, and the proportions are similar to those of statewide accounts.

Table A-10. Non-program electric utility by home type

	Single Family Detached	Attached/MF 2–4	Homes with Electric Service[61]
Sites	96	35	3,565,678
Atlantic City Electric	28%	6%	13%
Jersey Central Power & Light	32%	26%	26%
PSE&G	30%	63%	52%
Rockland Electric Company	6%	3%	2%
Other	3%	3%	8%

Electrical service

Energy models do not include information about the electrical service to a home, however this information was received for a handful of responses that were excluded from other analysis due to program participation but are included in Table A-11.

60 New Jersey Board of Public Utilities. (March 2022). NJ Natural Gas Switching Statistics – March 2022 https://www.state.nj.us/bpu/pdf/energy/NJ%20Switching%20Data%20March%202022%20-%20Gas%20(1).pdf (Accessed May 18, 2022)

61 New Jersey Board of Public Utilities. (March 2022). NJ Electricity Switching Statistics – March 2022 https://www.state.nj.us/bpu/pdf/energy/NJ%20Switching%20Data%20March%202022%20-%20Electric%20(1)%20(1).pdf (Accessed May 18, 2022)

Table A-11. Electrical service amperage by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	46	2	18	4
Minimum	150	200	100	150
Mean	218	200	164	175
Maximum	400	*200*	200	*200*

76% of the 16 survey responses we received building department records for match the building permit typically, a survey response of "151–250 Amps." The five remaining responses were split with 60% reporting an overly large capacity, and 40% under-reporting.

Photovoltaics

All PV installations with a known location are roof-mount. There are also two non-program Single-Family Detached homes with PV panels of unknown capacity that are not included in Table A-12.

Table A-12. Photovoltaic panel capacity by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	7	1	–	–
Minimum	2.2	3.8	–	–
Mean	7.2	3.8	–	–
Maximum	9.6	*3.8*	–	–

Electric vehicles

Because survey respondents were free to supply documentation of whichever equipment in their home they preferred, the counts in Table A-13 may not reflect electrical vehicle penetration in the overall population. However, it is interesting to note that occupants of Attached/MF 2–4 housing appear to have ready access to high-voltage (Level 2) charging.

Table A-13. Electric vehicles and chargers by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Plug-in Hybrid	2	–	1	–
Electric only	0	–	1	–
Chargers				
Level 1 (120V)	1	–	0	–
Level 2 (240V)	0	–	2	–
Unknown	1	–	0	–

Pools

The counts in Table A-14 may not be an accurate assessment of pool and hot tub penetration among new homes in New Jersey. These counts are based on inferences from construction permits and occasional evidence from aerial photographs. There was no appreciable difference between climate zones.

Table A-14. Pool and hot tub installations by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Pools	10	–	1	–
Hot tubs	6	–	1	–

Appliances

Refrigeration

Unfortunately, it is not possible to determine the ENERGY STAR status of the refrigerators in program homes. Verification requires either a model number, or volume and configuration details (e.g., top or bottom freezer, presence of ice-maker, etc.). None of this information is available in the program energy models, but the similar range of efficiency values (358–727 kWh/yr for program homes versus 331–826 kWh/yr for non-program homes), coupled with a lower average consumption, suggests that program home ENERGY STAR penetration is slightly higher than in non-program homes.[62]

Table A-15. Average specifications of primary refrigeration equipment by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	53	20	20	33
Volume (ft³)	24.7	–	22.7	–
kWh/yr	665	646	612	545
ENERGY STAR	61%	–	56%	–

The secondary refrigeration equipment in Table A-16 are an equal mix of equipment types: six coolers, seven freezers and eight refrigerators.[63]

Table A-16. Average specifications of secondary refrigeration equipment by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	16	–	4	–
Volume (ft³)	13.6	–	8.1	–
kWh/yr	431	–	327	–
ENERGY STAR†	43%	–	0%	

†The specification for coolers (Consumer Refrigeration version 5.1) was not issued until August 2021. Therefore, older coolers are unlikely to satisfy ENERGY STAR criteria, and indeed only a third of observed coolers complied.

