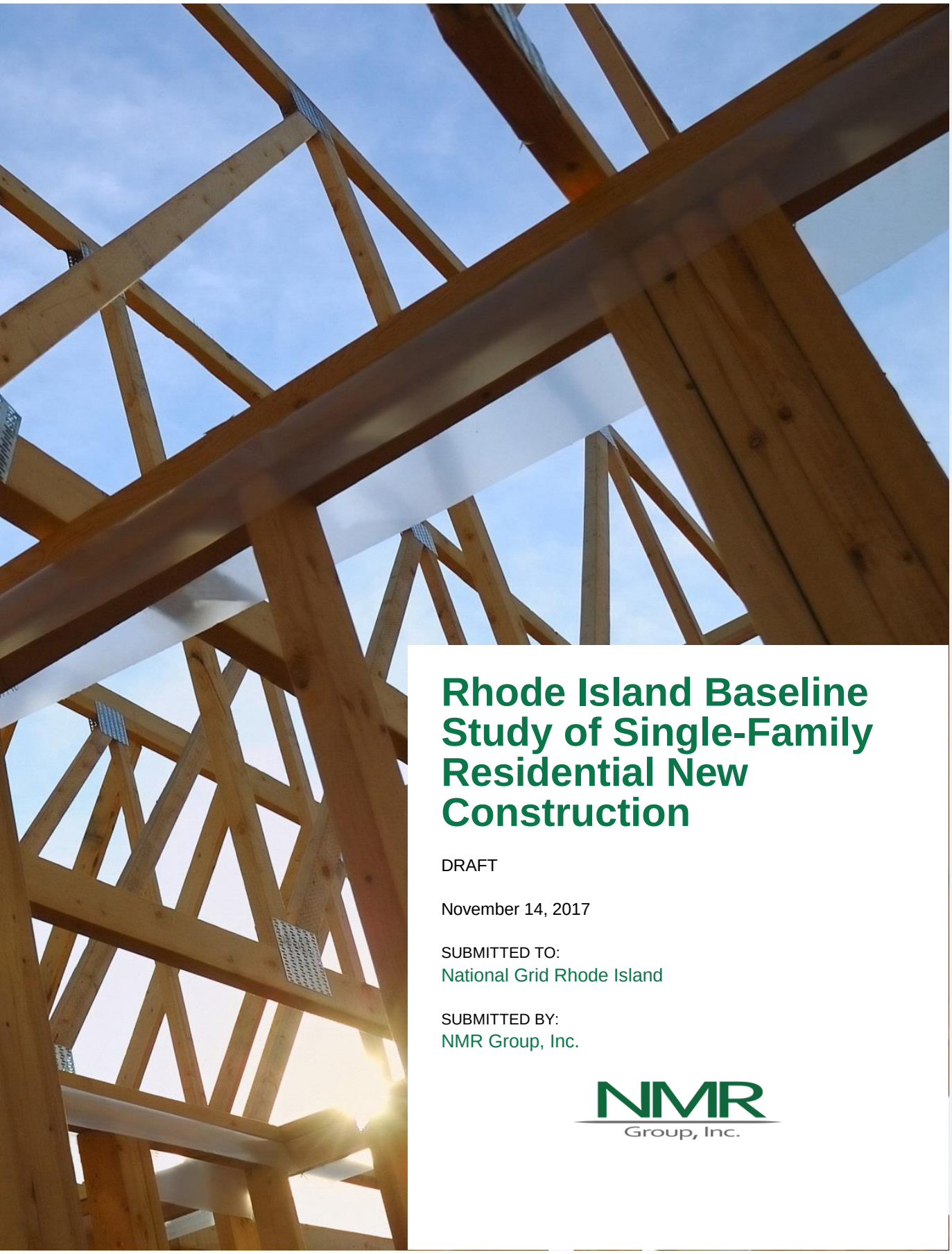

Rhode Island Baseline Study of Single-Family Residential New Construction

DRAFT

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SUBMITTED TO:
National Grid Rhode Island

SUBMITTED BY:
NMR Group, Inc.

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ES Executive Summary

The Code Compliance Enhancement Initiative (CCEI) is an effort sponsored by National Grid Rhode Island to improve code compliance among residential and commercial new construction projects. NMR conducted a three-part evaluation of the CCEI's impacts on code compliance, including (1) immediate surveys of CCEI training attendees, (2) follow-up interviews with CCEI trainees to see how training affected their work, and (3) a baseline study of 40 non-program homes to assess residential new construction (RNC) building practices. This report describes the results of the baseline study. The baseline study itself had two primary goals: to assess the code compliance of new homes built under the 2012 International Energy Conservation Code (IECC) cycle, and to update the User Defined Reference Home (UDRH) for National Grid's Residential New Construction (RNC) program, the market baseline against which the program calculates savings. This evaluation describes the inspected homes and assesses their compliance with code; the UDRH results and the analyses of the CCEI's trainings impacts are presented in separate reports.

The Rhode Island RNC program complements the CCEI program and provides financial incentives to builders to encourage efficient construction practices. The RNC program calculates energy savings by comparing the consumption of program homes to a hypothetical typical home. Periodic baseline studies such as this one inform the program administrators about how typical new homes are constructed. This allows the program to claim savings against true market conditions, rather than against assumptions about builder practices.

This study included site visits in 2017 to 40 new, non-program homes (19 spec- and 21 custom-built) across 48 Rhode Island cities and towns. On-site inspections focused on key energy-related aspects of the homes, including the thermal envelope, mechanical systems, lighting, appliances, and air infiltration. Home Energy Rating System (HERS) ratings were performed for all of the visited homes.[1] Sites were also compared against the requirements of the 2012 IECC in multiple ways – at the measure level, using the PNNL checklist approach, and using the MA-REC methodology.

Comment [KR1]: 40 homes in 48 jurisdictions?

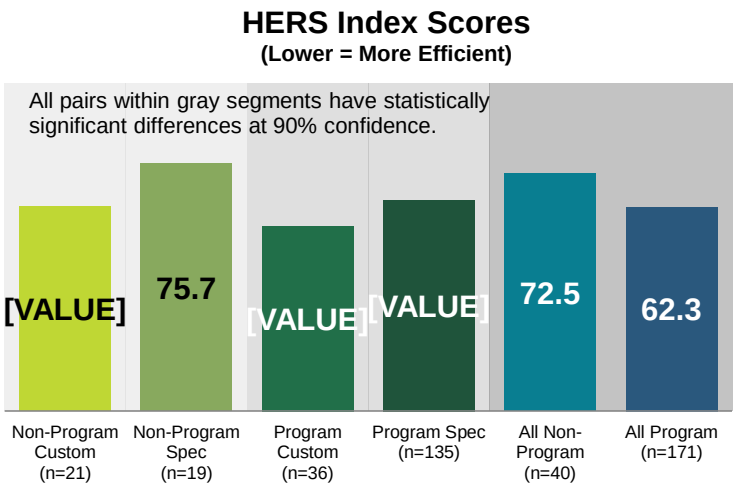
FINDINGS

This section offers a high-level summary of the findings presented in the body of the report.

[1] The HERS index is a nationally recognized rating system through which a home's energy-efficiency is measured. The index scores range from below zero to well above 100. A standard new home built at the time the index was created would have a rating of 100. A home with a score of 70 would be 30% more energy-efficient than home with a score of 100, while a home with a score of 130 would be 30% less energy-efficient.

Comparison to Program Homes

Program homes perform better overall than non-program homes.



Program homes performed better than non-program homes on nearly all analyzed measures – with statistically significant differences for most comparisons[2] – such as ceiling insulation, heating system AFUE, air leakage, duct leakage to the outside, and efficient lighting. However, program and non-program homes are not significantly different in terms of a few key measures, such as wall insulation, cooling system SEER, and total duct leakage. In fact, non-program homes have significantly more efficient water heater Energy Factors.

Program homes far outperform non-program homes in terms of duct leakage to the outside: 4.7 CFM25/100 sq. ft. of conditioned floor area (CFA) vs. 8.8[3] (lower values indicate less leakage), and slightly outperform in total duct leakage (18.3 vs. 20.6).[4] Both groups of homes fare poorly on average against the Rhode Island 2012 IECC, which requires total duct leakage to be no more than 8 CFM25/100 sq. ft. of CFA.

Importantly, program homes fare far better in terms of overall efficiency based on HERS Index scores.[5] Program homes have an average HERS Index score of 62, significantly better (lower) than the average score for non-program homes of nearly 73. Based on HERS Index scores, custom homes also outperform spec homes in both program and non-program samples; in fact, the average HERS Index score of non-program custom homes essentially matches the overall program average.

Comment [KR2]: Potential footnote: any significant difference between CFA in custom vs spec homes? HERS has historically favored larger homes.

Table 1~~Table 1~~ compares average non-program and program values for key measures. Most of the comparisons show statistically significant differences at the 90% confidence

[2] At the 90% confidence level.
[3] Significantly different.
[4] Not a significant difference.
[5] Program homes only perform worse in terms of average foundation wall R-value, and the difference is not significant.

level. Green-shaded cells indicate the better performing sample, on average, for that measure. Dark red text indicates significant differences at the 90% confidence level.

Table 1: Comparisons between Non-Program and Program Homes

	Non-program Homes (Weighted)	Program Homes (Unweighted)
Exterior wall: Average R-value	19.9 (n=40)	20.4 (n=171)
Exterior wall: Average U-value	0.064 (n=40)	0.062 (n=171)
Flat ceiling[2]: Average R-value	**33.4* (n=32)**	**38.6* (n=141)**
Flat ceiling[2]: Average U-value	**0.054* (n=32)**	**0.032* (n=141)**
Vaulted ceiling: Average R-value	**29.4* (n=22)**	**37.7* (n=101)**
Vaulted ceiling: Average U-value	**0.062* (n=22)**	**0.030* (n=101)**
Frame floor over basement: Average R-value	**20.6* (n=22)**	**29.6* (n=118)**
Frame floor over basement: Average U-value	**0.131* (n=22)**	**0.041* (n=118)**
Conditioned foundation wall: Average R-value	**7.9* (n=12)**	**18.4* (n=18)**
Unconditioned foundation wall: Average R-value	0.8 (n=22)	0.3 (n=117)
Attic duct supply: Average R-value	**7.3* (n=20)**	**8.0* (n=76)**
All other ducts: Average R-value	6.3 (n=29)	6.5 (n=117)
Duct leakage to outside: Average CFM25/100 sq. ft. CFA	**8.77* (n=36)**	**4.65* (n=128)**
Total duct leakage: Average CFM25/100 sq. ft. CFA	20.6 (n=37)	18.3 (n=128)
Air infiltration: Average ACH50	**5.24* (n=39)**	**4.14* (n=171)**
Fossil-fuel Heating System AFUE (systems with AFUE ratings)	**92.5* (n=39)**	**94.7* (n=164)**
Cooling System SEER (systems with SEER ratings)	14.1 (n=52)	14.2 (n=115)
Water Heater EF (systems with EF ratings)	**1.30* (n=43)**	**1.08* (n=171)**
Efficient lamp saturation	**66%* (n=40)**	**83%* (n=171)**

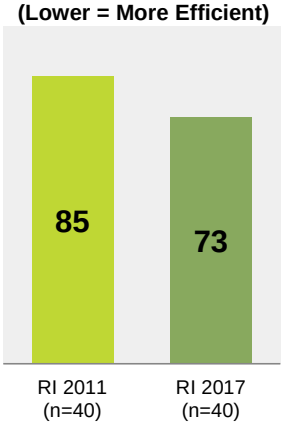
* Significantly different at the 90% confidence interval.
[1] Conditioned to ambient walls only.
[2] Includes hatch area.

Comparison to Previous 2011 Rhode Island Baseline

Non-program homes have improved since the previous baseline.

Since the 2011 Rhode Island baseline study, non-program homes have improved for most key measures associated with home efficiency. Duct leakage and efficient lighting saw particularly notable improvements, while shell measures saw limited improvement.

HERS Index Scores: Non-program
(Lower = More Efficient)



HERS Index Scores. The 2017 non-program homes have an average HERS Index score of 73, which is much better than the 2011 average of 85.

Envelope. Average per-home R-values for most key shell measures improved since 2011. Walls and floors both improved from R-18 to R-20. Flat ceilings improved slightly from R-35 to R-36. Vaulted ceilings saw a slightly negative change, from R-33 to R-29 (R-32 if an outlier is excluded).

Duct Leakage and Air Infiltration. Duct leakage to the outside improved a great deal – by 57% – from 20 CFM25/100 sq. ft. of CFA to 8.6. Air leakage improved by 12%, from 6.0 ACH50 to 5.3. Both improvements occurred even though Rhode Island's amendments to the 2012 IECC remove specific air infiltration requirements from the code and relax total duct leakage requirements.[6] However, total duct leakage, at 20.6 CFM25/100 sq. ft., is far higher (worse) than the Rhode Island 2012 IECC requirement of 8 or less. Only 10% of non-program homes meet that code requirement.

Heating. Fifteen percent of homes were heated with oil in 2011, but only six percent use oil for heating in 2017. Propane and electricity have increased in prevalence to compensate. In 2011, furnaces and boilers were both common (45% and 51%[7] of homes, respectively). As of 2017, furnaces have surged in market share: 70% of homes heat[8] with furnaces vs. only 23% with boilers.[9] The AFUE of fossil-fuel fired equipment improved since 2011, from 90.9 AFUE to 92.1.

Comment [KR3]: Just to clarify all this change didn't happen in one year.

Cooling. The efficiency of central air conditioning (CAC) systems has increased slightly since the 2011 study (13.2 SEER to 13.7 SEER). CAC is also more common than it was in the 2011 study (83% of homes vs. 64%).

[6] The standard version of the 2012 IECC requires total duct leakage of no more than 4 CFM25 per 100 square feet of conditioned floor area; the Rhode Island amendments allow twice as much total duct leakage: up to 8 CFM25/100 sq. ft. of CFA. However, there is no specific requirement for duct leakage to the outside. The 2009 IECC in Rhode Island allowed compliance with duct leakage either by limiting leakage to the outside to 8 CFM25 or total leakage to 12 CFM25 or less. The standard 2012 IECC also allows air infiltration of no more than 3 ACH50; the Rhode Island amendments do not have an ACH50 requirement, and only require blower door testing.
[7] Including combi appliances.
[8] This refers to the primary (largest capacity) heating system type in the home.
[9] Including combi appliances.

Water heaters. For water heater types present in both samples, the average efficiency of each type increased since 2011. There was more system diversity in 2017: heat pumps, combi appliances,[10] and commercial tanks were not present in 2011. Conventional electric storage tanks became the most common system (32%) in 2017, up from 15%. Heat pump water heaters were in second place (18%). Fossil fuel-fired indirect systems, instantaneous systems, and storage tanks used to make up three-fourths of water heaters in 2011, but in 2017 they were down to 42%.

Lighting. Seventy-seven percent of 2017 homes use high-efficiency bulbs in at least 50% of permanent sockets, a huge increase over the 8% of homes in 2011. Overall efficient bulb saturation is up to 58% of all sockets in Rhode Island based on sampled home results.

Code Compliance

The PNNL compliance assessment estimates non-program code compliance at 63%, and the MA-REC methodology estimates 80%.

This study assessed code compliance for the 40 non-program homes via two methods: (1) using the Pacific Northwest National Laboratory (PNNL) code compliance checklist approach, and (2) the MA-REC approach that uses energy modeling results to estimate code compliance.

PNNL approach. The PNNL 2012 IECC checklist allows homes to be scored for their code compliance using a point system, with different items given different relative weights (based on their impact on energy-efficiency).

On average, the non-program baseline homes achieved compliance scores (based on the percentage of achievable points they attained on the PNNL checklists) of 63% (weighted, and 67% unweighted) – a 100% score would represent compliance with every observable and applicable measure on the PNNL checklist. Non-program custom homes have significantly higher average compliance scores than spec homes, 74% vs. 59%. At a measure level, baseline homes fare worst with ceilings, achieving only 39% of the available compliance points for ceiling insulation. Homes achieve at least 60% compliance, on average, for most other measures.

By estimating that program homes would have achieved PNNL checklist compliance scores between 90% and 100%, the average overall statewide compliance score – including program and non-program homes – is estimated to fall between 69 and 71%.

MA-REC Approach. The MA-REC approach uses energy modeling to develop a scoring system that is more calibrated to estimated energy consumption than the PNNL approach is. Unlike the PNNL approach, the MA-REC approach focuses only on code requirements

[10] "Combi appliances" are boilers used to provide space heating and domestic hot water. These combination system boilers often resemble instantaneous water heaters.

that directly impact energy consumption. This methodology uses REM/Rate models to compare homes to IECC prescriptive requirements.

Using the MA-REC approach, we found that non-program compliance with the 2012 IECC (with Rhode Island-specific amendments) is 80%, on average. Custom homes (87%) display higher compliance rates than spec homes (78%), although the difference is not significantly different. At the measure level, ceiling insulation displays the lowest average compliance percentage, at 55%.

Program homes have a significantly higher average compliance rate (93%) than non-program homes. Statewide, accounting for both program homes and non-program homes, the compliance rate is 83%.[11]

Conclusions and Recommendations

Some of the following conclusions and recommendations are directly connected to the research questions guiding this evaluation, but others are based on the team's experience conducting the on-site visits.

Code Compliance. Statewide compliance in Rhode Island is relatively high (83%) using the MA-REC methodology. Among non-program homes, ceiling insulation displays the lowest measure-level compliance using both the MA-REC (55%) and PNNL (39%) compliance methodologies.

> **Recommendation**. The CCEI should focus future training efforts on measures displaying the lowest compliance amongst non-program homes. These include ceiling insulation, frame floor insulation, and duct leakage.

Air Leakage and Duct Leakage. Rhode Island adopted amendments to the 2012 IECC that resulted in less stringent air and duct leakage requirements relative to the base version of the 2012 IECC. Even so, non-program homes in Rhode Island improved considerably since the previous baseline study, particularly for duct leakage to the outside. Program homes in Rhode Island outperform non-program homes in terms of duct leakage to the outside and total duct leakage. However, total duct leakage is not a significant difference, and on average, even program homes perform well below the total duct leakage requirements of the amended 2012 IECC (18 CFM25/100 sq. ft. of CFA against the code requirement of no more than 8).

> **Recommendation**. The Rhode Island program should continue to promote efficient air infiltration and duct sealing practices in program homes. The program should pay particular attention to improving duct leakage results, which have not kept pace with Rhode Islands amended version of the 2012 IECC. The relatively poor performance of non-program homes – likely due, at least in part, to relaxed code requirements relative to the base version of the 2012 IECC – represents a continued savings opportunity.

[11] The statewide compliance rate was calculated using an estimated program penetration rate of 21%.

Overall program effectiveness. Program homes outperform non-program homes, and for both program and non-program homes, custom homes outperform spec homes.

> **Recommendation**. The program should continue its successful promotion of efficient new homes. In addition, the program should focus on working with program builders of spec homes to increase their efficiency, as these homes lag the custom homes by nearly 10 points on the HERS Index, on average.

Comment [KR4]: Again, want to note the degree to which CFA difference drives this.

REM/Rate Version. This study relied on REM/Rate Version 14 for modeling (the appropriate version for homes built during this period). Version 15 has since been released, and it offers homes the ability to take credit for savings associated with efficient domestic hot water distribution configurations, and for using drain water heat recovery systems.

> **Recommendation**. The RNC program should promote these practices among program homes to further drive savings for efficient practices unlikely to be seen in the broader market.

1 Section 1 Introduction and Methodology

This baseline study was commissioned by National Grid as part of a broader study to estimate the savings due to enhanced code compliance that may be attributed to National Grid's Code Compliance Enhancement Initiative (CCEI) in Rhode Island. The overall attribution study included three main evaluation activities: immediate surveys of CCEI training attendees, follow-up in-depth interviews with CCEI training attendees to see how training affected their work, and a residential baseline study to document the energy-efficiency of Rhode Island homes built three years into the 2012 International Energy Conservation Code (IECC) cycle.

Comment [KR5]: Delayed code update means this is no longer the end of cycle

The results of this baseline study were also used to update the User Defined Reference Home (UDRH), against which the National Grid's Residential New Construction (RNC) program claims savings. This report only presents the findings from the baseline study. The results of the other pieces of the attribution work, including the UDRH results, are presented in separate reports.

The attribution of savings to the CCEI efforts involved looking at the change in non-program building practices over time to determine if these were focus areas of CCEI activities. This included talking with CCEI training participants to see if they learned new information from the trainings and if they applied what they learned to their non-program projects.

1.1 Study Objectives and Background

1.1.1 Program and Evaluation Background

Rhode Island adopted an amended version of the 2012 IECC on July 1, 2013.[12] National Grid started the Rhode Island CCEI in 2013 to improve compliance with the new residential and commercial requirements of the 2012 IECC by offering classroom and in-field trainings. The CCEI offered residential and commercial training sessions for builders, subcontractors, architects, code officials, and other relevant audiences. Examples of training topics offered by the CCEI regarding the 2012 IECC requirements include:

- Overview of the 2012 IECC requirements
- Envelope and building science
- HVAC and indoor air quality
- Mechanical provisions
- Lighting, lighting control, and electrical provisions

[12] http://www.energy.ri.gov/documents/rfp/NGRID%20Code%20Compliance%20RFP,%202.12.2013.pdf

By conducting a baseline study of homes built later in the 2012 IECC code cycle, this study attempted to examine Rhode Island homes that could have been impacted by the CCEI's efforts.

The National Grid Rhode Island Residential New Construction (RNC) program provides financial incentives to builders to offset some of the marginal cost of building to above-code standards. The RNC program calculates gross savings by taking the REM/Rate energy models of program homes and comparing them to a market baseline.[13] By conducting periodic baseline studies, RNC program administrators can better understand the residential new construction market's change over time, and ensure that they are claiming savings for program homes against a baseline that describes real-world market conditions. The results of this baseline study were used to create a User Defined Reference Home (UDRH) to reflect typical non-program practices, against which the RNC program can compare its program homes. The UDRH details are presented in a separate report.

This report also serves to compare the results of the homes sampled in this 2017 baseline study to the homes sampled in the 2011 residential baseline (the previous residential new construction baseline done in Rhode Island), which covered homes constructed under the 2009 IECC.[14] This allows for program administrators to see changes in building practices over time.

1.1.2 Research Questions

The residential baseline study sought to answer the following questions:

- What is the energy code compliance level for single-family homes built three years into the 2012 IECC cycle?
- What building components are more efficient than prescriptive energy code levels? What components are less efficient than prescriptive code levels?
- What is the User Defined Reference Home (UDRH) for homes built in this period?
- How does compliance vary across compliance path types?
- How have compliance levels changed over time?
- What are the characteristics of homes' thermal envelopes (e.g., insulation, air leakage, duct leakage)?
- What are the efficiency-related characteristics of homes' heating, cooling, and water heating equipment?
- What are the characteristics of homes' other energy-related features, such as lighting and appliances?

[13] REM/Rate is a residential energy modeling software that estimates energy consumption of homes based on the features included in the energy model. The models include information about the building shell, mechanical systems, lighting and appliances, and other energy-related features. REM/Rate is a RESNET approved software used to calculate and generate HERS Index scores.

[14] http://www.rieermc.ri.gov/documents/evaluationstudies/2012/Final-RI-RNC-2011-Baseline-Report-sent-10-8-12.pdf

1.1.3 Research Tasks

To help answer the research questions identified above, the baseline study included the following tasks:

- Conduct on-site inspections at 40 non-program single-family homes.
- Estimate a real-world baseline using on-site findings.
- Produce Home Energy Rating System (HERS) scores for all 40 sites.
- Develop a new UDRH for the RNC program based on non-program measure-level efficiencies. (UDRH findings are presented in a separate report)
- Compare findings with the previous UDRH and previous studies.
- Compare non-program home efficiencies to program home efficiencies.

1.2 SAMPLING

The following subsection describes the methodology behind the baseline study, including sampling, recruitment, and inspection processes. For additional detail, see Appendix D.

1.2.1 Sampling Methodology

The sample design targeted a representative sample of newly constructed, attached and detached single-family homes in National Grid territory. The sample looked at homes permitted after the adoption of the 2012 IECC and focused on those built late in the 2012 IECC code cycle. To be eligible for the baseline study, homes needed to meet the following criteria:

Comment [KR6]: Adjust as above due to delay in code update

- Non-participant in the Rhode Island Residential New Construction program
- Built in the second half of 2014 or later (2015 and 2016), to ensure construction near the end of the 2012 IECC code cycle
    - Homes built in 2013 and early 2014 were excluded from the study because the CCEI trainings would have been less likely to have a measurable market-level impact so early in the roll out of the CCEI's efforts.
- No more than one home per housing development to avoid nearly identical homes in the sample
- Occupied by homeowner; not for sale or owned by the builder
    - This avoids biasing the sample toward efficiency-minded builders and increases the response rate (unoccupied homes result in returned recruitment mailers).
- Located in National Grid Rhode Island service territory

Comment [KR7]: ditto

1.2.2 Sample Targets

The on-site sample was designed to mirror the proportion of homes built in each Rhode Island county in 2014 and 2015 based on one-unit building permits issued in Rhode Island counties in 2014 and 2015. A 40-home sample was developed to reach the 90% confidence level with a 10% sampling error.

In addition to the specified number of on-site inspections by county, the study aimed to maintain at least a 60% spec-built home ratio, in line with the 2011 baseline study. An initial screening question during homeowner recruitment was used to determine if the home was spec- or custom-built:

How did you purchase your home?

1. Purchased land and worked with an architect and/or builder to build the home. (***Custom)***
2. Had a house plan and a lot and hired a contractor/builder to build the home. (***Custom)***
3. I am the owner and builder. (***Custom)***
4. Purchased a lot from a builder, selected one of several house plans offered by the builder and selected from various available upgrade options. (***Spec)***
5. Purchased a home that was under construction and selected from various available upgrade options. ***(Spec)***
6. Purchased a finished home. ***(Spec)***

1.3 Completed On-Site Inspections

National Grid provided address information for nearly 1,500 new electric service requests submitted in their territory to provide the population of homes for the study. These records were screened to remove ineligible sites. Due to low response rates from initial mailings, these records were supplemented via online research of real estate aggregator websites to find additional homes that were not included in the new service request records. Ultimately, 660 recruitment letters were mailed to a total of 417 potential participant homes.

Completed on-site inspections came close to matching the sampling plan targets show in Table 2~~Table 2~~. Kent County had one fewer site visit than targeted due to limited sample and non-response. In addition, we targeted a minimum of 60% spec-built homes in the sample, but experienced low response from homeowners of spec-built homes: 47.5% of the visited homes were spec-built.

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Table 2: Targeted and Completed Visits by County

County	Targeted On-Sites*	Completed On-sites		
		Spec	Custom	Total
Total	40	19	21	40
Providence	15 or 16	12	4	16
Washington	10 or 11	2	9	11
Newport	6	--	6	6
Kent	6	3	2	5
Bristol	2	2	--	2

*Due to rounding, Providence and Washington were given flexible targets.
The county-level proportionality was based on the U.S. Census, Building Permits Survey: https://www2.census.gov/econ/bps/

The inspections took place in 27 towns across the state of Rhode Island. Seventeen towns had one inspection each, eight towns had two inspections, one town had three inspections, and one town had four inspections. The location of each on-site and the custom/spec classification is shown in Figure 1~~Figure 1~~.

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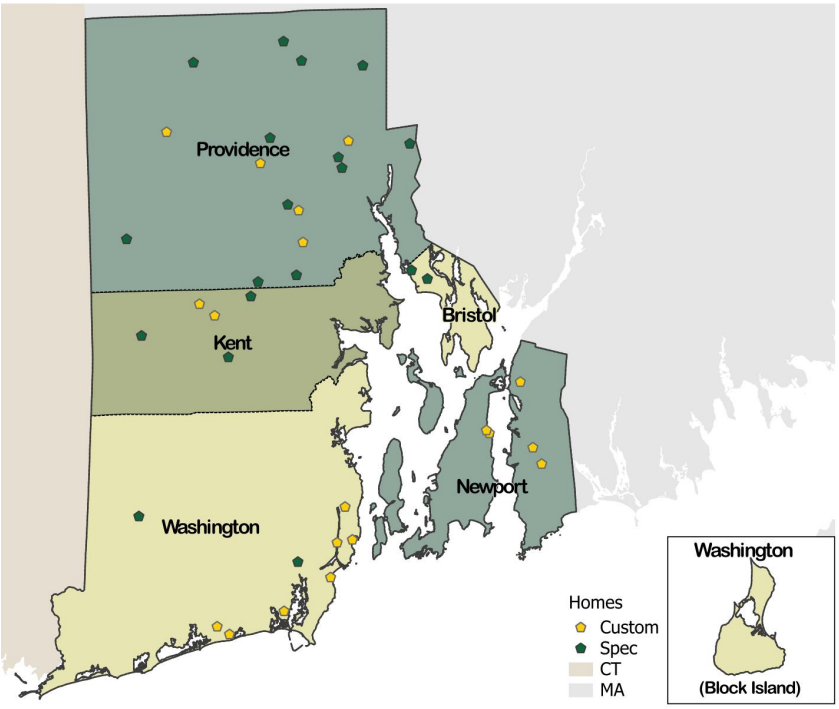
Figure 1: Statewide Map of On-site inspections



1.3.1 Building Department Visits

Building department visits were conducted to collect information about the energy code compliance paths followed for eligible homes. Twenty-seven building departments were visited in person. If an on-site visit was conducted in a town that was not visited, that building department was contacted to determine the home's compliance path.

1.4 On-Site Data Collection Procedures

This section outlines key aspects of the data collection process during on-site inspections.

Data were collected on-site using tablet computers and an electronic data collection form. Additional calculations and research on measures (e.g., calculating interior volume or looking up HVAC system efficiency) were performed as soon as possible after the site visit. An example of a data input screen can be found in Table 3~~Table 3~~. Data were collected on

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the following measures; additional detail on the data collection process can be found in Appendix D.

Table 3: Data Collection Inputs

General Info	Code Compliance	Shell Measures
➢ House type ➢ Conditioned Floor Area (CFA) ➢ Conditioned Volume (CV) ➢ Stories ➢ Bedrooms ➢ Thermostat type ➢ Faucet/shower flow rates ➢ Basement details ➢ Health and safety issues ➢ Home automation systems	➢ Envelope ➢ Heating and cooling ➢ Water heating ➢ Duct and pipe insulation ➢ Ventilation ➢ Pools	➢ Walls ➢ Ceiling ➢ Frame floors ➢ Rim/band joists ➢ Windows, doors, and skylights ➢ Slab floors ➢ Foundation walls ➢ Mass walls ➢ Sunspaces
Mechanical Equipment	**Diagnostic Tests**	**Lighting & Appliances**

• Heating and cooling equipment
• Water heating equipment
• Duct insulation
• Renewables
	• Blower door
	• Duct blaster
	  ○ Total leakage
	  ○ Leakage to outside (LTO)
		• Lighting
		  ○ Fixture type, location, and control
		• Appliances
		  ○ Refrigerators and freezers
		  ○ Dishwashers
		  ○ Washers and dryers
		  ○ Ovens and ranges
		  ○ Dehumidifiers

Comment [KR8]: Can this be restated as "Code Provisions". Compliance is more of an *output* based on this information.

1.5 Statistical Significance, Weighting, and Table Format

Tables in this report identify statistically significant differences at the 90% confidence level (p-value < 0.10). In most instances, comparisons were made between custom homes and spec homes. Values with statistically significant differences are bolded, red, and marked with an asterisk and footnote (Table 4~~Table 4~~).

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Values in "Custom" and "Spec" columns are unweighted. In most tables, the "All Homes" columns were weighted. If the "All Homes" column represented a sample size of less than ten, then values in the column were not weighted. The weights used for the "All Homes" values were based on whether the homes were custom homes or spec homes, and they

were set to match the custom and spec distribution in the relevant program home population.

Table 4: Example of Table Format Showing Percentages

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*count*	*count*	*count*
Characteristic 1	%*	%*	%
Characteristic 2	%	%	%

*Significantly different at the 90% confidence level.

In columns with sample sizes smaller than ten that show percentages, the table displays the counts along with the percentage. In addition, only groups with sample sizes of at least ten were tested for significant differences. Data in the "All Homes" column were not weighted if the total sample size was less than ten (Table 5~~Table 5~~).

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Table 5: Example of Table Format Showing Percentages, without Significance Testing

	Custom	Spec	All Homes (Unweighted)
n (count of relevant unit of analysis)	*<10*	*<10*	*<10*
Characteristic 1	# (%)	# (%)	# (%)
Characteristic 2	# (%)	# (%)	# (%)

Not tested for statistical significance.

For tables displaying descriptive statistics for a given measure, such as a minimum, maximum, mean (identified as "average"), and median value, only the means were tested for statistical significance (Table 6~~Table 6~~).

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Table 6: Example of Table Format Showing Descriptive Statistics

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*count*	*count*	*count*
Minimum	#	#	#
Maximum	#	#	#
Average	#*	#*	#
Median	#	#	#

*Significantly significant difference at the 90% confidence level.

In this report, graphics show the distribution of key values, such as average R-values or average efficiencies. Figure 2~~Figure 2~~ is an example, showing the distribution of HERS Index scores among sampled homes. In these figures, values associated with custom homes are pale green, and spec home values are dark green. The gray-shaded bands represent the middle 50% of values – the interquartile range. The pale gray upper band

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represents the quartile above the median, and the dark gray lower band represents the quartile below the median. The median value is between the two bands. If the values for a given measure are relatively close together, like in the example below, the quartile ranges will be relatively small and the bands will be narrow. If the values are spread widely, the bands will be wider. Narrower quartile ranges indicate a clustering of values.

Figure 2: Example Figure - HERS Index Scores

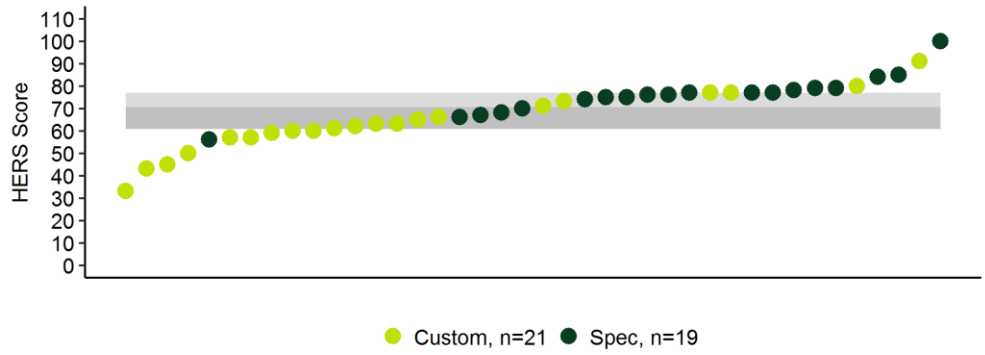

Figure 3~~Figure 3~~ shows a similar graphic, but, because fewer values cluster around the median, the quartile bands are wider. Some graphics, such as this one, also show the non-amended 2012 IECC prescriptive requirement as a reference point (these tend to fall close to the median value).

