Single-Family Weatherization Baseline Assessment (R5)

Final Report

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NMR Group, Inc.

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Project Oversight: EEB Evaluation Committee and EEB Evaluation Consultants: Lisa Skumatz (Skumatz Economic Research Associates / SERA) with assistance from Scott Dimetrosky (Apex Analytics) and Lori Lewis (AEC)

50-2 Howard Street, Somerville, MA 02144
Phone: (617) 284-6230 Fax: (617) 284-6239
www.nmrgroupinc.com

Abstract

In 2011, the State of Connecticut passed Public Act 11-9, *An Act Concerning the Establishment of the Department of Energy and Environmental Protection [DEEP] and Planning for Connecticut's Energy Future*, which specifies that the Conservation and Load Management Plan should propose ways in which the legislation's stated goal of weatherizing 80% of the residential units in the state by 2030 might be achieved. As a result of this legislation, the Connecticut Energy Efficiency Board (EEB) developed a draft weatherization standard (see Appendix L) that defines what constitutes *weatherization*. NMR Group, Inc. was asked to assess the current state of weatherization in Connecticut in an effort to provide DEEP, the EEB, and the electric and gas utilities ("the Companies") with information that would assist their planning efforts in pursuit of the weatherization goal.

The study involved on-site visits to 180 single-family homes across the state. The Team assessed compliance with the weatherization standard using both the *prescriptive* and *performance* paths described in the memorandum issued by the EEB on June 10, 2012.[1] As described in that document, in order to comply with the prescriptive approach a home must meet all of the criteria listed in Table AB-1. In order to comply with the performance approach, a home must demonstrate modeled energy usage (using REM/Rate models) that is equal to or less than the same home built according to the criteria listed in Table AB-1. Note that the weatherization standard does not address mechanical equipment efficiencies and as a result mechanical equipment does not influence compliance with the standard.

Table AB-1: Weatherization Prescriptive Checklist and Performance Modeling Inputs

Building Element	Prescriptive Requirements and Modeling Inputs for Performance Approach
Above Grade Walls	R-11
Flat Ceilings	R-30
Cathedral Ceilings	R-19
Unconditioned Basements & Crawlspaces	Floor separating basement from conditioned space above is insulated to R-13
Conditioned Basements & Crawlspaces	Interior walls fully insulated to R-5
Slab on Grade	R-5 four feet below grade; assume to proper depth if present
Windows	U-0.50 (Double pane or single pane with storm)
Air Leakage	9 ACH @ 50 Pascals based on HES program data
Duct Leakage for ducts outside conditioned space	16 CFM @ 25 Pascals per 100 sq. ft. of conditioned space based on HES program data
Duct Insulation: Unconditioned Basements	R-2
Duct Insulation: Unconditioned Attics and Crawlspaces	R-4.2

[1] Connecticut Energy Efficiency Board, "Public Act 11-80 Weatherization Definition and Determination," Memo provided to Department of Energy and Environmental Protection, June 10, 2012.

The evaluation determined 26% of the sampled homes (with a confidence interval of 21% to 31%) comply with the weatherization standard's performance path. Only 5% of the sampled homes comply with all applicable prescriptive requirements. Other highlights from the study include the following:

- Newer homes are significantly more likely than older homes to comply with the standard. For example, homes built in 2000 or later have a compliance rate of 87%, while homes built in 1939 or earlier have a compliance rate of 7%. This relationship is so strong that targeting homes built prior to 1980 (a weighted compliance rate of 10%) would provide the most effective way of increasing the percentage of weatherized homes across the state.
- Non-low-income homes (29% compliance) are significantly more likely than low-income homes (15% compliance) to comply with the standard. However, due to their small numbers (18% of all single-family homes in the state), targeting low-income homes will not yield large increases in the number of weatherized homes, though it will improve quality of life. That said, targeting older homes will capture many low-income residences as well.
- Compliant homes exceed the standard (when comparing the heating and cooling energy consumption of the "as built" model to the prescriptive weatherization model) by an average of 13%, while non-compliant homes fall below the standard by an average of 48%.
- Compliance with the individual measures listed in the standard ranged from a low of 15% (floors over unconditioned basements) to a high of 82% (windows). The three prescriptive components with the lowest compliance rates are floors over unconditioned basements (15%), flat ceilings (34%), and air leakage (39%).
- Compliant homes have a significantly lower average HERS index (score of 96) than non-compliant homes (score of 127). A lower HERS index indicates a more efficient home.
- Among the 180 homes visited as part of this study, 9% (16 homes) have asbestos or vermiculite present and an additional 4% (seven homes) have mold present.
- As-built homes have an average energy consumption, for heating and cooling end uses, of 125.7 MMBtu and average costs of $3,393, while weatherized homes have an average energy consumption of 100.4 MMBtu and costs of $2,784. These differences result in a 20% decrease for energy consumption and an 18% decrease for energy costs when comparing weatherized homes to as-built homes.