Cooking

Most survey respondents included their stove and/or oven within their response, allowing verification of the presence or absence of convection oven and often the appliance fuel. No induction stoves were recorded. However, this sample was supplemented with information from building department files. Some records included natural gas pipe diagrams which included kitchen equipment, while others had permits that indicated the presence of an electric range. If the electric range field was not ticked on a permit and there was other combustion equipment in the home the range was assumed to be gas,

[62] Among twelve survey responses with verified primary refrigerators which were discarded due to survey participation, five of eight detached homes (63%) had ENERGY STAR equipment, versus 75% of the refrigerators in four Attached/MF 2–4 program homes.

[63] Six discarded program-participant survey responses included verified secondary refrigeration equipment: three coolers, two freezers and one refrigerator. Only one of the six devices (16%) was ENERGY STAR.

and otherwise left blank. The REM/Rate models for program homes only include the oven fuel. However, a minimum percentage of electric stoves can be inferred from the penetration of induction stoves.

Table A-17. Stove specifications by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	60	20	25	33
Gas Range	78%	–	92%	–
Electric Range	22%	≥15%	8%	–
Induction	–	15%	–	0%

Cooking equipment details, such as an induction range or convection oven, have a negligible impact on the performance of an average home, and may be overlooked by some raters in the modeling process. Therefore, the penetration levels of these attributes for program homes in Table A-17 and Table A-18 may be underestimates. Similarly, it is not possible to identify induction stoves and convection ovens from permits alone.

Table A-18. Oven specifications by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	52	41	18	66
Gas Oven	65%	90%	72%	55%
Convection Oven	64%	10%	62%	30%

Dishwashers

Nearly every home includes an ENERGY STAR dishwasher, although the most efficient models consume 26% less energy (199 kWh/yr) than the minimally qualifying models (270 kWh/yr) that are commonly installed in both program and non-program homes.[64]

Table A-19. Average specifications of dishwashers by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	42	18	21	31
kWh/yr	266	270	261	279
ENERGY STAR	100%	100%	95%	90%

[64] Furthermore, a forthcoming revision to the ENERGY STAR specifications (version 7), is expected to reduce the permissible annual consumption to 240 kWh/yr, which may reduce future ENERGY STAR penetration levels.

Clothes washers

Accurate data entry for this appliance is complicated by interactions with other equipment. Clothes washer efficiency is tied to both hot water consumption and the clothes dryer. Therefore, standard practice for HERS ratings is to make a conservative selection among predefined efficiency levels when creating an energy model. As a result of this practice, precise efficiency ratings are frequently unavailable in program home energy models. The low ENERGY STAR penetration for program homes in Table A-20 should also be interpreted skeptically.[65]

Table A-20. Average specifications of clothes washers by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	24	20	19	33
Efficiency (IMEF)	3.53	–	2.42	–
ENERGY STAR	82%	20%	83%	24%

Clothes dryers

Like clothes washers, clothes dryers are often entered into models using default values. Therefore, the counts of program homes with non-default values in Table A-21 and Table A-22 are relatively small.[66]

Table A-21. Average specifications of gas clothes dryers by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	19	–	9	–
Efficiency (CEF)	3.39	–	3.4	–
ENERGY STAR	45%	–	56%	–

The program data includes several "gas" dryers with efficiencies that greatly surpass all other gas models currently listed in the ENERGY STAR Residential Clothes Dryer Product Finder. This suggests that these entries have an incorrect fuel selection in the energy model, and they have been recategorized as electric in Table A-22.

[65] Three of four detached home survey respondents omitted due to program participation owned ENERGY STAR clothes washers.

[66] Among six survey responses with dryer information omitted due to program participation, two thirds were gas (three detached, one Attached/MF 2–4) and one third were electric (two Attached/MF 2–4). One of three gas dryers was verified to be ENRGY STAR, and the average efficiency of those three dryers was 3.36 CEF.

Table A-22. Average specifications of electric clothes dryers by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	4	–	1	6
Efficiency (CEF)	3.75	–	3.94	3.85
ENERGY STAR	50%	–	100%	17%

Air cleaners and dehumidifiers

Air cleaners and dehumidifiers are traditionally not included in energy models, although recent updates to RESNET standards allow for the recording of dehumidifiers in future models.

