R1602 Residential New Construction Program Baseline Study

FINAL

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Abstract

This report describes a single-family, residential new construction (RNC) baseline study conducted in Connecticut for Eversource and United Illuminating (UI) Company ("the Companies"). The study was designed to assess (1) how the market has changed over time and (2) what changes in building practices have occurred since the previous baseline study. The study also updated the User Defined Reference Home (UDRH), the baseline used to calculate savings for the Companies' RNC program. The UDRH is described in Appendix F. Appendix G of this report describes the results of a billing analysis designed to assess the accuracy of REM/Rate model estimates of energy use. The baseline study and billing analysis, along with a process evaluation, are collectively referred to as the R1602 study; the process evaluation stands as a separate report. The Connecticut Energy Efficiency Board (EEB) has also planned a 2017 net-to-gross study of the RNC program (R1707).

This baseline study included site visits to 70 new, non-program single-family homes in Connecticut that were built under the 2009 International Energy Conservation Code (IECC). Data collection covered all aspects of energy performance, including building envelope, mechanical systems, lighting, appliances, and air infiltration. Home Energy Rating System (HERS) ratings were performed at all homes.

Comparisons between program data and the non-program on-site inspections revealed that program homes outperform non-program homes on every analyzed measure. These measures range from shell measures, to mechanical equipment, to overall HERS Index values. According to the analysis, program homes have an average HERS Index value of 48, which is much better than the average score for non-program homes of 70. Interestingly, the non-program average HERS Index of 70 meets the HERS Index requirement of the lowest RNC program tier.

Homes in this study have improved substantially from those in the previous Connecticut baseline study, conducted in 2011 (2006 IECC homes).[1] HERS Index values improved from 84, on average, to 70. Average R-values improved for every shell measure, as did heating and cooling system efficiencies. Efficient lighting use increased tremendously – 62% of homes use efficient lighting in the majority of their permanent sockets, compared to only 4% in the 2011 study. Duct leakage to the outside improved dramatically, a 65% improvement from the 2011 baseline, and air infiltration improved by 16%.

The billing analysis found that single-family program homes use about 8% more electricity (n=157) and 4% less natural gas (n=23) than estimated by program REM/Rate models. The study also found that non-program single-family homes used about 5% less electricity than estimated by their REM/Rate models; results for natural gas homes were inconclusive.

[1] https://www.energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf.

ES Executive Summary

The following document details the results of a single-family residential new construction (RNC) baseline study conducted for Eversource and United Illuminating (UI) Company ("the Companies"). The study was designed to answer two key questions about the market at the end of the 2009 IECC code cycle: (1) how has the market baseline changed over time, and (2) what kinds of changes in building practices and equipment have occurred? The baseline study and billing analysis, along with a process evaluation, are collectively referred to as the R1602 study; the process evaluation stands as a separate report. As a follow up of the R1602 study, the Connecticut Energy Efficiency Board (EEB) has planned a net-to-gross study of the RNC program for 2017 (R1707).

The Connecticut RNC program, offered by the Companies, provides financial incentives to builders and homeowners to encourage energy efficient construction and calculates savings by comparing its program homes to a market baseline. By conducting periodic baseline studies, the Companies can better understand the new construction market and claim savings against true market conditions.

This study included site visits in 2016 and 2017 to 70 new, non-program homes (46 spec- and 24 custom-built) across 48 Connecticut cities and towns.[2] On-site data collection covered all aspects of home energy performance, including building envelope, mechanical systems, lighting, appliances, and air infiltration. Home Energy Rating System (HERS) ratings were performed at all homes, and sites were evaluated against the requirements of the 2009 IECC.[3] These results were also used to update the User Defined Reference Home (UDRH), against which the program claims savings for program homes (Appendix F).

The billing analysis assessed the accuracy of energy use as estimated by REM/Rate models in comparison to actual billing data (Appendix G). The analysis included 157 electric-heated and 23 natural gas-heated program homes, and 26 electric-heated and five natural gas-heated non-program homes.[4]

FINDINGS

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

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[2] An explanation of the difference between custom and spec homes can be found in Section 1.2.2.
[3] The HERS index is 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.
[4] Section G.5.2 documents the data cleaning procedures that produced these sample sizes.

Comparison to Program Homes

Program homes perform much better than non-program homes.

Program homes performed significantly better than non-program homes on every analyzed measure. These include shell measures, mechanical equipment, and overall efficiency, as determined by HERS Index values. Program homes have an average HERS Index value of 48, which is significantly better (lower) than the average score for non-program homes of 70. The non-program average HERS Index value of 70 happens to meet the HERS Index requirement of the lowest RNC program Tier. If the REM/Rate models are re-run without their solar photovoltaic (PV) panels, the average HERS Index value for non-program homes increases to 72. The average HERS Index value of the program homes that do not have PV panels is 53.[5] Among both non-program and program homes, custom homes have significantly better HERS Index values than spec homes.

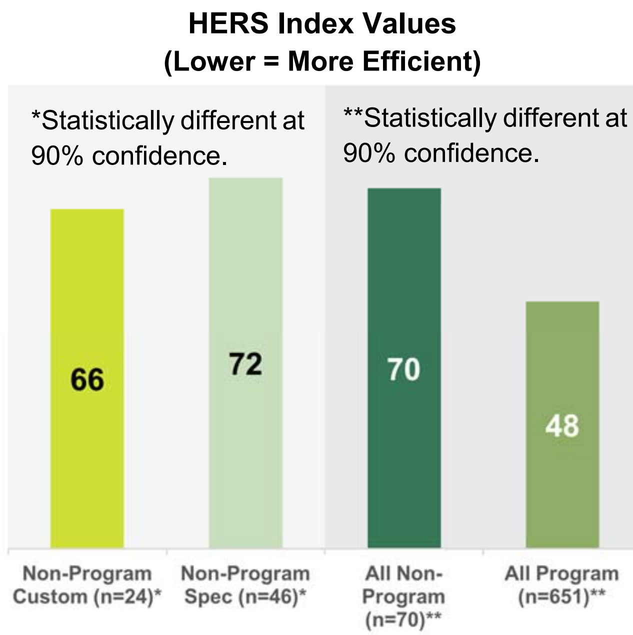


Table 1 compares non-program and program values for key measures, including R-values and U-values.[6] All comparisons show statistically significant differences between non-program and

[5] These differences between program and non-program homes are not directly comparable. For non-program homes, the models were re-run without the solar PV – these were the REM/Rate models created for this evaluation for inspected homes. For program homes, the average was based just on the program homes without solar PV, rather than adjusting the 99 program models themselves.

[6] "R-values" refer to the nominal value of insulation and are more efficient as larger numbers. U-values are calculated values by REM/rate that incorporate the nominal R-values of insulation, the R-values of the rest of the envelope assembly (such as drywall and framing), and the Grade of the installation. A lower U-value, or U-factor, is more efficient.

program homes at the 90% confidence level – the green-shaded cells show the better of the two values being compared, which happens to be the program homes in all cases.

Table 1: Comparisons between Non-Program and Program Homes

Average per Home Values	Non-Program Homes (Weighted)**	Program Homes (Unweighted)
n (homes)	*70*	*651*
Above grade exterior walls to ambient: R-value	20.8*	22.3*
Above grade exterior walls to ambient: U-value	0.062*	0.053*
Flat ceiling: R-value	36.9*	46.0 *
Flat ceiling: U-value	0.042*	0.024*
Vaulted ceiling: R-value	36.7*	40.0*
Vaulted ceiling: U-value	0.038*	0.029*
Frame floor over basement/crawl space: R-value	25.7*	28.0*
Frame floor over basement/crawl space: U-value	0.060*	0.045*
Conditioned foundation wall to ambient: R-Value	10.9*	16.3*
Duct leakage to the outside (CFM25 per 100 sq. ft. of conditioned area)	6.2*	1.9*
Total duct leakage (CFM 25 per 100 sq. ft of conditioned area)	18.7*	4.2*
Air infiltration (air changes per hour at 50 pascals “ACH50”)	4.9*	3.0*
Average heating system AFUE (systems with AFUE)	93.5	94.9
Average cooling system SEER (systems with SEER)	14.5*	15.3*
Average water heater Energy Factor (systems with Energy Factors)	0.98*	1.1*
Percent of sockets with efficient lamps	58%*	97%*
HERS Index value	69.8*	48.2*

R-values include cavity and continuous insulation.
U-values account for air barriers, R-value, installation quality, and framing.
*Statistically significant at the 90% confidence level.
**Homes were weighted by custom/spec status to match the custom/spec ratio in the program population.

Program Home Performance by Tier

When grouping program homes into three bins based on HERS Index categories that approximate the RNC program’s performance tiers, the best performing group is significantly more efficient on most measures than homes in the other two tiers. The more efficient values in each row are shaded in green; darker green is the most efficient[7] (Table 2).

Table 2: Program Home Performance by Performance Tier

Average per Home Values	HERS Index 70-61	HERS Index 60-51	HERS Index ≤50
n (homes)	81	252	*318*
Above grade exterior walls to ambient: R-value	21.7[c]	21.4[c]	23.2[a,b]
Above grade exterior walls to ambient: U-value	0.055[c]	0.056[c]	0.050[a,b]
Flat ceiling: R-value	46.2[b,c]	43.8[a,c]	48.1[a,b]
Flat ceiling: U-value	0.023[b]	0.025[a,c]	0.023[b]
Vaulted ceiling: R-value	37.6[c]	37.3[c]	41.4[a,b]
Vaulted ceiling: U-value	0.029	0.030[c]	0.028[b]
Frame floor over basement/crawl space: R-value	27.5	27.7	28.5
Frame floor over basement/crawl space: U-value	0.050	0.044	0.046
Conditioned foundation wall to ambient: R-Value	13.7[c]	15.3	16.8[a]
Duct leakage to the outside (CFM25 per 100 sq. ft. of conditioned area)	1.9[b,c]	2.2[a,c]	1.6[a,b]
Air infiltration (air changes per hour at 50 pascals "ACH50")	4.1[b,c]	3.3[a,c]	2.4[a,b]
Average heating system AFUE (systems with AFUE)	93.1[c]	94.3[c]	95.3[a,b]
Average cooling system SEER (systems with SEER)	13.0[b,c]	14.6[a,c]	16.3[a,b]
Average water heater Energy Factor (systems with Energy Factors)	0.72[b,c]	1.03[a,c]	1.15[b]
Percent of sockets with efficient lamps	87.9	97.6	97.0
HERS Index value	63.9[b,c]	55.2[a,c]	38.6[a,b]

[a] Significantly different from the "HERS Index 70-61" group.
[b] Significantly different from the "HERS Index 60-51" group.
[c] Significantly different from the "HERS Index ≤50" group.

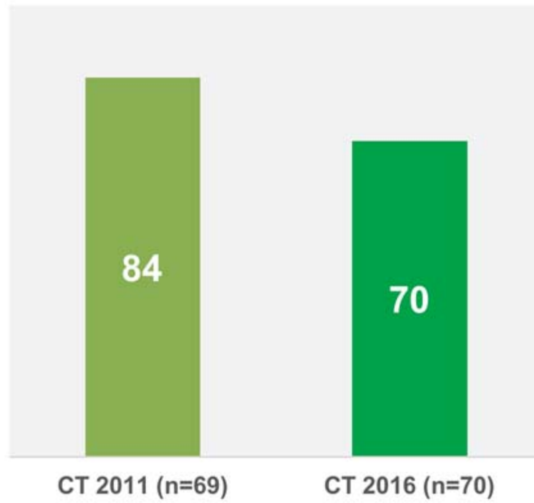
[7] The tiers correspond to the range of HERS Index values that qualify for each RNC program tier. For Tier 1, program homes achieve a HERS Index value between 70 and 61, for Tier 2, between 60 and 51, and for Tier 3, 50 or less before renewables are added. The analysis groups homes based on the HERS Index value they achieved, not the actual program Tier. Program-provided data did not include the program Tier achieved; we use HERS values to serve as a proxy for the program Tier. Note that 99 program homes had solar PV. The maximum (worst) HERS index value for program homes with solar PV is 42. The results in Table 2 assume that solar homes met the 50 HERS requirement without solar, and therefore would have qualified for Tier 3.

Comparison to Previous Studies

Non-program homes have improved substantially since the previous study.

Connecticut non-program homes in this 2016 baseline study improved substantially from the non-program homes in the 2011 study. [8]

HERS Index Values – Non-Program (Lower = More Efficient)



- **HERS Index values.** The 2016 non-program homes have an average HERS Index value of 70 with solar and 72 with solar PV systems removed from the models. Both values are much better than the 2011 average of 84.[9]
- **Envelope.** Average R-values for every shell measure improved over the 2011 baseline. Walls improved from R-19 to almost R-21, and flat and vault ceilings improved from R-34 and R-32, respectively, to almost R-37.
- **Duct Leakage and Air Infiltration**. Duct leakage to the outside improved by 65% since the 2011 baseline; air leakage improved by 16%.
- **Heating.** In the 2011 study, 20% of primary heating systems were oil-fired, but none were in 2016, and the share of boilers declined from 28% to 16%. The AFUE of fossil fuel fired equipment improved since 2011 from 90.7 AFUE to 93.8.
- **Cooling.** The prevalence and efficiency of central air conditioning systems has increased slightly since the 2011 study (13.4 SEER to 14.0 SEER). Homes without air conditioning were less common (4%) relative to 2011 homes (14%), and ductless mini splits showed up for the first time as primary systems.
- **Water heaters.** The average water heater Energy Factor improved from the 2011 to the 2016 studies for all system types, and heat pump water heaters showed up for the first time in the 2016 sample (6% of systems). From the 2011 to 2016 studies, Energy Factors in gas and propane-fired storage tanks improved from 0.61 to 0.65, instantaneous from 0.89 to 0.93, and electric storage from 0.90 to 0.93 without heat pumps and to 1.43 including heat pump water heaters. Conventional electric storage water heaters are common: they are found in 17% of systems (20% including commercial versions).

[8] https://www.energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf.
[9] The 2011 study reports an average HERS index of 82. That average was calculated using REM/Rate version 12.9.5 to model homes. To compare the 2011 study to the current study, all the homes from the 2011 study were remodeled in the REM/rate version 14.6, which was the REM/rate version used by program raters during the period of the current study. The average HERS Index value from the 2011 study homes (84), as modeled by REM/Rate version 14.6.4, is a better value to compare to than that of the current study (70) because it removes any differences in HERS scores resulting from changes in REM/Rate versions.

- **Lighting.** Sixty-two percent of 2016 homes use high efficiency bulbs in at least 50% of permanent sockets, which is a substantial increase over 2011 when it was only 4% of homes. On average, 54% of sockets in a home have efficient light bulbs: about 40% of sockets contain LEDs, 11% contain CFLs, and 4% contain fluorescent tubes.

Comparison to 2009 and 2012 IECC

Baseline averages meet 2009 IECC prescriptive requirements for most measures.

Program and non-program homes reviewed under this study were all built under the 2009 IECC, and, on average, homes meet the 2009 IECC prescriptive requirements for most measures listed below (Table 3). The 2012 IECC requirements are included for comparison only, as it was adopted by Connecticut in October of 2016 and did not apply to the sampled homes. Inspected homes fall short on far more measures for the 2012 IECC, which is more stringent than the 2009 IECC. The IECC prescriptive requirements are shaded green when the average baseline values meet that level of performance, and are shaded red when they do not.

Table 3: Key Measures Compared to 2009 IECC and 2012 IECC

Measure	Home Type	Value from Baseline	2009 IECC Requirement	2012 IECC Requirement
Exterior wall: R-value	Non-program	20.8	20 or 13+5[1]	20 or 13+5[1]
	Program	22.3	20 or 13+5[1]	20 or 13+5[1]
Flat ceiling: R-value	Non-program	36.9	38	49[2]
	Program	46.0	38	49[2]
Vaulted ceiling: R-value	Non-program	36.7	38[2]	49[2]
	Program	40.0	38[2]	49[2]
Frame floor over basement: R-value	Non-program	25.7	30[3]	30[3]
	Program	28.0	30[3]	30[3]
Conditioned foundation wall: R-value	Non-program	10.9	10/13[4]	15/19[4]
	Program	16.3	10/13[4]	15/19[4]
Air leakage (ACH50)	Non-program	4.9	7.0	3.0
	Program	3.0	7.0	3.0
Duct leakage (leakage to outside or total)	Non-program	6.2 LTO, 18.7 TDL	8.0 LTO	4.0 TDL[5]
	Program	1.9 LTO, 4.2 TDL	8.0 LTO	4.0 TDL[5]

[1] Requires R-20 or R-13 in the cavity with R-5 continuous.
[2] R-38 satisfies R-49 requirement where uncompressed R-38 batt extends over the wall plate at the eaves.
[3] R-19 satisfies requirement if it fills the entire cavity.
[4] For 2009 IECC, R-10 continuous or R-13 cavity. For 2012 IECC, R-15 continuous or R-19 cavity.
[5] 2012 IECC switched the duct leakage metric from "Leakage to outside" to "Total leakage."

Updated UDRH

On-site visits inform the updated UDRH.

Using on-site visit results, this study updates the RNC program's UDRH, the reference home against which program homes are compared to estimate program savings. The measure-level values used in the UDRH are generally based on the average values seen in visited non-program homes. Measure-level details of the features of the updated UDRH are described in Appendix F.

Billing Analysis

Consumption estimates from REM/Rate models are similar to actual billing data.

As shown in Table 4, the billing analysis found that single-family program homes use about 8% more electricity (n=157) and 4% less natural gas (n=23) than estimated by program REM/Rate models. The study also found that non-program single-family homes used about 5% less electricity than suggested by REM/Rate models; results for natural gas homes were inconclusive, largely due to limited homes with sufficient billing data.

Table 4: Ratio of Billing to REM/Rate Estimates of Use

Program Participation	Electric		Natural Gas	
	Sample Size	Ratio: Billing to REM/Rate Use	Sample Size	Ratio: Billing to REM/Rate Use
Program	157	1.08 (1.07 – 1.09)	23	0.96 (0.65 – 1.58)
Non-program[1]	26	0.95 (0.91 – 1.00)	5	0.67 (0.28 – 1.14)

[1] Using the same thermostat set points as program REM/Rate files (see Appendix G for details).
90% confidence intervals shown in parentheses.

Conclusions, Recommendations, and Considerations

While some of the following conclusions and recommendations arise directly from the specific research questions, some are also informed by the evaluation team's knowledge of the industry and their experiences conducting the Connecticut on-site visits. This list also includes one consideration, which is only a suggestion for a potential program opportunity rather than a direct recommendation.

Updating the UDRH. The baseline study onsite inspections, analysis of program data, and recent UDRH updates that took place for RNC programs in Rhode Island and Massachusetts were used to develop measure-level recommendations for updating the Connecticut RNC program's UDRH, including separate specifications for single-family and multifamily homes.

- **Recommendation**. The program should review and consider updating its UDRH with the values recommended in Appendix F.

Overall program effectiveness. Program homes far outperform non-program homes, but, on average, non-program homes meet the HERS requirement of the lowest program tier. The program also claims savings impacts based on the difference in consumption between program homes and the UDRH, but uses HERS Index tiers as the basis for program eligibility.

- **Recommendation**. The program should continue its successful promotion of high efficiency residential new construction, but be mindful that non-program homes, on average, are approaching the efficiency required by the program's lowest eligibility tier. Therefore, this study recommends that the program adjust its program participation requirements in order to maintain a substantial efficiency gap between program and non-program homes. Specifically, the study recommends that the program adjust its eligibility tiers in one of two ways: (1) adjust the HERS Index eligibility thresholds, or (2) make eligibility based on savings relative to the UDRH, rather than the HERS Index. If the program continues to use the HERS Index to determine eligibility, this study recommends that the program use a maximum HERS Index threshold lower than 70, and also consider making Tiers 2 and 3 more stringent. As an alternative to the HERS Index approach, this study recommends that the program consider an eligibility structure based on performance relative to the UDRH, using a program design similar to the comparable Massachusetts RNC program.[10]

Changing versions of REM/Rate. REM/Rate Version 14 was the most up-to-date version of the software that HERS raters would have used to model the homes included in this study, but Version 15 has been released for homes built since then. Version 15 includes the ability to model additional features of domestic hot water systems, such as the length of piping and the presence of drain water heat recovery systems.[11] If a home uses short and/or well-insulated water piping, or includes a drain water heat recovery system, REM/Rate 15 can model the associated energy savings.

- **Recommendation**. Now that REM/Rate can model energy savings associated with these features, program trainings should promote best practices around these water-related measures. By doing so, program homes have an additional opportunity to outperform and claim savings relative to non-program homes. The EEB's future baseline studies should also plan to include these additional data collection points to allow for comparison between program and non-program homes.

Insulation practices. High quality insulation installations yield greater energy savings than low quality installations. Auditors saw poor installation of insulation batts in non-program homes, while program homes have high rates of quality installations; HERS Index values factor in insulation installation quality, making this important to overall efficiency. For example, 20% of non-program homes have Grade I (high quality) exterior walls, versus 95% of program homes. For Grade II (fair to good quality insulation), that figure is 75% of non-program homes, but only 1% of program homes. Similarly, 25% of non-program homes have Grade I flat ceilings, but essentially all (99%) program homes do; 48% of non-program homes have Grade II flat ceilings compared to less than 1% of program homes.

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[10] https://www.masssave.com/-/media/Files/PDFs/Save/Residential/Blended-Savings-Approach.pdf?la=en&hash=902D8AAC1C6F3962919F50E27B95F50AD74E1C9F.

[11] A drain water recovery system was found in only one non-program home. Data was not collected on drain water recovery systems for program homes because REM/rate version 14 was used for all program homes; version 15 adds the ability to model these systems.

- **Recommendation**. If not already the case, the program trainings should pay special attention to promoting spray-applied or blown-in insulation materials whenever possible to avoid the gaps and compression that often result from using batts.

Program data issues. Data issues resulted in challenges with conducting the evaluation, particularly the billing analysis. Program records lacked unique identifiers and some records were duplicated or inconsistently labeled, making it challenging to properly identify a given site's tracking data, billing data, or REM/Rate model. The Companies are currently revamping their program data tracking systems.

- **Recommendation**. As discussed in the R1602 process evaluation report, the Companies should continue to improve their program tracking systems and consider consulting with database experts in this process. Including unique identifiers for individual sites/homes across datasets and programs would be particularly helpful for future evaluations.

Real-world HVAC installation practices. The estimates of saving are based only on the rated efficiencies of HVAC equipment. Studies have found that installation practices can reduce the actual efficiency achieved.

- **Consideration**. The Companies may want to consider incorporating Quality and Installation and Verification (QIV) protocols or real-world performance testing for mechanical equipment into their program, such as by making it a part of the QA/QC process, to ensure that the mechanical systems in program homes are performing as expected.[12] Similarly, the EEB may also consider incorporating real-world performance testing into future baseline studies to see if non-program homes are performing at their rated efficiencies. Incorporating performance testing into RNC programs or into baseline studies is not common practice, but it does represent a potential opportunity for the program to claim additional savings. If, for example, program homes were found to have mechanical equipment operating near the rated efficiency levels, and non-program homes were found to have installation problems (an untested hypothesis), the program may be able to justify claiming savings for the better performing equipment.

[12] Connecticut already offers a separate Quality and Installation and Verification (QIV) program that covers air conditioners, heat pumps, and furnaces. https://www.energizect.com/your-home/solutions-list/quality-installation-verification-program.

1 Section 1 Introduction and Methodology

This study was commissioned by Eversource and United Illuminating Company (the Companies) and the Connecticut Energy Efficiency Board (EEB) to include a baseline study, billing analysis, and process evaluation in support of the Connecticut Residential New Construction (RNC) program. The Connecticut RNC program provides incentives to home builders to build more efficiently than required by code. Collectively, these research efforts are referred to as the R1602 study. This report includes the results of the baseline study (including the features of the updated User Defined Reference Home) and the billing analysis[13]; the process evaluation results are provided to the Companies in a separate report.

1.1 Study Objectives and Background

1.1.1 Program and Evaluation Background

The Connecticut RNC program provides financial incentives to builders to offset some of the cost of building to a higher level of energy efficiency than required by code. In 2014, the program began replacing its prescriptive rebate offering with a tiered-incentive system dependent on home performance as measured by the HERS Index,[14] and by 2016 the program stopped offering prescriptive rebates. The changes also included bonus incentives for homes that qualify for energy-efficiency certifications and designations. In 2017, the program added Tier 4, which rewards homes achieving HERS Indices of 0, and adjusted the bonus incentives for ENERGY STAR and DOE Zero Energy Ready Home designations.

Table 5 presents the program's incentive structure.

[13] Appendix G describes the billing analysis objectives and methods.

[14] The HERS index is nationally recognized rating system through which a home's energy efficiency is measured. The index scores range from below zero to well above 100. At the time the index was created, a standard new home 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.

Table 5: RNC Program Incentive Structure (2015 – 2017)

Performance Level		Dwelling Type: Single-family	Dwelling Type: Single-family Attached	Dwelling Type: Multifamily (5 units or more)
HERS Rating Path				
Tier	**HERS Index**	**Rebate Amount (per project)**		
Tier 1	70-61	$3,000	$2,000	$1,500
Tier 2[1]	60-51	$4,000	$2,500	$2,000
Tier 3[1]	< = 50	$4,500	$3,000	$2,500
	Each point < 50[2]	+$50	+$40	+$25
Tier 4[1]	0 (2017 only)[2]	$7,000	$5,000	$3,750
Bonus Incentives				
Certifications		**Rebate Amount (per certification)[4]**		
ENERGY STAR	2015 – 2016	$750	$250	$250
	2017	$500	$250 per unit	$250 per unit
DOE Zero Energy Ready Home	2015 – 2016	$500	$250 per unit	$250 per unit
	2017	$750	$250	$250
LEED for Homes		$500	$250 per unit	$250 per unit
National Green Building Standard (NGBS)				
Passive House				

Sources: 2015, 2016, and 2017 program application forms.
[1] Must meet the Connecticut version of the Zero Energy Ready Home PV-Ready Checklist.
[2] Must reach a HERS Index value of 50 before renewables are added to the project.
[3] Up to two certifications per home.

To ascertain estimates of program penetration, counts of program participants from the Connecticut Statewide Energy Efficiency Dashboard[15] were compared to annual new construction permits from the U.S. Census[16]. While the new construction permit census data was able to be split between single-family and multifamily, the counts of program homes were inseparable. Therefore, penetration rates reported in Table 6 include both single-family and multifamily units.[17] Note that in 2014, the program limited the prescriptive path and pushed the performance path more than in the past. This led to a jump in participation for that year.

[15] https://ctenergydashboard.com/Login.aspx. The dashboard is maintained by Eversource, The United Illuminating Company, Connecticut Natural Gas Corporation, and Southern Connecticut Gas Company
[16] https://www.census.gov/construction/bps/stateannual.html
[17] For UDRH analysis, program counts were estimated for 2015 using the rating dates in REM/Rate files provided by the companies. Using that estimation, the program had a penetration of 7% in the single-family market in 2015. This is similar to the 8% estimated by the single-family and multifamily markets combined.

Table 6: Annual Program Penetration

Year	Single- Family Permits	Multifamily Permits	Program Units	Program Penetration
2013	3,156	2,268	885	16%
2014	3,083	2,246	1,827	34%
2015	2,584	3,493	505	8%
2016	2,662	2,842	905	16%

The program calculates gross savings by taking the REM/Rate energy models of the program homes and comparing them to a market baseline.[18] By conducting periodic baseline studies, the Companies can better understand how the residential new construction market is changing over time. In addition, this process allows them to claim savings for program homes against a baseline that describes actual market conditions.

In October of 2016, an amended version of the 2012 IECC went into effect in the state of Connecticut.[19] Given the lag time in the construction process, homes built under the new code are unlikely to be completed and occupied until mid-to-late 2017. As a result, this evaluation includes on-site inspections for homes built at the end of the 2009 IECC cycle as a means of updating the baseline efficiencies for new non-program homes.[20,21]

1.1.2 Research Questions

The entire R1602 study was designed to answer four key questions, with a focus on the market at the end of the 2009 IECC code cycle:

- How has the market baseline changed over time?
- What kinds of changes in building practices and equipment installations have occurred?
- To what extent is the program responsible for changes in building practices among participant builders?
- How accurately do program energy models reflect actual program home energy consumption and what are the appropriate adjustment factors to bring them into alignment?

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[18] 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 values.

[19] https://www.energycodes.gov/adoption/states/connecticut

[20] It should be noted that while Massachusetts has been conducting code compliance evaluations (and claiming savings from code compliance enhancement efforts) those results should not be leveraged to represent Connecticut code compliance: the differences in code adoption schedules, the presence of an alternative performance-based code option (i.e., stretch code), and the presence of utility compliance trainings make the Massachusetts compliance results non-transferrable to Connecticut.

[21] Note that the 2012 IECC includes significant changes in air leakage, duct leakage, lighting, and ceiling insulation requirements (a few others as well, but they are less important measures). That said, Massachusetts will have publicly available results that show the change from the end of the 2009 IECC cycle to the beginning of the 2012 IECC cycle; it seems reasonable for the Companies to apply adjustment factors based on the Massachusetts results given that CT recently adopted the 2012 IECC.

The baseline study itself was designed to answer the first two research questions, while the process evaluation and billing analysis help answer the second two questions.

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 70 non-program single-family homes.
- Estimate a real-world baseline using on-site findings.
- Produce Home Energy Rating System (HERS) scores for all 70 sites.
- Develop a new program UDRH based on non-program measure-level efficiencies. (UDRH findings are presented in Appendix F, and the updated UDRH will form the basis of the program's savings, as described in the Connecticut Program Savings Document.[22])
- Develop an adjustment factor for multifamily homes. (The adjustment factor is presented in the UDRH section of this report [F.4].)
- Compare findings with the previous UDRH and previous studies.
- Compare non-program home efficiencies to program home efficiencies.

The billing analysis, discussed in more detail in Appendix G, was designed with a very defined scope, to compare electric and natural gas energy use as estimated by REM/Rate models to actual billing data to determine how accurately program energy models reflect actual home energy consumption.

The research tasks associated with the process evaluation are described in a separate report.

1.2 Baseline Study Sampling

The following subsection describes the methodology behind the baseline study, including sampling, recruitment, and inspection processes. For additional detail on the baseline study's methodology, see Appendix D. (The methodology for the UDRH development is described in Appendix F and the methodology for the billing analysis is described in Appendix G.)

1.2.1 Baseline Study Sampling Methodology

The sample design targeted a representative sample of newly constructed, attached or detached, single-family homes in UI and Eversource electric service territories. To be eligible, homes needed to meet the following criteria:

- Non-participant in the Connecticut Residential New Construction program[23]

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[22] https://www.energizect.com/sites/default/files/2017%20CT%20Program%20Savings%20Document_Final.pdf
[23] Data was not provided/available to evaluators to screen against participation in any other Connecticut program, such as an equipment rebate or weatherization program. The available records were electric new service request data, and RNC program data, and those were used to identify eligible homes. Not accounting for participation in other programs could affect both RNC and non-RNC program homes, as incentivized measures could have been installed in both sets of homes.

- Built in 2014 or 2015, to ensure construction near the end of the 2009 IECC code cycle
- 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 United Illuminating (UI) or Eversource electric service territory

1.2.2 Baseline Study Sample Targets

The on-site sample was designed to mirror the proportion of homes built in each Connecticut county in 2014 and 2015, based on county-level permit data from the U.S. Census data for one-unit buildings. A 70-home sample was developed to reach the 90% confidence level with a 10% sampling error.[24]

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 2011 baseline study (the most recent Connecticut baseline study).[25] 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)***

The last aspect of the final sampling plan was to maintain a representative proportion of homes by service territory, which required at least seven on-site inspections in UI territory.

[24] 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.

[25] The differences between custom and spec-built homes are usually minor, but in some cases and for some measures they can be significant. A minimum 60% proportion of spec homes helped ensure that custom homes were not oversampled, in case the custom homes are more efficient than spec-built homes due to the fact that homeowners typically invest more resources into custom homes. The baseline study sample approximates the program split because there is little data available about the split between custom and spec-built homes in the broader market. Previous baseline study available at: https://www.energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf.

1.3 Completed On-Site Inspections

UI and Eversource provided address information for a total of nearly 10,000 new electric service requests submitted in their territory to provide the population of homes built in 2014 and 2015. Ultimately, 1,004 recruitment letters were mailed to potential participants.

Completed on-site inspections achieved the sampling plan targets, based on county-level proportionality and the desired custom-spec home ratio (Table 7). The on-site inspections included 66% spec-built and 34% custom-built homes. Eight homes were served by UI, and 63 were served by Eversource (one home was served by both).

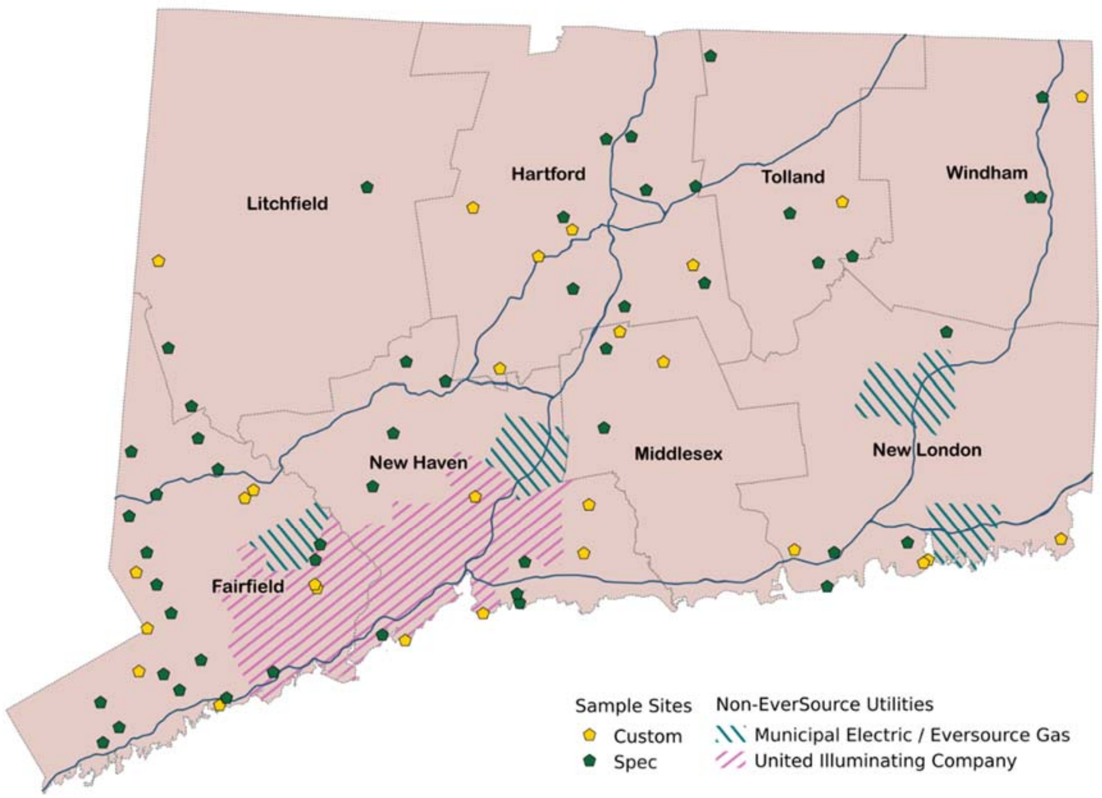
Table 7: Targeted and Completed Visits by County

County	Targeted On-Sites*	Completed On-Sites		
		Spec Homes	Custom Homes	Total
Total	*69*	*46*	*24*	*70*
Fairfield	24	18	7	25
Hartford	12	8	4	12
New Haven	12	8	4	12
New London	7	3	4	7
Middlesex	4	2	2	4
Tolland	4	3	1	4
Litchfield	3	2	1	3
Windham	3	2	1	3

*The values in this column sum to 69 homes. The 70th site was left as a floating site, to be filled based on the results of the recruiting effort. The 70th site was ultimately fielded in Fairfield.
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 48 towns across Connecticut. Thirty-one towns had one inspection each, 14 towns had two inspections, two towns had four inspections, and one town had three inspections. The location of each on-site and the custom/spec classification is shown in Figure 1.

Figure 1: Statewide Map of On-Site inspections



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

Table 8: 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 • Gas/electric account numbers • 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) • Ventilation (automatic ventilation systems only)	• Lighting ○ Fixture type, location, control • Appliances ○ Refrigerators and freezers ○ Dishwashers ○ Washers and dryers ○ Ovens and ranges ○ Dehumidifiers

1.5 Statistical Significance, Weighting, and Table Format

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 9).

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 10, 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 9: 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 10).

Table 10: 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 11). Only the values above the double breaker bar are weighted, meaning the mean, confidence intervals, and standard deviation are weighted. The minimum, median, maximum, and the percentiles show the distribution of the raw data, and are unweighted.

Table 11: Example of Table Format Showing Descriptive Statistics

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*Count (unweighted)*	*Count (unweighted)*	*Count (unweighted)*
Average	#* (unweighted)	#* (unweighted)	# (**weighted**)
90% CI Lower Bound	# (unweighted)	# (unweighted)	# (**weighted**)
90% CI Upper Bound	# (unweighted)	# (unweighted)	# (**weighted**)
Standard Deviation	# (unweighted)	# (unweighted)	# (**weighted**)
Minimum	# (unweighted)	# (unweighted)	# (unweighted)
10th Percentile	# (unweighted)	# (unweighted)	# (unweighted)
Median	# (unweighted)	# (unweighted)	# (unweighted)
90th Percentile	# (unweighted)	# (unweighted)	# (unweighted)
Maximum	# (unweighted)	# (unweighted)	# (unweighted)

*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 is an example, showing the distribution of HERS Index values 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 represented 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.

Figure 2: Example Figure - HERS Index Values

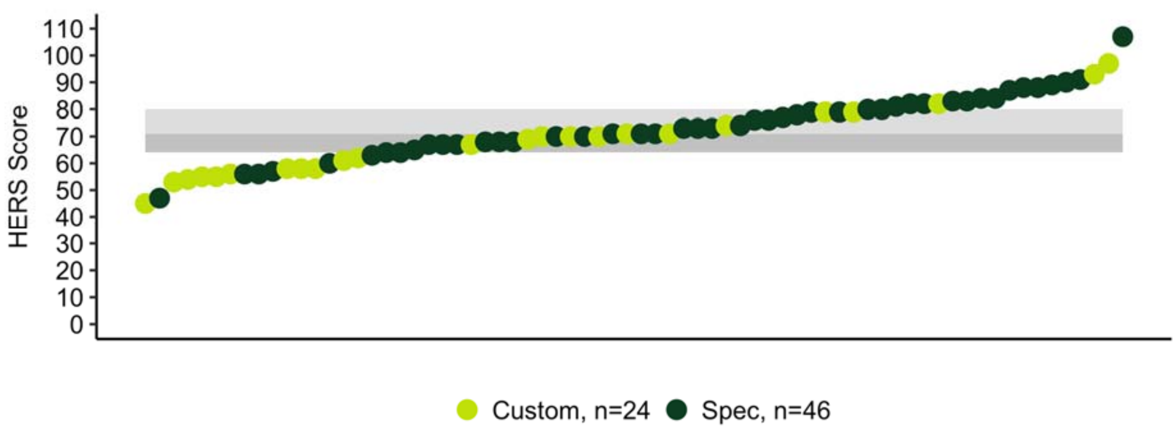
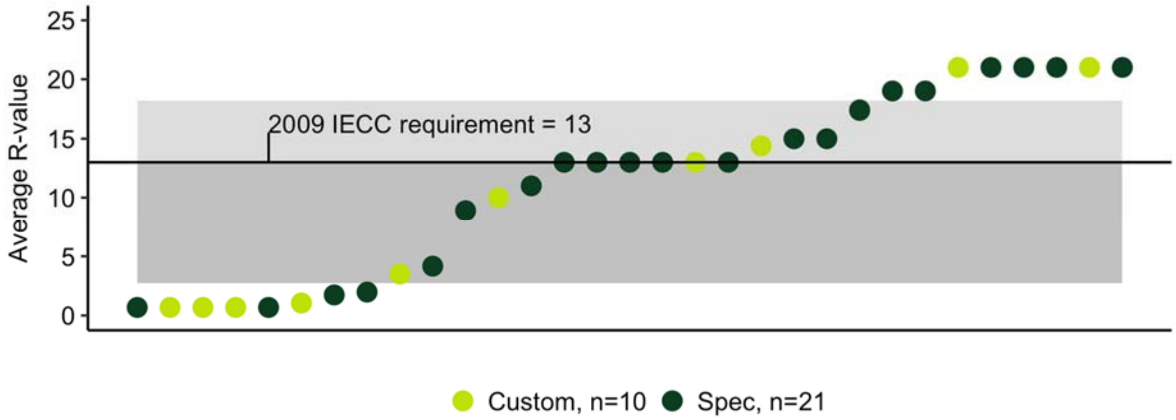


Figure 3 shows a similar graphic, but because fewer values cluster around the median, the quartile bands are wider. Some graphics, such as this one, also show the 2009 IECC prescriptive requirement as a reference point (these tend to fall close to the median value).

Figure 3: Example Figure - Foundation Wall Insulation



2 Section 2 Comparison to Previous Baseline Study

This section compares the 2016 Connecticut baseline results (2009 IECC homes) to the previous Connecticut baseline study conducted in 2011 (2006 IECC homes) to identify any changes in builder practices over time. For a comparison to a 2015 Massachusetts baseline study, which had the same code version as Connecticut, see Appendix H. Key findings from the Massachusetts comparison are identified below.

The 2011 Connecticut baseline results were unweighted. Because the comparisons are based on previous reported values, the differences between the study results were not tested for statistical significance.[26]

Key findings include the following:

- ***The average HERS Index value of 70 for non-program homes is much better than the 2011 Connecticut baseline average HERS Index value of 84.***
- ***Average R-values for every shell measure has improved over the 2011 Connecticut baseline.***
- ***Duct leakage to outside has improved by 65% between 2011 and the current Connecticut baseline, while air leakage improved by 16%.***
- ***Sixty-two percent of homes use high efficiency bulbs in at least 50% of permanent sockets, which is a substantial increase over 2011 when it was only 4% of homes.***
- ***The average HERS Index value of Connecticut homes (70) is slightly better than the 2015 Massachusetts baseline (74) (Massachusetts homes were also built to the 2009 IECC).***
- ***The Massachusetts sample has higher average R-values for flat ceilings and frame floors, while Connecticut has higher average wall and vaulted ceiling R-values. Massachusetts and Connecticut homes have similar duct leakage to outside and air infiltration values. Duct leakage to outside: 6.2 CFM25 in Connecticut, 6.3 in Massachusetts; air infiltration: 4.9 ACH50 in Connecticut, 4.8 in Massachusetts.***

[26] Additionally, some pieces of data describing the results of the 2016 Connecticut study in this section may appear slightly different than values shown elsewhere in the report; this is only because of slight differences in reporting or analysis methods between the 2016 Connecticut study and the previous studies. The analyses from this 2016 study were adjusted where necessary in this section to create comparable results across studies.

- ***Efficient bulb saturation in permanent sockets among the Connecticut sample (62% having at least 50% of permanent sockets with efficient lamps installed) is much better than the Massachusetts sample (40% meeting that threshold).***

2.1 Comparison to 2011 Connecticut Baseline Study (2006 IECC)

2.1.1 Key Characteristics of 2011 Baseline Study

- On-sites performed at 69 non-program, single-family homes in 61 cities/towns
- All homes permitted under 2006 IECC; completed between November 2009 and July 2011
- 47 spec homes and 22 custom homes in final sample
- Sites recruited through homeowners, not builders
- Sampling plan similar to 2016 Connecticut baseline
    - Based on number of one-unit building permits issued in Connecticut counties in 2010 (using Census data)
    - On-sites in each county proportional to permits issued in that county

2.1.2 Comparison Results

Conditioned Floor Area (CFA)

The 2016 Connecticut sample has a somewhat wider range of home sizes than the 2011 sample. On average, the 2016 homes were larger – 3,052 sq. ft. of CFA compared to 2,758 sq. ft. in 2011.

Table 12: Conditioned Floor Area (sq. ft.)

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
Minimum	880	627
Maximum	7,090	8,509
Average	2,758	3,052
Median	2,486	2,558

HERS Index values

The average HERS Index value declined (improved) from 84 in 2011 to 70 in 2016 (Table 13).[27] The 2016 sample has the best performing home of the two groups, with a HERS Index

[27] The 2016 baseline used REM/Rate version 14.6.2, while the 2011 baseline used REM/Rate version 12.9.5. In both studies, the REM/Rate version was selected to reflect the files made my program raters during the evaluated time frame. The 2011 study reports an average HERS index of 82. This average was calculated using REM/rate version 12.9.5 to model homes. To compare the 2011 study to the current study, all the homes from the 2011 study were re-modeled in the REM/rate version 14.6, which was the REM/rate version used by program raters during the period of the current study. The average HERS Index value from the 2011 study homes (84), as modeled by REM/rate version 14.6.2, is a better value to compare to than that of the current study (70) because it removes any differences resulting from changes in REM/rate version.

value of 45, compared to a low of 62 in the 2011 sample. However, the highest (worst) score in 2016 (108) is worse than the worst performing home in 2011 (102).

Table 13: HERS Index Values

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
Minimum (Best)	63	32
Maximum	105	108
Average	84	70

Building Envelope

Table 14 compares average R-values for key shell measures across the two Connecticut baseline samples. R-values for these shell measures—conditioned to ambient walls, flat and vaulted ceilings, and frame floors between conditioned space and unconditioned basements—increased since the previous baseline. Wall and flat ceiling R-values improved slightly, from R-19 to R-20.8 and R-34 to R-36.9, respectively. The largest gains were seen in vaulted ceilings (R-32 to R-36.7) and frame floors to unconditioned basements (R-20.5 to R-25.6).

Table 14: Wall, Ceiling, and Floor R-Values and IECC Code Requirements

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
Energy Code Version	2006 IECC	2009 IECC
Conditioned to Ambient Wall Insulation		
n (homes)	*69*	*70*
Average R-value	R-19	R-20.8
Prescriptive code requirement	R-19 or R-13+5*	R-20 or R-13+5*
Flat Ceiling Insulation		
n (homes)	*68*	*62*
Average flat ceiling R-value	R-34.0	R-36.9
Prescriptive code requirement	R-38	R-38
Vaulted Ceiling Insulation		
n (homes)	*20*	*39*
Average vaulted ceiling R-value	R-32.0	R-36.7
Prescriptive code requirement	R-38**	R-38**
Floor Insulation over Unconditioned Basements		
n (homes)	*57*	*51*
Average R-value	R-20.5	R-25.6
Prescriptive code requirement	R-30***	R-30***

* First value is cavity insulation, second is continuous insulation or insulated siding; "13+5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding.