Based on the findings of the evaluation, the Team identified the following conclusions and recommendations related to the weatherization standard.

- The current weatherization standard does not address multifamily buildings, which account for approximately 36% of the housing units in the State of Connecticut. The Team recommends that the EEB develop a weatherization standard and assess baseline compliance for multifamily buildings.
- Classifying basements as "conditioned" or "unconditioned" can be challenging and can have a significant impact on the compliance of homes with the weatherization standard. The Team recommends that the EEB consider the economic and energy impacts of basement insulation retrofits and adjust the weatherization standard accordingly.
- It is nearly impossible for an auditor to verify the presence, type, and R-value of slab insulation in existing homes. The Team recommends that the EEB consider removing the slab insulation requirement that exists in the current draft weatherization standard.
- Compliance is high for certain measures (e.g, 82% for windows and 81% for attic duct insulation) and low for others (15% for frame floor over unconditioned basements and 34% for flat ceiling insulation). The Team recommends that the EEB review the current standard definition and consider revisions to the efficiency levels required by the standard based on the study results.
- The current standard only addresses frame floor insulation over unconditioned basements and excludes other frame floor locations.[2] Additionally, the current standard does not address rim joist insulation. The Team recommends that the EEB consider adding details to the current standard that address all frame floor locations that are located over unconditioned space. Similarly, the EEB should consider adding a requirement to the standard that addresses rim joists.

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[2] Note, the Team included all locations in their assessment of the weatherization standard based on discussions with the EEB evaluation technical consultant. See Appendix F for additional details.

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Executive Summary

In 2011, the State of Connecticut passed Public Act 11-9, *An Act Concerning the Establishment of the Department of Energy and Environmental Protection [DEEP] and Planning for Connecticut's Energy Future,*[3] which specifies that the Conservation and Load Management Plan should propose ways in which the legislation's stated goal of weatherizing 80% of the residential units in the state by 2030 might be achieved. As a result of this legislation, the Connecticut Energy Efficiency Board (EEB), with considerable stakeholder input, developed a draft weatherization standard [4] for single-family homes [5] (from here on referred to as the "weatherization standard" or just "the standard") that defines what constitutes *weatherization* (see Appendix L). NMR Group, Inc., the primary Residential Area evaluation contractor, was asked to assess the current state of weatherization in Connecticut in an effort to provide DEEP, the EEB, and the electric and gas utilities ("the Companies") with information that would assist their planning efforts in pursuit of the weatherization goal.

In order to assess future progress toward this goal, DEEP and the EEB determined that they must first establish the baseline of homes that currently meet the weatherization standard. The primary objective of this study is to determine the percentage of single-family residential units in Connecticut that currently meet the standard. The weatherization standard allows for compliance to be assessed using either a prescriptive path or a performance path; the evaluation team assessed compliance with single-family residential units using both approaches. Although, Public Act 11-9 encompasses multifamily residential units as well as single-family units, at the request of DEEP and the EEB, NMR did not include multifamily units in this study (approximately 36% of all units), and all results are for single-family residential units only. The study included both single-family detached (i.e., stand-alone) and single-family attached (e.g., duplex or townhouse) homes, which together represent approximately 64% of all housing units in Connecticut. NMR worked with Home Energy Solutions (HES) vendors to collect the information necessary to estimate baseline weatherization conditions; this report collectively refers to NMR and the vendors as "the Team" or "the evaluators."

Secondary research objectives in this report include the following:

- Detail what percentage of single-family homes with various characteristics (e.g., low income vs. non-low income, fuel oil vs. natural gas heated homes, etc.) fall above and below the weatherization threshold.
- Characterize the weatherization-related features of single-family homes in Connecticut.

[3] http://www.cga.ct.gov/2011/act/pa/pdf/2011PA-00080-R00SB-01243-PA.pdf
[4] Connecticut Energy Efficiency Board, "Public Act 11-80 Weatherization Definition and Determination," Memo provided to Department of Energy and Environmental Protection, June 10, 2012.
[5] At this point there is no weatherization standard for multi-family buildings.