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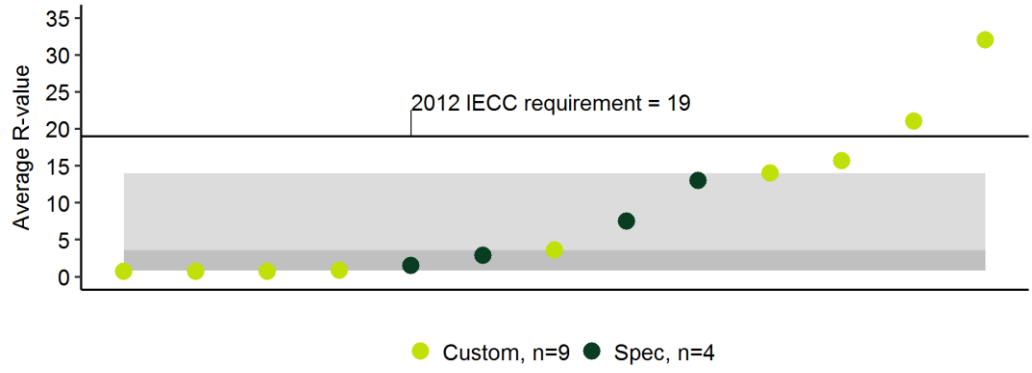
Figure 3: Example Figure - Foundation Wall Insulation



2 Section 2 Comparison to Previous Baseline Studies

This section compares the 2017 Rhode Island baseline results (homes built at the end of the 2012 IECC cycle) to the previous Rhode Island RNC baseline study conducted in 2011 (2009 IECC homes). This allows us to see changes in builder practices over time.

Comment [KR9]: Edit as above

This section also compares the 2017 Rhode Island baseline to a 2015 Massachusetts baseline study to allow for cross-state comparisons of homes built under a similar code version (2012 IECC). Readers should note that Rhode Island uses an amended version of the 2012 IECC, which relaxes several code requirements for measures such as air infiltration and duct leakage. In other words, the Massachusetts version of the 2012 IECC has more stringent requirements for some measures than the Rhode Island version, including for air infiltration and duct leakage – this should be considered when comparing values between the two samples of 2012 IECC homes.

The comparisons include key measures of the homes, such as HERS Index scores, shell measure R-values, air infiltration, duct leakage, lighting, and mechanical equipment. The first subsection compares the 2011 and 2017 Rhode Island baseline studies, and the second subsection compares the 2017 Rhode Island baseline and the 2015 Massachusetts baseline.[15]

Key findings include the following:

Rhode Island change over time: 2011 vs. 2017 baselines of non-program homes:

- The average HERS Index score of 73 for non-program Rhode Island homes is a major improvement over the 2011 baseline average of 85.
- Since the 2011 study, the average R-value has increased at least slightly for key shell measures (other than vaulted ceilings).
- Furnaces are far more common in 2017 than they were in 2011. They are primary heating systems in 70% of homes in 2017 homes, up from 45% in 2011. Boilers have sharply decreased in prevalence. They were primary systems in 48% of homes in 2011 (51% including combi appliances), but they are down to only 17% in 2017 (23% including combi appliances).
- Fifteen percent of homes were heated with oil in 2011; this is down to only six percent in 2017.
- The efficiency of fossil fuel-fired heating systems increased from 90.9 AFUE in 2011 to 92.1 in 2017.

[15] Values from previous baseline studies were weighted in those reports to represent statewide populations; we use those same weighted values for the basis of our comparisons. Because the comparisons are based on previously reported values, the differences between the study results were not tested for statistical significance.

- The average SEER of central air conditioners has only slightly increased from 13.2 to 13.7. However, central AC is more common than it used to be, up from 64% of homes in 2011 to 83% in 2017.
- The average efficiency of each water heater type has increased. There is also more water heater diversity in the 2017 sample, including heat pump water heaters, combi appliances, and commercial storage tanks, which were not seen previously. Electric systems are more common than in the past – the top two types are electric storage tanks (32%, up from 15% in 2011) and heat pump water heaters (18%).
- Duct leakage to outside improved dramatically since 2011 from 20.0 CFM25/100 sq. ft. of CFA to 8.6, a 57% improvement.
- Air infiltration improved modestly from about 6 ACH50 in 2011 down to 5.3 in 2017, a 12% improvement.
- Over three-quarters (77%) of 2017 homes had 50% or greater efficient bulb saturation in permanently installed light fixtures. This is a substantial increase over 2011, when only 8% of homes met this requirement.

Rhode Island (2017) vs. Massachusetts (2015) Baselines:

- The average HERS Index score of 70 in the Massachusetts sample is slightly better (lower) than the average of 73 in Rhode Island.
- Average R-values for shell measures are higher in Massachusetts for all measure types, particularly for flat ceilings (R-42 vs. R-36) and floors over basements (R-32 vs. R-20).
- Walls are quite similar (less than R-1 apart), and Rhode Island's vaulted ceilings would be slightly better on average if not for one home with uninsulated ceiling area.
- AFUE of fossil fuel-fired heating systems is somewhat higher in Massachusetts (94.2 vs. 92.8), while Rhode Island has a slightly higher average CAC SEER (13.7 vs. 13.3).
- The Massachusetts sample performs substantially better in terms of duct leakage. Average leakage to outside and total duct leakage values are 3.9 CFM25/100 sq. ft. of CFA and 9.0 in Massachusetts, respectively, compared to 8.6 and 20.6 in Rhode Island.
- Massachusetts homes perform better in terms of envelope leakage: 3.6 ACH50 in Massachusetts vs. 5.2 in Rhode Island.
- Efficient bulb saturation is much greater in Rhode Island – 58% of homes in Rhode Island have 75% or greater efficient bulb saturation in permanent fixtures compared to just 19% in Massachusetts.

2.1 Comparison to 2011 Rhode Island Baseline Study (2009 IECC)

2.1.1 Key Characteristics of 2011 Rhode Island Baseline Study

- On-sites performed at 40 non-program, single-family homes in Rhode Island, permitted under 2009 IECC cycle
- Ten homes completed in 2010 and 30 completed in 2011

- 26 spec homes and 14 custom homes
- Homes recruited through homeowners, not builders
- Sampling plan similar to 2016 Rhode Island baseline
  - Based on number of one-unit building permits issued in RI counties in 2010 (using Census data)
  - On-sites in each county proportional to permits issues in that county

2.1.2 Comparison Results

Conditioned Floor Area (CFA)

The average CFA of non-program homes has increased only slightly since the 2011 study, from 2,245 sq. ft. up to 2,339 sq. ft. (Table 7~~Table 7~~)

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Table 7: Conditioned Floor Area (CFA)

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
n (homes)	*40*	*40*
Minimum	935	1,115
Maximum	5,244	6,070
Average	2,245	2,339
Median	1,974	2,108

HERS Index Scores

The average HERS Index score improved from 85 in 2011 to 73 in 2017 (Table 8~~Table 8~~). The minimum and maximums are also quite a bit lower (better) than the 2011 sample.

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Table 8: HERS Index Scores

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
n (homes)	*40*	*40*
Minimum (best)	62	33
Maximum (worst)	117	100
Average	85	73
Median	85	72

Building Envelope

Table 9~~Table 9~~ compares average R-values for key shell measures across the two Rhode Island samples. Conditioned to ambient walls increased in average R-value from R-18.3 in 2011 to R-19.8 in 2017, nearly to the code requirement of R-20. The average R-value of framed floors over basements has increased slightly from R-18.3 in 2011 to R-20.0 in 2017.

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The R-value of flat ceilings has improved slightly from R-34.5 to R-36.1 (or R-37.4 if we exclude an unusual home with uninsulated ceilings in a “DIY” bonus room). Vaulted ceilings

perform somewhat worse than in the 2011 sample, dropping from R-33 in 2011 to R-29 (or to R-32 if we ignore the previously mentioned outlier with uninsulated ceiling area).

Table 9: Wall, Ceiling, and Floor R-Values

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
Conditioned to Ambient Wall Insulation		
n (homes)	*40*	*40*
Average R-value	18.3	19.8
Prescriptive code requirement	20 or 13+5*	20 or 13+5*
Flat Ceiling Insulation*		
n (homes)	*35*	*32*
Average flat ceiling R-value	34.5	36.1 (37.4 w/outlier)
Prescriptive code requirement	38	49
Vaulted Ceiling Insulation*		
n (homes)	19	22
Average vaulted ceiling R-value	33.0	29.4 (32.3 w/out outlier)
Prescriptive code requirement	38***	49***
Floor Insulation over Unconditioned Basements		
n (homes)	27	22
Average R-value	18.3	20.0
Prescriptive code requirement	30**	30**

* First value is cavity insulation, second is continuous insulation or insulated siding, so "13+5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding.
** Or insulation sufficient to fill the framing.
***Allows for up to 20% (capped at 500 sq. ft.) of ceiling to be as little as R-30.

Primary Heating Systems

Propane and natural gas are the dominant heating fuels in both samples (Table 10~~Table 10~~). The share of oil-fueled systems drops from 15% to 6% between 2011 and 2017. The share of furnaces among primary heating systems increases from 45% in 2011 to 70% in 2017. That increase comes at the expense of boilers, which drop from 48% of primary equipment in 2011 – the most common type observed in that sample –to 17% in 2017. The average AFUE among all fossil-fuel fired systems has increased slightly in 2017, from 90.9 in 2011 to 92.1.

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Table 10: Heating System Type, Fuel, and Efficiency

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
n (homes)	*40*	*40*
Primary Heating Fuel		
Propane	35%	45%
Natural gas	45%	42%
Oil	15%	6%
Electric	5%	7%
Primary Heating System Type		
Furnace	45%	70%
Boiler	48%	17%
Combi appliance	3%	6%
GSHP	3%	5%
ASHP	--	2%
Electric baseboard	3%	--
Overall AFUE (all fossil fuel systems)	90.9	92.1

Cooling Equipment

The proportion of homes without a cooling system dropped from 31% to 8% (Table 11~~Table 11~~). Central air conditioners (CACs) have grown in market share (primary CAC systems increased from 64% to 83% of homes) while heat pumps remain relatively uncommon as primary systems (6% of homes in 2011, and 8% in 2017). The average efficiency of CAC systems has increased only slightly from 13.2 SEER in 2011 to 13.7 in 2017. The cooling capacity per square foot of conditioned floor area (CFA) remains unchanged.

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Comment [KR10]: Worth making a recommendation here regarding focusing on right-sizing HVAC systems in trainings?

Table 11: Cooling Systems

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
Type of Primary Air Conditioning Installed		
n (homes)	*40**	*40*
Central air conditioning	64%	83%
Window/portable	--	1%
Ductless mini split	3%	--
No air conditioning	31%	8%
GSHP	3%	5%
ASHP	--	3%
CAC SEER		
n (CAC systems)	*40*	45
Average SEER	13.2	13.7
Cooling Capacity per sq. ft. of CFA		
n (homes)	*27*	*38*
Btu/hr. per 100 sq. ft. CFA	20.2	20.2

*Data on percent of systems for 2011 are unweighted.

Water Heating Equipment

Table 12~~Table 12~~ compares water heaters by type and fuel between the two baseline samples. In 2011, fossil-fuel fired indirect, instantaneous, and storage systems dominated the sample (76% all together). This was down to 42% in 2017. Electric conventional storage systems dominated in 2017 (32%) followed by efficient heat pump systems (18%) (these were not present in the 2011 sample).

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Table 12: Water Heater Type and Fuel

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
n (homes)	*41*	*43*
Storage, standalone (electric)	15%	32%
Heat pump water heater (electric)	--	18%
Storage, standalone (natural gas and propane)	20%	17%
Instantaneous (natural gas and propane)	27%	16%
Indirect w/ storage tank (fossil fuel-fired)	29%	9%
Combi appliance (natural gas and propane)	--	5%
Commercial storage (electric)	--	2%
Tankless coil (propane)	10%	1%

Table 13~~Table 13~~ shows a comparison of Energy Factors for water heating equipment types that are present in both the 2011 and 2017 samples (it excludes heat pump water heaters, combi appliances, and commercial electric storage systems, which were only present in the most recent study). The average Energy Factor has improved in the 2017

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sample relative to the previous baseline for every equipment type, though sample sizes are frequently limited.

Table 13: Water Heater Energy Factors (System Types Found in Both Studies)

	2011 Baseline (2009 IECC)		2017 Baseline (2012 IECC)	
	n (water heaters)	EF	*n (water heaters)*	EF
Electric storage, standalone	*6*	.91	*9*	.95
Natural gas and propane instantaneous	*11*	.87	*9*	.93
Natural gas and propane storage, standalone	*8*	.63	*5*	.68
Fossil fuel indirect w/ storage tank*	*12*	.81	*6*	.84
Tankless coil**	*4*	.48	*1*	.50

*Efficiency of indirect tanks based on boiler AFUE.
**Efficiency of tankless coils is a function of home size, based on bedroom count.

Duct Leakage and Air Infiltration

Table 14~~Table 14~~ shows a comparison of duct and air leakage data from the two samples. The average leakage to outside (the amount of duct leakage to areas outside the conditioned volume of the home) of duct systems has improved dramatically between the two baselines, from 20.0 CFM25 per 100 sq. ft. down to 8.6. Despite this huge improvement, the 2017 average is still just shy of the amended Rhode Island 2012 IECC code requirement of 8 CFM25/100 sq. ft. total leakage.

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The improvement in air leakage is less extreme, from an ACH50 just under 6.0 to 5.3. The Rhode Island amendments to the 2012 IECC do not dictate a specific ACH50 requirement, which makes it unsurprising that the numbers did not change dramatically over this period.

Table 14: Total Duct Leakage and Air Infiltration

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
Duct Leakage to the Outside (CFM25 per 100 sq. ft. CFA)		
n (homes tested)	*22*	*36*
Sampled homes	20.0	8.6
Code requirement	Leakage to outside ≤ 8 or Total leakage ≤ 12	No requirement
Air Infiltration (ACH50)		
n (homes tested)	*38*	*39*
Sampled homes	6.0	5.3
Code requirement	Visual or ≤ 7	Testing*

*RI amendments to 2012 IECC increase the total duct leakage allowance to 8 CFM25 per 100 sq. ft. of conditioned floor area and do not have an ACH50 requirement for air infiltration, only requiring testing.

Lighting

Table 15~~Table 15~~ illustrates a major increase in lighting efficiency. Only 8% of the 2011 baseline homes met the 2009 IECC standard (50% of hard-wired fixtures with efficient lamps); in the 2017 study, 77% meet that threshold. The 2012 IECC standards are stricter – 75% of fixtures must have efficient lamps, and over half (58%) of the 2017 baseline homes met that threshold (only 5% would have in the 2011 sample). This is a huge improvement, though the flip-side is that over 40% of the recently built homes do not meet the 2012 IECC's lighting requirement.

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Table 15: Proportion of Hard Wired Sockets with Efficient Bulb Types

	2011 Baseline (2009 IECC)	2017 Baseline (2012 IECC)
n (homes)	*38*	*40*
50% to 74% (2009 IECC = 50%+)	3%	19%
75% to 100% (2012 IECC = 75%+)	5%	58%

2.2 Comparison to the 2015 Baseline Study in Massachusetts (2012 IECC)

2.2.1 Key Characteristics of the 2015 Massachusetts Study

- On-sites were completed at 50 homes under the 2009 IECC code cycle, 50 homes under the 2012 IECC, and 46 homes under the Stretch Code (146 total).
  - Only the 2012 IECC homes are included in the comparison between Massachusetts and Rhode Island baselines.
- The 2012 IECC homes included in the sample were completed between 2014 and 2016, with 80% built in 2015.
- There were 40 spec homes and 10 custom homes in the sample.
- Sites were recruited through homeowners, not builders.
- The sampling plan was slightly different (more complex) than the 2017 Rhode Island baseline, based on the town-level cluster sampling.

2.2.2 Comparison Results

Conditioned floor Area (CFA)

Table 16~~Table 16~~ compares conditioned floor area (CFA) statistics for the Massachusetts 2012 IECC sample and the 2017 Rhode Island sample. Homes in the Massachusetts sample are slightly larger on average than their Rhode Island counterparts, with an average of 2,564 sq. ft. of CFA compared to 2,339 sq. ft. in Rhode Island.

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Table 16: Conditioned Floor Area (Sq. ft. of CFA)

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
n (homes)	*50*	*40*
Minimum	1,040	1,115
Maximum	5,041	6,070
Average	2,546	2,339
Median	2,536	2,108

HERS Index Scores

The Massachusetts sample outperforms the Rhode Island sample on the HERS index, with lower (better) scores for minimum, maximum, average and median values (Table 17~~Table 17~~). Massachusetts 2012 IECC homes average a HERS Index score of 70, three points better than the 73 in Rhode Island.

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Table 17: HERS Index Scores

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
n (homes)	*50*	*40*
Minimum (best)	38	33
Maximum (worst)	90	100
Average	70	73
Median	70	72

Building Envelope

Table 18~~Table 18~~ compares the R-values of key shell measures between the Massachusetts and Rhode Island samples. The Massachusetts sample has slightly higher average R-values for walls (R-20.6 vs. R-19.8). Flat ceilings in Rhode Island fall well below the Massachusetts homes, R-36.1 (or R-37.4 if we exclude an unusual home in Rhode Island that had uninsulated ceilings in a DIY bonus room) vs. R-42. Vaulted ceilings show mixed results: Massachusetts has R-31 on average, while Rhode Island has R-29 (or R-32 if we exclude the previously mentioned home with uninsulated ceiling area).

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Framed floors in Massachusetts had a higher average R-value (R-31.5) than floors in Rhode Island, which fall well below code at only R-20, on average. Several homes in the Rhode Island sample had uninsulated framed floors over unconditioned basements, which is the cause of the low average R-value.

Table 18: Wall, Ceiling, and Floor R-Values

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
Conditioned to Ambient Wall Insulation		
n (homes)	*50*	*40*
Average R-value	20.6	19.8
Prescriptive code requirement	20 or 13+5*	20 or 13+5*
Flat Ceiling Insulation		
n (homes)	*48*	*32*
Average flat ceiling R-value	42.4	36.1 (37.4 w/outlier)
Prescriptive code requirement	49	49
Vaulted Ceiling Insulation		
n (homes)	31	22
Average vaulted ceiling R-value	31.2	29.4 (32.3 w/out outlier)
Prescriptive code requirement	49***	49***
Floor Insulation over Unconditioned Basements		
n (homes)	44	22
Average R-value	31.8	20.0
Prescriptive code requirement	30**	30**

* First value is cavity insulation, second is continuous insulation or insulated siding, so "13+5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding.
** Or insulation sufficient to fill the framing
***Allows for up to 20% (capped at 500 sq. ft.) of ceiling to be as little as R-30.

Heating Equipment

Furnaces are the primary heating equipment in both the Massachusetts sample (90%) and the Rhode Island (70%) sample. There is greater variety among the Rhode Island sample in the equipment types present – there are ground source heat pumps and air source heat pumps present, while the Massachusetts 2012 sample has no heat pumps providing primary heat to homes. Furnaces in the Massachusetts sample average 94.2 AFUE, a slightly higher average efficiency than systems in Rhode Island (92.8).

Table 19: Heating System Type, Fuel, and Efficiency

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
n (homes)	*50*	*40*
Primary Heating Fuel		
Propane	34%	45%
Natural gas	64%	42%
Oil	2%	6%
Electric	--	7%
Heating System Type		
Furnace	90%	70%
Boiler	8%	17%
Combi appliance	2%	6%
GSHP	--	5%
ASHP	--	2%
Overall AFUE (furnaces)	94.2	92.8

Cooling Equipment

In both samples, central air conditioners are the dominant cooling system type (Table 20~~Table 20~~). Slightly fewer homes in Rhode Island had AC than in Massachusetts (8% lacked AC in Rhode Island vs. 6% in Massachusetts). The average SEER of central air conditioners is slightly higher in Rhode Island, and Rhode Island homes have slightly more cooling capacity per square foot of conditioned floor area (CFA).

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Table 20: Cooling Systems

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
Type of Primary Air Conditioning Installed		
n (homes)	*50*	*40*
Central air conditioning	90%	83%
GSHP	--	5%
ASHP	4%	3%
Window/portable	--	1%
No air conditioning	6%	8%
CAC SEER		
n (CAC systems)	*64*	*45*
Average SEER	13.3	13.7
Cooling Capacity per sq. ft. of CFA		
n (homes)	*47*	*37*
Btu/hr. per 100 sq. ft. CFA	17.9	20.2

Water Heating Equipment

Conventional electric storage systems are the most common system type found in Rhode Island, while natural gas storage systems were the most widespread in the Massachusetts sample (Table 21~~Table 21~~). Efficient natural gas and propane instantaneous systems are more common in the Massachusetts sample, making up a combined 28% of the equipment observed during on-sites compared to 16% in Rhode Island. Natural gas and propane commercial water heaters are absent from the Rhode Island sample but make up 12% of equipment in the Massachusetts sample. Rhode Island has a slightly higher, but similar, percentage of high efficiency heat pump water heaters (18% vs. 14% in Massachusetts).

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Table 21: Water Heater Type and Fuel

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
n (water heaters)	*51*	*43*
Storage, standalone	***38%***	***49%***
Electric	10%	32%
Natural gas	22%	9%
Propane	6%	8%
Heat pump water heater (electric)	***14%***	***18%***
Instantaneous	***28%***	***16%***
Natural gas	20%	10%
Propane	8%	6%
Indirect w/ storage tank	***4%***	***9%***
Oil	--	5%
Propane	--	3%
Natural gas	4%	1%
Combi appliance	***2%***	***5%***
Natural gas	--	4%
Propane	2%	1%
Commercial storage (electric)	***2%***	***2%***
Tankless coil (oil)	***2%***	***1%***
Commercial storage (natural gas)	***10%***	***--***
Commercial storage (propane)	***2%***	***--***

Table 22~~Table 22~~ compares Energy Factors for water heater types found in both the Massachusetts and Rhode Island samples. Equipment types in Rhode Island are at least as efficient as equipment in the Massachusetts sample across all types, and more efficient in most cases. Heat pump water heaters show the greatest difference – heat pumps in the Rhode Island sample have an average Energy Factor of 3.21 compared to 2.65 in Massachusetts.

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Table 22: Water Heater Energy Factors (System Types Found in Both Studies)

	2015 MA Baseline (2012 IECC)		2017 RI Baseline (2012 IECC)	
	n (water heaters)	EF	*n (water heaters)*	EF
Electric storage, standalone	*5*	.93	*9*	*.95*
Heat pump water heater	*7*	2.73	9	3.21
Natural gas and propane instantaneous	*14*	.91	9	.93
Natural gas and propane storage, standalone	*14*	.66	5	.68
Natural gas and propane indirect w/ storage tank*	*2*	.87	*4*	*.87*
Combi appliances	*3*	.94	2	.95

*Efficiency of indirect tanks based on boiler AFUE.

Duct Leakage and Air Infiltration

Average total duct leakage (TDL) in Massachusetts was 9 CFM25 per 100 sq. ft. CFA, less than half (far more efficient) than that in Rhode Island (20.6) (Table 23~~Table 23~~). Duct leakage to outside (LTO) in Massachusetts (3.9) was similarly less than half that of Rhode Island (8.6). To put this difference in context, it should be noted that amendments to the 2012 IECC code in Rhode Island relax the duct leakage requirement from 4 CFM25 of total leakage to 8 CFM25, meaning Massachusetts homes are held to much stricter duct leakage requirements. Nevertheless, the average score in Rhode Island does not meet code in Rhode Island, while the average score of the Massachusetts sample would meet the more stringent non-amended 2012 IECC requirement of 4 CFM25 per 100 sq. ft. of CFA.

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The Massachusetts sample also performs better in terms of average air infiltration, with an average ACH50 of 3.6 compared to 5.3 in the Rhode Island sample. Here again it should be noted that state amendments in Rhode Island do not require a minimum score for air infiltration while Massachusetts holds their homes to the 2012 IECC requirement of 3 ACH50 or less, which likely explains the gap in scores.

Table 23: Duct Leakage and Air Infiltration

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC*)
Duct Leakage to the Outside (CFM25 per 100 sq. ft. CFA)		
n (homes tested)	*98*	*36*
Sampled homes	3.9	8.6
Code requirement	No requirement	No requirement
Total Duct Leakage (CFM25 per 100 sq. ft. CFA)		
n (homes tested)	*98*	*37*
Sampled homes	9.0	20.6
Code requirement	≤ 4	≤ 8*
Air Infiltration (ACH50)		
n (homes tested)	*98*	*39*
Sampled homes	3.6	5.3
Code requirement	≤ 3	Testing*

*RI amendments to 2012 IECC lower the total duct leakage requirement to 8 CFM25 per 100 sq. ft. of conditioned floor area and do not have an ACH50 requirement for air infiltration, only requiring testing.

Lighting

Both samples of homes were built under the 2012 IECC requirement that 75% of hard-wired fixtures use high efficacy lamps. As Table 24~~Table 24~~ shows, compliance among Rhode Island homes is much higher than the Massachusetts sample – 58% of homes in Rhode Island comply with the requirement compared to just 19% in the Massachusetts sample.

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Table 24: Compliance with IECC Lighting Requirement

	2015 MA Baseline (2012 IECC)	2017 RI Baseline (2012 IECC)
n (homes)	*50*	*40*
Compliant (75%+ hard-wired fixtures with efficient lamps)	19%	58%

3 Section 3 Comparison to Program Homes

This section describes the comparison for key measures between the 40 sampled non-program homes and a population of program homes built during the study period. The average values from on-sites were compared to the REM/Rate files of 171 program homes.[16]

Key findings include the following:

- Program homes have an average HERS Index score of 62.3, which is significantly better (lower) than the average score for non-program homes (72.5).
  - For program and non-program homes, custom homes perform significantly better than spec homes (non-program: 62.5 vs. 75.7, program: 56.6 vs. 64.5).
  - The average HERS score (62.5) of non-program custom homes is essentially equivalent to the overall program average (62.3).
- Program homes performed significantly better than non-program homes on most analyzed measures.
  - For the following measures, program homes outperformed non-program homes, but the differences are not significant: wall R-value, R-value of ducts other than attic supplies, cooling system SEER, and total duct leakage.
  - Among analyzed measures, non-program homes outperform program homes in only two categories:
    - water heater Energy Factor (1.30 in non-program homes and 1.08 in program homes – a significant difference)
    - average R-value in unconditioned foundation walls (not a significant difference)

Comment [KR11]: Look for copy/paste errors of this same type.

[16] All non-program HERS models were created in REM/Rate version 14.6.4, the most up-to-date version of the software that would have been used for homes built at this time. All program home energy models were re-run in that same version of REM/Rate to ensure consistent comparisons. The Rhode Island RNC program provided evaluators with REM/Rate files for program homes built within the same time frame as the homes included in the on-site inspections.

3.1 HERS Index Score Comparison

Table 25~~Table 25~~ shows Home Energy Rating System (HERS) Index scores for program and non-program homes broken down by home type. A score on the HERS Index is a rating of a home's energy efficiency based on its energy attributes.[17] The HERS Index scores for non-program homes were modeled using data from on-site inspections conducted by NMR between March and May 2017. The HERS Index scores for program homes were modeled using data submitted to the program by HERS raters who were contracted by builders or homeowners as part of the program application process.

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The per-home average HERS Index score is 72.5 for non-program sampled homes.[18] Program homes have significantly lower (better) HERS Index scores than non-program homes, with an average of 62.3. Additionally, custom homes – both in the program and non-program home groups – have significantly lower HERS Index scores than spec homes (62.5 vs 75.7 in the non-program home sample, and 56.6 vs. 64.5 in the program home population).

Table 25: HERS Index Scores

	Non-program Homes			Program Homes		
	Custom	Spec	All Homes (Weighted)	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*	*36*	*135*	*171*
Minimum (Best)	33	56	33	8	45	8
Maximum	91	100	100	101	103	103
Average	**62.5[a]**	**75.7[a]**	**72.5[b]**	**56.6[c]**	**64.5[c]**	**62.3[b]**
Median	62	76	72	56	63	61

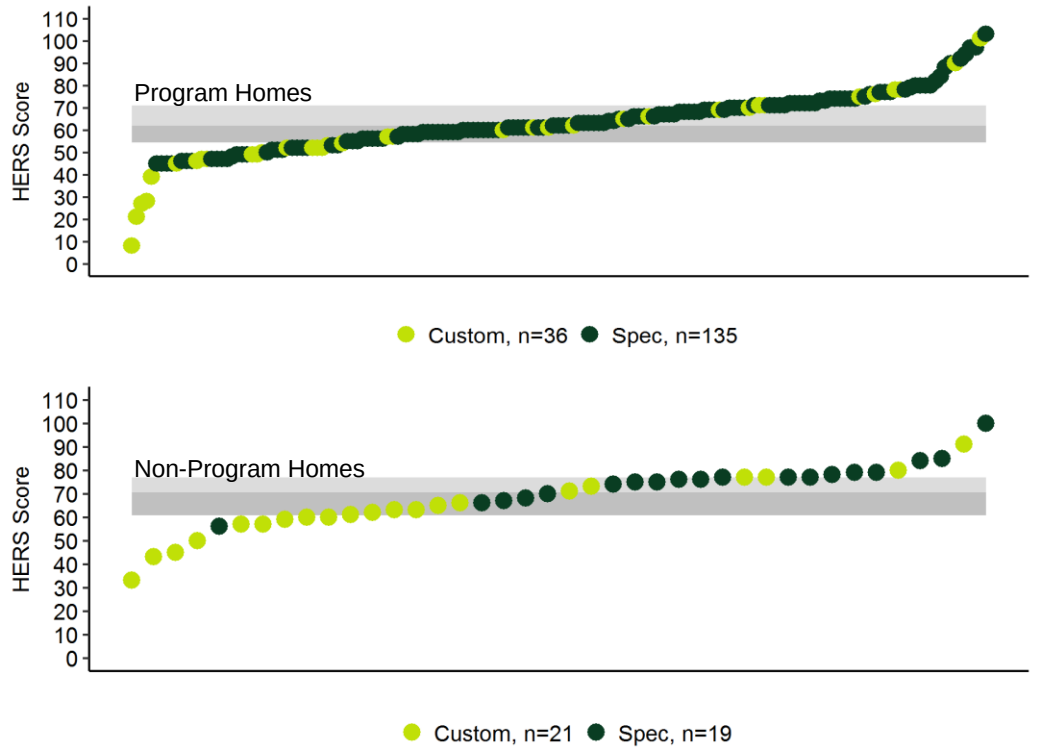
[a,b,c] Significantly different at the 90% confidence level.

Figure 4~~Figure 4~~ displays the HERS Index scores for new, program homes in the first graph, followed by sampled new, non-program homes in the second. The wider variance among program homes stands out, especially at the lower (better) end of the HERS index. Aside from the cluster of custom, program homes sitting below a HERS 40, the distribution of program and non-program homes follows a similar pattern.

[17] A HERS Index score is a standardized assessment of a home's energy-efficiency performance based on the home's construction and energy-using equipment. RESNET oversees the process of scoring homes using the HERS index. RESNET's HERS Index is a widely adopted rating system used across the United States with standardized procedures, evaluator certification, and quality control infrastructure. A score of 100 means the home is as efficient as the RESNET defined reference home, which is based on the 2006 IECC. A score of zero signifies that a home uses no more energy than it produces on site with renewable sources and a score of less than zero signifies that home produces more renewable energy on site than it consumes.

[18] The 72.5 is based on an average of 40 homes. This includes one home for which diagnostic testing (air leakage and duct leakage) was not performed due to a wood burning stove creating a fire hazard during the audit. To calculate a HERS Index score, the ACH 50 and duct leakage to outside were assumed to be equal to the average of the other 39 homes. If this home were excluded from analysis, the weighted average HERS Index score of the 39 homes would be 72.6 and the average of custom 20 custom homes remains 62.5.

Figure 4: Program and Non-program HERS Index Scores



Comparison of Key Measures

Table 26~~Table 26~~ compares the efficiency characteristics of program and non-program homes using various measures, such as building envelope R-values and U-values, air leakage, and duct leakage. R-values refer to nominal insulation values; U-values refer to REM/rate calculated data, which factor in additional features such as insulation grade and framing. Program homes performed significantly better than non-program in the following measures:

- Flat ceiling R-value and U-value
- Vaulted ceiling R-value and U-value
- Frame floor R-value and U-value
- Conditioned basement foundation wall R-value
- Attic duct supply R-value
- Per home average duct leakage to outside per 100 sq. ft. of conditioned floor area
- Per home average ACH50

In Table 26~~Table 26~~, the differences between the overall program and non-program samples are tested for statistical significance. Results for significance testing between the custom and spec samples in the non-program data collected during on-sites can be found in the respective report sections for each measure. Cells shaded in green reflect the most

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efficient value between program and non-program homes. This means, for measures where the program homes fare better, the program home cell is green, and vice-versa.

Table 26: Comparison Between Program and Non-Program Homes

	Non-program Homes			Program Homes		
	Custom	Spec	All Homes (Weighted)	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*	*36*	*135*	*171*
Above grade wall[1]: Average R-value	20.6 (n=21)	19.7 (n=19)	19.9 (n=40)	22.0 (n=36)	19.9 (n=135)	20.4 (n=171)
Above grade wall[1]: Average U-value	0.060 (n=21)	0.065 (n=19	0.064 (n=40)	0.056 (n=36)	0.063 (n=135)	0.062 (n=171)
Flat ceiling[2]: Average R-value	38.9 (n=13)	32.3 (n=19)	**33.4* (n=32)**	43.5 (n=25)	37.5 (n=116)	**38.6* (n=141)**
Flat ceiling[2]: Average U-value	0.039 (n=13)	0.056 (n=19)	**0.054* (n=32)**	0.028 (n=25)	0.033 (n=116)	**0.032* (n=141)**
Vaulted ceiling: Average R-value	36.8 (n=16)	23.7 (n=6)	**29.4* (n=22)**	37.1 (n=19)	37.9 (n=82)	**37.7* (n=101)**
Vaulted ceiling: Average U-value	0.032 (n=16)	0.085 (n=6)	**0.062* (n=22)**	0.031 (n=19)	0.030 (n=82)	**0.030* (n=101)**
Frame floor over unconditioned basement: Average R-value	22.5 (n=8)	19.5 (n=14)	**20.6* (n=22)**	29.5 (n=21)	29.7 (n=97)	**29.6* (n=118)**
Frame floor over unconditioned basement: Average U-value	0.121 (n=8)	0.132 (n=14)	**0.131* (n=22)**	0.038 (n=21)	0.41 (n=97)	**0.041* (n=118)**
Conditioned basement foundation wall: Average R-value	9.8 (n=8)	6.6 (n=4)	**7.9* (n=12)**	18.3 (n=7)	18.4 (n=11)	**18.4* (n=18)**
Unconditioned basement foundation wall: Average R-value	0.4 (n=8)	0.8 (n=14)	0.8 (n=22)	1.5 (n=20)	0.0 (n=97)	0.3 (n=117)
Attic duct supply: Average R-value	7.5 (n=7)	7.3 (n=13)	**7.3* (n=20)**	8.0 (n=11)	8.0 (n=65)	**8.0* (n=76)**
All other ducts: Average R-value	7.0 (n=13)	6.2 (n=16)	6.3 (n=29)	6.7 (n=19)	6.5 (n=98)	6.5 (n=117)
Duct leakage to outside: Average CFM25/100 sq. ft. CFA	5.13 (n=19)	9.94 (n=17)	**8.77* (n=36)**	4.18 (n=29)	4.78 (n=99)	**4.65* (n=128)**
Total duct leakage: Average CFM25/100 sq. ft. CFA	22.6 (n=20)	19.9 (n=17)	20.6 (n=37)	18.7 (n=29)	18.1 (n=99)	18.3 (n=128)
Air infiltration: Average ACH50	4.29 (n=20)	5.53 (n=19)	**5.24* (n=39)**	3.01 (n=36)	4.45 (n=135)	**4.14* (n=171)**
Fossil-fuel Heating System AFUE (systems with AFUE ratings)	93.0 (n=16)	92.4 (n=23)	**92.5* (n=39)**	92.8 (n=92.8)	95.2 (n=128)	**94.7* (n=164)**
Cooling System SEER (systems with SEER ratings)	14.6 (n=30)	13.5 (n=22)	14.1 (n=52)	14.8 (n=33)	14.0 (n=82)	14.2 (n=115)
Water Heater EF (systems with EF ratings)	1.43 (n=24)	1.25 n=19)	**1.30* (n=43)**	1.21 (n=36)	1.06 (n=135)	**1.08* (n=171)**
Efficient lamp saturation	71% (n=21)	63% (n=19)	**66%* (n=40)**	81% (n=36)	84% (n=135)	**83%* (n=171)**

* Significantly different at the 90% confidence interval.
[1] Conditioned to ambient walls only.
[2] Includes hatches since REM/rate does not distinguish between flat ceilings and hatches.