**Allows for up to 20% (capped at 500 sq. ft.) of cathedral ceiling to be as little as R-30.

*** Or insulation sufficient to fill the framing.

Primary Heating Systems

Propane and natural gas were the most common primary heating fuels (based on system capacity) in both samples (Table 15). The share of primary systems fueled by oil dropped from 20% in the 2011 sample to none in 2016. Furnaces were the most common primary heating system type in 2011 at 70% of primary systems and remained the most common in 2016 at 73%. The share of boilers in the 2016 sample dropped to 20% from 28% in 2011.[28] In place of boilers, these homes used more diverse equipment types such as ductless mini split air source heat pumps, traditional ducted split air source heat pumps, and combination appliances (instantaneous water heating systems that provide space heating and domestic hot water).

The average AFUE of fossil fuel-fired equipment increased from 90.7 in the 2011 sample to 93.8 in 2016.

Table 15: Primary Heating System Type, Fuel, and Efficiency

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
Primary Heating Fuel		
Propane	42%	48%
Natural gas	36%	45%
Oil	20%	--
Electric	1%	8%
Primary Heating System Type		
Furnace	70%	73%
Boiler	28%	16%
Combi appliance	1%	4%
Ductless mini split ASHP	--	4%
Electric baseboard	--	2%
GSHP	1%	1%
ASHP	--	1%
Overall AFUE (fossil fuel systems)	90.7	93.8

Cooling Equipment

Central air conditioning remains the dominant system type and their overall efficiency has hardly changed since the 2011 baseline. However, emerging technologies like ductless mini splits and ground source heat pumps (GSHP) are now present that were not found in the 2011 baseline. Similar percentages of homes (over four-fifths) have traditional central air (CAC) systems. In 2016, fewer homes lacked air conditioning (only 4% vs. 14% in 2011), and ductless mini splits were only present in the 2016 sample. Average SEER of CACs and GSHPs rose only slightly from the 2011 to 2016 study. In addition, the cooling capacity per

[28] The 20% is comprised of boilers (16%) and combi appliances (4%), which are boilers that provide space heating and domestic hot water.

square foot dropped slightly, meaning cooling systems were not as oversized as the systems in the previous study (oversized systems operate less efficiently than appropriately sized systems).

Table 16: Cooling Systems

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
Primary System Type		
n (homes)	*69*	*70*
Central air conditioning[1]	84%	85%
Ductless mini splits	--	5%
GSHP-closed loop	2%	3%
Window/portable	--	3%
No air conditioning	14%	4%
Cooling Efficiency		
CAC average SEER[1]	13.4 (n=76)	14.0 (n=76)
Ductless mini split average SEER	--	22.3 (n=5)
GSHP average EER	16.0 (n=1)	17.8 (n=3)
Cooling Capacity		
n (homes)	*59*	*65*
Btu/hr per sq. ft.	16.8	15.7
Sg. Ft per ton	714.3	764.3

[1] Includes one ducted ASHP used for cooling and heat.

Water Heating Equipment

Table 17 shows a comparison of water heaters by type and fuel.[29] The percentage of homes containing conventional natural gas and propane standalone systems dropped from 38% in the 2011 baseline to 34% in 2016. Efficient instantaneous systems (including combi appliances) are found in 31% of homes in the 2016 sample, compared to 22% of homes in 2011. Heat pump water heaters have begun to show up in 2016 sampled homes (6%) after not being present in the 2011 sample, while the share of homes with inefficient tankless coil

[29] The 2011 study included commercial-grade storage systems within the storage, standalone classification, but they are separated in this report. Those categories have been collapsed here for the 2016 sample to allow for a direct comparison.

systems drops from 7% to 1% (one home) in 2016. Standalone electric storage water heaters are about as common as they used to be, found in a little under one-fifth of homes.

Table 17: Water Heater Type and Fuel

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
Storage, standalone (natural gas and propane)	38%	34%
Instantaneous (natural gas and propane)	22%	25%
Storage, standalone (electric)	19%	18%
Indirect w/ storage tank (natural gas and propane)	13%	10%
Heat pump water heater (electric)	--	6%
Combi appliance (natural gas and propane)	--	6%
Tankless coil (propane)	7%	1%

Table 18 shows a comparison of Energy Factors for water heating equipment types present in both the 2011 and 2016 samples. The average Energy Factor has improved between 2011 and 2016 for every equipment type (excluding tankless coils, of which there is only one in the 2016 sample).[30] Conventional natural gas and propane storage systems have an average Energy Factor of 0.65 in 2016 compared to 0.61 in 2011, while instantaneous systems improve from 0.89 to 0.93. To allow a direct comparison between 2011 and 2016, commercial-grade systems are grouped with storage, standalone systems of the same fuel type to stay consistent with the 2011 baseline. As a result, estimated Energy Factors[31] for gas commercial systems are included here in 2016 averages, as they were in 2011.

Table 18: Water Heater Energy Factors

	2011 CT Baseline (2006 IECC)		2016 CT Baseline (2009 IECC)	
	n (homes)	EF	*n (homes)*	EF
Natural gas and propane storage, standalone	*26*	.61	*24*	.65
Natural gas and propane, instantaneous	*15*	.89	*18*	.93
Electric storage, standalone	*13*	.90	*13*	.93
Heat pump water heater	*0*	NA	*4*	3.04
Natural gas and propane indirect w/ storage tank	*9*	.82	*7*	.88
Tankless coil	*5*	.46	*1*	.45

[30] EFs for tankless coils are estimated using instructions in the NEHERS manual based on occupancy: 0.45 for three occupants, 0.50 for four occupants, .0.55 for five occupants and 0.60 for six occupants.
[31] Estimated EFs for commercial systems are calculated using the RESNET Energy Factor Calculator for Commercial DHW Tanks found here: http://www.resnet.us/uploads/documents/standards/Commercial_Hot_Water_EF_Calculator_12-10.xls

Duct Leakage and Air Infiltration

The IECC 2006 did not have performance requirements for duct leakage or air infiltration, instead requiring that air and duct sealing be confirmed with a visual inspection. With the adoption of 2009 IECC, allowable duct leakage to the outside was capped at 8 CFM50 per 100 sq. ft. of conditioned space, or total leakage less than or equal to 12 CFM25 per 100 sq. ft. of conditioned space. Average leakage to outside numbers dropped substantially between the 2011 and 2016 samples, falling from 17.7 CFM50 per 100 sq. ft. to 6.2 in 2016 on average – a 65% improvement and well below the 2009 IECC requirements.[32] Part of the reduction in duct leakage could have come from an increased amount of ducts in conditioned space. In the previous baseline, 3% of homes with ducts had all their ducts in conditioned space; in the 2016 baseline, that number is 8%.

Additionally, this follows a trend recently observed in Massachusetts, where duct leakage improved from 12.4 in 2011 to 3.9 in 2015. This trend was also observed in Rhode Island, where duct leakage improved from 20.0 in 2011 to 8.6 in 2017. This marked improvement across New England could signify and an increased attention to duct sealing in the industry, driven at least partially by code changes.

The 2009 IECC also requires a visual inspection of air sealing to meet air leakage requirements, but added an option to pass the home using a blower door test and an ACH50 value of 7 or less. Homes in the 2016 sample show improvement over 2011, with the average ACH50 dropping from 5.8 to 4.9.

Table 19: Duct Leakage to Outside and Air Infiltration

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
Relevant prescriptive codes	2006 IECC	2009 IECC
Duct Leakage to the Outside (CFM25/100 sq. ft. of CFA)		
n (homes tested)	*61*	*60*
CFM25 per 100 sq. ft. of conditioned space	17.7	6.2
Code requirement	Visual inspection for duct sealing	≤ 8 CFM25 per 100 sq. ft.
Air Infiltration (ACH50)		
n (homes tested)	*69*	*70*
ACH50	5.8	4.9
Code requirement	Visual inspection for air sealing	Visual or ≤ 7

Lighting

Table 20 illustrates the major shift between the 2011 and 2016 baselines in the proportion of hard-wired (permanent) fixtures containing efficient bulbs (CFLs, LEDs, and fluorescents). Only three homes (4%) in the 2011 sample would meet 2009 IECC prescriptive code

[32] 7.9 CFM25/100 sq. ft. is the per home leakage value; on a per system level, the leakage is lower, at 6.0 CFM25/100 sq. ft.

requirement that 50% of fixtures use high efficacy lamps. In 2016, that proportion rises to 62%. Seventy-five percent of homes in the 2011 sample used high efficiency bulbs in 10% or less of fixtures, but this number falls to just 3% in the 2016 sample.

Table 20: Share of Hard-Wired fixtures with Efficient Bulb Types

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
10% of less	75%	3%
11% to 30%	15%	15%
30% to 49%	6%	21%
50% to 79%	1%	31%
80% to 100%	3%	31%

Table 21 shows the percent of sockets that have efficient lamps in the average home. In the 2011 baseline only 10% of sockets had efficient lamps. In the 2016 baseline that number has increased to 54%. That increase is largely driven by CFLs which went from being in 6% of sockets to 40% of sockets. LEDs which were in less than one percent of sockets in the 2011 baseline are in 11% percent of sockets in the 2016 baseline.

Table 21: Penetration of Efficient Lamps

	2011 CT Baseline (2006 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*69*	*70*
CFLs	6%	40%
LEDs	<1%	11%
Fluorescent tubes	3%	4%
Efficient Lamps	10%	54%

3 Section 3 Comparison to Program Homes

This section describes comparison for key measures between the 70 sampled non-program homes and program homes built at a similar time frame.[33] The on-site sample was compared to the REM/Rate files of 651 program homes.[34]

Key findings include the following:

- ***Program homes performed significantly better than the non-program homes on every analyzed measure. These measures range from shell measures, to mechanical equipment, to the overall efficiency as determined by the HERS Index value.***

- ***Program homes have an average HERS Index value of 48, which is significantly better (lower) than the average score for non-program homes (70).***

3.1 Comparison of Key Measures

Table 22 compares the program and non-program homes for measures such as envelope R-values, U-values, air leakage, and duct leakage. Program homes performed significantly better than non-program homes in every analyzed measure. Significance was only tested between the overall values for program and non-program homes. Significance testing between custom and spec homes is in the individual sections of this report for each measure.

[33] Appendix G presents the results of the comparison of REM/Rate and billing data estimates of energy use for both program and non-program homes; these results are not included in this section.

[34] 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 Connecticut 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. After removing duplicates and incomplete files, 651 files remained for analysis.

Table 22: Comparison Between Program and Non-Program Homes

Measure	Non-program Homes			Program Homes		
	Custom	Spec	All Homes (Weighted)	Custom	Spec	All Homes (Unweighted)
n (homes)	*24*	*46*	*70*	*278*	*373*	*651*
Above grade exterior wall[1]: average R-value	22.4 (n=24)	19.7 (n=46)	**20.8* (n=70)**	23.2 (n=278)	21.6 (n=373)	**22.3* (n=651)**
Above grade exterior wall[1]: average U-value	0.064 (n=24)	0.058 (n=46)	**0.062* (n=70)**	0.051 (n=278)	0.054 (n=373)	**0.053* (n=651)**
Flat ceiling: average R-value	39.7 (n=19)	35.2 (n=43)	**36.9* (n=62)**	46.6 (n=191)	45.7 (n=357)	**46.0* (n=548)**
Flat ceiling: average U-value	0.026 (n=19)	0.029 (n=43)	**0.042* (n=62)**	0.024 (n=191)	0.024 (n=357)	**0.024* (n=548)**
Vaulted ceiling: average R-value	38.3 (n=15)	35.3 (n=24)	**36.7 * (n=39)**	41.7 (n=170)	37.0 (n=102)	**40.0* (n=272)**
Vaulted ceiling: average U-value	0.034 (n=15)	0.039 (n=24)	**0.038* (n=39)**	0.027 (n=170)	0.030 (n=102)	**0.029* (n=272)**
Frame floor[2]: average R-value	26.9 (n=20)	24.6 (n=33)	**25.7* (n=53)**	29.4 (n=155)	26.6 (n=153)	**28.0* (n=308)**
Frame floor[2]: average U-value	0.066 (n=20)	0.055 (n=33)	**0.060* (n=53)**	0.042 (n=155)	0.049 (n=153)	**0.045* (n=308)**
Conditioned basement foundation wall: average R-value	9.7 (n=10)	14.0 (n=21)	**10.9* (n=31)**	18.0 (n=113)	14.4 (n=110)	**16.3* (n=223)**
Unconditioned basement foundation wall: average R-value	1.5 (n=20)	1.0 (n=31)	**0.23* (n=51)**	2.8 (n=142)	3.8 (n=151)	**3.3* (n=293)**
Attic duct supply: average R-value	6.9 (n=14)	6.2 (n=26)	**6.5* (n=40)**	8.8 (n=84)	8.2 (n=202)	**8.4* (n=286)**
All other unconditioned ducts: average R-value	6.4 (n=20)	5.4 (n=37)	**5.8* (n=57)**	8.2 (n=123)	7.7 (n=138)	**7.9* (n=261)**
Average leakage to outside per hundred SQFT[3]	5.1 (n=18)	6.8 (n=42)	**6.2* (n=60)**	1.88 (n=227)	1.89 (n=328)	**1.88* (n=555)**
Average total duct leakage per hundred SQFT[4]	15.4 (n=17)	20.7 (n=38)	**18.7* (n=55)**	3.9 (n=303)	4.5 (n=331)	**4.2 (n=634)**
Average ACH50	4.60 (n=24)	5.10 (n=46)	**4.9* (n=70)**	2.43 (n=265)	3.40 (n=358)	**2.99* (n=623)**
Average heating system AFUE (systems with AFUE)	94.9 (n=23)	93.0 (n=54)	93.5 (n=77)	95.2 (n=167)	94.7 (n=291)	94.9 (n=458)
Average cooling system SEER (systems with SEER)	15.5 (n=28)	14.0 (n=53)	**14.5 (n=81)**	16.4 (n=191)	14.7 (n=326)	**15.3 (n=517)**
Average water heater EF	1.04 (n=25)	0.88 (n=47)	**0.98 (n=72)**	1.22 (n=741)	1.00 (n=1052)	**1.09 (n=1793)**
Average HERS Index value	67.0 (n=24)	74.4 (n=46)	**69.8* (n=70)**	43.2 (n=278)	51.9 (n=373)	**48.2* (n=651)**

All R-values are the actual rated R-values of the insulation itself, including cavity and continuous insulation. The U-values are the REM/Rate calculated values that account for air barriers, R-value, installation quality, and framing.
*Statistically significant at the 90% confidence level. For this table, only the overall program and non-program values were tested for statistically significant differences.
[1] Includes only walls between conditioned and ambient space.
[2] Includes frame floors between conditioned space and unconditioned basements or enclosed crawl space.
[3] Program data only include observations entered by raters as “Total Duct Leakage to Outside.”
[4] Program data only include observations entered by raters as “CFM at 25 Pascals.”

3.2 HERS Index value Comparison

The per-home average HERS Index value is 69.8 for the non-program homes if solar PV is included and 71.5 if the models are re-run without solar PV systems. Table 23 only reports HERS Index values with solar PV included since solar PV was not removed from program homes. For details on non-program HERS Index values with solar PV removed, see the following chapter.

Program homes have significantly lower HERS Index values than non-program homes with an average of 48.2. In both program and non-program homes, custom homes have significantly better HERS Index values than spec homes. The best non-program HERS Index value is 45, and the worst is 108.

Table 23: HERS Index values

	Non-program Homes			Program Homes		
	Custom	Spec	All Homes (Weighted)	Custom	Spec	All Homes (Unweighted)
n (homes)	*24*	*46*	*70*	*279*	*399*	*678*
Minimum (best)	45	47	32	-22*	3	-22*
Maximum	97	108	108	70	70	70
Average	**67.0[a]**	**74.4[a]**	**69.8[b]**	**43.2[c]**	**51.9[c]**	**48.2[b]**
Median	68	74	71	48	54	51

[a,b,c] Statistically significant at the 90% confidence level.

* A negative score is the result of a home consuming less energy than it produces on site with renewable sources.

Section 4 General Characteristics

This section presents the general characteristics of the sampled homes, including home size, home type, year built, HERS Index values, thermostat set points, water fixture flow rates, home automation systems, and pools. The sampled homes are all homes that did not participate in the program.

Key findings include the following:

- ***The average HERS Index value for sampled homes is 70. Custom homes have significantly better (lower) HERS Index values than spec homes: 66 vs. 72, respectively. For reference, the RNC program requires a HERS Index value of 70 or lower for single-family homes: a sizeable percentage – 47% – of the non-program homes met that program threshold.[35]***

- ***The average home size is 3,052 square feet, with no significant differences between custom and spec homes.***

- ***Inspected homes were primarily detached single-family homes (89%). The spec homes were significantly more likely than the custom homes to be attached. Eighty percent of the spec homes were detached, but all of the custom homes were detached.***

- ***Programmable thermostats make up 69% of all thermostats, Wi-Fi units make up 16%, and manual units make up 15% – the vast majority of the market is made of units that can be programmed to save energy. Custom homes are significantly more likely than spec homes to have a Wi-Fi enabled thermostat (29% vs. 4%), less likely to have a manual thermostat (13% vs. 26%), and less likely to have a programmable thermostat (67% vs. 74%).***

- ***Homes have average flow rates of 1.5 GPM for bathroom sinks, 1.8 GPM for kitchen sinks, 1.9 for utility sinks,[36] and 2.3 for shower heads.[37] Aerators are extremely common, found on 97% of faucets.***

- ***Over one-third (38%) of homes have home automation features of some sort, such as AV, home security, and HVAC systems; 21% have home automation***

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[35] The RNC program has additional requirements other than meeting the HERS threshold, but this is a key requirement.

[36] 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.

[37] The federal standard for faucet flow rates is no more than 2.2 GPM and 2.5 GPM for shower heads. The U.S. EPA's WaterSense water conservation labeling and certification program has a maximum allowable flow rate of 1.5 GPM for bathroom sinks (kitchen sinks are not covered) and 2.0 GPM for shower heads. https://energy.gov/eere/femp/best-management-practice-7-faucets-and-showerheads; https://www.epa.gov/watersense/product-specifications; http://www.allianceforwaterefficiency.org/uploadedFiles/US-Water-Product-Standards-Matrix_2016-11-07.pdf.

systems that can be used to control energy consumption, such as HVAC, lighting, and outlet controls. Custom homes are more likely than spec homes to have a home automation system installed (58% vs. 27%).

- ***Pools and hot tubs were uncommon, found in only four homes.***

4.1 General Characteristics of Inspected Homes

The 70 inspected homes included single-family attached and detached custom and spec homes. Town assessor databases were consulted to determine the year that each home was built. All homes were built between 2014 and 2016. There were no statistically significant differences between the years when custom and spec homes were built. Figure 4 shows examples of the different sizes of homes inspected.

Figure 4: Examples of Inspected Homes

As shown in Table 24, the majority of inspected homes (89%) are detached single-family homes. All the custom homes are single-family detached homes, while 80% of the spec homes are detached and the remaining 20% are attached. The differences between the percentage of custom and spec homes that are detached or attached are statistically significant.

Table 24: House Type

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Detached single-family	**100%***	**80%***	89%
Attached single-family	**0%***	**20%***	11%

* Statistically significant at the 90% confidence level.

Inspected homes ranged in size from 627 to 8,509 square feet of conditioned floor area (CFA),[38] with an overall average of 3,052 square feet (Table 25 and Figure 5). CFA includes all finished and/or fully conditioned spaces on all floors of a home. There are no statistically significant differences between the CFA of custom and spec homes.

Table 25: Conditioned Floor Area (CFA)

CFA (square feet)	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	3,113	3,009	3,052
90% CI Lower Bound	2,624	2,554	2,721
90% CI Upper Bound	3,603	3,465	3,383
Standard Deviation	1,399	1,840	1,660
Minimum	627	1,361	627
10th Percentile	1,586	1,495	1,515
Median	2,869	2,293	2,512
90th Percentile	5,479	6,260	5,832
Maximum	6,653	8,509	8,509

No statistically significant differences at the 90% confidence level.

Figure 5: Conditioned Floor Area[39]

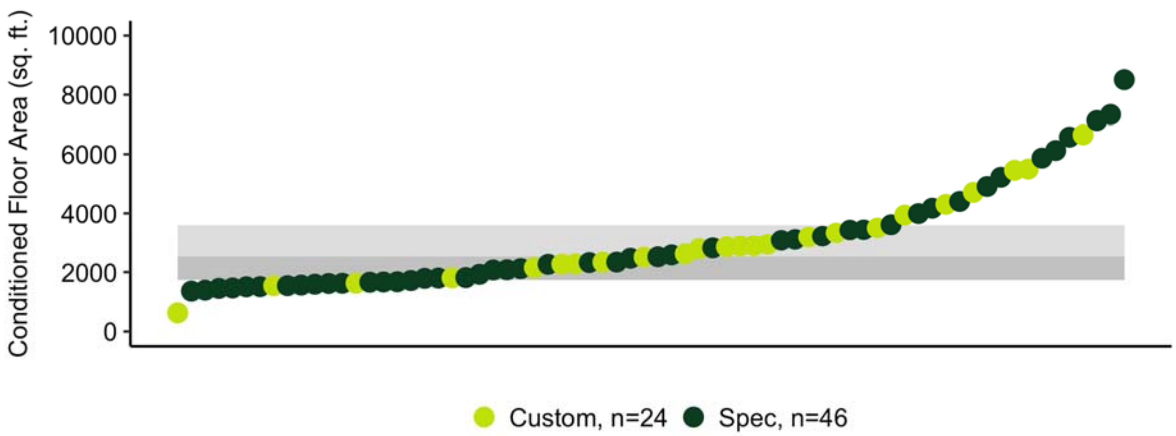

Table 26 displays the foundation types of sampled homes split into three groups: “Below Grade Only,” “On Grade or Above Grade Only,” and “Mixed Grade.” The majority of homes (58%) have foundations entirely below grade. One-fourth (28%) of homes have mixed-grade

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38 CFA is defined in accordance with RESNET standards: “The finished floor area in square feet of a home that is conditioned by heating or cooling systems, measured in accordance with ANSI Standard Z765-2003 with exceptions as specified in Appendix A of this Standard.” This includes all finished space within the thermal envelope regardless of HVAC equipment, and includes all unfished space that is intentionally directly conditioned. See http://www.resnet.us/standards/Floor_Area_Interpretation.pdf

39 Throughout this report, charts of this type present an ordered scatterplot of values of interest. The gray bars indicate the interquartile range, with the dividing line between the bars indicating the median value.

foundations, which are mostly walk-out basements. The most common type of foundation is a completely below grade unconditioned basement or enclosed crawl space (41% of homes).

Table 26: Foundation Type

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Below Grade Only	**50%**	**65%**	**58%**
Conditioned basement	--	7%	4%
Unconditioned basement or enclosed crawl space	42%	41%	41%
Conditioned basement and unconditioned basement	8%	15%	12%
Unconditioned basement and open crawl space	--	2%	1%
On Grade or Above Grade Only	**12%**	**13%**	**13%**
Slab	8%	13%	11%
Above conditioned garage	4%	--	2%
Mixed Grade	**37%**	**21%**	**28%**
Conditioned basement and unconditioned basement	25%	13%	18%
Conditioned basement	4%	9%	7%
Unconditioned basement and on-grade slab	8%	--	3%

4.2 HERS Index Values

Table 27 and Figure 6 show Home Energy Rating System (HERS) Index values for the sampled homes. A lower HERS Index value represents a more efficient home.[40] The average HERS Index value is 69.8. On average, the custom homes have significantly better HERS Index values than spec homes: 66 vs. 72, respectively. The best (lowest) HERS Index value is 32 and the worst (highest) is 108. Since the program does not claim any savings from solar, HERS Index values with solar PV removed from homes is also reported. The average HERS Index Value without solar PV is 71.5.

[40] A HERS Index value 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.

Table 27: HERS Index Values[41]

	Custom	Spec	All Homes (Weighted)	All Homes (PV Removed) (Weighted)
n (homes)	*24*	*46*	*70*	*70*
Average	**66.3***	**72.4***	69.8	71.5
90% CI Lower Bound	61.6	69.1	67.1	69.1
90% CI Upper Bound	70.9	75.7	72.5	73.9
Standard Deviation	13.9	13.7	14.0	12.2
Minimum (best)	43	32	32	47
10th Percentile	53	57	54	56
Median	69	73	71	71
90th Percentile	81	88	88	88
Maximum (worst)	97	108	108	108

*Significantly different at the 90% confidence level.

Figure 6: HERS Index values

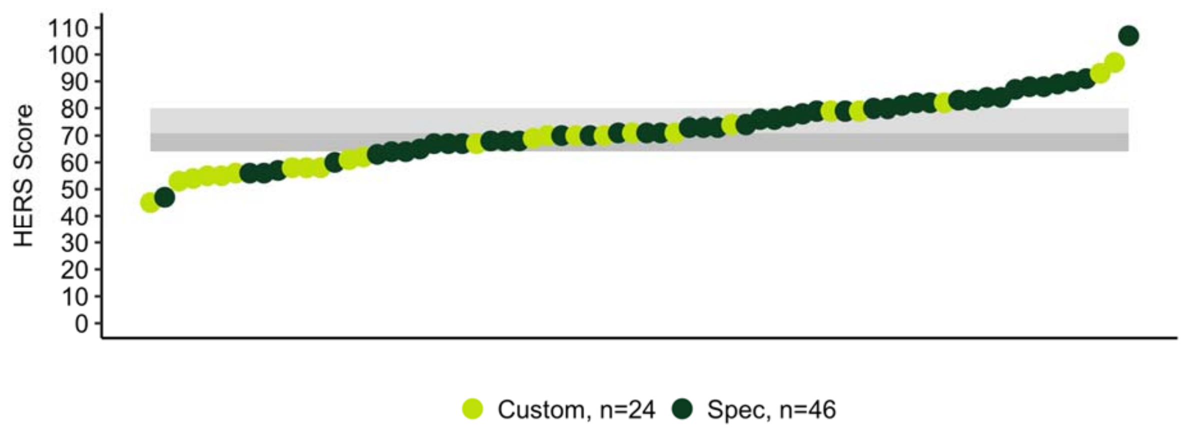


Figure 7 shows the relationship between HERS Index values and conditioned floor area for custom and spec homes. It appears that HERS Index values and conditioned floor area are negatively correlated, but the correlation is very weak for both groups: the r-square value for the custom trend is only 0.316, and the r-square for the spec trend is only 0.0262.

[41] For comparison, based on data collected in existing homes in Connecticut for the 2013 Single-Family Weatherization Baseline Assessment (n=180 homes), the weighted statewide average HERS Index value for existing homes is 118.6, higher (worse) than the maximum HERS Index value observed among sampled new homes, indicating that new homes are, on average, built to be far more efficient than existing home stock.

Figure 7: HERS Index Values by Conditioned Floor Area

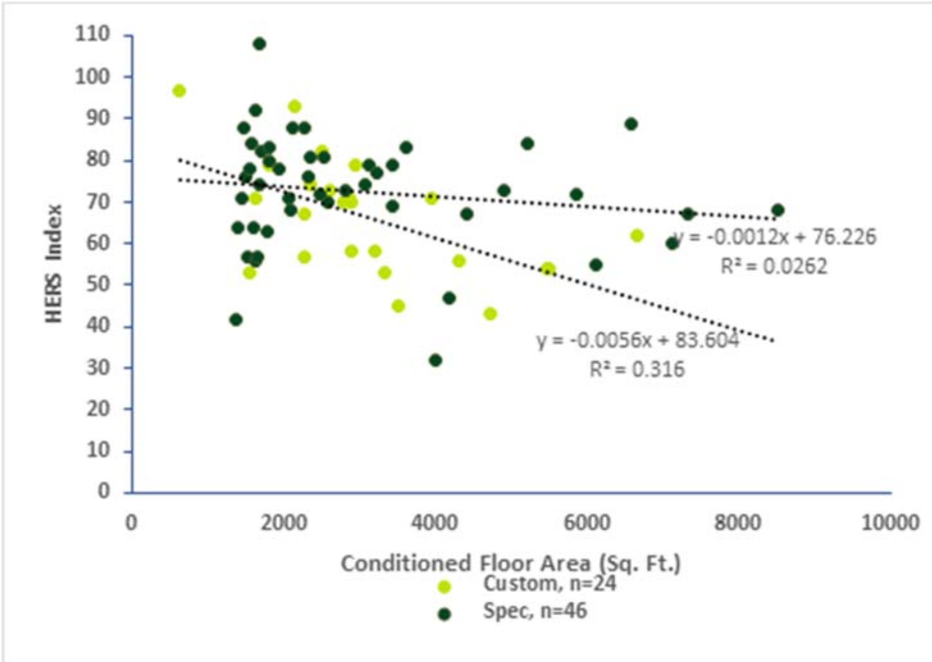
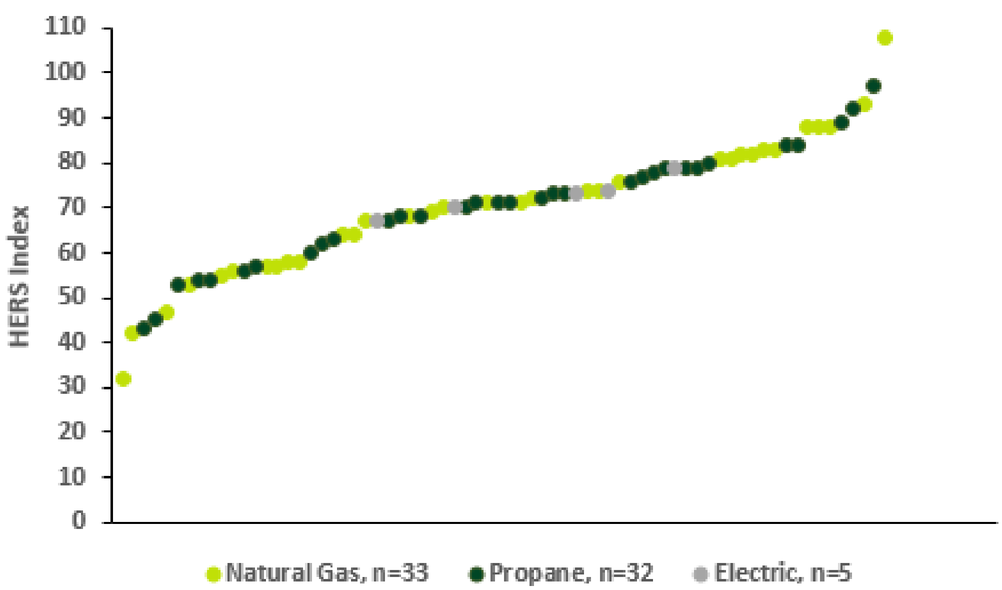


Figure 8 shows the HERS Index values of sampled homes split by primary fuel type. HERS Index values do not vary much based on fuel type. The average HERS Index value is 70.1 for natural gas homes, 70.2 for propane homes, and 72.6 for electric homes. There is no significant difference between natural gas and propane homes. The electric group was too small for significance testing.

Figure 8: HERS Index Values by Primary Fuel Type



4.3 Thermostats

Thermostat types and set points were recorded for each of the 70 homes where full on-site inspections were completed. Recorded thermostats fall into one of three categories: manual, programmable, or Wi-Fi enabled.[42]

Table 28 shows that across all the thermostats in visited homes, programmable thermostats are the most common (70%), followed by Wi-Fi units (16%), and manual units (15%). Custom homes are significantly more likely to have Wi-Fi enabled thermostats and less likely to have manual or programmable thermostats.

Table 28: Distribution of Thermostat Types

Thermostat Type	Custom	Spec	All Homes (Weighted)
n (thermostats)	*61*	*107*	*168*
Programmable	**61%***	**76%***	69%
Manual	**8%***	**20%***	15%
Wi-Fi	**31%***	**5%***	16%

* Statistically significant at the 90% confidence level.

Table 29 shows that nearly three-fourths of inspected homes (71%) have at least one programmable thermostat. Custom homes are significantly more likely than spec homes to have at least one Wi-Fi enabled thermostat (29% as compared to 4%). Spec homes are significantly more likely than custom homes to have manual thermostats, and more likely to have programmable thermostats.

Table 29: Penetration of Thermostat Types in Sampled Homes

Thermostat Type	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Programmable	**67%***	**74%***	71%
Manual	**13%***	**26%***	20%
Wi-Fi	**29%***	**4%***	15%

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

Table 30 shows the number of thermostats in sampled homes (a proxy for the number of zones in the home). There was no significant difference between custom and spec homes. The majority of homes (51%) have two thermostats (or zones). Less than one-fifth of homes (15%) have only one. The analysis of zones does not control for home size. The average number of zones per home is two.

[42] 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 30: Number of Thermostats in Sampled Homes

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
One	8%	20%	15%
Two	46%	54%	51%
Three	29%	11%	18%
Four	17%	7%	11%
Five	--	7%	4%
Six	--	2%	1%

No statistically significant differences at the 90% confidence level.

Participants were asked what temperature they set their thermostats to in both the summer and winter, and auditors inspected the thermostats to confirm this information. 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.

Average set points were determined for summer and winter hours. When all thermostat types were aggregated, no statistically significant differences were found between custom and spec house thermostat set points, as shown in Table 31.[43] The average thermostat set point is 72.4 in the summer and 66.3 in the winter. The overall set point values are presented here rather than 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.

[43] 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.

Table 31: Combined Average Thermostat Set Points

Thermostat Set Points	Custom		Spec		All Homes (Weighted)	
	Summer	Winter	Summer	Winter	Summer	Winter
n (thermostats with relevant set points)	*50*	*60*	*93*	*105*	*143*	*165*
Average	72.8	66.0	72.1	66.5	72.4	66.3
90% CI Lower Bound	72.0	65.3	71.3	66.0	71.8	65.9
90% CI Upper Bound	73.6	66.6	72.8	67.1	72.9	66.7
Standard Deviation	3.4	3.1	4.3	3.4	4.0	3.3
Minimum	66	54	62	58	62	54
10th Percentile	68.5	62.1	66.7	62.0	68.0	62.0
Median	73	66	72	66	72	66
90th Percentile	78.0	69.9	79.0	71.0	78.0	70.4
Maximum	82	72	83	75	83	76

No statistically significant differences at the 90% confidence level

4.4 FAUCETS AND SHOWER HEADS

As shown in Table 32, the average flow rate is 1.5 GPM for bathroom sinks, 1.8 GPM for kitchen sinks, 1.9 GPM for utility sinks, and 2.3 GPM for shower heads.[44] These values include only those faucets with labeled flow rates. For reference, the maximum allowable flow rate under federal law is 2.2 GPM for bathroom and kitchen sinks and 2.5 GPM for shower

[44] 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.

heads.[45] There were no significant differences in flow rates for faucets and shower heads between custom and spec homes.

Table 32: Faucet and Shower Head Flow Rates

Flow Rates (GPM)	Custom	Spec	All Homes (Weighted)
Bathroom Sinks			
n (faucets)	*98*	*180*	*278*
Average	1.5	1.5	1.5
90% CI Lower Bound	1.5	1.5	1.5
90% CI Upper Bound	1.6	1.5	1.5
Standard Deviation	0.2	0.1	0.2
Minimum	1.2	1.2	1.2
10th Percentile	1.5	1.5	1.5
Median	1.5	1.5	1.5
90th Percentile	1.5	1.5	1.5
Maximum	2.5	2.2	2.5
Kitchen Sinks			
n (faucets)	*22*	*50*	*72*
Average	1.7	1.8	1.8
90% CI Lower Bound	1.6	1.7	1.7
90% CI Upper Bound	1.8	1.8	1.8
Standard Deviation	0.2	0.2	0.2
Minimum	1.5	1.5	1.5
10th Percentile	1.5	1.5	1.5
Median	1.8	1.8	1.8
90th Percentile	2.1	2.2	2.2
Maximum	2.2	2.2	2.2
Utility Sinks			
n (faucets)	*11**	*8**	*19*
Average	2.0	1.8	1.9
90% CI Lower Bound	1.8	1.7	1.8
90% CI Upper Bound	2.1	1.8	2.0
Standard Deviation	0.2	0.1	0.2
Minimum	1.8	1.5	1.5
10th Percentile	1.8	1.5	1.8
Median	1.8	1.8	1.8
90th Percentile	2.2	**	2.2
Maximum	2.2	1.8	2.2
Shower Heads			
n (shower heads)	*74*	*129*	*203*
Average	2.3	2.4	2.3
90% CI Lower Bound	2.2	2.3	2.3
90% CI Upper Bound	2.4	2.4	2.4
Standard Deviation	0.3	0.2	0.3
Minimum	1.3	1.8	1.3
10th Percentile	2.0	2.0	2.0
Median	2.5	2.5	2.5
90th Percentile	2.5	2.5	2.5
Maximum	2.6	2.5	2.6

No significant differences at the 90% confidence level. Unknown flow rates excluded from results.
Not tested for statistical significance.
** Value not calculated due to small sample size.

[45] http://www.allianceforwaterefficiency.org/uploadedFiles/US-Water-Product-Standards-Matrix_2016-11-07.pdf

Faucet aerators are nearly ubiquitous; all the inspected homes had at least one (Table 33). Ninety-seven percent of all faucets had aerators installed. All the kitchen sinks had aerators, almost all the bathroom sinks had aerators (97%), and most (86%) of the utility sinks had aerators. There are no significant differences between custom and spec houses in terms of the frequency of aerators.

Table 33: Percentage of Faucets with Aerators

Faucet Type	Custom	Spec	All Homes (Weighted)
n (faucets)	*144*	*274*	*418*
All sinks (n=418)	97%	97%	97%
Kitchen sinks (n=72)	100%	100%	100%
Bathroom sinks (n=278)	98%	97%	97%
Utility sinks (n=19)	86%	86%	86%

No statistically significant differences at the 90% confidence level.

4.5 Home Automation Systems

Home automation systems provide users with the ability to manage and control home devices and appliances via the Internet. Over one-third (38%) of homes have some type of home automation system (Table 34), including systems that control HVAC equipment, home security systems, lighting, audio/visual (AV) components, garage doors, and individual outlets. Custom homes are significantly more likely than spec homes to have these systems, particularly HVAC and home security automation systems. Overall, 21% of homes have home automation systems that can be used to control energy consumption, namely through HVAC, lighting, and outlet controls. Every home that has lighting or outlet controls automation systems also has HVAC automation systems.

Table 34: Distribution of Home Automation System Types by Home Type

Home Automation System Type	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*45*	*69*
Any type	**58%***	**27%***	38%
Home security	**42%***	**20%***	29%
HVAC	**38%***	**9%***	21%
AV	4%	9%	7%
Garage doors	8%	2%	5%
Lighting	8%	--	4%
Individual outlets	8%	--	4%

*Statistically significant at the 90% confidence level.
This information was not collected in one home, and it was excluded from the analysis.
Percentages do not sum to more than 100% because some homes have more than one type of automation system, and some have none.

4.6 Pools and Hot Tubs

Pools and hot tubs were uncommon in sampled homes—they were only present in four homes. Only one home has a heated pool, one has an unheated pool, one has a hot tub, and one home has both a heated pool and a hot tub, resulting in 3% of homes having heated pools, 1% having unheated pools, and 3% having hot tubs (Table 35). There were no heated pools or hot tubs in the spec home sample.

Table 35: Heated Pools and Hot Tubs

Type	Custom	Spec	All Homes
n (homes)	*24*	*46*	*70*
Heated pool	8%	--	3%
Unheated pool	--	2%	1%
Hot tub	8%	--	3%

No statistically significant differences at the 90% confidence level.

5

Section 5 Building Envelope

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

Below is a list of key findings about the shell measures in the sampled homes.

- ***The average R-value of conditioned to ambient walls is R-20.8—just above the 2009 IECC prescriptive standard of R-20[46]. Custom homes are significantly better on average than spec homes (R-22.4 vs. R-19.7).***

- ***The average R-value of flat ceilings is R-36.9 and R-36.7 for vaulted ceilings—just below the 2009 IECC prescriptive standard of R-38.[47] Custom homes have significantly higher flat ceiling average R-values than spec homes (R-39.7 vs. R-35.2).***

- ***The average R-value of frame floors over basements, garages, ambient, and crawl spaces combined (R-27.2) is slightly less than the 2009 IECC requirement of R-30.***

- ***Custom homes are significantly more likely than spec homes to have Grade I installations in walls to ambient conditions (33% vs 11%), flat ceilings (37% vs 18%), and vaulted ceilings (40% vs 8%).***

- ***Fiberglass batts are by far the most common type of insulation in walls, ceilings, and floors. Custom homes are significantly less likely than spec homes to use these in walls, ceilings, and floors.***

- ***The average R-value of foundation walls in conditioned basements is R-10.9 (the maximum is R-21). Sixty percent of homes with conditioned basements meet the 2009 IECC prescriptive code requirement of R-10 continuous or R-13 cavity insulation – five homes (18%) have completely uninsulated foundation walls in conditioned basements, which are far below the prescriptive code threshold.***

- ***On average, 18% of exterior wall area is made up of glazing.***

- ***On average, only 27% of window area is southern facing. Increasing this percentage can result in lower heating and cooling loads, but this requires***

[46] 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.
[47] R-38 is the requirement for flat ceilings and vaulted ceilings, but vaulted ceilings may have up to 500 sq. ft., or up to 20% of total ceiling area (whichever is less) insulated to R-30.

orienting more homes to face north or south (only 27% of sampled homes), rather than east or west (47% of sampled homes).

5.1 Shell Measure Data Collection

A building's envelope is formed by the walls, floors, and ceilings that separate conditioned space from unconditioned or ambient space, along with the homes' windows and doors.[48] Data were collected 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 and garages. The foundation wall, slab floor, and window sections focus on measures found in conditioned space. For details on other types of walls (e.g., walls to garages or basements), ceilings (e.g., hatches), and floors (e.g., floors above ambient space) see Appendix C.

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 were verified using visual inspection or 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 insulation 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. Instances of more than one insulation material per home comprised insignificant areas and are thus not reported in the insulation type tables, but are 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 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

[48] 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.

installations will perform better (lower consumption values, and better HERS Index values) 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 walls that separate conditioned space from ambient space, garages, unconditioned basements, attics, and adjoining units (adiabatic walls).[49] 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, nine out of ten homes (91%) have walls between conditioned space and garages, seven out of ten (71%) have walls between conditioned space and unconditioned basements, and more than half have (58%) have walls between conditioned space and attics. There are no significant differences between custom and spec homes.

Table 36: Above-Grade Wall Location Prevalence

Wall Location	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Conditioned/ambient	100%	100%	100%
Conditioned/garage	88%	93%	91%
Conditioned/unconditioned basement	75%	67%	71%
Conditioned/attic	54%	61%	58%
Conditioned/adiabatic	4%	29%	13%
Unconditioned basement/ambient	38%	22%	28%
Unconditioned basement/garage	17%	20%	18%

No significant differences at the 90% confidence level.

As shown in Table 37, conditioned to ambient walls comprise the vast majority of total envelope wall area across the entire sample (79%). For this reason, this section focuses on these types of walls. Custom homes have a significantly larger share of envelope wall area bordering ambient space than do spec homes (85% vs. 76%) and significantly less adiabatic wall area.

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

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

Wall Location (Across All Wall Area in Sample)	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Conditioned/ambient	**85%***	**76%***	79%
Conditioned/garage	7%	9%	8%
Conditioned/unconditioned basement	5%	5%	5%
Adiabatic	**0%***	**6%***	4%
Conditioned/attic	3%	4%	3%

*Statistically significant difference at the 90% confidence level.

5.2.1 Average Values for All Above Grade Wall Types

R-values. Table 38 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 average R-value for the total envelope wall area across all 70 homes is R-18.2. The average R-value across all conditioned to ambient walls is R-19.8. The data are unweighted and significance testing was not performed since this table is based on square-footage.

Table 38: Average R-Value Across All Wall Area in Sample by Wall Location

Wall Location	Custom	Spec	All Homes (Unweighted)
n (homes)	*24*	*46*	*70*
Conditioned/ambient	21.1	19.1	19.8
Conditioned/garage	20.3	17.8	18.5
Conditioned/unconditioned basement	15.3	6.0	7.7
Conditioned/attic	18.2	17.3	17.6
Across all wall locations	20.6	17.1	18.2

Not tested for statistical significance.
Adiabatic and walls in unconditioned space are excluded from these results.

Table 39 shows that the per-home average R-value for envelope walls is R-19.6.[50] Custom homes have significantly higher wall R-values than spec homes (R-21.8 vs R-18.3). These averages demonstrate that overall, homes generally come close to complying with the 2009

[50] Excludes adiabatic walls (abutting conditioned space) and walls in unconditioned space, such as any above grade walls in unconditioned basements.

(and 2012) IECC requirement of R-20 for walls; however custom homes tend to outperform the prescriptive code standard while spec homes underperform, on average.

Table 39: Wall R-Values
(Conditioned to Ambient, Garage, Basement, and Attic Combined)

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	**21.8***	**18.3***	19.6
90% CI Lower Bound	20.1	17.4	18.7
90% CI Upper Bound	23.6	19.2	20.5
Standard Deviation	5.3	3.7	4.7
Minimum	14	7	7
10th Percentile	19	13	14
Median	20	19	19
90th Percentile	29	21	22
Maximum	36	30	36

*Significantly different at the 90% confidence level.
R-value verified at 73% of homes.
Adiabatic walls and walls in unconditioned space are excluded from these results.

Table 40 compares all exterior walls in conditioned space (excluding adiabatic walls) to the prescriptive requirement of R-20. While only 40% of homes have wall R-values that meet the prescriptive standard, an additional quarter (27%) of homes are just 5% below code at R-19. This is the result of fiberglass batts for 2x6 walls coming in two different standard R-values: R-19 and R-21. Depending on which R-value a builder chooses, a wall will just exceed or just miss the 2009 IECC R-20 requirement. Not meeting the prescriptive code standard does not, however, necessarily mean that the home failed to comply with code. Homes can be below prescriptive code standards for a given measure and still comply on the whole via a performance compliance path.

Table 40 also shows that custom homes perform better than spec homes on average. Custom homes have a significantly larger share of homes with wall R-values that exceed code than do spec homes (59% vs 28%). They also have a significantly larger share of homes that have R-values at least 30% better than code (17% vs 2%).