- Detail the characteristics of homes' thermal envelopes (wall insulation, ceiling insulation, air infiltration, duct leakage, etc.), including visually inspecting homes' thermal envelopes using infrared cameras.
- Detail the characteristics of homes' heating, cooling, and water heating equipment.
- Detail the characteristics of other energy-related features (e.g., appliances).

The findings detailing the characteristics of homes' thermal envelopes, mechanical systems, and other energy-related features can be found in the main body of this report.

Sampling Plan

The study focused exclusively on single-family homes, both detached (stand-alone homes) and attached (side-by-side duplexes and townhouses that have a wall dividing them from attic to basement and that pay utilities separately). Multifamily units—even smaller ones with two-to-four units—were excluded from the study due to the complexity of including them in the evaluation. Specifically, multifamily units would be difficult to recruit for this study as these units have a higher proportion of renters; the need to secure landlord permission—and the difficulties in doing so—reduced the likelihood that the team would have permission to enter such buildings to perform a weatherization assessment. Additionally, it can be challenging to assess the efficiency of the buildings without having access to all of the units. From a logistics perspective, it would be quite difficult to coordinate participation of multiple tenants (renters or condominium owners) within the same building in order to achieve the most reliable study results. All of these factors lend themselves to a more expensive study, and the evaluators were directed to exclude them for this reason. The evaluators relied on a disproportionately stratified design that aimed to achieve 10% sampling error or better at the 90% confidence level across all of Connecticut and also for several subgroups of interest (Table ES-1, shaded cells).[6] This level of precision means that one can be 90% confident that the results are a reasonably (±10% or less) accurate description of all the single-family homes in Connecticut. The Team based all precisions on a coefficient of variation of 0.5.[7] For more details on the sampling methodology, see the Sampling Methodology section in the main body of the report.

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[6] The final sample did not achieve 90/10 precision for low-income households—although the sampling error of 14% is close to the desired 10%—and sampled fewer than expected renters (although the evaluators had not expected to achieve 90/10 precision for renters). The Team does not know the direction of bias due to the uncertainty surrounding the characteristics of households that did not participate in the study and whether those characteristics differ from the sample of homes that did participate in the study.

[7] The coefficient of variation measures the dispersion of data in a series of data points; it is commonly used to estimate sampling error when measuring the efficiency of measures installed in weatherization efforts.

Table ES-1: Sample Design Planned and Actual, with Sampling Error

Single-family Segment	Planned Sample Size	Actual Sample Size	Precision
Overall	180	180	**6%**
Low-income	68	34	14%
Non-low-income	76	146	**7%**
Income eligibility not identified	36*	0*	n/a
Fuel oil heat	109	111	**8%**
All other heating fuels	71**	69**	**10%**
Own	159	177	**6%**
Rent	21	3	47%

*The survey approach for identifying household income asked respondents if their income was above or below a certain amount based on their family size. This unobtrusive approach meant that the evaluators were able to identify the income status for all participants in the onsite study.

**The evaluators planned for 47 of these homes to heat with natural gas, and 46 of the homes in the final sample actually did so.

Weatherization Assessment

The Team assessed compliance with the weatherization standard by using the performance approach subject to the definition laid out by the EEB for the purposes of this project (see Appendix L).[8] This document states that in order to comply with the performance-based approach, a home must demonstrate modeled energy usage that is equal to or less than the same home built to the criteria listed in Table ES-2. As shown, all of the items listed in the weatherization standard are related to the building envelope. The EEB and DEEP excluded mechanical equipment from the standard for the following reasons: it can be difficult to induce early retirement, mechanical equipment is covered through non-weatherization related program activities, and much of the mechanical equipment currently in use will be replaced with new equipment by 2030, when compliance with the standard is expected to be 80%.

Table ES-2: Weatherization Prescriptive Checklist and Performance Modeling Inputs

Building Element	Prescriptive Requirements and Modeling Inputs for Performance Approach
Above Grade Walls	R-11
Flat Ceilings	R-30
Cathedral Ceilings	R-19
Unconditioned Basements & Crawlspaces	Floor separating basement from conditioned space above is insulated to R-13
Conditioned Basements & Crawlspaces	Interior walls fully insulated to R-5
Slab on Grade	R-5 four feet below grade; assume to proper depth if present
Windows	U-0.50 (Double pane or single pane with storm)
Air Leakage	9 ACH @ 50 Pascals based on HES program data
Duct Leakage for ducts outside conditioned space	16 CFM @ 25 Pascals per 100 sq. ft. of conditioned space based on HES program data
Duct Insulation: Unconditioned Basements	R-2
Duct Insulation: Unconditioned Attics and Crawlspaces	R-4.2

The evaluators used REM/Rate™ software to model each of the 180 homes audited as part of this study. REM/Rate is a residential energy analysis software that is commonly used to model the performance of residential buildings; the software is most notably used by the ENERGY STAR® Homes program, though not exclusively. In order to assess performance-based compliance, each site was modeled once with the energy efficiency characteristics that were identified onsite (the "as-built" model) and once using the efficiency specifications provided in Table ES-2 (the "weatherized" model). Appendix F provides more details on the modeling inputs.