In addition, survey respondents were free to submit documentation of whichever equipment in their home they preferred, meaning the counts in Table A-23 and Table A-24 should not be used to infer equipment penetration levels.

Table A-23. Air cleaner ENERGY STAR status by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	2	–	2	–
ENERGY STAR	50%	–	100%	–

Table A-24. Dehumidifier ENERGY STAR status by home type and program status

	Single-Family Detached		Attached/MF 2–4	
	Non-Program	Program	Non-Program	Program
Sites	1	–	5	–
ENERGY STAR	100%	–	60%	–

Mechanical equipment

Furnaces are the primary heat source in every Single-Family Detached and Attached/MF 2–4 program home—serving more than 90% of heating load—except for the single home with a heat pump. Non-program homes are also primarily served by furnaces, although there is more diversity among equipment types from a handful of Climate Zone 5 homes heated with boilers.

Boilers

Table A-25 suggests that boiler-based heating is rare in Climate Zone 4, and more prevalent in Attached/MF 2–4 non-program homes than Single-Family Detached. Surprisingly, boilers in four of nine homes are part of a hydro-air system and four of the five homes with hydronic boilers have central air conditioners. This suggests that reduced construction costs or space savings from not installing ductwork are not primary motivations for the installation of boilers, nor is the desire to use the boiler to supply domestic hot water.

Table A-25. Boiler penetration by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	39	40	15	5	14	11	26	6
Boilers	–	4	–	–	–	5	–	–
Penetration	–	10%	–	–	–	45%	–	–
Hydro-air	–	5%	–	–	–	18%	–	–

Half of the boilers with known efficiency in Table A-26 are ENERGY STAR.

Table A-26. Boiler efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	2	–	–	–	2	–	–
Boilers	–	2	–	–	–	2	–	–
Minimum AFUE	–	84	–	–	–	83	–	–
Mean AFUE	–	89	–	–	–	89	–	–
Maximum AFUE	–	94	–	–	–	95	–	–
ENERGY STAR	–	50%	–	–	–	50%	–	–

Furnaces

All furnaces with a known fuel source in Table A-27 are natural gas, apart from one oil-fired furnace in a detached non-program home in Climate Zone 4. Program homes are much more likely to have ENERGY STAR furnaces installed than non-program homes.

Table A-27. Furnace efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	26	26	15	5	5	3	26	6
Furnaces	36	37	19	7	7	4	26	6
Minimum AFUE	80	80	93	96	80	92	95	95
Mean AFUE	91.7	90.6	95.6	96.2	89.2	92.1	95.8	95.9
Maximum AFUE	97	96.1	96.5	97	96	92.1	96.1	96.1
ENERGY STAR	36%*	36%*	89%	100%	14%*	0%	100%	100%

*** *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.**

Fireplaces

Approximately one fourth of non-program homes (24%) with known heating equipment have gas fireplaces. REM/Rate models usually do not include fireplaces, and there are none recorded in the analyzed program home models.

Table A-28. Fireplaces by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	39	40	–	–	12	11	–	–
Sites w/ Fireplaces	33%	20%	–	–	33%	27%	–	–
Average Fireplaces	1.0	1.5	–	–	1.33	1.0	–	–

Heat pumps

Both heat pumps in Table A-28 are ductless mini-splits. In addition, a third home—also a non-program Single-Family Detached in Climate Zone 5—included evidence of an unspecified heat pump in its permits, while an Attached/MF 2–4 home survey response that was discarded due to program participation had an 8.2 HSPF ductless mini-split.

Table A-29. Heat pump heating efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	1	–	–	–	–	1	
Heat Pumps	–	3	–	–	–	–	1	–
Minimum HSPF	–	9	–	–	–	–	10	–
Mean HSPF	–	9	–	–	–	–	10	–
Maximum HSPF	–	9	–	–	–	–	10	–
ENERGY STAR	–	100%	–	–	–	–	100%	–

The mini-split for the program home discarded from the survey was 14 SEER.