4 Section 4 General Characteristics

This section presents the general characteristics of the sampled homes included in the baseline, including home size, home type, year built, HERS Index scores, thermostat set points, water fixture flow rates, home automation systems, and pools.

Key findings include the following:

- The average HERS Index score of the sampled homes is 73.
- The average home size is 2,339 square feet. Custom homes have an average CFA of 3,099 square feet, significantly larger than spec homes (2,097 square feet).
- Programmable thermostats are the most common thermostat type in both custom and spec homes. They make up 83% of thermostats, and are found in 79% of homes. Only 13% of thermostats are manual units, and a very small share, only 4%, are Wi-Fi units. Thermostats in custom homes have higher summer set points (73°F) than spec homes (70°F).
- Ninety-seven percent of all sinks are equipped with a faucet aerator. All kitchen sinks have faucet aerators.

4.1 General Characteristics of Inspected Homes

The 40 inspected homes include single-family attached and detached custom and spec homes. All inspected homes were built between 2015 and 2017 and have between two and five bedrooms, with a median of three bedrooms. There are no statistically significant differences between custom and spec homes in terms of their number of bedrooms or the year built. Figure 5~~Figure 5~~ shows examples of the different sizes of inspected homes.

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Figure 5: Examples of Inspected Homes

As shown in Table 27~~Table 27~~, the majority of inspected homes (96%) are detached single-family homes. All custom homes are single-family detached homes, while 95% of spec homes are detached and 5% are attached.

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Table 27: House Type

House Type	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Detached Single	100%	95%	96%
Attached	--	5%	4%

No statistically significant differences at the 90% confidence level.

Inspected homes range in size from 1,115 to 6,070 square feet of conditioned floor area (CFA), with an overall average of 2,339 square feet. CFA includes all finished and/or fully conditioned spaces on all floors of a home. As shown in Table 28~~Table 28~~, there is a statistically significant difference between the average CFA of custom and spec homes, though only of about 100 square feet, on average. Custom homes have an average CFA of 3,099 square feet, whereas spec homes have an average CFA of 2,097 square feet.

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Table 28: Conditioned Floor Area (CFA)

CFA (square feet)	Custom	Spec	All Homes
n (homes)	*21*	*19*	*40*
Minimum	1,300	1,115	1,115
Maximum	6,070	3,535	6,070
Average	**3,099***	**2,097***	2,339
Median	3,048	2,053	2,108

* Statistically significant at the 90% confidence level.

Figure 6~~Figure 6~~ displays the distribution of home sizes in CFA for the 40 sampled homes.

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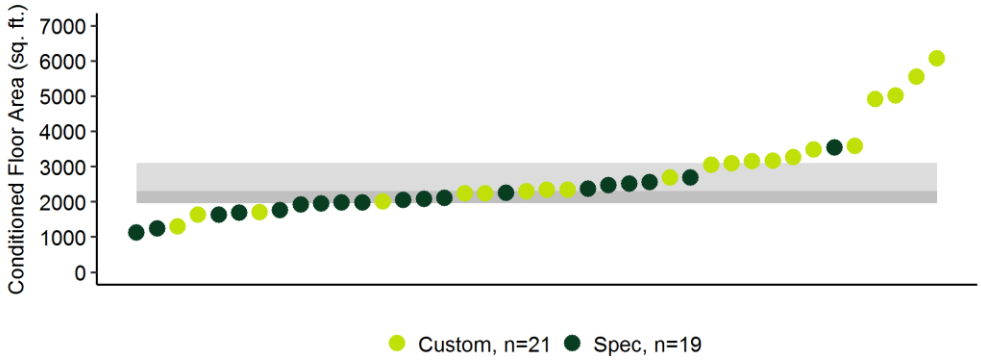
Figure 6: Conditioned Floor Area (CFA) per Home



4.2 HERS INDEX SCORES

Table 29~~Table 29~~ and Figure 7~~Figure 7~~ show Home Energy Rating System (HERS) Index scores for the sampled homes. A lower HERS Index score represents a more efficient home.[19] The average HERS Index score is 72.5. On average, the custom homes have significantly better HERS Index scores than spec homes: 62 vs. 76, respectively. The best (lowest) HERS Index score is 33 (a custom home) and the worst (highest) is 100 (a spec home).The worst score (100) is comparable to a home built to the requirements of the 2006 IECC, two code versions behind the applicable code in Rhode Island for sampled homes (the 2012 IECC).

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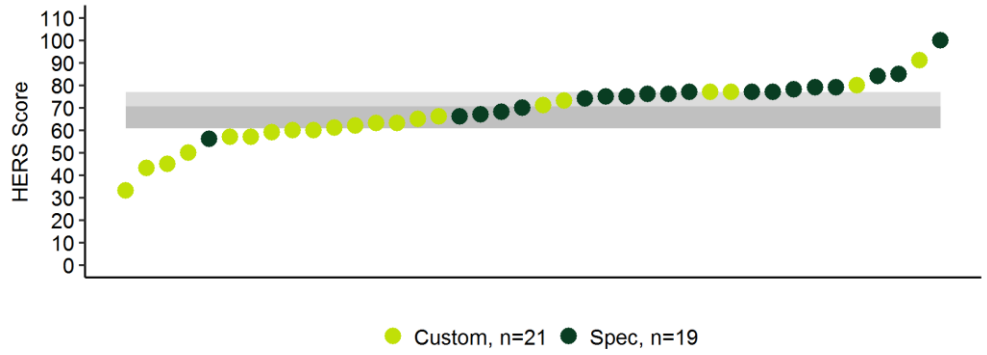
Since the RNC program does not claim savings from solar PV, analysis of HERS Index scores with solar PV removed from homes is also included. Two homes had solar PV. While removing PV from those homes alters their HERS Index scores individually quite drastically, the over average HERS Index score only increases by 0.7 to 73.2.

Table 29: HERS Index Score Statistics

	Custom	Spec	All Homes (Weighted)	All Homes Excluding Solar PV (Weighted)
n (homes)	21	19	*40*	*40*
Minimum (best)	33	56	33	45
Maximum (worst)	91	100	100	100
Average	**62.5***	**75.7***	72.5	73.2
Median	62	76	71	72

[19] A HERS Index score is a standardized assessment of a home's energy-efficiency performance based on the home's construction and energy-using equipment. RESNET oversees the process of scoring homes using the HERS index. RESNET's HERS index is a widely-adopted rating system used across the United States with standardized procedures, evaluator certification, and quality control infrastructure. A score of 100 means the home is as efficient as the RESNET defined reference home, which is based on the 2006 IECC. A score of zero signifies that a home uses no more energy than it produces on site with renewable sources, and a score of less than zero signifies that home produces more renewable energy on site than it consumes.

Figure 7: Sampled Home HERS Index Score Distribution



4.3 Faucet and Shower Head Flow Rates

As shown in Table 30~~Table 30~~, the average flow rate is 1.5 gallons per minute (GPM) for bathroom sinks, 1.8 GPM for kitchen sinks, 2.0 GPM for utility sinks, and 2.4 GPM for shower heads. These values include only those faucets with labeled flow rates.[20] For reference, the maximum allowable flow rate under federal law is 2.2 GPM for bathroom sinks and 2.5 GPM for shower heads.[21] There are no significant differences in flow rates for faucets and shower heads between custom and spec homes.

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[20] The actual average flow rate for utility sinks could be higher, as these averages only included rated faucets and some utility sinks did not have published flow rates.
[21] http://www.allianceforwaterefficiency.org/uploadedFiles/US-Water-Product-Standards-Matrix_2016-11-07.pdf

Table 30: Faucet and Showerhead Flow Rates (GPM)

	Custom	Spec	All Homes (Weighted)
Bathroom Sinks			
n (faucets)	*74*	*58*	*132*
Minimum	1.2	1.2	1.2
Maximum	2.2	2.2	2.2
Average	1.5	1.5	1.5
Median	1.5	1.5	1.5
Kitchen Sinks			
n (faucets)	*22*	*12*	*34*
Minimum	1.8	1.5	1.5
Maximum	2.5	2.2	2.5
Average	1.9	1.8	1.8
Median	1.8	1.8	1.8
Utility Sinks			
n (faucets)	*6**	*1**	*7*
Minimum	1.8	2.2	1.8
Maximum	2.2	2.2	2.2
Average	1.9	2.2	2.0
Median	1.8	2.2	2.0
Shower Heads			
n (showerheads)	*52*	*35*	*87*
Minimum	2.0	2.0	2.0
Maximum	2.5	2.5	2.5
Average	2.4	2.4	2.4
Median	2.5	2.5	2.5

No statistically significant differences at the 90% confidence level.
Fixtures with unknown flow rates are excluded from these results.
*Not tested for statistical significance.

Faucet aerators are nearly ubiquitous; all inspected homes have at least one aerator (Table 31~~Table 31~~). Ninety-seven percent of all faucets have aerators installed, reducing their flow rates. All the kitchen sinks have aerators, almost all the bathroom sinks have aerators (96%), and most (80%) of the utility sinks have aerators. There are no significant differences between custom and spec houses in terms of the frequency of aerators.

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Table 31: Percentage of Faucets with Aerators

	Custom	Spec	All Homes (Weighted)
n (faucets)	*120*	*80*	*200*
All sinks (n=200)	96%	98%	97%
Kitchen sinks (n=42)	100%	100%	100%
Bathroom sinks (n=150)	95%	97%	96%
Utility sinks (n=8)	86%	100%	80%

No statistically significant differences at the 90% confidence level.

4.4 THERMOSTATS

Thermostat types and set points were recorded for the 40 sampled homes. Thermostats fell into one of three categories: manual, programmable, or Wi-Fi enabled (including "smart" thermostats).[22]

Table 32~~Table 32~~ shows that the distribution of thermostat types is similar across custom and spec homes. Programmable thermostats were the most common (83%), followed by manual units (13%), and Wi-Fi units (4%).

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Table 32: Distribution of Thermostats

Thermostat Type	Custom	Spec	All Homes (Weighted)
n (thermostats)	*44*	*35*	*79*
Programmable	89%	80%	83%
Manual	11%	14%	13%
Wi-Fi	--	6%	4%

No statistically significant differences at the 90% confidence level.

Programmable thermostats are common in homes. Table 33~~Table 33~~ shows that most inspected homes (79%) had at least one programmable thermostat, while only 16% had at least one manual thermostat, and only 5% had at least one Wi-Fi enabled thermostat. Custom and spec homes have similar types of thermostats.

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[22] Wi-Fi thermostats include any thermostats that can be controlled remotely (e.g., from smart phones) and/or have smart learning capabilities (such as the Nest thermostat).

Table 33: Penetration of Thermostat Types

Thermostat Type	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Programmable	90%	79%	79%
Manual	14%	16%	16%
Wi-Fi	--	5%	5%

No statistically significant differences at the 90% confidence level.
Percentages sum to more than 100% because some homes have more than one thermostat.

Participants were asked what temperature setpoints they use in the summer and winter, and auditors performed visual inspections to confirm. Summer set points were observed less often than winter set points because some homes did not have air conditioning, and because some homeowners had not yet used their air conditioning or had not yet programmed their thermostats for the summer season.

Custom homes have an average summer set point of 73.3°F, significantly warmer than that of spec homes, 70°F (Table 34~~Table 34~~). Average set points were calculated for summer and winter hours.[23] The average set point values across the 24-hour period are presented here. Average summer and winter set points are shown instead of day vs. night set points because some homeowners use their systems more heavily during the day, and some use them more heavily in the evening or at night.

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Table 34: Combined Average Set Points (°F)
(Base: All Thermostats)

	Custom		Spec		All Homes (Weighted)	
	Summer	Winter	Summer	Winter	Summer	Winter
n (set points)	*86*	*88*	*61*	*70*	*147*	*158*
Minimum	67	60	65	50	66	63
Maximum	80	75.5	76	74	78	74.8
Average	**73.3***	66.8	**70***	66.5	71	67
Median	74	67	70	67	71	67

* Statistically significant at the 90% confidence level.

[23] Day and night set points were determined by reviewing the programmed set points for programmable and Wi-Fi enabled thermostats and by asking occupants for manual thermostats. There is no differentiation between occupied and unoccupied daytime set points.

4.5 Pools and Hot Tubs

Pools and hot tubs were uncommon in sampled homes – they were only present in two homes, both custom. One home has a hot tub and one home has an unheated pool (Table 35~~Table 35~~).

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Table 35: Pools and Hot Tubs

Type of Pool	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Heated Pool	--	--	--
Unheated Pool	5%	--	3%
Hot Tub	5%	--	3%

No statistically significant differences at the 90% confidence level.

5 Section 5 Building Envelope

This section describes the features of the building shell, also referred to as the envelope, of the sampled homes, including insulation, framing, foundation walls, slab floors, and windows.

Key findings include the following:

- The average R-value of conditioned to ambient walls in the sample is R-19.8 – just below the 2012 IECC prescriptive requirement of R-20.[24] If two particularly under-insulated homes are excluded, the average R-value would be a bit higher, at R-20.6.
- The average R-value of flat ceilings is R-36.1, well below the 2012 IECC prescriptive requirement of R-49. Custom homes (R-40.1) have a significantly higher average R-value than spec homes (R-35.3).
- The average R-value for vaulted ceilings is R-29.4, also well below the 2012 IECC prescriptive requirement of R-49 (small sample sizes prevent significance testing between custom and spec homes).
- The average R-value of framed floors over unconditioned basements is R-20, below the 2012 IECC prescriptive requirement of R-30. Although, most such floors were either uninsulated, or insulated right to R-30, and none met Grade I installation standards.
    - Thirty percent of total floor area over unconditioned basements (28% of homes with these floors) is uninsulated.
- Fiberglass batts are the dominant insulation type in walls (70%), flat ceilings (72%), vaulted ceilings (61%), and frame floors over basements (60%).
- For walls and flat ceilings, custom homes have significantly higher rates of Grade I installs than spec homes (walls: 43% vs. 0%; flat ceilings: 31% vs. 0%). This is, at least partially, driven by custom builders' more frequent use of continuous, blown-in or spray-applied products.
- Foundation walls in conditioned space were insulated to an average R-value of R-7.9. Ten of twelve homes with foundation walls in conditioned space did not meet the 2012 IECC prescriptive requirement of R-19 cavity or R-15 continuous, the remaining two exceeded requirements.
- On average, 10% of the exterior wall area in sampled homes is made up of glazing.
- On average, 26% of glazing is southerly oriented. Increasing this percentage can result in lower summer cooling loads and winter heating loads, but this requires orienting more homes to face north or south (35% of sampled homes) rather than east or west (47% of sampled homes).

[24] R-20 is the prescriptive code requirement for cavity insulation. Prescriptive code also allows homes to comply by using R-13 cavity insulation when combined with R-5 continuous insulation.

5.1 SHELL MEASURE DATA COLLECTION

A building's thermal envelope is formed by the walls, floors, and ceilings that separate conditioned space from unconditioned or ambient space, along with any windows and doors.[25] For this study, inspectors gather data on R-values, framing, insulation type, and installation grade for envelope measures, such as walls, ceiling and frame floors. Data were also collected on the level of insulation for foundation walls and slab floors in conditioned spaces, and the area, orientation, and frame material of windows.

The above grade walls section details walls between conditioned and ambient space, the ceiling section details flat and vaulted ceilings, and the frame floor section details floors over unconditioned basements. The foundation wall, slab floor, and window sections focus on measures found in conditioned space. For details on shell measures that are either less common or typically make up a small amount of the overall shell area, such as walls to garages or basements, attic hatches, and floors above garages or ambient space, see Appendix C~~Appendix C~~.

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***Verified and Assumed Values*.** Data for R-values, insulation type, and insulation grade can be difficult to confirm during post-construction audits in which visibility is limited. Data in the visited homes were verified using visual inspection or other documentation. R-values were also verified based on confirmed insulation type and thickness. When data could not be verified, assumptions were made based on similar verified assemblies in the home. In rare cases in which an educated guess was impossible, the feature was marked as unknown. In the tables below, verified and assumed values are included while unknown values are either classified as unknown or excluded from the table altogether. Footnotes for each R-value and insulation table quantify the percentage of homes that had verified data for that table. All framing values were verified by visual inspection, documentation, or homeowner knowledge and thus proportions of verified values for framing tables are not reported.

Primary Framing and Insulation. In each section below, tables report on primary framing and insulation. "Primary" refers to the framing or insulation that comprised the majority of the total area of the specific measure at that home. Ceilings, walls, or floors in homes may have multiple insulation or framing types, but the primary type is that which comprises the largest area in each home. Table footnotes state the percentage of homes that have additional framing types for the applicable measure. In instances of more than one insulation material per measure in a home (an attic with fiberglass batts in one area and cellulose in another, for example), the secondary material generally represents a small area, and is thus not reported in the insulation type tables, though it is factored into R-value calculations.

Insulation Assessments. RESNET standards require that insulation be assigned a Grade based on the quality of installation. Grade I indicates a high-quality installation, Grade II is a

[25] Because doors are such a small portion of the building shell, information on doors was collected and included in the REM/Rate models, but not included in reporting.

typical or fair installation, and Grade III is a relatively poor installation (within limits). REM/Rate models take insulation grade into account; homes with better quality insulation installations will perform better (lower consumption values, and better HERS Index scores) than homes with worse installation grades. A summary of the technical requirements for these insulation grades are defined as follows:

- Grade I: Negligible void areas, compression or incomplete fill ≤ 2%, fitted neatly around obstructions
- Grade II: Void areas ≤ 2%, compression or incomplete fill ≤ 10%
- Grade III: Void areas ≤ 5%

The complete RESNET standards can be found in Appendix A, along with photos showing examples of the various insulation grades.

5.2 Above Grade Walls

Above Grade Wall Types and Locations. Data were collected on the walls that separate conditioned space from ambient space, garages, unconditioned basements, attics, and adjoining units (adiabatic walls).[26] Table 36~~Table 36~~ shows the percentage of homes that have walls in each of these locations. In addition to conditioned to ambient (exterior) walls, which are present at every home, almost four out of five homes (77%) have walls between conditioned space and garage, seven out of ten (69%) have walls between conditioned space and unconditioned basements, and more than half (56%) have walls between conditioned space and attics. Spec homes are significantly more likely than custom homes to have walls between conditioned space and unconditioned basements.

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Table 36: Above-Grade Wall Location Prevalence

Wall Location	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Conditioned/ambient	100%	100%	100%
Conditioned/garage	86%	74%	77%
Conditioned/unconditioned basement	**38%***	**79%***	69%
Conditioned/attic	43%	63%	56%
Sealed attic/ambient	24%	0%	6%
Conditioned/adiabatic	0%	5%	4%
Unconditioned basement/ambient	33%	53%	48%
Unconditioned basement/garage	14%	16%	15%

Statistically significant difference at the 90% confidence level.
Percentages sum to more than 100% because most homes have more than one wall type.

[26] Adiabatic walls are excluded from most analyses. They are not significant sources of thermal loss since they abut conditioned space.

As Table 37~~Table 37~~ shows, conditioned to ambient walls make up the vast majority of total envelope wall area across the entire sample (85%) and are thus the most important wall location in determining the energy-efficiency of a home. As such, the following section will focus solely on conditioned to ambient walls. Similar information on other wall locations (and across all wall types) can be found in Appendix C.

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Table 37: Percent of Total Wall Area in Sample Represented by Each Wall Location

Wall Location (Across All Wall Area in Sample)	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*
Conditioned/Ambient	86%	82%	85%
Conditioned/Garage	6%	8%	7%
Conditioned/Attic	4%	5%	4%
Conditioned/Unconditioned Basement	2%	5%	3%
Sealed Attic/Ambient	2%	0%	1%

Significance testing was not performed on tables with a base of square footage.

5.2.1 Conditioned to Ambient Walls

Exterior walls between conditioned and ambient space have great impact on overall energy-efficiency given that they comprise 85% of the total envelope wall area across the entire sample. Table 38~~Table 38~~ through Table 40~~Table 40~~ display data on conditioned to ambient wall R-values, framing, insulation type, and insulation grade. Similar details for other wall locations that represent smaller proportions of total envelope area (e.g., walls to garage, unconditioned basement, and attic) can be found in Appendix C.

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R-values. The average R-value for conditioned to ambient walls (19.8) hovers right at the 2012 IEEC requirement of R-20 (Table 38~~Table 38~~). There is no significant difference between custom and spec homes. The sample would show an average R-value of R-20.6 – slightly above code – if not for two low-performing homes. One home had a large area of uninsulated exterior wall in a fully conditioned (heated) walkout basement (the homeowner reported plans to insulate these walls in the future), and another had a finished, uninsulated room above the garage that the homeowner had finished (but not insulated).

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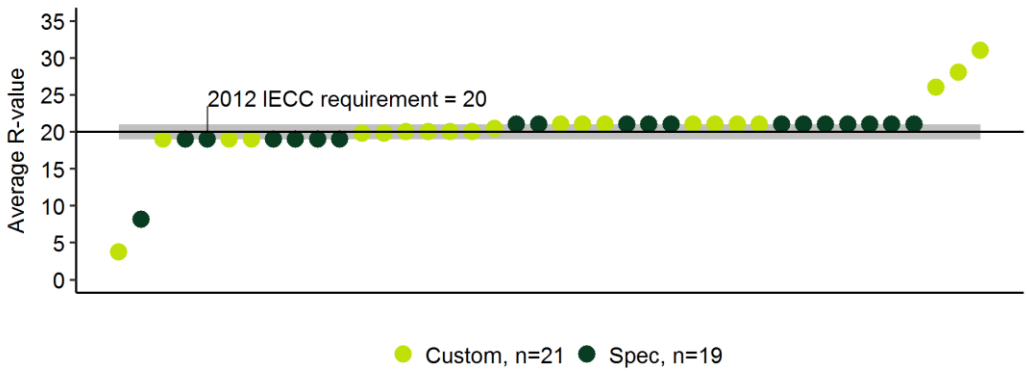
Table 38: Conditioned/Ambient Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	3.7	8.1	3.7
Maximum	31.0	21.0	31.0
Average	20.6	19.7	19.8
Median	20.4	21.0	21.0

No statistically significant differences at the 90% confidence level.
R-value verified at 68% of homes

Figure 8~~Figure 8~~ shows the distribution of per-home average R-values for conditioned to ambient walls in the sample. Most homes sit at or near the 2012 IECC prescriptive requirement of R-20, with a few outliers on either end of the range.

Figure 8: Average Conditioned/Ambient Wall R-values per Home



Primary Framing. Almost every home (97%) has 2x6 framing with studs spaced 16 inches apart. While spec homes only have 2x6 framing, there is no significant difference between samples in terms of the majority framing type. The 5.5" deep cavities in 2x6 walls can achieve R-values of up to R-21 using commonly-available fiberglass batts and up to about R-39 with certain types of high density spray foam.[27] Only one home uses 2x4 framing as the main framing type; this created cavities that are too shallow to meet code using fiberglass batts (without a layer of continuous insulation in addition), but spray foam was used to meet code. One home has timber framing with structural insulated panels (SIPS) between the timber posts, and another home uses insulate concrete forms (ICF).

Table 39: Conditioned/Ambient Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
2x6, 16" on center	86%	100%	97%
2x4, 16" on center	5%	--	1%
Timber framing (with SIPS)	5%	--	1%
ICF	5%	--	1%

No significant differences at the 90% confidence level.
Five percent of homes have an additional framing type.

[27] R-values per inch from Krigger, John. *Residential energy: cost savings and comfort for existing buildings.* 6th edition. Saturn Resource Management. 2013.

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Primary Insulation. Table 40~~Table 40~~ shows the primary insulation material and installation grade for conditioned to ambient walls in each home. Fiberglass batts are the most common insulation type. Seventy percent of homes only use fiberglass batts and an additional 1% use a combination of fiberglass batts layered with polyisocyanurate. Custom homes are significantly less likely than spec homes to use fiberglass batts (43% vs 79%) or rock wool batts (0% vs 21%), instead using various blown-in insulations or structural insulation.

Most homes (74%) have Grade II insulation; however, Grade II was the standard assumption when grades were unverifiable. Custom homes are significantly more likely to have Grade I installations than spec homes (43% vs 0%) and significantly less likely to have Grade II installations (43% vs 84%).

Nine out of ten homes (92%) have only cavity insulation, 5% have only continuous insulation, and 3% use cavity along with continuous insulation as the primary insulation method.

Table 40: Conditioned/Ambient Wall Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Insulation Type			
Fiberglass batts	**43%***	**79%***	70%
Rock wool	**0%***	**21%***	16%
Open cell spay foam	29%	--	7%
Cellulose – dense pack	5%	--	1%
Closed cell spray foam	5%	--	1%
ICF	5%	--	1%
SIP	5%	--	1%
Fiberglass batts + Polyisocyanurate	5%	--	1%
Closed cell spray foam + Rock wool	5%	--	1%
Insulation Installation Grade			
Grade I	**43%***	**--***	10%
Grade II	**43%***	**84%***	74%
Grade III	5%	16%	13%
No cavity insulation (continuous only)	10%	--	2%

*Statistically significant difference at the 90% confidence level.
Insulation type was verified at 100% of homes and installation grade was verified at 52% of homes.

5.3 CEILINGS

The following section describes on-site data collected on two main types of ceilings:

- Flat ceilings, where there is attic space above the ceiling, which can also be thought of as unconditioned attic floors.

- Vaulted ceilings, which refer to a ceiling assembly that has no attic space above it and is insulated at the roof deck/rafters.

Attic hatches are the third ceiling type for which data were collected during on-sites. Because they comprise such a small percent of ceiling area, they are excluded here; a discussion on hatches can be found in Appendix A.[28]

Ceiling Types. Table 41~~Table 41~~ shows the proportion of homes with flat, vaulted, and hatch ceiling areas. In the statewide sample, 91% of homes have a flat ceiling, 42% have vaulted ceilings, and 71% have attic hatches. All spec homes had flat ceilings, while 62% of custom homes had flat ceilings. Vaulted ceilings were found in three-quarters of customs homes and one-third of spec homes. There was a statistically significant difference for both ceiling types.

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Table 41: Ceiling Type Prevalence

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Flat	**62%***	**100%***	91%
Vaulted	**76%***	**32%***	42%
Hatch	**29%***	**84%***	71%

* Statistically significant difference at the 90% confidence level. Percentages sum to more than 100% because some homes have more than one type.

Table 42~~Table 42~~ shows the percentage of total ceiling area across the sample, which is made up of the three recorded ceiling types. Hatches are a negligible percentage of total area, though their tendency to be under-insulated (only R-16 in homes, on average) does cause problems for energy-efficiency. In the statewide sample, 60% of total ceiling area was flat ceiling, 40% was vaulted ceiling, and less than 1% was attic hatch.

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Table 42: Ceiling Type as Percentage of Total Ceiling Area

	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*
Flat attic	43%	90%	60%
Vaulted	57%	9%	40%
Hatch	<1%	<1%	<1%

* Since the base for this analysis is square footage, the values are not weighted and significance testing was not performed.

[28] In REM/rate attic hatches are grouped with flat ceilings. Given that hatches are often uninsulated, this can lead to significant reductions in overall flat ceiling R-values. To give a more precise view of building practices, we split flat ceilings from hatches. If the two are grouped together, the per-home average R-value for flat ceilings is R-33.4 compared to R-36.1 for flat ceilings alone (without hatches included).

5.3.1 Flat Ceilings

As shown in Table 42~~Table 42~~, flat ceilings comprise 60% of total ceiling area across the entire sample, and, since warm air rises, the thermal performance of flat ceilings is critical to overall home efficiency. Table 43~~Table 43~~ through Table 45~~Table 45~~ summarize the R-value, primary framing, and primary insulation characteristics of flat ceilings in sampled homes.

There is one home (a spec home) that is an outlier in terms of average R-value; it has a sizeable portion of uninsulated ceiling (mostly vaulted, some flat) in a "DIY" bonus room finished by the homeowner. The impact of this ceiling assembly will be referenced below in the discussion of flat and vaulted ceilings to give an idea of average values with the outlier excluded.

R-values. The average R-value of flat ceilings (R-36.1) is well below the 2012 IECC requirement of R-49 (Table 43~~Table 43~~). Flat ceilings in custom homes have a significantly higher average R-value (R-40.1) than spec homes (R-35.3). By removing the spec home with a partially uninsulated flat ceiling from the analysis, the average statewide R-value would rise to R-37.4, and the average in spec homes would rise from R-35.3 to R-36.9.

Table 43: Average Flat Ceiling R Value Per Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*19*	*32*
Minimum	37.0	7.5	7.5
Maximum	51.8	38	51.8
Average	**40.1***	**35.3***	36.1 (37.4 w/outlier)
Median	38.0	38	38.0

*Statistically significant difference at the 90% confidence level.
R-values verified at 95% of homes.

Figure 9~~Figure 9~~ displays the per-home average R-values for flat ceilings in the sample. R-values rarely stray far from the median of R-38. The particularly under-insulated home (R-7.5) discussed above is visible to the left, as is another spec home with a fully, but still under-insulated, ceiling assembly.

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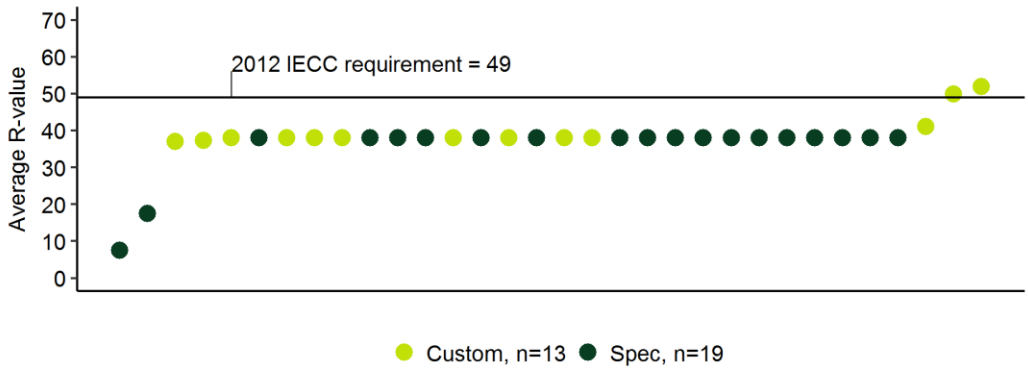
Figure 9: Average Flat Ceiling R-values per Home



Primary Framing. Table 44~~Table 44~~ shows the primary framing type in flat ceilings in the sample. The most common by far is truss framing, which uses either 2x4 or 2x6 bottom chords. Truss framing is found in 66% of homes in the sample. There are no significant differences between custom and spec homes.

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Table 44: Flat Ceiling Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	13	19	32
Truss	54%	69%	66%
2x10, 16" OC	15%	16%	16%
2x8, 16" OC	8%	11%	10%
2x8, 24" OC	--	5%	4%
2x6, 24" OC	8%	--	1%
2x12, 16" OC	8%	--	1%
2x12, 24" OC	8%	--	1%

No statistically significant differences at the 90% confidence level.
Two homes have an additional, secondary framing type not included in this table.

Primary Insulation. Fiberglass batts are the dominant insulation type in flat ceilings – found in 72% of homes in the statewide sample – and are the most common type in both custom and spec homes (Table 45~~Table 45~~). Mineral wool batts are the next most common, in only 18% of homes (21% of spec homes and no custom homes). Loose blown cellulose is the next most common, in only 5% of homes (31% of custom homes and no spec homes). The differences between custom and spec homes for mineral wool and cellulose is statistically significant.

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Half of all homes with observed attic insulation have Grade III (poor) attic insulation installations. There are significant differences between custom and spec homes in the proportion of Grade I and Grade III insulation installations – custom homes have

significantly more Grade I insulation and spec homes have significantly more Grade III. The high rates of blown-in cellulose in the custom homes drive these ratings – it is easier to achieve Grade I installs with blown-in or spray-applied materials, which are easier to install evenly than batt material.

Table 45: Flat Ceiling Primary Insulation Statistics**

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*19*	*32*
Insulation Type			
Fiberglass batts	62%	74%	72%
Mineral wool batts	**--***	**21%***	18%
Loose-blown cellulose	**31%***	**--***	5%
Blown-in fiberglass	--	5%	4%
Open cell spray foam	8%	--	1%
Insulation Installation Grade			
Grade I	**31%***	**--***	5%
Grade II	62%	42%	45%
Grade III	**8%***	**58%***	50%

* Statistically significant difference at the 90% confidence level.
**Three homes have secondary insulation types not reported here.
Insulation type verified at 97% of homes and Grade verified at 90% of homes.

5.3.2 Vaulted Ceilings

Vaulted ceilings comprise 40% of total ceiling area across the entire sample. Table 46~~Table 46~~ through Table 48~~Table 48~~ summarize the R-values, primary framing, and primary insulation characteristics of vaulted ceilings.

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R-values. The average vaulted ceiling R-value (R-29.4) is much lower than the 2012 IECC requirement of R-49. Vaulted ceilings in custom homes have an average R-value of 36.8 compared to an average of R-23.7 in spec homes (the previously discussed home with uninsulated vaulted ceilings lowers the average R-value in a small sample [*n*=6]). Excluding the uninsulated vaulted ceiling home would raise the statewide average R-value of vaulted ceilings from R-29.4 to R-32.3 – still well below the 2012 IECC prescriptive requirement. Within the spec sample, the average would increase from R-23.7 to R-28.2 by excluding that home with uninsulated ceilings.

Table 46: Average Vaulted Ceiling R-Value Per Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*16*	*6*	*22*
Minimum	19.0	0	0
Maximum	48.0	30.0	48.0
Average	36.8	23.7	29.4 (32.3 w/out outlier)
Median	38.0	30.0	36.5

Significance testing not done due to limited sample size.
R-values verified at 85% of homes.

Figure 10~~Figure 10~~ shows the spread of average R-values for homes with vaulted ceilings. Again, the home with an uninsulated vaulted assembly stands far below the rest, though only one home approaches the 2012 IECC requirement.

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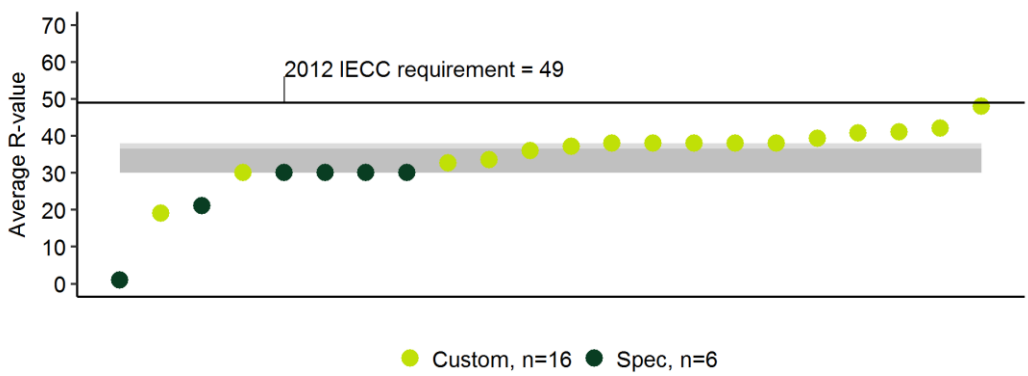
Figure 10: Average Vaulted Ceiling R-values per Home



Primary Framing. As shown in Table 47~~Table 47~~, the most common framing for vaulted ceilings is 2x10, 16" OC, found in 30% of the statewide sample. The next most common is 2x12, 16" OC framing, found in 19% of homes.