[8] Described in the memorandum issued by the Connecticut Energy Efficiency Board, "Public Act 11-80 Weatherization Definition and Determination," Memo provided to Department of Energy and Environmental Protection, June 10, 2012.

Overview of Weatherization Results

Overall, 26% of the sampled homes (with a 90% confidence interval of 21% to 31%[9]) comply with weatherization standard (Table ES-3 and Figure ES-1). Non-low-income homes (29%) are much more likely to comply with the standard than are low-income homes (15%). Similarly, the 16 homes heated primarily by electricity (50%) are much more likely than homes heated by natural gas (22%) and homes heated by oil and other fuels (25%) to be compliant with the standard.

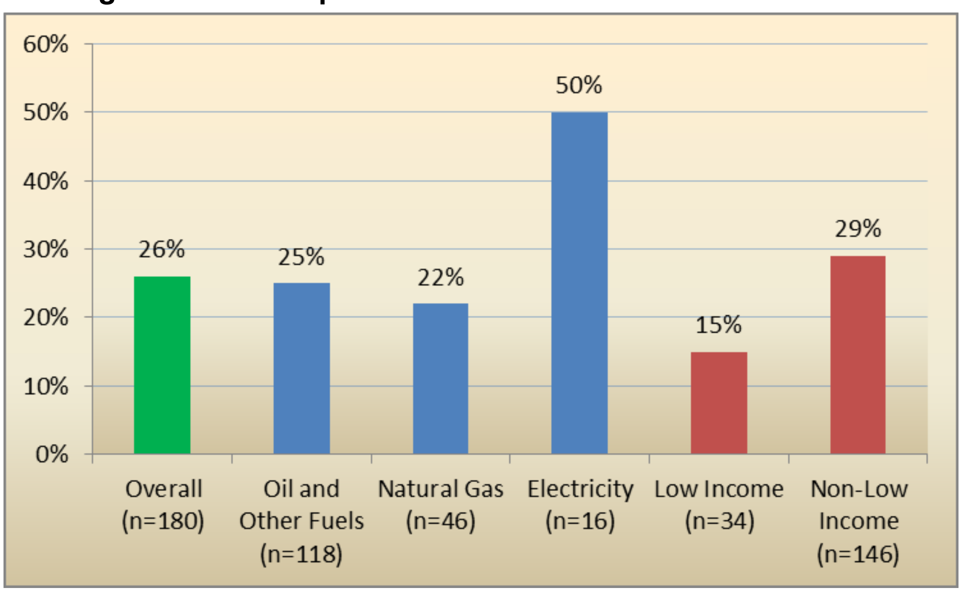
Table ES-3: Weatherization Assessment

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil and Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**	
n	*118*	*46*	*16*	*34*	*146*	*180*
Homes Meet or Exceed Wx Standard	25%[a]	22%[b]	50%[a,b]	15%[c]	29%[c]	26%
Homes Below Wx Standard	75%[a]	78%[b]	50%[a,b]	85%[c]	71%[c]	74%

[a,b,c] Statistically significant difference at the 90% confidence level.[10]

Figure ES-1: Compliance with the Weatherization Standard



[9] To put this in laymen's terms, if this study were repeated 100 times using the same sampling plan, 90% of the time the percentage of homes meeting the standard would fall between 21% and 31%.
[10] See Section 1.1 for a summary of what these letters represent.

The bullets below highlight the key findings discussed in the rest of the executive summary. Each bullet contains a link to the associated table or figure in the more detailed section of the executive summary where the evaluators present additional findings (see Additional Weatherization Results).