Table A-30. Heat pump cooling efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	–	1	–	–	–	–	1	
Heat Pumps	–	3	–	–	–	–	1	–
Minimum SEER	–	18	–	–	–	–	22	–
Mean SEER	–	18	–	–	–	–	22	–
Maximum SEER	–	18	–	–	–	–	22	–
ENERGY STAR	–	100%	–	–	–	–	100%	–

Air conditioners

The majority of Single-Family Detached and Attached/MF 2–4 homes have central air conditioning, and no program homes are built without air conditioning.

Table A-31. Air conditioner penetration by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	42	44	15	5	14	13	26	6
Penetration	86%	93%	100%	100%	86%	85%	100%	100%

Program homes are twice as likely to install ENERGY STAR air conditioners (Table A-32).

Table A-32. Central air conditioner efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	22	27	15	5	6	5	26	6
Air Conditioners	54	73	19	7	17	13	26	6
Minimum SEER	13	13	14	15	13	13	14	15
Mean SEER	13.7	14.1	15.2	15.5	13.5	13	15.6	15.7
Maximum SEER	16	17.8	16	17.3	15	13	17	16
ENERGY STAR	41%*	56%*	100%	100%	43%*	0%*	100%	100%

*** *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.**

Thermostats

Programmable or more advanced thermostat styles account for most installations across all home categories in Table A-33. Energy models do not indicate whether a thermostat includes smart or Wi-Fi-enabled features, however five of eleven program home survey respondents reported the use of smart thermostat features in Table A-34.

Table A-33. Thermostat type by home type and program status

<table>
<tr><th></th><th colspan="4">Single-Family Detached</th><th colspan="4">Attached/MF 2–4</th></tr>
<tr><th></th><th colspan="2">Non-Program</th><th colspan="2">Program</th><th colspan="2">Non-Program</th><th colspan="2">Program</th></tr>
<tr><th></th><th>CZ 4</th><th>CZ 5</th><th>CZ 4</th><th>CZ 5</th><th>CZ 4</th><th>CZ 5</th><th>CZ 4</th><th>CZ 5</th></tr>
<tr><td>Sites</td><td>20</td><td>14</td><td>15</td><td>5</td><td>8</td><td>3</td><td></td><td></td></tr>
<tr><td>Thermostats</td><td>21</td><td>19</td><td>–</td><td>–</td><td>9</td><td>4</td><td>–</td><td>–</td></tr>
<tr><td>Manual</td><td>5%</td><td>0%</td><td>0%</td><td>0%</td><td>22%</td><td>0%</td><td>4%</td><td>17%</td></tr>
<tr><td>Programmable</td><td>35%</td><td>53%</td><td rowspan="2">100%</td><td rowspan="2">100%</td><td>33%</td><td>50%</td><td rowspan="2">96%</td><td rowspan="2">83%</td></tr>
<tr><td>Wi-Fi or Smart</td><td>60%</td><td>47%</td><td>44%</td><td>50%</td></tr>
</table>

As shown in the bottom two rows of Table A-34, half of survey respondents do not use the automatic temperature adjustment features of their thermostats. A third of occupants set their heating to a fixed temperature.

Table A-34. Heating season thermostat usage by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program†		Non-Program		Program†	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Addresses‡	28	36	5	2	11	12	3	1
Smart thermostat	18%	17%	20%	50%	27%	25%	–	–
Program schedule	25%	42%	60%	50%	–	25%	33%	–
Adjust manually	21%	8%	20%	–	36%	25%	33%	100%
Fixed temperature	36%	33%	–	–	36%	25%	33%	–

† Program values in this table are from survey respondents, not program data.
‡ Because thermostat use is occupant-driven, this table contains each applicable survey response i.e., the two CZ4 Single-Family Detached addresses and six CZ5 Attached/MF 2–4 occurring in the same three developments have not been condensed into one and three records respectively.

As with the heating season usage style, half of survey respondents do not use their thermostats' automatic temperature features in the summer. Furthermore, a third of non-program home occupants set their air conditioner to a fixed temperature in Table A-35.