Table 40: Conditioned Walls–Average R-Value vs. 2009 IECC Prescriptive Requirements
(Conditioned to Ambient, Garage, Basement, and Attic Combined)

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	--	*Worse: 42%**	15%	*Worse: 71%**	9%	*Worse: 60%*
15% to < 30% worse	4%		4%		4%	
5% to 15% worse	30%		41%		20%	
R-19 (< 5% worse)	*8%*		*11%*		*27%*	
R-21 (< 5% better)	*4%*	*Better: 59%**	*7%*	*Better: 28%**	*12%*	*Better: 40%*
5% to 15% better	34%		19%		18%	
15% to < 30% better	4%		--		2%	
30+% better	**17%***		**2%***		8%	

*Statistically significant difference at the 90% confidence level.
Adiabatic walls and walls in unconditioned space are excluded from these results.

5.2.2 Conditioned to Ambient

Exterior walls between conditioned and ambient space have great impact on overall energy efficiency given that they comprise 79% of the total envelope wall area across the entire sample. Table 41 through Table 43 display data on conditioned to ambient wall R-values, framing, insulation type, and insulation grade. Details on the other envelope wall types (e.g., walls to garage, unconditioned basement, and attic) can be found in Appendix C.

R-values. The average R-value for conditioned to ambient walls (20.8) surpasses the 2009 IECC prescriptive standard of R-20 cavity insulation (Table 41). Custom homes have a significantly higher average R-value than spec homes (R-22.4 vs. R-19.7). The 2009 IECC prescriptive standard also allows for homes to pass with at least R-13 cavity insulation combined with at least R-5 continuous insulation – one home complied using this alternative insulation configuration.

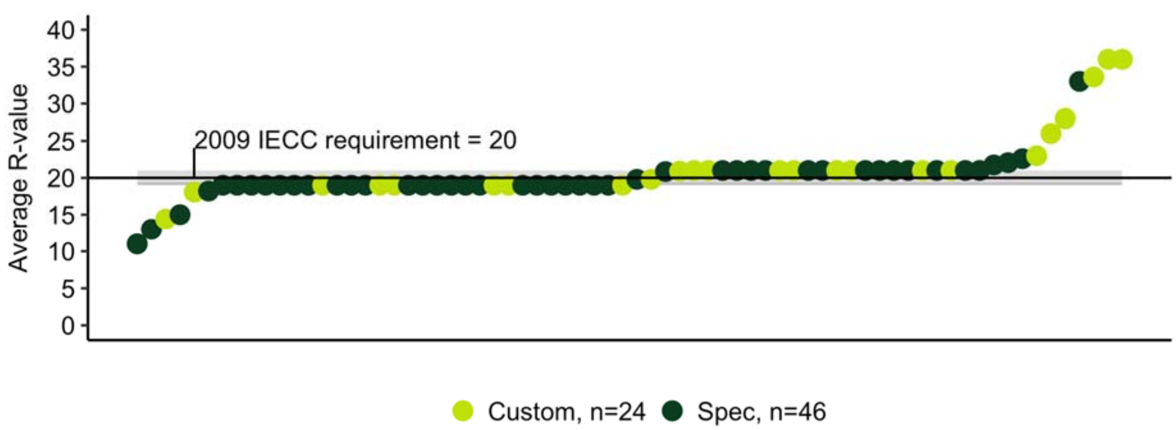
Table 41: Conditioned/Ambient Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	**22.4***	**19.7***	20.8
90% CI Lower Bound	20.5	19.0	20.0
90% CI Upper Bound	24.3	20.4	21.7
Standard Deviation	5.6	2.9	4.4
Minimum	14	11	11
10th Percentile	19	19	19
Median	21	19	19
90th Percentile	32	21	23
Maximum	36	33	36

*Significantly different at the 90% confidence level
R-value verified at 73% of homes.

Figure 9 shows the distribution of average R-values for conditioned/ambient walls by site. The great majority of sites have values close to the 2009 IECC prescriptive requirement of R-20.

Figure 9: Conditioned/Ambient Wall Insulation



Primary Framing. More than nine out of ten homes (93%) have 2x6 framing with studs spaced either 16 or 24 inches apart. Such cavity depths can achieve R-values of up to R-21 using readily available fiberglass batts and up to about R-38.5 using high density polyurethane spray.[51] Six percent of homes have 2x4 framing which creates cavities that are

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

too shallow to meet code using fiberglass batts but can reach code with other foam materials, or when combined with continuous insulation. Finally, one home in the sample has structural insulated panels (SIPS) providing continuous R-36 insulation with empty 2x4 cavities on the interior side.[52]

Table 42: Conditioned/Ambient Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
2x6, 16" on center	87%	93%	91%
2x4, 16" on center	4%	7%	6%
2x6, 24" on center	4%	--	2%
SIPS	4%	--	2%

No significant differences at the 90% confidence level.
One percent of homes had an additional framing type. Only primary framing is included in the table.

Primary Insulation. Table 43 shows the primary insulation and installation grade for conditioned to ambient walls in each home. Fiberglass batts are the most common insulation type by far. Seventy-three percent of homes use only fiberglass batts and an additional 6% use fiberglass batts layered with another insulation material. Custom homes are significantly less likely to use fiberglass batt insulation than spec homes (54% vs 87%) and instead use various blown-in insulations such as spray foam, rock wool, or cellulose. Structural insulated panels (SIPS) were only present in one custom home.

Only 20% of homes have verified Grade I insulation installations. Most homes (75%) have Grade II insulation; however, Grade II was the standard assumption when grades were unverifiable. There is no significant difference between custom and spec homes in insulation installation grade.

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[52] This is a common practice with SIPS, as this additional framing creates space for electrical wiring and other mechanical conduits.

Nine out of ten homes (91% have only cavity insulation, 7% have both cavity and continuous insulation, and 1% has only continuous insulation.

Table 43: Conditioned/Ambient Wall Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Insulation Type			
Fiberglass batts	**54%***	**87%***	73%
Closed-cell spray foam	13%	4%	8%
Open-cell spray foam	8%	4%	6%
Fiberglass batts + Closed-cell spray foam	4%	2%	3%
Cellulose - dense pack	4%	--	2%
Blown-in rock wool	4%	--	2%
SIPS	4%	--	2%
Fiberglass batts + XPS	4%	--	2%
Closed-cell spray foam + polyisoscyanurate	4%	--	2%
Fiberglass batts + polyethylene	--	2%	1%
Insulation Installation Grade			
Grade I	**33%***	**11%***	20%
Grade II	63%	85%	75%
Grade III	--	4%	3%
No cavity insulation	4%	--	1%

*Statistically significant difference at the 90% confidence level.
Insulation type was verified at 100% of homes and installation grade was verified at 40% of homes.

5.3 Ceilings

The following section describes data collected on two different types of ceilings:

- Flat ceilings, which can be thought of as the floors of unconditioned attics
- Vaulted ceilings, which refer to sloped ceilings that have no attic space above and are insulated at the roof deck/rafters

Data were also collected on attic hatches, but since hatches comprise a small percent of total ceiling area, the discussion of hatches is in Appendix C.

Ceiling Types. Table 44 shows the percentage of homes that have each type of ceiling. Nearly nine out of ten homes (89%) have flat ceilings and more than half have vaulted ceilings

(58%) and hatches (60%). Custom homes are significantly less likely than spec homes to have flat ceilings (79% vs 96%) and hatches (46% vs 70%).

Table 44: Ceiling Type Prevalence

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Flat	**79%***	**96%***	89%
Vaulted	63%	54%	58%
Hatch	**46%***	**70%***	60%

* Statistically significant difference at the 90% confidence level.

Across the entire sample, 71% of the total ceiling area is flat attic, 29% is vaulted and less than one percent is attic hatch. There is no significant difference between custom and spec homes (Table 45).

Table 45: Percent of Total Ceiling Area in Sample by Ceiling Type

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Flat attic	65%	75%	71%
Vaulted	35%	25%	29%
Hatch	<1%	<1%	<1%

There are no statistically significant differences at the 90% confidence level.

R-values. Table 46 shows the average R-value for the total ceiling area and for the total area of each ceiling type across the entire sample. One home with unknown R-values is excluded. The average R-value for the total ceiling area across all 69 homes is R-34.5. The average R-value across the ceiling square footage in the sample is R-35.8 for flat ceiling area and R-37.3 for vaulted ceiling area. The data are unweighted and significance testing was not performed since this table is based on square-footage.

Table 46: Average R-Value Across All Ceiling Area in Sample by Ceiling Type

Ceiling Type	Custom	Spec	All Homes (Unweighted)
n (homes)	*24*	*45*	*69*
Flat	38.3	34.6	35.8
Vaulted	37.9	36.8	37.3
Hatch	3.7	1.9	1.6
Across all ceiling types	37.4	33.0	34.5

Not tested for statistical significance.

Table 47 shows the average per home R-value for all ceiling types. The per-home average ceiling R-value of R-36 is less than the 2009 IECC requirement of R-38.[53] Custom homes have a significantly higher average R-value (R-39.2) than spec homes (R-33.6).

Table 47: Ceiling R-Values (Flat, Vaulted, and Hatch Combined)

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*45*	*69*
Average	**39.2***	**33.6***	36.0
90% CI Lower Bound	36.8	31.8	34.5
90% CI Upper Bound	41.7	35.3	37.5
Standard Deviation	7.3	7.0	7.6
Minimum	22	18	18
10th Percentile	30	27	27
Median	38	34	36
90th Percentile	48	40	44
Maximum	51	62	62

*Significantly different at the 90% confidence level.
R-values were verified at 96% of homes.
One home lacked documentation and attic access and was not included in the table.

Table 48 compares the average ceiling R-value per home with the 2009 IECC prescriptive requirement of R-38. Just over one-third of homes (36%) have average ceiling R-values that are at or better than code. Custom homes have better compliance than spec homes. Custom homes have significantly fewer homes that are worse than code (42% vs 72%), more homes that are better than code (50% vs 28%), and more homes that are fifteen to thirty percent better than code (17% vs 0%). As with walls, not meeting the prescriptive code requirement

[53] R-49 in 2012 IECC.

does not necessarily mean that homes fail to comply with code; homes can comply based on a performance compliance path for the whole building shell.

Table 48: Ceilings–Average R-Value vs. 2009 IECC Prescriptive Requirements (Flat, Vaulted, and Hatch Combined)

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	4%	*Worse: **42%****	6%	*Worse: **72%****	6%	*Worse: 63%*
15% to < 30% worse	**13%***		**36%***		28%	
<15% worse	25%		30%		29%	
At code	*8%*		*7%*		*7%*	
<15% better	25%	*Better: **50%****	10%	*Better: **28%****	17%	*Better: 29%*
15% to < 30% better	**17%***		**0%***		7%	
30+% better	8%		2%		5%	

*Statistically significant difference at the 90% confidence level.

5.3.1 Flat Ceilings

Flat ceilings comprise 71% of total ceiling area across the entire sample, and are therefore crucial in determining energy efficiency. Table 49 through Table 51 and Figure 10 summarize the R-value, primary framing and primary insulation characteristics of the flat ceilings of sampled homes.

R-values. The average per home R-value of flat ceilings (R-36.9) is slightly less than the 2009 IECC prescriptive code requirement of R-38. Custom homes have a significantly higher average R-value (R-39.7) than spec homes (R-35.2). The average R-values of flat ceilings in custom homes meet the 2009 IECC prescriptive requirement while flat ceilings in spec homes do not.

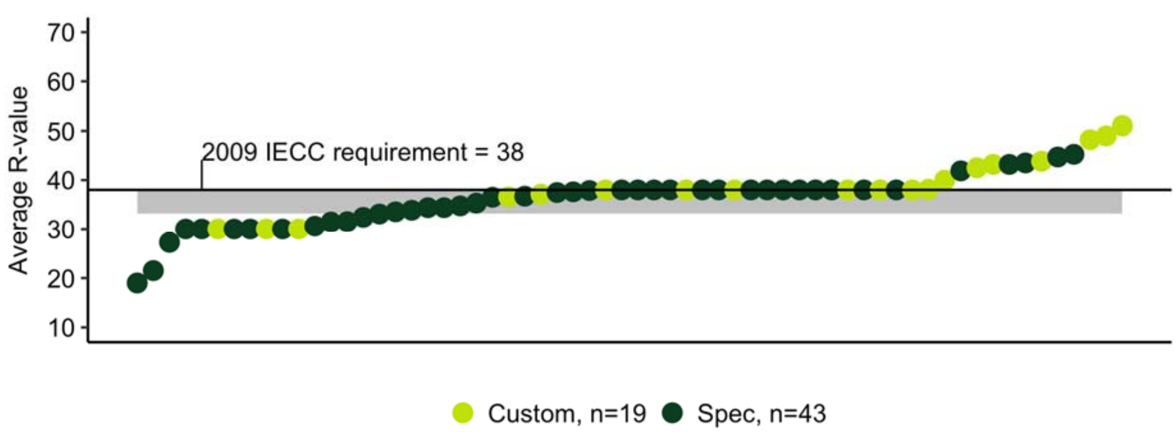
Table 49: Flat Ceiling R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*19*	*43*	*62*
Average	**39.7***	**35.2***	36.9
90% CI Lower Bound	37.7	33.8	35.7
90% CI Upper Bound	41.8	36.6	38.2
Standard Deviation	5.5	5.5	5.9
Minimum	30	19	19
10th Percentile	35	30	30
Median	38	37	38
90th Percentile	48	41	43
Maximum	51	45	51

* Statistically significant difference at the 90% confidence level.
R-values were verified at 95% of homes.
One home is excluded from the table because its R-value was undeterminable.

Figure 10 shows the average R-value of flat ceiling insulation at each sampled home. There is a similar share of custom and spec homes with an R-38 average, but it is clear that there are more spec homes with averages below the IECC requirement.

Figure 10: Flat Ceiling Insulation



Primary Framing. Table 50 shows the primary framing dimensions and spacing for flat ceilings. More than one-fourth (29%) of homes with flat ceilings use primarily 2x10 framing in their flat ceilings, either in 16 inch or 24 inch on-center (OC) spacing, 19% use 2x4 framing and 17% use 2x8 framing. There is no significant difference between custom and spec homes.

Table 50: Flat Ceiling Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*19*	*44*	*63*
2x10, 16” OC	31%	23%	26%
2x4, 24” OC	5%	22%	16%
2x8, 16” OC	11%	18%	15%
2x6, 24” OC	21%	5%	11%
2x12, 16” OC	5%	11%	9%
I-Joist	16%	--	6%
2x6, 16” OC	--	9%	6%
2x10, 24” OC	--	5%	3%
2x4, 16” OC	--	5%	3%
2x12, 24” OC	5%	2%	3%
2x8, 24” OC	5%	--	2%

No statistically significant differences at the 90% confidence level.
Fourteen percent of homes had an additional framing type not included in this table.

Primary Insulation. Three-fifths (60%) of homes with flat ceiling use fiberglass batts as the primary insulation material in those ceilings. Blown-in fiberglass insulation is the second most frequent flat ceiling insulation type, present at 23% of applicable homes. An additional 3% have fiberglass batt insulation covered by blown-in fiberglass. There is no significant difference between custom and spec homes in terms of insulation material (Table 51).

Flat ceiling insulation is properly installed to Grade I at one-fourth (25%) of homes. Significantly more custom homes have Grade I installation than do spec homes (37% vs 18%). Conversely, spec homes are more likely to have Grade II insulation than custom homes (32% vs 59%).

Table 51:Flat Ceiling Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*19*	*44*	*63*
Insulation Type			
Fiberglass batts	63%	59%	60%
Blown-in fiberglass	21%	25%	23%
Loose-blown cellulose	5%	5%	5%
Open-cell spray foam	5%	5%	5%
Blown-in Fiberglass + fiberglass batts	--	5%	3%
Closed-cell spray foam	5%	--	2%
Unknown	--	2%	1%
Insulation Installation Grade			
Grade I	**37%***	**18%***	25%
Grade II	**32%***	**59%***	48%
Grade III	32%	23%	26%

* Statistically significant difference at the 90% confidence level.
Insulation type was verified at 98% of homes and installation grade verified at 89% of homes.

5.3.2 Vaulted Ceilings

Vaulted ceilings comprise 29% of total ceiling area across the entire sample. Table 52 through Table 54 and Figure 11 summarize the R-values, primary framing and primary insulation characteristics of vaulted ceilings.

R-values. The average vaulted ceiling R-value (R-36.7) is less than the 2009 IECC prescriptive requirement of R-38.[54] There is no significant difference between custom and spec homes.

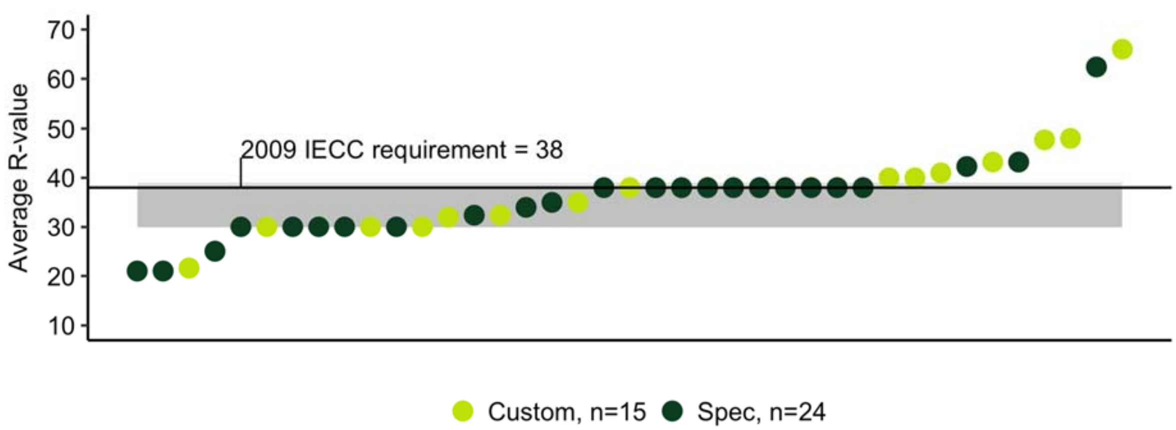
[54] This comparison is made for reference only, because (1) homes can fail to meet certain prescriptive standards and still comply based on performance compliance paths, and (2) vaulted ceilings may have up to 500 sq. ft., or up to 20% of ceiling area (whichever is less) insulated to R-30. R-38 is increased to R-49 in the 2012 IECC.

Table 52: Vaulted Ceiling R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*15*	*24*	*39*
Average	38.3	35.3	36.7
90% CI Lower Bound	33.8	32.5	34.2
90% CI Upper Bound	42.8	38.0	39.1
Standard Deviation	10.5	8.3	9.3
Minimum	22	21	21
10th Percentile	30	27	29
Median	38	38	38
90th Percentile	48	41	44
Maximum	66	62	66

No significant differences at the 90% confidence level.
R-values verified at 80% of homes.
One home with unknown R-values is excluded.

Figure 11: Vaulted Ceiling Insulation



Primary Framing. As shown in Table 53, the most common framing for vaulted ceilings is 2x10 (41% of applicable homes), followed by 2x12 (34%), and 2x8 (19%). There is no significant difference in framing between custom and spec homes.

Table 53: Vaulted Ceiling Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*15*	*25*	*40*
2x10, 16" OC	47%	32%	39%
2x12, 16" OC	20%	32%	27%
2x8, 16" OC	13%	24%	19%
2x12, 24" OC	7%	8%	7%
SIPS	7%	--	3%
2x6, 24" OC	7%	--	3%
2x10, 24" OC	--	4%	2%

No significant differences at the 90% confidence level.

Primary Insulation. Table 54 shows that fiberglass batts are the most common primary insulation type for vaulted ceilings (52% of applicable homes), followed by open-cell spray foam (20%), and closed-cell spray foam (9%). Custom homes are significantly less likely than spec homes to have fiberglass batt insulation (27% vs 72%), and significantly more likely to have closed-cell spray foam (20% vs 0%).

Of homes with vaulted ceilings, one-fourth (23%) have Grade I installation, half (49%) have Grade II, and another fourth (26%), Grade III. Custom homes are significantly more likely to have Grade I installation than spec homes (40% vs 8%).

Table 54: Vaulted Ceiling Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*15*	*25*	*40*
Insulation Type			
Fiberglass batts	**27%***	**72%***	52%
Open-cell spray foam	20%	20%	20%
Closed-cell spray foam	**20%***	**0%***	9%
Blown-in fiberglass	7%	4%	5%
Blown-in rock wool	7%	--	3%
Dense-pack cellulose	7%	--	3%
SIPS	7%	--	3%
Fiberglass batts + XPS	7%	--	3%
Unknown	--	4%	2%
Insulation Installation Grade			
Grade I	**40%***	**8%***	23%
Grade II	40%	56%	49%
Grade III	13%	36%	26%
No cavity insulation	7%	--	3%

* Statistically significant difference at the 90% confidence level.
Insulation type verified at 85% of homes and installation grade verified at 57% of homes.

5.4 Frame Floors

The auditing process involved collecting data on the frame floors over unconditioned spaces and over ambient conditions. Ninety-two percent of homes have such frame floors serving as the thermal boundary. The other homes either have slab floors or conditioned basements. Data were collected on the following types of frame floor area:

- 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 crawl spaces

Frame Floor Types and Locations. Of the 65 homes with frame floors serving as the thermal boundary (floors), 80% have floors over unconditioned basements, more than two-thirds (69%) have floors over garage, nearly half (45%) have floors over ambient space, and only 6% have floors over enclosed crawl spaces (Table 55).

Table 55: Frame Floor Location Prevalence

Floor Location	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*42*	*65*
Conditioned/unconditioned basement	87%	74%	80%
Conditioned/garage	61%	74%	69%
Conditioned/ambient	48%	43%	45%
Conditioned/enclosed crawl space	4%	7%	6%

No significant differences at the 90% confidence level.

Floors over unconditioned basement make up the majority (64%) of total floor area across the entire sample, followed by floors over garages (30%), enclosed crawl spaces (4%) and ambient conditions (2%) (Table 56).

Table 56: Percent of Total Floor Area in Sample by Floor Location

Floor Location (Across All Floor Area in Sample)	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*42*	*65*
Conditioned/unconditioned basement	67%	62%	64%
Conditioned/garage	29%	31%	30%
Conditioned/enclosed crawl space	2%	5%	4%
Conditioned/ambient	2%	2%	2%

No significant differences at the 90% confidence level.

R-values. Table 57 shows the average R-values for each floor type across the entire sample. The average R-value for all floor types is R-21.0. All of the floors types have an average below the 2009 IECC prescriptive code requirement of R-30.[55] Uninsulated floors over unconditioned basements bring down the overall average. There is no statistical difference between custom and spec homes.

[55] No change to requirement in the 2012 IECC.

Table 57: Average R-Value Across All Frame Floor Area in Sample by Floor Location

Floor Location	Custom	Spec	All Homes (Unweighted)
Conditioned/unconditioned basement	13.9	23.7	18.7
Conditioned/garage	28.8	27.0	27.6
Conditioned/ambient	27.7	27.2	27.4
Conditioned/enclosed crawl space	30.0	22.6	23.5
Across all floor locations	16.7	24.6	21.0

Not tested for statistical significance.

The average per-home R-value of floors when combining all locations is R-27.2; there is no significant difference between custom and spec homes (Table 58). The average R-value was negatively affected by one home with a completely uninsulated basement ceiling (and uninsulated foundation walls) and three homes with partially uninsulated basement ceilings.

Note that the average reported in Table 57 (21.0) is quite different from the average in Table 58 (27.2). Table 57 looks at all the floors across the sample as if they were one giant floor, while Table 58 presents the average R-value on a per-home basis (it is an average of averages). For Table 58, the average R-value is calculated for each home and then those values are used to calculate a per-home average. For this reason, homes with low insulation values and large floors areas have a stronger effect on the overall average in Table 57 than they do in Table 58, where each home is a unit of analysis.

Table 58: Frame Floor R-Values

(Floors over Basement, Garage, Ambient, and Crawl Space Combined)

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*42*	*65*
Average	27.9	26.7	27.2
90% CI Lower Bound	24.6	24.9	25.5
90% CI Upper Bound	31.3	28.4	28.9
Standard Deviation	9.8	6.8	8.1
Minimum	0	13	0
10^{th} Percentile	19	19	19
Median	30	30	30
90^{th} Percentile	36	30	35
Maximum	54	43	54

No significant differences at the 90% confidence level.
R-value verified at 86% of homes.

While the average per home R-value for all floor locations is slightly below the 2009 IECC prescriptive code requirement of R-30[56], most homes (53%) have average R-values that are at or better than that code standard, as shown in Table 59. A much greater share of homes has frame floor R-values that are 30% or more below code than is the case for above-grade walls or ceilings (30% vs. 9% for above-grade walls and 6% for ceilings). As with walls and ceilings, not meeting the prescriptive code requirement does not necessarily mean that a home does not comply with code, as it could still comply via a performance path.

Table 59: Frame Floor – Average R-Value vs. 2009 IECC Prescriptive Requirements
(Floors over Basement, Garage, Ambient, and Crawl Space Combined)

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	26%	*Worse: 39%*	33%	*Worse: 52%*	30%	*Worse: 47%*
15% to < 30% worse	4%		5%		5%	
<15% worse	9%		14%		12%	
At code	***21%***		***31%***		***27%***	
<15% better	26%	*Better: 39%*	7%	*Better: 16%*	15%	*Better: 26%*
15% to < 30% better	9%		7%		8%	
>30 % better	4%		2%		3%	

No significant differences at the 90% confidence level.

5.4.1 Conditioned to Unconditioned Basement Frame Floors

This section describes floors over unconditioned basements, the most prevalent type of frame floor in the sampled homes. For data on the other types of floors (e.g., floors over ambient, and crawl spaces) see Appendix C.

R-values. On a per-home basis, floors over unconditioned basements have an average R-value of R-25.6 (Table 60). There is no significant difference between custom and spec homes.

[56] 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.

Table 60: Conditioned/Unconditioned Basement Frame Floor R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	20	31	51
Average	26.9	24.5	25.6
90% CI Lower Bound	23.2	22.5	23.7
90% CI Upper Bound	30.7	26.4	27.6
Standard Deviation	10.2	6.7	8.5
Minimum	0	13	0
10th Percentile	19	16	19
Median	30	29	30
90th Percentile	31	30	30
Maximum	54	38	54

No significant differences at the 90% confidence level.
Auditors verified R-values for 96% of floors above unconditioned basements by visual inspection.

The distribution of average R-values for frame floors over unconditioned basements in Figure 12 shows that most sites have frame floors with one of two R-values, R-30 or R-19. R-19 fiberglass insulation is sized to fit in 2x6 cavities, but few homes have 2x6 floor framing (see Table 62), indicating that the framing type did not drive the choice to use below-code insulation.

Figure 12: Conditioned/Unconditioned Basement Frame Floor Insulation

Table 61 compares the R-values of floors over unconditioned basements to the 2009 IECC prescriptive requirement of R-30. More than half (52%) of all conditioned to unconditioned floors meet the prescriptive code requirement.

Table 61: Conditioned/Unconditioned Basement Frame Floors – Average R-value vs. 2009 IECC Prescriptive Requirements

Avg. R-Value vs. Code	Custom		Spec		All Homes (Weighted)	
30+% worse	30%	*Worse: 40%*	45%	*Worse: 54%*	39%	*Worse: 49%*
15% to < 30% worse	5%		3%		4%	
<15% worse	5%		6%		6%	
At code (R-30)	***35%***		***32%***		***34%***	
<15% better	15%	*Better: 25%*	10%	*Better: 13%*	12%	*Better: 18%*
15% to < 30% better	5%		3%		4%	
>30% better	5%		--		2%	

No significant differences at the 90% confidence level.

Primary Framing. I-joists[57] are the most common framing type in floors above unconditioned basements for all homes (57%). Custom homes are significantly more likely to have I-joist framing (75%) than spec homes (39%).

Table 62: Conditioned/Unconditioned Basement Frame Floor Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	20	31	51
I-joist	**75%***	**39%***	57%
2x10, 16" OC	20%	32%	27%
2x8, 16" OC	5%	13%	9%
2x10, 12" OC	--	6%	3%
2x12, 16" OC	--	6%	3%
2x6, 16" OC	--	3%	2%

*Statistically significant difference at the 90% confidence level.
Six percent of homes had an additional framing not included in this table.

As shown in Table 63, the vast majority (92%) of homes with conditioned to unconditioned basement floors are insulated with fiberglass batts. Every spec home has fiberglass batt insulation in the basement ceiling while significantly fewer custom homes (80%) have the

57 "I-joists" are a type of high-strength, engineered structural framing that resembles a capital "I" when viewed in cross-section. Two pieces of wood serve as flanges, which are joined by a web, often made of oriented strand board or something similar.

same. Most homes have Grade III insulation installations (55%) followed by Grade II (39%). There is no significant difference between custom and spec homes in installation grades.

Table 63: Conditioned/Unconditioned Basement Frame Floor Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*31*	*51*
Insulation Type			
Fiberglass batts	**80%***	**100%***	92%
Closed-cell spray foam	5%	--	2%
Open-cell spray foam	5%	--	2%
Mineral wool batts	5%	--	2%
None	5%	--	2%
Insulation Installation Grade			
Grade I	10%	--	5%
Grade II	35%	42%	39%
Grade III	50%	58%	55%
No cavity insulation	5%	--	2%

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

5.4.2 Conditioned to Garage Frame Floor

Floors over garages comprise 30% of the total floor area in the sample. R-values for floors above garages were only verified for 82% of homes with such floors since the finishing of garage limited access. Floors above garages have an average R-value of 29.3 which is just under the 2009 IECC prescriptive requirement of R-30. There is no significant difference between custom and spec homes (Table 64).

Table 64: Conditioned/Garage Frame Floor R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*14*	*31*	*45*
Average	30.0	28.9	29.3
90% CI Lower Bound	26.0	27.0	27.5
90% CI Upper Bound	33.9	30.9	31.2
Standard Deviation	9.1	6.6	7.5
Minimum	19	13	13
10th Percentile	19	19	19
Median	30	30	30
90th Percentile	36	38	38
Maximum	54	43	54

No significant differences at the 90% confidence level.

Similarly, to floors above basements, the most common framing for floors above garages are I-joists (45%), followed by 2x10 16” OC (34%). Every home has large enough framing to provide R-30 insulation using fiberglass batts with a finished garage ceiling (Table 65).

Table 65: Conditioned/Garage Frame Floor Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*14*	*31*	*45*
I-Joist	57%	39%	45%
2x10, 16” OC	29%	39%	34%
2x12, 16” OC	14%	13%	13%
2x8, 16” OC	--	6%	4%
2x10, 12” OC	--	3%	2%

No significant differences at the 90% confidence level.

Overall, 82% of conditioned to garage floors have fiberglass batt insulation. Spec homes are significantly more likely than custom homes to have fiberglass batt insulation (94% to 64% respectively) (Table 66). Most floors over garages (55%) have Grade II insulation installations followed by Grade III (36%). Most floors over garages (55%) have Grade II insulation installations, followed by Grade III (36%).

Table 66: Conditioned/Garage Frame Floor Primary Insulation Type and Grade

Wall Location	Custom	Spec	All Homes (Weighted)
n (homes)	*14*	*31*	*45*
Insulation Type			
Fiberglass batts	**64%***	**94%***	82%
Open-cell spray foam	21%	6%	12%
Closed-cell spray foam	7%	--	3%
Mineral wool batts	7%	--	3%
Insulation Installation Grade			
Grade I	14%	3%	7%
Grade II	57%	55%	55%
Grade III	29%	42%	36%

*Statistically significant difference at the 90% confidence level.
Insulation type was verified at 98% of homes and grade was verified at 62% of homes.

5.5 Foundation Walls

The foundation wall analysis presented below focuses only on homes with foundation walls in conditioned space. The 2009 IECC prescriptive code requires that foundation walls in conditioned space be insulated to R-10 with continuous insulation or to R-13 with cavity insulation.[58] Unconditioned basements do not have to be insulated; the frame floor above the basement is usually the thermal boundary in such cases.

While it is straightforward to assess the insulation on the interior of foundation walls, exterior foam board insulation can be difficult to verify because it is frequently cut off near grade, rather than continuing up to the siding. However, exterior insulation is rare in general and none was observed among sampled homes.

5.5.1 Conditioned Basement Walls

R-values. The average R-value is R-10.9, below the 2009 IECC prescriptive code requirement for conditioned basement foundation walls (R-13 cavity insulation, or R-10 continuous insulation). Five homes with conditioned basements (two spec, three custom) were uninsulated (Table 67).

Table 67: Foundation Wall R-Values (Conditioned Basements)

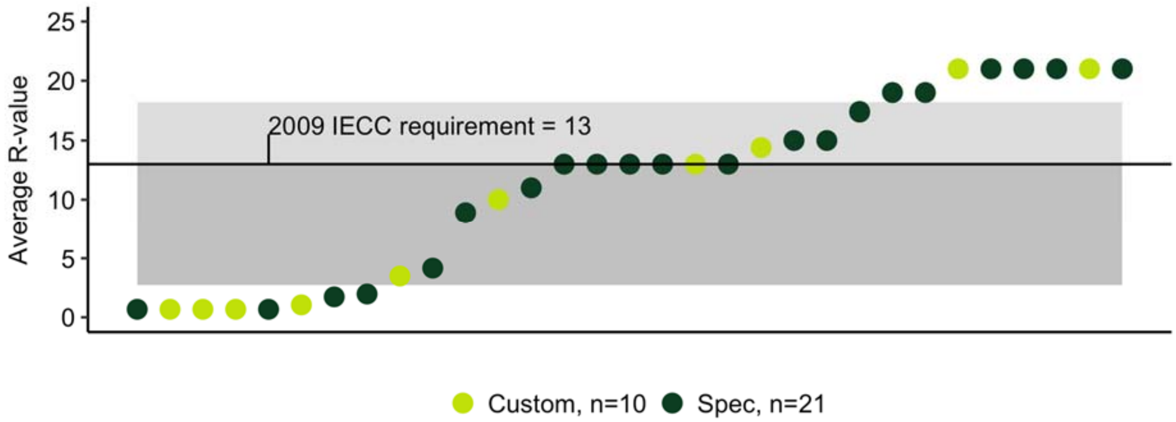
R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*10*	*21*	*31*
Average	8.4	12.5	10.9
90% CI Lower Bound	3.4	9.9	8.5
90% CI Upper Bound	13.4	15.2	13.3
Standard Deviation	8.6	7.1	7.8
Minimum	0	0	0
10th Percentile	0	0	9
Median	7	13	13
90th Percentile	21	21	21
Maximum	21	21	21

No significant differences at the 90% confidence level.

Figure 13 shows that the below-code average R-value for foundation walls in conditioned basements is driven by the large share of homes with no or very little foundation wall insulation: ten of the 31 sites have an average R-value less than R-5.

[58] The 2012 IECC requires either R-15 continuous or R-19 in the cavity.

Figure 13: Foundation Wall Insulation (Conditioned Basements)



Sixty percent of homes meet or exceed the 2009 IECC prescriptive code requirement for foundation wall insulation in conditioned basements (Table 68). Only 6% of foundation wall area was insulated with continuous insulation, therefore the R-13 cavity insulation portion of the R-10/13 requirement is most relevant when evaluating insulation levels.[59]

Table 68: Foundation Walls in Conditioned Basements–Average R-Values vs. 2009 IECC Prescriptive Requirements

Avg. R-Value vs. Code	Custom	Spec	All Homes (Weighted)
n (homes)	*10*	*21*	*31*
Below code (<R10/13)	50%	33%	40%
At code (=R10/13)	20%	24%	22%
Above code (>R10/13)	30%	43%	38%

No significant differences at the 90% confidence level.

Fiberglass batts are the primary foundation wall insulation in 61% of homes (Table 69), accounting for 54% of wall area. However, spray foam covers more area in custom homes than fiberglass batts (43% and 36% respectively). Although one third of custom homes have uninsulated conditioned basements, only 10% of foundation wall area in custom homes is uninsulated compared to 21% in spec homes; 17% overall. This disparity is due to the nature of these spaces (e.g., small mudrooms versus larger living spaces.)

59 Because all continuous insulation was rigid foam board (RFB), no RFB was used in cavities, and no homes used both cavity and continuous insulation. Continuous insulation statistics are the same as those for RFB in Table 69.

Table 69: Foundation Wall Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*10*	*21*	*31*
Fiberglass batt	**30%***	**81%***	61%
Rigid foam board	10%	--	4%
Spray foam	30%	5%	15%
None	30%	14%	21%
Insulation Installation Grade			
n (homes)	*6***	*19***	*25*
Grade I	30%	5%	15%
Grade II	30%	81%	61%
Grade III	--	5%	3%
No cavity insulation	40%	10%	22%

*Significantly different at the 90% confidence level.
**Not tested for statistical significance.

5.5.2 Unconditioned Basement Foundation Walls

Code does not require foundation walls in unconditioned basements to be insulated. It is therefore unsurprising that all but one home with an unconditioned basement space had uninsulated foundation walls. The exception was a custom home in which both the conditioned and unconditioned basement areas were insulated with R-10 of rigid foam board.

5.6 SLABS

Verification of the presence, and especially R-value, of slab insulation post construction is often impossible. However, in some cases documentation was available via building plans or conversations with those involved in the building's construction. The following section describes information about the slabs in conditioned spaces, either for homes with slab on grade construction, or homes with conditioned basements.

The 39 homes with slab floors have a mix of on grade, mixed grade, and below grade slab locations, with no significant differences between custom and spec homes (Table 70).

Table 70: Slab Floor Location

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*26*	*39*
On grade	15%	38%	29%
Mixed grade	31%	31%	31%
Below grade	54%	31%	40%

No significant differences at the 90% confidence level.

The 2009 IECC prescriptive code[60] requires that on grade slabs have a four-foot-wide band of R-10 insulation under the perimeter of the slab. Only three homes (one custom, two spec) had fully documented under-slab insulation. One spec home had the required R-10, and the other had R-7.5 cavity insulation in a sub-floor built atop the slab. The custom home had R-7 insulation. Plans for another custom home and two spec homes indicated the presence of slab insulation, but not the R-value, which was assumed to be R-10. Documentation for another eight homes (four custom, four spec) indicated no insulation was present. These observations are summarized in Table 71.

Table 71: Slab Floors–Average R-Values vs. 2009 IECC Prescriptive Requirements

Avg. R-Value vs. Code	Custom	Spec	All Homes (Weighted)
n (homes)	*6*	*8*	*14*
Below code (<R10)	83%	63%	73%
At code (=R10)	17%	38%	27%
Above code (>R10)	--	--	--
Average R-value	2.8±3	4.7±3	3.8±2

Not tested for statistical significance.

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 prescriptive code. There were only two sampled homes with heated slabs, both custom built. One was verified to have perimeter and under slab insulation of unknown R-value, and the other was shown to be uninsulated in photos of the home's construction.

5.7 WINDOWS

This section describes the characteristics of door and window glazing in conditioned walls. When documentation of glazing properties was unavailable, a reflection test was used to determine if the windows had a low-E coating. Similarly, the presence of injection plugs in the frame between the panes of glass was used to infer the presence of argon or similar insulating gas fills. Due to the imprecision of this method—manufacturing techniques vary—the proportion of argon windows may be under-reported.

Custom homes are significantly more likely to have wood-framed windows and less likely to have vinyl windows than spec homes. Table 72 also shows that metal and especially fiberglass-framed windows are uncommon.

[60] Same requirement in the 2012 IECC.

Table 72: Presence of Window Frame Types

Frame Type	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*47*	*70*
Vinyl	**63%***	**89%***	78%
Wood	**79%***	**57%***	66%
Metal	13%	13%	13%
Fiberglass	4%	2%	3%

*Significantly different at the 90% confidence level.

Per Table 73, double pane low-E windows are the most common construction in both custom and spec homes – found in 97% of all sampled homes – however, custom homes are significantly more likely to feature argon-filled double pane low-E windows (21% of custom homes vs. 2% of spec homes).

Table 73: Presence of Glazing Types

Glazing Type	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*47*	*70*
Double pane, low-E	96%	98%	97%
Double pane	50%	57%	54%
Double pane, low-E, argon	**21%***	**2%***	10%
Triple pane, low-E, argon	4%	2%	3%
Single pane	--	2%	1%

*Significantly different at the 90% confidence level.

In Table 74, which describes the proportion of window types across all sampled homes, it becomes clear that plain double pane windows represent a small fraction of overall glazing, despite being present in 54% of homes. This disparity is due to the frequent use of uncoated glass for door lights.

Table 74: Percent of Total Glazing Area in Sample by Glazing Type

Glazing Type	Custom	Spec	All Homes (Weighted)
n (homes)	*23*	*47*	*70*
Double pane, low-E	**72%***	**93%***	83%
Double pane, low-E, argon	**22%***	**1%***	11%
Double pane	5%	5%	5%
Triple pane, low-E, argon	1%	--	1%
Single pane	--	<1%	<1%

*Significantly different at the 90% confidence level.

The 2009 IECC prescriptive maximum U-factor for windows is 0.35, and there is no solar heat gain coefficient requirement.[61] Documented U-factor and SHGC information was only available for seven homes (four custom, three spec), typically for only one or two windows. Although it is best practice to select the most appropriate window characteristics for each window's orientation, it is common 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 only 8% of sampled window area – are summarized in Table 75.

Table 75: Documented Window Property Statistics

	All Homes (Unweighted)	
	U-factor	SHGC
n (homes)	*7*	
Average	0.31	0.33
90% CI Lower Bound	0.29	0.26
90% CI Upper Bound	0.33	0.39
Standard Deviation	0.03	0.09
Minimum	0.27	0.23
10th Percentile	0.28	0.24
Median	0.30	0.31
90th Percentile	0.34	0.45
Maximum	0.36	0.45

Not tested for statistical significance.

When no efficiency information was available, the REM/Rate defaults in Table 76 were used for building energy models. However, it is worth noting that these values are based on outdated standards; window technology has improved since these values were developed.[62] For instance, it has been estimated that in 2010, 80% of the market had windows with U-

[61] The 2012 IECC maximum is 0.32.

[62] They are based on Table 27-5 "Overall Coefficients of Heat Transmission of Various Fenestration Products (Btu/h · ft^2 · °F)" in the 1993 edition of ASHRAE Fundamentals.

factors of 0.35, but using REM/Rate default values results in only 65% of the sample having a U-factor of 0.36 or better (Table 76).[63]

Table 76: REM/Rate Default Values vs. 2009 IECC Code Requirement

Window Type	U-factor	SHGC	Share of Total Area in Sample (Weighted)
Vinyl frame, double pane, low-E	0.36	0.45	54%
Wood frame, double pane low-E	0.39	0.46	28%
Vinyl frame, double pane low-E, argon	0.33	0.45	6%
Wood frame, double pane low-E, argon	0.36	0.45	5%
Wood frame, double pane	0.49	0.58	3%
Vinyl frame, double pane	0.46	0.57	2%
Fiberglass frame, double pane, low-E	N/A	N/A	1%
2009 IECC code requirement	*0.35*	*N/A*	*N/A*

5.7.1 Glazing Percentage

In Table 77, glazing percentages are calculated by dividing total glazing area of doors and windows by the total conditioned/ambient wall area of the home.[64]

Table 77: Glazing Percentage of Exterior Wall Area

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	18.2%	17.9%	18.0%
90% CI Lower Bound	16.3%	16.7%	17.0%
90% CI Upper Bound	20.3%	19.0%	19.0%
Standard Deviation	5.6%	4.5%	5.0%
Minimum	8%	10%	8%
10th Percentile	13%	13%	13%
Median	18%	17%	17%
90th Percentile	29%	24%	24%
Maximum	30%	36%	36%

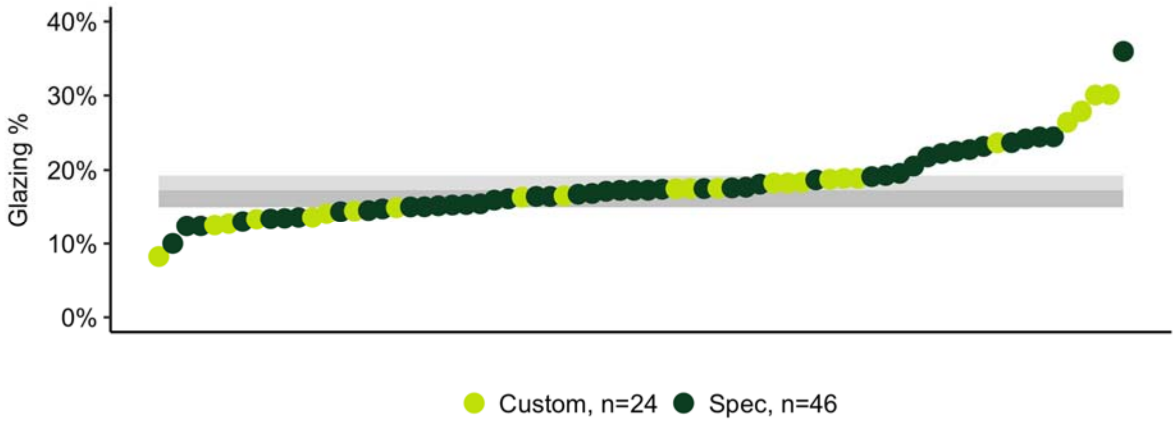
No significant differences at the 90% confidence level.

As can be seen in Figure 14, the distribution of glazing percentages is fairly flat, although at the extremes homes have nearly half (8%) or twice (36%) as much window area as the average home (18%).

63 https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/windows_doors/Draft6_V1_Criteria_Analysis_Report.pdf

64 The denominator used for Table 77 is the entire exterior wall area for each home, including the openings for windows and doors. It is not the net of wall area after subtracting window and door area.

Figure 14: Glazing Percentage of Exterior Wall Area by Home



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 78 shows that southerly oriented windows represent 27% of exterior glazing on average.[65]

Table 78: Southerly Oriented Glazing Statistics

Orientation-weighted % S/SE/SW Glazing	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	27.9%	26.8%	27.3%
90% CI Lower Bound	22.3%	22.4%	23.9%
90% CI Upper Bound	33.6%	31.2%	30.7%
Standard Deviation	16.2%	17.9%	17.1%
Minimum	2%	--	--
10th Percentile	4%	3%	4%
Median	31%	27%	29%
90th Percentile	51%	51%	50%
Maximum	60%	70%	70%

No significant differences at the 90% confidence level.

This figure could be improved if developers arranged more of their homes to face north or south. Homes are generally wider from side to side than they are deep, from front to back, so by facing homes to the north or south, there is more room for south-facing windows and solar PV systems. Developers can accomplish this in new developments by aligning major streets on an east-west axis rather than north-south. The Pacific Northwest National

[65] Southwest and southeast 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.