- Newer homes are significantly more likely than older homes to comply with the standard. For example, homes built in 2000 or later have a compliance rate of 87%, while homes built in 1939 or earlier have a compliance rate of 7% (Table ES-6).
- Non-low-income homes (29% compliance) are significantly more likely than low-income homes (15% compliance) to comply with the standard (Figure ES-1).
- On average, compliant homes exceed the standard (when comparing the heating and cooling energy consumption of the "as built" model to the prescriptive weatherization model) by 13%, while non-compliant homes fall below the standard by 48% (Figure ES-2).
- Just 5% of the sampled homes comply with all applicable prescriptive requirements (Figure ES-3).
- Compliance with the individual measures listed in the standard ranged from 15% (floors over unconditioned basements) to 82% (windows) (Figure ES-3). The three prescriptive components with the lowest compliance rates are floors over unconditioned basements (15%), flat ceilings (34%), and air leakage (39%).
- Six measures show statistically significant differences in average efficiency when comparing compliant homes to non-compliant homes (Table ES-7). These measures include:
    - Conditioned to ambient wall insulation – R-15.1 vs. R-7.6
    - Flat ceiling insulation – R-32.5 vs. R-17.2
    - Conditioned to unconditioned basement frame floor insulation – R-9.9 vs. R-2.6
    - Conditioned to garage frame floor insulation – R-22.4 vs. R-13.2
    - Air infiltration – 6.6 ACH50 vs. 13.2 ACH50
    - Duct leakage to the outside – 13.7 CFM25/100 sq. ft. vs. 19.8 CFM25/100 sq. ft.
- Compliant homes have a significantly lower (better) average HERS index (score of 96) than non-compliant homes (score of 127) (Figure ES-4).

Advanced statistical modeling (see Appendix K for details) also revealed that older homes—particularly those that do not heat with electricity and have not taken part in HES—provide the greatest opportunity to move the state closer to achieving 80% weatherization. Although the study found that low-income homes were less likely to meet the standard than non-low-income homes, status as a low-income home was not a defining characteristic of non-weatherized homes. Targeting older homes for weatherization would capture many low-income homes and improve quality of life, but targeting low-income homes would not lead to large increases in the number of weatherized homes.

Additional Weatherization Results

The remainder of this executive summary provides high-level information on some of the important issues related to the estimated weatherization baseline. Readers seeking more detailed results should refer to the main body of the report and the appendices.

Performance-Based Results

The analyses show that most homes that do comply with the standard just barely do so but the homes that do not comply with the standard often miss by a wide margin. Table ES-4 shows the amount by which homes either exceed or fall below the weatherization standard when comparing the heating and cooling energy consumption (in MMBtu) of the "as built" and "weatherized" energy models. The majority of homes that comply with the standard (94%) do so by a margin of 25% or less, while just 6% comply by a margin of more than 25%. Distance from the prescriptive baseline among non-compliant homes is more varied, with roughly one-third of homes (36%) falling below the standard by 25% or less, while the other two-thirds of homes (65%) fall below the standard by 26% or more. See

Figure A-10 in Appendix A for additional details on the level at which homes either exceed or fall below the weatherization standard

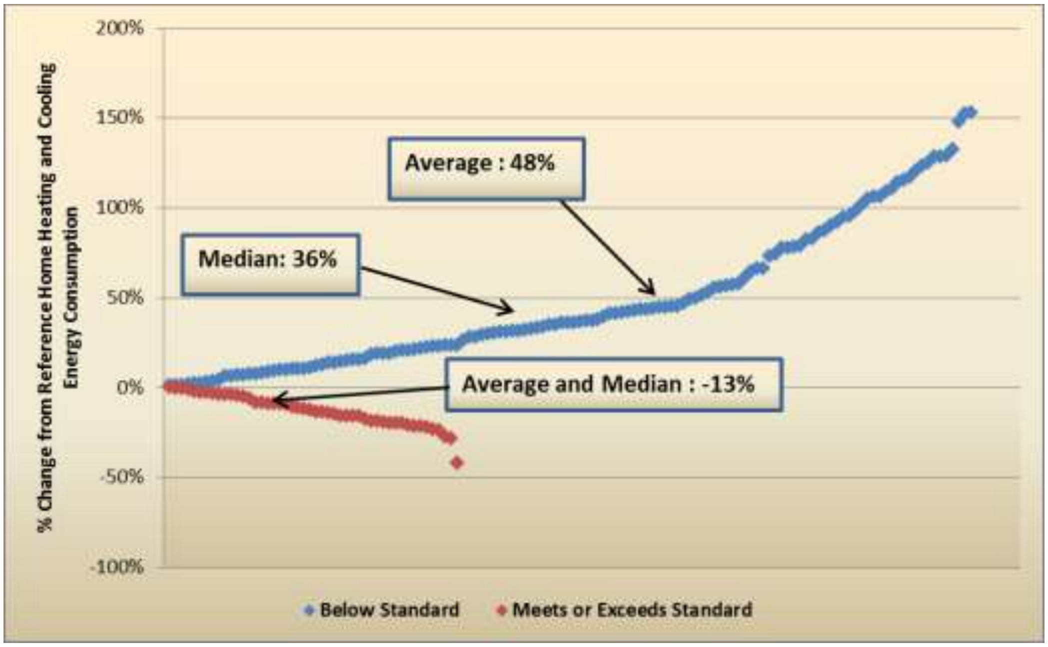
Table ES-4: Distance (%) from the Heating and Cooling Energy Consumption (MMBtu) of the Performance-Based Baseline