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Table 47: Vaulted Ceiling Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	16	6	22
2x10, 16" OC	25%	2 (33%)	30%
2x12, 16" OC	31%	--	19%
2x10, 24" OC	0%	2 (33%)	13%
2x8, 24" OC	0%	1 (17%)	9%
Unknown	0%	1 (17%)	9%
Truss	13%	--	5%
2x12, 24" OC	13%	--	5%
2x8, 16" OC	6%	--	3%
2x6, 24" OC	6%	--	3%
SIPS*	6%	--	3%

*This home had visible timber framing with varied dimensions running between SIPS panels in ceiling.
No significance testing done due to limited sample sizes.

Primary Insulation. As in flat ceilings, the most common insulation found in vaulted ceilings is fiberglass batts. This is present in 61% of sampled homes (Table 48~~Table 48~~). Auditors most frequently observed Grade II insulation (37%), followed by Grade I (30%). Two homes did not receive insulation grades, as one used continuous insulation, which does not receive a grade, and one was uninsulated.

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Table 48: Vaulted Ceiling Primary Insulation Statistics**

	Custom	Spec	All Homes (Weighted)
n (homes)	*16*	*6*	*22*
Insulation Type			
Fiberglass batts	31%	5 (83%)	61%
Open cell spray foam	44%	--	19%
None	0%	1 (17%)	8%
Closed cell spray foam	19%	--	8%
SIPS	6%	--	3%
Insulation Installation Grade			
Grade I	69%	--	30%
Grade II	19%	3 (50%)	37%
Grade III	6%	2 (33%)	22%
No cavity insulation grade (continuous, or uninsulated)	6%	1 (17%)	12%

* Statistically significant at the 90% confidence level.
**Two homes have secondary insulation types not reported here.
Insulation type was verified in 86% of homes and Grade was verified in 73% of homes.

5.4 Frame Floors

Ninety percent of homes in the sample have framed floors that serve as a portion of the thermal boundary – either a single type or a combination of the following types:

- Conditioned floors over unconditioned basements (also referred to as basement ceilings)
- Conditioned floors over garages (also referred to as garage ceilings)
- Conditioned floors over ambient (outdoor) conditions
  - These areas are often small, as they are cantilevered out into space, either with or without support columns below, and can be referred to as bump-out floor area.
- Conditioned floors over enclosed crawl spaces

The remainder of the homes are either completely slab on-grade (no basement) or completely over a conditioned basement, in which case, the thermal boundary shifts to the basement walls and slab floor, rather than the basement ceiling.

Frame Floor Types and Locations. Of the 36 homes with framed floors forming a part of the thermal boundary, 68% have framed floor over an unconditioned basement, about half (49%) have a framed floor over a garage, and a quarter (25%) have framed floor over ambient conditions (Table 49~~Table 49~~). There are statistically significant differences

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between custom and spec homes in the proportion of homes with framed floors over unconditioned basements and over garages.

Table 49: Frame Floor Location Prevalence

	Custom	Spec	All Homes (Weighted)
n (homes)	*17*	*19*	*36*
Conditioned/unconditioned basement	**47%***	**74%***	68%
Conditioned/garage	**77%***	**42%***	49%
Conditioned/ambient	41%	21%	25%
Conditioned/enclosed crawl space	12%	0%	2%

*Statistically significant at the 90% confidence level

Floors over unconditioned basements make up the majority (70%) of total envelope floor area across the entire sample, followed by floors over garages (24%), enclosed crawl spaces (4%) and ambient conditions (2%) (Table 50~~Table 50~~).

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Table 50: Floor Location as Percent of Total Floor Area in Sample

	Custom	Spec	All Homes (Unweighted)
n (homes)	*17*	*19*	*36*
Conditioned/unconditioned basement	60%	81%	70%
Conditioned/garage	29%	19%	24%
Conditioned/enclosed crawl space	8%	0%	4%
Conditioned/ambient	3%	<1%	2%

5.4.1 Conditioned to Unconditioned Basement Framed Floors

This section presents data collected for floors over unconditioned basements, the most prevalent type of floor in sampled homes (70% of total floor area across the entire sample) and therefore, the most impactful on the efficiency of the building shell. For data on the other types of floors (e.g., floors over garage, ambient, and crawl spaces) see Appendix C.

R-values. Floors over unconditioned basements, which are present in 22 homes in the sample, have an average R-value of R-20 and a median of R-30. Only two homes are anything other than uninsulated or R-30 (the 2012 IECC prescriptive requirement) (Table 51~~Table 51~~).

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Table 51: Average Conditioned/Unconditioned Basement Frame Floor R-Value

	Custom	Spec	All Homes (Weighted)
n (homes)	*8*	*14*	*22*
Minimum	0	0	0
Maximum	30.0	30.0	30.0
Average	22.5	19.5	20.0
Median	30.0	30.0	30.0

Significance testing not done due to limited sample size.
R-values verified at 100% of homes.

Figure 11~~Figure 11~~ shows how most of the 22 homes with floors over unconditioned basements fall in one of two groups: either at the median value of R-30 or at R-0 (fully uninsulated). Only two homes fall in the middle, meaning that 40% do not meet the 2012 prescriptive standard of R-30.

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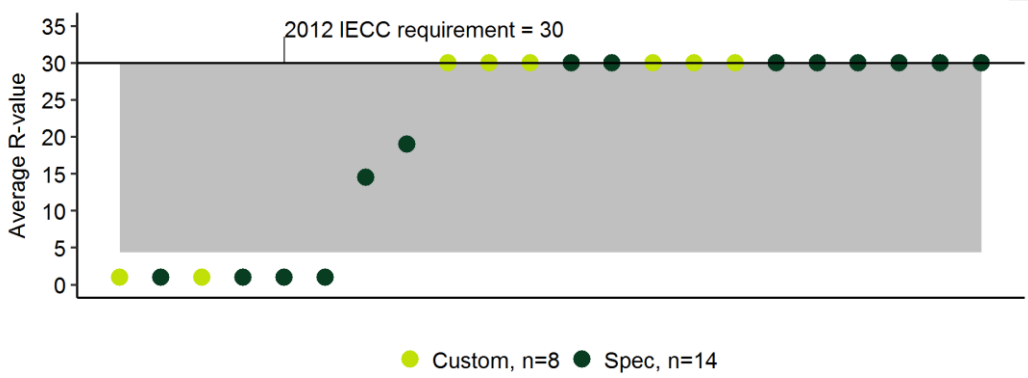
Figure 11: Conditioned/Unconditioned Basement Frame Floor Insulation



Primary Framing. Most homes use either 2x10 16" OC framing (47%) or I-joists (46%) for unconditioned basement ceilings.[29]

[29] Three homes had framed floor area with a secondary framing type not reported here, all secondary framing was 2x10x16.

Table 52: Conditioned to Unconditioned Basement Frame Floor Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	8	14	22
2x10, 16" OC	2 (25%)	50%	47%
I-joist	5 (63%)	43%	46%
2x12, 16" OC	--	7%	6%
Truss	1 (13%)	--	2%

No statistically significant difference at the 90% confidence level.
Three homes had an additional framing type; only primary framing is included in the table.

Primary Insulation. Fiberglass batts are the most common insulation type for unconditioned basement ceilings (60%) (Table 53~~Table 53~~). The only other insulation type present among this floor type was mineral wool batts (12%), and the remaining quarter (28%) were uninsulated. Almost half (47%) of homes with floors over unconditioned basement had Grade II installations and a quarter (25%) had Grade III. No Grade I installs were seen, which is unsurprising given that fiberglass batts are often relatively compressed to be able to fit in basement ceilings without falling down.

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Table 53: Type & Grade of Conditioned to Unconditioned Basement Frame Floor Primary Insulation

	Custom	Spec	All Homes (Weighted)
n (homes)	*8*	*14*	*22*
Insulation Type			
Fiberglass batts	6 (75%)	57%	60%
None	2 (25%)	29%	28%
Mineral wool batts	--	14%	12%
Insulation Installation Grade			
Grade I	--	--	--
Grade II	6 (75%)	43%	47%
Grade III	--	29%	25%
No cavity insulation	2 (25%)	29%	28%

*No statistically significant difference at the 90% confidence level.
Insulation type verified at 100% of homes and grade verified at 100% of homes.

5.5 Foundation Walls[30]

This section describes foundation walls in conditioned space. Because the 2012 IECC prescriptive code does not require foundation walls to be insulated in unconditioned basements, the thermal boundary in those homes is the frame floor above the basement. The 2012 IECC prescriptive code requirement for foundation wall insulation is R-15 for continuous insulation, R-19 for cavity insulation, or a combination of at least R-5 continuous and R-13 cavity insulation.

The presence, R-value, and grade of insulation on conditioned foundation walls can be difficult to ascertain – interior insulation can be covered by drywall in finished spaces, and exterior insulation can be cut off at grade and not visible from the surface. Auditors probe interior framed walls, infer from insulation in other locations, or utilize plans and information from people involved in the construction of the home to determine if insulation is present on the interior or exterior of walls.

5.5.1 Conditioned Basement Walls

R-values. Three homes have completely uninsulated foundation walls between conditioned basements and unconditioned spaces (Table 54~~Table 54~~). The average per home R-value of foundation walls in conditioned basements is R-7.9. Eighty-three percent of homes fail to meet 2012 IECC insulation requirements, the other 17% exceed this requirement. These numbers are broken down in greater detail below, though sample sizes for custom and spec homes are limited.

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Table 54: Foundation Wall Insulation Statistics

	Homes with Conditioned Foundation Walls
n (homes)	*12*
Less than R-15/19	83%
R-15/19	--
More than R-15/19	17%
R-value Statistics	
Minimum R-value	0.0
Maximum R-value	32.0
Average R-value	7.9
Median R-value	4.8

*R-values fully verified at 11 of 13 homes, partially verified at 12.

Three custom homes do not have insulation on foundation walls in conditioned spaces, two are partially uninsulated, and the rest are fully insulated. No spec homes have entirely

[30] Please note this section only represents insulation that is in contact with the masonry foundation walls. Walkout basements often have insulated wood-framed stud walls located above masonry foundation walls. These wood-framed walls are discussed in section 0~~1.1~~.

uninsulated foundation walls in conditioned basements – two are partially insulated and two are fully insulated, though not to 2012 IECC prescriptive requirements (Table 55~~Table 55~~).

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Table 55: Conditioned Basement Foundation Wall Insulation

	Custom	Spec	All Homes (Weighted)
n (homes)	*9*	*4*	*13*
Minimum	0.0	2.9	0.0
Maximum	32.0	13.0	32.0
Average	9.8	6.6	7.9
Median	4.8	5.7	4.8

Not tested for significance due to limited sample size.

Figure 12~~Figure 12~~ displays the per-home average R-values of conditioned foundation walls. These walls are frequently insulated under code requirements, and the custom and statewide averages are pulled up by a particularly well insulated basement (R-32).

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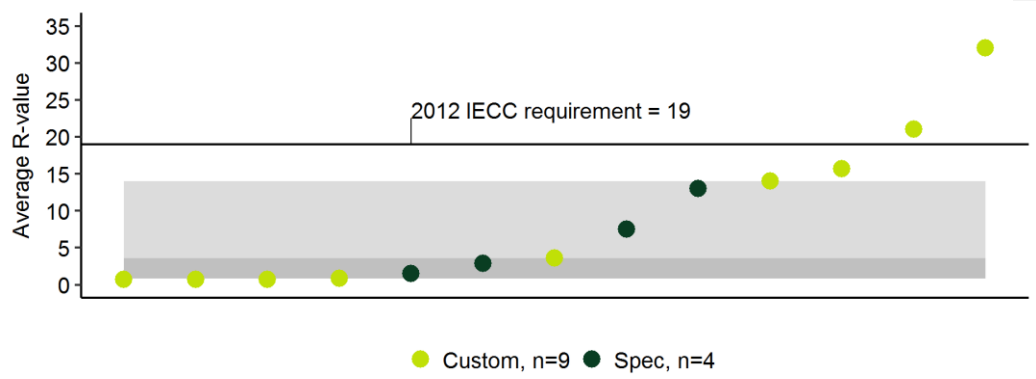
Figure 12: Foundation Wall Insulation (Conditioned Basements)



Primary Insulation. Table 56~~Table 56~~ displays the types of primary insulation found on foundation walls in conditioned spaces; a wide variety of materials were used in these 13 homes with such foundation walls. Fiberglass batts are the most common primary insulation type, covering the majority of wall area in four homes – in one instance installed in combination with expanded polystyrene. Four homes have no insulation on the majority of conditioned foundation wall area. Eight homes have framing on conditioned foundation walls with cavity insulation installed – three have Grade I installs and five have Grade II installs.

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Table 56: Foundation Wall Insulation Type and Grade*

	Custom	Spec	All Homes (Weighted)
n (homes)	*9*	*4*	*13*
Fiberglass batts	--	3 (75%)	46%
Closed-cell spray foam	2 (22%)	--	9%
Extruded polystyrene (XPS)	--	1 (25%)	15%
Expanded polystyrene (EPS)	1 (11%)	--	4%
Open-cell spray foam	1 (11%)	--	4%
Fiberglass batts + XPS	1 (11%)	--	4%
None	4 (44%)	--	18%
Insulation Grade			
n (homes)	*9*	*4*	*13*
Grade I Installation	3 (33%)	--	13%
Grade II Installation	2 (22%)	3 (75%)	54%
Grade III Installation	--	--	--
No cavity insulation (continuous or uninsulated)	4 (44%)	1 (25%)	33%

*Insulation type was verified at all homes, and insulation grade was verified at six of eight homes with cavity insulation.
Not tested for significance due to limited sample size.

5.6 SLABS

Auditors collected data on slab construction and insulation at sites where the slab forms part of the thermal envelope (i.e., homes with conditioned basements or slab on-grade construction). Verifying the presence, and especially R-value, of slab insulation post-construction is virtually impossible. However, documentation was available in some cases via building plans or conversations with those involved in the building's construction.

Homes with slab construction most often had a mix of on- and below-grade slab (44% of homes with conditioned slabs), either in homes with a conditioned walkout basement or in homes with a mix of basement and on-grade construction (Table 57~~Table 57~~).

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Table 57: Slab Floor Location

	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*6*	*17*
Mixed grade	64%	2 (33%)	44%
On grade only	27%	2 (33%)	31%
Below grade only	9%	2 (33%)	25%

*Not tested for significance due to limited sample size.

The 2012 IECC prescriptive code requires on grade slabs with a floor surface within a foot below grade to be insulated to R-10. Table 58~~Table 58~~ breaks down R-value statistics for homes with on-grade slab, where slab insulation R-value could be confirmed through plans,

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documents, or persons present at the pouring of the slab. Five of these slabs are confirmed to be uninsulated, lowering the average of the seven homes to R-4.

Table 58: Documented Slab Insulation R-values vs. Prescriptive Code Requirements*

	Custom	Spec	All Homes (Unweighted)
n (homes)	*5*	*2*	*7*
Below code (<R10)	3 (60%)	2 (100%)	5 (71%)
At code (=R10)	1 (20%)	--	1 (14%)
Above code (>R10)	1 (20%)	--	1 (14%)
Average R-value	5.6	0	4.0

Not tested for significance due to limited sample size.
Unweighted due to small sample size.

In addition to the under-slab insulation requirements above, heated slabs are required to have R-5 insulation along the vertical edge of the perimeter under 2012 IECC prescriptive code. There are only two sampled homes with heated slabs, both custom homes. One home was verified by the homeowner (and builder) to have perimeter and under slab insulation; however, the R-value could not be verified. The presence of slab insulation could not be verified at the other home.

5.7 Windows

This section describes the characteristics of door and window glazing in above-grade, framed, conditioned walls (i.e., excluding basement foundation walls and glazing in walls in unconditioned spaces). When documentation of glazing properties is unavailable, a reflection test is used to determine if the windows have a low-E coating. Similarly, the presence of injection plugs in the frame between the panes of glass can be used in some cases to infer the presence of argon or similar insulating gas fills. Due to the imprecision of this method – manufacturing techniques vary – the proportion of gas-filled windows may be under-reported.

Spec homes are significantly more likely than custom homes to have vinyl-framed windows. ,Table 59~~Table 59~~ also shows that fiberglass and metal-framed windows are uncommon.

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Table 59: Presence of Window Frame Types

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Vinyl	**76%***	**100%***	94%
Wood	62%	53%	55%
Fiberglass	14%	11%	11%
Metal	10%	--	2%

*Significantly different at the 90% confidence level.
Percentages sum to more than 100% because some homes have more than one type.

Table 60~~Table 60~~ shows double pane low-E windows are the most common glazing type in both custom and spec homes, found in 80% of sampled homes. Argon-filled glazing assemblies are more common in custom homes, though there are no significant differences between custom and spec homes in the prevalence of any glazing type.

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Table 60: Presence of Glazing Types

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Double pane, low-E	67%	84%	80%
Double pane	62%	68%	67%
Double pane, low-E, argon	43%	21%	26%
Triple pane, low-E, argon	5%	--	1%

No significant differences at the 90% confidence level.
Percentages sum to more than 100% because some homes have more than one type.

Table 61~~Table 61~~ describes the proportion of glazing area by window type across sampled homes. While uncoated double pane windows are present in 67% of homes, they only make up 5% of total glazing area; uncoated double-pane glazing is often found in doors, where glazing area tends to be small. Over 90% of all glass area is double-pane and low-e (either with or without argon).

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Table 61: Percent of Total Glazing Area in Sample by Glazing Type

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Double pane, low-E	**45%***	**79%***	74%
Double pane, low-E, argon	**47%***	**16%***	20%
Double pane	5%	5%	5%
Triple pane, low-E, argon	3%	--	<1%
Single pane	--	<1%	<1%

*Significantly different at the 90% confidence level.

The 2012 IECC prescriptive maximum U-factor for windows is 0.32, with a solar heat gain coefficient (SHGC) of 0.55.[31] Documented U-factor and SHGC information was only available for nine of the visited homes (five custom and four spec). Builders could ideally choose windows with different characteristics based on the orientation of the window (to allow more or less solar heat gain), but it is common practice for all windows of the same type in a home to have identical properties. Consequently, when documented values were available in a home, they were applied to all windows of similar construction. These recorded values – representing 24% of sampled window area – are summarized in Table 62~~Table 62~~. Readers should avoid drawing too many conclusions about these values, given that so few homes had these values documented.

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Table 62: Documented Window Property Statistics

	All Homes (Unweighted)	
	U-factor	SHGC
n (homes)	*9*	
Minimum	0.25	0.21
Maximum	0.37	0.33
Average	0.31	0.27
Median	0.30	0.27

Not tested for statistical significance.

When no efficiency information was available, the REM/Rate defaults in Table 63~~Table 63~~ were used for building energy models. However, these assumptions are based on legacy standards, while window technology has improved and standards have changed since these values were developed.[32] For instance, it is estimated that EnergyStar Version 3 windows, with a maximum U-factor of 0.35, represented more than 80% of the market in 2010.[33]

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[31] The U-factor is the reciprocal of the R-value; a higher U-factor means a window is less efficient. Likewise, a lower SHGC is also usually desirable, representing a greater fraction of reflected solar energy and lower cooling costs. https://archive.org/details/gov.law.icc.iecc.2012

[32] They are based on Table 27-5 "Overall Coefficients of Heat Transmission of Various Fenestration Products (Btu/h · ft2 · °F)" in the 1993 edition of ASHRAE Fundamentals.

[33] https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/windows_doors/Draft6_V1_Criteria_Analysis_Report.pdf

Table 63: REM/Rate Default versus 2012 IECC Code Requirement

Window Type	U-factor	SHGC	%Total Area in Sample (Unweighted)
Vinyl frame, double pane, low-E	0.36	0.45	59%
Vinyl frame, double pane, low-E, Argon	0.39	0.46	22%
Wood frame, double pane low-E, Argon	0.36	0.45	7%
Wood frame, double pane, low-E	0.33	0.45	5%
Wood frame, double pane	0.49	0.58	3%
Vinyl frame, double pane	0.46	0.57	1%
Vinyl frame, triple pane, low-E, argon	0.36	0.52	1%
Metal frame, double pane	0.87	0.73	<1%
Metal frame, Double pane, low-E, Argon	0.50	0.52	<1%
Fiberglass frame, double pane	n/a	n/a	<1%
Fiberglass frame, double pane, low-E	n/a	n/a	<1%
2012 IECC Code Requirement	*0.32*	*n/a*	

5.7.1 Glazing Percentage

In Table 64~~Table 64~~, glazing percentages are calculated by dividing total glazing area of door and window glazing by the total conditioned to ambient wall area of the home.

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Table 64: Glazing Percentage of Exterior Wall Area

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	5%	6%	5%
Maximum	18%	19%	19%
Average	10.6%	9.7%	10.2%
Median	10%	9%	9%

No significant differences at the 90% confidence level.

In northern latitudes, windows that face south are preferable to other orientations because they minimize summer insolation (heat and light gained from the sun), while maximizing it in the winter. Table 65~~Table 65~~ shows that southerly oriented windows represent 26% of exterior glazing on average across all homes in the sample.[34]

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[34] South-west and south-east facing windows are included as well as windows that face due South, but the former are given a weight of 0.707 instead of 1 due to their oblique orientation.

Table 65: Southerly Oriented Glazing Statistics

Orientation-weighted % S/SE/SW Glazing	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	--	3%	<1%
Maximum	60%	48%	60%
Average	29.6%	25.1%	26.2%
Median	31%	25%	26%

No statistical significance at the 90% confidence level.

This percentage could be improved if developers arranged more homes to face north or south. Because homes are usually wider from side to side than they are deep (front to back), there is more room for south-facing windows and solar PV systems when facing homes to the north or south. Developers can accomplish this in new developments by aligning major streets on an east-west axis rather than north-south. The Pacific Northwest National Laboratory (PNNL) recommends that sub-divisions be designed such that roads are generally east-west and the longest axis of homes are north-south.[35] In addition to solar gain by the home through windows, building orientation influences the orientation and solar gain of roof pitches, as well as their suitability for renewable energy installations.

To place these southerly glazing statistics in context, Table 66~~Table 66~~ outlines the average distribution of window area around a home and Table 67~~Table 67~~ provides the proportions of homes that face each of the cardinal and ordinal directions. Over 70% of glazing is distributed over the front and back of a home, while just 35% of homes are built with a north or south orientation.

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Table 66: Average Window Area Distribution[36]

Glazing Distribution	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Back	40.3%	46.1%	44.2%
Front	20.6%	29.7%	26.6%
Sides	39.1%	24.2%	29.2%

No statistical significance at the 90% confidence level.

[35] "Building Energy Resources Center: Site Planning - Lot Orientation," *U.S. Department of Energy*, Feb. 1 2012, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//1401 via https://www.energycodes.gov/sites/default/files/documents/ta_site_planning-lot_orientation.pdf

[36] Equi-distribution is a standard assumption in energy models, including HERS.

Table 67: Site Orientation

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
North	9.5%	10.5%	10%
Northeast	4.8%	5.3%	5%
East	19%	26.3%	25%
Southeast	9.5%	5.3%	6%
South	19%	26.3%	25%
Southwest	14.3%	5.3%	7%
West	23.8%	21.1%	22%
Northwest	--	--	--

No statistical significance at the 90% confidence level.

Figure 13~~Figure 13~~ is a wind rose or coxcomb pie chart of the statewide orientation data in Table 67~~Table 67~~. Values are represented by sector length, and position around the compass corresponds to home orientation. It is the relative length of the wedges and their distribution that is the most important; therefore, it might be helpful to think of this as a round histogram.

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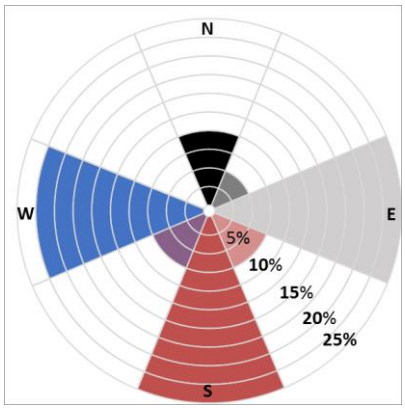
Figure 13: Site Orientation



6 Section 6 Mechanical Equipment

This section presents the findings for mechanical equipment identified during on-site inspections. The results cover heating, cooling, water heating equipment, and an assessment of equipment sizing.

Key findings include the following:

Heating

- Propane and natural gas are the dominant heating fuels (45% and 42% of homes, respectively). Custom homes are more likely than spec homes to heat with electricity: 30% of custom homes have heat pumps (GSHP or ducted ASHP) as primary heating systems, while none of the spec homes do.
- Furnaces are the most common primary heating system (70% of homes). Spec homes are more likely than custom to have furnaces (84% vs. only 24%); custom homes have a wider variety of system types (e.g., GSHPs and ASHPs).
- Natural gas and propane furnaces have average AFUEs of 92.2 and 93.3. Only 25% of all heating systems (unweighted) are ENERGY STAR qualified.

Cooling

- Central air conditioning is common; it is found in 83% of homes. The average CAC SEER is 13.7. Few homes have heat pumps as primary cooling systems (less than 10%). Eight percent of homes do not have cooling systems.
- Only 12% of CAC systems were ENERGY STAR qualified. Custom homes are significantly more likely to have ENERGY STAR CAC systems (35% vs. 5%). All but two of the 13 heat pump systems were ENERGY STAR.

Water Heating

- Half (49%) of the water heaters are conventional storage tanks, fueled by electricity (32%), natural gas (9%), or propane (8%). Eighteen percent of water heaters are highly efficient, electric heat pump models (3.21 EF on average).
- Spec homes are significantly more likely to use electric standalone systems, while custom homes are significantly more likely to use instantaneous and indirect systems fueled by propane.
- Electricity is by far the most common fuel type used by equipment in the weighted statewide sample (53%), driven by the large proportions of electric standalone and heat pump systems.
- Water heaters in custom homes are far more likely than spec homes to be ENERGY STAR qualified (72% vs. 39%).

6.1 Heating Equipment

Heating equipment was categorized as primary or supplemental. Primary equipment is the equipment with the largest capacity or serving the largest portion of the home's square footage. For example, some homes have just one natural gas furnace and no other source of heat. For those homes, the furnace is the primary system. Other homes have two furnaces that each use natural gas. In those instances, both furnaces count as primary systems and the home would be categorized as having a primary system type of "furnace" and fuel of "natural gas." Any equipment type that did not supply the majority of a home's heating load is designated as "supplemental."

6.1.1 Primary Heating Systems – Fuel and Type

Table 68~~Table 68~~ and Table 69~~Table 69~~ characterize the fuel and system type of each home's primary heating system. Each home comprises a single observation; if a home has two natural gas furnaces, those furnaces count as one observation for the home. If a home had multiple types of heating systems, then the system type that had the greater capacity or served the larger floor area was identified as primary, such that in these two tables, there is only one record per home.

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The vast majority of homes (87%) use either a propane or natural gas heating system. Custom homes are significantly more likely than spec homes to use electricity as their primary fuel source – largely due to presence of heat pumps among primary heating systems in custom homes (Table 69~~Table 69~~).

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Table 68: Primary Heating Fuel

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Propane	38%	47%	45%
Natural gas	24%	47%	42%
Electricity	**29%***	**--***	7%
Oil	10%	5%	6%

*Significantly different at the 90% confidence level.

The majority of homes (70%) use furnaces as their primary heating system (Table 69~~Table 69~~). Spec homes are significantly more likely than custom homes to use furnaces and significantly less likely to use hydro-air boilers and ground-source heat pumps (GSHPs).In fact, spec homes *only* use furnaces, boilers, or combi appliances (on-demand boilers also providing domestic hot water). Custom homes have a wider variety of primary heating systems.

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Table 69: Primary Heating System Type

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Furnace	**24%***	**84%***	70%
Boiler (forced hot water)	5%	11%	9%
Boiler (hydro-air)	**33%***	**--***	8%
Combi appliance	10%	5%	6%
GSHP	**19%***	**--***	5%
ASHP	10%	--	2%

*Significantly different at the 90% confidence level.

6.1.2 Primary Heating Systems - Location

Sixty-two percent of the primary heating equipment is in unconditioned basements or enclosed crawl spaces[37] (Table 70~~Table 70~~). Spec homes are significantly more likely to have the primary heating system in an unconditioned basement/enclosed crawlspace or attic, while custom homes are significantly more likely to have the primary heating system located in a conditioned area.

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Table 70: Primary Heating System Location

	Custom	Spec	All Homes (Weighted)
*n (primary heating systems)***	*21*	*22*	*43*
Unconditioned basement/enclosed crawl space	**38%***	**68%***	62%
Attic	**5%***	**23%***	19%
Conditioned area	**52%***	**9%***	18%
Garage or open crawl space	5%	--	1%

*Significantly different at the 90% confidence level.
**Some homes have multiple primary systems (e.g., two furnaces of the same type).

6.1.3 Heating System Efficiency

The average AFUE across all fossil-fuel fired systems (furnaces, boilers, etc.) is 92.1.

Table 71~~Table 71~~ and Table 72~~Table 72~~ describe the efficiency of natural gas and propane furnaces, respectively. Propane furnaces have a slightly higher average efficiency (93.3 AFUE) than natural gas furnaces (92.2 AFUE). Code only requires that heating equipment meet federal minimum standards (80 AFUE), [38] and all furnaces in inspected homes meet

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[37] Note that the counts in this table are not the count of homes, but the count of heating systems that match the primary fuel and equipment type for each home. For example, if a home has two natural gas furnaces, that would have counted as one entry for the entire home in the previous tables in terms of the home's primary system type and fuel, but in the table below, those furnaces would be treated separately. If one furnace was in a basement and one was in an attic, both would be included in the table below, with each treated as a primary system (hence the system count being somewhat higher than the number of homes).
[38] Source: http://www.ecfr.gov/cgi-bin/text-

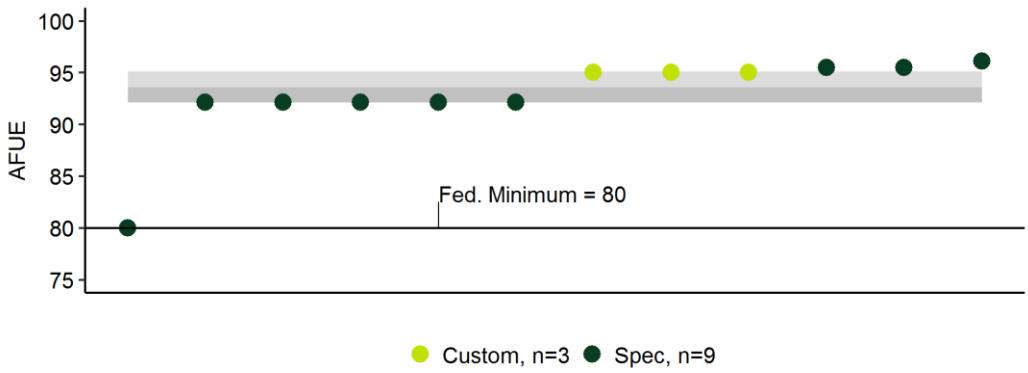
the federal standards – the lowest efficiency furnaces are found in attics and have AFUEs of 80. There are no significant differences between custom and spec homes for natural gas or propane furnace AFUE.

Table 71: Natural Gas Furnace AFUE

	Custom	Spec	All Homes (Weighted)
n (natural gas furnaces)	*3*	*9*	*12*
Minimum	95.0	80.0	80.0
Maximum	95.0	96.1	96.1
Average	95.0	92.0	92.2
Median	95.0	92.1	92.1

Figure 14~~Figure 14~~ displays the AFUE of natural gas furnaces. As shown, most furnaces sit in a narrow band around the median value of 92.2, with the lone low value being one of the aforementioned 80 AFUE attic furnaces.

Figure 14: Natural Gas Furnace AFUE



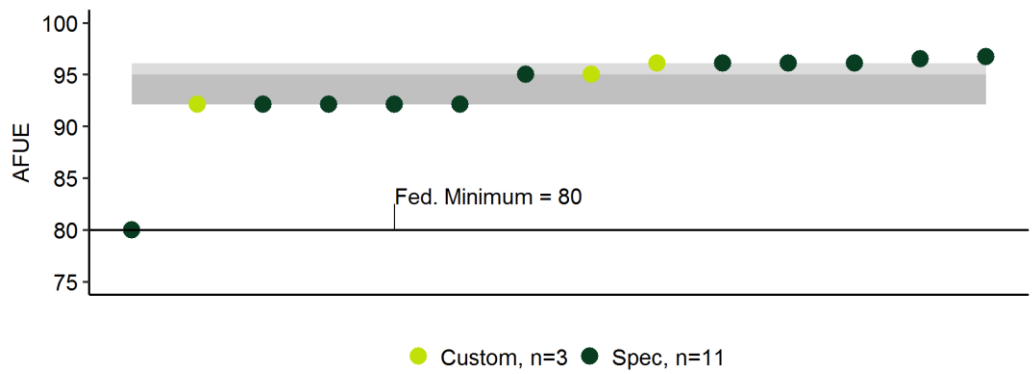
idx?SID=a9921a66f2b4f66a32ec 851916b7b9d9&mc=true&node=se10.3.430_132&rgn=div8

Table 72: Propane Furnace AFUE

	Custom	Spec	All Homes (Weighted)
n (propane furnaces)	*3*	*11*	*14*
Minimum	92.1	80.0	80.0
Maximum	96.1	96.7	96.7
Average	94.4	93.2	93.3
Median	95.0	95.0	95.0

Propane furnace AFUE values fall largely in a small band around the median of 95, with a single low value (an attic furnace) at 80 AFUE (Figure 15~~Figure 15~~).

Figure 15: Propane Furnace AFUE



All the boilers in the inspected homes meet federal standards of a minimum AFUE of 82 (Table 73~~Table 73~~). Propane boilers in inspected homes are, on average, more efficient than natural gas boilers (94.9 vs 92.6 AFUE, respectively), but this difference is based on small sample sizes.

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Table 73: Boiler AFUE (Unweighted)

	Natural Gas Boiler	Propane Boiler	Oil Boiler
n (boilers)	*5*	*5*	*3*
Minimum	84.2	94.0	85.3
Maximum	95.0	95.5	87.0
Average	92.6	94.9	85.6
Median	94.3	95.1	85.3

Includes combi appliance boilers.
Not tested for statistical significance.

6.1.4 Furnace ECMs

An electronically commutated motor (ECM) is a brushless DC motor that offers efficiency gains relative to the industry standard permanent split capacitor (PSC) motor.[39] Table 74~~Table 74~~ shows the percentage of furnaces equipped with ECMs – only 9% of furnaces in the statewide sample have an ECM.