Laboratory (PNNL) recommends that sub-divisions be designed such that roads are generally East-West and the longest axis of homes are North-South.[66]

Models by the Efficient Windows Collaborative calculate that the impact of shifting from 55% south-facing windows to 55% north-, east- or west-facing windows with 0.29 U-factor/0.50 SHGC glazing is comparable to that of doubling the glazing area of a home with equally-distributed windows, resulting in a 12% increase in the annual heating and cooling energy use associated with glazing.[67]

To place these southerly glazing statistics in context, Table 79 shows the average distribution of window area around the sampled homes and Table 80 provides the proportions of homes that face each direction.

Table 79: Average Window Area Distribution[68]

Glazing Distribution	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Back	37%±5%	41%±3%	39%±3%
Front	28%±13%	29%±11%	29%±9%
Sides	36%±9%	30%±5%	32%±5%

No significant differences at the 90% confidence level.

Table 80: Site Orientation

Glazing Distribution	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
North	13%	17%	15%
Northeast	13%	4%	8%
East	25%	22%	23%
Southeast	4%	2%	3%
South	8%	15%	12%
Southwest	4%	4%	4%
West	21%	26%	24%
Northwest	13%	9%	10%

No significant differences at the 90% confidence level.

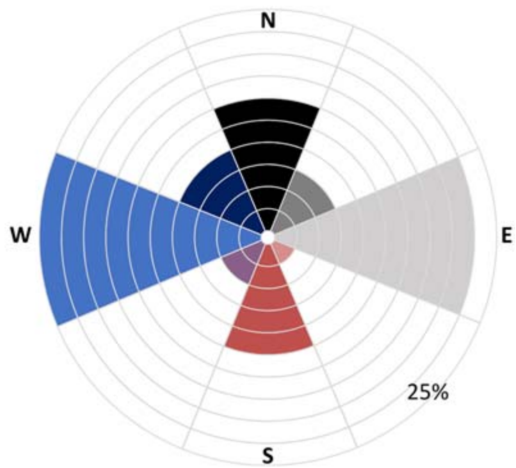
[66] "Building Energy Resources Center: Site Planning - Lot Orientation," *U.S. Department of Energy*, Feb. 1 2012, http://resourcecenter.pnl.gov/cocoon/morf/ResourceCenter/article//1401 via https://www.energycodes.gov/sites/default/files/documents/ta_site_planning-lot_orientation.pdf

[67] This is a non-profit consortium advocating for efficient window orientation and labeling. Note that the models in "Design Guidance for New Windows in a Cold Climate," (found here: http://www.efficientwindows.org/downloads/ColdDesignGuide.pdf) were set in climate zone 6A, whereas Connecticut is zone 5A.

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

Figure 15 is a wind rose or coxcomb pie chart of the statewide orientation data in Table 80, which it may be helpful to think of as a round histogram. Values are represented by sector length, and their position around the compass corresponds to home orientation. The relative length of the wedges indicates the prevalence of sampled homes facing a given direction – most face west and east, which shows wasted opportunity in terms of maximizing south-facing windows.

Figure 15: Orientation of Sampled Homes



6 Section 6 Mechanical Equipment

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

Key findings include the following:

Heating

- ***All primary heating systems meet the minimum federal efficiency standards and 42% are ENERGY STAR qualified. Propane and natural gas boilers have AFUEs of 91.8 and 94.0 on average (minimum federal requirement of 82 AFUE), and 93.2 and 94.2 for propane and natural gas furnaces (minimum federal requirement of 80 AFUE).***
- ***Custom homes are significantly more likely to use propane heating systems and boilers, while spec homes are significantly more likely to use natural gas heating systems and furnaces.***

Cooling

- ***Central air conditioning is the dominant primary cooling system, found in 85% of all homes inspected. These are 14.0 SEER, on average, far below the average SEER of the five ductless mini split systems (22.3 SEER), but only slightly above the 13 SEER federal minimum.***
- ***Ductless mini splits and ground source heat pumps combined make up the primary cooling systems in 8% of homes.***
- ***Only 32% of all central air conditioners are ENERGY STAR qualified (n=76); the five ductless mini split and the three ground source heat pump systems are ENERGY STAR qualified.***

Water Heating

- ***Residential standalone storage units make up 40% of water heaters, followed by instantaneous systems (26%), commercial storage units (12%), indirect storage tanks (9%), heat pump water heaters (6%), combination appliances (5%), and an inefficient tankless coil system (1%).***
- ***Custom homes have significantly more instantaneous systems than spec homes (48% vs. 11%) and significantly more indirect systems (20% vs. 2%). Spec homes have significantly more storage, standalone systems (60% of all spec systems vs. only 12% in custom homes).***

- ***Standalone electric storage water heaters are the single most common system type when the categories are broken down by fuel (17% – up to 20% when including the electric commercial-grade systems).***

- ***Heat pump water heaters make up 6% of systems.***

- ***Custom homes tend to use larger storage water heaters than spec homes, though average home sizes are similar. Two-thirds of custom home storage water heaters are greater than 50 gallons, compared to only one third in spec homes.***

6.1 Heating Equipment

Data were collected on all equipment used to heat the living space in sampled homes. Heating equipment was then split into primary and supplemental categories. 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 81 and Table 82 characterize the fuel and system type of each home's primary heating system. Each house comprises a single observation; if a house has two natural gas furnaces that heat the entire house, those two furnaces count as one observation for the home. If a home had multiple types of heating systems, then the system 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.

Custom homes are significantly more likely than spec homes to have a propane heating system and less likely to have a natural gas heating system. This suggests that custom homes are frequently built in locations that do not have natural gas infrastructure. Eight percent of homes use electricity as their primary fuel source; none of the homes use oil as their primary fuel source.

Table 81: Primary Heating Fuel[69]

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Propane	**63%***	**37%***	48%
Natural gas	**25%***	**59%***	45%
Electricity	13%	4%	8%

*Significantly different at the 90% confidence level.

A large majority (73%) of homes use furnaces as their primary heating system (Table 82). Spec homes are more likely than custom homes to have a furnace and less likely to have a boiler. There were 13 homes with multiple primary heating units, 11 homes with multiple furnaces, and two homes with multiple ductless ASHP split systems.

Table 82: Primary Heating Type

Type	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Furnace	**58%***	**83%***	73%
Boiler (hydro-air)	**25%***	**4%***	13%
Combi appliance	4%	4%	4%
Boiler (forced hot water)	--	4%	3%
Ductless mini split	8%	--	4%
Electric baseboards	4%	--	2%
ASHP	--	2%	1%
GSHP-closed loop	--	2%	1%

*Significantly different at the 90% confidence level.

6.1.2 Primary Heating Systems – Location

The location of the primary heating systems is shown in Table 83.[70] Over half of the primary heating equipment is in unconditioned basements or enclosed crawl spaces (53%). Over one-third of the heating systems are in a conditioned space (37%), while only five percent of primary heating systems are in attic space and five percent are in a garage or open crawlspace. 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

[69] As a comparison, primary heating fuel in existing Connecticut homes visited for the 2013 Single-Family Weatherization Baseline Assessment (n=180 homes) broke down as: 64% oil, 24% natural gas, 8% electric, 2% propane, 1% pellet, and 1% wood.

[70] For mini-splits, a system is defined based on the number of outdoor units; each outdoor unit counts as one system, so a home with two outdoor units connected each to two indoor heads (four zones) has two systems.

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).

Table 83: Primary Heating System Location

Location	Custom	Spec	All Homes (Weighted)
*n (primary heating systems)***	*26*	*57*	*83*
Unconditioned basement/enclosed crawl	62%	49%	53%
Conditioned area	31%	40%	37%
Garage or open crawl space	4%	5%	5%
Attic	4%	5%	5%

No statistically significant differences 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

Table 84 shows the Annual Fuel Utilization Efficiency (AFUE) statistics of all sampled natural gas furnaces and Table 85 shows this for propane furnaces. Natural gas furnaces have a slightly higher average efficiency (94.2 AFUE) compared to propane furnaces (93.2 AFUE). There are no significant differences between custom and spec homes for natural gas furnaces. For propane furnaces, spec homes have a significantly lower average AFUE than custom homes (91.0 vs. 95.3).

Table 84: Natural Gas Furnace AFUE

	Custom	Spec	All Homes (Weighted)
n (natural gas furnaces)	*4*	*31*	*35*
Average	91.5	94.6	94.2
90% CI Lower Bound	82.5	94.1	93.2
90% CI Upper Bound	100†	95.1	95.1
Standard Deviation	7.7	1.6	3.2
Minimum	80.0	92.1	80.0
10th Percentile	80.0	92.1	92.1
Median	95.3	95.0	95.0
90th Percentile	95.5	96.6	96.4
Maximum	95.5	97.0	97.0

No statistically significant differences at the 90% confidence level.
†Value adjusted due to calculated results outside of possible values.

Figure 16 shows the distribution of natural gas furnace AFUE – most fall far above the 2009 IECC requirement of 78 and the minimum federal requirement of 80. The 2009 IECC requires a minimum AFUE of 78 for gas- or oil-fired furnaces, though the federal minimum standard increased to 80 AFUE for non-weatherized gas furnaces in 2015. The federal standards supersede the IECC requirements. All furnaces in inspected homes meet the federal requirement. ENERGY STAR status of heating equipment is discussed separately below.

Figure 16: Natural Gas Furnace AFUE

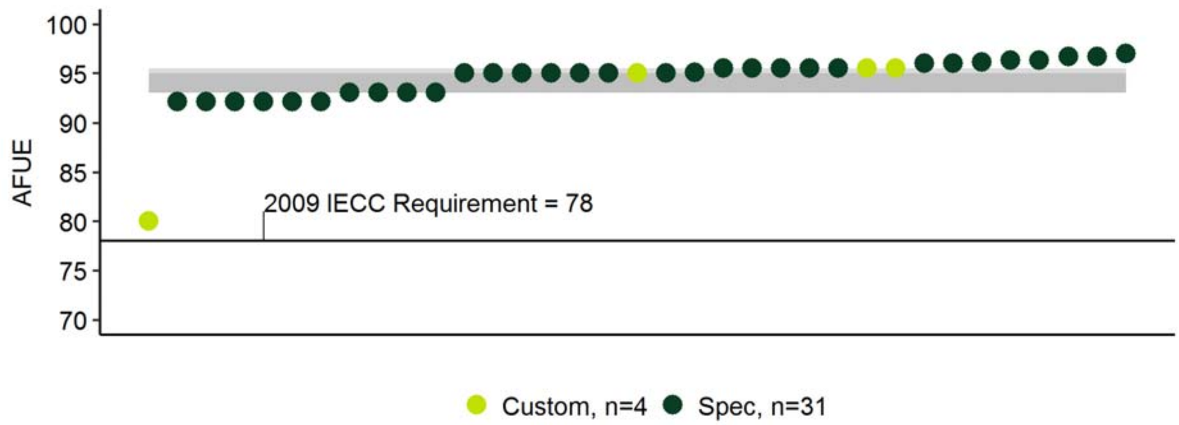


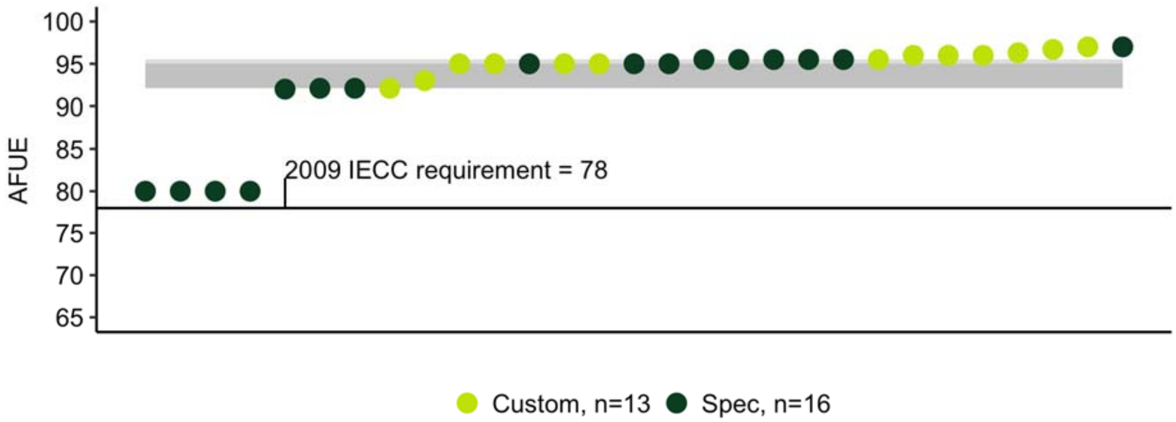
Table 85: Propane Furnace AFUE

	Custom	Spec	All Homes (Weighted)
n (propane furnaces)	*13*	*16*	*29*
Average	**95.3***	**91.0***	93.2
90% CI Lower Bound	94.6	88.0	91.6
90% CI Upper Bound	96.0	93.9	94.8
Standard Deviation	1.4	6.7	5.1
Minimum	92.1	80.0	80.0
10th Percentile	92.5	80.0	80.0
Median	95.5	95.0	95.0
90th Percentile	96.9	96.0	96.7
Maximum	97.0	97.0	97.0

*Significantly different at the 90% confidence level.

As with natural gas furnaces, AFUE for propane furnaces falls largely in a narrow band from 92 to 97, though there are more 80 AFUE propane furnaces (Figure 17).

Figure 17: Propane Furnace AFUE



All the gas fired boilers in the inspected homes meet the federal standard of a minimum AFUE of 82 (Table 86). Natural gas boilers in inspected homes on average are more efficient then propane boilers (94.0 vs 91.8 AFUE). Oil boilers are not present in any of the homes.

Table 86: Boiler AFUE*

	Natural Gas Boiler (Unweighted)	Propane Boiler (Unweighted)
n (boilers)	*5*	*8*
Average	94.0	91.8
90% CI Lower Bound	92.4	87.7
90% CI Upper Bound	95.3	95.0
Standard Deviation	1.5	5.5
Minimum	91.3	82.1
10th Percentile	91.3	82.1
Median	94.3	94.0
90th Percentile	95.0	95.0
Maximum	95.0	95.0

*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 permanent split capacitor (PSC) motors.[71] Table 87 shows the percentage

[71] 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 of 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.

of furnaces equipped with ECMs. Thirty-eight percent of furnaces have an ECM. Custom homes are significantly more likely to have an ECM (59%) compared to spec homes (28%).

Table 87: Frequency of ECMs in Furnaces

ECM Status	Custom	Spec	All Homes (Weighted)
n (furnaces)	*17*	*47*	*64*
No	**41%***	**72%***	62%
Yes	**59%***	**28%***	38%

*Significantly different at the 90% confidence level.

6.1.5 Heat Pump Efficiency

Nine heat pump heating systems were found during on-site inspections. Five of these systems (three ductless mini splits, one GSHP-closed loop, and one ASHP) are the primary source of heat for the home. The rest serve as supplemental systems; ductless mini split ASHPs are often used to heat an individual room such as a bonus room over a garage or a finished basement. Table 88 summarizes the heating efficiency data for all the heat pump systems. The heat pump heating efficiencies are rated in heating in heating season performance factors (HSPF). 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.

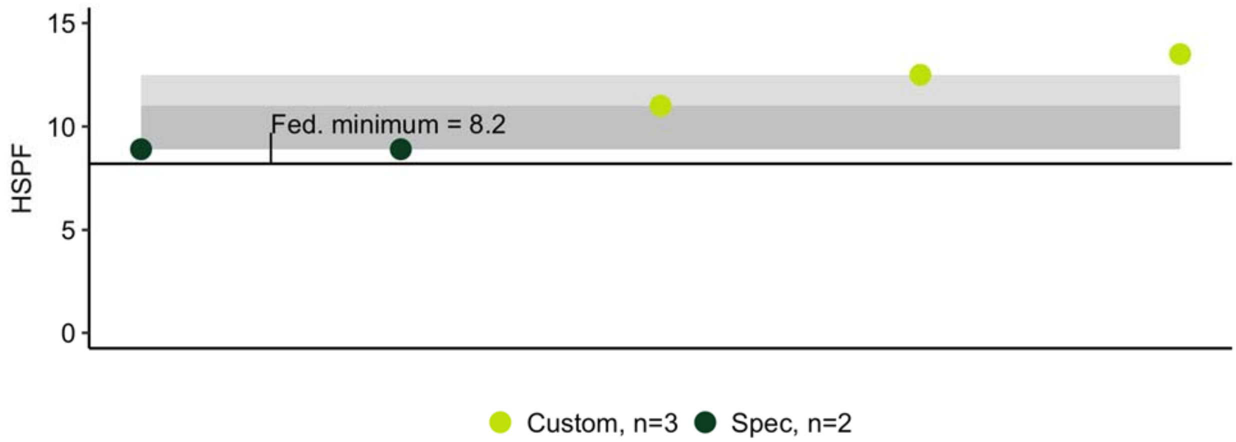
Table 88: Heat Pump Efficiency (HSPF)
(Base: All heat pump systems)

	Ductless Mini split (Unweighted)	GSHP–Closed Loop (Unweighted)	ASHP (Unweighted)
n (heat pumps)	*5*	*3*	*1*
Average	11.0	13.3	8.2
90% CI Lower Bound	9.0	10.2	**
90% CI Upper Bound	12.9	16.4	**
Standard Deviation	2.1	1.9	**
Minimum	8.9	11.3	8.2
10th Percentile	8.9	11.3	8.2
Median	11.0	13.6	8.2
90th Percentile	13.5	15.0	8.2
Maximum	13.5	15.0	8.2

**Value not calculated due to small sample size.

Figure 18 shows the distribution of the HSPF values for the five ductless mini split systems in sampled homes.

Figure 18: Ductless Mini Split HSPF



6.1.6 Heating ENERGY STAR Status

Table 89 shows the ENERGY STAR status of each piece of equipment that was designated as a primary heating system. Overall, 42% of primary heating systems are ENERGY STAR qualified. Two systems have no obtainable data concerning ENERGY STAR status and are marked as "Don't know." Significantly more custom homes (58%) have ENERGY STAR primary heating systems compared to spec homes (32%).

Table 89: Primary Heating System ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (primary heating systems)	*26*	*57*	*83*
No	**42%***	**67%***	57%
Yes	**58%***	**32%***	42%
Don't know	--	2%	1%

*Significantly different at the 90% confidence level.

Table 90 shows the ENERGY STAR percentage for most heating equipment types (excluding electric baseboard, fireplaces, and stoves). The table includes primary and supplemental heating equipment. Almost one-third (30%) of all furnaces are ENERGY STAR qualified. Looking at fuel-fired heating equipment (furnaces, boilers, and combi appliances) 39% of equipment is ENERGY STAR qualified.

Table 90: Heating Equipment ENERGY STAR Status (Unweighted)

System Type	*n*	Yes	No	DK	ENERY STAR Specifications
Furnace	64	19 (30%)	45 (70%)	--	95 AFUE, ECM, 2% air leakage
Boiler (hydro-air)	8	8 (100%)	--	--	90 AFUE
Ductless mini split	5	5 (100%)	--	--	8.5 HSPF
Combi appliance	3	3 (100%)	--	--	90 AFUE
GSHP-closed loop	3	1 (33%)	2 (67%)	--	3.6 COP (water:air) 3.1 COP (water:water)
Heat pump water heater	1	1 (100%)	--	--	2.0 EF or UEF (≤ 55 gallons) 2.2 EF or UEF (>55 gallons)
Boiler (forced hot water)	2	--	2 (100%)	--	90 AFUE
ASHP	1	--	--	1 (100%)	8.5 HSPF
Total	87	37 (43%)	49 (56%)	1 (1%)	--

Not tested for statistical significance.

6.1.7 Heating Capacity

Table 91 shows the heating system capacity per square foot of conditioned floor area. 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.

Table 91: Heating Capacity per Square Foot of Conditioned Floor Area (BTU/hr/ft^2)

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	35.4	36.3	36.0
90% CI Lower Bound	30.7	31.1	32.3
90% CI Upper Bound	40.1	41.5	39.6
Standard Deviation	13.5	21.0	18.1
Minimum	15.9	9.3	9.3
10th Percentile	19.4	20.8	21.9
Median	33.5	30.8	32.4
90th Percentile	50.6	54.5	52.2
Maximum	82.0	120.6	120.6

No statistically significant differences at the 90% confidence level.

6.1.8 Supplemental Heating Systems

Table 92 shows the counts of supplemental heating systems. Seven total homes have a supplementary heating system. Several homes have multiple supplemental heating systems. The most frequent supplemental heating system type are electric baseboards, followed by

GSHPs and stoves.[72] Three homes use electric baseboards, two homes use stoves, one home uses ductless mini splits, one home uses GSHPs, and one home uses a heat pump water heater as supplemental heat.

All supplemental heating systems use electricity for fuel except for the two stoves, which use wood. The heat pump water heater found in a custom home is used for radiant floor heating. As previously described, supplemental systems are defined as those systems that do not match the primary system type identified based on capacity or floor area served. If, for example, a home has two furnaces and a smaller capacity ductless mini split, the ductless mini split is the supplemental heating system type.

Table 92: Supplementary Heating Systems

Type	Custom	Spec	All Homes (Weighted)
n (supplementary heating systems)	*6*	*4*	*10*
Electric baseboard	1 (17%)	2 (50%)	28%
GSHP-closed loop	2 (33%)	--	22%
Stove	2 (33%)	--	22%
Ductless mini split	--	2 (50%)	17%
Heat pump water heater**	1 (17%)	--	11%

Not tested for statistical significance.
**Heat pump water heater used for radiant floor heating.

6.2 Cooling Equipment

The following section characterizes the cooling equipment found during on-site inspections.

6.2.1 Primary Cooling Equipment – Type

Table 93 shows the primary cooling system for each home. Central air conditioners (CAC) are the primary cooling system type in most homes (85%), with ductless ASHP split systems and GSHPs as the next most common primary system.[73] Four percent of homes (three homes) did not have air conditioning. For the following table, and as with the heating section, each home is treated as one observation, and the type of cooling equipment, if any, of the

[72] One home had a boiler and two GSHPs. The boiler had a larger capacity than the two GSHPs combined; therefore, it was deemed the primary system by the definition of primary systems used in this study and recent studies in Massachusetts and Rhode Island. The GSHPs are the primary system for cooling.
[73] One home had a traditional ASHP system, which is essentially a CAC system with the ability to provide heating as well.

same type that supplies the largest portion of the cooling load is identified as the primary system type.[74]

Table 93: Primary Cooling Type per Home

Type	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Central air conditioner*	79%	89%	85%
CAC (cooling only)	79%	87%	84%
ASHP (cooling + heating)	--	2%	1%
Ductless split ASHP	8%	2%	5%
GSHP-closed loop	4%	2%	3%
Room air conditioner	4%	2%	3%
None	4%	4%	4%

No statistically significant differences at the 90% confidence level.
*Includes one home with an ASHP system.

Of the sixty homes with CAC as the primary cooling system, 25% (15 homes) had more than one system in the home.[75] Of the three homes with ductless split ASHPs, one home had a large multi-split system (multiple indoor heads attached to a single outdoor unit), the second had two multi-split systems, and the third had two mini-split systems (a single indoor head attached to a single outdoor unit), making five systems total, of varying capacities. Of the two homes with GSHPs, one had a single system and one had two. For the two homes using room air conditioners, one home had two of them and the other had three.

6.2.2 Primary Cooling System – Locations

Table 94 shows the location of all primary cooling systems.[76] Most of the primary cooling systems (62%) are in unconditioned areas, including basements, crawl spaces, attics, and garages. As with heating systems, the base for this table is not the count of homes, but the count of cooling systems that match the primary equipment type for each home – if a home has more than one of the same type of primary cooling system, both are included in this table (which is why the number of systems shown is higher than the number of homes with cooling

[74] For example, a home with two air conditioning systems, one in the basement and one in the attic, is treated as having a CAC system as the primary cooling system type.
[75] Two systems in 14 homes, three systems in one home.
[76] For mini-splits, a system is defined based on the number of outdoor units; each outdoor unit counts as one system, so a home with two outdoor units connected each to two indoor heads (four zones) has two systems.

systems).[77] In this study, there was only one supplemental cooling system (a room air conditioner in a home with CAC system). It is excluded from this table of primary systems.

Table 94: Location of Primary Cooling Systems

	Custom	Spec	All Homes (Weighted)
*n (primary cooling systems)***	*33*	*56*	*89*
Unconditioned basement/enclosed crawl	55%	52%	53%
Conditioned area	36%	41%	39%
Attic	9%	4%	6%
Garage or open crawl space	--	4%	2%

No statistically significant differences at the 90% confidence level.
**Some homes have multiple primary systems (e.g., two furnaces of the same type).

Table 95 shows the location of primary cooling systems by system type. Most primary CAC systems (61%) are installed in unconditioned basements or crawl spaces. The head/blower portion of ductless mini splits and room air conditioners are, by their nature, installed in conditioned spaces; two of the three primary GSHP systems were installed in unconditioned space.

[77] If the home has two CAC systems, one in the attic and one in the basement, both are recorded in this table, as both are primary systems of the same type. If the home had a powerful CAC system and a small mini split, only the CAC system would be included in this location table, as that is the one primary system type.

Table 95: Location of Primary Cooling Systems by Type

System Type/Location	Custom	Spec	All Homes (Only CAC weighted)
*n (primary cooling systems**)*	*33*	*56*	*89*
Central Air Conditioner†			
n (CAC systems)	*25*	*51*	*76*
Unconditioned basement/ enclosed crawl	68%	57%	61%
Conditioned area	20%	37%	30%
Attic	12%	4%	8%
Garage or open crawlspace	--	2%	1%
Ductless Mini Split			
n (DMS systems)	3	2	5
Conditioned area	3 (100%)	2 (100%)	5 (100%)
GSHP-Closed Loop			
n (GSHP systems)	2	1	3
Conditioned area	1 (50%)	--	1 (33%)
Garage or open crawl space	--	1 (100%)	1 (33%)
Unconditioned basement/ enclosed crawl	1 (50%)	--	1 (33%)
Room Air Conditioner+			
n (RACs)	3	2	5
Conditioned area	3 (100%)	2 (100%)	5 (100%)

No statistically significant differences at the 90% confidence level.
**Some homes have multiple primary systems, e.g., two CAC systems of the same type.
†Includes one ducted ASHP system, providing cooling and heating.
+Excluded is one other RAC, as it was not a primary system in the home.

6.2.3 Cooling System Efficiency

Table 96 shows the Seasonal Energy Efficiency Ratio (SEER) and Energy Efficiency Ratio (EER) statistics of all cooling systems in sampled homes. Central air conditioners[78] had a lower average efficiency (14.0 SEER) compared to ductless mini splits (22.3 SEER). This is expected, though the sample of mini-splits in this case is small. There are only five systems (three multi-split systems and two single-head mini-splits) across three homes, including two that were quite efficient (one over 26 and the other over 30 SEER). Room air conditioners and GSHPs have average efficiencies of 10.3 EER[79] and 17.8 EER respectively.

[78] For this analysis, the one ducted ASHP – essentially a CAC system that can also provide heating – is treated as if it were a CAC system.
[79] One additional air conditioner – a wall-mounted unit specifically designed for wine cellars was excluded from these analyses due to lack of efficiency information.

The current federal minimum standard is 13 SEER for central air conditioners and 14 SEER for heat pumps.[80] All equipment found in the study meets the federal minimum standard at the time of manufacture.

There is no significant difference between the efficiency of CACs in custom and spec homes (the only cooling equipment type with sufficient sample to test for significance).

[80] For all cooling standards, including standards for RACs, see US Department of Energy: Office of Energy Efficiency & Renewable Energy – *CFR 430.32 13.0.* https://www.gpo.gov/fdsys/pkg/CFR-2013-title10-vol3/pdf/CFR-2013-title10-vol3-part430-subpartC.pdf

Table 96: Cooling System Efficiency

Central Air Conditioner (SEER)+	Custom	Spec	All Homes (Weighted)
n (CAC systems)	*25*	*51*	*76*
Average	14.3	13.8	14.0
90% CI Lower Bound	13.8	13.6	13.8
90% CI Upper Bound	14.9	14.0	14.3
Standard Deviation	1.6	0.9	1.3
Minimum	13.0	13.0	13.0
10th Percentile	13.0	13.0	13.0
Median	13.5	13.5	13.5
90th Percentile	16.0	15.0	16.0
Maximum	18.0	16.0	18.0
Ductless Mini Split (SEER)	**Custom**	**Spec**	**All Homes (Unweighted)**
n (DMS systems)	3	2	5
Average	25.2†	18.0†	22.3
90% CI Lower Bound	15.3	**	16.9
90% CI Upper Bound	35.0	**	27.7
Standard Deviation	5.9	**	5.7
Minimum	18.9	18.0	18.0
10th Percentile	18.9	18.0	18.0
Median	26.1	18.0	18.9
90th Percentile	30.5	18.0	30.5
Maximum	30.5	18.0	30.5
GSHP – Closed Loop (EER)	**Custom**	**Spec**	**All Homes (Unweighted)**
n (GSHP systems)	2	1	3
Average	19.0†	15.4†	17.8
90% CI Lower Bound	10.8	**	13.7
90% CI Upper Bound	27.2	**	21.9
Standard Deviation	1.8	**	2.5
Minimum	17.7	**	15.4
10th Percentile	17.7	**	15.4
Median	19.0	**	17.7
90th Percentile	20.3	**	20.3
Maximum	20.3	**	20.3
Room Air Conditioner (EER)*	**Custom**	**Spec**	**All Homes (Unweighted)**
n (RACs)	3	2	5
Average	10.7†	9.8†	10.3
90% CI Lower Bound	9.2	9.4	9.6
90% CI Upper Bound	12.2	10.1	11.1
Standard Deviation	0.9	0.1	0.8
Minimum	9.7	9.7	9.7
10th Percentile	9.7	9.7	9.7
Median	11.2	9.8	9.8
90th Percentile	11.2	9.8	11.2
Maximum	11.2	9.8	11.2

†Not tested for statistical significance.

+Includes one ducted ASHP system, providing cooling and heating.

*Excludes one room air conditioner (wine cellar-specific unit) without efficiency information.

Figure 19 and Figure 20 show the distribution of SEER ratings for cooling equipment across the same scale. The great majority of CAC systems fall in a narrow band of values: most central air conditioners are 13 to 16 SEER (two are 18 SEER). There are only three homes with ductless split systems in the sample – five systems total (two homes each had two systems), ranging from 18 to over 30 SEER. The CAC values cluster close to the federal minimum, while the ductless mini splits have a broader range and fall well above the federal minimum, on average.

Figure 19: Central A/C SEER

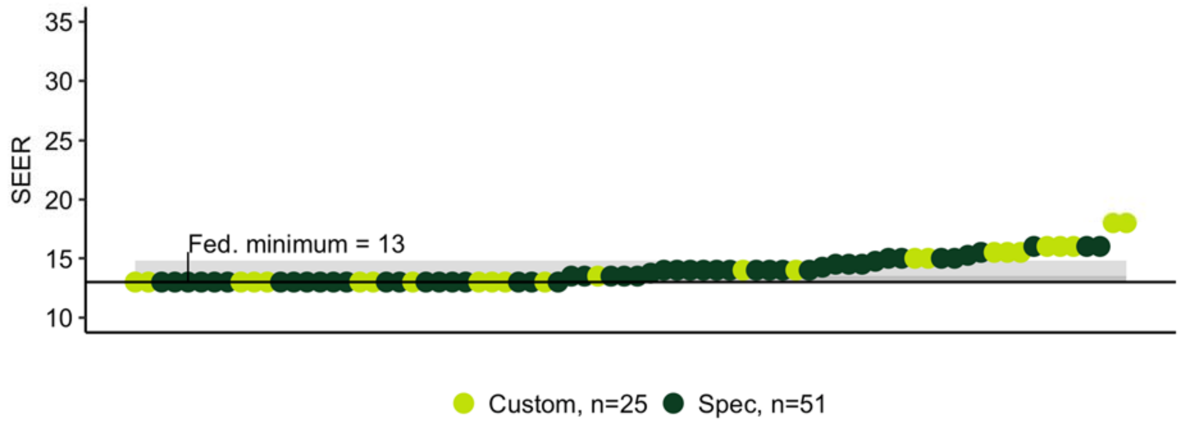


Figure 20: Ductless Mini Split SEER

6.2.4 Cooling System ENERGY STAR Status

Table 97 shows the ENERGY STAR status for all cooling systems. Overall, only about one-third of central air conditioners qualify as ENERGY STAR, while all five ductless mini split systems and all three GSHPs qualify. Only two of the six RACs qualify for ENERGY STAR status.

Table 97: Cooling Equipment ENERGY STAR Status

Type/ENERGY STAR Status	Custom	Spec	All Homes (Only CAC Weighted)
n (all cooling systems)	33	57	90
Central Air Conditioning (ENERGY STAR: ≥15 SEER)			
n (CAC systems)	*25*	*51*	*76*
Yes	40%	27%	32%
No	60%	73%	68%
Ductless Mini Split (ENERGY STAR: ≥15 SEER)			
n (DMS systems)	3	2	5
Yes	3 (100%)	1 (100%)	5 (100%)
No	--	--	--
GSHP-Closed Loop (ENERGY STAR: ≥ 17.1 EER for water:air and ≥ 16.1 EER for water:water)			
n (GSHP systems)	2	1	3
Yes	2 (100%)	1 (100%)	3 (100%)
No	--	--	--
Room Air Conditioner (ENERGY STAR: varies based on capacity)			
n (RACs)	3	3*	6
Yes	2 (67%)	--	2 (33%)
No	1 (33%)	3 (100%)	4 (67%)

No statistically significant differences at the 90% confidence level.
*Includes a secondary RAC not previously included in stats due to lack of specific efficiency information.

6.2.5 Cooling Capacity

Table 98 shows the permanently installed cooling system capacity normalized by the home's conditioned floor area; the table excludes room ACs as those are not permanent to the home, leaving 65 homes with permanent AC systems. The statewide average is 15.7 btu/hr per sq. ft.[81] Combined with the average conditioned floor area of 3,052 sq. ft., the average cooling capacity in the average-sized home is about four tons (47,916 Btu/hr).

[81] On average, this represents 764 sq. ft. served for each ton of cooling.

Table 98: Permanently Installed Cooling Capacity per Square Foot Conditioned Floor Area
(Homes with Permanently Installed AC – no RACs)

	Custom	Spec	All Homes (Weighted)
n (homes)	*22*	*43*	*65*
Average	16.6	15.1	15.7
90% CI Lower Bound	14.9	13.8	14.7
90% CI Upper Bound	18.2	16.4	16.7
Standard Deviation	4.5	5.0	4.8
Minimum	7.9	6.6	6.6
10th Percentile	13.2	9.5	9.9
Median	15.5	15.3	15.3
90th Percentile	22.2	21.0	21.4
Maximum	27.5	30.1	30.1

No statistically significant differences at the 90% confidence level.

6.2.6 Supplemental Cooling Systems

Across the board, homes generally only have one type of cooling system present. Only one home had more than one cooling system – a small cooling unit for a wine cellar in addition to the CAC system installed in the home. In some cases, homes have more than one cooling system (two CAC systems, for example), but these were multiple primary systems – one or more system of the same type, just installed in components rather than as one larger piece of equipment.

6.3 Water Heating

This section describes the type of water heaters found during onsite inspections. Natural gas and propane instantaneous water heaters are the most common water heater types, with traditional natural gas and propane standalone systems following close behind. Heat pump water heater systems make up only a small portion of water heating equipment and are outnumbered three-to-one by traditional electric resistance water heaters. Most homes have one water heater; one home had two electric standalone units and another had two natural gas instantaneous systems.

6.3.1 Water Heater Types

The most common water heater types are residential standalone storage units (40%), followed by instantaneous systems (26%), commercial-sized standalone storage units (12%), indirect-fired storage tanks (9%),[82] heat pump water heaters (6%), combination appliances

[82] One home that used an indirect storage tank with a natural gas boiler also used a desuperheater from a GSHP.

(instantaneous systems providing space heating and water heating) (5%), and inefficient boilers with tankless coil systems (1%).

Natural gas and propane instantaneous water heaters make up 26% of all water heaters. Natural gas and propane residential standalone storage systems make up 23% (30% when including commercial-sized systems). Standalone electric storage water heaters are the single most common system type when the categories are broken down by fuel (17%—up to 20% when including the electric commercial-grade systems).

Standalone electric (26%) and natural gas (21%) storage tanks are more common in spec homes than in custom homes (4% in each), with a statistically significant difference in both cases. Instantaneous propane systems are found in 36% of custom homes but are not found in any spec homes, with a statistically significant difference (Table 99).

Table 99: Water Heater Type by Fuel

	Custom	Spec	All Homes (Weighted)
n (water heaters)	25	47	72
Storage, standalone	***12%****	***60%****	***40%***
Electric	**4%***	**26%***	17%
Natural gas	**4%***	**21%***	14%
Propane	4%	13%	9%
Instantaneous	***48%****	***11%****	***26%***
Propane	**36%***	**0%***	15%
Natural gas	12%	11%	11%
Commercial Water Heater	***8%***	***14%***	***12%***
Natural gas	4%	6%	5%
Propane	4%	4%	4%
Electric	--	4%	3%
Indirect w/ storage tank	***20%****	***2%****	***9%***
Natural gas	12%	2%	6%
Propane	8%	--	3%
Heat Pump Water Heater (Electric)	***8%***	***4%***	***6%***
Combi Appliance	***4%***	***6%***	***5%***
Propane	4%	4%	4%
Natural gas	--	2%	1%
Tankless coil (Propane)	***--***	***2%***	***1%***

*Statistically significant at the 90% confidence level

6.3.2 Water Heater Fuel

Natural gas and propane are the most common water heating fuels (38% and 37%, respectively). In total, gas-fueled systems (i.e., propane and natural gas) were found in 75% of homes, compared to electric in 25%. Custom homes were significantly more likely to use propane systems than homes in the spec sample (56% vs. 23%), while spec homes were significantly more likely to use electric systems (34% vs. 12%). The higher frequency of propane water heaters in custom homes is likely the result of more custom homes than spec homes being built in areas that do not have natural gas infrastructure.

Table 100: Water Heater Fuel[83]

	Custom	Spec	All Homes (Weighted)
n (water heaters)	*25*	*47*	*72*
Natural gas	32%	43%	38%
Propane	**56%***	**23%***	37%
Electric	**12%***	**34%***	25%

*Statistically significant at the 90% confidence level

6.3.3 Water Heater Storage Volume

Spec homes are significantly more likely to have the smallest storage capacity water heaters – 68% of the spec sample use systems with capacities between 40 and 50 gallons, compared to 33% in the custom sample (Table 101). On the larger end, homes in the custom sample use systems with over 75 gallons of storage 33% of the time, compared to just 8% in the spec sample. This difference is not explained by home size – custom homes average 3,113 sq. ft. of CFA, compared to 3,009 sq. ft. in spec homes in our statewide sample.

Table 101: Water Heater Storage Capacity

Gallons	Custom	Spec	All Homes
n (water heaters w/ tanks)	*12*	*38*	*50*
40 to 50	**33%***	**68%***	59%
51 to 60	17%	--	5%
61 to 75	17%	24%	22%
Greater than 75	**33%***	**8%***	14%

*Statistically significant at the 90% confidence level

6.3.4 Water Heater Efficiencies

Table 102 summarizes the average Energy Factors of each system type.[84] Since there are no significant differences in the average Energy factors of equipment in custom and spec homes, just the weighted statewide data are presented here. For a detailed breakdown of

[83] As a comparison, primary water heating fuel in existing Connecticut homes visited for the 2013 Single-Family Weatherization Baseline Assessment (n=184 water heaters) broke down as: 50% oil, 23% natural gas, 23% electric, and 4% propane.

[84] Beginning in June 2017, federal standards for water heaters changed to require a “Uniform Energy Factor” (UEF) instead of an Energy Factor (EF). UEF’s are calculated differently than EFs, in that water heaters are binned based on their capacity to provide hot water in the first hour of use, and then have their efficiency rated in their bin. For future reference, while no unit conversion exists between the two metrics, NMR ran a regression of 94 water heaters from the Federal Trade Commission database that had both EF and UEF ratings and found EF = 1.0339*UEF – 0.123 with an R^2=0.9779.

water heater Energy Factors, please see Appendix E. Consistent with previous baseline studies, Energy Factors for indirect water heaters were calculated as 92% of the boiler efficiency.[85] Energy Factors for commercial systems are reported separately in Table 103.

Table 102: Average Water Heater Energy Factors

Type	*n*	All Homes
Natural gas and propane storage, standalone (weighted)	*18*	.67±.01
Natural gas and propane instantaneous (weighted)	*17*	.93±.02
Electric storage, standalone (weighted)	*13*	.93±.01
Natural gas and propane indirect w/ storage tank (unweighted)	*6*	.88±.03
Heat pump water heater (unweighted)	*4*	3.04±.21
Combi appliances (unweighted)	*4*	.93±.02
Boiler with tankless coil (unweighted)	*1*	.45[86]

Table 103 shows the calculated Energy Factors for commercial water heaters. These values were calculated using the RESNET Commercial Hot Water EF Calculator, which incorporates tank size, thermal efficiency, standby loss, and number of bedrooms in the home.[87] Overall, fossil fuel-fired commercial tanks have an average calculated Energy Factor of 0.57. Excluded from this table are the two commercial electric water heaters identified during on-sites, which both have Energy Factors of .86.

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[85] 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.
[86] Source: NEHERS Manual. Tankless coil Energy Factor is determined using the number of occupants in the home.
[87] Energy factors of commercial water heaters were estimated using RESNET's calculator available at http://www.resnet.us/uploads/documents/standards/Commercial_Hot_Water_EF_Calculator_12-10.xls.

Table 103: Estimated Commercial Water Heater Energy Factors (Gas and Propane)*

	Custom	Spec	All Homes (Unweighted)
n (water heaters)	*2*	*5*	*7*
Average	.64	.54	.57
90% CI Lower Bound	**	.48	.52
90% CI Upper Bound	**	.61	.62
Standard Deviation	**	.06	.07
Minimum	.64	.50	.50
10th Percentile	**	.50	.50
Median	.64	.50	.58
90th Percentile	**	**	**
Maximum	.64	.64	.64

*There are two electric commercial water heaters that each have an energy factor 0.86 that are excluded from this table.
**Not calculated due to small sample size.

The seven fossil fuel-fired commercial water heaters are rated based on their thermal efficiency, rather than Energy Factor. There was little variation among the systems; every water heater had a thermal efficiency of either .80 or .82 in the custom and spec samples.

Table 104: Commercial Water Heater Thermal Efficiencies

	Custom	Spec	All Homes (Unweighted)
n (water heaters)	*2*	*5*	*7*
Average	.81	.80	.81
90% CI Lower Bound	.75	.80	.80
90% CI Upper Bound	.87	.81	.81
Standard Deviation	.014	.01	.01
Minimum	.80	.80	.80
10th Percentile	.80	.80	.80
Median	.81	.80	.80
90th Percentile	**	**	**
Maximum	.82	.82	.82

**Not calculated due to small sample size.

Table 105 shows the Energy Factors for the four combi appliances, which are instantaneous boilers designed to provide both space heating and water heating to the home, found during on-site inspections.[88] Since there are only four combi appliances in the sample, they have been grouped together here. As with commercial water heaters, there was limited variation in the efficiencies of these systems.

[88] When no Energy Factor is given for a combi unit, it is assumed that the EF is equal to the rated AFUE of the equipment from the AHRI database.

Table 105: Combi Appliance Water Heater Energy Factors

	EF (Unweighted)
n (water heaters)	*4*
Average	.93
90% CI Lower Bound	.91
90% CI Upper Bound	.95
Standard Deviation	.017
Minimum	.91
10th Percentile	.91
Median	.93
90th Percentile	**
Maximum	.93

**Value not calculated due to small sample size

6.3.5 Water Heater ENERGY STAR Status

The frequency of ENERGY STAR-rated systems is reported in Table 107. Slightly more than half of water heaters (53%) in the statewide sample are ENERGY STAR rated. A higher proportion of systems in the custom sample are ENERGY STAR rated, though the difference compared to spec homes is not significant. Fifty-one percent of systems in the spec sample are not ENERGY STAR, compared to 16% in the custom sample, which is a statistically significant difference. Among all systems eligible for ENERGY STAR qualification (not marked “NA” below), 59% were ENERGY STAR.

Table 106: Water Heater ENERGY STAR Specifications

Type	Specification
Natural gas and propane storage, standalone	0.67 EF (≤55 Gallons) 0.77 EF (>55 Gallons)
Natural gas and propane instantaneous	0.90 EF
Electric storage, standalone	2.0 EF (≤55 Gallons) 2.2 EF (>55 Gallons)
Heat pump water heater	2.0 EF (≤55 Gallons) 2.2 EF (>55 Gallons)
Combi appliances	0.90 EF

Table 107: Proportion of ENERGY STAR Water Heaters

ENERGY STAR Status	Custom	Spec	All Homes (Weighted)
n (water heaters)	*25*	*47*	*72*
Yes	64%	45%	53%
No	**16%***	**51%***	36%
NA[89]	**20%***	**4%***	11%

*Statistically significant at the 90% confidence level.

[89] Systems such as indirect storage tanks are not assessed by ENERGY STAR, and make up this N/A sample.

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 joist pans), location, insulation type, and insulation R-value. Auditors used the manufacturer rated R-values, which range from R-4.2 to R-10.0, although actual R-value varies based on installation practices.

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

- ***Three-fourths of homes with ducts meet the mandatory 2009 IECC duct leakage requirements. Compared to spec homes, custom homes are significantly more likely to comply with the duct leakage requirements.***

- ***Two-fifths of homes satisfy all 2009 IECC prescriptive code requirements for duct insulation: R-8 for attic supplies, R-6 for all others. The average insulation level for ducts in unconditioned space (excluding attic supplies) is R-5.8.***

7.1 Duct Location

All but seven inspected homes (90%) have duct systems. Only 8% (six homes) have all ducts installed in conditioned space, 69% have at least some ducts installed in conditioned space, and 13% have no ducts installed in conditioned space (Table 108).

Table 108: Duct Location

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
All ducts in conditioned space	4%	11%	8%
Some ducts in conditioned space	63%	74%	69%
No ducts in conditioned space	21%	7%	13%
No ducts	13%	9%	10%

No statistically significant differences at the 90% confidence level.