(Base: All homes)

	Statewide Weighted			
	0-10%	**11-25%**	**26-50%**	**>50%**
n	*20*	*25*	*3*	--
Homes Meet or Exceed Standard	43%	51%	6%	--
n	*23*	*25*	*39*	*45*
Homes Below Standard	17%	19%	30%	35%

Figure ES-2 displays the distance from the standard in heating and cooling energy consumption (MMBtu), more specifically by showing the percent change in heating and cooling energy consumption for each home relative to its "weatherized" counterpart. The blue points indicate homes that had heating and cooling energy consumption greater than that of the "weatherized" home, while red points indicate homes that had heating and cooling energy consumption less than that of the "weatherized" home. Figure A-10 in Appendix A displays the same information in the form of a histogram.

Figure ES-2: Percent Change from Reference Home Heating and Cooling Energy Consumption*



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

Ten percent of the 180 homes visited for this study were found to have participated in the HES program, which is similar to the historical program participation rate for the broader population (meaning the sample homes displayed no bias in their HES participation). As shown in Table ES-5, homes that had previously participated in the HES program are more likely to meet the weatherization requirements than homes that have not participated in the HES program (39% and 25%, respectively); however, the difference is not significant at the 90% confidence level. This likely reflects the fact that many HES participants receive only the core services and either are not eligible to receive or choose not to adopt the deeper measures outlined in the standard.[11]

As noted above, the difference in compliance between HES participants and non-participants is not significant at the 90% confidence level. To explore this issue further, the Team used a regression model to identify key attributes that should be targeted in order to increase compliance with the weatherization standard. The regression model indicates that HES non-participants should be targeted to increase compliance with the standard. In fact, participation in the HES program was one of three variables that the model identified as a significant contributor to compliance with the standard (see Appendix K for additional details).

Table ES-5: Weatherization by HES Participation

(Base: All homes)

	Statewide Weighted	
	Participant	**Non-Participant**
n	*18*	*162*
Homes Meet or Exceed Wx Standard	39%	25%
Homes Below Wx Standard	61%	75%

[11] For example, many homeowners may need above grade wall insulation but choose not to adopt the measure for any one of a number of reasons.

Table ES-6 shows that newer homes are significantly more likely to meet the weatherization standard than older homes. Homes built between 1980 and 1989 (48%) are substantially more likely to meet the standard than homes built prior to that period. This jump may be due to the fact that the State began enforcing energy code requirements around 1980.[12] Although the sample of homes built in or after 1980 is small, these homes show a steady increase in compliance with the standard each decade starting with the 1980s. The overall sample of the audited homes accurately reflects the ages of homes in the actual population (see Appendix I, Table I-5).

Table ES-6: Weatherization by Home Age

(Base: All homes)

	Statewide Weighted					
	1939 or earlier	1940 to 1959	1960 to 1979	1980 to 1989	1990 to 1999	2000 or later
n	*29*	*46*	*49*	*25*	*15*	*16*
Percent of Single-Family Homes in Sample	16%	26%	27%	14%	8%	9%
Percent of Single-Family Homes Statewide	18%	27%	27%	12%	8%	8%
Homes Meet or Exceed Wx Standard	7%[a,b,c]	6%[d,e,f]	16%[g,h,i]	48%[a,d,g,j]	67%[b,e,h]	87%[c,f,i,j]
Homes Below Wx Standard	93%[a,b,c]	94%[d,e,f]	84%[g,h,i]	52%[a,d,g,j]	33%[b,e,h]	13%[c,f,i,j]

[a,b,c,d,e,f,g,h,i,j] Statistically significant difference at the 90% confidence level.