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Table 74: Frequency of ECMs in Furnaces

	Custom	Spec	All Homes (Weighted)
n (furnaces)	*6*	*20*	*26*
No	100%	90%	91%
Yes	--	10%	9%

Heat Pump Efficiency

Sampled homes had twelve heat pump heating systems.[40] Six systems (four GSHPs and two ASHPs) serve as the primary source of heat for the homes. The rest serve as supplemental systems; ductless mini-split heat pumps, for example, are often used to heat individual rooms, such as a bonus room over a garage or a finished basement. Table 75~~Table 75~~ summarizes the heating efficiency data for all the heat pump systems. The heat pump heating efficiencies are rated by their heating season performance factors (HSPF).[41]

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Table 75: Heat Pump Efficiency (HSPF, Unweighted)

	Ductless mini-split	GSHP– closed loop	ASHP
n (heat pumps)	*2*	*6*	*4*
Minimum	8.8	11.9	7.7
Maximum	11.0	15.0	10.5
Average	9.9	13.4	9.4
Median	9.9	13.5	9.8

6.1.5 Heating ENERGY STAR Status

The ENERGY STAR status of each piece of equipment designated as a primary heating system is shown in Table 76~~Table 76~~. Almost a quarter of primary systems (24%) are

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[39] ECMs offer two major advantages over PSC motors. First, ECMs use significantly less electricity than PSC motors while producing comparable air flow. Second, ECMs are variable speed motors with the flexibility to adjust air flow depending on the demand being called for by the furnace or central air conditioning system. Not all ENERGY STAR-qualified furnaces have ECM motors – some have multi-speed fans but not fully variable ECMs.

[40] As with central AC split systems, a split heat pump "system" includes an outdoor unit and one or more attached indoor units.

[41] A HSPF rating is calibrated over an entire season and represents the ratio of the total heat supplied over the watt-hours consumed during that time.

ENERGY STAR qualified. Custom homes (62%) are significantly more likely than spec homes (14%) to have ENERGY STAR systems.

Table 76: Heating System ENERGY STAR Status (Primary Systems Only)

	Custom	Spec	All Homes (Weighted)
*n (primary heating systems)***	*21*	*22*	*43*
No	**38%***	**86%***	76%
Yes	**62%***	**14%***	24%

*Significantly different at the 90% confidence level.
**Some homes have multiple primary systems, e.g., two furnaces of the same type.

Table 77~~Table 77~~ summarizes the ENERGY STAR status for all heating equipment, excluding fireplaces and stoves. The table includes primary and supplemental heating equipment. Only 80% of furnaces are ENERGY STAR qualified. Looking at fossil fuel-fired heating equipment (furnaces, boilers, and combi appliances), 25% of equipment is ENERGY STAR qualified.

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Table 77: All Heating Equipment ENERGY STAR Status (All Systems; Unweighted Unless Noted)

System Type	*n*	Yes	No
Furnace (weighted)	*35*	6%	94%
Boiler (hydro-air)	*7*	5 (71%)	2 (29%)
ASHP	*4*	1 (14%)	3 (86%)
GSHP	*6*	--	6 (100%)
Combi appliance	*3*	3 (100%)	--
Boiler (forced hot water)	*3*	2 (67%)	1 (33%)
Ductless mini-split	*2*	2 (100%)	--
Total (weighted)	*51*	*25%*	*75%*

6.1.6 Heating Capacity

Table 78~~Table 78~~ shows per-home statistics on the heating system capacity per square foot of conditioned floor area of sampled homes. The total capacity in Btu/hr. of all the heating equipment in each home is summed and then divided by the square feet of conditioned floor area in the home. Compared to spec homes, custom homes have a significantly smaller average heating capacity per square foot of conditioned floor area, meaning spec home systems are oversized relative to custom home systems.

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Table 78: Heating Capacity per Square Foot of Conditioned Floor Area (BTU/hr/ft^2)

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	13.2	23.1	13.2
Maximum	67.8	103.1	103.1
Average	**34.9***	**45.8***	43.2
Median	36.7	40.3	39.6

*Significantly different at the 90% confidence level.

6.1.7 Supplemental Heating Systems

Table 79~~Table 79~~ displays the types of supplemental heating systems found in sampled homes. Eight homes use supplementary heating systems, and several homes have multiple supplemental heating systems. The most frequent supplemental heating system types are ducted air-source heat pumps (ASHP). All supplemental heating systems use electricity for fuel, except for the stoves, which use wood.

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Table 79: Supplementary Heating Systems
(Base: All supplemental heating systems)

	Custom	Spec	All Homes (unweighted)
n (supplementary heating systems)	*10*	*1*	*11*
ASHP	3 (30%)	--	33%
Stove	1 (10%)	1 (100%)	22%
Electric radiant floor (electric resistance)	2 (20%)	--	22%
GSHP-closed loop	2 (20%)	--	22%
Ductless mini-split	2 (20%)	--	22%

6.2 Cooling Equipment

The following section describes the cooling equipment seen in the sample homes.

6.2.1 Primary Cooling Equipment - Type

Central air conditioning (CAC) is present in 83% of all homes, in 90% of spec homes, and 62% of custom homes (a statistically significant difference) (Table 80~~Table 80~~). Some custom homes have air source heat pumps and ground source heat pumps, but those are not in spec homes at all. This proportion, compared to the absence of heat pumps in spec homes, is a statistically significant difference.

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Table 80: Primary Cooling Type per Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Central air conditioner	**62%***	**90%***	83%
None	--	10%	8%
GSHP-closed loop	**19%***	**--***	5%
ASHP**	**14%***	**--***	3%
Room air conditioner	5%	--	1%

* Statistically significant at the 90% confidence level.
**Includes one home with a large multi-split system with both ducted and ductless distribution systems.

6.2.2 Cooling Equipment – Location

Table 81~~Table 81~~ provides the locations of all primary cooling equipment. Over two-thirds of primary cooling systems are located in unconditioned spaces, such as basements, crawlspaces and attics – nearly one-third (30%) are in conditioned space. The differences between custom and spec homes in the proportion of systems located in conditioned space (57% versus 18%, respectively) and in unconditioned basements (29% versus 55%, respectively) are statistically significant.

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Table 81: Location of Primary Cooling Systems

Location	Custom	Spec	All Homes (Weighted)
*n (primary cooling systems**)*	*35*	*22*	*57*
Unconditioned basement/enclosed crawl	**29%***	**55%***	47%
Conditioned area	**57%***	**18%***	30%
Attic	14%*	27*	23%

* Statistically significant at the 90% confidence level.
** Some homes have multiple primary systems (e.g., two CAC systems of the same type).

Table 82~~Table 82~~ shows the location of the all cooling systems – primary and supplemental[42] – separated by system type. Only one-fourth of CAC systems are installed in conditioned space; custom homes are significantly more likely than spec homes to have that arrangement. Four of the six GSHP systems (67%) were installed in conditioned space, and three of the five ducted ASHP systems were installed in conditioned space as well. The head or blower portion of ductless mini-splits and room air conditioners are, by their nature, installed in conditioned spaces.

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[42] All cooling systems were, in fact, primary systems, except for the two ductless mini-split heat pumps.

Table 82: Location of All Cooling Systems by Type

System Type/Location	Custom	Spec	All Homes (Only CAC Weighted)
*n (primary cooling systems**)*	*35*	*22*	*57*
Central Air Conditioner			
n (CAC systems)	*23*	*22*	*45*
Unconditioned basement/enclosed crawl	35%	55%	50%
Conditioned area	**52%***	**18%***	26%
Attic	13%	27%	24%
GSHP-Closed Loop			
n (GSHP systems)	*6*	--	*6*
Conditioned area	4 (67%)	--	4 (67%)
Unconditioned basement/enclosed crawl	2 (33%)	--	2 (33%)
ASHP			
n (ASHP systems)	*5*	--	*5*
Conditioned area	3 (60%)	--	3 (60%)
Attic	2 (40%)	--	2 (40%)
Ductless Mini-Split*			
n (DMS systems)	*2*	--	*2*
Conditioned area	2 (100%)	--	2 (100%)
Room Air Conditioner			
n (RAC systems)	*1*	--	*1*
Conditioned area	1 (100%)	--	1 (100%)

* Statistically significant at the 90% confidence level.
** Some homes have multiple primary systems (e.g., two CAC systems of the same type).
***Both ductless mini-split systems are supplemental systems, not primary.

6.2.3 Cooling System Efficiency

Model numbers for cooling units were recorded during on-site inspections to verify the listed efficiencies of all cooling equipment.[43] The Seasonal Energy Efficiency Ratio (SEER) for all central air conditioning systems in sampled homes ranges from 13 SEER to 16 SEER, with a weighted average of 13.7 SEER (Table 83~~Table 83~~). Current federal minimum standards require 13 SEER[44] for split-system air conditioners in the Northeast climate zone.

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[43] Energy-efficiency values were verified using the Air Conditioning, Heating, and Refrigeration Institute's (AHRI) Directory of Certified Product Performance. https://www.ahridirectory.org/ahridirectory/pages/home.aspx
[44] US Department of Energy: Office of Energy Efficiency & Renewable Energy—*CFR 430.32*
https://www.gpo.gov/fdsys/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-part430-subpartC.pdf

Table 83: Central Air Conditioning Efficiency (SEER)

	Custom	Spec	All Homes (Weighted)
n (CAC systems)	*23*	*22*	*45*
Minimum	13.0	13.0	13.0
Maximum	16.0	15.0	16.0
Average	14.0	13.5	13.7
Median	13.0	13.5	13.5

No statistically significant differences at the 90% confidence level.

Figure 16~~Figure 16~~ displays the spread of CAC system SEER in the sample. All systems meet the federal minimum efficiency requirement of 13 and fall within a relatively narrow range of efficiency values.

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Figure 16: Central AC SEER

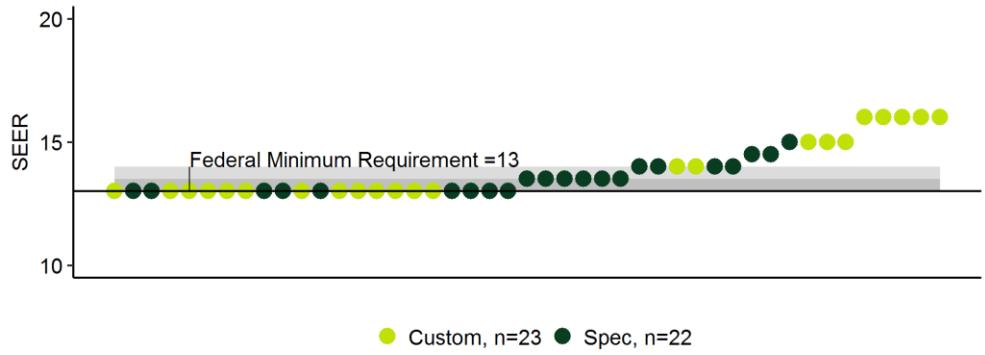

Table 84~~Table 84~~ displays efficiencies for all heat pumps in sampled homes, including the SEER of ducted air source heat pumps (ASHP) and ductless mini-splits, and the Energy Efficiency Ratios (EER) of ground source heat pumps (GSHP). Federal minimum standards for ASHPs increased from 13 SEER to 14 SEER January 1, 2015; one home has a system that predates this change.

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Table 84: Heat Pump Efficiency (Unweighted)

	GSHP (EER)	ASHP-Split (SEER)	Ductless Mini-Split (SEER)
n (systems)	*6*	*5*	*2*
Minimum	17.0	13.0	18.0
Maximum	26.1	16.8	21.5
Average	19.4	15.3	19.8
Median	18.1	16.0	19.8

Not tested for statistical significance.

6.2.4 Cooling ENERGY STAR Status

Only 12% of the 45 CAC systems met ENERGY STAR criteria at the date of manufacture (Table 85~~Table 85~~).[45] Only 5% of systems in spec homes were ENERGY STAR, compared to 35% in custom homes. This is a statistically significant difference.

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Table 85: Central Air Conditioner ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (CACs)	23	22	45
Yes	**35%***	**5%***	12%
No	**65%***	**95%***	88%

*Statistically significant at the 90% confidence level.

Only custom homes used heat pumps for cooling; Table 86~~Table 86~~ shows that all but two of these 13 systems were ENERGY STAR.

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Table 86: Heat Pump ENERGY STAR Status (Unweighted)

	GSHP	ASHP	Ductless Mini-split
n (systems)	6	5	2
Yes	100%	60%	100%
No	--	40%	--

Not tested for statistical significance.

6.2.5 Cooling Capacity

Cooling capacity per square foot of conditioned floor area is presented in Table 87~~Table 87~~. Values range from 7.1 to 35.4 for all homes with cooling and average 20.2 Btu/h per square foot.

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[45] At the time of this report, ENERGY STAR criteria required 15 SEER for CAC systems. ENERGY STAR – Air-Source Heat Pumps and Central Air Conditioners https://www.energystar.gov/products/heating_cooling/heat_pumps_air_source/key_product_criteria

Table 87: Installed Cooling Capacity per Square Foot Conditioned Floor Area

(Base: Homes with Cooling)

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*17*	*38*
Minimum	7.1	11.4	7.1
Maximum	35.4	32.9	35.4
Average	19.6	20.4	20.2
Median	18.2	19.9	19.8

No statistically significant differences at the 90% confidence level.

6.2.6 Supplemental Systems

Generally, homes only have one type of cooling system. Only two visited homes had a supplemental cooling system that differed from the primary system type: both were ductless heat pumps installed to supplement the homes' main CAC systems. In some cases, homes have more than one cooling system (two CAC systems, for example), but these are multiple primary systems (i.e., two smaller systems rather than one larger system of the same type).

6.3 Water Heating Equipment

This section describes the type of water heaters found during onsite inspections, including their fuels, capacity, and efficiency.

6.3.1 Water Heating Types

Standalone electric water heaters are the most common type, comprising 32% of water heaters (Table 88~~Table 88~~). Heat pump water heaters are the next most common (18%), followed by natural gas and propane instantaneous systems (16%). Electric storage tank systems are extremely common in spec homes, making up 42% of equipment in spec homes compared to just 4% in custom homes (a statistically significant difference). Instantaneous and indirect systems fueled by propane are significantly more likely to be found in custom homes than in spec homes.

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Table 88: Water Heater Type by Fuel

Type and Fuel	Custom	Spec	All Homes (Weighted)
n (water heaters)	24	19	43
Storage, standalone	***8%****	***64%****	***49%***
Electric	**4%***	**42%***	32%
Natural gas	4%	11%	9%
Propane	--	11%	8%
Heat pump water heater (electric)	***25%***	***16%***	***18%***
Instantaneous	***29%***	***11%***	***16%***
Natural gas	8%	11%	10%
Propane	**21%***	**--***	6%
Indirect w/ storage tank	***21%***	***5%***	***9%***
Oil	4%	5%	5%
Propane	**13%***	**--***	3%
Natural gas	4%	--	1%
Combi appliance	***4%***	***5%***	***5%***
Natural gas	--	5%	4%
Propane	4%	--	1%
Commercial storage (electric)	**8%**	**--**	**2%**
Tankless coil (oil)	**4%**	**--**	**1%**

*Statistically significant at the 90% confidence level

6.3.2 Water Heater Fuel

Electricity is the most common water heating fuel in the statewide sample (53%), followed by natural gas (24%) and propane (18%). Custom homes (38%) are significantly more likely to use propane than spec homes (11%).

Table 89: Water Heater Fuel

	Custom	Spec	All Homes (Weighted)
n (water heaters)	24	19	43
Electric	38%	58%	53%
Natural gas	17%	26%	24%
Propane	**38%***	**11%***	18%
Oil	8%	5%	6%

*Statistically significant at the 90% confidence level

6.3.3 Water Heater Storage Volume

The vast majority (89%) of water heaters with tank storage (out of 31 total) fall in the 40 to 50-gallon storage range (Table 90~~Table 90~~). All storage water heaters in the spec sample fall in this storage range, a significant difference from custom homes, for which 47% of

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water heaters store between 40 and 50 gallons. Custom homes are significantly more likely than spec homes to use larger capacity systems (greater than 75 gallons).

Table 90: Water Heater Storage Capacity (Gallons)

	Custom	Spec	All Homes (Weighted)
n (water heaters w/ tanks)	15	16	31
Less than 40	13%	--	3%
40 to 50	**47%***	**100%***	89%
51 to 60	7%	--	1%
Greater than 75	**33%***	**--***	7%

*Statistically significant at the 90% confidence level

6.3.4 Water Heater Efficiency

Table 91~~Table 91~~ summarizes the average Energy Factors for each system type in the sample. Heat pump water heaters dominate the efficiency ratings, with average Energy Factors of 3.21, while other efficient system types, such as electric storage systems or combi appliances have average Energy Factors in the mid-90's. Because sample sizes are limited and there is little variation between custom and spec homes, statewide averages are reported here. Energy Factors for indirect water heaters were calculated as 92% of the boiler efficiency, and are therefore a function of the boilers to which they are attached.[46] Not included in this table is one tankless coil system – unusual in new homes – with an estimated Energy Factor of .50, a function of the home's occupancy.[47]

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Table 91: Average Water Heater Energy Factors

	n	All Homes (Unweighted)
Electric storage, standalone	*9*	.95
Heat pump water heater	*9*	3.21
Natural gas and propane instantaneous	*9*	.93
Natural gas and propane storage, standalone	*5*	.68
Natural gas and propane indirect w/ storage tank	*4*	.87
Combi appliances	*2*	.95
Commercial storage (electric)	*2*	.85
Oil indirect w/ storage tank	*2*	.79

6.3.5 Water Heater ENERGY STAR Status

Overall, 46% of water heaters are ENERGY STAR models (Table 92~~Table 92~~). Excluded from this table are systems that are not given ENERGY STAR ratings, such as indirect

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[46] Source: NEHERS manual. Indirect-fired tank (integrated): The annual efficiency of an indirect-fired tank (insulated and set up as a separate zone off the heating boiler) is calculated as 92% of the boiler efficiency.
[47] Source: NEHERS Manual. Tankless coil Energy Factor is determined using the number of occupants in the home.

tanks (with efficiencies based on their associated boilers). Custom homes are significantly more likely to have ENERGY STAR systems – 72% vs. 39% in spec homes (Table 92~~Table 92~~).

Table 92: ENERGY STAR Water Heaters**

	Custom	Spec	All Homes (Weighted)
n (water heaters)	*18*	*18*	*36*
Yes	**72%***	**39%***	46%
No	**28%***	**61%***	54%

*Statistically significant at the 90% confidence level.
**Excludes types that are not rated by ENERGY STAR.

7 Section 7 Ducts

This section presents findings on duct leakage and duct insulation. For all supply and return ducts located in unconditioned space, auditors recorded the duct type (metal, flexible, or panned joists), location, insulation type, and insulation R-value. Auditors used the manufacturer rated R-values, which range from R-4.2 to R-12.0. The actual R-values vary based on installation practices (i.e., compressed insulation performs worse than uncompressed insulation).

The list below presents key findings for ducts in sampled homes.

- Only 10% of homes meet the Rhode Island-amended 2012 IECC prescriptive requirement of 8 CFM25 per 100 sq. ft. or less of total duct leakage.
- Forty-three percent of homes satisfy the 2012 IECC prescriptive code requirements for duct insulation (R-8 for attic supplies and R-6 for other locations).

7.1 Duct Location

All but two inspected homes (94%) have duct systems. Nine of 40 homes – only 13% (weighted) – have ducts located entirely in conditioned space, 22 homes (63%) have ducts partially located in conditioned space, and seven (18%) have all ducts located in unconditioned space.

As shown in Table 93~~Table 93~~, custom homes are significantly more likely than spec homes to have all ducts in conditioned space (38% vs. 5%, respectively). Locating ducts in conditioned space improves a home's efficiency because duct leakage is not a significant energy penalty when the leakage is occurring within the conditioned envelope of the home.

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Table 93: Duct Location

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
All ducts in conditioned space	**38%***	**5%***	13%
Some ducts in conditioned space	43%	68%	63%
No ducts in conditioned space	19%	16%	18%
No ducts	--	11%	6%

*Significantly different at the 90% confidence level.

7.2 Duct Leakage

Duct leakage to the outside (LTO) testing quantifies leakage from ducts to areas outside of conditioned space. Rhode Island's amended version of the 2012 IECC does not require ducts to meet a particular LTO threshold, but the following values are provided for

reference, as they do affect a home's efficiency. The LTO is higher (worse) in spec homes than in custom homes (Table 94~~Table 94~~), and it is a statistically significant difference.[48] Duct systems that are entirely in conditioned space were assigned an LTO value of zero.

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Table 94: Duct Leakage to the Outside (CFM25/100 sq. ft.)

	Custom	Spec	All Homes (Weighted)
n (homes)	*19*	*17*	*36*
Minimum (best)	0.0	0.0	0.0
Maximum	17.6	29.6	29.6
Average	**5.1***	**9.7***	8.6
Median	4.4	7.7	7.3

*Significantly different at the 90% confidence level.

Figure 17~~Figure 17~~ plots the duct LTO values for the sampled homes.

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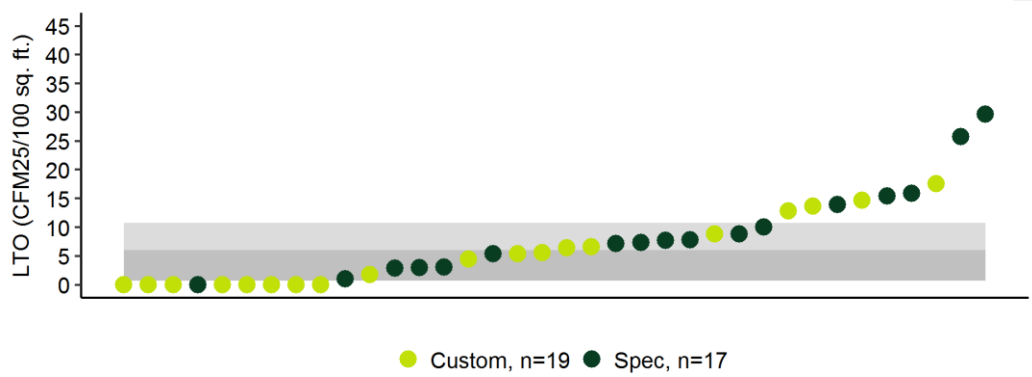
Figure 17: Leakage to Outside (Homes)



Total duct leakage (TDL) quantifies the total leakage of the duct system regardless of where the leaks are. The average TDL value is slightly higher in custom homes, though this difference is not statistically significant at the 90% confidence level (Table 95~~Table 95~~).

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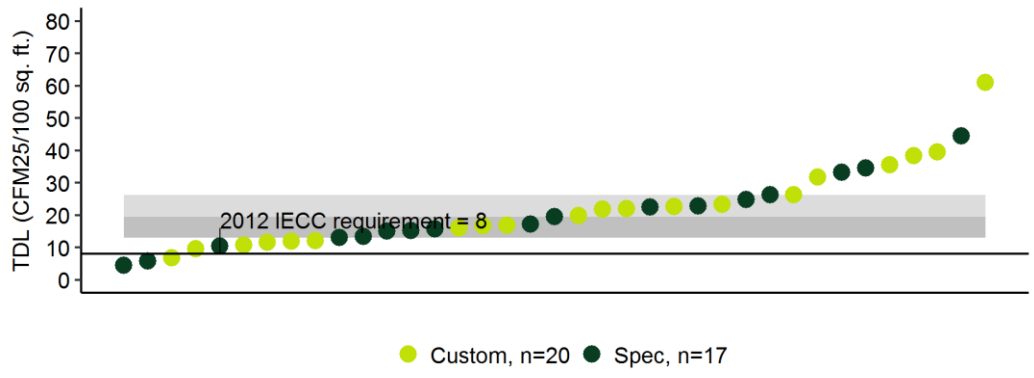
[48] LTO was not measured for three duct systems, either because the pressure in the ducts couldn't be reached during testing, or there were registers the auditors were unable to cover.

Table 95: Total Duct Leakage (CFM25/100 sq. ft.)

	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*17*	*37*
Minimum (best)	6.8	4.4	4.4
Maximum	60.9	44.4	60.9
Average	22.6	19.9	20.6
Median	20.7	17.1	17.5

No statistically significant differences at the 90% confidence level.

Figure 18: Total Duct Leakage (Homes)



The 2012 IECC with Rhode Island amendments requires a total leakage value of less than or equal to 8 CFM25 per 100 square feet of conditioned floor area. Compliance with Rhode Island's duct leakage requirements is shown in Table 96~~Table 96~~. Only 10% of homes with ducts meet these mandatory duct leakage requirements.

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Table 96: Compliance with Mandatory Duct Leakage Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*17*	*37*
Complies	5%	12%	10%
Fails	95%	88%	90%

No statistically significant differences at the 90% confidence level.

7.3 Duct Insulation

This section describes the R-value of duct insulation alone, excluding any additional protection afforded by the uncommon practice of burying ducts in ceiling insulation.[49]

Two-fifths (43%) of homes satisfy all 2012 IECC prescriptive code requirements for duct insulation (R-8 for attic supplies and R-6 for all others). The average duct insulation level for homes with ducts in unconditioned space is R-6.6 (Table 97~~Table 97~~).

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Table 97: Duct Insulation in Unconditioned Space

Duct Insulation Level	Homes with Ducts in Unconditioned Space
2012 IECC Compliance	
n (homes)	*29*
Below 2012 IECC	57%
Meets 2012 IECC*	36%
Exceeds 2012 IECC	7%
R-value	
n (homes)	*29*
Minimum	0
Maximum	9
Average	6.6
Median	6.8

*R-8 for attic supply, R-6 for all others

Table 98~~Table 98~~ displays homes' average R-values for duct insulation by location. These average values range from R-7.3 for attic supply ducts to R-6.5 for other ducts in unconditioned space; code requires R-8 and R-6 respectively. Additional subsets of ducts in unconditioned space (attic returns, unconditioned basements, and other locations) are also included.

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[49] Two custom homes had some duct work, insulated to R-8, covered by ceiling insulation.

Table 98: Average Insulation R-value for Ducts in Unconditioned Space by Location

	Custom		Spec		All Homes (Weighted)	
	n (homes)	R-value	*n (homes)*	R-value	*n (homes)*	R-value
Attic supply	*7*	7.5	*13*	7.3	*20*	7.3
Unconditioned ducts (except for attic supply)	*13*	7.3	*16*	6.4	*29*	6.5
*Unconditioned basement**	*8*	7.3	*12*	6.0	*20*	6.2
*Attic return**	*7*	7.3	*12*	7.2	*19*	7.3
*Other**	*3*	8.0	*1*	6.0	*4*	6.9

*Subset of "unconditioned ducts" row. Subset counts do not sum to the "unconditioned ducts" count because some homes have more than one of these duct locations.

Statewide, 76% of homes (71% custom, 77% spec) have some attic supply ducts that are insulated to R-8 or greater. Overall compliance with code requirements shown in Table 99~~Table 99~~ is slightly lower in the spec and statewide samples due to un(der)insulated duct areas.

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Table 99: Attic Supply Duct Insulation R-values vs. Prescriptive Code Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*7*	*13*	*20*
Below code (<R8)	29%	46%	44%
At code (=R8)	57%	46%	48%
Above code (>R8)	14%	8%	9%

As outlined in Table 100~~Table 100~~, 95% of all homes comply with insulation code requirements for ducts in unconditioned space (other than attic supply ducts).

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Table 100: Unconditioned Duct Insulation R-values (Excluding Attic Supply) vs. Prescriptive Code Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*16*	*29*
Below code (<R6)	0%	6%	5%
At code (=R6)	31%	25%	26%
Above code (>R6)	69%	69%	69%

No statistically significant differences at the 90% confidence level.

7.4 Duct and Insulation Types

Apart from two custom homes,[50] all audited homes were constructed with a mixture of sheet metal and flexible ducts. Table 101~~Table 101~~ summarizes the fraction of total area (across the entire sample) each combination of duct material and insulation account for in different parts of the home. There were no statistically significant differences between custom and spec homes in insulation or duct material across duct locations.

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Overall, flex duct and sheet metal ducts are equally prevalent, and fiberglass (flex duct and sheet metal duct wrap) is the most common form of insulation. The low proportion of metallized bubble wrap insulation is fortunate because its use is controversial. Some critics claim the reported insulation value of R-4.2 – already below the R-8 average for attic supplies and R-6 average for other ducts required by code – is closer to R-1 based on ASTMC518 testing.[51]

Uninsulated duct work in unconditioned space was only observed in one home (a spec home), accounting for 80% of that home's return duct area.

Table 101: Duct Material and Insulation as a Percent of Total Duct Area by Location

Duct Location and Construction			Custom	Spec	All Homes (Weighted)
		n (homes)	*7*	*13*	*20*
Attic	Flex	Fiberglass	57%	61%	60%
	Metal	Fiberglass	43%	34%	36%
		Bubble	--	5%	4%
		n (homes)	*3*	*1*	*4*
Other	Flex	Fiberglass	29%	50%	42%
	Metal	Fiberglass	4%	--	2%
		Bubble	67%	50%	56%
		n (homes)	*8*	*12*	*20*
Unconditioned basement	Flex	Fiberglass	42%	43%	43%
	Metal	Fiberglass	47%	44%	44%
		Bubble	11%	5%	7%
		Uninsulated	--	8%	7%

[50] One ducted with metal only, and the other with flex duct only plus a duct board plenum constructed in conditioned space.

[51] http://www.greenbuildingadvisor.com/blogs/dept/qa-spotlight/bubble-wrap-duct-insulation-good-idea http://www.energy-experts.net/home/articles/the-truth-about-foil-faced-bubble-wrap/ However, flex duct insulation is also viewed in some circles as not meeting the stated insulation R-values: http://aceee.org/files/proceedings/2006/data/papers/SS06_Panel1_Paper18.pdf

8 Section 8 Air Infiltration

This section describes the results of the blower door diagnostic tests conducted at the sampled homes. Blower door tests quantify the air leakage or infiltration of the building envelope.

Key findings include the following:

- The average ACH50 value is 5.3. On average, custom homes perform better than spec homes, with an average ACH50 of 4.3 and 5.6, respectively – a statistically significant difference. Higher values indicate leakier, less efficient homes.
- Ninety-two percent of tested homes would fail the unamended 2012 IECC prescriptive requirement of 3 ACH50 or lower, but Rhode Island did not adopt this requirement from the boilerplate version of the 2012 IECC.

8.1 Blower Door Test Results

Auditors conducted blower door tests at 39 of 40 inspected homes and calculated the air changes per hour at 50 pascals of pressure (ACH50) (a metric for assessing the tightness of the building shell). The amended Rhode Island 2012 IECC code requires blower door testing to be done in new construction homes, but there is no specific ACH50 requirement.

Table 102~~Table 102~~ shows air infiltration statistics in ACH50 for sample homes. Average ACH50 is lower (better) in custom homes (4.3) than spec homes (5.6) (a statistically significant difference). The average ACH50 in the statewide sample is 5.3, well above the 2012 IECC requirement of 3 ACH50 (recognizing that Rhode Island did not adopt this requirement from the standard 2012 IECC provisions).

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Table 102: Air Infiltration (ACH50)

Air Infiltration ACH50	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*19*	*39*
Minimum	0.8	4.2	0.8
Maximum	10.4	6.9	10.4
Average	**4.3***	**5.6***	5.3
Median	4.4	5.8	5.7

*Statistically significant at the 90% confidence level.

Table 103~~Table 103~~ shows the would-be compliance among sampled homes against the 2012 IECC mandatory air infiltration requirements *adopted in other states – this is not a requirement in Rhode Island*. As shown, only 8% of homes in the statewide sample would meet the ACH50 air infiltration requirement used in the standard 2012 IECC, and 92% would not. Meeting this air infiltration threshold is significantly higher among custom homes

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– no spec homes would meet the 3 ACH50 requirement, while 30% of custom homes would.

Table 103: Compliance with Mandatory Air Infiltration (ACH50) Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*19*	*39*
Complies	**30%***	**0%***	8%
Fails	**70%***	**100%***	92%

*Statistically significant at the 90% confidence level.

Figure 19~~Figure 19~~ shows the distribution of the ACH50 values for the sampled homes, and shows how the vast majority fall above (fare worse) the 2012 IECC requirement in effect in many other states that adopted an unamended version of the energy code.

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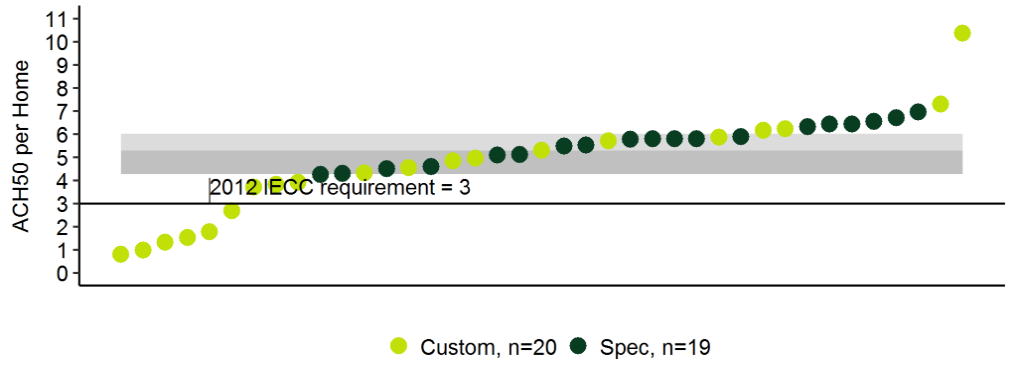
Figure 19: ACH50 per Home



9 Section 9 Ventilation

Data was collected on automatic ventilation systems in homes, including bathroom fans using timers or occupancy sensors, and heat recovery ventilation (HRV) and energy recovery ventilation (ERV) systems. [52]

Key findings include the following:

- Mechanical ventilation systems are present in only 6% of sampled homes – three custom homes have HRV systems and two custom homes have ERV systems. No homes had automatic bath fans that could turn on via a timer or based on occupancy.

Heat recovery ventilation (HRV) and energy recovery ventilation (ERV) systems were identified in 6% of homes (five custom homes). There were no automatic bathroom fans or whole house fans in any of the inspected homes.

Typical manual switch bathroom fans do not satisfy code requirements for mechanical ventilation and were not recorded during site visits. Due to the small sample size, the specific rated efficiencies are unweighted.

HRVs. A total of four HRV systems were observed in three custom homes with the following specifications:

- **Efficiency.** Sensible recovery efficiencies ranging from 57% to 75%, averaging 65%. Average rated power consumption of 54 watts.
- **Flow Rates.** Ranging from 57 CFM to 132 CFM, averaging 87 CFM.
- **Controls.** Three timers and one dehumidistat,

ERVs. A total of three ERV systems were observed in two custom homes. All three systems were the same ERV brand and model.

- **Efficiency.** The model has a sensible recovery of 71% and a total recovery of 48%. Power consumption is 102 watts.
- **Flow Rate.** Flow rate is 126 CFM.
- **Controls.** Two timers and one dehumidistat.

[52] The difference between an Energy Recovery Ventilator (ERV) and a Heat Recovery Ventilator (HRV) is that in an ERV, the heat exchanger transmits some amount of water vapor along with the heat energy, whereas only heat is transferred in a HRV.

10 Section 10 Lighting

This section describes the types of lighting seen in homes during on-site inspections.

Key findings include the following:

- Efficient lamps (LEDs, CFLs, and fluorescents) fill 66% of sockets.
- LEDs are the most common lamp type, found in 50% of all sockets.
- Fifty-eight percent of homes meet the 2012 IECC requirement that 75% of lamps in hard-wired fixtures be high-efficacy.
- Custom homes have a significantly higher proportion of LEDs and a significantly lower proportion of inefficient lamps when compared to spec homes.