Table A-35. Cooling season thermostat usage by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program†		Non-Program		Program†	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Addresses‡	28	36	5	2	11	12	3	1
Smart thermostat	14%	19%	40%	50%	27%	25%	–	–
Program schedule	32%	39%	60%	50%	–	25%	33%	–
Adjust manually	18%	14%	–	–	45%	17%	33%	100%
Fixed temperature	36%	28%	–	–	27%	33%	33%	–

† Program values in this table are from survey respondents, not program data.
‡ Because thermostat use is occupant-driven, this table contains each applicable survey response i.e., the two CZ4 Single-Family Detached addresses and six CZ5 Attached/MF 2–4 occurring in the same three developments have not been condensed into one and three records respectively.

The winter night-time setbacks—difference between day and night settings—for non-program homes in Table A-36 are lower than those in program homes.

Table A-36. Average heating season setpoints by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program†		Non-Program		Program†	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Addresses‡	27	34	5	2	11	12	3	1
Weekday – daytime	68.9	69.4	67.8	73.0	69.8	70.8	68.3	70.0
Weekend – daytime	70.3	70.2	67.8	73.0	70.5	71.0	68.5	70.0
Nights	69.2	68.8	65.6	68.0	69.5	69.9	65.5	62.0
Extended away	65.3	64.9	62.2	65.0	68.1	65.4	65.5	65.0

† Program values in this table are from survey respondents, not program data.
‡ Because thermostat use is occupant-driven, this table contains each applicable survey response i.e., the two CZ4 Single-Family Detached addresses and six CZ5 Attached/MF 2–4 occurring in the same three developments have not been condensed into one and three records respectively.

Table A-37 suggests that homeowners do not setback their thermostats at night, and non-program Attached/MF 2–4 homes in Climate Zone 4 appear to increase air conditioner usage at night.

Table A-37. Average cooling season setpoints by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program†		Non-Program		Program†	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Addresses‡	28	35	5	2	11	12	3	1
Weekday – daytime	74.0	73.7	75.6	77.5	72.2	74.8	73.0	75.0
Weekend – daytime	73.1	73.9	76.6	77.5	72.5	74.3	73.0	75.0
Nights	72.7	73.3	76.2	79.0	71.6	74.2	72.3	75.0
Extended away	77.8	78.3	76.6	81.5	75.8	79.1	76.7	75.0

† Program values in this table are from survey respondents, not program data.
‡ Because thermostat use is occupant-driven, this table contains each applicable survey response i.e., the two CZ4 Single-Family Detached addresses and six CZ5 Attached/MF 2–4 occurring in the same three developments have not been condensed into one and three records respectively.

Mechanical ventilation

As shown in Table A-38, the information on the mechanical ventilation of non-program homes is scarce. However, since program homes are primarily low-efficiency exhaust-only systems such as bath fans, it is unlikely that those of the average non-program home are more performant despite the apparent prevalence of central fan integrated supply (CFIS) systems.

Table A-38. Primary mechanical ventilation by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	1	3	15	5	1	2	27	6
Exhaust-only/Bath fan	100%	33%	100%	80%	100%	100%	93%	83%
Air Cycler (CFIS)	–	67%	–	–	–	–	7%	–
HRV/ERV	–	–	–	20%	–	–	–	17%

All homes have low levels of compliance with mandatory code requirements for fan efficacy as shown in Table A-39. The efficiency of the two program-home HRV/ERVs are modest, and insufficient to classify the equipment as either a heat recovery ventilator (HRV) or energy recovery ventilator (ERV). The detached home's HRV/ERV recovers 66% of sensible energy, but only 36% of total energy. The attached home's HRV/ERV features a 63% sensible recovery rate and 19% total recovery.

Table A-39. Fan efficacy by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	1	2	15	5	0	1	27	6
Exhaust-only/Bath	3.1	11.0	4.4	3.8	–	3.1	4.4	5.3
Air Cycler (CFIS)	–	–	–	–	–	–	0.5	–
HRV/ERV	–	–	–	1.7	–	–	–	0.5
Code Compliant†	0%	0%	7%	25%	–	0%	19%	0%

† There are no HRV/ERV's efficacy requirements in IECC 2015, but IECC 2018 requires 1.2 CFM/W or less.