Prescriptive-Based Results

While compliance with the weatherization standard is primarily assessed using the performance-based approach, the evaluators also analyzed compliance with the prescriptive approach. In order to comply with the prescriptive approach, a home must meet or exceed all of the applicable requirements listed in Table ES-2. This analysis determined the following:

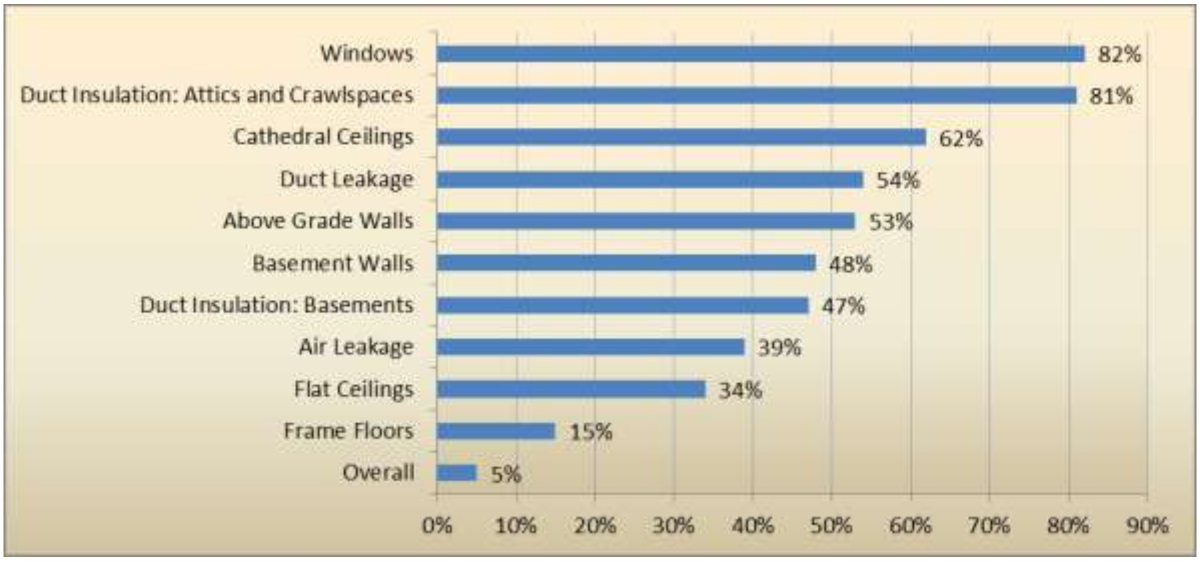
- Just 5% of the sampled homes comply with all applicable prescriptive requirements, which stands in contrast to the 26% of homes with meet the standard based on the performance-based approach (Table ES-3 and Figure ES-3).
- Compliance with the individual measures listed in the standard ranged from 15% (floors over unconditioned basements) to 82% (windows) (Figure ES-3).

The difference between performance and prescriptive-based compliance is not surprising, as the performance approach allows for trade-offs in the efficiency of individual home components that

[12] As stated by the Department of Energy when referring to Connecticut residential energy codes, “In 1979, legislation was passed requiring that the State Building and Fire Safety Code Department promote and ensure the design and construction of energy-conserving buildings and the use of renewable resources.” https://www.energycodes.gov/adoption/states/connecticut

the "all-or-none" prescriptive approach does not.[13] Appendix A presents histograms that display the distribution of efficiency levels for most of the measures outlined in the standard; these may be helpful for the EEB when reviewing the current standard requirements.

Figure ES-3: Compliance with Prescriptive Weatherization Requirements



[13] For example, if a home has ceiling insulation exceeding the prescriptive requirement of R-30, then the home is credited for that additional insulation through the modeling process in the performance approach, while under the prescriptive approach the home simply meets the requirement and receives no additional credit. If the same home failed to meet any other prescriptive requirement, it would not be considered weatherized.

Performance vs. Prescriptive Results

Twenty-six percent of homes comply with the weatherization standard using the performance-based approach, while only 5% comply with all applicable prescriptive requirements. Table ES-7 displays the prescriptive measure-level compliance for homes that meet and do not meet the performance-based weatherization standard. As shown, homes that meet or exceed the weatherization standard using the performance path are significantly more likely than non-compliant homes to meet the measure level prescriptive requirements for the following measures: all above-grade wall locations, flat ceilings, vaulted ceilings, all frame floor locations except conditioned to ambient floors, conditioned foundation walls, windows, air leakage, and duct insulation in unconditioned basements.