10.1 Lighting Data Collection

Auditors collected data on all lighting fixtures, including the location, type (hard-wired or plug-load), number of sockets, and lamp (bulb) type(s). For this analysis, tamp types considered to be energy-efficient are compact fluorescent (CFL) bulbs, light-emitting diodes (LEDs, including integrated LED fixtures), and fluorescent tubes. Inefficient types include incandescent, halogen, and uncommon types such as xenon lamps. Only 8% of all lamps are installed in plug-in fixtures; the rest are hard-wired. The tables below include either all lamps observed or only those in hard-wired fixtures (as indicated in the tables' titles).

10.2 Lighting Results

Sixty-six percent of sockets have efficient lamps installed (LEDs, CFLs, or fluorescents). Custom homes have a significantly higher proportion of efficient lamps installed (71% vs. 63% in spec homes). Half of all lamps are LEDs. On average, there are 90 sockets per home in the statewide sample (Table 104~~Table 104~~).

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Table 104: Socket Saturation (Hard-wired and Plug-in Fixtures)

	Custom	Spec	All Homes (Weighted)
n (sockets)	*2,602*	*1,495*	*4,097*
Average number of total sockets	**124***	**79***	90
% of sockets containing LED lamps	**55%***	**48%***	50%
% of sockets containing CFL lamps	**10%***	**12%***	12%
% of sockets containing fluorescent tubes	**6%***	**3%***	4%
% of sockets not containing energy-efficient lamps	**29%***	**37%***	34%

*Statistically significant at the 90% confidence level.

The 2012 IECC specifies that a minimum of 75% of the lamps in permanently installed lighting fixtures (i.e., hard-wired, not plug-in) shall be high-efficacy lamps.[53] Table 105~~Table 105~~ shows that custom and spec homes are relatively similar (i.e., non-significant differences) in terms of the efficient socket saturation in hard-wired (permanent) fixtures when grouped into bins to better show the distribution of efficient lighting in homes.

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Table 105: Energy-Efficient Lamp Saturation in Hard-Wired Fixtures

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
10% or less	--	5%	4%
11% to 30%	5%	16%	13%
30% to 49%	10%	5%	6%
50% to 74%	29%	16%	19%
75%+ (2012 IECC requirement)	57%	58%	58%

No statistically significant differences at the 90% confidence level.

Table 106~~Table 106~~ condenses these values to provide a clear look at how homes compare to the code standard. Fifty-eight percent of homes in the statewide sample meet 2012 IECC lighting requirements. The difference in compliance rates between custom and spec homes is not significant.

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Table 106: Compliance with 2012 IECC Lighting Requirement

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Less than 75% of sockets in hard-wired fixtures with high efficacy lamp	43%	42%	42%
75% or more sockets in hard-wired fixtures with high efficacy lamp	57%	58%	58%

*Statistically significant at the 90% confidence level.

Table 107~~Table 107~~ shows the average efficient lamp saturation per home for each room type (e.g., this table shows that, on average, homes in the sample have 64% of their bedroom sockets filled with efficient lamps). Laundry or utility rooms and rooms in the "other" category – which includes closets and other less-common rooms types observed during on-sites – have the highest average proportion of efficient socket saturation among all room types in the weighted statewide sample. Dining rooms, foyers, and attics have the lowest average proportions of efficient bulb saturation among surveyed room types.

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[53] High efficacy is defined by IECC as 60 lumens per watt for lamps over 40 watts, 50 lumens per watt for lamps over 15 watts to 40 watts, 40 lumens per watt for lamps 15 watts or less. As shown on pg. 65: https://www.resnet.us/uploads/documents/conference/2012/pdfs/Barcik-Energy_Code-IECC2012_vs_2009IECC.pdf. This requirement does not apply to homes that follow the performance path for code compliance.

Table 107: Average Home-Level Socket Saturation by Room Type (All Fixture Types)

Room	Custom		Spec		All Homes (Weighted)	
	Number of Homes	Avg. % of Sockets with Energy-Efficient Lamps	Number of Homes	Avg. % of Sockets with Energy-Efficient Lamps	Number of Homes	Avg. % of Sockets with Energy-Efficient Lamps
Laundry/utility	16	89%	13	85%	29	86%
Other	21	82%	18	85%	39	84%
Office	10	78%	6	77%	16	77%
Garage	19	83%	15	69%	34	73%
Basement	16	92%	15	68%	31	73%
Bathroom	21	67%	19	69%	40	69%
Hallway/stairway	20	75%	17	66%	37	68%
Exterior	21	80%	19	61%	40	66%
Living room	21	62%	19	63%	40	63%
Bedroom	21	65%	19	63%	40	64%
Kitchen	21	74%	19	61%	40	64%
Dining room	13	66%	15	47%	28	51%
Foyer	9	51%	5	47%	14	48%
Attic	11	73%	8	13%	19	30%

Table 108~~Table 108~~ show the percent of all sockets containing efficient lamps, broken down by room type. While the previous table showed the average room-level saturation, this table shows the saturation across all sockets in all such room types. For example, this table shows that across all sockets in bedroom fixtures, 63% are efficient lamps. Interestingly, rooms in the "other" category, consisting of closets and uncommon room types; laundry and utility rooms; and garages, show the highest levels of efficient bulb saturation, rather than other high-use areas, such as kitchens, bathrooms, and living rooms.

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Table 108: Efficient Socket Saturation by Room Type (All Fixture Types)

Room	Custom		Spec		All Homes (Weighted)	
	n (sockets)	% of Sockets with Energy-Efficient Lamps	n (sockets)	% of Sockets with Energy-Efficient Lamps	n (sockets)	% of Sockets with Energy-Efficient Lamps
Other	169	79%	84	86%	253	83%
Laundry/utility	53	75%	24	83%	77	80%
Garage	187	86%	87	75%	274	79%
Office	62	77%	23	74%	85	75%
Basement	138	95%	113	64%	251	72%
Bathroom	350	63%	227	74%	577	70%
Hallway/stairway	194	64%	76	67%	270	66%
Exterior	348	81%	188	54%	536	63%
Bedroom	260	63%	193	63%	453	63%
Kitchen	259	73%	174	58%	433	62%
Living room	413	60%	179	63%	592	62%
Foyer	35	46%	26	58%	61	54%
Attic	23	78%	9	11%	32	40%
Dining room	111	63%	92	25%	203	35%

11 Section 11 Appliances

This section summarizes information about the appliances seen in visited homes, including refrigerators, freezers, dishwashers, ovens and ranges, clothes washers, dryers, and dehumidifiers.

Key findings include the following:

- **ENERGY STAR appliances are prevalent among new homes.** ENERGY STAR primary refrigerators (63%), dishwashers (91%), clothes washers (78%), and dehumidifiers (70%) are especially common.
- **Primary Refrigerators.** Almost two thirds (63%) are ENERGY STAR products. Fifty-eight percent of primary refrigerators are larger than 25 cubic feet, and the average rated energy consumption is 675 kWh/year.
- **Secondary Refrigerators.** Thirty-three percent of homes have at least one secondary refrigerator. Thirty-two percent are ENERGY STAR products, 63% are less than 10 cubic feet, and the average rated energy consumption is 377 kWh/year. Ten standalone freezers were observed (23% of homes), three of which (30%) are ENERGY STAR products.
- **Dishwashers.** Ninety-five percent of homes have dishwashers, and 91% are ENERGY STAR products. The average rated energy consumption is 265 kWh/year.
- **Ranges.** Fifty-nine percent of ovens were convection ovens; just 8% of ranges were induction.
- **Clothes Washers.** All but one home had a clothes washer; 78% are ENERGY STAR products. For washers with available data, the average rated energy consumption is 163 kWh/year, and the average Integrated Modified Energy Factor (IMEF) is 2.25.
- **Clothes Dryers.** Clothes dryers are present in all but one home, and 17% of the 42 dryers observed are ENERGY STAR products. Seventy-eight percent of dryers are fueled by electricity, 77% use a moisture sensor, and the average Energy Factor for dryers with available data is 3.91.
- **Dehumidifiers.** Dehumidifiers are present in nine homes (17%) and 70% are ENERGY STAR models.

11.1 Refrigerators and Freezers

11.1.1 Primary Refrigerators

At least one refrigerator was present in every home inspected. The most used, centrally located refrigerator was designated the "primary" refrigerator. Table 109~~Table 109~~ displays the ENERGY STAR status, volume, and configuration of primary refrigerators, all of which were manufactured since 2014.

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ENERGY STAR. Almost two-thirds (63%) of primary refrigerators are ENERGY STAR qualified.[54] Custom and spec homes had a similar proportion of ENERGY STAR qualified primary refrigerators.

Volume. Fifty-eight percent of primary refrigerators were larger than 25 cubic feet and 91% were greater than 20 cubic feet.

Configuration. Two-thirds of primary refrigerators have a bottom freezer configuration (70%). Bottom freezers were significantly more likely to be ENERGY STAR qualified than side-by-side refrigerators (78% vs. 21%). Custom homes had significantly more bottom freezer refrigerators than spec homes (90% vs. 63%).

Table 109: Primary Refrigerators

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*21*	*19*	*40*
Yes	67%	63%	64%
No	33%	37%	36%
Volume (ft^3)			
>25	43%	63%	58%
23-25	10%	21%	18%
20-22	**43%***	**5%***	14%
16-19	5%	11%	9%
Configuration			
Bottom freezer	**91%***	**63%***	70%
Side by side	**5%***	**26%***	21%
Top freezer	--	11%	8%
Single door	5%	--	1%

*Significantly different at the 90% confidence level.

Energy Consumption. Table 110~~Table 110~~ shows the electric consumption of the primary refrigerators with available consumption data. The average kWh per year consumption is 674, with a range from 330 to 784 at the high end.

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[54] For a refrigerator to qualify as an ENERGY STAR product, it must have a measured energy use 10% less than the federal minimum energy-efficiency standard. Standards are based on volume, configuration, and functionality of the refrigerator.
https://www.energystar.gov/products/appliances/refrigerators/key_product_criteria

Table 110: Primary Refrigerator Rated Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*21*	*19*	*40*
Minimum	330	404	330
Maximum	784	780	784
Average	638	685	674
Median	633	709	701

No statistically significant differences at the 90% confidence level.

11.1.2 Secondary Refrigerators

Thirty-three percent of homes had at least one secondary refrigerator. Secondary refrigerators, often used to store surplus food or as beverage centers, differed from primary refrigerators in that they tended to be older, smaller, less energy-efficient, and have a top freezer or single door configuration. Twenty-two secondary refrigerators were found during the on-site inspections. The key findings about the secondary refrigerators in sampled homes are described below. Table 111~~Table 111~~ provides additional detail, including ENERGY STAR status, volume, age, and configuration.

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ENERGY STAR. Nearly one-third (32%) of secondary refrigerators were ENERGY STAR qualified (at the date of manufacture). Custom homes had a higher proportion of ENERGY STAR qualified secondary fridges than spec homes.

Volume. The majority (63%) of secondary refrigerators were less than 10 cubic feet; only 9% were in the 22 to 25 cubic foot range (over half of the secondary refrigerators are mini-fridges or beverage centers). The average volume for secondary refrigerators was 9.7 cubic feet, less than half of the average volume of primary refrigerators (24.9 ft^3).

Age. Forty-one percent of secondary refrigerators were manufactured since 2014. The oldest secondary refrigerator was manufactured in the early 1990's.

Configuration. Over half (52%) of secondary refrigerators were either a mini fridge or beverage center. Top freezers were the second most frequent configuration.

Table 111: Secondary Refrigerators

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*16*	*6*	*22*
ENERGY STAR Status			
Yes	31%	33%	32%
No	63%	50%	56%
Don't Know	6%	17%	12%
Volume (ft^3)			
<10	38%	83%	63%
16-19	25%	--	11%
20-22	31%	--	14%
22-25	--	17%	9%
Don't Know	6%	--	3%
Age			
2015	44%	33%	38%
2014	6%	--	3%
2013	13%	--	5%
2012	6%	17%	12%
2006-2010	6%	17%	12%
2001-2005	6%	17%	12%
1996-2000	6%	--	3%
1991-1995	6%	17%	12%
Don't Know	6%	--	3%
Configuration			
Mini-fridge	25%	67%	49%
Top freezer	56%	--	24%
Single door	13%	17%	15%
Side by side	--	17%	9%
Beverage center	6%	--	3%

Not tested for statistical significance.

Energy Consumption. Table 112~~Table 112~~ shows the electric consumption of the secondary refrigerators for which energy consumption data were available.[55] The large range from the lowest to the highest consumers is partially due to a large variance in size among secondary refrigerators. The average is 377 kWh/year, which is 56% of the average primary refrigerator's rated energy consumption, while secondary refrigerators were, on average, about one-third (39%) of the volume of primary refrigerators.

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[55] Electrical consumption data was unavailable for three secondary refrigerators. Factors included nameplates being inaccessible, old age, and lack of product information available.

Table 112: Secondary Refrigerator Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*13*	*6*	*19*
Minimum	236	235	235
Maximum	767	577	767
Average	388	369	377
Median	385	351	385

Not tested for statistical significance.

11.1.3 Freezers

There were ten sampled homes (23%) with standalone freezers. Table 113~~Table 113~~ summarizes the categorical data collected on standalone freezers: ENERGY STAR status, volume, age, and configuration. The small sample size (10) should be considered when reviewing the results.

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ENERGY STAR. Three (30%) standalone freezers were ENERGY STAR qualified.

Volume. Half (50%) of freezers have a volume between 5 and 15 cubic feet.

Age. Over one-third (40%) of freezers were larger than 15 cubic feet. Fifty percent of freezers were manufactured since 2014. The oldest freezer was manufactured in the early 1990's.

Configuration. Four-fifths of freezers were upright and 20% were chest-style.

Table 113: Freezer Categorical Summary

	Custom	Spec	All Homes (Unweighted)
n (freezers)	*6*	*4*	*10*
ENERGY STAR Status			
No	4 (67%)	2 (50%)	6 (60%)
Yes	2 (33%)	1 (25%)	3 (30%)
Don't Know	--	1 (25%)	1 (10%)
Volume (ft^3)			
<5	--	1 (25%)	1 (10%)
5-10	--	2 (50%)	2 (20%)
10-15	3 (50%)	--	3 (30%)
15-20	3 (50%)	1 (25%)	4 (40%)
Age			
1991-1995	1 (17%)	--	1 (10%)
2001-2005	1 (17%)	1 (25%)	2 (20%)
2006-2010	1 (17%)	--	1 (10%)
2011-2013	1 (17%)	--	1 (10%)
2014	--	1 (25%)	1 (10%)
2015	2 (33%)	1 (25%)	3 (30%)
2016	--	1 (25%)	1 (10%)
Configuration			
Upright	6 (100%)	2 (50%)	8 (80%)
Chest	--	2 (50%)	2 (20%)

Not tested for statistical significance.
Unweighted results due to small sample size.

Energy Consumption. Rated energy consumption data were available for ten freezers (Table 114~~Table 114~~). The overall average rated energy consumption was 445 kWh/year.

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Table 114: Freezer Rated Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Unweighted)
n (freezers)	*6*	*4*	*10*
Minimum	318	240	240
Maximum	621	431	621
Average	543	298	445
Median	575	260	299

Not tested for statistical significance.
Unweighted results due to small sample size.

11.2 DISHWASHERS

Of the sampled homes, 38 of the 40 had dishwashers, and one home had three.

ENERGY STAR. For a dishwasher to qualify as ENERGY STAR, it must be 12% more efficient than non-certified models and more efficient than models that only meet the federal minimum standard for energy-efficiency.[56] Almost every dishwasher (91%) was ENERGY STAR qualified at the time of manufacture.

Table 115: Dishwasher ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*19*	*41*
Yes	96%	90%	91%
No	4%	10%	9%

No statistically significant differences at the 90% confidence level.

Age. Table 116~~Table 116~~ shows the year of manufacture for dishwashers. Most dishwashers were manufactured in 2016 (76%). Spec homes had significantly more dishwashers manufactured in 2016, while custom homes had significantly more dishwashers manufactured in 2014 and 2015.

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Table 116: Dishwasher Age

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*19*	*41*
2016	**18%***	**95%***	76%
2015	**68%***	**5%***	21%
2014	**14%***	**--***	3%

*Significantly different at the 90% confidence level

Energy Consumption. Table 117~~Table 117~~ shows the rated energy consumption of all dishwashers. The average for all dishwashers was 265 kWh/year. As of January 2016, the ENERGY STAR criterion for dishwashers is 270 kWh/year or less; 95% of the dishwashers met the new ENERGY STAR criterion[57], though only 76% of dishwashers in the sample were manufactured in 2016.

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Table 117: Dishwasher Rated Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*19*	*41*
Minimum	218	258	218
Maximum	294	305	305
Average	263	266	265
Median	260	260	260

No statistically significant differences at the 90% confidence level.

[56] Source: https://www.energystar.gov/products/appliances/dishwashers
[57] https://www.energystar.gov/products/appliances/dishwashers/key_product_criteria

11.3 Ovens and Ranges

Type. Most units (60%) were combined ovens and ranges.[58] Spec homes were significantly more likely to have a combined oven and range than custom built homes. Overall, 59% of ovens were convection ovens; 8% of ranges were induction.

Table 118: Oven and Range Types

	Custom	Spec	All Homes (Weighted)
n (systems)	*37*	*22*	*59*
Oven and range	**32%***	**63%***	60%
Oven only	41%	22%	22%
Range only	27%	15%	18%

*Significantly different at the 90% confidence level

Fuel. Propane was most prevalent in cooking ranges, while electricity was most common for ovens. Spec homes were significantly more likely to have propane for both range and oven, while custom homes were significantly more likely to have electric fuel for both range and oven.

Table 119: Range Fuel

	Custom	Spec	All Homes (Weighted)
n (ranges)	*22*	*19*	*41*
Propane	**23%***	**58%***	49%
Natural gas	23%	37%	33%
Electric	**54%***	**5%***	18%

*Significantly different at the 90% confidence level

Table 120: Oven Fuel

	Custom	Spec	All Homes (Weighted)
n (ovens)	*27*	*19*	*46*
Electric	**78%***	**26%***	41%
Natural gas	**11%***	**37%***	29%
Propane	**11%***	**37%***	29%

*Significantly different at the 90% confidence level

11.4 Clothes Washers

Clothes washers were present in 39 homes; two homes had two clothes washers. Only three homes had clothes washers located in unconditioned space. Altogether, there were

[58] "Oven and range" refers to a standard oven with a range on top. "Oven only" and "range only" types signify ovens and ranges that were separate units.

41 clothes washers surveyed during on-site inspections – 24 front load and 17 top load models.

ENERGY STAR. Seventy-eight percent of clothes washers were ENERGY STAR qualified. Table 121~~Table 121~~ shows the ENERGY STAR status for all clothes washers[59]. Additionally, 94% of front load washers are ENERGY STAR certified compared to only 51% of top load washers. Front load washers are significantly more likely to be ENERGY STAR qualified than top load washers.

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Table 121: Clothes Washer ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (washers)	*23*	*18*	*41*
Yes	78%	78%	78%
No	22%	22%	22%

No statistically significant differences at the 90% confidence level.

Energy Consumption. The average statewide rated consumption of clothes washers was 163 kWh/year.

Table 122: Clothes Washer Rated Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Weighted)
n (washers)	*23*	*18*	*41*
Minimum	75	85	75
Maximum	289	370	370
Average	149	168	163
Median	138	118	120

No statistically significant differences at the 90% confidence level.

The Integrated Modified Energy Factor (IMEF) is an energy performance metric used by ENERGY STAR for residential clothes washers as of March 7, 2015. Prior to this transition, the metric used was the Modified Energy Factor.[60] The IMEF is the same as the MEF with an additional adjustment for low-power mode energy consumption. The higher the IMEF, the more energy-efficient the clothes washer is (Table 123~~Table 123~~).

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[59] ENERGY STAR certified clothes washers use 25% less energy and 40% less water than regular washers.
[60] A conversion factor was applied to all clothes washers were only MEF data was available to determine the equivalent IMEF. IMEF = (MEF-.503)/.95.

Table 123: Clothes Washer IMEF

	Custom	Spec	All Homes (Weighted)
n (washers)	*23*	*17*	*40*
Minimum	.83	1.29	0.331
Maximum	2.98	2.92	3.10
Average	2.17	2.11	2.25
Median	2.38	2.06	2.38

No statistically significant differences at the 90% confidence level.

11.5 DRYERS

Dryers were present in 39 of the 40 sampled homes, and three homes had two dryers. A total of 42 clothes dryers were present in homes. Two homes have dryers located in unconditioned space.

ENERGY STAR. Table 124~~Table 124~~ shows that 17% of dryers were ENERGY STAR qualified. ENERGY STAR qualified dryers use 20% less energy than conventional models without sacrificing features or performance.[61]

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Table 124: Dryer ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*18*	*42*
Yes	17%	17%	17%
No	83%	83%	83%

No statistically significant differences at the 90% confidence level.

Fuel. A majority (78%) of dryers were electric and one-fifth (21%) used natural gas, as shown in Table 125~~Table 125~~.

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Table 125: Dryer Fuel

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*18*	*42*
Electric	79%	78%	78%
Natural gas	17%	22%	21%
Propane	4%	--	1%

No statistically significant differences at the 90% confidence level.

Energy Consumption. Dryers with a moisture sensor reduce energy usage by ending the drying cycle when clothes are dry, rather than after a set drying time. Moisture sensors were present in 77% of dryers.

[61] https://www.energystar.gov/products/appliances/clothes_dryers

Table 126: Dryer Moisture Sensor Status

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*18*	*42*
Yes	75%	78%	77%
No	25%	22%	23%

No statistically significant differences at the 90% confidence level.

Table 127~~Table 127~~ shows Energy Factor ratings for dryers.[62] Dryers were only recently required to have Energy Factor ratings; 17% of the sampled dryers did not have Energy Factor ratings. The statewide average energy factor was 3.91. Spec homes had a slightly higher energy factor than custom homes, indicating more energy-efficient dryers on average.

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Table 127: Dryer Energy Factor

	Custom	Spec	All Homes (Weighted)
n (dryers)	*20*	*15*	*35*
Minimum	3.00	3.73	3.00
Maximum	4.53	4.53	4.53
Average	3.75	3.98	3.91
Median	3.73	3.80	3.79

No statistically significant differences at the 90% confidence level.

11.6 DEHUMIDIFIERS

Dehumidifiers were present in nine (17%) of the sampled homes, and one home had two. Seventy percent were ENERGY STAR qualified (Table 128~~Table 128~~).[63]

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Table 128: Dehumidifier ENERGY STAR Status

	Custom	Spec	All Homes
n (systems)	*8*	*2*	*10*
Yes	6 (75%)	1 (50%)	7 (70%)
No	2 (25%)	1 (50%)	3 (30%)

Not tested for statistical significance.
Unweighted results due to small sample size.

[62] The Energy Factor is a ratio of the weight in pounds of clothes divided by the energy used during dryer operation. ENERGY STAR now uses the Combined Energy Factor, which also incorporates the standby energy use into the denominator.

[63] As of October 25, 2016, dehumidifiers that have a capacity of less than 75 pints per day must have an Energy Factor greater than or equal to 2.00. Dehumidifiers that are larger than 75 pints per day, must have an Energy Factor greater than or equal to 2.80.

Most dehumidifiers (80%) were manufactured after 2013; 20% were manufactured before 2010.

Table 129: Dehumidifier Age

	Custom	Spec	All Homes
n (systems)	*8*	*2*	*10*
2016	1 (13%)	--	1 (10%)
2015	3 (38%)	1 (50%)	4 (40%)
2014	2 (25%)	--	2 (20%)
2013	1 (13%)	--	1 (10%)
2006-2010	--	1 (50%)	1 (10%)
1996-2000	1 (13%)	--	1 (10%)

Not tested for statistical significance.
Unweighted results due to small sample size.

12 Section 12 Renewable Energy

Of the 40 inspected homes, only two homes (2%, weighted) had solar photovoltaic (PV) systems for on-site power generation – both custom homes. There were no homes with wind power or solar thermal hot water systems.

Below are the key details associated with the inspected PV systems.

- **Array Area**. PV array areas of 596 and 352 sq. ft.
- **Power Production.** Production capacities of 9.4 and 4 kilowatts.
- **Inverter Efficiencies.** Inverter efficiencies of 97% and 98%.
- **Array Orientation.** Both systems are oriented to the South.

13 Section 13 Code Compliance

This section describes the results of two separate code compliance analyses of the inspected homes – a review of the homes' code compliance based on filling out Pacific Northwest National Laboratory (PNNL) code compliance checklists, and the MA-REC approach that uses energy modeling results to estimate code compliance. The results of both approaches are presented separately. Ten of the 40 visited homes followed the UA trade-off compliance path and 30 followed the prescriptive compliance path.

Key findings are detailed below.

PNNL Approach

- None of the non-program homes visited as part of the baseline study met all the checklist requirements. On average, non-program homes achieved 63% (weighted; 67% unweighted) of the available checklist points. Custom homes have a significantly higher average compliance score compared to spec homes (74% vs. 59%).
- Among non-program homes, custom homes following the UA trade-off path have the highest average compliance score (86% of available checklist points), while spec homes following the prescriptive path have the lowest average compliance rate (57%).
- Non-program homes attain at least three-fifths (60%) of the available points for most measure categories (walls, ceilings, air leakage, duct leakage, etc.), on average; slabs (47%) and ceilings (39%) have the lowest compliance scores.
- Overall, homes in Rhode Island meet 69%, 70%, or 71% of the 2012 IECC PNNL checklist points, based on compiling program and non-program homes and assuming either a 90%, 95%, or 100% compliance score among program homes.

MA-REC Approach

- Statewide compliance among all new single-family homes in Rhode Island is 83% using the MA-REC compliance methodology.
- Compliance among non-program homes, using the MA-REC approach, is 80%. This is significantly lower than the program home compliance score of 93%.
- Program homes perform significantly better than non-program homes for many measures, including important measures such as air leakage, duct leakage, ceiling insulation, and frame floor insulation.
- There are no significant differences among non-program homes when comparing MA-REC compliance levels for homes that were permitted under different compliance paths (i.e., prescriptive or UA trade-off).

13.1 PNNL Approach

The following section describes the methodology and results of the PNNL approach to assessing code compliance among the inspected homes in the baseline study.

13.1.1 PNNL Methodology

The 2012 IECC checklist, developed by PNNL, scores code compliance on a point system; each measure is assigned a value of one, two, or three points based on its relative importance. Building-level compliance is calculated as the total points awarded for measures marked compliant divided by total possible points available for all applicable measures. (Homes are not penalized if an item on the checklist is not applicable or not observable.)

The team calculated sample-wide compliance with PNNL checklists using two approaches:

- Calculating the percentage of the homes with a checklist score of 100%
- Calculating the average compliance score across homes

The latter method was adopted for this study because it allows for the assessment of how close to full compliance a home is, rather than just assigning it a passing or failing grade. None of the homes included in this report complied with all applicable requirements and, as a result, the statewide compliance rate would be zero for all sampled homes if the requirement was that a home must be 100% compliant with all applicable measures.

The checklist allows users to assess compliance differently based on the compliance path chosen by the builder: the prescriptive approach, the UA trade-off approach, or the performance approach. For this study, evaluators visited and called building departments to identify the compliance approach used for the visited homes; none of the homes followed the performance path. These compliance paths, as defined by the DOE,[64] are detailed below.

- **Prescriptive Path:** This is the simplest compliance path. The requirements do not vary by building size, shape, window area, and so forth. The 2006, 2009, and 2012 IECC have a single table of requirements for insulation R-values, window and door U-factors, and Solar Heat Gain Coefficient (SHGC). There is a corresponding U-factor table that permits compliance of less common component types (e.g., structural insulated panels), albeit without any cross-component trade-offs.[65] The 2009 and 2012 IECC also include a requirement for efficient lighting fixtures.[66]
- **UA Trade-off:** This is the path predominantly used by the REScheck™ software. Based on the prescriptive U-factor table, it allows trade-offs whereby some envelope energy-efficiency measures can fall below code requirements if balanced by other envelope measures that exceed code requirements.
- **Performance Path:**[67] This path allows compliance if the home has a calculated annual energy consumption (or energy cost) equal to or less than that of a standard

[64] http://www.energycodes.gov/sites/default/files/documents/IECC2009_Residential_Nationwide_Analysis.pdf
[65] Under the prescriptive path, the U-factor table can be used as an alternative to the table summarizing R-value requirements. Note that this is not the same as the UA Trade-off approach, since using the U-factor table under the prescriptive path does not allow for trade-offs between building components.
[66] The lighting requirement also applies to the UA Trade-off approach in the 2009 IECC, but it does not apply to the performance path. It is a mandatory requirement under the 2012 IECC.
[67] The annual energy costs are only calculated for space heating, space cooling, and water heating end uses.

reference design that just meets the code's prescriptive requirements. This path allows for crediting energy-efficiency measures not accounted for in the other paths, such as renewable energy measures. The 2009 and 2012 IECC are augmented in Massachusetts by a state amendment that allows for performance-based code compliance by achieving a Home Energy Rating System (HERS) rater-verified HERS rating of 75 or lower under the 2009 IECC and 65 or lower under the 2012 IECC.

Evaluators populated checklists for each home differently depending on the compliance approach the builder followed (according to building department calls and visits). Under the prescriptive approach, applicable and observable items were marked as compliant or noncompliant. Under the trade-off or performance approaches, certain measures were marked as compliant even if they did not meet the prescriptive compliance levels. As the 2009 and 2012 IECC checklist instructions note, this is appropriate assuming that "a valid worksheet or software report was submitted showing a compliant building."[68]

The checklist itself is not a compliance path*, but rather a means of assessing compliance*. For example, if a home achieved compliance via the trade-off approach, then the builder should have submitted a REScheck report to the building department indicating compliance with the energy code. In this case, the home may not meet the prescriptive requirements listed in the checklist, but it would be considered compliant for all shell measures because the REScheck documentation proves that the home complied via the trade-off approach.

In addition to assessing the compliance scores of non-program homes that were part of the baseline study, we also estimated the average overall statewide compliance scores by considering the scores of program homes. PNNL checklists were not completed for program homes. Therefore, the Team created three scenarios, assuming that on average, program homes achieve either 90%, 95%, or 100% compliance with the PNNL checklists. The Team estimated the program penetration rate and then blended the PNNL compliance score results for non-program homes with those three program compliance scenarios to create an overall estimate of statewide compliance scores, including program and non-program homes.

13.1.2 PNNL Approach Findings

Table 130~~Table 130~~ summarizes checklist compliance results. On average, weighted results indicate homes attain 63% of the possible points on the 2012 IECC checklist. Custom homes have a significantly higher average compliance score compared to spec homes (74% vs. 59%). The data are based on results from analysis of up to 63 checklist items.

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[68] The presence of this documentation was verified in jurisdictions where auditors physically visited the building department. In all other jurisdictions, building department documentation was verified via email or phone.

Table 130: PNNL Compliance Results

	Custom	Spec	All Homes (Weighted)
n (non-program homes)	*21*	*19*	*40*
Minimum	51%	35%	35%
Maximum	96%	82%	96%
Unweighted average	**74%***	**59%***	67%
Weighted average	--	--	63%
Median	72%	60%	62%
Percent of homes 100% compliant	0%**		

*Significantly different at the 90% confidence level.
**Percent of homes with 100% checklist compliance.

Based on building department visits and phone calls, ten homes followed the UA trade-off approach and 30 followed the prescriptive approach (Table 131~~Table 131~~).[69] The UA trade-off path allows builders to exceed the prescriptive code requirements for a given measure and fall below the prescriptive standards in others so long as the entire thermal envelope of the building meets a certain overall U-value.

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Table 131: Compliance Path Distribution

	Custom	Spec	All Homes (Weighed)
n (non-program homes)	*21*	*19*	*40*
Prescriptive	14 (68%)	16 (57%)	30 (59%)
UA trade-off	7 (86%)	3 (71%)	10 (77%%)

No statistically significant differences at the 90% confidence level.

Average compliance scores for ten key measure types are summarized in Table 132~~Table 132~~. While few measures surpass 90% compliance (meaning homes attain 90% of available points for that measure, on average), most are over 60%. Ceilings and slabs have the lowest compliance scores, while windows and HVAC have the highest. Custom homes have a higher score in every category except for windows and HVAC, though these differences are generally not significant.

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[69] The team reviewed the paperwork filed for each of the homes included in this study. The paperwork did not reveal a compliance path for 15 of the 40 homes; these homes were assumed to follow the prescriptive compliance path.

Table 132: Average PNNL Checklist Scores by Requirement Category

	Custom	Spec	All Homes (Weighted)
n (non-program homes)	*21*	*19*	*40*
Above-grade walls	85%	68%	72%
Windows	90%	100%	96%
Air leakage**	80%	70%	73%
Ducts	78%	62%	66%
HVAC	73%	78%	77%
Lighting	67%	58%	60%
Ceiling	49%	36%	39%
Frame floors	75%	58%	62%
Foundation walls	71%	50%	59%
Slabs	**84%***	**--***	47%
Other	100%	--	100%

*Significantly different at the 90% confidence level.

** An air leakage value of 4.675 ACH50 was used for compliance.

13.1.3 Statewide PNNL Compliance with Program Home Assumptions

The information above represents only non-program single-family new construction in Rhode Island. To develop an estimate of statewide compliance that reflects the market as a whole, program homes need to be included.

Using the 2014 and 2015 program records, the Team estimates that the program has an overall RNC market share of 21%. To estimate statewide compliance using the PNNL approach, the Team used these penetration rates along with assumptions about program home compliance rates to develop a range of compliance estimates that captures both program and non-program single-family homes built in 2014 and 2015. Specifically, we assumed compliance rates of 90%, 95%, and 100% for program homes. Including program homes in the compliance assessment significantly increases compliance, from a weighted average of 63% in the non-program sample up to between 69% and 71% [depending on the level of assumed program compliance] (Table 133~~Table 133~~).

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Table 133: Statewide PNNL Compliance Assuming Various Compliance Scores for Program Homes

Program Home Compliance Score Scenario	Statewide Compliance
90% compliance	69%
95% compliance	70%
100% compliance	71%

13.2 MA-REC APPROACH

The following section describes the methodology and results of the MA-REC approach to assessing code compliance.

13.2.1 MA-REC Methodology

The MA-REC approach uses energy modeling to develop a code compliance scoring system that is more calibrated to estimated energy consumption than is the PNNL approach. Unlike the PNNL approach, the MA-REC approach focuses only on code requirements that directly impact energy consumption. The methodology does not account for administrative or non-energy-related code requirements, and it does not consider the compliance path utilized by the builder. This methodology compares homes to the 2012 IECC prescriptive requirements. Thus, the MA-REC approach does not account for trade-offs that may take place under the UA trade-off and performance paths for compliance. For this reason, it is possible that the MA-REC approach overstates the level of non-compliance and potential savings associated with homes that use the UA trade-off or performance paths for compliance. These paths allow for prescriptive non-compliance with certain measures assuming there are other measures that exceed the prescriptive requirements. The MA-REC approach does not attempt to address these complicating factors and this should be considered when reviewing the results associated with this methodology.

The MA-REC approach utilizes REM/Rate energy consumption estimates to determine the relative importance of various code-related building components.[70] The consumption estimates of individual measures are compared to the overall estimated consumption for a sample of homes to develop a detailed point system that is calibrated to overall estimated energy consumption.

A ten-point scale is used in which the most impactful measure (in terms of relative estimated energy consumption) receives an achievable score of ten points. Other measures are compared to the most important measure to develop an achievable point value between zero and ten points. The following formula provides an example of how the total possible points for each measure is developed (in this case, assuming window U-factor was the most important measure in terms of relative consumption):

$$Points_{Possible} = \frac{(P_{TC} \times 10)}{W_{TC}}$$

Where:

$$P_{TC} = Percentage\ of\ Total\ Consumption\ for\ Any\ Measure$$

$$W_{TC} = Window\ Pecentage\ of\ Total\ Consumption$$

The example below details how this calculation works for lighting.