7.2 Duct Leakage

Duct leakage to the outside (LTO) quantifies duct leakage that occurs outside the building envelope. The average LTO is higher in spec homes than in custom homes, though it is not a statistically significant difference (Table 109). LTO was not measured for six duct systems, either because the test equipment could not reach adequate test pressure in the ducts or there were registers the auditor was unable to cover. For this reason, these average measured values may be lower than the true values, assuming the systems that were unable to reach pressure because they were leaky.

Table 109: Duct Leakage to Outside (CFM25/100 ft^2)

	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*42*	*60*
Average	**5.1***	**6.8***	6.2
90% CI Lower Bound	2.6	5.5	5.0
90% CI Upper Bound	7.7	8.1	7.4
Standard Deviation	6.2	5.2	5.6
Minimum (Best)	0.0	0.0	0.0
10th Percentile	0.0	0.0	0.0
Median	4.0	6.0	5.0
90th Percentile	9.1	13.7	13.4
Maximum (Worst)	28.3	19.1	28.3

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

Figure 21 shows that about two-thirds of sites have duct leakage to outside values below (better than) the maximum allowed by the 2009 IECC.

Figure 21: Duct Leakage to Outside

In the 2012 IECC, the metric for duct leakage changed from leakage to outside to total duct leakage. The 2012 IECC specifies total duct leakage of 4.0 CFM25/100 sq. ft. of CFA or less. Total duct leakage measures the total leakage of the duct system, regardless of where the leaks are. In sampled homes, the average total duct leakage is 18.7 CFM25 per 100 square feet of conditioned floor area. Ducts in custom homes show 26% lower total duct leakage on average compared to spec homes, which is a significant difference (Table 110). Total duct leakage was not measured for eight homes (four custom and four spec) because either the test equipment could not reach adequate test pressure in the ducts or there were registers that could not be sealed.

Table 110: Total Duct Leakage (CFM25/100 ft^2)

	Custom	Spec	All Homes (Weighted)
n (duct systems)	*17*	*38*	*55*
Average	15.4	20.7	18.7
90% CI Lower Bound	12.3	17.7	16.4
90% CI Upper Bound	18.4	23.7	20.9
Standard Deviation	7.1	10.8	9.9
Minimum (Best)	2.9	6.6	2.9
10th Percentile	5.4	8.2	7.8
Median	15.4	17.7	16.6
90th Percentile	27.2	36.8	34.8
Maximum (Worst)	30.3	48.9	48.9

* Significantly different at the 90% confidence level.

Total duct leakage values cover a wider range than leakage to outside (Figure 22). Roughly two-thirds of duct systems exceed (i.e., are leakier than) the 2009 IECC maximum allowable total duct leakage standard of 12 CFM25/100 sq. ft. of CFA. (Homes can fail this standard but still meet the 2009 IECC based on having acceptable levels of LTO.)

Figure 22: Total Duct Leakage

Compliance rates with the 2009 IECC duct leakage requirements are shown in Table 111. The 2009 IECC requires duct leakage to outside to be less than or equal to 8 CFM25 per 100 square feet of conditioned floor area *or* total leakage less than or equal to 12 CFM25 per 100 square feet of conditioned floor area. As shown, three fourths of homes with ducts meet mandatory duct leakage requirements. Custom homes are significantly more likely to comply with 2009 IECC duct leakage requirements compared to spec homes.

Table 111: Compliance with Mandatory Duct Leakage Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*42*	*60*
Complies	**94%***	**67%***	75%
Fails	**6%***	**33%***	25%

*Significantly different at the 90% confidence level.

7.3 Duct Insulation

This analysis explores the R-value of duct insulation alone, excluding any additional protection afforded by the uncommon practice of burying ducts in ceiling insulation.[90]

Table 112: Insulation R-value for Ducts in Unconditioned Space by Location

Location	Custom	Spec	All Homes (Weighted)
Attic supply	6.9±1.0 (n=14)	6.2±0.7 (n=26)	6.5±0.6 (n=40)
Uncond. (excl. attic supply)	6.4±0.7 (n=20)	5.4±0.7 (n=37)	5.8±0.5 (n=57)
Unconditioned basement	6.1±0.9 (n=16)	5.1±0.9 (n=24)	5.6±0.6 (n=41)
Attic return	7.0±0.6 (n=14)	6.3±0.7 (n=27)	6.6±0.5 (n=41)
Other	6.1 (n=1)	6.0±0.6 (n=5)	6.0±0.7 (n=6)

No significant differences at the 90% confidence level.

Statewide, 62% of homes (83% custom, 45% spec) have some attic supply ducts that are insulated to R-8 or greater. R-8 is the requirement for attic supply ducts in both the 2009 IECC and 2012 IECC. Overall compliance with the 2009 IECC code requirements, shown in Table 113, is slightly lower due to un(der)insulated duct areas.

[90] Five of fifty-seven homes had some duct work covered by ceiling insulation. Two custom homes and one spec home had fully R-8 attic supply ducts covered by insulation, another spec home had a mixture of exposed and under-ceiling insulation ducts, and finally one custom home had ducts in a bed of blown-in cellulose.

Table 113: Attic Supply Duct Insulation vs. 2009 IECC Prescriptive Code Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*14*	*26*	*40*
Below code (<R8)	**50%***	**65%***	59%
At code (=R8)	43%	31%	36%
Above code (>R8)	7%	4%	5%

* Significantly different at the 90% confidence level.

Both the 2009 and the 2012 IECC require all other ducts in unconditioned space to have R-6 insulation. As outlined in Table 114, three quarters of all homes (74%) comply with insulation code requirements for non-attic supply ducts in unconditioned space.

Table 114: Unconditioned Duct Insulation (Excluding Attic Supply) vs. 2009 IECC Prescriptive Code Requirements

	Custom	Spec	All Homes (Weighted)
n (homes)	*20*	*37*	*57*
Below code (<R6)	15%	35%	27%
At code (=R6)	20%	22%	23%
Above code (>R6)	65%	43%	51%

No statistically significant differences at the 90% confidence level.

7.4 Duct and Insulation Types

All homes were constructed with a mixture of sheet metal and flexible ducts. Table 115 summarizes the fraction of total duct length each combination of duct material and insulation account for in different parts of the home.

Overall, flex duct is the most common form of ductwork and fiberglass (either built into flex duct or wrapped around sheet metal) is the most common form of insulation. It appears that bubble-wrapped metal ducts are more common in unconditioned basements than attics, but the difference is not statistically significant. Even so, the use of foil-faced bubble wrap insulation is controversial because some critics claim that 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.[91] In this analysis, the value indicated on the insulation was used for all calculations.

Uninsulated ducts in unconditioned space were observed in 14% of homes: five basements (one custom, four spec) and three attics (one custom, two spec). The uninsulated ductwork

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[91] 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/ Although flex duct insulation levels are not without their own issues of misapprehension/misrepresentation http://aceee.org/files/proceedings/2006/data/papers/SS06_Panel1_Paper18.pdf

represented 3 to 33% of supply duct area and 10 to 25% of return duct area. The 25% uninsulated return duct is due to the presence of panned joists in a custom home.

Table 115: Duct Material and Insulation Area by Location

Duct Location and Construction			Custom	Spec	All Homes
		n (homes)	*14*	*27*	*41*
Attic	Flex	Fiberglass	52%	57%	55%
	Metal	Bubble	19%	13%	15%
		Fiberglass	29%	29%	29%
		Uninsulated	<1%	2%	1%
		n (homes)	*2*	*8*	*10*
Other	Flex	Fiberglass	--	61%	54%
	Metal	Fiberglass	39%	--	4%
		Bubble	61%	39%	41%
		n (homes)	*16*	*24*	*40*
Uncond. basement	Flex	Fiberglass	44%	41%	42%
	Joist pan	Uninsulated	1%	--	1%
	Metal	Bubble	21%	26%	24%
		Fiberglass	33%	30%	31%
		Uninsulated	--	3%	1%

No statistically significant differences at the 90% confidence level.

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:

- ***About 90% of the sampled homes complied with the 2009 IECC air infiltration requirement of 7 ACH50 or less.***
- ***The average ACH50 is 4.9. The average value of custom homes is 4.6, and 5.1 for spec homes, but this is not a significant difference.***

8.1 Blower Door Test Results

Inspectors conducted blower door tests at all 70 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 average ACH50 was 4.9, with no significant differences between custom and spec homes (Table 116). The overall range was quite broad: from around 1 ACH50 to over 12.

Table 116: Air Infiltration

ACH50	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Average	4.6	5.1	4.9
90% CI Lower Bound	3.7	4.7	4.5
90% CI Upper Bound	5.4	5.5	5.3
Standard Deviation	2.4	1.7	2.0
Minimum	1.2	1.8	1.2
10th Percentile	1.5	2.9	2.6
Median	4.2	5.0	4.5
90th Percentile	7.7	7.4	7.5
Maximum	12.4	9.7	12.4

No statistically significant differences at the 90% confidence level.

Figure 23 graphically displays the distribution of homes' ACH50 values, the vast majority of which fall far below the 2009 IECC requirement of 7.

Figure 23: Air Infiltration (ACH50)

The 2009 IECC requires an ACH50 of no more than 7, while the 2012 IECC requires no more than 3. Eighty-nine percent of homes met this requirement, while 11% did not. There are no statistically significant differences between custom and spec homes in terms of compliance with the 2009 IECC (Table 117).

Table 117: Compliance with 2009 IECC Air Infiltration Requirement (ACH50 ≤ 7)

	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Complies	88%	89%	89%
Fails	12%	11%	11%

No statistically significant differences at the 90% confidence level.

9

Section 9 Ventilation

Data were 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. [92]

Key findings include the following:

- ***Mechanical ventilation systems were present in 11% of homes, including two homes with bath automatic bathroom exhaust fans, two homes with HRVs, and three homes with ERVs.***

Bathroom fans. Two homes had bathroom fan ventilation systems. Both ventilation systems ran on a timer control. In one home, fans ran for two hours throughout the day, and in the other, the system ran continuously.

HRVs. Two homes had HRV systems with the following specifications:

- **Efficiency.** Sensible recovery efficiencies of 60% and 71%.
- **Flow Rates.** 149 CFM and 117 CFM.
- **Controls.** One dehumidistat and one timer.

ERVs. Three homes had ERV systems, with the following specifications:

- **Efficiency.** Sensible recovery efficiencies of 64%, 67%, and 72%; total recovery efficiencies of 61%, 46%, and 48%, respectively.
- **Flow rates.** 120, 297, and 106 CFM.
- **Controls.** Two timers and one dehumidistat.

[92] 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 presents the findings from the lighting inventory performed during on-site inspections.

Key findings include the following:

- ***LED bulbs are the most common lamp type, filling 40% of all sockets. Efficient lamps (LEDs, CFLs, and fluorescents) fill 54% of all sockets.***
- ***Sixty-two percent of all homes meet the 2009 IECC requirement that 50% of lamps in hard-wired fixtures use high-efficiency lamps.***
- ***Compared to spec homes, custom homes are significantly more likely to have CFL and LED lamps installed in sockets and fixtures, significantly less likely to have incandescent lamps installed, and significantly more likely to meet 2009 IECC prescriptive lighting requirements.***

10.1 Lighting Data Collection

Auditors collected data on all light fixtures, including the location, fixture type (hard-wired or plug-in),[93] number of sockets, and lamp types. Lamp types considered to be energy-efficient are compact fluorescents (CFLs), light-emitting diodes (LEDs, including integrated LED fixtures), and fluorescent tubes. Inefficient types include incandescent, halogen, and other uncommon types, such as xenon. Because 88% percent of all lamps were installed in hard-wired fixtures, the analyses below include either all lamps or only those in hard-wired fixtures (as indicated in table titles).

10.2 Lighting Results

Forty-six percent of sockets have inefficient lamps installed and 54% have efficient varieties (LEDs, CFLs, or fluorescent bulbs) (Table 118). Across all custom homes, there is a significantly higher percentage of efficient lamps than in spec homes (62% vs. 48%).[94] On average, there are 120 sockets per home.

[93] Hard-wired fixtures are permanently installed fixtures (e.g., ceiling fixtures, sconces, vanity fixtures, etc.); plug-in fixtures are removable, non-permanent fixtures that plug in to an outlet (e.g., task lamps).

[94] There are statistically significant differences between custom and spec homes in the percentage of sockets containing LEDs, CFLs, and fluorescents, in addition to the percentage with efficient vs. inefficient bulbs.

Table 118: Socket Saturation (All Fixture Types)

	Custom	Spec	All Homes (Weighted)**
n (homes)	*3,097*	*5,201*	*8,298*
% of sockets containing LED lamps	**50%***	**31%***	40%
% of sockets containing CFL lamps	**7%***	**14%***	11%
% of sockets containing fluorescent tubes	**5%***	**3%***	4%
% of sockets containing inefficient lamps	**38%***	**52%***	46%

*Statistically significant at the 90% confidence level. Significance tested at the socket level, not home level.

Table 119 shows the differences in the proportions of hard-wired sockets containing efficient lamp types in custom and spec homes, most of which are not statistically significant.

Table 119: Energy Efficient Lamp Saturation in Hard-Wired Fixtures

Percent of Sockets with Energy-Efficient Lamp	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
10% or less	--	4%	3%
11% to 30%	8%	20%	15%
30% to 49%	17%	24%	21%
50% to 74%	29%	28%	29%
75% to 100%	**46%***	**24%***	33%

*Statistically significant at the 90% confidence level.

The 2009 IECC specifies that a minimum of 50% of the lamps in permanently installed lighting fixtures shall be high-efficacy lamps.[95] Sixty-two percent of homes meet the 2009 IECC requirements.[96] Custom homes are significantly more likely to meet this requirement than spec homes (75% vs. 52%). If we were to compare these results to 2012 IECC requirements, where 75% of lamps in permanently installed fixtures are required to be high efficacy lamps, the compliance rate would drop to 33%. Like with 2009 IECC requirements, custom homes would be significantly more likely to meet 2012 IECC requirements.

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[95] 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 explained here: https://www.energycodes.gov/sites/default/files/documents/cn_high-efficacy_lighting_in_new_homes.pdf. This requirement does not apply to homes that follow the performance path for code compliance.
[96] Thirty-three percent meet the 2012 IECC requirement that 75% of lamps in permanent fixtures need to be high efficacy.

Table 120: Compliance with 2009 IECC Prescriptive Lighting Requirement

Percent of Fixtures with Energy-Efficient Lamps in the Home	Custom	Spec	All Homes (Weighted)
n (homes)	*24*	*46*	*70*
Less than 50% of hard-wired fixtures with high efficacy lamps	**25%***	**48%***	38%
50% or more hard-wired fixtures with high efficacy lamps	**75%***	**52%***	62%

*Statistically significant at the 90% confidence level.

Table 121 shows the proportion of all sockets containing energy-efficient lamps by room type – efficient lamps saturation ranges from 47% to 69% for all room types. Laundry and utility rooms (along with the "other" category – which contains closets and less-common room types) have among the highest levels of energy-efficient lamp saturation across the three samples. Dining rooms (44%) and foyers (56%) show the lowest efficient lamp saturation in custom homes, while bedrooms and exterior areas have the lowest rates in spec homes, at 46% each. In the statewide sample, dining rooms (47%) and exterior areas (51%) have the lowest efficient lamp saturation rates.

Table 121: Percent of Sockets (All Fixture Types) Containing Energy-Efficient Bulbs by Room

Room Type	Custom		Spec		Statewide	
	Number of Homes	Avg. % of Sockets with EE Lamps	Number of Homes	Avg. % of Sockets with EE Lamps	Number of Homes	Avg. % of Sockets with EE Lamps (Weighted)
Other	23	74%	42	65%	65	69%
Laundry/ utility	21	72%	43	65%	64	68%
Basement	22	75%	35	57%	57	65%
Hall	24	68%	43	63%	67	65%
Kitchen	24	69%	46	60%	70	64%
Garage	20	64%	46	61%	66	62%
Office	15	77%	31	52%	46	62%
Bath	24	68%	46	51%	70	58%
Attic	15	64%	22	49%	37	56%
Foyer	19	56%	36	54%	55	55%
Living	24	59%	46	52%	70	55%
Bedroom	24	61%	46	46%	70	52%
Exterior	24	60%	45	46%	69	51%
Dining	18	44%	38	49%	56	47%

Significance testing not performed for room level data.

11

Section 11 Appliances

This section summarizes findings on the sampled homes' appliances, including refrigerators (both primary and secondary), freezers, dishwashers, ovens and ranges, clothes washers, dryers, and dehumidifiers.

Key findings include the following:

- ***ENERGY STAR qualified appliances are prevalent in newly constructed homes. ENERGY STAR primary refrigerators (68%), dishwashers (93%), clothes washers (85%), and dehumidifiers (91%) were especially common.***

- ***Primary Refrigerators. Every home had at least one refrigerator. Two-thirds (68%) of primary refrigerators were ENERGY STAR products. Across the sample, 53% of primary refrigerators were larger than 25 cubic feet. The average rated energy usage was 628 kWh/year.***

- ***Secondary Refrigerators. Forty-four percent of homes had at least one secondary refrigerator. Secondary refrigerators differed from primary refrigerators in that they tended to be older, smaller, less energy efficient, and have a top freezer or single door configuration. Only 14% of homes had standalone freezers, and three of them (27%) were ENERGY STAR qualified.***

- ***Dishwashers. All but two of the 70 homes had a dishwasher, and one home had two. Ninety-three percent of dishwashers were ENERGY STAR qualified. The average rated energy usage was 267 kWh/year.***

- ***Ranges. Forty percent of ranges were natural gas, 37% were propane, and 23% were electric. Thirty-two percent of electric ranges were induction models.***

- ***Clothes Washers. Clothes washers were present in every home, including two homes with two washers. Of the 72 clothes washers in the sample, 85% were ENERGY STAR qualified. Of the washers with available information, 167 kWh/year is the average rated energy usage and 2.29 is the average integrated modified energy factor.***

- ***Clothes Dryers. Clothes dryers were present in every home, including two homes with two dryers. Twenty-two percent of dryers were ENERGY STAR qualified, and eighty-five percent were electric. Seventy-eight percent had a moisture sensor feature. The average energy factor (of those with available information) is 3.56. Spec homes were significantly more likely to have an ENERGY STAR dryer than custom homes (31% vs. 8%).***

- ***Dehumidifiers. Dehumidifiers were present in 30% of homes and 91% were ENERGY STAR models.***

11.1 Primary Refrigerators

The refrigerator that was used most was considered the "primary" refrigerator. Table 122 displays the ENERGY STAR status, volume, and configuration of these refrigerators. Over 93% of primary refrigerators were manufactured since 2014.

ENERGY STAR. Two-thirds (68%) of the primary refrigerators in the sample are ENERGY STAR qualified. 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.[97]

Volume. Fifty-three percent of primary refrigerators were larger than 25 cubic feet and 95% were greater than 20 cubic feet.

Configuration. Two-thirds of primary refrigerators have a bottom freezer configuration (68%). Bottom freezer models (68%) were significantly more likely to be ENERGY STAR qualified than side-by-side (29%) models.

Table 122: Primary Refrigerators

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*24*	*46*	*70*
ENERGY STAR Status			
Yes	75%	63%	68%
No	25%	37%	32%
Volume (ft^3)			
<16	8%	--	4%
16-19	--	2%	1%
20-22	17%	26%	22%
23-25	21%	20%	20%
>25	54%	52%	53%
Configuration			
Bottom freezer	71%	65%	68%
Side by side	21%	33%	28%
Top freezer	8%	2%	5%

No significant differences at the 90% confidence level.

Table 123 summarizes the annual electricity consumption of all primary refrigerators.[98] The average rated annual energy usage is 628 kWh/year, and there are no significant differences

[97] Source: https://www.energystar.gov/products/appliances/refrigerators/key_product_criteria
[98] Unlike ENERGY STAR ratings, electric consumption figures do not factor in varying sizes of refrigerators and are thus not a good indicator of efficiency.

between custom and spec homes. There is a range of 573 kWh/year between the lowest and highest consumption refrigerators.[99]

Table 123: Primary Refrigerator Rated Energy Consumption (kWh/Year)

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*24*	*46*	*70*
Average	629	627	628
90% CI Lower Bound	*580*	*602*	*604*
90% CI Upper Bound	*670*	*653*	*652*
Standard Deviation	*139.5*	*103.5*	*118.6*
Minimum	312	442	312
10th Percentile	*429*	*480*	*456*
Median	690	634	642
90th Percentile	*757*	*757*	*753*
Maximum	832	885	885

No statistically significant differences at the 90% confidence level.

11.2 Secondary Refrigerators

The key findings about the secondary refrigerators in sampled homes are described below, and Table 124 provides additional detail. This analysis of secondary refrigerators generally excludes five wine coolers, for which data were inconsistently available. Forty-four percent of homes had at least one secondary refrigerator.

ENERGY STAR. Less than one-fourth (23%) of secondary refrigerators were ENERGY STAR qualified. Spec homes were significantly more likely to have an ENERGY STAR secondary refrigerator.

Volume. The majority (61%) of secondary refrigerators were less than 10 cubic feet, and only 2% were larger than 25 cubic feet. This is to be expected since over half of the secondary refrigerators are mini-fridges or beverage centers. Spec homes were significantly more likely to have medium-size refrigerators (10 to 15 cubic feet), while custom homes were significantly more likely to have larger secondary refrigerators, between 20 and 22 cubic feet.

Age. In the sample, 67% of secondary refrigerators were manufactured since 2014. The oldest secondary refrigerator was manufactured in the early 1970's. Spec homes were significantly more likely to have a secondary refrigerator manufactured in 2016.

Configuration. Statewide, top freezers were the most frequent configuration for secondary refrigerators by a slim margin. Over half (56%) of secondary refrigerators were either a mini fridge or wine fridge configuration. Secondary refrigerators in spec homes were significantly more likely to have a single door configuration.

[99] The lowest consumption primary refrigerator (312 kWh/year) was also small for a primary refrigerator, with a volume of only 10 cubic feet.

Table 124: Secondary Refrigerators

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*13*	*28*	*41*
ENERGY STAR Status			
No	85%	64%	72%
Yes	**8%***	**32%***	23%
Don't know	7%	4%	5%
Volume (ft^3)			
<10	62%	61%	61%
10-15	**0%***	**14%***	9%
16-19	8%	18%	14%
20-22	**31%***	**4%***	14%
>25	--	4%	2%
Age			
1970-1975	--	4%	2%
1996-2000	8%	--	3%
2001-2005	15%	--	6%
2006-2010	8%	7%	7%
2011	--	4%	2%
2012	--	4%	2%
2013	8%	4%	5%
2014	23%	14%	18%
2015	31%	25%	27%
2016	**0%***	**36%***	22%
Don't know	8%	4%	5%
Configuration			
Top freezer	31%	32%	32%
Beverage center	31%	29%	29%
Mini fridge	31%	25%	27%
Single door	**0%***	**11%***	7%
Bottom freezer	7%	--	3%
Side by side	--	4%	2%

*Significantly different at the 90% confidence level

Table 125 shows the electric consumption of the secondary refrigerators for those that had rated energy consumption data available.[100] The large range from the lowest to the biggest consumers is partially due to a large variance in size among secondary refrigerators. The average is 360 kWh/year, which is 57% of the average primary refrigerator's rated energy

[100] Electrical consumption data were unavailable for eight secondary refrigerators. Factors included: nameplates being inaccessible, old age, and lack of product information available.

consumption; secondary refrigerators were, on average, about 40% the size of primary refrigerators.

Table 125: Secondary Refrigerator Rated Energy Consumption (kWh/yr)

	Custom	Spec	All Homes (Weighted)
n (refrigerators)	*12*	*25*	*37*
Average	398	337	361
90% CI Lower Bound	318	303	326
90% CI Upper Bound	478	370	396
Standard Deviation	154.1	99.1	125.0
Minimum	240	160	160
10^{th} Percentile	243	204	207
Median	436	336	337
90^{th} Percentile	691	483	514
Maximum	745	517	745

No statistically significant differences at the 90% confidence level.

11.3 Freezers

There were only ten (14%) sampled homes with standalone freezers. Table 126 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.

ENERGY STAR. Three (27%) standalone freezers were ENERGY STAR qualified.

Volume. Over half (52%) of freezers have a volume between five and 15 cubic feet. One-fifth (18%) of freezers had a volume greater than 20 cubic feet.

Age. In the sample, 45% of freezers were manufactured since 2014. The oldest freezer was manufactured between 1986-1990. Overall, spec homes had newer freezers compared to custom homes.

Configuration. Sixty-one percent of freezers were upright and 39% were chest configurations.

Table 126: Freezers

	Custom	Spec	All Homes (Weighted)
n (freezers)	*3*	*7*	*10*
ENERGY STAR Status			
Yes	--	3 (43%)	3 (27%)
No	3 (100%)	4 (57%)	7 (73%)
Volume (ft^3)			
<5	--	1 (14%)	1 (9%)
5-10	--	3 (43%)	3 (27%)
10-15	2 (67%)	--	2 (25%)
15-20	--	1 (14%)	1 (9%)
>20	--	2 (29%)	2 (18%)
DK	1 (33%)	--	1 (13%)
Age			
1986-1990	1 (33%)	--	1 (13%)
1996-2000	--	1 (14%)	1 (9%)
2001-2005	1 (33%)	--	1 (13%)
2006-2010	1 (33%)	--	1 (13%)
2011-2013	--	1 (14%)	1 (9%)
2014	--	1 (14%)	1 (9%)
2015		3 (43%)	3 (27%)
2016	--	1 (14%)	1 (9%)
Configuration			
Upright	2 (67%)	4 (57%)	6 (61%)
Chest	1 (33%)	3 (43%)	4 (39%)

Not tested for statistical significance.

Energy consumption data were available for nine freezers (Table 127). The overall average rated energy consumption was 433 kWh/year.

Table 127: Freezer Rated Energy Consumption (kWh/yr)

	Custom	Spec	All Homes (Unweighted)
n (freezers)	*2*	*7*	*9*
Average	488	419	434
90% CI Lower Bound	355	234	292
90% CI Upper Bound	1330	603	576
Standard Deviation	188.8	250.7	229.2
Minimum	354	172	172
10th Percentile	354	172	172
Median	488	298	354
90th Percentile	**	**	**
Maximum	621	816	816

Not tested for statistical significance.

11.4 Dishwashers

Of the sampled homes, 68 of the 70 had dishwashers, and one home had two. 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.[101] Almost every dishwasher (93%) was ENERGY STAR qualified at the time of manufacture.

Table 128: Dishwasher ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*47*	*69*
Yes	96%	92%	93%
No	4%	8%	7%

No statistically significant differences at the 90% confidence level.

Most dishwashers were manufactured in 2014 (45%) (Table 129).

[101] Source: https://www.energystar.gov/products/appliances/dishwashers

Table 129: Dishwasher Age

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*47*	*69*
2014	55%	38%	45%
2015	32%	40%	37%
2016	14%	21%	18%

No statistically significant differences at the 90% confidence level.

Table 130 shows the rated energy consumption of all dishwashers. The average for all dishwashers was 267 kWh/year. As of January 26, 2016, the ENERGY STAR criterion for dishwashers is 270 kWh/year; statewide, 84% of the dishwashers in inspected homes met the new ENERGY STAR criterion,[102] though only 18% of dishwashers in the sample were manufactured in 2016.

Table 130: Dishwasher Rated Energy Consumption

	Custom	Spec	All Homes (Weighted)
n (dishwashers)	*22*	*47*	*69*
Average	268	267	267
90% CI Lower Bound	262	264	264
90% CI Upper Bound	273	270	270
Standard Deviation	14.6	11.4	12.5
Minimum	240	231	231
10th Percentile	258	259	259
Median	265	268	268
90th Percentile	291	279	280
Maximum	307	307	307

No statistically significant differences at the 90% confidence level.

11.5 Ovens and Ranges

"Oven and range" refers to a standard combined oven and range unit. "Oven only" and "range only" types signify ovens and ranges that were separate units. Most units (60%) were combined ovens and ranges. Table 131 shows the types of ovens and ranges found during

102 https://www.energystar.gov/products/appliances/dishwashers/key_product_criteria

on-site inspections. Overall, 72% of ovens were convection ovens. One-fourth of ovens were electric; 23% of ranges were electric, and of those, 32% were induction.

Table 131: Oven and Range Types

	Custom	Spec	All Homes (Weighted)
n (systems)	*33*	*60*	*93*
Oven and range	55%	63%	60%
Oven only	24%	22%	23%
Range only	21%	15%	18%

No statistically significant differences at the 90% confidence level.

The fuel type for all ranges and ovens is displayed in Table 132 and Table 133. Natural gas was most prevalent in both ranges and ovens. Spec homes were significantly more likely to have natural gas for both range and oven, while custom homes were significantly more likely to have propane fuel for both range and oven. This is likely due to more custom homes being built in locations without natural gas infrastructure.

Table 132: Range Fuel

	Custom	Spec	All Homes (Weighted)
n (ranges)	*25*	*47*	*72*
Natural gas	**16%***	**57%***	40%
Propane	**52%***	**26%***	37%
Electric	32%	17%	23%

*Significantly different at the 90% confidence level

Table 133: Oven Fuel

	Custom	Spec	All Homes (Weighted)
n (ovens)	*26*	*51*	*77*
Natural gas	**19%***	**55%***	40%
Propane	**50%***	**24%***	34%
Electric	31%	22%	25%

*Significantly different at the 90% confidence level

11.6 Clothes Washers

Clothes washers were present at all 70 homes. Two homes had two clothes washers. Only two homes had clothes washers located in unconditioned space. Altogether, there were 72 clothes washers surveyed during on-site inspections: 42 front load and 30 top load models.

Of the sampled homes, 85% of all clothes washers were ENERGY STAR qualified. Table 134 shows the ENERGY STAR status for all clothes washers.[103] All front load washers were ENERGY STAR qualified compared to only 67% of top load washers. Front load washers were significantly more likely to be ENERGY STAR qualified than top load washers.

Table 134: Clothes Washer ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (washers)	*24*	*48*	*72*
Yes	79%	90%	85%
No	17%	10%	13%
Don't know	4%	--	2%

No statistically significant differences at the 90% confidence level.

Table 135 shows the rated energy consumption of all the clothes washers[104]. The average statewide rated consumption of clothes washers was 167 kWh/year.

Table 135: Clothes Washer Rated Energy Consumption

	Custom	Spec	All Homes (Weighted)
n (washers)	*19*	*48*	*67*
Average	147	153	151
90% CI Lower Bound	130	134	137
90% CI Upper Bound	164	171	164
Standard Deviation	42.9	75.8	65.9
Minimum	100	85	85
10th Percentile	109	90	92
Median	130	129	130
90th Percentile	220	257	243
Maximum	241	470	470

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 (MEF).[105] The IMEF is the same as the MEF with an additional factor for low-power mode energy consumption.[106] The higher the IMEF, the more energy efficient the clothes washer is. The average IMEF was similar between custom and spec homes, as shown in Table 136.

[103] ENERGY STAR certified clothes washers use 25% less energy and 40% less water than regular washers.
[104] Energy consumption data for three clothes washers were unavailable.
[105] A conversion factor was applied to all clothes washers were only MEF data were available to determine the equivalent IMEF. IMEF = (MEF-.503)/.95.
[106] https://www.energystar.gov/products/appliances/clothes_washers/key_product_criteria

Table 136: Clothes Washer IMEF

	Custom	Spec	All Homes (Weighted)
n (washers)	*16*	*47*	*63*
Average	2.36	2.25	2.29
90% CI Lower Bound	2.15	2.10	2.17
90% CI Upper Bound	2.57	2.40	2.41
Standard Deviation	0.479	0.614	0.573
Minimum	1.29	0.83	0.83
10th Percentile	1.49	1.29	1.29
Median	2.38	2.38	2.38
90th Percentile	2.87	2.93	2.92
Maximum	2.93	3.10	3.10

No statistically significant differences at the 90% confidence level.

11.7 Dryers

Dryers were present at all sampled homes, and two homes had two dryers. Two homes have dryers in unconditioned space. A majority (85%) of dryers were electric.

Table 137 shows that 22% of dryers were ENERGY STAR qualified. ENERGY STAR qualified dryers use 20% less energy than conventional models.[107] Spec homes (31%) were significantly more likely to have an ENERGY STAR qualified dryer than custom homes (8%). The ENERGY STAR standard for dryers is relatively new, going into effect in early 2015.

Table 137: Dryer ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*48*	*72*
Yes	**8%***	**31%***	22%
No	83%	69%	75%
Don't know	8%	--	3%

*Significantly different at the 90% confidence level

The fuel type for each dryer is displayed in Table 138. Most dryers use electricity (85%), followed by natural gas (10%), and propane (5%). Notably, the electric dryer saturation (85%) is much higher than the electric penetration of ranges and ovens (23% and 25%, respectively).

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

Table 138: Dryer Fuel

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*49*	*72*
Electric	88%	83%	85%
Natural gas	**4%***	**15%***	10%
Propane	8%	2%	5%

*Significantly different at the 90% confidence level

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 78% of dryers.

Table 139: Dryer Moisture Sensor Status

	Custom	Spec	All Homes (Weighted)
n (dryers)	*24*	*48*	*72*
Yes	71%	83%	78%
No	29%	17%	22%

No statistically significant differences at the 90% confidence level.

Table 140 shows the Energy Factor ratings for dryers.[108] Energy factor data were available for 92% of dryers in the sample. The statewide average energy factor was 3.56.

Table 140: Dryer Energy Factor

	Custom	Spec	All Homes (Weighted)
n (dryers)	*21*	*45*	*66*
Average	3.44	3.64	3.56
90% CI Lower Bound	3.27	3.51	3.46
90% CI Upper Bound	3.63	3.77	3.67
Standard Deviation	0.475	0.506	0.499
Minimum	2.71	2.67	2.67
10th Percentile	3.01	3.30	3.02
Median	3.30	3.73	3.73
90th Percentile	4.22	4.43	4.33
Maximum	4.50	4.52	4.52

No statistically significant differences at the 90% confidence level.

[108] 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.

11.8 DEHUMIDIFIERS

Dehumidifiers were present at 21 (30%) of the sampled homes, and three homes had two dehumidifiers. Nine-tenths of dehumidifiers were ENERGY STAR qualified (Table 141).[109]

Table 141: Dehumidifier ENERGY STAR Status

	Custom	Spec	All Homes (Weighted)
n (dehumidifiers)	*9*	*15*	*24*
Yes	89%	93%	91%
No	11%	7%	9%

Not tested for statistical significance.

Most dehumidifiers (63%) were manufactured after 2012, 30% were manufactured in 2012 or earlier, and 7% had undeterminable ages.

Table 142: Dehumidifier Age

	Custom	Spec	All Homes (Weighted)
n (dehumidifiers)	*9*	*15*	*24*
2001-2005	11%	--	5%
2006-2010	11%	27%	20%
2011	11%	--	5%
2013	--	7%	4%
2014	--	13%	7%
2015	44%	33%	38%
2016	22%	7%	14%
Don't know	--	13%	7%

Not tested for statistical significance.

[109] As of October 25th, 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.

12

Section 12 Renewable Energy

Of the 70 inspected homes, only five homes (7%, weighted) had solar photovoltaic (PV) systems for on-site power generation: three spec homes and two custom homes. There were no homes with wind power or solar thermal hot water systems.

Array Area. Average square footage of the photovoltaic arrays was 347 sq. ft.

Power Production. Average power production was 5.6 kilowatts, with electric power production ranging from 2.7 to 10 kilowatts.

Inverter Efficiency. The average inverter efficiency was 97% for the five photovoltaic systems.

Array Orientation. Three of the systems were oriented South, one to the West, and one to the Southeast.

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 REM/Rate energy models take into account the insulation grades; building assemblies that are recorded as having Grade I installations perform better in the energy simulation than those modeled as Grade II or Grade III, for example.

The RESNET definitions of Grade I, Grade II, and Grade III installation are provided below.[110]

> **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.

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

Figure 24 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.[111]

Figure 24: Grade I Closed-Cell Spray Foam—Exterior Walls

Figure 25 shows a Grade II install of unfaced fiberglass batts in a conditioned basement.[112] 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.

[111] 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.
[112] The basement in this case was considered conditioned volume, not conditioned floor area.

Figure 25: Grade II Fiberglass Batts—Basement Walls

Figure 26 shows R-21 fiberglass batts in a 2x4 wall cavity. This installation automatically receives a Grade III designation due to the fact that 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."

Figure 26: Grade III Fiberglass Batts—Attic Kneewalls

Figure 27 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 with substantial gaps and compression.

Figure 27: Grade II Fiberglass Batts—Frame Floor

Figure 28 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.

Figure 28: Grade III Fiberglass Batts—Frame Floor

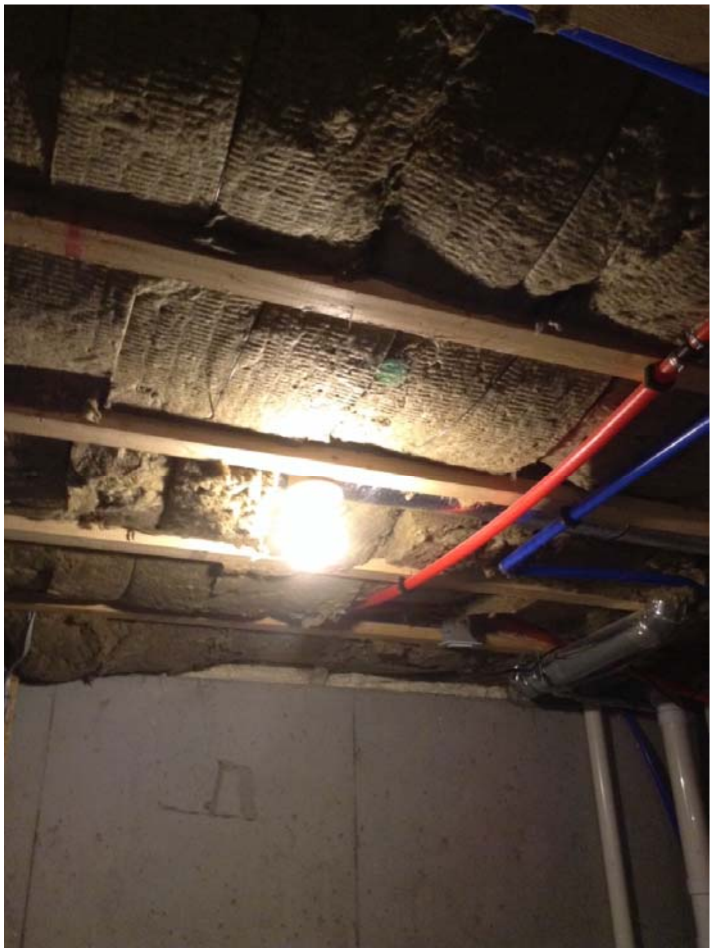


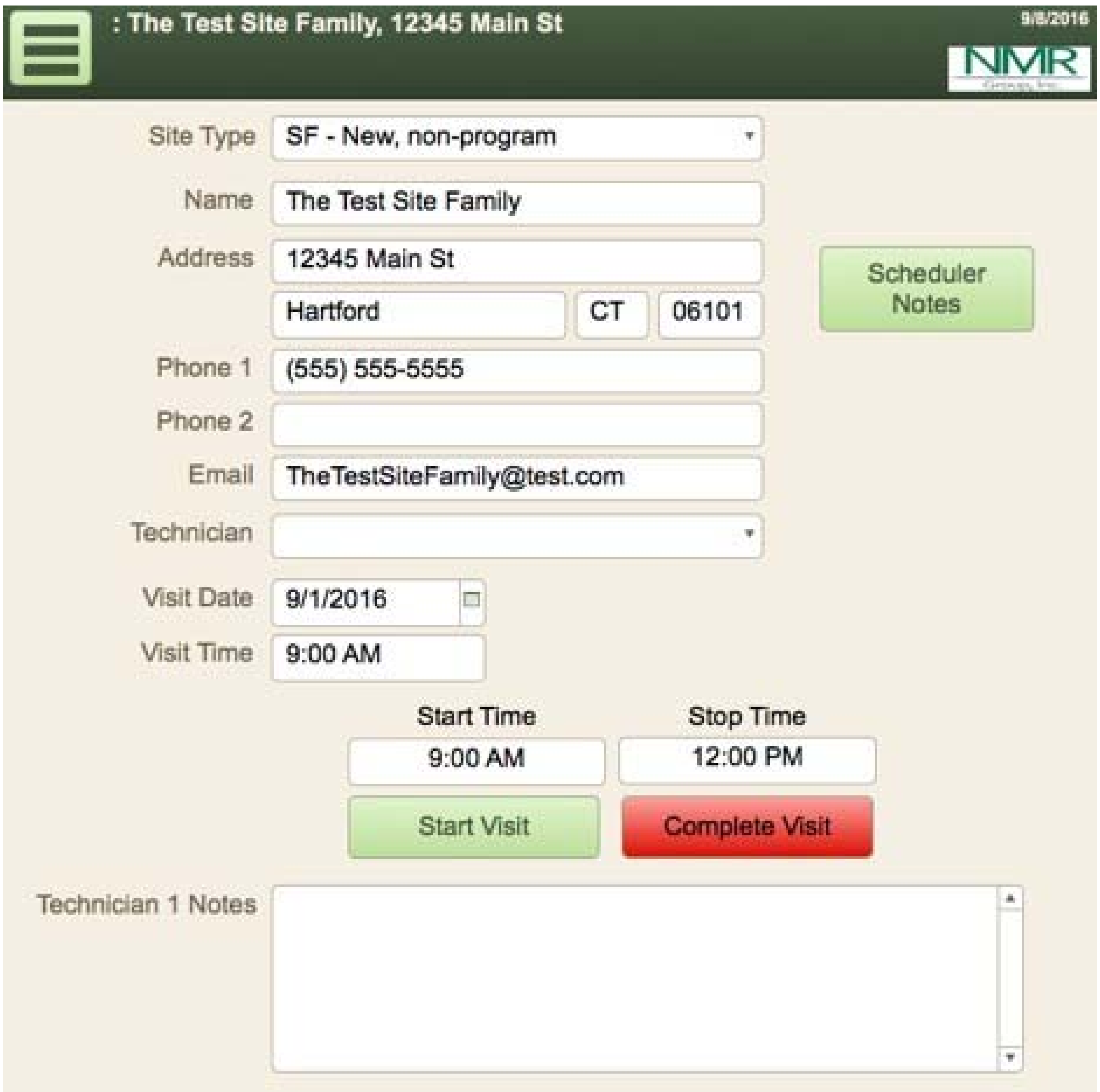
Figure 29 shows a Grade I installation of blown cellulose in an attic. This received a Grade I designation because the cellulose is blown in evenly, filling all of the cavities with no gaps or voids and little to no compression. In addition, this attic has baffles at the eaves, which is required for attic insulation to achieve a Grade I installation.

Figure 29: 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 30 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.

Figure 30: Data Collection Form Example – General Characteristics



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

While Section 5 described the details of the conditioned to ambient walls, flat and vaulted ceilings, and frame floors over unconditioned basements (the most important wall, ceiling, and floor types in terms of energy consumption), this section provides detail about the insulation and framing for other types of walls, ceilings, and floors that form smaller percentages of a home's total wall area:

- 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 Secondary Above Grade Wall Details

Walls between conditioned space and garage, unconditioned basement, or attic comprise 18% of the envelope wall area across the sample. The R-values, framing types, insulation type and grade for such walls are described individually below.

C.1.1 Conditioned to Garage Walls

Walls between conditioned space and garages comprise 9% of the total envelope wall area across the sample. Table 143 through Table 145 display data on conditioned to garage wall R-values, framing, insulation type, and grade.

R-values. The average R-value of conditioned to garage walls (19.6) nearly meets the 2009 IECC prescriptive standard of R-20. Custom homes have significantly higher R-values than do spec homes (21.3 vs 18.5). On average, conditioned to garage walls in custom homes surpass code while such walls in spec home fail to meet code (Table 143).

Table 143: Conditioned/Garage Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*43*	*64*
Average	**21.3***	**18.5***	19.6
90% CI Lower Bound	19.3	17.5	18.7
90% CI Upper Bound	23.3	19.4	20.6
Standard Deviation	5.5	3.7	4.7
Minimum	11	11	11
10th Percentile	19	13	13
Median	21	19	19
90th Percentile	27	21	21
Maximum	36	33	36

*Significantly different at the 90% confidence level.
R-value verified at 66% of homes.

Primary Framing. Like walls to ambient space, garage walls most frequently have 2x6 framing with studs spaced either 16 or 24 inches apart (81%). However, garage walls are more likely to have thinner framing than conditioned to ambient walls. One in five homes with garage walls have 2x4 framing that is too shallow to meet code prescriptive standards with conventional fiberglass batts alone. There is no significant difference between conditioned to garage walls in custom and spec homes.

Table 144: Conditioned/Garage Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	21	43	64
2x6, 16” OC	86%	74%	79%
2x4, 16” OC	10%	21%	18%
SIPS	5%	--	2%
2x6, 24” OC	--	2%	1%

There are no statistically significant differences at the 90% confidence level.
One home has a garage wall with an additional type of framing. Only primary framing is counted.

Primary Insulation. Table 145 shows the primary insulation and installation grade for conditioned to garage walls in each home. Nearly 4 out of 5 homes (79%) have fiberglass batts. Eight percent of homes use exclusively closed-cell spray foam and another 7% use open-cell spray foam. There is no significant difference between custom and spec homes in types of insulation

Only 14% of homes have insulation installed properly to Grade I. The most common installation grade is Grade II (77%). Custom homes are significantly more likely to have insulation at Grade I that spec homes primarily due to their increased likelihood to have sprayed or blown-in insulation.

Table 145: Conditioned/Garage Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*21*	*43*	*64*
Insulation Type			
Fiberglass batts	67%	86%	78%
Closed-cell spray foam	14%	5%	8%
Open-cell spray foam	10%	5%	7%
Cellulose-dense pack	5%	2%	3%
SIPS	5%	--	2%
Fiberglass batts + Closed-cell spray foam	--	2%	1%
Insulation Installation Grade			
Grade I	**29%***	**5%***	14%
Grade II	67%	84%	77%
Grade III	--	12%	7%
No cavity insulation	5%	--	2%

*Statistically significant difference at the 90% confidence level.
Insulation type was verified at 95% of homes and installation grade was verified at 37% of homes.

C.1.2 Conditioned to Unconditioned Basement Above Grade Walls

Walls between conditioned space and unconditioned basements comprise 5% of the total envelope wall area across the entire sample. Table 146 through Table 148 display data on conditioned to unconditioned basement wall R-values, framing, insulation type, and grade.