Water heaters

The majority of program homes possess instantaneous water heaters, as do Attached/MF 2–4 non-program homes in Climate Zone 4. Stand-alone storage systems are more common in non-program homes, especially high-volume tanks among detached homes in Climate Zone 5.

Table A-40. Water heater style by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	29	33	15	5	10	9	27	6
Water Heaters	29	35	15	5	10	9	27	6
Combination boiler	0%	0%	0%	0%	0%	11%	0%	0%
Instantaneous	21%	26%	100%	100%	60%	22%	81%	100%
Stand-alone storage	69%	74%	0%	0%	40%	67%	19%	0%
Ave. Volume	54.7	62.3	–	–	52.7	55.2	46	–

Two-fifths of non-program homes with combustion water heaters in Table A-41 meet ENERGY STAR v 3.2 criteria—the standard in effect when the homes were constructed—whereas 100% of the program home models include ENERGY STAR water heaters. This table includes one detached non-program home in Climate Zone 5 with propane equipment, and excludes a single detached non-program home in Climate Zone 4 with an oil-fired water heater of unknown efficiency.

Table A-41. Gas† water heater efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	20	26	15	5	8	7	27	6
Water Heaters	26	36	15	5	10	10	27	6
Minimum EF‡	0.59	0.59	0.90	0.92	0.61	0.61	0.90	0.90
Mean EF‡	0.73	0.76	0.94	0.95	0.85	0.73	0.94	0.93
Maximum EF‡	0.99	0.99	0.97	0.97	0.99	0.99	0.99	0.97
ENERGY STAR	36%*	50%*	100%	100%	56%*	29%*	100%	100%

† Includes both natural gas and propane-fired equipment; propane in one non-program detached home in CZ5.
‡ Water heaters in some non-program homes were rated in UEF, which have been converted to EF.
* *Potentially* significant difference. Due to the nature of the data collection and small sample sizes, it is not possible to offer firm declarations of statistical significance. However, the Z-scores for these values are potentially distinct from those of the corresponding program homes at the 90% confidence level.

Three of the thirty-seven non-program homes with verified water heater combustion exhaust type had gravity vent water heaters. This style of exhaust is more prone to backdraft and carbon monoxide problems than direct vent or power vent equipment.

As can be seen from the efficiencies below 1.00 in Table A-42, there are no heat pumps among the small number of electric water heaters in program and non-program homes.

Table A-42. Electric water heater efficiency by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	1	–	–	–	–	1	3	–
Water Heaters	1	–	–	–	–	1	3	–
Minimum EF	0.95	–	–	–	–	0.95	0.93	–
Mean EF	0.95	–	–	–	–	0.95	0.94	–
Maximum EF	0.95	–	–	–	–	0.95	0.95	–
ENERGY STAR	0%	–	–	–	–	0%	0%	–

Hot water distribution

According to the program home models provided, none of the program homes include fully insulated hot water systems or 100% low-flow fixtures. Although insufficient information about water fixtures was available for non-program homes, the survey responses allowed the team to document water pipe material (Table A-43) and verify that insulation was absent in all cases. While the polymers which are the majority of hot water piping in non-program homes are modestly better insulators than copper, they still require insulation to reduce energy loss. However, the building code pipe insulation requirement is limited to the prescriptive path. It is possible that some builders were relying on an exception that does not require piping in conditioned space to be insulated, even though basement classification is a notoriously challenging and potentially subjective aspect of rating homes.[67]

Table A-43. Hot water pipes by home type and program status

	Single-Family Detached				Attached/MF 2–4			
	Non-Program		Program		Non-Program		Program	
	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5	CZ 4	CZ 5
Sites	20	21	15	5	4	6	24	6
Copper	25%	38%	–	–	25%	17%	–	–
PEX	70%	58%	–	–	75%	67%	–	–
PVC	5%	14%	–	–	0%	17%	–	–

[67] The prevalence of different basement types as determined by the team's review of available details may be found in Table 1 8.

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