[70] REM/Rate is an energy modeling tool that is used to develop Home Energy Rating Scores (HERS) and to support many residential new construction programs.

$$Points\ Possible\ Lighting\ is\ 4.1. = \frac{(8.2\% \times 10)}{20\%}$$

Where:

$$P_{TC\ \text{Lighting}} = Percentage\ of\ Total\ Consumption\ for\ Lighting\ is\ 8.2\%$$

$$W_{TC} = Window\ Pecentage\ of\ Total\ Consumption\ is\ 20\%$$

Once the point system is developed, 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 actually exists, and the other is a code-built model that represents the same home built to meet prescriptive code requirements. The measure-level percentage change between the code-built models and as-built models is used to assign a point value to each of the measures included in this methodology. If the as-built model meets or exceeds the code for a given measure (less consumption), that measure is provided with the total possible points.[71] If the as-built model is less efficient than code, then the measure is provided with partial credit depending on the percentage change of the as-built consumption relative to the code-built consumption. The following formulas are used for these calculations:

$$PC_{Base} = \frac{(CB_{Cons} - AB_{Cons})}{AB_{Cons}}$$

Where:

$$PC_{Base} = Percentage\ difference\ between\ "code - built"\ and\ "as - built"\ models$$

$$AB_{Cons} = As - built\ consumption$$

$$CB_{Cons} = Code - built\ consumtpion$$

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

$$Percentage\ difference\ for\ Lighting\ (PC_{Base})\ is - 0.4\ = \frac{(3\ \text{MMBtu} - 5\ \text{MMBtu})}{5\ \text{MMBtu}}$$

Where:

$$AB_{Cons} = 5\ MMBtu\ for\ Lighting\ Consumption$$

$$CB_{Cons} = 3\ MMBtu\ for\ Lighting\ Consumption$$

The last step in the calculations is to convert the percentage difference in consumption between the models into an adjusted score for that component.

Where:

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

$$Points_{Scored} = \begin{cases} Points_{Possible} \times (1 + PC_{Base}) \; if \; PC_{Base} < 0 \\ Points_{Possible} \; if \; PC_{Base} \geq 0 \end{cases}$$

Once again, this step is shown using the same lighting example from above. The first equation from above is used since the code-built model is more efficient than the as-built model. Had the as-built model been more efficient than the code-built model, the home in this example would receive the full 4.1 points for lighting.

$$\text{Points Scored for Lighting is } 2.5 = 4.1 \times (1 - 0.4)$$

Where:

$$PC_{Base} \; for \; Lighting = -0.4$$

$$Points \; Possible \; Lighting = 4.1$$

Specifically, this methodology includes points and compliance calculations 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
- Roof insulation and installation quality
- Slab insulation and installation quality
- Window efficiency

The number of points applied to individual components varies depending on the sample of homes and the code that is under consideration. For example, the distribution of points for 2006 IECC compliance would differ from 2009 IECC compliance because certain measures (i.e., air infiltration and lighting efficiency) are not applicable to the 2006 IECC. 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 critically important for the sample to represent the market. However, the relative number of possible points across the codes is not a critical comparison because the objective of this methodology is to compare compliance percentages. The total possible points simply provides an anchor with which to calculate the compliance percentages, or for determining the relative weight of each measure. This approach is similar to the PNNL scoring system, in which the total possible points varies across different codes due to the number and importance of various code requirements and scores are normalized from 0% to 100% to facilitate cross code comparisons.

The measure-level point allocations for this study are shown in Table 134~~Table 134~~.

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Table 134: Points and Relative Weights by Measure

Measure	Points	Weight
Window and skylight U-factor	10.0	20%
Air leakage	9.7	19%
Above grade wall insulation and installation	8.8	17%
Ceiling insulation and installation	5.8	12%
Duct leakage and insulation	5.1	10%
Frame floor insulation and installation	4.2	8%
Lighting	4.1	8%
Slab insulation and installation	1.3	3%
Foundation wall insulation and installation	1.3	3%

13.2.2 MA-REC Approach Findings

Overall MA-REC compliance among the non-program baseline homes is 80% and, as shown in Table 135~~Table 135~~, there is no significant difference in MA-REC compliance between compliance paths. Compliance scores show a strong correlation with HERS ratings (-0.585, meaning higher compliance correlates with lower HERS rating) at the 99.9% confidence level.

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Table 135: Measure-Level MA-REC Compliance by Compliance Path

Building System	Prescriptive	UA Trade-off	Unknown	All Homes (Weighted)†
n	15	10	15	40
Windows	89%	92%	92%	90%
Air leakage	80%	82%	88%	83%
Above grade walls	83%	84%	85%	84%
Ceilings	52%	55%	60%	55%
Ducts	72%	56%	83%	72%
Frame floors	70%	75%	67%	70%
Lighting	91%	78%	92%	88%
Slabs	94%	93%	99%	95%
Foundation walls	89%	80%	84%	86%
TOTAL	79%	78%	83%	80%

In Table 136~~Table 136~~, MA-REC compliance of different measures in custom and spec homes is shown. The only significant difference between groups is for ceiling insulation.

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Table 136: Measure-Level MA-REC Compliance by Builder

Building System	Custom	Spec	All Homes (Weighted)
n	21	19	40
Windows	90%	91%	90%
Air leakage	88%	81%	83%
Above grade walls	89%	82%	84%
Ceilings	**80%**	**47%**	55%
Ducts	85%	68%	72%
Frame floors	84%	65%	70%
Lighting	92%	87%	88%
Slabs	97%	95%	95%
Foundation walls	79%	88%	86%
TOTAL	87%	78%	80%

* Significantly different at the 90% confidence level.
† Values are weighted.

13.2.3 MA-REC - Cross-Code Comparisons

The state energy conservation code SBC-8-2013[72] lists amendments to the 2012 IECC specific to Rhode Island. Table 137~~Table 137~~ lists the amended state code in the center, flanked by the preceding and subsequent base codes for comparison. Note that the rows specifying building shell insulation levels are split in two columns for the state energy conservation code. This is because, as amended, the code contains one table (R402.1.1) with R-values equivalent to 2009 IECC and another (R402.1.3) with industry standard U-factors from 2012 IECC. Consequently, many homes were constructed with the insulation values listed in R402.1.1. See Table 138~~Table 138~~ for a summary of which fraction of homes employed the values from R402.1.1 versus R402.1.3.

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[72] http://sos.ri.gov/assets/downloads/documents/SBC8-RI-state-energy-conservation-code.pdf

Table 137: Comparison of Key Requirements Across Codes

Measure	2009 IECC	2012 IECC-RI		2012 IECC
		R402.1.1	R402.1.3	
Wall insulation	R-20 or R-13+5 (U-.057)	R-20 or R-13+5 (U-.057)	R-20 or R-13+5 (U-.057)	R-20 or R-13+5 (U-.057)
Ceiling insulation	R-38 (U-.030)	R-38 (U-.030)	R-49 (U-.026)	R-49 (U-.026)
Floor insulation	R-30 (U-.033)	R-30 (U-.033)	R-30 (U-.033)	R-30 (U-.033)
Foundation wall insulation	R-10/13 (U-.059)	R-10/13 (U-.059)	R-15/19 (U-.050)	R-15/19 (U-.050)
Slab insulation	R-10, 2ft	R-10, 2ft	R-10, 2ft	R-10, 2ft
Windows	U-0.35	U-0.35	U-0.32	U-0.32
Air infiltration	Requires air sealing. Compliance is assessed through visual inspection or air infiltration testing (7 ACH50).	The building or dwelling unit shall be tested and the air leakage rate shall be verified.[73]		Requires air sealing. Compliance is assessed via air infiltration testing (3 ACH50).
Duct leakage	Requires duct sealing, which is assessed through testing (8 CFM25/100 ft^2 leakage to the outside)	Requires duct sealing, which is assessed through duct leakage testing (8 CFM25/100 ft^2 of total leakage).		Requires duct sealing, which is assessed through testing (4 CFM25/100 ft^2 of total leakage).
Duct insulation	Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.	Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.		Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.
Lighting	50% high efficacy lamps in permanently installed fixtures.	75% high efficacy lamps in permanently installed fixtures.		75% high efficacy lamps in permanently installed fixtures.

Table 138~~Table 138~~ shows which fraction of homes match the different prescriptive code insulation levels in R402.1.1 and R402.1.3 of SBC8-2013; windows are omitted since few verified values were available. This table uses the nominal R-value of the primary insulation type in the homes, and does not account for framing factor, installation grade, or secondary construction types.

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[73] To calculate MA-REC compliance in a manner that would facilitate comparison with other baseline results, a proxy requirement of 4.675 ACH50 was used. This is midpoint between the mean infiltration rates in program and sample non-program homes; 4.11 and 5.24 ACH50 respectively.

Table 138: Majority Insulation Levels

	Non-Program		Program	
	Ceiling	Foundation Wall	Ceiling	Foundation Wall
n	40	12	162[74]	17
Exactly R402.1.1	65%	17%	19%	--
Meet or exceed R402.1.1	88%	58%	85%	82%
Meet or exceed R402.1.3	5%	33%	22%	47%

In addition to a comparison between the compliance levels using R402.1.1 and R402.1.3 insulations levels, Table 139~~Table 139~~ also includes compliance levels for the recent baseline study of homes built in Massachusetts during the beginning of its 2012 IECC code cycle. The lightly shaded rows (Windows, Ceilings, Foundation Walls) are the measures for which the prescriptive code R-values and U-factors are not equivalent. Compliance values in non-shaded rows may differ between the R402.1.1 and R402.1.3 columns due to synergistic effects and changes in the relative weights (Table 140~~Table 140~~) of measures. Overall compliance between R402.1.3 and R402.1.1 are similar since window compliance is high in both cases. In addition, windows, air leakage and above grade walls combined are five times as important as ceilings.

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Table 139: MA-REC Compliance Comparisons

Building System	2012 IECC-RI R402.1.3†	2012 IECC-RI R402.1.1†	2012 IECC MA, early code cycle
n	40	40	50
Windows	90%	96%	96%
Air leakage[1]	83%	85%	81%
Above grade walls	84%	86%	89%
Ceilings	**55%***	71%	**88%***
Ducts[1]	72%	77%	74%
Frame floors	70%	76%	81%
Lighting	**88%***	90%	**64%***
Slabs[2]	95%	96%	92%
Foundation walls	86%	85%	84%
OVERALL	80%	85%	83%

* Significantly different at the 90% confidence level.
† Values are weighted.
[1] Non-amended IECC 2012 requirements are stricter in Massachusetts.
[2] Amended IECC 2012-RI slab insulation requirement is stricter in Rhode Island.

[74] Nine of the 171 single family program homes built in 2015 could not be processed due to errant floor and dishwasher entries.

Table 140: Comparison of Relative Weights by Measure

Measure	2012 IECC-RI R402.1.3	2012 IECC-RI R402.1.1	2012 IECC MA, early code cycle
Windows	20%	20%	19%
Air leakage	19%	19%	15%
Above grade walls	17%	17%	19%
Ceilings	12%	12%	9%
Ducts	10%	10%	13%
Frame floors	8%	8%	8%
Lighting	8%	8%	12%
Slabs	3%	3%	2%
Foundation walls	3%	3%	2%

13.2.4 Program Home Comparison

As can be seen in Table 141~~Table 141~~, the statewide compliance rate using the MA-REC approach is 83%. Compliance for all measures and overall compliance is higher in program homes than non-program homes. These results are congruent with the comparison of key measures in Section 3. Of note are the differences in weights for windows, air leakage, and foundation walls. The difference in window weighting is driven by the frequent, unavoidable use of configuration-specific defaults for non-program homes audited post-occupancy, versus NFRC label or other manufacturer information collected during construction for program homes.[75] It was previously established in Section 3 that program homes have lower air leakage,[73~~67~~] reducing the weight of this measure in program homes. Similarly, the weights of foundation walls shifted because 30% of non-program homes have conditioned basements (three of which are completely uninsulated) versus 11% of program homes (two of which are uninsulated). Consequently, other measures in program homes – particularly above grade walls – are weighted more highly than in non-program homes to take up the slack left by higher performing windows, air leakage, and foundation walls in program homes.

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[75] The modal values of the majority window types are U-0.36 and SHGC-0.45 in non-program homes versus U-0.30, SHGC-0.28 in program homes.

Table 141: Comparison of Program and Non-Program Compliance (R402.1.3)

Building System	Non-Program		Program		Statewide
	Compliance†	Weights	Compliance	Weights	Compliance
n	40		162		202
Windows	90%	20%	96%	16%	91%
Air leakage	**83%***	19%	**95%***	13%	86%
Above grade walls	84%	17%	92%	24%	86%
Ceilings	**55%***	12%	**89%***	13%	62%
Ducts	**72%***	10%	**91%***	12%	76%
Frame floors	**70%***	8%	**88%***	10%	74%
Lighting	**88%***	8%	**99%***	8%	90%
Slabs	95%	3%	100%	3%	96%
Foundation walls	**86%***	3%	**97%***	1%	88%
OVERALL	**80%***	100%	**93%***	100%	83%

* Significantly different at the 90% confidence level.
† Values are weighted.

A Appendix A Insulation Grades

The Residential Energy Services Network (RESNET) provides guidelines and definitions for defining the quality of insulation installation. RESNET has specified three grades for designating the quality of insulation installation; the grades range from Grade I (the best) to Grade III (the worst).

The RESNET definitions of Grade I, Grade II, and Grade III installation are provided below.[76]

> **Grade I:** "Grade I" shall be used to describe insulation that is generally installed according to manufacturer's instructions and/or industry standards. A "Grade I" installation requires that the insulation material uniformly fills each cavity side-to-side and top-to-bottom, without substantial gaps or voids around obstructions (such as blocking or bridging), and is split, installed, and/or fitted tightly around wiring and other services in the cavity... To attain a rating of "Grade I", wall insulation shall be enclosed on all six sides, and shall be in substantial contact with the sheathing material on at least one side (interior or exterior) of the cavity…Occasional very small gaps are acceptable for "Grade I" … Compression or incomplete fill amounting to 2% or less, if the empty spaces are less than 30% of the intended fill thickness, are acceptable for "Grade I".
>
> **Grade II:** "Grade II" shall be used to describe an installation with moderate to frequent installation defects: gaps around wiring, electrical outlets, plumbing and other intrusions; rounded edges or "shoulders"; or incomplete fill amounting to less than 10% of the area with 70% or more of the intended thickness (i.e., 30% compressed); or gaps and spaces running clear through the insulation amounting to no more than 2% of the total surface area covered by the insulation.
>
> **Grade III:** "Grade III" shall be used to describe an installation with substantial gaps and voids, with missing insulation amounting to greater than 2% of the area, but less than 5% of the surface area is intended to occupy. More than 5% missing insulation shall be measured and modeled as separate, uninsulated surfaces…

Below are some examples of insulation installation and the corresponding grade applied by auditors. A brief description of the reasoning behind the grade designation is described for each example. Please note that these photographs were not all taken during the site visits for this study, and they are not meant to show the good and bad building practices observed during the site visits. Rather, these pictures are meant to provide visual examples of typical insulation installation grades.

[76] Residential Energy Services Network. (2013). *Mortgage Industry National Home Energy Rating Systems Standards.* Oceanside, CA: Residential Energy Services Network.

Figure 20~~Figure 20~~ shows a conditioned attic with closed-cell spray foam applied to the walls. This installation received a Grade I installation because the closed-cell spray foam has little to no gaps, has no compression, and the cavity is enclosed on all six sides.[77]

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Figure 20: Grade I Closed-Cell Spray Foam – Exterior Walls

Figure 21~~Figure 21~~ shows a Grade II install of unfaced fiberglass batts in a conditioned basement.[78] The insulation has gaps in the corners of certain bays and there is some compression – though relatively minor compression overall. The insulation is enclosed on all six sides including the air barrier, warranting a Grade II designation.

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[77] In the case of spray foam, a cavity may be open to the attic and still receive a Grade I installation because the spray foam itself is an air barrier.
[78] The basement in this case was considered conditioned volume, not conditioned floor area.

Figure 21: Grade II Fiberglass Batts – Basement Walls

Figure 22~~Figure 22~~ shows R-21 fiberglass batts in a 2x4 wall cavity. This installation automatically receives a Grade III designation since the insulation is not enclosed on the vented attic side. According to the RESNET standards on Grade III installation, "this designation shall include wall insulation that is not in substantial contact with the sheathing on at least one side of the cavity, or wall insulation in a wall that is open (unsheathed) on one side and exposed to the exterior, ambient conditions or a vented attic or crawlspace."

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Figure 22: Grade III Fiberglass Batts – Attic Kneewalls

Figure 23~~Figure 23~~ shows a Grade II installation of fiberglass batts in a frame floor cavity. While the insulation has a fair amount of compression, the gaps are minimal. The primary reason for the Grade II designation is that the fiberglass batts are in substantial contact with the subfloor. This example shows an installation that is right on the boundary of Grade II and Grade III installation. It should be noted that the bay with ductwork on the right side of the image would certainly represent a Grade III installation due to substantial gaps and compression.

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Figure 23: Grade II Fiberglass Batts – Frame Floor

Figure 24~~Figure 24~~ shows frame floor insulation that received a Grade III designation. The insulation was installed incorrectly, with the batting cut and installed perpendicular because the width was not the correct size. This install caused excessive gaps, compression, and sagging in the insulation. The sagging insulation creates an air space between the insulation and the subfloor, which ultimately diminishes the insulating characteristics of the fiberglass batts.

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Figure 24: Grade III Fiberglass Batts – Frame Floor

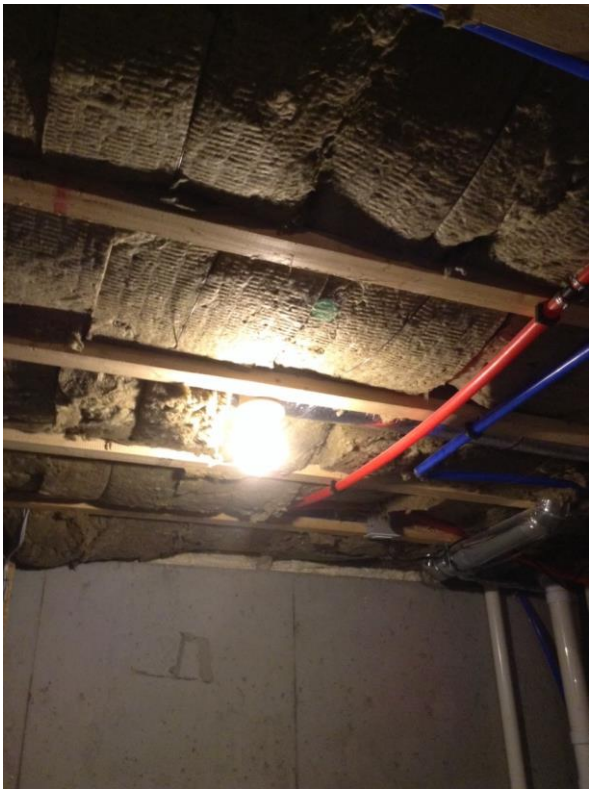

Figure 25~~Figure 25~~ shows a Grade I installation of blown cellulose in an attic. This received a Grade I designation because the cellulose is blown in evenly, filling all of the cavities with no gaps or voids and little to no compression. In addition, this attic has baffles at the eaves, which is required for attic insulation to achieve a Grade I installation.

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Figure 25: Grade I Blown Cellulose – Attic

B Appendix B Screen Shot from Data Collection Form

Below is an example of one of the data collection input pages used to collect data during on-site visits. Figure 26~~Figure 26~~ shows a screen where field auditors can enter information about the home and the site visit, such as the homeowner's name or when they started and concluded the visit. The information shown in the data entry fields is not actual customer data, but is purely for demonstration purposes.

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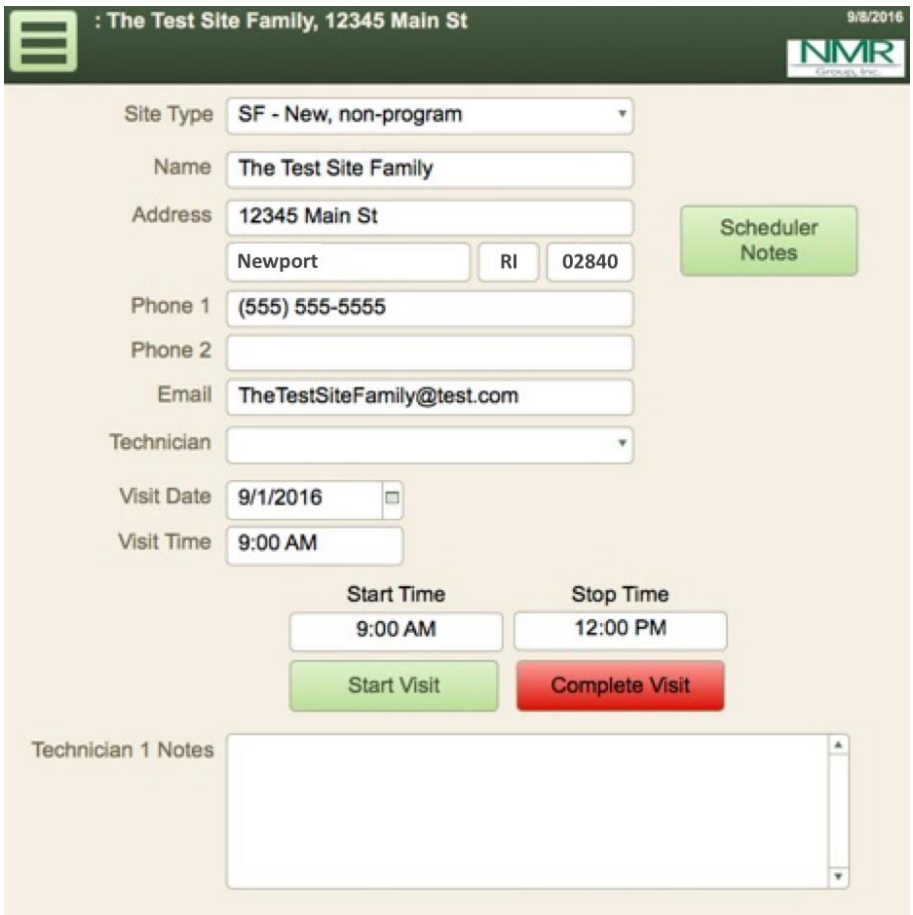
Figure 26: Data Collection Form Example – General Characteristics



C Appendix C Shell Measure Details for Less Common Wall, Ceiling, and Floor Types

This section provides information about the building envelope beyond the summary information presented in the body of the report. In addition, it shows information about building envelope components that are less critical in terms of driving a home's energy-efficiency, such as walls abutting buffer spaces (garages, attics, etc.), as opposed to walls exposed to ambient conditions. These types of components also typically reflect a relatively small amount of a home's envelope, relative to the other components described in the body of the report.

This section provides details about the following:

- Walls between conditioned spaces and garages
  - The walls dividing a home from an abutting garage
- Walls between conditioned spaces and unconditioned basements
  - Often forming the walls of a stairwell leading down to a basement
- Walls between conditioned spaces and attics
  - Common on Cape Cod-style homes, homes with dormers, or other attic spaces that abut the conditioned space; knee-walls, the short walls on upper floors that support the sloping roof rafters, are common examples of walls separating conditioned space from attics
- Attic hatches
  - Small openings into flat attics that are often either rectangular board to push up or drop-down stairs
- Floors between conditioned spaces and garages
  - Present in homes that have finished bonus rooms over garages
- Floors between conditioned spaces and ambient
  - Typically, very small areas serving as the floor of cantilevers and bay windows
- Floors between conditioned spaces and enclosed crawl spaces

C.1 Above Grade Walls

C.1.1 Average R-values for All Above Grade Wall Types

R-values. Table 142~~Table 142~~ shows the average R-value for the total envelope wall area and for the total area of each wall type across the entire sample. The envelope includes all walls that are between conditioned space and any unconditioned or ambient space. The average R-value across all envelope wall area in the statewide sample is 16.2. The average R-value across all conditioned to ambient wall area is 16.8. The data is unweighted and significance testing was not performed since this table is based on square-footage.

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Table 142: Average R-Value Across All Envelope Wall Area in Sample

R-Value (Average Across All Wall Area in Sample)	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*
Conditioned/ambient	15.8	18.5	16.8
Conditioned/garage	18.7	19.5	19.1
Conditioned/unconditioned basement	16.1	5.6	7.1
Conditioned/attic	20.2	11.4	15.1
Sealed attic/ambient	20.7	--	20.7
Across all wall locations	16.2	16.3	16.2

Table 143~~Table 143~~ shows that the per-home average R-value for envelope walls is 18.9. The average R-value is brought down by three homes that have little to know insulation in walls bordering unconditioned basements, garages, or attics. There was no significant difference between custom and spec homes. These averages demonstrate that overall, homes generally come close to complying with the 2012 IECC requirement of R-20 for walls.

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Table 143: Average Wall R-Values (Conditioned to Ambient, Garage, Basement, and Attic Combined)

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	4.2	6.3	4.2
Maximum	30.3	21.0	30.3
Average	20.3	18.4	18.9
Median	20.0	19.2	20.0

No statistically significant differences at the 90% confidence level.
R-values verified at 68% of homes.

Table 144~~Table 144~~ compares average wall R-values to the prescriptive requirement of R-20. While only 51% of homes have wall R-values that meet prescriptive code levels, note that an additional quarter (25%) of homes are just 5% below code at R-19 (Table 144~~Table 144~~). This is the result of 5.5-inch-thick fiberglass batts coming in two different standard R-values: R-19 and R-21. Five and a half-inch fiberglass batts are the most frequently used insulation type. Depending on which R-value a builder chooses, a wall assembly will just exceed, or just miss, the 2012 IECC R-20 requirement.[79] There were no significant differences between custom and spec homes.

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[79] Walls can also comply with the 2012 IECC requirements if they have R-13 cavity insulation and R-5 continuous insulation. No homes complied under this exemption that would not have otherwise complied.

Table 144: Envelope Wall – Average R-Value vs. Prescriptive Requirements

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	5%	*Worse: 38%*	11%	*Worse: 53%*	9%	*Worse: 49%*
15% to < 30% worse	0%		0%		0%	
5% to 15% worse	14%		16%		15%	
R-19	***19%***		***26%***		***25%***	
R-21	***24%***	*Better: **62%***	***32%***	*Better: **47%***	***30%***	*Better: **51%***
5 % to15% better	24%		16%		18%	
15% to < 30% better	10%		0%		2%	
30+% better	**5%**		0%		1%	

No statistically significant differences at the 90% confidence level.

C.1.2 Conditioned to Garage

Walls between conditioned space and garages only make up 7% of total envelope wall area but are the second largest wall type after conditioned and ambient walls. Table 148~~Table 148~~ through Table 150~~Table 150~~ summarize the R-value, framing, and insulation characteristics of walls to garages.

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R-values. The average R-value for conditioned to garage walls (19.5) is close to the 2012 IEEC requirement of 20 (Table 38~~Table 38~~).

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Table 145: Conditioned/Garage Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*14*	*32*
Minimum	13.0	13.0	13.0
Maximum	37.1	21.0	19.7
Average	20.0	19.3	19.5
Median	19.9	21.0	20.0

No statistically significant differences at the 90% confidence level.
R-value verified at 79% of homes

Primary Framing. Four out of five homes with walls to garages have 2x6 framing in said walls. Fourteen percent of homes have 2x4 framing and another 1% have timber framing.

Table 146: Conditioned/Garage Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*14*	*32*
2x6, 16" on center	78%	86%	84%
2x4, 16" on center	17%	14%	15%
Timber framing	6%	--	1%

No significant differences at the 90% confidence level.
No homes had an additional framing type.

Primary Insulation. Table 40~~Table 40~~ shows the primary insulation and installation grade for conditioned to garage walls in each home. Fiberglass batts are the most common insulation type in of garage walls (63%), followed by rock wool batts (21%). Custom homes are significantly more likely to have Grade I installations than spec homes (39% vs 14%) and significantly less likely to have Grade II installations (50% vs 86%).

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Table 147: Type & Grade of Conditioned/Garage Wall Primary Insulation by Percent of Homes

	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*14*	*32*
Insulation Type			
Fiberglass batts	50%	71%	63%
Rock wool	6%%	29%	21%
Open cell spay foam	22%	--	7%
Cellulose – dense pack	6%	--	1%
Closed cell spray foam	6%	--	1%
EPS	6%	--	1%
SIP	6%	--	1%
Insulation Installation Grade			
Grade I	**39%***	**14%***	10%
Grade II	**50%***	**86%***	73%
Grade III	6%	--	11%
No cavity insulation	6%	--	1%

*Statistically significant difference at the 90% confidence level.
Insulation type was verified at 97% of homes and installation grade was verified at 52% of homes.

C.1.3 Conditioned to Unconditioned Basement

Exterior walls between conditioned and unconditioned basement comprise 3% of the total envelope wall area across the entire sample. Table 148~~Table 148~~ through Table 150~~Table 150~~ display data on conditioned to unconditioned basement wall R-values, framing, insulation type, and grade.

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R-values. The average R-value for conditioned to ambient walls (R-15.4) is below the 2012 IEEC requirement of R-20 (Table 38~~Table 38~~). The overall average R-value is brought down by two homes that had no insulation in the conditioned to unconditioned basement walls.

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Table 148: Conditioned/Unconditioned Basement Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*8*	*15*	*23*
Minimum	13.0	0.0	0.0
Maximum	21.0	21.0	21.0
Average	16.5	15.2	15.4
Median	15.0	15.0	15.0

No statistically significant differences at the 90% confidence level.
R-value verified at 52% of homes

Primary Framing. Unlike in walls to ambient or garage, the most frequent framing type in walls to unconditioned basement is 2x4, 16" on center (56%). The remaining 43% is 2x6 framing. There is no significant difference between custom and spec homes.

Table 149: Conditioned/Unconditioned Basement Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*8*	*15*	*23*
2x4, 16" on center	5 (63%)	53%	56%
2x6, 16" on center	3 (38%)	47%	43%

No significant differences at the 90% confidence level.
Three homes had an additional framing type.

Primary Insulation. Table 40~~Table 40~~ shows the primary insulation and installation grade for conditioned to unconditioned basement walls in each home. Fiberglass batts are present in 75% of walls to unconditioned basements. Another 12% of walls to unconditioned basements have rock wool. Six percent of homes with unconditioned basements (all of which are spec homes) have no insulation in said walls. Three-fourths (74%) of walls with unconditioned basements had Grade II insulation installations.

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Table 150: Type & Grade of Conditioned/Unconditioned Basement Wall Primary Insulation by Percent of Homes

	Custom	Spec	All Homes (Weighted)
n (homes)	*8*	*15*	*23*
Insulation Type			
Fiberglass batts	7 (88%)	73%	75%
Rock wool	--	20%	17%
Open cell spay foam	1 (13%)	--	2%
None	--	7%	6%
Insulation Installation Grade			
Grade I	1 (13%)	7%	7%
Grade II	6 (75%_	73%	74%
Grade III	1 (13%)	13%	13%
No cavity insulation	--	7%	6%

No statistically significant difference at the 90% confidence level.
Insulation type was verified at 92% of homes and installation grade was verified at 39% of homes.

C.1.4 Conditioned to Attic

Walls between conditioned space and attics comprise only 4% of the total envelope wall area across the entire sample. Table 151~~Table 151~~ through Table 153~~Table 153~~ display data on conditioned to ambient wall R-values, framing, insulation type, and grade.

R-values. The average R-value for conditioned to attic walls (R-17.8) is less than the 2012 IEEC requirement of R-20 (Table 38~~Table 38~~).

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Table 151: Conditioned/Attic Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*9*	*12*	*21*
Minimum	13.0	1.2	1.2
Maximum	21.0	21.0	21.0
Average	19.2	17.5	17.8
Median	20.0	20.0	20.0

No statistically significant differences at the 90% confidence level.
R-value verified at 71% of homes

Primary Framing. More than half (58%) of homes with walls to attic space have 2x6 framing with studs spaced 16 inches apart. The next most frequent framing type is 2x4, 16" on center.

Table 152: Conditioned/Attic Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*9*	*12*	*21*
2x6, 16" on center	5 (56%)	58%	58%
2x4, 16" on center	1 (1%)	33%	29%
2x4, 24" on center	2 (22%)	8%	11%
2x6, 24" on center	1 (11%)	--	2%

No significant differences at the 90% confidence level.
One home had an additional framing type.

Primary Insulation. Table 40~~Table 40~~ shows the primary insulation and installation grade for conditioned to ambient walls in each home. Fiberglass batts are the most frequent insulation type, present in 62% of attic walls, followed by rock wool in 27%. More than half (58%) of attic walls have Grade II insulation installations. There was no significant difference between custom and spec homes for either insulation type or grade for attic walls.

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Table 153: Type & Grade of Conditioned/Attic Wall Primary Insulation by Percent of Homes

	Custom	Spec	All Homes (Weighted)
n (homes)	*9*	*12*	*21*
Insulation Type			
Fiberglass batts	7 (78%)	58%	62%
Rock wool	--	33%	27%
Open cell spay foam	1 (11%)	--	2%
Blown in cellulose	1 (11%)	--	2%
None	--	8%	7%
Insulation Installation Grade			
Grade I	2 (22%)	--	4%
Grade II	5 (56%)	58%	58%
Grade III	2 (22%)	33%	31%
No cavity insulation	--	8%	7%

No statistically significant difference at the 90% confidence level.
Insulation type was verified at 95% of homes and installation grade was verified at 67% of homes.

C.2 CEILINGS

C.2.1 R-value Statistics (All Ceiling Types)

Table 154~~Table 154~~ displays average R-values for each ceiling type, and all ceilings, across their respective total areas. Among all homes in the sample, flat ceilings average R-

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34 across all flat ceiling area, vaulted ceilings average R-28.4, and the average across all ceiling area is R-30.7.

One spec home had a large portion of uninsulated ceiling area – mostly vaulted, with some flat –above a bonus room, a scenario caused by "DIY" renovations. Due to the ability of uninsulated portions of a building shell assembly to degrade the overall R-value of that assembly significantly,[80] the average R-value of vaulted ceilings in the spec sample is much lower than the custom sample. If the uninsulated flat and vaulted ceiling sections in that home are removed as outliers, the averages for vaulted ceilings would rise from R-7.6 in spec homes to R-26.4, and from R-28.4 to R-36.9 in the statewide sample. The impact on flat ceilings was less extreme but still significant – the average for spec homes rises from R-31 to R-36, and statewide from R-34.4 to R-37.5.

Table 154: Average R-Value Across All Ceiling Area in Sample

	Custom	Spec	All Homes (Unweighted)
n (homes)	*21*	*19*	*40*
Flat	39.7	31.0	34.4
Vaulted	38.2	7.6	28.4
Hatch	2.6	1.8	2.0
Across all ceiling types	38.2	23.0	30.7

* Since the base for this analysis is square footage, the values are not weighted and significance testing was not done.
Insulation R-values were verified for 91% of recorded ceiling assemblies.

Table 155~~Table 155~~ shows the average per-home R-value across ceiling types. The average ceiling R-value per home in the statewide sample is 33.2, well below the IECC 2012 requirement of R-49.[81] The same spec home mentioned in the paragraph above, with a large uninsulated section of ceiling, shows up here as the outlier with an R-value of R-3.3. The average R-value of ceilings in custom homes is R-38.2, while in spec homes it is 31.5 – a statistically significant difference. Performing the analysis without the uninsulated outlier discussed above would raise the average R-value in spec homes to 33.4 and the statewide average to R-34.5.