R-values. The average R-value of walls between conditioned space and unconditioned basements (14.7) is far below the code prescriptive standard of R-20 (Table 146). This low value is due to a high frequency of thin framing (discussed below with Table 147) as well as four homes that have no insulation in their basement walls at all. There is no significant difference between custom and spec homes.

Table 146: Conditioned/Unconditioned Basement Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*31*	*49*
Average	16.1	13.6	14.7
90% CI Lower Bound	14.7	11.6	13.4
90% CI Upper Bound	17.5	15.6	16.1
Standard Deviation	3.5	6.8	5.7
Minimum	12	0	0
10th Percentile	13	0	9
Median	15	13	14
90th Percentile	21	21	21
Maximum	22	21	22

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

Primary Framing. As mentioned above, the majority (58%) of conditioned to unconditioned basement walls have 2x4 framing which greatly limit the potential R-values. Using fiberglass batt insulation, which is the most commonly used type of insulation, R-20 is not achievable in 2x4 framing unless one side of the wall is unfinished. In a completely finished 2x4 wall, the maximum achievable R-value using readily available fiberglass batts is R-15. Code prescriptive standard R-values are achievable using other types of insulation such as closed-cell spray foam or open-cell spray foam and indeed four homes use spray foam in 2x4 cavities. Larger 2x6 framing is present in 39% of homes with walls to unconditioned basements. There is no significant difference in framing between custom and spec homes

Table 147: Conditioned/Unconditioned Basement Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	18	31	49
2x4, 16” OC	61%	55%	58%
2x6, 16” OC	39%	39%	39%
SIPS	--	3%	2%
2x6, 12” OC	--	3%	2%

*There are no statistically significant differences at the 90% confidence level.
Two homes have an additional framing type. Only primary framing is included in the table.

Primary Insulation. Fiberglass batts are the most common type of insulation and are present in 81% of conditioned to unconditioned basement walls. Nearly one in ten (9%) homes with walls between conditioned and unconditioned basements have no insulation in said walls. There is no significant difference in insulation types between custom and spec homes.

Only 13% of homes have insulation installed to Grade I standards. Nearly two-thirds (62%) are installed at Grade II. There is no significant difference between grade in custom and spec homes.

Table 148: Conditioned/Unconditioned Basement Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*18*	*31*	*49*
Insulation Type			
Fiberglass batts	83%	77%	81%
None	--	16%	9%
Cellulose -dense pack	6%	3%	4%
Open-cell spray foam	6%	3%	4%
Rock wool	6%	--	2%
Insulation Installation Grade			
Grade I	17%	10%	13%
Grade II	61%	61%	62%
Grade III	22%	13%	17%
No cavity insulation	--	16%	9%

There are no statistically significant differences at the 90% confidence level.
Insulation type was verified at 92% of homes and installation grade was verified at 50% of homes.

C.1.3 Conditioned to Attic Above Grade Walls

Walls between conditioned space and attics comprise 4% of the total envelope wall area across the entire sample. Table 149 through Table 151 display data on conditioned to attic wall R-values, framing, insulation type, and grade.

Primary Insulation. As shown in Table 151, fiberglass batts are present at 88% of attic walls. Closed-cell spray foam is significantly more frequent in custom homes (23%) than in spec homes (0%). Two-thirds of attic walls (68%) have Grade II insulation installations. Custom homes are significantly more likely to have Grade I (31%) installation than spec homes (4%).

R-values. As Table 149 shows, the average attic wall R-value is 20. This exactly meets the 2009 IECC prescriptive standard. There is no significant difference between custom homes and spec homes.

Table 149: Conditioned/Attic Wall R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*28*	*41*
Average	20.9	19.4	20.0
90% CI Lower Bound	17.7	17.7	18.4
90% CI Upper Bound	24.1	21.1	21.6
Standard Deviation	7.0	5.5	6.1
Minimum	13	9	9
10th Percentile	13	14	13
Median	19	19	19
90th Percentile	29	21	27
Maximum	38	38	38

No significant differences at the 90% confidence level.
R-values verified at 80% of homes.

Primary Framing. Two thirds (63%) of attic walls have 2x6 framing and one-third (32%) use 2x4 framing. There is no significant difference between custom and spec homes (Table 150).

Table 150: Conditioned/Attic Wall Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	13	28	41
2x6, 16" OC	62%	64%	63%
2x4, 16" OC	38%	29%	32%
2x4, 24" OC	--	4%	2%
2x8, 16" OC	--	4%	2%

*There are no statistically significant differences at the 90% confidence level.
Two homes have an additional framing type. Only primary framing is included in the table.

Primary Insulation. As shown in Table 151, fiberglass batts are present at 88% of attic walls. Closed-cell spray foam is significantly more frequent in custom homes (23%) than in spec homes (0%). Two-thirds of attic walls (68%) have Grade II insulation installations. Custom homes are significantly more likely to have Grade I (31%) installation than spec homes (4%).

Table 151: Conditioned/Attic Wall Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*13*	*28*	*41*
Insulation Type			
Fiberglass batts	77%	93%	88%
Closed-cell spray foam	**23%***	**--***	7%
Open-cell spray foam	--	4%	2%
Closed-cell spray foam + Fiberglass batts	--	4%	2%
Insulation Installation Grade			
Grade I	**31%***	**4%***	14%
Grade II	54%	79%	68%
Grade III	15%	18%	17%

* Statistically significant difference at the 90% confidence level.

C.2 Secondary Ceiling Details

Hatches make up less than one percent of the total ceiling area across the entire sample. Table 152 and Table 153 summarize the R-values and insulation type for hatches. There is no framing table because hatches are entrances to attics and thus don't have framing. Hatches are typically either a rectangular piece of wood that can be pushed upwards to gain attic access, or a drop down hinged wooden rectangle with fold out steps.

C.2.1 Hatch Ceiling

Table 152 shows that the average R-value for attic hatches is 13.2 and that there is no significant difference in R-values at custom and spec homes. Twenty-two homes (41% of homes with hatches) have hatches with no insulation at all.

Table 152: Hatch Ceiling R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*32*	*43*
Average	16.2	11.8	13.2
90% CI Lower Bound	9.8	7.3	9.5
90% CI Upper Bound	22.6	16.3	16.9
Standard Deviation	13.0	15.5	14.7
Minimum	0	0	0
10th Percentile	0	0	0
Median	13	0	0
90th Percentile	38	38	38
Maximum	38	38	38

No significant differences at the 90% confidence level.

Table 153 shows the types of insulation on attic hatches at each home. More homes have hatches with no insulation (43%) than any other type of insulation. Of homes with insulated hatches, fiberglass batts are the most frequent.

Table 153: Hatch Ceiling Primary Insulation Type

Wall Location	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*32*	*43*
None	**18%***	**56%***	43%
Fiberglass batts	36%	34%	34%
XPS	36%	3%	13%
EPS	9%	3%	5%
Polyisocyanurate	--	3%	2%

*Statistically significant difference at the 90% confidence level.

C.3 Secondary Frame Floor Details

The following sections characterize floors between conditioned space and ambient space, or crawl space. Together, these two types of floor make up 6% of total frame floor area across the entire sample. Floors over crawl space comprise 4%, and floors over ambient space comprise 2%.

C.3.1 Conditioned to Enclosed Crawlspace Frame Floor

Only four homes had floors over enclosed crawl space. The floors have an average R-value of 26.1. Significance testing was not performed due to small sample sizes (Table 154).

Table 154: Conditioned/Enclosed Crawlspace Frame Floor R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Unweighted)
n (homes)	*1*	*3*	*4*
Average	30	24.3	26.1
90% CI Lower Bound	30	18.2	21.2
90% CI Upper Bound	30	30.5	31.0
Standard Deviation	0	6.4	5.9
Minimum	30	17	17
10th Percentile	30	19	20
Median	30	26	28
90th Percentile	30	29	30
Maximum	30	30	30

No significant differences at the 90% confidence level.

All floors above enclosed crawl spaces have large enough cavities for R-30 insulation. Two homes have 2x10 16"OC, one has 2x12 16"OC and the last has I-joists. Samples are too small to test for significance between custom and spec homes (Table 155).

Table 155: Conditioned/Enclosed Crawl Space Frame Floor Primary Framing

Framing	Custom	Spec	All Homes (Unweighted)
n (homes)	*1*	*3*	*4*
2x10, 16" OC	1 (100%)	1 (33%)	2 (50%)
2x12, 16" OC	0 (--)	1 (33%)	1 (25%)
I-Joist	0 (--)	1 (33%)	1 (25%)

Not tested for statistical significance.

All four floors to enclosed have fiberglass batt insulation. None have grade I installation. Two have grade II installation and two have grade III installation. Samples are too small to test for significance between custom and spec homes (Table 156).

Table 156: Conditioned/Enclosed Crawl Space Frame Floor Primary Insulation Type and Grade

	Custom	Spec	All Homes (Unweighted)
n (homes)	*1*	*3*	*4*
Insulation Type			
Fiberglass batts	1	3	4
Insulation Installation Grade			
Grade I	0	0	0
Grade II	0	2	2
Grade III	1	1	2

Not tested for statistical significance.

C.3.2 Conditioned to Ambient Frame Floor

The average per-home R-value for frame floors over ambient space is 29.3 and there was no significant difference between custom and spec home (Table 157). On average, conditioned to ambient floors almost meet the 2009 IECC code prescriptive standard of R-30.

Table 157: Conditioned/Ambient Frame Floor R-Values

R-Value (Average per Home)	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*18*	*29*
Average	29.5	29.2	29.3
90% CI Lower Bound	24.9	26.7	27.0
90% CI Upper Bound	34.1	31.7	31.7
Standard Deviation	9.2	6.4	7.6
Minimum	19	13	13
10th Percentile	19	21	19
Median	30	30	30
90th Percentile	30	32	32
Maximum	54	43	54

No significant differences at the 90% confidence level.
R-values were verified at 66% of homes.

Unlike the previous floor locations, the most frequent framing type for floors over ambient space is 2x10 16” OC (47%), followed by I-joists (40%). Only one home (3%) has framing that is too shallow to achieve R-30 with typical fiberglass batts, but this was a small amount of square footage. There was no significant difference between custom and spec homes (Table 158).

Table 158: Conditioned/Ambient Frame Floor Primary Framing

	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*18*	*29*
2x10, 16” OC	36%	56%	47%
I-joist	55%	28%	40%
2x8, 16” OC	--	11%	6%
2x12, 24” OC	9%	--	4%
2x6. 16” OC	--	6%	3%

No significant differences at the 90% confidence level

Most floors over ambient space have fiberglass batt insulation (82%). Only 11% of such floors have proper Grade I insulation. There was no significant difference between custom and spec homes for either insulation type or installation grade (Table 159).

Table 159: Conditioned/Ambient Frame Floor Primary Insulation Type and Grade

	Custom	Spec	All Homes (Weighted)
n (homes)	*11*	*18*	*29*
Insulation Type			
Fiberglass batts	72%	89%	82%
Closed-cell spray foam	9%	--	4%
Open-cell spray foam	9%	11%	10%
Mineral wool batts	9%	--	4%
Insulation Installation Grade			
Grade I	18%	6%	11%
Grade II	45%	61%	55%
Grade III	36%	33%	35%

There are no statistically significant differences at the 90% confidence level.

D Appendix D Detailed Baseline Study Methodology

This section provides additional methodology detail about the baseline study beyond that described in Section 1.

D.1 Baseline Study Sampling

D.1.1 Baseline Study Sampling Methodology

The sample design targeted a representative sample of newly constructed, attached or detached, single-family homes in UI and Eversource electric service territories. The sampled homes were selected based on location, utility provider, and whether homes were spec- or custom-built. To be eligible, homes needed to meet the following criteria:

- Non-participant in the Connecticut Residential New Construction program
- Built in 2014 or 2015, to ensure construction near the end of the 2009 IECC code cycle
- 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 United Illuminating (UI) or Eversource electric service territory

D.1.2 Baseline Study Sample Targets

The on-site sample was designed to mirror the proportion of homes built in each Connecticut county in 2014 and 2015, based on county-level permit data from the U.S. Census data for one-unit buildings. A 70-home sample was developed to reach the 90% confidence level with a 10% sampling error.[113] While the sample was proportional to construction activity at the county level, town-level new construction activity was also taken into account.[114]

[113] 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.

[114] Targeting town-level proportionality was not a requirement for the study, but was an internal metric kept in mind throughout the recruiting process to ensure a representative distribution of homes within each county.

Table 160: 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	*5,196*	*100%*	*70**	*100%*
Fairfield	1,787	34%	24	34%
Hartford	926	18%	12	17%
New Haven	906	17%	12	17%
New London	526	10%	7	10%
Middlesex	305	6%	4	6%
Tolland	311	6%	4	6%
Litchfield	242	5%	3	4%
Windham	193	4%	3	4%

*The values in this column sum to 69 homes. The 70th site was left as a floating site, to be filled based on the results of the recruiting effort. The 70th site was ultimately fielded in Fairfield.
**U.S. Census, Building Permits Survey: https://www2.census.gov/econ/bps/

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 2011 baseline study (the most recent Connecticut baseline study).[115] 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)***

The last aspect of the final sampling plan was to maintain a representative proportion of homes by service territory, which required at least seven on-site inspections in UI territory.

[115] The differences between custom and spec-built homes are usually minor, but in some cases and for some measures they can significant. A minimum 60% proportion of spec homes helped ensure that custom homes were not oversampled, in case the custom homes are more efficient than spec-built homes due to the fact that homeowners typically invest more resources into custom homes. The baseline study sample approximates the program split because there is little data available about the split between custom and spec-built homes in the broader market. Previous baseline study available at: https://www.energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf.

D.1.3 Baseline Study Sample Frame Development

UI and Eversource provided address information for a total of nearly 10,000 new electric service requests submitted in their territory to provide the population of homes built in 2014 and 2015. New electric service requests are an unbiased way to identify newly-constructed homes because they include the full population of new homes within a utility service territory. However, the Connecticut new electric service request data included sites that were ineligible for the baseline study, such as renovations, multifamily projects, and commercial facilities. 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 records were screened until a sample frame of ten times the number of targeted inspections was achieved for each county.

In some counties, a mailing size of ten times the number of targeted sites was not sufficient to recruit enough sites for that county. In those cases, additional sites were reviewed from the new service request list, and additional mailings were sent to those sites.

D.1.4 Baseline Study Recruitment

The overall completion rate based on the number of total mailings was 7%. Recruitment letters were mailed in waves based on county population and county proximity. The most populous counties were targeted first. Eight waves of recruitment letters were sent to 1,004 homes. Forty-four homeowners expressed interest in participating, but were not scheduled due to having already met county-level quotas. The new service requests lists from Eversource and UI contained enough records to recruit 70 homes without sending more than one mailing to any site.

The recruitment letters described the study to homeowners and 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. Recruiters scheduled site visits based on proximity to other scheduled sites and homeowner availability.

Table 161: Mailings by County

County	Number of Mailings	Proportion of Mailings
Total	1,004	100%
Fairfield	451	45%
New Haven	175	17%
Hartford	148	15%
New London	70	7%
Tolland	60	6%
Middlesex	40	4%
Litchfield	30	3%
Windham	30	3%

D.2 COMPLETED ON-SITE INSPECTIONS

Completed on-site inspections achieved the sampling plan targets, based on county-level proportionality and the desired custom-spec home ratio (Table 162). The on-site inspections included 66% spec-built and 34% custom-built homes. Eight homes were served by UI, and 63 were served by Eversource (one home was served by both).

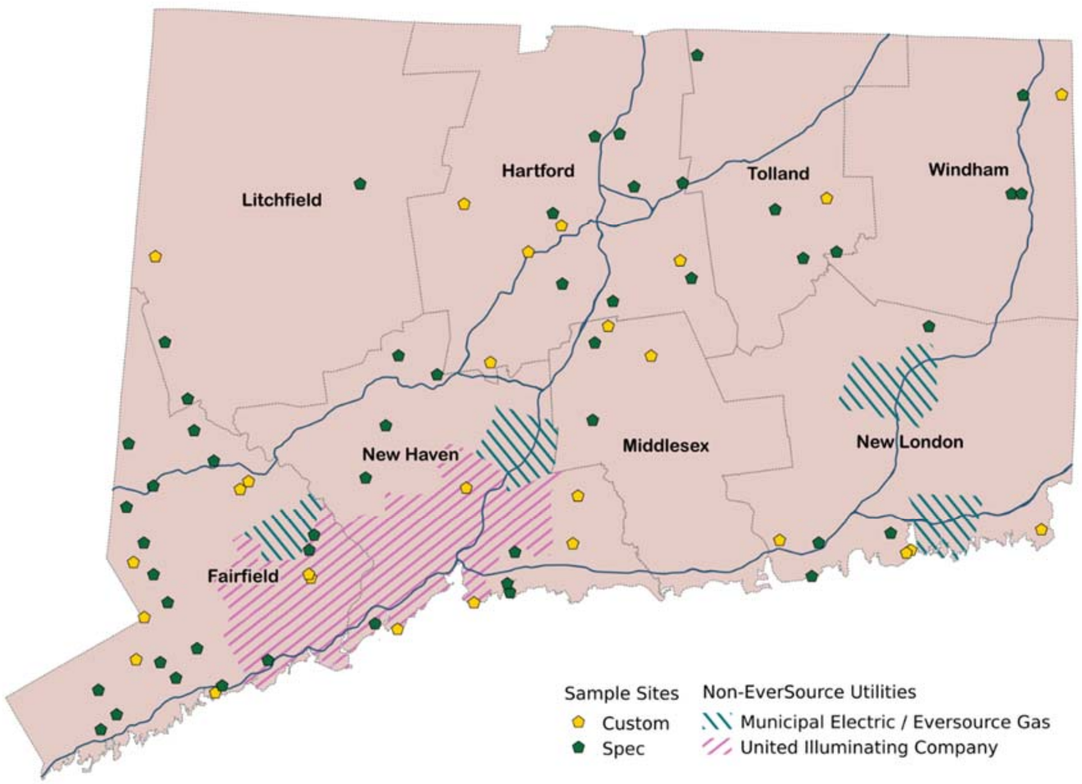
Table 162: Targeted and Completed Visits by County

County	Targeted On-Sites*	Completed On-Sites		
		Spec Homes	Custom Homes	Total
Total	*69*	*46*	*24*	*70*
Fairfield	24	18	7	25
Hartford	12	8	4	12
New Haven	12	8	4	12
New London	7	3	4	7
Middlesex	4	2	2	4
Tolland	4	3	1	4
Litchfield	3	2	1	3
Windham	3	2	1	3

*The values in this column sum to 69 homes. The 70th site was left as a floating site, to be filled based on the results of the recruiting effort. The 70th site was ultimately fielded in Fairfield.
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 48 towns across Connecticut. Thirty-one towns had one inspection each, 14 towns had two inspections, two towns had four inspections, and one town had three inspections. The location of each on-site and the custom/spec classification is shown in Figure 31.

Figure 31: Statewide Map of On-Site inspections



D.3 BASELINE STUDY SAMPLING ERROR

As described in Section 1.2.2, the sampling plan was designed to achieve a maximum 10% sampling error at the 90% confidence level. Using the data collected during the study, the actual coefficients of variation and estimates of precision can be calculated for key home characteristics. The collected data show that some building features are far more variable across homes than others. In the current study, duct leakage and air infiltration are the most variable, and HVAC system efficiencies are the least variable.

Table 163 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 ±0.9% to ±7.9% at the 90% confidence level for all measures except total duct leakage (±11.2%) and duct leakage outside the thermal envelope (±18.5%).

Within the sample of custom homes, only air infiltration (±17.9%) and duct leakage (total: ±18.4%; to outside: 43.5%) have relative precisions worse than the targeted 10%. Within the spec home sample, only the duct leakage relative precisions (total: ±13.4%; to outside: 19.8%) are worse than the 10% target.

Table 163: Coefficients of Variation and Relative Precision for Key Measures

	Custom			Spec			All		
Parameter	N	CV	Rel. Prec.	N	CV	Rel. Prec.	N	CV	Rel. Prec.
AFUE of fossil fuel fired heating systems	25	0.04	±1.2%	53	0.05	±1.1%	78	0.05	±0.9%
Central air conditioning SEER	25	0.11	±3.7%	51	0.07	±1.5%	76	0.09	±1.6%
Conditioned/ambient wall insulation R-value	128	0.23	±3.3%	235	0.15	±1.7%	363	0.20	±1.7%
HERS Index value	24	0.19	±6.4%	46	0.15	±3.7%	70	0.17	±3.3%
Flat ceiling insulation R-value	32	0.15	±4.3%	75	0.25	±4.7%	107	0.22	±3.5%
Vaulted ceiling insulation R-value	22	0.29	±10.3%	24	0.24	±7.9%	46	0.27	±6.6%
Air infiltration—ACH50	24	0.53	±17.9%	46	0.33	±8.0%	70	0.40	±7.9%
Total duct leakage—CFM25/100 sq. ft	23	0.54	±18.4%	42	0.53	±13.4%	65	0.55	±11.2%
Duct leakage to outside—CFM25/100 sq. ft.	23	1.27	±43.5%	51	0.86	±19.8%	74	0.96	±18.5%

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 Appendix B. Data were collected on the following measures.

Table 164: Data Collection Inputs

<table>
<tr><th>General Info</th><th>Code Compliance</th><th>Shell Measures</th></tr>
<tr><td>• House type
• Conditioned Floor Area (CFA)
• Conditioned Volume (CV)
• Stories
• Bedrooms
• Thermostat type
• Faucet/shower flow rates
• Basement details
• Gas/electric account numbers
• Health and safety issues
• Home automation systems</td><td>• Envelope
• Heating and cooling
• Water heating
• Duct and pipe insulation
• Ventilation
• Pools</td><td>• Walls
• Ceiling
• Frame floors
• Rim/band joists
• Windows, doors, and skylights
• Slab floors
• Foundation walls
• Mass walls
• Sunspaces</td></tr>
<tr><th>Mechanical Equipment</th><th>Diagnostic Tests</th><th>Lighting & Appliances</th></tr>
<tr><td>• Heating and cooling equipment
• Water heating equipment
• Duct insulation
• Renewables</td><td>• Blower door
• Duct blaster
  ○ Total leakage
  ○ Leakage to outside (LTO)
• Ventilation (automatic ventilation systems only)</td><td>• Lighting
  ○ Fixture type, location, control
• Appliances
  ○ Refrigerators and freezers
  ○ Dishwashers
  ○ Washers and dryers
  ○ Ovens and ranges
  ○ Dehumidifiers</td></tr>
</table>

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 2009 IECC 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

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 165). 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.

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 10, 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. Custom homes were weighted to 1.21, and spec homes were weighted to 0.89, in order to match the custom and spec distribution in the sample (33% custom and 67% spec) to the distribution in the relevant program home population (41% custom and 59% spec).

Table 165: 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. This highlights that the percentages were based on a small number of homes or measures. 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 166).

Table 166: 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 167).

Table 167: Example of Table Format Showing Descriptive Statistics

	Custom	Spec	All Homes (Weighted)
n (count of relevant unit of analysis)	*Count (unweighted)*	*Count (unweighted)*	*Count (unweighted)*
Average	**#*** (unweighted)	**#*** (unweighted)	# (**weighted**)
90% CI Lower Bound	# (unweighted)	# (unweighted)	# (**weighted**)
90% CI Upper Bound	# (unweighted)	# (unweighted)	# (**weighted**)
Standard Deviation	# (unweighted)	# (unweighted)	# (**weighted**)
Minimum	# (unweighted)	# (unweighted)	# (unweighted)
10th Percentile	# (unweighted)	# (unweighted)	# (unweighted)
Median	# (unweighted)	# (unweighted)	# (unweighted)
90th Percentile	# (unweighted)	# (unweighted)	# (unweighted)
Maximum	# (unweighted)	# (unweighted)	# (unweighted)

*Significantly significant difference at the 90% confidence level.

Throughout the report, graphics are presented that show the distribution of key values, such as average R-values or average efficiencies. Figure 32 is an example, showing the distribution of HERS Index values 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 represented 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.

Figure 32: Example Figure - HERS Index values

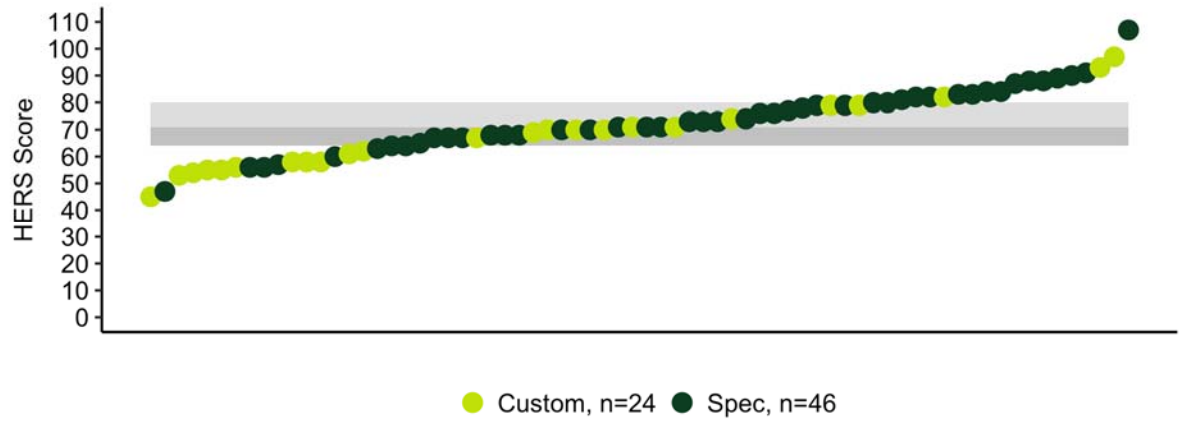
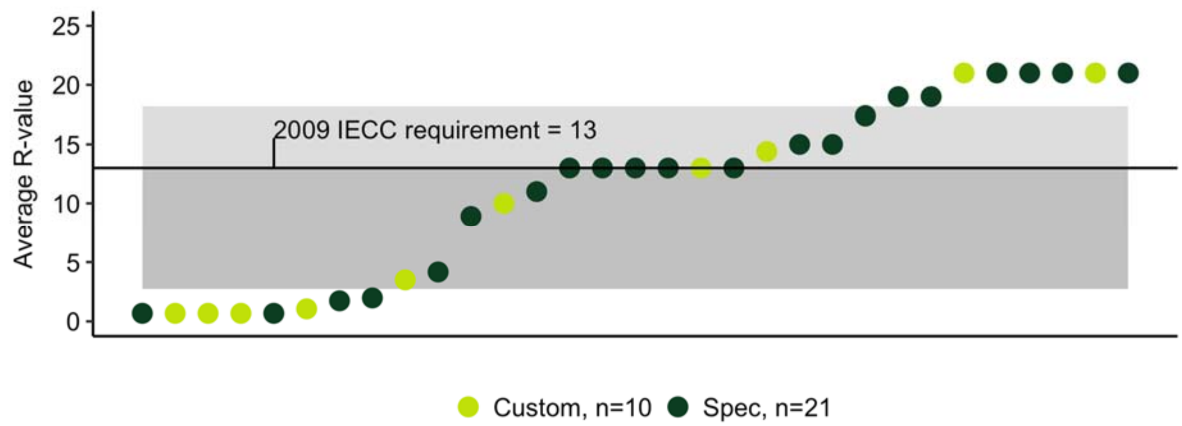


Figure 33 shows a similar graphic, but because fewer values cluster around the median, the quartile bands are wider. Some graphics, such as this one, also show the 2009 IECC prescriptive requirement as a reference point (these tend to fall close to the median value).

Figure 33: Example Figure - Foundation Wall Insulation



D.6 Company Data Issues

As described in more detail in the process evaluation piece of the R1602 study and in memo from NMR to the EEB on April 11, 2017, the Companies' program staff faced hurdles in compiling data to support evaluation efforts, resulting in complications in the evaluation process. These data issues largely affected the R1602 billing analysis and baseline study efforts and included incorrect data extractions from program databases, duplicated home records, unclear identifiers to link projects across datasets, and unclear site descriptions. Similarly, it appeared that lack of systematic data storage, such as clearly labeled and finalized REM/Rate files, led to incomplete program datasets and burdened the Companies' program staff when trying to compile the information to serve evaluation efforts. The REM/Rate files for program homes, for example, included duplicated and non-final models, requiring an additional layer of analysis to identify to final versions from among those provided. The Companies are currently revamping their program data tracking systems, which may alleviate some of these concerns for future evaluations.

E

Appendix E Detailed Water Heater Energy Factor Statistics

Table 168 describes the Energy Factors of all sampled water heater types with multiple instances, along with custom and spec comparisons.

Table 168: Water Heater Energy Factor Statistics by Type and Fuel[116]

Storage, Standalone (Natural Gas and Propane)	Custom	Spec	All Homes (Weighted)
n (water heaters)	*2*	*16*	*18*
Average	.66	.68	.67
90% CI Lower Bound	.60	.67	.66
90% CI Upper Bound	.72	.68	.68
Standard Deviation	.014	.02	.02
Minimum	.65	.63	.63
10th Percentile	.65	.64	.65
Median	.66	.68	.67
90th Percentile	**	.70	.70
Maximum	.67	.70	.70
Instantaneous (Natural Gas and Propane)	**Custom**	**Spec**	**All Homes (Weighted)**
n (water heaters)	*12*	*5*	*17*
Average	.92	.96	.93
90% CI Lower Bound	.90	.94	.91
90% CI Upper Bound	.95	.97	.95
Standard Deviation	.05	.013	.05
Minimum	.82	.94	.82
10th Percentile	.82	.94	.82
Median	.95	.95	.95
90th Percentile	.97	**	.97
Maximum	.97	.97	.97
Storage, Standalone (Electric)	**Custom**	**Spec**	**All Homes (Weighted)**
n (water heaters)	*1*	*12*	*13*
Average	.95	.93	.93
90% CI Lower Bound	**	.92	.92
90% CI Upper Bound	**	.94	.94
Standard Deviation	**	.02	.02
Minimum	.95	.91	.91
10th Percentile	**	.91	.91
Median	.95	.94	.95
90th Percentile	**	.95	.95
Maximum	.95	.95	.95

[116] Note that some of the values presented here may vary from those in the comparison sections of the report, due to slightly different units of analysis (homes vs. systems, for example) between the different baseline reports.

Indirect w/ Storage Tank (Natural Gas and Propane)	Custom	Spec	All Homes (Unweighted)
n (water heaters)	*5*	*1*	*6*
Average	.89	.86	.88
90% CI Lower Bound	.85	**	.85
90% CI Upper Bound	.92	**	.91
Standard Deviation	.04	**	.03
Minimum	.87	.86	.86
10th Percentile	.87	**	.86
Median	.87	.86	.87
90th Percentile	**	**	**
Maximum	.95	.86	.95
Heat Pump	**Custom**	**Spec**	**All Homes (Unweighted)**
n (water heaters)	*2*	*2*	*4*
Average	3.09	2.99	3.04
90% CI Lower Bound	2.90	1.45	2.80
90% CI Upper Bound	3.28	4.54	3.29
Standard Deviation	.04	.35	.21
Minimum	3.06	2.75	2.75
10th Percentile	3.06	2.75	2.75
Median	3.09	2.99	3.09
90th Percentile	**	**	**
Maximum	3.12	3.24	3.24
Combi Appliance (Natural Gas and Propane)	**Custom**	**Spec**	**All Homes (Unweighted)**
n (water heaters)	*1*	*3*	*4*
Average	.93	.93	.93
90% CI Lower Bound	**	.90	.91
90% CI Upper Bound	**	.97	.95
Standard Deviation	**	.02	.017
Minimum	.93	.91	.91
10th Percentile	**	.91	.91
Median	.93	.94	.93
90th Percentile	**	**	**
Maximum	.93	.95	.95

**Value not calculated due to small sample size.

F

Appendix F UDRH Updates

F.1 Summary of Recommended UDRH Inputs

This appendix provides the recommended User Defined Reference Home (UDRH) inputs for Eversource and United Illuminating's (the Companies') RNC program. The recommendations in this appendix are based on the results of the baseline study onsite inspections, analysis of program data, and recent UDRH updates that took place in Rhode Island and Massachusetts.[117] On August 23, 2017, the study issued a memo listing the recommended UDRH inputs for each measure. The following section details the reasoning behind the decisions that went into finalizing those UDRH inputs.

Table 169 lists the data sources used in the R1602 study to develop the recommended UDRH inputs. Values that feed into the recommended UDRH inputs include: the results of the non-program onsite results, the current UDRH, standard market practices, features of 2015 program homes, or the features of the program homes being rated.[118] The table also notes – at a high level – other key UDRH revisions that are recommended, such as adding inputs or revising the way in which measures are categorized.

Table 169: Recommended Sources and Other Adjustments for UDRH Revisions

Measure	Recommended Source	Other Recommended Adjustments
Above Grade Walls	Onsite results	Use different values for different wall locations
Frame Floors	Onsite results	Adjust how floors are grouped; use different values for different locations
Ceilings	Onsite results	--
Foundation Walls	Onsite results	Add specification to UDRH
Slab Floors	Standard market practices	Add specification to UDRH
Windows	Current UDRH (U-factor); MA baseline (SHGC)	Add specification for SHGC to UDRH
Skylights	Rated home	--
Doors	Rated home	Remove specification from UDRH
Air Infiltration	Onsite results	--
Duct Leakage to Outside	Onsite results	--

[117] See "Final 2016 UDRH Inputs: Addendum to 2015-16 Massachusetts Single-Family Code Compliance/Baseline Study" 2017 and "Final 2017 UDRH Inputs: Results from Rhode Island Single-Family New Construction Baseline". 2017.

[118] In REM/Rate, a program home is being compared to a similar, hypothetical home – the UDRH. If, for a particular measure, the UDRH is said to have a feature that is the same as the "rated home," that means that the rated home is not being penalized or rewarded for having that feature – it is present in the rated home, and the exact same feature is present in the UDRH.

Measure	Recommended Source	Other Recommended Adjustments
Duct Insulation	Onsite results	Decrease number of separate duct locations; downgrade bubble-wrap R-value
Heating	Onsite results (natural gas/propane/GSHP) and program home results (ASHP/DMSHP)	Adjust inputs for various fuel and distribution system types; assume unconditioned spaces for single-family and conditioned spaces for multifamily
Cooling	Onsite results	Create one input for all AC system types; assume unconditioned spaces for single-family and conditioned spaces for multifamily
Water Heaters	Onsite results (gas/propane, electric), rated home (oil)	Create one input for all electric water heaters; segment values by system fuel and type
Lighting	Onsite results	--
Thermostat Type	Onsite results	Set UDRH to programmable; rated home no longer automatically reassigned to programmable
Thermostat Setpoints	Onsite results	--
Mechanical Ventilation	Rated home	Remove ventilation from UDRH to avoid rewarding homes without ventilation

F.2 UDRH Methodology

F.2.1 Data Collection

As previously discussed, the R1602 baseline study included onsite visits in 2016 and 2017 to 70 new, non-program single-family homes (46 spec- and 24 custom-built) across 48 Connecticut cities and towns. Data collection covered all aspects of home energy performance, including building envelope, mechanical systems, lighting, appliances, and air infiltration. Home Energy Rating System (HERS) ratings were performed at all homes, and sites were evaluated against the requirements of the 2009 IECC.[119] This data collection formed the basis of the values suggested for the updated UDRH.

F.2.2 Analysis

The process of developing the UDRH recommendations included analyses of the following:

- Non-program home data collected during the R1602 baseline study onsite visits
- Program REM/Rate files for single-family and multifamily homes that participated in the RNC program in 2015
- A review of the recent UDRH update process in Massachusetts and Rhode Island

[119] The HERS index is 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.

The key elements of the analysis are as follows:

- **Recommendation inputs.** Generally, the recommended UDRH value for single-family homes is based on the mean value from the R1602 non-program baseline study, and in some cases, is adjusted based on the findings from the recently updated UDRH values that were created for the Massachusetts[120] and Rhode Island[121] RNC programs.
- **Weighting.** All non-program averages are weighted based on custom/spec home designations to represent the custom/spec splits identified in the RNC program. Details on the weighting methodology can be found in the R1602 RNC Baseline Study report. All program averages are unweighted.
- **Multifamily adjustment factor.** The multifamily recommendations are based on applying an adjustment factor to the recommended single-family value. As described in the Multifamily Estimation Methods Section, the adjustment factors were derived by comparing the results of single-family and multifamily program units that participated in the 2015 RNC program. In some instances, the adjustment factor was not used and a different value is recommended.

F.3 Measure-Specific Findings

The tables in this section are organized as follows:

- **UDRH specification.** The current UDRH specifications (i.e., those currently used by the RNC program to calculate savings for program homes) are compared to the following two values:
  1) the mean value from the non-program single-family homes that were included in the R1602 baseline study, and
  2) the mean value from the program REM/Rate files for single-family homes that participated in the RNC program in 2015.
- **Recommendations.** For each measure, the suggested values to include in the updated UDRH are presented separately for single-family and multifamily units. These recommended values are found in the far-right columns of each table in bold red font. The logic behind each single-family UDRH recommendation is described above the corresponding table.

F.3.1 Above Grade Walls

➢ ***Recommendation: Assign above-grade wall Uo-values by specific location, and base insulation values on onsite results.***

The current UDRH classifies all above grade walls into only two generic categories: unconditioned walls and conditioned walls. The R1602 study recommends adding new wall

[120] http://ma-eeac.org/wordpress/wp-content/uploads/Single-Family-Code-Compliance-Baseline-Study-Volume-5-2.pdf.
[121] Report not yet published, but UDRH finalized in August 2017.

locations to the UDRH using the Uo values from the baseline sample, as proposed below, including walls that abut (1) ambient space, (2) garages, (3) unconditioned attics, and (4) unconditioned basements (Table 170).[122] These walls were all assigned the same value in the previous Connecticut UDRH; if that approach were used again, the Uo value would be 0.062 for all wall types. By splitting them out, these walls in program homes will be compared to the less efficient wall assemblies found in the baseline results (0.091 for walls abutting unconditioned basements, for example), increasing the potential for savings relative to the previous UDRH approach in Connecticut.

This splitting out of above-grade wall locations also matches the method recently adopted in Rhode Island; the Massachusetts study did not split out wall locations, and kept the simpler approach of using one UDRH value for all conditioned walls.

The multifamily specifications were developed by applying an adjustment factor to the single-family specifications, except for conditioned to garage walls and all unconditioned walls. These locations were not identified in the multifamily program data; as a result, the study recommends applying the single-family recommendation to multifamily units for these locations.

Table 170: Above Grade Wall Average Uo Values – Current Inputs and Study Results and Suggestions[1]

Above Grade Wall Type and Location	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Between Conditioned Space and:					
Ambient	0.068	0.062 (n=70)	0.055 (n=198)	**0.062**	**0.059**
Garage	0.068	0.066 (n=62)	0.056 (n=136)	**0.066**	**0.066**
Attic	0.068	0.068 (n=41)	0.059 (n=42)	**0.068**	**0.067**
Basement	0.068	0.091 (n=48)	0.077 (n=38)	**0.091**	**0.098**
Between Unconditioned Space and:					
Any Unconditioned Location	0.098	0.098 (n=27)	0.058 (n=7)	**0.098**	**0.098**

[1] “Uo values,” a measurement of thermal performance, refer to the average weighted U-value across the wall assembly.

[122] Average Uo values for non-program and program homes are derived from REM/Rate energy modeling software and account for insulation R-values, insulation installation quality, framing factors, etc.

F.3.2 Frame Floors

- ***Recommendation: Base frame floor values on onsite visit results. Use one Uo value for floors over unconditioned basements and enclosed crawl spaces, and a different Uo value for floors over garage, ambient space, and open crawl spaces.***

The current UDRH uses the same Uo value for frame floors over unconditioned basements, enclosed crawl spaces, and open crawl spaces, a different value for floors over garages, and another for floors over ambient space. This study recommends following the baseline study findings, which results in one UDRH value for floors over garages, ambient space, and open crawl spaces, and one value for floors over unconditioned basements and enclosed crawl spaces (Table 171).[123]

Splitting out these various frame floor locations is similar to the process used in the newly updated Rhode Island UDRH. In 2016, Massachusetts used a simpler approach, and specified a single value for all floors over unconditioned space based solely on the baseline results for floors over unconditioned basements.

No floors over garage or open crawl space were present in the multifamily sample. Therefore, those measures were assigned the recommended multifamily specification for floors over ambient space. This is consistent with the recommended single-family specifications which have the same recommended UDRH value for all three floor locations.

Table 171: Frame Floor Average Uo Values – Current Inputs and Study Results and Suggestions

Frame Floor Location	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Over Unconditioned Basement or Enclosed Crawl Space	0.074	0.061 (n=51)	0.049 (n=97)	**0.061**	**0.043**
Over Garage	0.052	0.047 (n=44)	0.032 (n=104)	**0.047**	**0.048**
Over Ambient Space	0.060	0.047 (n=29)	0.032 (n=49)	**0.047**	**0.048**
Over Open Crawl Space	0.074	NA	0.032 (n=5)	**0.047**	**0.048**

F.3.3 Ceilings

- ***Recommendation: Update the single-family ceiling Uo-values with those collected through onsite visits, and assign multifamily values using the adjustment factor.***

The study recommends updating the current single-family specification to the new non-program average from the baseline sample (Table 172). The Massachusetts 2016 UDRH

[123] There were no floors over open crawl spaces in the R1602 site visits, but in the new UDRH, these are given the same value as floors over ambient space because they have similar thermal properties.

update also used the values from its most recent baseline study. The Rhode Island UDRH update did not make changes to its specifications for flat or vaulted ceilings, due to an outlier in the recent baseline study that would have shifted the baseline to a less efficient standard. Multifamily values were created using the program home adjustment factor.

Table 172: Ceiling Average Uo Values – Current Inputs and Study Results and Suggestions

Ceiling Type	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Flat	0.044	0.042 (n=64)	0.025 (n=157)	**0.042**	**0.041**
Vaulted	0.042	0.038 (n=39)	0.028 (n=106)	**0.038**	**0.036**

F.3.4 Foundation Walls

- ***Recommendation: Add foundation walls specifications to the UDRH given their prevalence, and base the R-values on onsite findings. For conditioned basements, forego the multifamily adjustment factor.***

Foundation walls are not included in the current Connecticut UDRH specification, meaning that the reference home is modeled with the same foundation wall as the rated home. The study recommends adding foundation walls into the new UDRH, particularly because conditioned basement areas were present in 44% of non-program homes, resulting in a sizeable dataset of insulation values on which to base the UDRH inputs.[124]

Further, the study recommends adopting the average conditioned foundation wall R-value found during onsite visits (10.9; Table 173). Massachusetts and Rhode Island apply nearly identical R-values for their conditioned foundation wall UDRH inputs (R-10.4 and R-10.65, respectively).[125]

The unconditioned foundation wall recommended value (R-0.23) is also based on onsite findings. The Rhode Island UDRH update also set its specification based on onsite findings; Massachusetts, however, chose a value of R-0 to reflect the common practice of not insulating unconditioned foundation walls, given that the vast majority of the sampled homes lacked such insulation.

No conditioned foundation walls were present in the multifamily sample; therefore, the multifamily recommendation is the same as the single-family recommendation. All

[124] There were five non-program homes that had uninsulated conditioned basements and one non-program home with an insulated unconditioned basement. Building code does not require insulation on foundation walls in unconditioned basements and the standard practice of builders in the RNC program is to not insulate this wall type. Not insulating these foundation walls was standard practice in non-program homes.

[125] While Massachusetts used the results of its baseline study to determine its R-value, the recent Rhode Island UDRH update did not follow the same method – high variability in the onsite findings resulted in using a value that was the average of the previous UDRH input and the findings from the RI baseline sample.

unconditioned foundation walls in the multifamily sample were completely uninsulated, thus resulting in a recommended R-value of zero.

Table 173: Foundation Wall Average R-Values – Current Inputs and Study Results and Suggestions

Foundation Wall Type	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Conditioned	NA	10.9 (n=31)	14.89 (n=88)	**10.9**	**10.9**
Unconditioned	NA	0.23 (n=51)	2.26 (n=96)	**0.23**	**0**

F.3.5 Slab Floors

- ***Recommendation: Given lack of available data from onsite visits, apply slab R-values based on standard practices instead of onsite results. Use the same values for single-family and multifamily specifications.***

It is difficult to verify slab insulation in non-program homes because inspections are conducted after construction is complete, and slab insulation is at that point often covered by soil or the house itself.[126] Therefore, this study recommends mirroring the UDRH inputs chosen in the Massachusetts and Rhode Island studies.

In recent UDRH studies for Rhode Island (2017) and Massachusetts (2016), low sample sizes compelled the studies to recommend values that reflected standard practices instead of values based on non-program baseline averages. The final values were selected in Massachusetts based on the typical insulation values seen in Massachusetts program REM/Rate files, in combination with input from the industry experts consulted in the UDRH development process; Rhode Island mirrored those results. Both states adopted the same values: R-10 perimeter and R-15 under for heated slabs, R-5 perimeter for on-grade unheated slabs and R-0 for below grade unheated slabs. The study recommends following the same logic for the Connecticut UDRH update.

[126] To verify slab R-values in the study, auditors searched for visible insulation onsite, asked homeowners for any documentation or plans they had on the premises, and asked homeowners if they knew anything about the slab insulation.

This study also recommends using those same single-family values for the multifamily specifications. Given the lack of single-family data from the onsite visits, there is no reliable comparison point from which to create a multifamily adjustment factor.

Table 174: Slab Floors Average R-Values – Current Inputs and Study Results and Suggestions

Slab Floor Type	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Unheated					
Below Grade					
Under insulation	Same as rated home	1.10 (n=28)	2.25 (n=79)	**0**	**0**
Perimeter insulation	Same as rated home	0.42 (n=28)	2.18 (n=79)	**0**	**0**
On-Grade					
Under insulation	Same as rated home	1.41 (n=23)	3.87 (n=44)	**0**	**0**
Perimeter insulation	Same as rated home	0.38 (n=23)	7.88 (n=44)	**5**	**5**
Heated					
Below Grade					
Under insulation	Same as rated home	NA	9.17 (n=3)	**15**	**15**
Perimeter insulation	Same as rated home	NA	4.00 (n=3)	**10**	**10**
On-Grade					
Under insulation	Same as rated home	5.0 (n=2)	10.07 (n=7)	**15**	**15**
Perimeter insulation	Same as rated home	5.0 (n=2)	7.35 (n=7)	**10**	**10**

F.3.6 Windows

- ***Recommendation: Do not change the current window U-factor specification. Adopt the SHGC input used in Massachusetts.***

As shown in Table 175, the study recommends keeping the current U-factor input (0.30) given that the Connecticut baseline had (1) a small sample size of homes with known window specifications, and (2) a worse average value from among the windows with verified details than the current specification. The current U-factor specification is higher (worse) than the program average and equivalent to the value recently adopted in Massachusetts. The study also recommends adopting a SHGC input of 0.30 to match that of Massachusetts, again to account for the small sample size of homes with verified window details in Connecticut.

The Massachusetts baseline included building department visits, which allowed for additional data gathering about window details in new homes (33 homes had verified window information in the Massachusetts sample). The Massachusetts specifications were updated to 0.30 for both U-factor and SHGC, supporting the credibility of the recommended specifications.

The multifamily inputs are based on an adjustment factor from the program home data.

Table 175: Window Average U-Factor and SHGC-Value – Current Inputs and Study Results and Suggestions

Unit of Measurement	Current UDRH Input	Average Results[1]		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
U-Factor	0.30	0.31 (n=7)	0.29 (n=198)	**0.30**	**0.31**
SHGC	Same as rated home	0.33 (n=7)	0.27 (n=198)	**0.30**	**0.29**

[1] The values are based on documented U-Factor and SHGC information from visible National Fenestration Rating Council stickers, plans, or REScheck documentation for seven non-program homes and program REM/rate file reviews of 198 program homes.

F.3.7 Skylights

- ***Recommendation: For skylights, continue to use the U-factors and SHGC values from the rated home.***

Average U-value and SHGC values for program homes are derived from three values found during analysis of REM/Rate files; no confirmed values were found during onsite visits for non-program homes. The current UDRH specification for skylights mirrors the design of the rated home, meaning that the UDRH will have the same kind of skylight as the rated home. Given the lack of verifiable data from the baseline sample, the study recommends keeping the skylight UDRH inputs the same as the rated home. This also matches the approach in Rhode Island and Massachusetts.

Table 176: Skylight Average U-Factor and SHGC-Value – Current Inputs and Study Results and Suggestions

Unit of Measurement	Current UDRH Input	Average Results[1]		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Uo	Same as rated home	No verifiable data	0.30 (n=3)	**Same as rated home**	**Same as rated home**
SHGC	Same as rated home	No verifiable data	0.43 (n=3)	**Same as rated home**	**Same as rated home**

F.3.8 Doors

- ***Recommendation: For doors, use the U-values from the rated home, rather than the current input.***

Given the lack of verifiable data from onsite visits (door specification stickers are generally removed upon installation), the study recommends setting the door specification to be the same as the rated home (Table 177). Rhode Island and Massachusetts had similar issues with collecting door data in completed homes. In Rhode Island, the specification is the same as the rated home and in Massachusetts, the REM/Rate default U-value (0.35) is used in the UDRH.

Table 177: Doors Average U-Factor – Current Inputs and Study Results and Suggestions

Unit of Measurement	Current UDRH Input	Average Results[1]		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Uo	0.268	No verifiable data	0.19 (n=198)	**Same as rated home**	**Same as rated home**

[1] Onsite visits did not document U-values for doors at non-program homes. The average value for program homes is derived from program REM/Rate files of 198 participating homes.

F.3.9 Air Infiltration

- ***Recommendation: Use the diagnostic test results from the study's onsite visits to create ACH50 inputs. Assign the UDRH to the same shelter class as the rated home.***

The study recommends adopting the non-program average air infiltration of 4.9 ACH50 for air leakage, which is based on diagnostic tests at all 70 homes in the Connecticut baseline study (Table 178). Massachusetts and Rhode Island also relied on their baseline study results to make ACH50 updates. For multifamily homes, an adjustment factor was used to create an ACH50 value for the UDRH input.

Shelter class is a measurement of a site's wind conditions, and it impacts a home's air infiltration. The study recommends continuing the practice of siting the UDRH in the same shelter class as the rated home, to create a consistent comparison between the program home and the reference home.

Table 178: Air Infiltration – Current Inputs and Study Results and Suggestions

Unit of Measurement	Current UDRH Input	Average Results[1]		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Air Infiltration (ACH50)	5.8	4.9 (n=70)	2.7 (n=198)	**4.9**	**11.1**
Shelter Class[2]	Same as rated home	3.0 (n=70)	3.9 (n=198)	**Same as rated home**	**Same as rated home**

[1] The average air infiltration (ACH50) from the baseline study is based on blower door testing at 70 non-program homes and program records of blower door testing at 198 program homes.
[2] Shelter class is a 1 to 5 scale used by REM/Rate that describes a site's wind exposure, where 1 means "No obstructions or local shielding whatsoever" and 5 means "Very heavy shielding surrounding house perimeter, provided by closely spaced homes, mature trees & bushes, etc."

F.3.10 Duct Leakage to the Outside

- ***Recommendation: Use the diagnostic test results from the study's onsite visits to create duct leakage to the outside inputs.***

Table 179 suggests that the UDRH use the onsite visit average result of 6.2 CFM25 per 100 square feet of conditioned floor area (CFA) for the duct leakage to the outside UDRH values in single-family homes (a substantial improvement compared to the current UDRH value of 17.7). For this study, duct systems located entirely within conditioned space were assumed to have zero duct leakage to the outside. This assumption is consistent with program practices.[127] Homes with zero duct leakage are included in the non-program and program averages.

Adopting the non-program average from the baseline study as the UDRH specification matches the logic of the recent UDRH updates in Massachusetts and Rhode Island.

An adjustment factor was used for the input for the multifamily home input.

Table 179: Duct Leakage to Outside – Current Inputs and Study Results and Suggestions

Unit of Measurement	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
CFM_{25} per 100 sq. ft. of CFA	17.7	6.2 (n=60)	1.8 (n=185)	**6.2**	**7.7**

[127] These systems were tested and some displayed some duct leakage to the outside. Most programs do not require that HERS raters test these systems and instead assume that they have zero duct leakage to the outside. For this reason, the duct leakage associated with systems located in conditioned space was assumed to be zero even if the system was tested and displayed some amount of leakage.

F.3.11 Duct Insulation

- ***Recommendation: Alter duct insulation specifications to include only two duct categories: supply ducts in unconditioned attics, and supply or return ducts in all other unconditioned locations. Use the baseline findings for R-values, but downgrade all instances of bubble-wrap insulation in the baseline study to R-2, creating a less efficient baseline than if nominal values were used.***

The current UDRH applies different specifications for return and supply ducts in several locations (attics, crawl spaces, basements, etc.). This study recommends simplifying the specifications to include values for only two categories: (1) supply ducts in unconditioned attics and (2) all other supply and return ducts in unconditioned locations (Table 180). Ducts in conditioned space would be modeled the same in the UDRH and rated home. This matches the designations in Connecticut's energy code and the Massachusetts UDRH; the Rhode Island study adopted a more complicated specification with different values for more of the separate duct locations.

Additionally, the study recommends adopting a UDRH specification for duct insulation that downgrades the R-value of all the bubble wrap insulation seen in the onsite visits from R-4 (the typical R-value reported by the manufacturers) to R-2; studies and industry experts estimate that R-2 is a better estimate of the actual performance of this insulation than the R-4 estimated by manufacturers. Accordingly, the suggested single-family inputs are based on the values from the Connecticut baseline study, except that all instances of bubble wrap insulation were reassigned an insulation value of R-2, creating a lower overall average.[128]

Massachusetts and Rhode Island both followed this protocol, and used their baseline results to determine the UDRH inputs, but reassigned all instances of bubble wrap insulation found in their baseline studies to R-2.

Multifamily inputs were created using a multifamily adjustment factor based on program home data.

However, it is important to note that unless program homes also "de-rate" bubble wrap duct insulation to R-2, they will appear to have savings that are not actually realized. Connecticut could decide to adopt the non-program average values to remove the need for this adjustment in program homes.

[128] The program should ensure that program raters also decrease the R-value of bubble wrap duct insulation in order to maintain consistency with the recommended UDRH inputs.

Table 180: Duct Insulation in Unconditioned Spaces R-Values – Current Inputs and Study Results and Suggestions

Unconditioned Duct Locations	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Attic (Supply Only)	7.7	6.5 (n=40)	8.6 (n=85)	**5.54**	**5.15**
Other Unconditioned Spaces (Supply and Return Ducts)	NA	5.8 (n=57)	7.9 (n=261)	**4.91**	**4.97**

F.3.12 Heating

- ***Recommendation: Leverage non-program home onsite results for natural gas and propane systems and ground source heat pump systems, but apply program home results for air source heat pumps and ductless mini-splits. Combine natural gas and propane distribution system specifications. Use unconditioned space as the UDRH location of heating equipment in single-family homes, and conditioned space for multifamily homes.***

The current UDRH specifications are split by fuel type and use the same AFUE across distribution system types. The recommendations by fuel type, as shown in Table 181, are as follows:

- **Natural gas and propane.** The study recommends adopting the logic used in the recent Rhode Island UDRH update that combines natural gas and propane specifications, but provides different inputs for each distribution type. For example, natural gas and propane furnaces and hydro-air boilers (air distribution) are grouped, and treated separately from hydronic distribution systems (boilers). Unit heaters are rare, and this study recommends they be treated in the UDRH the same as the rated home.
- **Oil.** The recommendation for oil-fueled systems is to treat them the same as the rated home, since no such systems were found in the Connecticut onsite visits. This approach would match the Rhode Island logic.
- **Air source heat pumps (electric).** For ducted air source heat pumps and ductless mini-splits, the non-program averages from the onsite visits are more efficient than the program average. Therefore, the study recommends using the program homes' average HSPF for the single-family specification instead of the higher non-program average. The multifamily recommendation is the single-family recommendation adjusted by the multifamily adjustment factor.
- **Ground source heat pumps (electric).** The study recommends applying the non-program homes' average COP for single-family homes. Since there were no ground source heat pumps in the multifamily sample, the recommended multifamily specification is the same as the single-family recommendation.

- **Dual fuel.** No dual-fuel heat pumps were found during the baseline onsite visits; the recommended specification reflects the same logic used in the previous Connecticut UDRH by adopting the new ASHP specifications (HSPF) for both single-family and multifamily homes.

The current UDRH location specification for single-family systems is the same as the rated home, but this study recommends that the UDRH input for single-family homes' heating systems be unconditioned space, given that this is the most common location in non-program and program homes. The percentage of systems in unconditioned space is 70% for non-program homes and 68% for program homes. The previous baseline study had 75% of systems located in unconditioned space. For multifamily equipment, almost all program equipment is in conditioned space (91% of systems), and that is recommended as the UDRH location input for heating systems in multifamily homes.

Table 181: Heating Systems – Current Inputs and Study Results and Suggestions

Fuel and System Type[1]	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Natural Gas (AFUE)					
Air Distribution	92.4	94.1 (n=40)	94.8 (n=73)	**93.8**	**95.4**
Hydronic Distribution	92.4	NA	92.4 (n=8)	**89.6**	**91.2**
Unit Heater	92.4	NA	NA	**Same as rated home**	**Same as rated home**
Propane (AFUE)					
Air Distribution	92.1	93.4 (n=32)	94.7 (n=58)	**93.8**	**95.4**
Hydronic Distribution	92.1	89.6 (n=5)	95.0 (n=6)	**89.6**	**91.2**
Unit Heater	92.1	NA	NA	**Same as rated home**	**Same as rated home**
Oil (AFUE)					
Air Distribution	84.5	NA	NA	**Same as rated home**	**Same as rated home**
Hydronic Distribution	84.5	NA	86.50 (n=1)	**Same as rated home**	**Same as rated home**
Unit Heater	84.5	NA	NA	**Same as rated home**	**Same as rated home**
Electric and Other Fuels					
Kerosene Unit Heater (AFUE)	83.3	NA	NA	**Same as rated home**	**Same as rated home**

Fuel and System Type[1]	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
ASHP & Ductless Mini-Split (HSPF)	8.9	10.5 (n=6)	10.0 (n=16)	**10.0**	**9.0**
GSHP (COP)	3.3	4.0 (n=3)	4.1 (n=55)	**4.0**	**4.0**
Dual-Fuel Heat Pump (HSPF)	8.9, 13.0	NA	NA	**10.0**	**9.0**
Location					
Location	NA	Unconditioned space	Unconditioned space	**Unconditioned Space**	**Conditioned Space**

[1] "Air distribution systems" include furnaces and hydro-air boilers. "Hydronic distribution systems" include forced hot water boilers and wall-mounted tankless combined appliances.

F.3.13 Cooling

- ***Recommendation: Create a single average SEER value across all CAC, ducted ASHPs, and ductless mini-splits based on onsite results; use that same efficiency for the GSHP input (after converting from SEER to EER). Locate single-family cooling equipment in unconditioned space for the UDRH, and multifamily equipment in conditioned space.***

The current UDRH uses the same specification for central air conditioners (CAC), ducted air source heat pumps, and ductless mini-split heat pumps. The study recommends continuing that practice by selecting a new SEER that is the average of the CAC, air source heat pump, and ductless mini-split efficiency ratings included in the R1602 non-program home onsite visits, and in addition, assigning that same value to GSHPs (which requires a conversion from SEER to EER).

This recommendation follows Massachusetts' approach, which used the same method of using one efficiency value as the comparison point for all cooling systems, allowing program homes to take credit for using ever more efficient cooling systems.[129]

The location input is unconditioned space for single-family homes. The percentage of systems in unconditioned space is 68% for non-program homes, and 69% for program homes. For multifamily equipment, all program equipment is in conditioned space (100% of systems), and that is recommended as the UDRH input for multifamily homes.

[129] The 14.9 SEER value was converted to 12.2 EER for GSHP systems. To convert SEER to EER the following equation was used: $EER = -0.02 \times SEER^2 + 1.12 \times SEER$

Table 182: Cooling Systems – Current Inputs and Study Results and Suggestions

Fuel and System Type[1]	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
CAC, ASHP, & Ductless Mini-Split (SEER)	NA	14.6 (n=81)	14.9 (n=151)	**14.6**	**14.4**
Ground Source Heat Pump (EER)	14.1	18.0 (n=3)	24.3 (n=55)	**12.2**	**12.1**
Dual-Fuel Heat Pump (SEER)	13.0	NA	NA	**14.6**	**14.4**
Location	Same as rated home	Unconditioned Space	Unconditioned Space	**Unconditioned Space**	**Conditioned Space**

F.3.14 Water Heaters

- ***Recommendation: Split water heater UDRH values into three fuel categories: natural gas and propane, oil, and electric. For gas/propane, use onsite values, split by water heater type (storage, integrated, or instantaneous). For oil, keep UDRH input same as the rated home. For electric, use one UDRH value for all electric systems, regardless of system type. For multifamily values, use adjustment factors where possible, and default to single-family values for system types with limited data.***

Water heater efficiency is rated in terms of the energy factor (EF) and recovery efficiency (RE). UEF is a newer replacement for Energy Factor, but REM/Rate still uses EF, rather than UEF, for modeling.

F.3.14.1 Single-Family Water Heater UDRH Inputs

As shown in Table 183, the study makes the following recommendations for single-family water heater UDRH inputs, which are also in keeping with the logic recently adopted in Rhode Island.[130]:

- **Natural gas and propane.** As with heating systems, the study recommends combining natural gas and propane specifications and using the average non-program efficiencies of propane and natural gas systems from the onsite visits, and using separate efficiency values for the three main system categories, conventional storage, integrated, and instantaneous.[131]

[130] All logic matches the Rhode Island water heater inputs except for with integrated systems for which Rhode Island based its increase in efficiency solely on the increase in boiler efficiency.

[131] Storage systems use large tanks to hold hot water; integrated systems combine space heating and domestic hot water functions; and instantaneous systems provide on-demand water heating with a small or no tank (minimizing standby losses). Systems with tanks that perform both space and water heating are included with

- **Oil.** Since no oil-fueled water heaters were found in the baseline study, the recommended specification for such systems is to be the same as the rated home.
- **Electric, including heat pump water heaters (HPWH).** All electric water heaters, including resistance and heat pumps should be combined into a single specification based on the average efficiency of all such systems from the non-program onsite visits.[132] This results in a UDRH input for electric water heaters that is higher than the average efficiency of standard electric resistance water heaters. Using this approach, program homes essentially need to incorporate these high efficiency HPWH systems in order to demonstrate energy savings relative to such an efficient UDRH input.

F.3.14.2 Multifamily Water Heater UDRH Inputs

The study makes the following recommendations for water heaters in multifamily projects:

- **Natural gas and propane systems.** As with single-family homes, group gas and propane systems, and split by system type, and use a multifamily adjustment factor to create the efficiency values.[133]
- **Oil.** As with single-family homes, no oil systems were present in the multifamily program homes, so the study recommends keeping the UDRH specification to be the same as the rated home for oil water heaters.
- **Electric, including HPWHs.** The study recommends no adjustment factor for these systems, using the same value for single-family and multifamily systems. There were not enough HPWHs seen in multifamily program homes to create a reliable adjustment factor.[134]
- **Recovery Efficiency.** Additionally, the multifamily recommendation for RE for integrated systems is the same as the single-family recommendation; there was not enough data to estimate a multifamily adjustment factor. Program REM/Rate files do not include RE values for instantaneous systems, which would have been used to create a multifamily adjustment factor; for these instantaneous systems, the multifamily RE recommendation is based on the ratio of the single-family EF to the single-family RE.[135]

The location specification of water heaters for all groups is unconditioned space. The percent of water heaters in unconditioned space is 69% in non-program homes, and 71% in program homes. For multifamily equipment, most program equipment is in conditioned space (94% of systems), and that is recommended as the UDRH input for multifamily homes.

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integrated systems. Wall-mounted combined appliances (with a very small or no tank) that are used for both space and water heating are included with instantaneous systems.

[132] The current UDRH uses the same input for both conventional electric and heat pump water heaters. However, the RE for these two system types is calculated based only on electric conventional systems since REM/rate does not allow a RE value to be entered for heat pumps.

[133] There were no multifamily propane systems, so these values are based on natural gas values.

[134] Using an adjustment factor would have resulted in a multifamily UDRH EF input of 0.76, which is too low to serve as a realistic comparison point.

[135] REM/Rate files do not include an option to record the RE for instantaneous systems; this is not a deficiency in the program data.

Table 183: Water Heaters – Current Inputs and Study Results and Suggestions

Fuel and System Type	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Natural Gas (EF, RE) (Suggested inputs same as propane)					
Conventional Storage	0.62, 0.79	0.65, 0.56 (n=15)	0.72, 0.84 (n=26)	**0.65, 0.79**	**0.72, 0.90**
Integrated	0.87, 0.79	0.89, 0.92 (n=4)	NA	**0.83, 0.92**	**0.92, 0.92**
Instantaneous	0.62, 0.81	0.96, 0.87 (n=9)	0.94 (n=56)	**0.94, 0.95**	**0.97, 0.98**
Propane (EF, RE) (Suggested inputs same as natural gas)					
Conventional Storage	0.60, 0.80	0.64, 0.57(n=10)	0.72, 0.82 (n=43)	**0.65, 0.79**	**0.72, 0.90**
Integrated	0.88, 0.80	0.76, 0.91 (n=3)	0.87 (n=3)	**0.83, 0.92**	**0.92, 0.92**
Instantaneous	0.62, 0.81	0.92, 0.69 (n=12)	0.93 (n=28)	**0.94, 0.95**	**0.97, 0.98**
Oil (EF, RE)					
Conventional Storage	0.63, 0.80	NA	0.55, 0.55 (n=1)	**Same as rated home**	**Same as rated home**
Integrated	0.79, 0.80	NA	NA	**Same as rated home**	**Same as rated home**
Instantaneous	Same as rated home[136]	NA	NA	**Same as rated home**	**Same as rated home**
Electric (EF, RE)					
All Types	0.90, 0.98	1.42, 0.98 (n=19)	1.93, 0.98 (n=39)	**1.42, 0.98**	**1.42, 0.98**
Location					
Location	Same as rated home	Uncond. Space	Uncond. Space	**Uncond. Space**	**Conditioned Space**

F.3.15 Lighting

- ***Recommendation: Assume efficient lighting saturation is in line with the average non-program homes visited during R1602 onsite visits.***

[136] These are functionally NA given that instantaneous, oil-fired systems are not systems that are normally seen in the residential market.

The efficient lighting percentages include CFL and LED bulbs. This is a percentage of efficient hardwired fixtures that are found in qualifying locations.[137] The current UDRH does not claim savings from lighting but sets the specification to 50% to match 2009 IECC. The team recommends adopting the non-program average of 54% (Table 184). This would match the logic of Rhode Island but not of Massachusetts which specifies lights as “same as rated home.”

Table 184: Lighting – Current Inputs and Study Results and Suggestions

Lighting	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Percentage of Fixtures with LED and CFL Bulbs	50%	54% (n=70)	84% (n=198)	**54%**	**41%**

F.3.16 Thermostats

- ***Recommendation: Apply the average thermostat setpoints from the non-program homes to both single-family and multifamily projects, and set programmable thermostats as the UDRH input for thermostat type, but do not reassign rated home to have a programmable thermostat.***

As recently adopted in Rhode Island, R1602 study recommends using the non-program average setpoint values for single-family homes. The current UDRH specification for thermostats is set at 68F for heating, and 75F for cooling; R1602 recommends adjusting these to 69F and 73F, respectively (Table 185). It is also recommended to use the single-family non-program values for the multifamily specifications because the multifamily sample data is based on pre-occupancy HERS rater estimates, and does not accurately reflect occupant behavior.

The study also recommends setting the UDRH thermostat type to be a programmable thermostat for single-family and multifamily homes, as these are the vast majority of installed units in both cases (from R1602 onsite visits and multifamily program homes). The previous UDRH reassigned both the reference home and the rated home to be programmable. In other words, no matter what thermostat type was present in the rated home, the UDRH comparison would assume that both the rated home and the reference home had programable thermostats. This new arrangement requires homes to use programmable thermostats to avoid a penalty relative to the UDRH.

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[137] REM/Rate has four separate lighting inputs. The value presented in this table includes the percentage of CFL and LED hardwired fixtures that are found in all rooms of the home except the following: garage, exterior, unfinished basements, and closets. Garage fixtures, exterior fixtures, and the percentage of hard-wired fixtures that are pin-based fluorescent tubes are all separate REM/Rate lighting inputs. Specific values for these REM/Rate inputs can be provided if necessary.

Table 185: Thermostat Type and Degrees Fahrenheit Setpoints – Current Inputs and Study Results and Suggestions

End-use	Current UDRH Input	Average Results		Suggested Inputs	
		Non-Program (R1602 site visits)	Program (2015 program data)	Single-Family	Multifamily
Type					
Heating and Cooling	Programmable (for UDRH and rated home)[138]	Majority Programmable	Majority Programmable	**Programmable**	**Programmable**
Setpoints (Degrees F)					
Heating	68	69 (n=330)	69 (n=212)	**69**	**69**
Cooling	75	73 (n=275)	76 (n=212)	**73**	**73**

F.3.17 Mechanical Ventilation

- ***Recommendation: Apply the mechanical ventilation of the home being rated.***

Mechanical ventilation in the current UDRH is set to be exhaust only and based on ASHRAE 62.2 (Table 186). There were only seven non-program homes in the sample with ventilation systems: two bathroom fans on automatic timers, two HRV systems, and three ERV systems. The study recommends changing to a specification of "same as rated home" to avoid penalizing program homes for which the increased energy consumption of ventilation systems would reduce savings.

Table 186: Mechanical Ventilation – Current Inputs and Study Results and Suggestions

	Current UDRH Input	Suggested Inputs	
		Single-Family	Multifamily
Mechanical Ventilation	Exhaust only, based on ASHRAE 62.2	**Same as rated home**	**Same as rated home**

F.4 Multifamily Estimation Methods

The study estimated recommended specifications for multifamily projects by applying a multifamily adjustment factor to the single-family recommended specifications. A literature review was conducted of multifamily baseline studies in New England from the last ten years

[138] The current UDRH file sets the thermostat type to programmable for both the UDRH and the rated home, regardless of what is in the rated home. The suggested input would only set the UDRH to have a programmable thermostat, which would drive program homes to include programmable thermostats to avoid being penalized relative to the UDRH.

to inform the multifamily adjustment factors by measure. Surveyed studies included the following:

- A 2012 study for Massachusetts looking at low and high rise new construction and retrofits[139]
- A 2015 study for New York looking at low and high rise new construction[140]
- A 2017 study for Massachusetts looking at Multifamily High Rise New Construction[141]

None of these multifamily studies provided sufficient detail to create direct comparisons between single-family and multifamily homes at the measure level. In addition, these studies consider buildings built in different time periods than those included in the R1602 baseline study. Therefore, program data gathered for this study was leveraged to estimate multifamily adjustment factors.

The Companies' program data included REM/Rate models for both single-family and multifamily units. The multifamily adjustment factor is the multifamily program value represented as a proportion of the single-family program value. To calculate multifamily adjustment factors for each measure, the single-family program average value was compared to the multifamily program average. The difference in efficiency between the single-family and multifamily samples was calculated as ratio change from the single-family efficiency. That ratio was then added to 1.0 to calculate the multifamily adjustment factor – the value that the single-family home average values were multiplied by to create the estimated multifamily efficiency value. Table 187 lists the multifamily adjustment factors by measure.

For example, looking specifically at conditioned to ambient above grade walls, single-family program homes had an average U-value of 0.055 and multifamily program homes had an average of 0.052. The difference between these two values represented as a percentage of the single-family program value is -5.45%. To get the MF adjustment factor, the percentage change is added to 1.0 as a decimal (-.0545) to get 0.9455. To estimate the MF recommended specification the SF recommended specification is multiplied by the MF adjustment factor: 0.062 * 0.9455 = 0.059.

For some measures, it was impossible to calculate a multifamily adjustment factor because that measure was not present in the multifamily program sample or the single-family program sample. Those measures have factors listed as "NA." The logic used to make recommendations for the multifamily specification for those measures is described in the individual sections of this memo. Typically, if an adjustment factor is "NA," the multifamily recommendation is the same as the single-family recommendation due to lack of better data. Additionally, for measures in which the single-family recommendation is "same as rated home" the multifamily recommendation is also "same as rated home."

[139] http://web.mit.edu/cron/project/EESP-Cambridge/Articles/MA%20RR_LI%20-%20Multifamily%20Potential%20Study_FINAL_Report%20and%20Appendix_17MAY2012.pdf

[140] https://www.nyserda.ny.gov/-/media/Files/Publications/building-stock-potential-studies/residential-baseline-study/Vol-2-Multifamily-Res-Baseline.pdf

[141] http://ma-eeac.org/wordpress/wp-content/uploads/Addendum-to-MA-Multifamily-High-Rise-Baseline-Study.pdf

The multifamily adjustment factor for ACH50 (2.263) seems particularly large. This is not because of a difference in testing methods between single-family and multifamily homes. Multifamily units that participate in the RNC program receive individual blower door tests just like single-family homes. In both cases, all measured air leakage is treated as air leakage to outside. However, the large difference in average ACH50 between single-family program and multifamily program homes could be the result of a difference in requirements: single-family homes are required to have an ACH50 of 4 or less, while multifamily units are required to have an air leakage of no more than 0.25 CFM50 per square foot of enclosure surface area. The two metrics are not readily comparable.

Table 187: Multifamily Adjustment Factors

Measure	Ratio Difference between SF and MF Program Data	Multifamily Adjustment Factor (1+Avg. Ratio Difference)
Above Grade Walls		
Conditioned to Ambient U-value	-0.0545	0.9455
Conditioned to Garage U-value	NA	NA
Conditioned to Attic U-value	-0.0169	0.9831
Conditioned to Unconditioned Basement and Enclosed Crawl Spaces U-value	0.0779	1.0779
All Unconditioned to Any U-value	NA	NA
Frame Floors		
Conditioned over Unconditioned Basement and Enclosed Crawl Spaces U-value	-0.2924	0.7076
Conditioned over Garage U-value	NA	NA
Conditioned over Ambient U-value	0.0185	1.0185
Conditioned over Open Crawl U-value	NA	NA
Ceilings		
Flat Attic U-value	-0.0283	0.9717
Vaulted U-value	-0.0636	0.9364
Foundation Walls		
All Conditioned R-Value	NA	NA
All Unconditioned R-Value	-1.0000	0.0000
Slab Floors		
On Grade Unheated Slab Under R-Value	3.9122	4.9122
On Grade Unheated Slab Perim R-Value	0.2690	1.2690
On Grade Heated Slab Under R-Value	NA	NA
On Grade Heated Slab Perim R-Value	NA	NA
Below Grade Unheated Slab Under R-Value	NA	NA
Below Grade Unheated Slab Perim R-Value	NA	NA
Below Grade Heated Slab Under R-Value	NA	NA

Measure	Ratio Difference between SF and MF Program Data	Multifamily Adjustment Factor (1+Avg. Ratio Difference)
Below Grade Heated Slab Perim R-Value	NA	NA
Windows		
U-value	0.0185	1.0185
SHGC	-0.0303	0.9697
Skylights		
U-value	NA	NA
SHGC	NA	NA
Doors		
Door U-value	NA	NA
Air Infiltration		
ACH50	1.2630	2.2630
Shelter Class	NA	NA
Heating Systems		
Natural Gas Air Distribution AFUE	0.0238	1.0238
Natural Gas Hydronic Distribution AFUE	0.0206	1.0206
Natural Gas Unit Heater AFUE	NA	NA
Propane Air Distribution AFUE	0.0081	1.0081
Propane Hydronic Distribution AFUE	NA	NA
Propane Unit Heater AFUE	NA	NA
Oil Air Distribution AFUE	NA	NA
Oil Hydronic Distribution AFUE	NA	NA
Oil Fired Unit Heater AFUE	NA	NA
Wood Fuel Fired Unit Heater % EFF	NA	NA
Kerosene Fuel Fired Unit Heater AFUE	NA	NA
ASHP & Ductless Mini-Splits HSPF	-0.0955	0.9045
GSHP COP	NA	NA
Dual Fuel Heat Pump HSPF (AFUE)	NA	NA
Cooling Systems		
Central Air-Split Conventional SEER	0.0125	1.0125
ASHP & Ductless Mini-splits SEER	-0.0819	0.9181
Air conditioner SEER (CAC, ASHP, Ductless Mini-spit)	-0.0168	0.9832
GSHP EER	NA	NA
Water Heaters		
Natural Gas Conventional EF (RE)	0.1806 (0.14)	1.1806 (1.14)
Natural Gas Integrated EF (RE)	NA	NA
Natural Gas Instantaneous EF (RE)	0.0319 (NA)	1.0319 (NA)

Measure	Ratio Difference between SF and MF Program Data	Multifamily Adjustment Factor (1+Avg. Ratio Difference)
Propane Conventional EF (RE)	NA	NA
Propane Integrated EF (RE)	NA	NA
Propane Instantaneous EF (RE)	NA	NA
Oil Conventional EF	NA	NA
Oil Integrated EF	NA	NA
Oil Instantaneous EF	NA	NA
Heat Pump	-0.1065	0.8935
Electric Conventional EF	0.0110	1.0110
Electric Integrated EF	NA	NA
Electric Instantaneous EF	NA	NA
Heat Pump and Electric Conventional EF	-0.4663	0.5337
Duct Insulation		
Attic Supply Ducts	-0.0698	0.9302
All Other Ducts in Unconditioned Space	0.0109	1.0109
Duct Leakage		
Leakage to Outside CFM25/100Sqft	0.2486	1.2486
Lighting		
CFL Lighting	-0.2443	0.7557
Thermostats		
Heating and Cooling Set Points	NA	NA

G Appendix G Billing Analysis

This appendix describes the results of the billing analysis performed as part of the R1602 study, along with related recommendations stemming from this analysis.

G.1 Introduction

The baseline study portion of the R1602 study comprises the main body of this report, while this appendix summarizes the results of the billing analysis, related recommendations, and the underlying methodology.

The billing analysis has a very defined scope: it compares electric and natural gas energy use as estimated by REM/Rate models and to actual billing data to determine how accurately program energy models reflect actual home energy consumption. The study relied solely on data contained in the REM/Rate files or billing data, as the approach did not involve collecting the characteristics of program households or the post-occupancy appliances and other products used in program homes. Thus, the analysis compares, but does not attempt to explain differences in, REM/Rate estimates and billing data.

G.2 Billing Analysis Findings and Recommendations

This analysis found that single-family program homes used about 8% *more* electricity (n=157) and 4% less natural gas (n=23) than estimated by program REM/Rate models.[142] The study also found that non-program single-family homes used about 5% less electricity than suggested REM/Rate models; results for natural gas homes were inconclusive. Table 188 lists the ratios of energy use as estimated through billing analysis and REM/Rate models (with confidence intervals in parentheses).

The Companies provided the billing data and program REM/Rate files; REM/Rate models for non-program homes were created by evaluators as part of the baseline study.[143] The RNC program uses REM/Rate models to estimate energy use and determine the efficiency level of program homes.

[142] The program also incents the building of energy-efficient multifamily buildings. They have been excluded from this analysis because such factors as different dates and length of occupation and energy use in common areas, among others, complicate both REM/Rate modeling and billing analysis, which would have muddied any energy-use ratios developed from this study.

[143] Data was not provided/available to evaluators to screen against participation in any other Connecticut program, such as an equipment rebate or weatherization program. The available records were electric new service request data and RNC program data, which were both used to identify RNC program homes. Not accounting for participation in other programs could affect both RNC and non-RNC program homes. The implication is that as-built usage may be understated for both types of homes, leading to lower ratios of billing to REM/Rate use than under as-built conditions.

Table 188: Ratio of Billing to REM/Rate Estimates of Use

RNC Program Participation	Electric		Natural Gas	
	Sample Size	Ratio: Billing To REM/Rate Use	Sample Size	Ratio: Billing To REM/Rate Use
Program	157	1.08 (1.07 – 1.09)	23	0.96 (0.65 – 1.58)
Non-program[1]	26	0.95 (0.91 – 1.00)	5	0.67 (0.28 – 1.14)

[1] Using the same thermostat set points as program REM/Rate files (see report for details).

Other key findings of the study include the following:

- Program REM/Rate models tend to underestimate overall annual consumption, while non-program REM/Rate models tend to overestimate overall annual consumption.
- Estimated program and non-program energy use rarely differs statistically—exceptions include REM/Rate estimated heating and cooling electricity use and billing estimated natural gas overall use.
- The lack of a single unique identifying number across datasets—program participation lists, REM/Rate files, electric billing data, and natural gas billing data—greatly constrained the study's ability to match records and provide analyses of the full population of participants.

Small sample sizes of households with usable billing data that were matched to REM/Rate files preclude the billing analysis study from making recommendations for program or PSD changes. However, the billing analysis experience leads to the following specific data tracking recommendations:

- Effective, efficient evaluation requires the existence of unique identifying numbers across datasets. To facilitate evaluation for the RNC program, the Companies should assign a common identifier for billing, REM/Rate files, and program tracking databases. This needs to be done early in the program-participation process, as designated homes often go through the program-review process prior to being assigned a final street address or account number.
- For all programs, the electric and gas utilities should track the following for each program participant in the program tracking database: program participant or project identification number, electric account number (in addition to the participant or project identification number), natural gas account number (if applicable), and primary heating fuel (if known).
- The project number or unique identifier needs to be used consistently in any program-related files, including updating the program homes database and REM/Rate files to note whether the project met qualification requirements or discontinued its program participation.

G.3 Billing Analysis Methodology

The study calculated the alignment of actual and predicted energy use as the ratio of consumption from billing data to the consumption predicted by REM/Rate models[144]:

$$Energy\ Use\ Ratio = \ (Annual\ billing\ usage)/(Annual\ REM/Rate\ usage)$$

Energy-use ratios lower than 1.0 indicate that the program may be saving more energy than it is claiming, while those greater than 1.0 indicate that the program may be saving less energy than it is claiming. The study carried out the analyses for both program and non-program homes and for electric and natural gas fuels, as shown in Table 189.

The program homes analysis assessed usage for 180 program homes that participated in the program between January 1, 2014 and June 30, 2016 and also had ample billing data for the analysis. The billing records provided by the Companies for each home begin with the date the newly constructed home had service installed and end on June 30, 2016. The program homes analysis compared billing data with RNC program REM/Rate files.

The non-program homes analysis assessed usage for 31 non-program homes with ample billing data for the analysis. These 31 homes are a subset of the 70 visited as part of the Task 4: Baseline Study. The billing analysis of non-program homes compared the REM/Rate calculations developed through the baseline study with electric and gas utility billing data for homes requesting new service between January 1, 2014 and February 28, 2017. The non-program homes analysis offers insight into the general accuracy of engineering models compared to actual use. As shown in Section G.5.2, the electric non-program homes are somewhat smaller than Eversource electric homes (2,454 square feet vs. 3.156 square feet, respectively) and comparable to UI electric (2,227 square feet). The natural gas non-program homes are comparable to the Eversource natural gas homes (2,301 square feet vs. 2,663 square feet, respectively).

Table 189: Billing Analysis Sample[1]

RNC Program Participation	Eversource	UI	Total
Program[2]			
Electric - Electric heating	59	1	60
Electric - Non-electric heating	76	22	98
Natural Gas	23	--	23
Non-program[2]			
Electric	21	5	26
Natural Gas	5	--	5

[1] Section G.5.2 provides a detailed assessment of the data cleaning process that led to these sample sizes and compares known characteristics of program and non-program homes.
[2] Program homes include those participating between January 1, 2014 and June 30, 2016.
[3] Non-program homes are those that requested new service between January 1, 2014 and February 28, 2017 but did not otherwise take part in the program.

[144] The same version of REM/Rate was used to carry out the predicted consumption levels for program and non-program homes.

The study performed billing analysis on the following groups of program participants:

- Electric program overall and for Eversource and UI
- Electric non-program overall
- Natural gas program for Eversource only (as no UI natural gas customer had sufficient data to complete the analysis)
- Natural gas non-program for Eversource only (as no UI natural gas customer had sufficient data to complete the analysis)

G.3.1 Seasonal Degree Day Method

The analysis relied on the Seasonal Degree Day (SDD) method, which normalizes billing data to average weather conditions as captured in the *typical meteorological year*. The method uses two main inputs:

- **Heating degree days (HDDs)**. HDDs are a measure of how many degrees and days the outside air temperature necessitated indoor heating.
- **Cooling degree days (CDDs)**. Similarly, CDDs are a measure of how many degrees and days the outside air temperature was warm enough that air conditioning would likely have been used.

The study used data from the Bridgeport Sikorsky Memorial and Hartford Bradley International Airports.[145] HDD data indicate that participants living near Hartford (inland) face significantly colder temperatures than those living near Bridgeport (on Long Island Sound). The modeling approach factors this difference into its calculations.

The SDD method estimates three types of energy use: heating, cooling, and overall. The method estimates energy use overall and for HDDs and CDDs. Thus, an estimate of *electric heating use* in a home that uses oil for space and water heating captures additional electricity use during heating days. This may be from supplemental heating or additional cooking and lighting. The report does not estimate natural-gas use for cooling, given the general lack of a relationship between the two.

G.3.2 Data Cleaning Procedures

This section summarizes the data cleaning procedures. Section G.5.2 provides a more detailed accounting of the impact of these decisions on final sample sizes.

Construction periods and pre-occupation vacancies create unique challenges in cleaning and preparing billing data for newly constructed homes. Residential new construction homes pose a unique challenge in billing data cleaning. Nearly all billing analyses must address issues related to extended vacancies and outlying usage for very

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[145] Bridgeport and Hartford may not be the nearest weather stations for every home, especially those located near state borders. However, not all weather stations keep data at the necessary level of detail, and more detailed matching expend additional evaluation resources. To streamline the analysis, this study uses these two Connecticut stations. As *R91 Review of Impact Evaluation Best Practices* suggests, future studies may want to consider expanding the potential list of weather stations for homes near state borders. Report available at https://www.energizect.com/sites/default/files/R91%20-%20Review%20of%20Impact%20Evaluation%20Best%20Practices_Final%20Report_3.30.16.pdf

short periods. New construction exacerbates these challenges, as the construction period could be included in the billing data, the account holder changes between the construction period and regular occupation, and the date the household moves into the home is often unknown to the utility. In billing analyses of existing homes programs, the home has typically had electric service for many years, and the date the new household took possession is easy to identify by a newly opened account number at an existing premise and meter.

The analysis required the matching of three sets of data supplied by the Companies: billing data, REM/Rate files, and inclusion on participant lists. The Companies provided the evaluation team with lists of participants, billing data, and REM/Rate files. While the billing data and program tracking data list account numbers to identify unique program participants, REM/Rate files are not assigned account numbers (many are not occupied when the files are created and REM/Rate files are specific to a site, rather than by occupant, and can have multiple occupant records). Only *site address* appears as a common identifier across the three files. However, the addresses in the three datasets are not consistently recorded. The cleaning process involves manually fixing inconsistencies whenever possible to improve the matching process. Yet, many addresses still failed to match, often because the newly constructed homes lacked a permanent address when the HERS raters created the program REM/Rate files.[146]

A program site may have multiple program participants and billing accounts. Another limitation is that a site will often have more than one account number, such as for the contractor's account number and billing data during the period of construction, followed by the occupant's account number and billing data during the period of occupancy. During the cleaning process, the study used the most recent account number so that each REM/Rate file is associated with only one participant's billing account.

This study established the occupancy periods and the presence of ample billing records using the following procedures:

1. Leveraging billing period start and end dates to determine whether usage covers a span of at least 12 months; flags sites with less than 12 months of usage
2. Identifying and flagging sites with negative usage, which suggests PV generation
3. Visually inspecting usage for patterns that suggest seasonal occupancy or construction (e.g., low during peak seasons suggests seasonal occupancy or high usage during off-peak seasons suggests construction related to the use of high-wattage lighting and electric construction equipment)
4. Visually examining usage for periods of partial occupancy (e.g., occupant moves into the home over a period of months, which is indicated by lower usage in the earlier records than the rest of the year)
5. Removing sites with less than 12 months of observations after adjusting for seasonal/partial occupancy and construction

[146] For example, the REM/Rate file may have listed a lot number, or sometimes even the name of a city and the builder or owner with no further details.

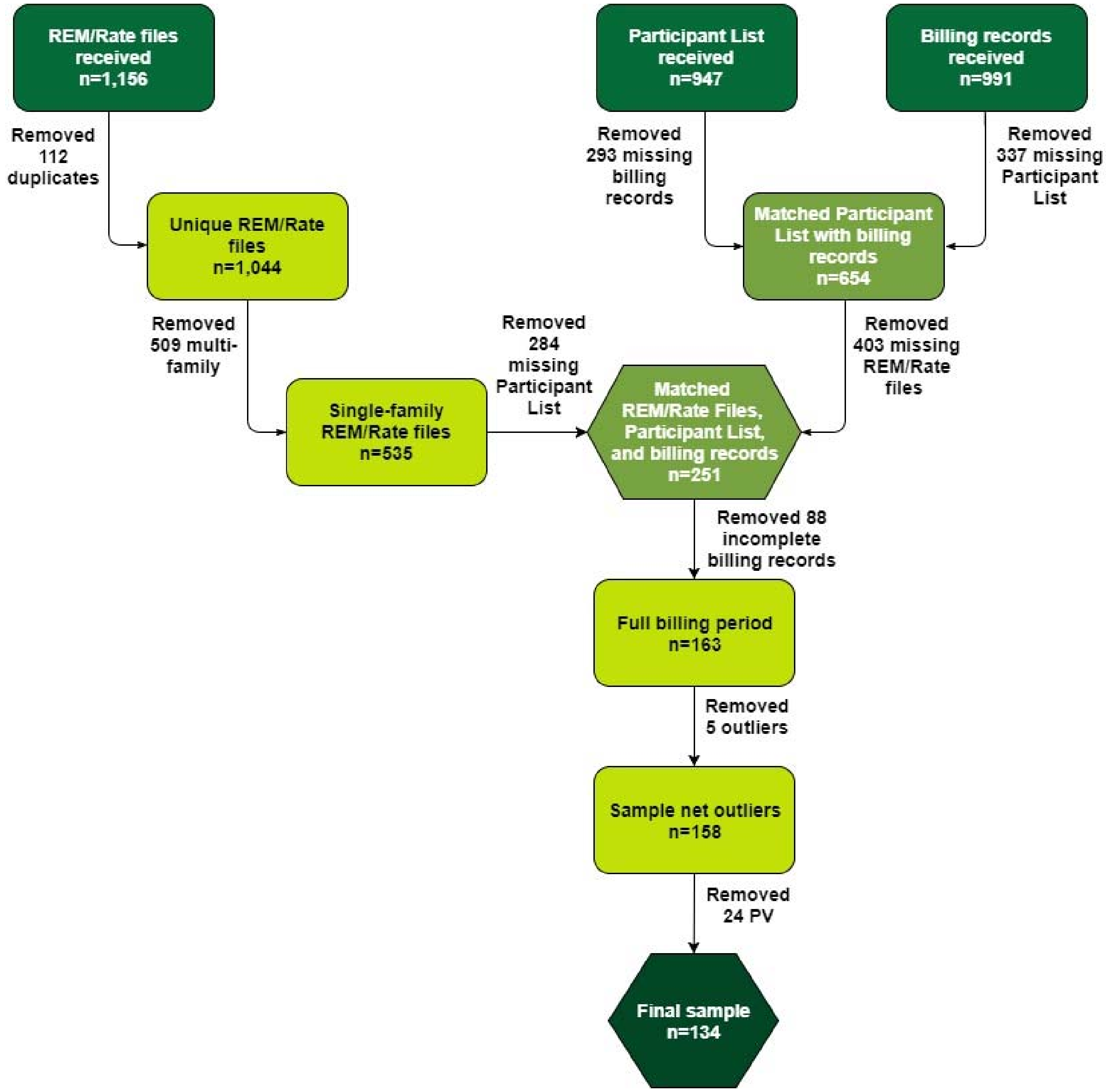
Natural gas homes also make up a limited portion of the participant list, which limits sample sizes for natural gas homes. In addition, the natural gas records also suffered from the same challenges as electric records with matching billing, program, and REM/Rate files or having ample months of data to estimate annual use.

The study also identified homes with outlying usage. The data cleaning process searches for outliers in the program data by examining two types of "percentage difference" calculations: (1) the difference between normalized and non-normalized billing usage and (2) the difference between the normalized annual billing usage and REM/Rate annual usage. The process also plots the REM/Rate usage and normalized billing usage on separate axes. Section G.5.1 provides a discussion on methodology used to identify outliers.