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[80] A 4 sq. ft. attic hatch at R-0 degrades the overall R-value of a 936 sq. ft. ceiling, otherwise insulated to R-38, down to R-33. For example (https://www.dos.ny.gov/dcea/pdf/Energy/RmanappndxA.pdf).
[81] The 2012 IECC contains an exemption for vaulted ceilings that have cavities too small to meet the R-49 requirement. Such ceilings must have R-30 insulation and cannot comprise more than 20% of the total ceiling area for the home. With the exemption, the lowest allowable R-value for a home's ceiling area overall is R-45.2. No home complied under this exemption.

Table 155: Average Ceiling R-Value Per Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*19*	*40*
Minimum	29.5	3.3	3.3
Maximum	48.0	38.0	48.0
Average	**38.2***	**31.5***	33.2
Median	38.0	33.3	37.5

*Statistically significant difference at the 90% confidence level.
Insulation R-values were verified for 91% of recorded ceiling assemblies.

Table 156~~Table 156~~ compares the average ceiling R-value per home with the 2012 IECC prescriptive requirement of R-49. On a per-home basis, none of the homes in the sample have an average R-value that meets the R-49 requirement. This can be caused by general under-insulation of celling assemblies, or by having one or more pieces of a ceiling assembly (like an attic hatch) under or uninsulated, degrading the overall average R-value. Spec homes are significantly more likely than custom homes to have ceilings insulated at least 30% worse than code. Custom homes are significantly more likely than spec homes to have ceilings insulated to between 15% and 30% below code or 15% or less below code.

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Table 156: Ceiling– Average R-Value vs. 2012 Prescriptive Requirements

	Custom		Spec		All Homes (Weighted)	
30+% worse	**14%***	*Worse:*	**58%***	*Worse:*	48%	*Worse:*
15% to < 30% worse	**71%***		**42%***		49%	
<15% worse	**14%***		**--***		4%	
At code	***0%***		***0%***		***0%***	

*Statistically significant difference at the 90% confidence level.

C.2.2 Attic Hatches

Hatches make up less than one percent of the total ceiling area across the entire sample, though prescriptive code does require that they be insulated to the same level as flat attic assemblies. Table 157~~Table 157~~ and Table 158~~Table 158~~ summarize the R-values and insulation types of attic hatches observed during on-sites. Hatches are generally either rectangular pieces of wood or sheetrock that can be pushed upwards to gain attic access, or a drop-down hinged wooden staircase.

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Table 157~~Table 157~~ shows R-value statistics for attic hatches, the average per-home R-value for attic hatches in the sample is R-15.9. Half of homes in the sample with attic hatches (eleven homes) have no insulation on the hatch.

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Table 157: Average Hatch Ceiling R Value Per Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*6*	*16*	*22*
Minimum	0	0	0
Maximum	38	38	38
Average	19.3	15.5	15.9
Median	20	0	5

R-values verified at 91% of homes

Table 158~~Table 158~~ breaks down the types of insulation found on attic hatches in the sample. The most common type of insulation is fiberglass batts (33%), though uninsulated hatches are the most common (54%).

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Table 158: Hatch Insulation Types

	Custom	Spec	All Homes (Weighted)
n (homes)	*6*	*16*	*22*
None	2 (33%)	56%	54%
Fiberglass batts	3 (50%)	31%	33%
XPS	1 (17%)	6%	7%
Mineral wool batts	--	6%	6%

Insulation type verified at 100% of homes.

C.3 Frame Floors

The following sections characterize floors between conditioned space and garages, ambient space, or enclosed crawl spaces. Together these three types of floors make up only 30% of total frame floor area across the entire sample. Floors above garages comprise 24% of total floor area, floors over crawlspace comprise 4%, and floors over ambient space comprise 2%.

Verification of Characteristics. Auditors do not have to make many assumptions about the insulation in framed floors over basements; the insulation is typically accessible and visible. Insulation can be more difficult to access in enclosed floor cavities over garages and over ambient space. Of the 36 homes with framed floors forming part of the thermal boundary, insulation type was verified in 89%, insulation R-value was verified in 81%, and insulation grade was verified in 78%.

C.3.1 R-values for all Floor Types

Table 159~~Table 159~~ shows the average R-values across all framed floor area for each floor type in the sample. There is a large portion of framed floor area in the sample that is uninsulated despite its location at the thermal boundary of homes. Due to the ability of

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uninsulated portions of a building shell assembly to degrade the overall R-value of that assembly significantly,[82] the overall average R-value of framed floors in the sample is only R-4.1. Framed floors located between conditioned space and unconditioned basements are the main cause – there is a total of just over 30,000 sq. ft. of framed floor area between conditioned space and unconditioned basements, and over 9,000 sq. ft. of that is uninsulated.

Table 159: Average R-Value Across All Frame Floor Area in Sample

	Custom	Spec	All Homes (Unweighted)
n (homes)	*17*	*19*	*36*
Conditioned/unconditioned basement	3.4	2.9	3.1
Conditioned/garage	32.9	9.5	16.8
Conditioned/ambient	9.3	30.0	11.2
Conditioned/enclosed crawl space	30.3	--	30.3
Across all floor locations	5.2	3.3	4.1

Because most homes have insulation in framed floors forming the thermal boundary, the average R-value across framed floor types on a per-home basis is much higher than average R-values across total floor area. Framed floors in the statewide sample are insulated to R-22.5 on average, which still falls well below the 2012 IECC requirement for R-30 insulation in framed floors over unconditioned space (Table 160~~Table 160~~). Average framed floor R-values in both custom (R-29.4) and spec (R-20.7) homes fail to meet 2012 IECC requirements. The difference between custom and spec homes in average R-value is statistically significant.

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Table 160: Average Frame Floor R Value Per-Home

	Custom	Spec	All Homes (Weighted)
n (homes)	*17*	*19*	*36*
Minimum	0	0	0
Maximum	48.0	30.0	48.0
Average	**29.4***	**20.7***	22.5
Median	30.0	30.0	30.0

*Statistically significant at the 90% confidence level.

While the average per-home R-value for all floor locations is below the 2012 IECC code requirement of R-30[83], the majority (67%) of the weighted statewide sample have floors that meet or exceed the 2012 IECC requirements (Table 161~~Table 161~~). Thirty-seven

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[82] A 4 sq. ft. attic hatch at R-0 degrades the overall R-value of a 936 sq. ft. ceiling, otherwise insulated to R-38, down to R-33, for example (https://www.dos.ny.gov/dcea/pdf/Energy/RmanappndxA.pdf).
[83] The code does allow homes to have floor R-values less than R-30 if the insulation fills the cavity with a minimum allowable R-value of R-19; however, none of the audited homes met code under this exemption.

percent of spec homes have framed floors insulated to an R-value at least 30% worse than prescriptive code requirement, compared to 12% of custom homes (a statistically significant difference).

Table 161: Frame Floor– Average R-Value vs. Prescriptive Requirements

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	12%*	*Worse: 12%*	37%*	*Worse: 37%*	32%	*Worse: 32%*
15% to < 30% worse	--		--		--	
<15% worse	--		--		--	
At code	***59%***		***63%***		***62%***	
<15% better	6%	*Better: 30%*	--	*Better: --*	1%	*Better: 5%*
15% to < 30% better	12%		--		2%	
>30% Better	12%		--		2%	

*Statistically significant at the 90% confidence level.

C.3.2 Conditioned to Garage Frame Floors

R-values for floors above garages were verified for only 67% of homes with such floors due to limited access to the cavity after the area is finished. Floors above garages have an average per-home R-value of 27.7, which is just under the 2012 IECC code requirement of R-30. All framed floors over garages in custom homes met or exceeded code requirements.

Table 162: Average Conditioned to Garage Frame Floor R Value Per-Home

R-Value (Average Per-Home)	Custom	Spec	All Homes (Weighted)**
n (homes)	*13*	*8*	*21*
Minimum	30.0	0	0
Maximum	48.0	30.0	48.0
Average	33.9	24.9	27.7
Median	30.0	30.0	30.0

No statistically significant differences at the 90% confidence level.
R-values verified at 67% of homes.

Two-thirds (67%) of framed floors over garages are framed with 2x10, 16” OC framing, and I-joist framing is found in another 28% of floors. One home (2%) had both 2x12, 16” OC and truss framing in the floors over garage.

Table 163: Conditioned to Garage Frame Floor Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*8*	*21*
2x10, 16" OC	23%	88%	67%
I-joist	62%	13%	28%
2x12, 16" OC	8%	--	2%
Truss	8%	--	2%

No statistically significant difference at the 90% confidence level.

Fiberglass batts are the most common type of insulation in framed floors over garages, filling 82% of such floors. Closed cell and open cell spray foam are the other types found during field inspections. Both types were only identified in custom homes. Due to the prevalence of fiberglass batt insulation, most floor cavities in the statewide sample were graded as either Grade II (43%) or Grade III (39%).

Table 164: Type & Grade of Conditioned to Garage Frame Floor Insulation by Percent of Homes

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*8*	*21*
Insulation Type			
Fiberglass batts	69%	7 (88%)	82%
Closed cell spray foam	15%	--	5%
Open cell spray foam	15%	--	5%
None	--	1 (13%)	8%
Insulation Installation Grade			
Grade I	31%	--	10%
Grade II	54%	3 (38%)	43%
Grade III	15%	4 (50%)	39%
Uninsulated	--	1 (13%)	8%

No statistically significant difference at the 90% confidence level.

C.3.3 Conditioned to Ambient Frame Floors

The average per-home R-value for frame floors over ambient space meets 2012 IECC code requirements at R-31. (Table 165~~Table 165~~). R-values were verified for nine of the eleven framed floors in the sample.

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Table 165: Average Conditioned to Ambient Frame Floor R Value Per-Home

R-Value (Average Per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*7*	*4*	*11*
Minimum	0	30.0	0
Maximum	48.0	30.0	48.0
Average	31.6	30.0	31.0
Median	34.0	30.0	30.0

No significant difference at the 90% confidence level.

The majority (81%) of framed floors over ambient conditions are framed with 2x10, 16" OC framing. (Table 166~~Table 166~~). I-joist framing (14%) and 2x12, 16" OC framing (5%) make up the remainder of framing types observed.

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Table 166: Conditioned to Ambient Frame Floor Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*7*	*4*	*11*
2x10, 16" OC	3 (43%)	4 (100%)	81%
I-joist	3 (43%)	--	14%
2x12, 16" OC	1 (14%)	--	5%

*No statistically significant differences at the 90% confidence level.

Fiberglass batt insulation is the most common insulation type found in framed floors over ambient conditions (60%). Closed and open cell spray foam and mineral wool batts were the other types observed (Table 167~~Table 167~~).

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Table 167: Type & Grade of Conditioned to Ambient Frame Floor by Percent of Homes

Wall Location	Custom	Spec	All Homes (Weighted)
n (homes)	*7*	*4*	*11*
Insulation Type			
Fiberglass batts	2 (29%)	3 (75%)	60%
Mineral wool batts	--	1 (25%)	17%
Closed cell spray foam	2 (29%)	--	10%
Open cell spray foam	2 (29%)	--	10%
None	1 (14%)	--	5%
Insulation Installation Grade			
Grade I	3 (43%)	--	14%
Grade II	2 (29%)	2 (50%)	43%
Grade III	1 (14%)	2 (50%)	38%
None	1 (15%)	--	5%

No statistically significant difference at the 90% confidence level.

C.3.4 Conditioned to Enclosed Crawlspace Frame Floor

Just two homes have framed floors over an enclosed crawl space; both are custom homes. One is framed with I-joists and insulated to R-30 with Grade II fiberglass batts. The other is framed with 2x10, 16'' OC framing and insulated with Grade I closed cell spray foam.

D Appendix D Detailed Methodology

This section provides methodology details beyond that described in Section 1.

D.1 SAMPLING

The following subsection describes the detailed methodology behind the baseline study, including sampling, recruitment, and inspection processes.

D.1.1 Sampling Methodology

The sample design targeted a representative sample of newly constructed, attached or detached single-family homes in National Grid territory, permitted after the adoption of the 2012 IECC, focusing on those built late in the 2012 IECC code cycle. To be eligible for the baseline study, homes needed to meet the following criteria:

- Non-participant in the Rhode Island Residential New Construction program
- Built in the second half of 2014 or later (2015 and 2016), to ensure construction near the end of the 2012 IECC code cycle
  - Homes built in 2013 and early 2014 were excluded from the study because the impact of CCEI trainings would have been less likely to have a measurable market-level impact so early in the roll out of the CCEI's efforts.
- No more than one home per housing development to avoid nearly identical homes in the sample
- Occupied by homeowner; not for sale or owned by the builder
  - This avoids biasing the sample toward efficiency-minded builders and increases the response rate (unoccupied homes result in returned recruitment mailers).
- Located in National Grid Rhode Island service territory

Building departments were also visited throughout Rhode Island to determine the code compliance path used for eligible homes included in the recruiting effort.

D.1.2 Sample Targets

The on-site sample was designed to mirror the proportion of homes built in each Rhode Island county in 2014 and 2015, based on one-unit building permits issued in Rhode Island counties in 2014 and 2015. A 40-home sample was developed to reach the 90% confidence level with a 10% sampling error.[84]

The proportional distribution of building permits on a county-by-county basis resulted in 41 homes for the total sample. The two counties with the largest targeted sample size,

[84] Using a proportional county-by-county sampling approach resulted in a sample size of only 69 homes, so the final home was left as a "floating" site. The team ultimately fielded the final site in Fairfield county, the county with the most new construction.

Providence and Washington, were identified as the potential counties to have one less site visit, given the number that were already planned for those counties.

Table 168: Sampling Plan by County

County	One-Unit Building Permits (2014-2015)	Percent of One-Unit Building Permits (2014-2015)	Number of Targeted On-Site Inspections (2014-2015)	Percent of Targeted On-Site Inspections
Total	*1,637*	*100%*	*40*	*100%*
Providence	636	39%	15 or 16	38% or 40%
Washington	456	28%	10 or 11	25% or 28%
Newport	238	15%	6	15%
Kent	236	14%	6	15%
Bristol	71	4%	2	5%

In addition to the specified number of on-site inspections by county, the study targeted at least a 60% spec-built home ratio (in keeping with the previous Rhode Island baseline study).[85] An initial screening question during homeowner recruitment was used to determine if the home was spec- or custom-built:

How did you purchase your home?

1. Purchased land and worked with an architect and/or builder to build the home. (***Custom)***
2. Had a house plan and a lot and hired a contractor/builder to build the home. (***Custom)***
3. I am the owner and builder. (***Custom)***
4. Purchased a lot from a builder, selected one of several house plans offered by the builder, and selected from various available upgrade options. (***Spec)***
5. Purchased a home that was under construction and selected from various available upgrade options. ***(Spec)***
6. Purchased a finished home. ***(Spec)***

D.1.3 Recruiting Sample Development

The initial recruiting sample was a list of 1,496 addresses with new electric service requests provided by National Grid. New electric service requests are an unbiased way to identify newly-constructed homes because they should include the entire population of new homes within a service territory. The provided data set included ineligible sites, such as multifamily projects or renovations; those records were removed from the sample frame.

After removing clearly ineligible sites, records within each county were selected at random and manually reviewed to determine if they were eligible for the study, based on the previously mentioned criteria. To account for non-responses, the new service request

[85] http://www.rieermc.ri.gov/documents/evaluationstudies/2012/Final-RI-RNC-2011-Baseline-Report-sent-10-8-12.pdf

records were screened until a sample frame of ten times the number of targeted inspections was achieved for each county, except for counties with fewer records, in which case all eligible records were included in the sample frame.

In some counties, there was insufficient sample to recruit enough participants, and the team performed additional online research using real estate aggregator websites to identify new homes that were eligible for the study.

D.1.4 Building Department Visits

Building department visits were conducted after the recruiting sample was developed. These visits were performed to collect information regarding code compliance paths for the recruiting sample. The visits were conducted at building departments that had five or more potential on-site targets. A total of 27 building departments were visited, with varying degrees of success in ascertaining compliance path documentation. However, if an on-site visit was conducted in a town that was not visited initially, the corresponding building department was contacted to determine the energy code compliance path after completion of the on-site. Overall, there were 219 homes with information collected from building departments, but only 15% had a REScheck document verifying the energy code compliance path.[86]

D.1.5 Recruitment

The overall completion rate based on the number of total mailings was 6%. Recruitment letters were mailed in waves based on county population and county proximity. The most populous counties were targeted first. A total of seven waves of letters were sent out to 417 homes.

The recruitment letters described the study to homeowners, noted the $200 incentive, and included a postage-paid postcard for homeowners to return to indicate their interest in participating. Eligible homeowners who returned postcards were contacted by a recruiter and scheduled for a site visit. Recruits scheduled site visits based on proximity to other scheduled sites and homeowner availability.

[86] There was a total of 32 homes with a REScheck available in building department records. One home did not list the compliance path, and five homes were listed as 2009 IECC compliant.

Table 169: Mailings by County

County	Number of Mailings	Proportion of Mailings
Total	660	100%
Providence	343	52%
Washington	152	23%
Newport	48	7%
Kent	67	10%
Bristol	50	8%

Additional research was conducted to identify more spec- built homes due to a limited presence of spec homes in the initial sample and the lack of homeowner response to early rounds of mailings. This process involved a manual search for newly constructed homes through the real estate search engine website. These addresses were cross-referenced with National Grid RNC program data to verify they were not program participants. The additional sample was then screened and recruited in the same manner as the original new electric service data request.

D.2 Completed On-Site Inspections

There were 40 on-site visits completed among the five counties in Rhode Island. The completed on-site visits were close, but did not exactly meet the targeted plan. Due to sample and recruiting constraints, Kent county had one less visit than targeted. Additionally, the response from eligible spec homes was not sufficient to meet the targeted 60% to 40% spec versus custom-built split.

Table 170: Targeted and Completed Visits by County

County	Targeted On-Sites*	Completed On-sites		
		Spec	Custom	Total
Total	40	19	21	40
Providence	15 or 16	12	4	16
Washington	10 or 11	2	9	11
Newport	6	--	6	6
Kent	6	3	2	5
Bristol	2	2	--	2

*Due to rounding, Providence and Washington were given flexible targets.
The county-level proportionality was based on the U.S. Census, Building Permits Survey: https://www2.census.gov/econ/bps/

The inspections took place in 27 towns across the state of Rhode Island. Seventeen towns had one inspection each, eight towns had two inspections, one town had three inspections,

and one town had four inspections. The location of each on-site and the custom/spec classification is shown in Figure 27~~Figure 27~~.

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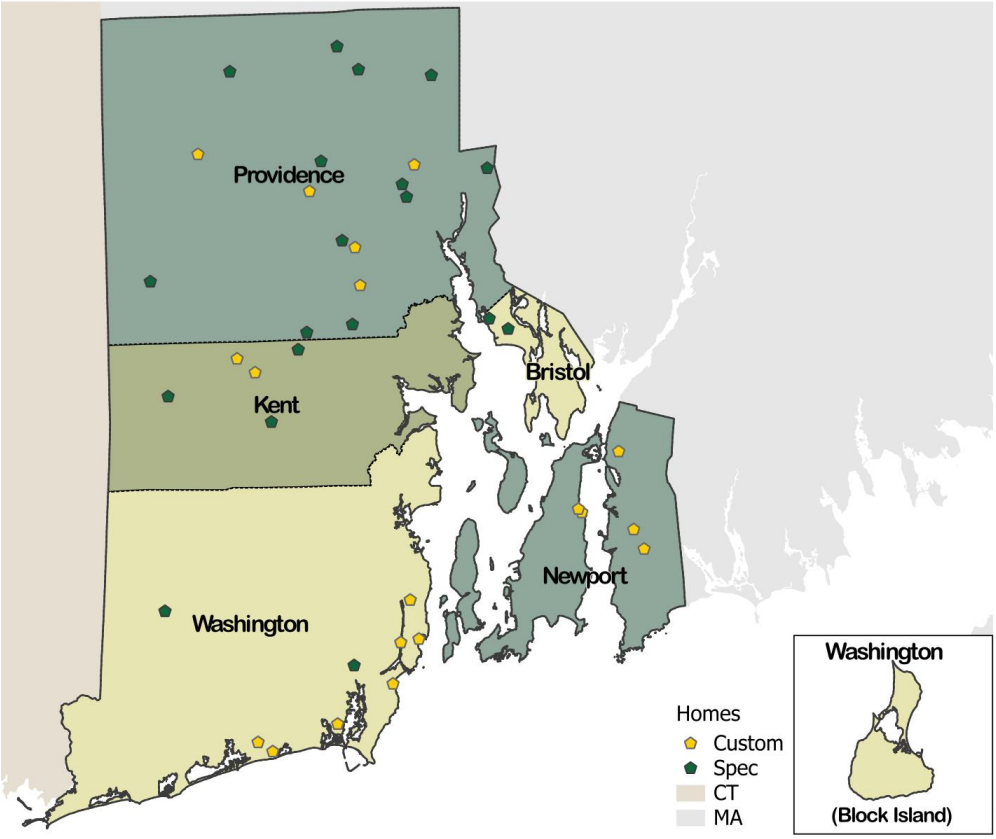
Figure 27: Statewide Map of On-site inspections



D.3 SAMPLING ERROR

As described in Section 1.2.2, the on-site sample targets were developed to achieve a maximum 10% sampling error at the 90% confidence level. Using the data collected during the study, actual coefficients of variation and estimates of relative precision can be calculated for key home characteristics. Some features are far more variable than others. In the current study, duct leakage and air infiltration are the most variable, and HVAC system efficiencies are the least variable.

Table 171~~Table 171~~ shows the coefficients of variation and relative precisions at the 90% confidence level for several key building components and measurements that influence a home's energy-efficiency. Relative precisions across all homes range from ±1.2% to ±8.8% at the 90% confidence level for all measures except air infiltration and duct leakage.

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Within the sample of custom homes, only duct leakage (total: ±15.7%; to outside: ±24.5%) has a relative precision worse than the targeted 10% (air infiltration is extremely close, at ±10.2%). Within the spec home sample, only duct leakage (total: ±24.2%; to outside: ±33.3%) and vaulted ceilings (±34.5%) are worse than the 10% target. One of these spec homes home had a rare situation with uninsulated vaulted ceilings. Excluding that outlier, the CV and relative precision values for vaulted ceilings in spec homes fall to 0.14 and ±10.5%, respectively.

Table 171: Coefficients of Variation and Relative Precision for Key Measures

Parameter	Custom			Spec			All		
	N	CV	Rel. Prec.	N	CV	Rel. Prec.	N	CV	Rel. Prec.
HERS Index score	21	0.19	±6.7%	19	0.12	±4.4%	40	0.17	±4.4%
AFUE of fossil-fuel fired heating systems	16	0.04	±1.7%	23	0.05	±1.7%	39	0.05	±1.2%
Central air conditioning SEER	22	0.09	±3.2%	16	0.04	±1.8%	38	0.08	±2.0%
Conditioned/ambient wall insulation R-value	111	0.28	±4.4%	80	0.20	±3.8%	191	0.25	±3.0%
Vaulted ceiling insulation R-value	21	0.16	±5.9%	6	0.51	±34.5%	27	0.28	±8.8%
Flat ceiling insulation R-value	15	0.12	±4.9%	24	0.24	±8.2%	39	0.20	±5.4%
Air infiltration – ACH50	20	0.56	±20.5%	19	0.15	±5.5%	39	0.39	±10.2%
Duct leakage to outside – CFM25/100 Sq. Ft.	34	1.16	±32.7%	22	0.95	±33.3%	56	1.11	±24.5%
Total duct leakage – CFM25/100 Sq. Ft	32	0.71	±20.8%	22	0.69	±24.2%	54	0.70	±15.7%

D.4 On-Site Data Collection Procedures

This section outlines key aspects of the data collection process during on-site inspections.

D.4.1 Data Collection Inputs

Data were collected on-site using tablet computers and an electronic data collection form. Additional calculations and research on measures (e.g., calculating interior volume or looking up HVAC system efficiency) were performed as soon as possible after the site visit. An example of a data input screen can be found in Table 172~~Table 172~~. Data were collected on the following measures.

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Table 172: Data Collection Inputs

General Info	Code Compliance	Shell Measures
• House type • Conditioned Floor Area (CFA) • Conditioned Volume	• Envelope • Heating and cooling • Water heating • Duct and pipe	• Walls • Ceiling • Frame floors • Rim/band joists

(CV) • Stories • Bedrooms • Thermostat type • Faucet/shower flow rates • Basement details • Health and safety issues • Home automation systems	insulation • Ventilation • Pools	• Windows, doors, and skylights • Slab floors • Foundation walls • Mass walls • Sunspaces
Mechanical Equipment	**Diagnostic Tests**	**Lighting & Appliances**

• Heating and cooling equipment
• Water heating equipment
• Duct insulation
• Renewables
	• Blower door
	• Duct blaster
	  ○ Total leakage
	  ○ Leakage to outside (LTO)
		• Lighting
		  ○ Fixture type, location, control
		• Appliances
		  ○ Refrigerators and freezers
		  ○ Dishwashers
		  ○ Washers and dryers
		  ○ Ovens and ranges
		  ○ Dehumidifiers

D.4.2 On-Site Data Collection Process

The on-site data collection process relies on visual verification of measures and, where necessary, review of available documentation about the home's construction, or even conversations with homeowners.

On-site visual verification of the actual components. Field observations were the first and most important source of data. When direct access to the component was not possible, the area around the component was examined to gather information. For example, when trying to determine exterior wall insulation, auditors might have removed an electrical outlet cover and probe to determine the presence of insulation.

On-site visual verification of similar components. After exhausting opportunities to examine the actual component, similar building components were assessed to inform the data collection. For example, the insulation installation grade in a visible walk-out basement wall might be used to inform the assessment of the insulation quality in another similar wall.

On-site discussion with homeowner or review of building documentation. Homeowners can be valuable sources of information regarding their home, particularly if they were involved in its construction. Given that homeowners are generally not construction experts, their feedback is used to supplement, not replace, field observations.

For example, a homeowner might have seen the installation of their home's slab and may have pictures or details about the insulation materials used.

D.4.2.1 Insulation Assessments

RESNET standards require that insulation be assigned a Grade based on the quality of installation. Grade I indicates a high-quality installation, Grade II is a typical or fair installation, and Grade III is a relatively poor installation (within limits). A summary of the technical requirements for these insulation Grades are defined as follows:

- Grade I: Negligible void areas, compression or incomplete fill ≤ 2%, fitted neatly around obstructions
- Grade II: Void areas ≤ 2%, compression or incomplete fill ≤ 10%
- Grade III: Void areas ≤ 5%

The complete RESNET standards can be found in Appendix A, along with photos showing examples of the various insulation grades.

When insulation was not visible (e.g., an enclosed cavity), the installation Grade was determined based on other areas of the home. For example, if exterior wall insulation was visible in an unfinished walkout basement and assigned a Grade II installation, then the above grade walls for that home were typically also given that Grade. Grade I installations can be achieved with any insulation material, but are most often seen with blown-in or spray-applied materials.

Fiberglass batting is a default assumption for insulation type when that insulation has been seen elsewhere in a home. It is possible, using this assumption, that the prevalence of fiberglass batting may be overstated in the analysis.

D.4.2.2 Basement Conditioning

For this study, RESNET guidelines for assessing basement conditioning were followed. Accordingly, a basement area was considered conditioned if any of the following criteria were true:

- The basement was directly and fully conditioned, or open to directly conditioned space
- A small register cut into an HVAC duct system in a large basement is not sufficient to consider that basement fully and directly conditioned; to be fully conditioned, the basement needs a comparable number of registers as would be present in a finished space of that same size.
- The basement was fully finished
- The basement was fully insulated (within the thermal boundary of the home)

Any basement that did not meet one of these three requirements was considered unconditioned. Some homes have both conditioned and unconditioned basement areas.

D.4.2.3 Diagnostic Tests

Blower door tests were used to measure the air leakage of the building envelope. Duct blaster tests were used to measure the duct leakage in all homes with ductwork, assuming

the registers (air distribution vents) were accessible. Total duct leakage was measured (all duct leakage in a home, even air leaking into conditioned space); leakage to outside was also measured (duct leakage outside of the thermal envelope). Total duct leakage measures the overall tightness of a duct system, but the leakage to outside test is more critical in terms of assessing energy-efficiency, as this leakage escapes the home and is wasted.

D.4.2.4 Unobservable Building Components

One of the challenges of inspecting completed homes is that some building components are not accessible or visible post-construction. The following list represents the building components that are typically difficult to verify or inspect in a completed home:

- Slab insulation
- Exterior foundation wall insulation
- Enclosed cavity insulation (such was walls and vaulted ceilings)
- Rated window efficiencies
- Garage ceiling and cantilevered frame floor insulation

Slab insulation is rarely visible once the slab has been poured. Exterior foundation wall insulation can be verified when it extends above grade, but below-grade insulation is inaccessible. The insulation material in enclosed cavities, such as walls and vaulted ceilings, can be determined by probing penetrations in the wall or ceiling, such as at holes, seams, or around electrical outlets. However, this may not allow the auditors to also determine the R-value or insulation grade. Lastly, window U and SHGC values are difficult to document in occupied homes because builders or homeowners often remove the NFRC labels from the windows.

D.4.3 Code Compliance

On-site inspections also included an assessment of various 2012 IECC requirements. While Rhode Island adopted an amended version of the 2012 IECC, some of the Rhode Island amendments were not clear and appeared to include a mix of 2012 and 2009 IECC values.[87] Accordingly, after discussion with the program administrators, comparisons were made to the unamended prescriptive code requirements.

Code compliance was assessed for envelope measures, such as for appropriate insulation R-values and the presence of a posted energy code compliance certificate. HVAC compliance included assessing the amount of duct and pipe insulation and HVAC system sizing. The presence of energy-saving features on pools and snow-melt systems were also assessed. Some code compliance assessments were made on site, while others were made after the audit, based on the results of the data collected on-site.

D.5 Statistical Significance, Weighting, and Table Format

[87] http://www.sos.ri.gov/assets/downloads/documents/SBC8-RI-state-energy-conservation-code.pdf

Tables in the report identify statistically significant differences at the 90% confidence level (p-value < 0.10). In most instances, comparisons were made between custom homes and spec homes. Values with statistically significant differences are bolded, red, and marked with an asterisk and footnote (Table 173~~Table 173~~). A statistically significant difference indicates that there is a 90% chance that the two populations represented by the sample groups being compared are truly different from one another, and a 10% chance that the measured difference would have happened by random sampling error. This is not a guarantee that the groups being compared are different; it is an indication that there is sufficient evidence to conclude with 90% confidence that they are different.

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Values in "Custom" and "Spec" columns are unweighted. In most tables, the "All Homes" columns were weighted. If the "All Homes" column represented a sample size of less than ten, then values in the column were not weighted. The weights used for the "All Homes" values were based on whether the homes were custom homes or spec homes, and were weighted to match the custom and spec distribution in the relevant program home population.

Table 173: Example of Table Format Showing Percentages

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*count*	*count*	*count*
Characteristic 1	**%***	**%***	%
Characteristic 2	%	%	%

*Significantly different at the 90% confidence level.

In columns with sample sizes smaller than ten that show percentages, the table displays the counts along with the percentage. In addition, only groups with sample sizes of at least ten were tested for significant differences. Data in the "All Homes" column were not weighted if the total sample size was less than ten (Table 174~~Table 174~~).

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Table 174: Example of Table Format Showing Percentages, without Significance Testing

	Custom	Spec	All Homes (Unweighted)
n (count of relevant unit of analysis)	*<10*	*<10*	*<10*
Characteristic 1	# (%)	# (%)	# (%)
Characteristic 2	# (%)	# (%)	# (%)

Not tested for statistical significance.

For tables displaying descriptive statistics for a given measure, such as a minimum, maximum, mean (identified as "average"), and median value, only the means were tested for statistical significance (Table 175~~Table 175~~).

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Table 175: Example of Table Format Showing Descriptive Statistics

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*count*	*count*	*count*
Minimum	#	#	#
Maximum	#	#	#
Average	#*	#*	#
Median	#	#	#

*Significantly significant difference at the 90% confidence level.

Throughout the report, graphics show the distribution of key values, such as average R-values or average efficiencies. Figure 2~~Figure 2~~ is an example, showing the distribution of HERS Index scores among sampled homes. In these figures, values associated with custom homes are pale green and spec home values are dark green. The gray-shaded bands represent the middle 50% of values – the interquartile range. The pale gray upper band represents the quartile above the median, and the dark gray lower band represents the quartile below the median. The median value is between the two bands. If the values for a given measure are relatively close together, like in the example below, the quartile ranges will be relatively small and the bands will be narrow. If the values are spread widely, the bands will be wider. Narrower quartile ranges indicate a clustering of values.

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Figure 28: Example Figure - HERS Index Scores

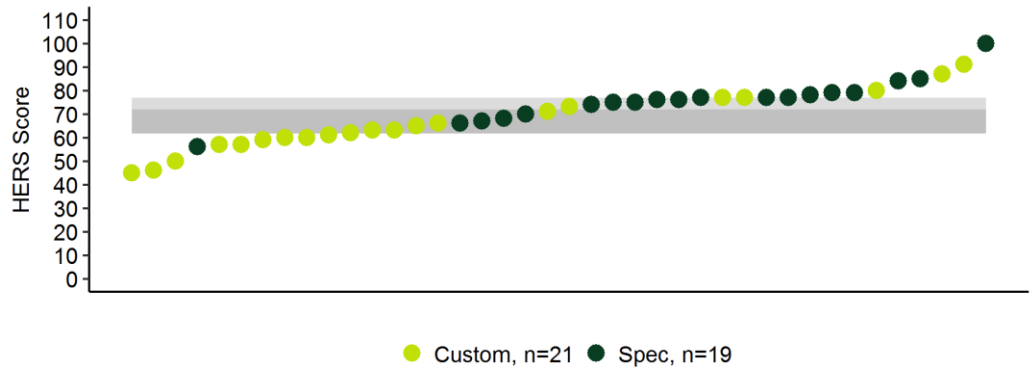

Figure 3~~Figure 3~~ shows a similar graphic, but because fewer values cluster around the median, the quartile bands are wider. Some graphics, such as this one, also show the non-amended 2012 IECC prescriptive requirement as a reference point (these tend to fall close to the median value).

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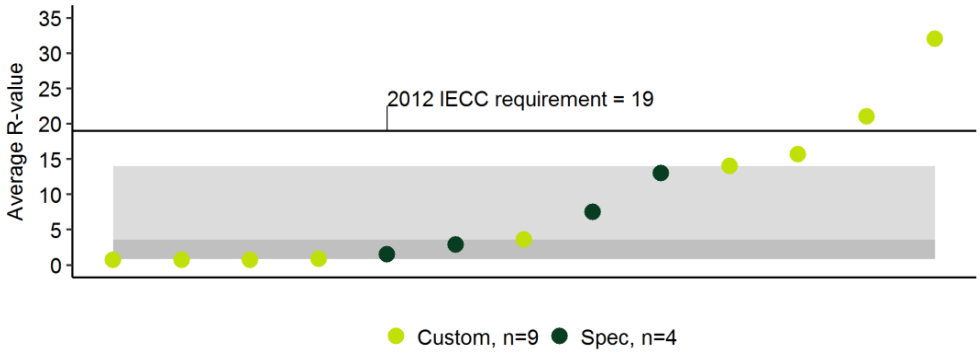
Figure 29: Example Figure - Foundation Wall Insulation