The study identified and removed homes with PV installed from the analysis. The billing data provided by the Companies usually detail the amount of electricity consumed at the site in monthly intervals. However, if the site generates its own electricity using PV, then the billing data detail net usage (usage less kWh generated). Initial inquiries to the Companies led the evaluation contactor to mistakenly conclude that they did not track generation in the billing data; more recently, the Companies explicitly stated that they do track generation. Given the challenges of integrating generation and billing data, the EA team directed NMR to forego a PV analysis at this time. The study recognizes the lack of PV as a shortcoming of the approach, given the increasing importance of PV and other renewable technologies in the program (see Recommendations).

Figure 34 presents the full data cleaning process for Eversource Electric program homes, the largest of the study groups. Section G.5.2 includes tables that outline the impact of the cleaning process on sample sizes for all program and non-program homes for both Eversource and UI.

Figure 34: Data Cleaning Process Summary for Eversource Electric



G.3.3 Thermostat Set Points

To increase comparability, the study developed non-program home REM/Rate files using similar thermostat settings as used in program REM/Rate files. Because program REM/Rate files typically are developed prior to the home being occupied, HERS raters use assumed default thermostat settings in the models. The default values are 68 Fahrenheit (F) for heating and 78F for cooling assumed in many of the program REM/Rate files.[147] The baseline study estimates energy use using lived-in set points in non-program homes with a range between 68F and 70F for heating and 70F and 78F for cooling, which aligns with its objective of describing non-program homes. This billing analysis instead seeks to use non-program homes as a comparison to program homes. Therefore, the study reran non-program REM/Rate models using default thermostat settings and reports results for these altered models throughout.

G.4 Analysis and Results

Using the equation below, this study estimated energy-use ratios that compare energy consumption from billing records to the consumption estimates from REM/Rate models. The analysis provides results for all electricity and natural gas uses in a home and isolates use during heating and cooling periods when possible and appropriate.

$$Energy\ Use\ Ratio = \ (Annual\ billing\ usage)/(Annual\ REM/rate\ usage)$$

The key findings are as follows:

- Billing analysis and REM/Rate align most closely for overall estimates of household energy use and for cooling use, but diverge more for estimates of heating use.
- Program homes use about 8% more electricity (n=157) and 4% less natural gas (n=23) than estimated from REM/Rate.
- Non-program home electricity (n=26) use was about 5% less than suggested by REM/Rate and natural gas (n=5) use was about 33% less.

This section describes these analysis (including their strengths and weaknesses) and presents results by utility and heating and cooling use, when appropriate.

G.4.1 Electric Billing Analysis

The electric billing analysis includes both program and non-program homes from both Eversource and UI. The report lists program home electric results separately for each utility, but combines them for non-program homes due to small sample sizes. Heating and cooling estimates refer to energy use on HDDs and CDDs, and the resulting consumption figures include not only heating and cooling energy consumption, but also other energy-consuming features (e.g., lighting, pool pumps) that could coincide with additional heating or cooling load.

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[147] A few program REM/Rate files used 75F.

G.4.1.1 Program Homes

The electric billing analysis for all program homes suggests that heating use was 28% higher than suggested by REM/Rate, cooling use was 10% higher, and overall use was 8% higher. Table 190 compares the normalized billing data and REM/Rate modeled electric consumption by end use and presents the corresponding energy-use ratios. These results suggest an energy-use ratio of 1.28 for heating, 1.10 for cooling, and 1.08 overall.

- **The electric billing analysis for electric heating program homes suggests that heating use was 4% higher than suggested by REM/Rate, cooling use was 15% lower, and overall use was 3% higher.** These results suggest an energy-use ratio of 1.04 for heating, 0.85 for cooling, and 1.03 overall for electric heated homes.
- The electric billing analysis for fossil fuel heating program homes suggests that heating use was 232% higher than suggested by REM/Rate, cooling use was 30% higher, and overall use was 14% higher. Results suggest an energy-use ratio of 3.31 for heating, 1.30 for cooling, and 1.14 overall for fossil-fuel heated homes. The reason for the large difference between heat consumption estimates from the billing data and the REM/Rate models is unclear. It could be due to occupant behavior (e.g., supplemental electric heat being used that was not part of the REM/Rate models) or the inherent challenges with disaggregating billing data consumption into heating-specific end use, unlike REM/Rate, which disaggregates its estimates into heating, cooling, hot water, and lighting/appliance consumption.

Table 190: Program Homes – Billing and REM/Rate Usage & Energy-Use Ratios (Electric)[1]

End use	Average kWh/year		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model	
All Homes (n=157)			
Heating	2,712 (2,342 – 3,082)	2,115 (1,759 – 2,471)	1.28 (1.26 – 1.31)
Cooling	988 (884 – 1,091)	897 (830, 964)	1.10 (1.09 – 1.11)
Overall	11,310 (10,464 – 12155)	10,467 (9,802 – 11,133)	1.08 (1.07 – 1.09)
Electric heated homes (n=59)[2]			
Heating	5,237 (4,620 – 5,855)	5,032 (4,525 – 5,540)	1.04 (0.89 – 1.21)
Cooling	887 (724 – 1,050)	1,045 (938 – 1,151)	0.85 (0.64 – 1.14)
Overall	15,427 (14,061 – 16,793)	14,937 (13,799 – 16,075)	1.03 (0.92 – 1.16)
Fossil fuel heated homes (n=98)			
Heating	1,192 (981 – 1,402)	359 (296 – 422)	3.31 (2.58 – 4.26)
Cooling	1,048 (913 – 1,182)	808 (724 – 892)	1.30 (1.10 – 1.53)
Overall	8,831 (7,979 – 9,684)	7,776 (7,400 – 8,152)	1.14 (1.02 – 1.26)

[1] Confidence intervals shown in parentheses.
[2] Includes four homes that use electric and fossil fuel heating.

The energy-use ratios differ between Eversource and UI program homes, which is likely due to a mixture of home size and the moderating effects of Long Island Sound on the climate in UI territory. For example, the UI heating ratio is quite high (2.25) compared to Eversource's ratio (1.26). The overall UI ratio is 0.91, while that of Eversource is 1.1 (Table 191). However, the low UI sample size (n=23) limits the ability to generalize results and draw any conclusions of significant differences between the Companies. Because UI had only one electric heating home, the table does not separate results for electric and fossil fuels and the results mirror those in Table 190. Section G.5.3 details the electric billing analysis by Company.

Table 191: Program Homes – Energy-Use Ratios by Company (Electric)

End use	UI (n=23)	Eversource (n=134)
Heating	2.25	1.26
Cooling	1.14	1.10
Overall	0.91	1.10

G.4.1.2 Non-program Homes

Billing analysis and REM/Rate models for non-program homes align well overall, but differ substantially for heating use. The energy-use ratio for heating is 1.80, cooling is 1.05, and overall is 0.95. The small sample size of 26 homes limits the generalizability of results. Table 192 compares the normalized billing data and REM/Rate modeled electric consumption.[148]

Table 192: Non-program Homes – Billing and REM/Rate Usage & Energy-Use Ratios (Electric)[1]

End use / Thermostat Settings	Average kWh/year (n=26)		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model	
Heating	2,163 (1,475 – 2,851)	1,199 (514 – 1,885)	1.80 (1.56 – 2.11)
Cooling	1,044 (783 – 1,305)	998 (819 – 1,178)	1.05 (0.97 – 1.12)
Overall	9,300 (7,677 – 10,924)	9,764 (8,730 – 10,797)	0.95 (0.91 – 1.00)

[1] Confidence intervals shown in parentheses.

G.4.1.3 Program and Non-Program Means and Energy-Use Ratio Comparisons

Electricity use estimated from REM/Rate files shows some significant differences between program and non-program homes, but the differences are not significant when estimated from billing data. The program and non-program equivalence of means test, shown in Table 193, determines that normalized billing data use do not differ statistically. Likewise, REM/Rate estimates of cooling and overall use do not differ significantly between program and non-program homes. However, heating use estimated from REM/Rate models differs significantly between the two types of homes.

[148] Billing analysis results are not broken out by heating fuel type due to the low sample size for electric heated homes (n=3).

Table 193: Program and Non-Program Equivalence of Means Test Results (Electric)[1]

End use	Program Average kWh/year (n=157)	Non-program Average kWh/year (n=26)	Difference	p-value
Normalized Billing Data				
Heating	2,712 (224)	2,163 (403)	549 (574)	0.34
Cooling	988 (63)	1,044 (153)	56 (166)	0.74
Overall	11,310 (950)	9,300 (511)	2,010 (1,315)	0.13
REM/Rate Model				
Heating*	2,115 (215)	1,119 (401)	916 (554)	0.10
Cooling	897 (41)	998 (105)	102 (108)	0.35
Overall	10,467 (402)	9,764 (605)	704 (1,020)	0.49

[1] Standard errors for use for each group are reported in parentheses. The standard error measures the statistical accuracy of an estimate.

* Significant difference between program home and non-program home use at the 90% confidence level.

Electricity use estimated from REM/Rate files shows some significant differences between program and non-program fossil fuel heated homes. Although the analysis does not suggest separate energy-use ratios for electric- and fossil fuel heated non-program homes due to sample size, the energy-use estimates for fossil fuel heated non-program homes warranted closer attention. As with program homes, REM/Rate files show lower electricity use for heating during heating months relative to the estimates from the billing analysis. As previously discussed, this could be due to behavior issues, such as higher electric supplemental heat being used than assumed in REM/Rate models. It could also be because the billing analysis is not able to perfectly isolate out this consumption, whereas REM/Rate completely separates consumption into heating, cooling, hot water, and lighting/appliance end uses. The program and non-program equivalence of means test, shown in Table 194, determines that the normalized billing data do differ statistically for heating use. Likewise, REM/Rate estimates of heating, cooling, and overall use do differ significantly between program and non-program homes.

Table 194: Program and Non-Program Equivalence of Means Test Results for Fossil Fuel Heated Homes (Electric)[1]

End use	Program Average kWh/year (n=98)	Non-program Average kWh/year (n=22)	Difference	p-value
Normalized Billing Data				
Heating	1,192 (127)	2,060 (376)	869 (319)	0.01
Cooling	1,048 (81)	1,100 (169)	52 (186)	0.78
Overall	8,831 (513)	9,090 (1013)	258 (1,168)	0.82
REM/Rate Model				
Heating*	359 (38)	855 (308)	496 (167)	0.00
Cooling	808 (51)	1,014 (112)	206 (118)	0.08
Overall	7,776 (226)	9,530 (631)	1,754 (557)	0.00

[1] Standard errors for use for each group are reported in parentheses. The standard error measures the statistical accuracy of an estimate.
* Significant difference between program home and non-program home use at the 90% confidence level.

Results suggest that the REM/Rate estimates for program homes tend to underestimate overall electric consumption, whereas the non-program homes tend to overestimate it. The overall electric energy-use ratio is 1.03 for electric heating program homes, 1.14 for fossil fuel heating program homes, and 0.95 for non-program homes. The differences between billing and REM/Rate estimates could reflect assumptions built into either billing or REM/Rate models or variations in measurement between individual HERS raters (who gathered data for program models) and evaluation staff (who gathered data for non-program models).

G.4.2 Natural Gas Billing Analysis

Few homes with natural gas service had adequate billing data for inclusion in the analysis, so the results have limited generalizability. As explained in Section G.5.2, the small number of records provided by the Companies with sufficient post-occupancy billing periods, and the small number of participant accounts that could be match with REM/Rate files, mean that the analysis for natural gas focuses on 23 Eversource program homes and five Eversource non-program homes. UI billing records did not cover an adequate amount of time to estimate weather normalized use.[149]

G.4.2.1 Program Homes

The results suggest a natural gas energy-use ratio of 0.85 for heating and 0.96 overall for program homes, meaning the program may be saving more than it is claiming.

[149] As natural gas is used for space and water heating and cooking, the study does not address cooling use for this fuel.

Normalized billing data indicate that program homes use 543 CCF/year for heating, with overall use totaling 758 CCF/year, on average (Table 195). In contrast, REM/Rate modeling indicates usage of 642 CCF/year for heating and 789 CCF/year in total, on average.

Table 195: Program Homes – Billing and REM/Rate Usage & Energy-Use Ratios (Natural Gas)[1]

End use	Average CCF/year (n=23)		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model	
Heating	543 (433 – 653)	642 (400 – 844)	0.85 (0.76 – 0.94)
Overall	758 (625 – 891)	789 (537 – 1,041)	0.96 (0.65 – 1.58)

[1] Confidence intervals shown in parentheses.

G.4.2.2 Non-program Homes

The energy-use ratios for the five non-program natural gas homes are relatively low, implying that REM/Rate models underestimate use in comparison to actual billing records. The analysis suggests non-program natural gas energy-use ratios of 0.60 for heating and 0.67 overall (Table 196). Because the Companies provided usable billing data for only five non-program homes in Eversource service territory, the results are indicative only and *should not be generalized.*

Table 196: Non-program Homes – Billing and REM/Rate Usage & Energy-Use Ratios (Natural Gas)[1]

End use	Average CCF/year (n=5)[2]		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model (Lived-in)	
Heating	364 (190 – 539)	604 (477 – 769)	0.60 (0.28 – 0.99)
Overall	451 (212 – 691)	672 (524 – 820)	0.67 (0.28 – 1.14)

[1] Confidence intervals shown in parentheses.
[2] Note the small sample size.

G.4.2.3 Program and Non-Program Means and Energy-Use Ratio Comparisons

The study only found one significant difference in estimated use between program and non-program homes: overall use based on billing data.

The program and non-program equivalence of means test, shown in Table 197, determines that the normalized billing data average is not statistically different for heating, but is statistically different at the 90% confidence level for overall use (even when considering the small sample sizes). Results for the average CCF/year for the REM/Rate Model indicate that program and non-program averages are not statistically different at the 90% confidence level across all end uses.

Table 197: Program and Non-Program Equivalence of Means Test Results (Natural Gas)

End use	Program Average CCF/year (n=23)	Non-program Average CCF/year (n=5)	Difference	p-value
Normalized Billing Data				
Heating	543 (64)	364 (82)	178 (144)	0.23
Overall*	758 (77)	452 (112)	306 (175)	0.09
REM/Rate Model				
Heating	642 (140)	604 (133)	38 (115)	0.90
Overall	789 (146)	672 (155)	117 (319)	0.72

[1] Standard errors for use for each group are reported in parentheses. The standard error measures the statistical accuracy of an estimate.
* Significant difference between program home and non-program home use at the 90% confidence level.

In contrast to non-program homes, the overall energy-use ratio (0.96) for natural gas program homes suggest that the REM/Rate estimate for program homes is a fairly accurate reflection of actual home energy consumption. In contrast, the REM/Rate estimate for non-program homes tends to overestimate overall natural gas annual consumption (0.60 for heating and 0.67 overall); however, the small sample size limits the generalizability of this result.

G.5 Supporting Information

G.5.1 Identifying Outliers

Before calculating the energy-use ratios, the study searched for outliers by examining two percentage difference calculations. The first is the percentage difference between normalized and non-normalized billing usage. The second is the percentage difference between the normalized annual billing usage and REM/Rate annual usage. The exploration suggests five outlier sites of more than three standard deviations from the mean.

G.5.1.1 Calculating Percentage Differences

The study used the following formula to calculate percentage difference rather than percentage change. This is because the variables used to identify outliers are not a change of one another.

$$\frac{|normalized\ usage - non - normalized\ usage|}{\frac{(normalized\ usage + non - normalized\ usage)}{2}} \times 100$$

Similarly, the formula for percentage difference between normalized annual billing usage and REM/Rate annual usage is:

$$\frac{|normalized\ usage - REM/rate\ usage|}{\frac{(normalized\ usage + REM/rate\ usage)}{2}} \times 100$$

G.5.1.2 Eversource

Figure 35 shows a scatterplot of REM/Rate use by normalized billing usage, with suspected outliers identified. The dark green highlights the non-outlier sites used in our analysis (134 sites), the orange markers are the outliers identified when comparing normalized versus non-normalized billing usage (three sites), and the orange markers outlined in black are outliers identified when analyzing energy-use ratios and the visual (two sites).

Figure 35: Eversource Normalized Billing Data Usage vs REM/Rate usage (n=139)

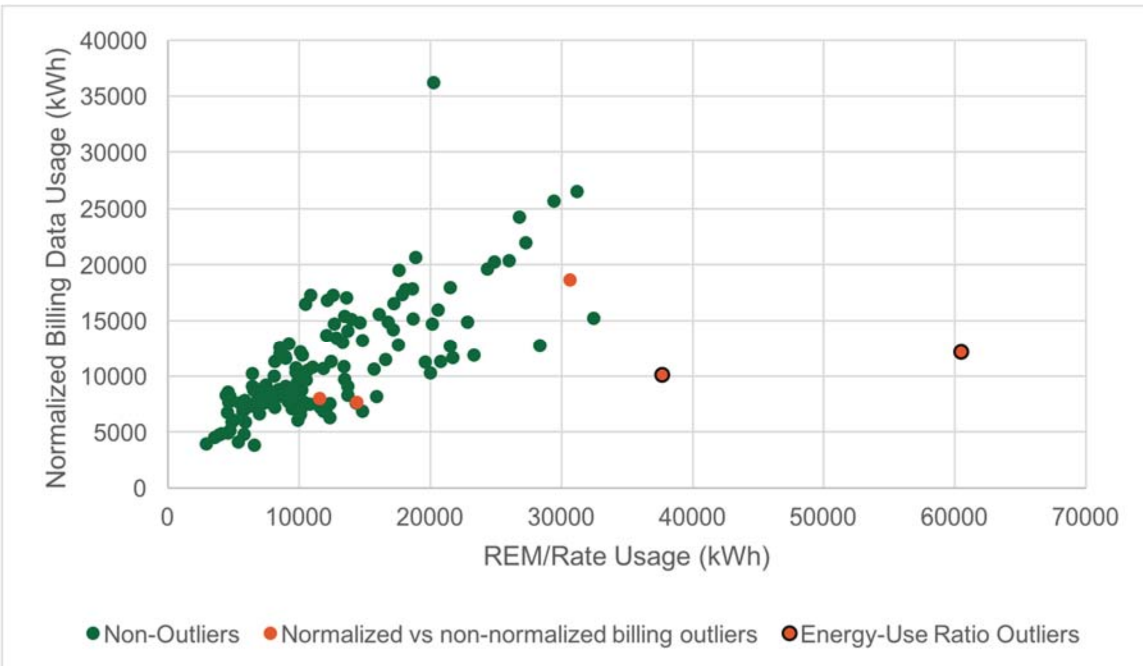
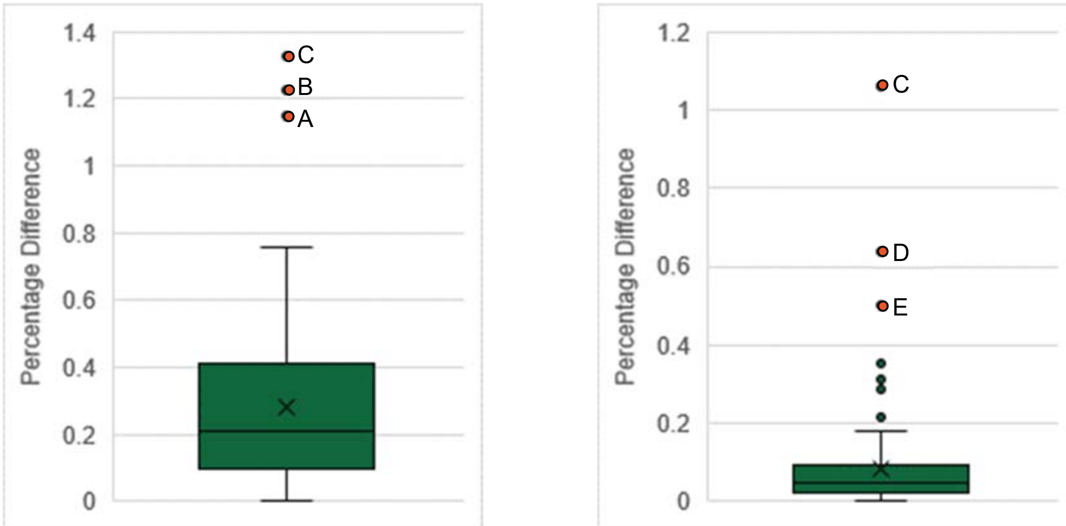


Figure 36 identifies the five outliers in box and whiskers plots, and Table 198 provides a description of the sites. Site C exhibits a 106% difference between its non-normalized and normalized usage while also exhibiting a 133% difference between the normalized usage and reported REM/Rate usage. While Sites A and B do not show large differences between the normalized and non-normalized usage, they have a 115 and 123% difference between the normalized billing usage and the REM/Rate usage, respectively. Site D exhibits the second largest difference (66%) between normalized annual usage and non-normalized annual usage, while Site E represents the third largest difference (64%).

Figure 36: Box and Whiskers – Percentage Differences (n=139)



(a) Billing vs. REM/Rate

(b) Normalized vs. Non-normalized Billing

Further investigation into these homes did not reveal anomalies in the billing data that would suggest reporting error, home vacancies, or inclusion of home construction. The homes tend to be large consumers of electricity, and they either have a pool or they are located on a waterfront (Table 198).

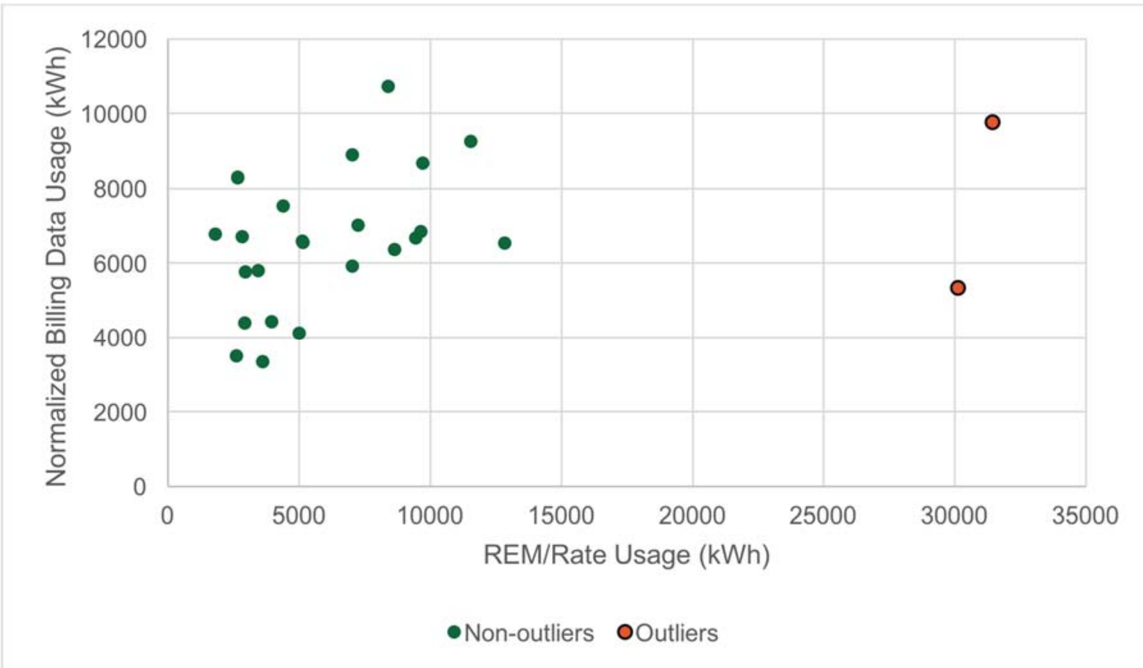
Table 198: Eversource Participant Energy-Use Ratio Outliers

Site	Percentage difference between normalized and non-normalized usage	Percentage difference between normalized usage and REM/Rate usage	Weather Station	Site Address Description
A	0%	**115%**	Bradley International Airport	4 bdrm, 2.5 ba, 1400-1500 sqft, waterfront property on a beach w/ dock
B	11%	**123%**	Bridgeport Sikorsky Memorial Airport	5 bdrm, 2 ba, 2800-2900 sqft
C*	**106%**	**133%**	Bridgeport Sikorsky Memorial Airport	5 bdrm, 4 ba, 3500-3600 sqft, heated pool, 7 fireplaces
D	**66%**	61%	Bradley International Airport	3 bdrm, 2 full ba, 5 partial ba, 2900-3000 sqft
E	**64%**	36%	Bridgeport Sikorsky Memorial Airport	4 bdrm, 2.5 ba, 2300-2400 sqft

G.5.1.3 United Illuminating

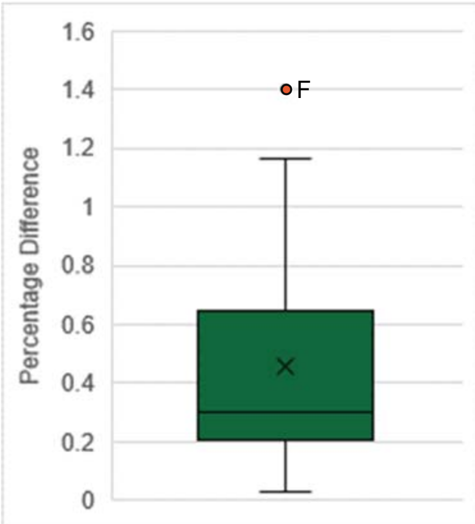
Figure 37 shows a scatterplot of REM/Rate usage by normalized billing usage (with the outliers indicated). The dark green highlights the non-outlier sites used in our analysis (23 sites) and the orange markers outlined in black show the outliers, which were identified when analyzing energy-use ratios and the visual (two sites).

Figure 37: UI Normalized Billing Data Usage vs REM/Rate usage

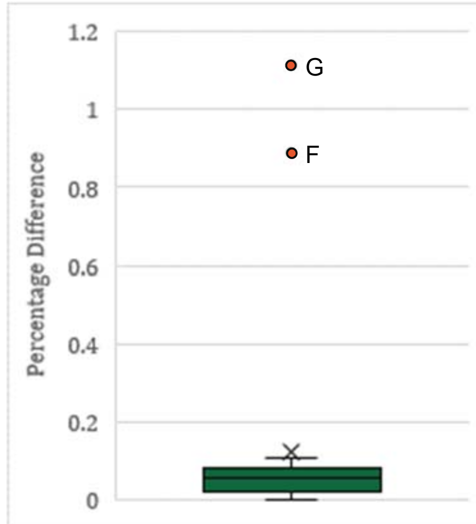


Two UI households (sites F and G) exhibit outlying usage in both assessments (Figure 38). The identification of outliers for UI followed similar procedures as for Eversource.

Figure 38: Box and Whiskers – Percentage Differences (n=25)



(a) Billing vs. REM/Rate



(b) Normalized vs. Non-normalized Billing

A closer look at the two UI sites' billing data does not find anomalies that would suggest reporting error, seasonal occupancy, or inclusion of the construction period. Table 199 lists the two outlier sites and their descriptions. Sites F and G exhibit particularly large differences between the normalized annual usage and the reported REM/Rate annual usage. Site F exhibits a 111% difference between its non-normalized and normalized usage while also exhibiting a 140% difference between the normalized usage and reported REM/Rate usage. Similarly, Site G exhibits a 129% difference between its non-normalized and normalized usage while also exhibiting a 151% difference between the normalized usage and reported REM/Rate usage.

Table 199: Non-PV Realization rate outliers

Site	Percentage difference between normalized and non-normalized usage	Percentage difference between normalized usage and REM/Rate usage	Weather Station	Site Address Description
F*	**111%**	**140%**	Bridgeport Sikorsky Memorial Airport	3 bdrms, 2.5 baths, 2000-3000 sqft
G*	**129%**	**151%**	Bridgeport Sikorsky Memorial Airport	3 bdrms, 2ba, 1200-1300 sqft

* Indicates a site that is an outlier on both assessments between (1) the normalized annual usage and the reported REM/Rate annual usage and (2) its non-normalized and normalized usage.

G.5.2 Data Cleaning and Household Characteristics

The lack of REM/Rate files, the exclusion of PV homes, and data cleaning left a final sample of 180 program homes and 31 non-program homes. Table 200 and Table 202 provide comparisons of the number of accounts received and cleaned for electric service and natural gas service, respectively. The single most common reason for removing homes from the analysis is that we could not match them to REM/Rate files. The next most common was if the accounts received were not on participant lists. The third most common was inadequate months of data (i.e., less than 12). And finally, when more than one participant account is associated with a single program site, the most recent account with the most complete set of billing data is kept. Some accounts are removed for more than one reason; for example, some lacked a REM/Rate file and had less than 12 months of data.

Table 201 and Table 203 provide additional details about the number of REM/Rate files received and cleaned for the electric and gas programs, respectively. The most common reason a REM/Rate file was removed from the analysis was that it was a multifamily site. The second reason was that it did not match with an account on the participant list.

Sample sizes for natural gas are even lower. The primary reason for the small sample size is because the Companies provided relatively few natural gas records because many of the homes lack natural gas service (reflecting the lack of gas lines in these newly developed area). The second reason for the small sample size is that many accounts received were not on the participant list. Finally, many of the sites lacked REM/rate files.

Table 200: Program and Non-Program Billing Data Cleaning – Electric

Category	Program		Non-program[1]	
	Eversource	UI	Eversource	UI
Number of accounts received	991	52	63	8
Not on participant lists	337	--	N/A	N/A
Missing REM/Rate files[2]	403	--	N/A	N/A
PV Installed	24	1	4	1
Statistical outlier	5	2	--	--
All other reasons[3]	88	26	39	2
Final Sample Size	134	23	21	5

[1] The evaluation team visited 70 homes with one home receiving natural gas from Eversource and electricity from UI.
[2] The evaluation team prepared REM/Rate files for non-program homes.
[3] These include less than 12 months of usable data (the most common), extended vacancies, and location in a multifamily building.

Table 201: Program REM/Rate File Cleaning – Electric[1]

Category	Program	
	Eversource	UI
Number of sites received	1,156	440
Duplicate records	112	35
Multifamily	509	311
Not on participant list	284	45
PV Installed	24	1
Statistical outlier	5	2
All other reasons[2]	88	23
Final Sample Size	134	23

[1] The evaluation team prepared REM/Rate files for non-program homes.
[2] These include less than 12 months of usable data (the most common), extended vacancies, and location in a multifamily building.

Table 202: Program and Non-Program Billing Data Cleaning – Natural Gas

Category	Program		Non-program	
	Eversource	UI	Eversource	UI
Number of accounts received	386	318	10	6
Not on participant lists	192	192	N/A	N/A
Missing REM/Rate file[1]	127	110	N/A	N/A
All other reasons[2]	44	15	5	6
Final Sample Size	23	1	5	0

[1] The evaluation team prepared REM/Rate files for non-program homes.
[2] These include less than 12 months of usable data (the most common), extended vacancies, and location in a multifamily building.

Table 203: Program REM/Rate File Cleaning – Natural Gas[1]

Category	Program	
	Eversource	UI
Number of sites received	1,156	440
Duplicate records	112	35
Multifamily	509	311
Not on participant list	468	78
All other reasons[2]	44	15
Final Sample Size	23	1

[1] The evaluation team prepared REM/Rate files for non-program homes.
[2] These include less than 12 months of usable data (the most common), extended vacancies, and location in a multifamily building.

Table 204 and Table 205 describe some of the principal use characteristics of each group of homes based on information available in the REM/Rate files. The billing analysis **did not** allow one to control for these characteristics, but understanding the characteristics can inform the interpretation of the models.

Table 204: Principal Use Characteristics – Electric Sample

Characteristic	Program		Non-program
	Eversource (n=134)	UI (n=23)	Combined (n=26)
Average Conditioned Area (sq. ft.)	3,156	2,227	2,454
Number of bedrooms	3	3	3
Primary Heating Fuel			
% Primary heating with natural gas	35%	87%	46%
% Primary heating with electricity	11%	--	15%
% Primary heating with delivered fuel	23%	13%	38%
% without heating fuel information	32%	--	--
Homes with Specified Heating/Cooling Systems			
% with Air-source heat pump	4%	--	--
% with Ground-source heat pump	29%	--	4%
% with Dual-fuel heat pump	2%	--	--
% with Central Air Conditioning	57%	78%	85%

Table 205: Principal Use Characteristics – Gas Sample

Characteristic	Program	Non-program
	Eversource (n=21)	Eversource (n=5)[1]
Average Conditioned Area (sq. ft.)	2,663	2,301
Number of bedrooms	4	3
Primary Heating Fuel		
% Primary heating with natural gas	100%	80%
% Primary heating with electricity	--	20%
Homes with Other Heating/Cooling System Type		
% with Air-source heat pump	--	--
% with Ground-source heat pump	9%	--
% with Dual-fuel heat pump	--	--

[1] Note small sample size.

Table 206 reports the conditioned floor area for electric program and non-program homes. Program homes ranged in size from 671 to 9,212 square feet of conditioned floor area (CFA), with an average of 3,156 square feet for Eversource homes and 2,227 for UI homes. Non-program homes ranged in size from 627 to 5458 square feet, with an average of 2,454 square feet. CFA includes all finished and/or fully conditioned spaces on all floors of a home. There is a statistically significant difference at the 90% confidence level between the average CFA of program and non-program homes (p-value = 0.06).

Table 206: Conditioned Floor Area (CFA) – Electric Sample

CFA (square feet)	Program		Non-program
	Eversource (n=134)	UI (n=23)	Combined (n=26)
Average	3,156	2,227	2,454
90% CI Lower Bound	2,943	1,935	2,106
90% CI Upper Bound	3,368	2,520	2,802
Standard Deviation	128	817	1,038
Minimum	672	1,331	627
10th Percentile	1,672	1,360	1,452
Median	2,734	2,000	2,395
90th Percentile	5,066	3,501	3,942
Maximum	9,212	3,900	5,458

Table 207 reports the conditioned floor area for gas program and non-program homes. Gas homes ranged in size from 1,200 to 6,113 square feet of CFA, with an average of 2,744 square feet for program homes and 2,307 for non-program homes. There are no statistically significant differences between the CFA of gas program and non-program homes.

Table 207: Conditioned Floor Area (CFA) – Gas Sample

CFA (square feet)	Program	Non-program
	Eversource (n=23)	Eversource (n=5)[1]
Average	2,744	2,307
90% CI Lower Bound	2,405	1,702
90% CI Upper Bound	3,084	2,911
Standard Deviation	948	634
Minimum	1,200	1,800
10th Percentile	2,144	1,800
Median	2,569	2,118
90th Percentile	3,582	3,331
Maximum	6,113	3,331

[1] Note the small sample size.

No statistically significant differences at the 90% confidence level.

G.5.3 Electric Billing Analysis by Company

G.5.3.1 Eversource

Estimated electric energy-use ratios for Eversource program homes equal 1.26 for heating, 1.10 for cooling, and 1.10 overall. Normalized billing data indicate that Eversource program homes use 3,080 kWh/year for heating and 1,039 kWh/year for cooling, with total electricity use of 12,223 kWh/year, on average (Table 208). In contrast, REM/Rate modeling indicates use of 2,435 kWh/year for heating, 947 kWh/year for cooling, and 11,138 kWh/year in total, on average.

Table 208: Eversource Program Homes – Billing and REM/Rate Usage & Energy-Use Ratios (Electric)[1]

End use	Average kWh/year (n=134)		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model	
Heating	3,080 (2,590 – 3,570)	2,435 (1,1957 – 2,912)	1.26 (1.24 – 1.29)
Cooling	1,039 (901 – 1,178)	947 (861 – 1,034)	1.10 (1.08 – 1.11)
Overall	12,223 (11,134 – 13,313)	11,138 (10,265 – 12,011)	1.10 (1.09 – 1.11)

[1] Confidence intervals shown in parentheses.

G.5.3.2 United Illuminating

The billing analysis of UI program homes suggests electric energy-use ratios of 2.25 for heating, 1.14 for cooling, and 0.91 overall, but the low sample size (23) limits the ability to generalize study results to all UI RNC single-family homes. Normalized billing data indicate that UI program homes use 568 kWh/year for heating and 688 kWh/year for cooling, with overall use totaling 5,986 kWh/year, on average (Table 209). In contrast, REM/Rate modeling indicates use of 253 kWh/year for heating, 601 kWh/year for cooling, and 6,559 kWh/year in total, on average.

The differences in both billing analysis and REM/Rate estimated heating and cooling electricity use between UI and Eversource reflects a mixture of home size and the moderating effects of Long Island Sound on the climate in UI's service territory. Still, it appears that UI program participants use double the electricity for heating than estimated by REM/Rate.

Table 209: UI Program Homes – Billing and REM/Rate Usage & Energy-Use Ratio (Electric)[1]

End use	Average kWh/year (n=23)		Energy-Use Ratio
	Normalized Billing Data	REM/Rate Model	
Heating	568 (331 – 805)	253 (185 – 321)	2.25 (2.02 – 2.48)
Cooling	688 (456 – 919)	601 (428 – 775)	1.14 (1.04 – 1.25)
Overall	5,986 (4,608 – 7,363)	6,559 (5,759 – 7359)	0.91 (0.87 – 0.96)

[1] Confidence intervals shown in parentheses.

H Appendix H Comparison to 2015 Massachusetts Baseline Study (2009 IECC)

H.1 Key Characteristics of 2015 Massachusetts Study

The Massachusetts homes built at the end of 2009 IECC (between 2013 and 2016) provide a strong comparison to the 2016 Connecticut baseline, as they were built to similar code requirements. The Massachusetts study[150] included the following:

- On-sites at 50 homes completed late in the 2009 IECC code cycle, 50 homes completed under the 2012 IECC, and 46 homes completed under the Stretch Code
  - Only the 2009 IECC homes are included in the comparisons between the Massachusetts and Connecticut baseline studies
- 2009 IECC homes included in the sample were completed between late 2013 and early 2015, with the majority completed in 2014
- Thirty-seven spec homes and 13 custom homes
- Site recruited through homeowners, not builders
- Sampling plan slightly different (more complex) than 2016 Connecticut baseline, based on town-level cluster sampling

H.2 Comparison Results

Conditioned Floor Area

The Connecticut sample had a much larger average CFA than the Massachusetts 2009 IECC sample: 3,052 sq. ft. of CFA compared to 2,324. Connecticut also had a larger range of home sizes.

Table 210: Conditioned Floor Area (sq. ft.)

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*50*	*70*
Minimum	896	627
Maximum	4,927	8,509
Average	2,324	3,052
Median	2,338	2,558

150 http://ma-eeac.org/wordpress/wp-content/uploads/Single-Family-Code-Compliance-Baseline-Study-Volume-1.pdf.

HERS Index values

The Connecticut sample fairs slightly better than the Massachusetts sample by mean HERS Index value – averaging 70 versus 74 in Massachusetts. This is despite Massachusetts having by far the best-performing home (lowest HERS Index value) among both samples (the median value in Connecticut is lower – 71, rather than 76 in Massachusetts) (Table 211).

Table 211: HERS Index values

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*50*	*70*
Minimum (best)	10	32
Maximum (worst)	104	108
Average	74	70
Median	76	71

Building Envelope

Table 212 compares the R-values of key shell measures between the Massachusetts and Connecticut samples. The Connecticut sample has higher average R-values in conditioned to ambient walls and vaulted ceilings, while the Massachusetts sample averages higher R-values in flat ceilings and frame floors between conditioned space and unconditioned basements. [151]

[151] "R-values" refers to the average nominal R-values of the combination of cavity and any continuous insulation.

Table 212: Wall, Ceiling, and Floor R-Values

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
Energy code version	2009 IECC	2009 IECC
Conditioned to Ambient Wall Insulation		
n (homes)	*50*	*70*
Average R-value	R-20.3	R-20.8
Prescriptive code requirement	R-20 or R-13+5*	R-20 or R-13+5*
Flat Ceiling Insulation*		
n (homes)	*49*	*62*
Average flat ceiling R-value	R-39.0	R-36.9
Prescriptive code requirement	R-38	R-38
Vaulted Ceiling Insulation		
n (homes)	*30*	*39*
Average vaulted ceiling R-value	R-33.7	R-36.7
Prescriptive code requirement	R-38**	R-38**
Floor Insulation over Unconditioned Basements		
n (homes)	*45*	*51*
Average R-value	R-29.6	R-25.6
Prescriptive code requirement	R-30***	R-30***

* First value is cavity insulation, second is continuous insulation or insulated siding; "13+5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding.
**Cathedral ceiling exception: code allows for up to 20% (capped at 500 sq. ft.) of ceiling to be as little as R-30, if in a cathedral ceiling.
*** Or insulation sufficient to fill the framing.

Heating Equipment

Furnaces are the primary heating equipment in all but three homes in the Massachusetts sample, with the remainder being single instances of a boiler, a combi appliance, and a ducted air source heat pump. The Connecticut sample has a more diverse group of heating equipment, though furnaces are still the primary equipment type in 73% of homes. Fossil fuel systems in the Connecticut sample are slightly more efficient on average than those in the Massachusetts sample. Connecticut also has a higher proportion of homes that use propane as their primary fuel (48% compared to 22%). This could be due to custom homes in Connecticut being built in locations that do not have natural gas infrastructure.

Table 213: Heating System Type, Fuel, and Efficiency

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*50*	*70*
Primary Heating Fuel		
Propane	22%	48%
Natural gas	74%	45%
Oil	2%	--
Electric	2%	8%
Primary Heating System Type		
Furnace	94%	73%
Boiler	2%	16%
Combi appliance	2%	4%
Ductless mini split ASHP	--	4%
Electric baseboard	--	2%
GSHP	--	1%
ASHP	2%	1%
Overall AFUE (fossil fuel systems)	92.0	93.8

Cooling Equipment

Cooling equipment statistics are similar between the two samples, with most homes in each having central air conditioning (CAC) systems installed. The average primary CAC SEER is slightly higher in the Connecticut sample (13.9 versus 13.5), while the Massachusetts sample has a slightly higher cooling capacity per square foot of conditioned space (Table 214).

Table 214: Cooling Systems

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
Primary System Type		
n (homes)	*50*	*70*
Central air conditioning	88%	85%
Ductless mini splits	2%	5%
GSHP-closed loop	--	3%
Window/portable	2%	3%
No air conditioning	8%	4%
CAC SEER		
n (systems)	*64*	*76*
Average SEER	13.5	14.0
Cooling Capacity		
n (homes)	*45*	*65*
Btu/hr per sq. ft.	17.6	15.7
Sq. ft. served per ton	681.8	764.3

Water Heating Equipment

Both Massachusetts and Connecticut homes have similar rates of standalone storage tank systems (including commercial systems), while Massachusetts homes have more natural gas or propane instantaneous systems. In the Massachusetts sample, 36% of water heaters were gas or propane instantaneous systems, compared to 26% in Connecticut. Combi appliances and indirect systems are more common in Connecticut (Table 215). Heat pump water heaters represent 6% of systems in both samples.

Table 215: Water Heater Type and Fuel

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
n (water heaters)	*50*	*72*
Storage, standalone	***46%***	***40%***
Electric	14%	17%
Natural gas	28%	14%
Propane	4%	9%
Instantaneous	***36%***	***26%***
Propane	--	15%
Natural gas	36%	11%
Commercial storage, standalone	***8%***	***12%***
Natural gas	4%	5%
Propane	4%	4%
Electric	--	3%
Indirect w/ storage tank	***2%***	***9%***
Natural gas	2%	6%
Propane	--	3%
Heat pump water heater (electric)	***6%***	***6%***
Combi appliance	***2%***	***5%***
Propane	--	4%
Natural gas	2%	1%
Tankless coil (propane)	***--***	***1%***

Table 216 compares Energy Factors for system types found in the Massachusetts and Connecticut samples. Unlike in the previous section comparing the two Connecticut baseline studies, estimated commercial Energy Factors are excluded here. For the most part, the Energy Factors for common equipment types do not differ significantly between the samples, which indicates a similarity in these markets. The largest difference among common types is in electric storage systems, where the average Energy Factor is .93 in the Connecticut sample, compared to .90 in the Massachusetts sample. Heat pump water heaters have higher Energy Factors in the Connecticut sample, though there are a limited number of heat pumps in each sample.

Table 216: Water Heater Energy Factors

	2015 MA Baseline (2009 IECC)		2016 CT Baseline (2009 IECC)	
	n (water heaters)	EF	*n (water heaters)*	EF
Natural gas and propane storage, standalone	*16*	.67	*18*	.67
Natural gas and propane instantaneous	*18*	.94	*17*	.93
Electric storage, standalone	*7*	.90	*13*	.93
Natural gas and propane indirect w/ storage tank	*1*	.87	*6*	.88
Heat pump water heater	*3*	2.66	*4*	3.04
Combi appliances	*3*	.94	*4*	.93

Duct Leakage and Air Infiltration

The Connecticut homes have duct leakage to outside values comparable to the Massachusetts homes (6.2 CFM25 in Connecticut and 6.3 in Massachusetts). Blower door numbers are quite similar as well: 4.8 ACH50 in Massachusetts and 4.9 ACH50 in Connecticut (Table 217).

Table 217: Duct Leakage to Outside and Air Infiltration

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
Energy code version	2009 IECC	2009 IECC
Duct Leakage to the Outside (CFM25/100 sq. ft. of CFA)		
n (homes tested)	*47*	*60*
CFM25 per 100 square feet of conditioned space	6.3	6.2
Code requirement	≤ 8 CFM25 per 100 sq. ft.	≤ 8 CFM25 per 100 sq. ft.
Air Infiltration (ACH50)		
n (homes tested)	*50*	*70*
ACH50	4.8	4.9
Code requirement	Visual or ≤ 7	Visual or ≤ 7

Lighting

Both samples of homes were completed under the 2009 IECC requirement that 50% of hard-wired fixtures be high-efficacy lamps. As Table 218 shows, 62% of the Connecticut sample meets these requirements, compared to just 40% of the Massachusetts sample. This study did not directly ascertain why the Connecticut homes' efficient lighting saturation is higher than in Massachusetts, but we suspect that we are seeing indications of the rapid change in the lighting market. Homes in the Massachusetts study were completed in late 2013 through 2015, while Connecticut homes were completed from 2014 through 2016.Similarly, the Massachusetts homes were visited in mid-2015 through mid-2016, while Connecticut homes were visited from late 2016 through early 2017. Given that many of the Connecticut homes were completed and visited after most of the Massachusetts homes, this could potentially have allowed sufficient time for the Connecticut homes to show evidence of the rapidly changing lighting market.

Table 218: Compliance with 2009 IECC Lighting Requirement

	2015 MA Baseline (2009 IECC)	2016 CT Baseline (2009 IECC)
n (homes)	*49*	*70*
Less than 50% of hard-wired fixtures with high efficacy bulbs	60%	38%
50% or more hard-wired fixtures with high efficacy bulbs	40%	62%
Efficient bulb socket saturation	45%	54%