Six measures show statistically significant differences in average efficiency when comparing performance-based compliant homes to non-compliant homes. These measures include:

- Conditioned to ambient wall insulation – R-15.1 vs. R-7.6
- Flat ceiling insulation – R-32.5 vs. R-17.2
- Conditioned to unconditioned basement frame floor insulation – R-9.9[14] vs. R-2.6
- Conditioned to garage frame floor insulation – R-22.4 vs. R-13.2
- Air infiltration – 6.6 ACH50 vs. 13.2 ACH50
- Duct leakage to the outside – 13.7 CFM25/100 sq. ft. vs. 19.8 CFM25/100 sq. ft.

Three measures—air leakage, flat ceiling insulation, and conditioned to ambient wall insulation—appear to present the largest opportunities in non-compliant homes. This is due to the fact that these measures are found in nearly all homes (it is possible, but very rare, for a home to have no flat ceiling insulation) and, as mentioned above, have significantly lower average efficiency levels in non-compliant homes than in compliant homes. The main body of the report provides additional details on non-compliant homes, including analysis by heating fuel and income status.

On average, using the performance-based modeling approach, as-built models show significantly higher heating and cooling energy costs ($3,393) than their weatherized counterparts ($2,784) (see Section 3.4 for additional details).

[14] Even in complying homes the average conditioned to unconditioned basement frame floor insulation R-value is below the current weatherization standard requirement of R-13. Connecticut's New Construction Baseline Study, which was finalized in 2012, shows that new homes in Connecticut have an average conditioned to unconditioned basement insulation R-value of R-20.5, well above the current standard requirement. This suggests that conditioned to unconditioned basement insulation is more of an issue in older homes, which dominated the weatherization baseline sample. The baseline study can be found here: http://energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf

Table ES-7: Prescriptive Compliance and Efficiencies by Performance-Based Compliance Results*

(Base: All Homes)

Measure or Characteristic	Requirement (and Units)	Statewide Weighted					
		Homes Meet or Exceed Performance Wx Standard			Homes Below Performance Wx Standard		
		n	% Prescriptive Compliance	Average Value	*n*	% Prescriptive Compliance	Average Value
Conditioned to Ambient Walls	R-11	*48*	96%[a]	15.1[b]	*132*	42%[a]	7.6[b]
Conditioned to Garage Walls	R-11	*40*	92%[a]	13.5[b]	*80*	61%[a]	8.4[b]
Conditioned to Attic Walls	R-11	*27*	85%[a]	12.7[b]	*74*	49%[a]	7.8[b]
Conditioned to UC Basement Walls	R-11	*30*	43%[a]	6.5[b]	*81*	19%[a]	2.5[b]
Flat Ceilings	R-30	*45*	75%[a]	32.5[b]	*129*	21%[a]	17.2[b]
Vaulted Ceilings	R-19	*27*	96%[a]	26.0[b]	*80*	51%[a]	15.4[b]
Conditioned to UC Basement Frame Floor	R-13	*31*	31%[a]	9.9[b]	*89*	10%[a]	2.6[b]
Conditioned to Garage Frame Floor	R-13	*29*	89%[a]	22.4[b]	*43*	59%[a]	13.2[b]
Conditioned to Ambient Frame Floor	R-13	*22*	62%	16.6[b]	*54*	52%	11.5[b]
Conditioned to Enclosed Crawl Frame Floor	R-13	*2*	100%[a]	29.0[b]	*23*	26%[a]	9.1[b]
Walls in Conditioned Basements & Crawlspaces	R-5[1]	*29*	71%[a]	8.3[b]	*68*	40%[a]	4.1[b]
Windows	U-0.50[2]	*48*	93%[a]	DK**	*132*	78%[a]	DK**
Air Leakage[3]	9 ACH50	*48*	96%[a]	6.6[b]	*132*	19%[a]	13.2[b]
Duct Leakage to the Outside	16 CFM25/100 sq. ft.	*20*	63%	13.7[b]	*53*	51%	19.8[b]
Duct Insulation: Unconditioned Basements	R-2	*16*	71%[a]	3.8[b]	*31*	38%[a]	1.8[b]
Duct Insulation: Unconditioned Attics & Crawlspaces	R-4.2	*19*	89%	4.8	*44*	77%	4.4

[1] Interior walls must be fully insulated.
[2] Alternatively any double pane window or single pane with a storm window is considered compliant.
[3] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.
[a,b] Statistically significant difference at the 90% confidence level.
*Slab on grade is a prescriptive requirement, but is not presented here because inspectors were unable to verify the presence, type, and R-value of slab insulation for all homes with on-grade slabs.
**Auditors were unable to determine the U-value of windows in the majority of the inspected homes.

HERS Ratings by Compliance

Table ES-8 presents the average Home Energy Rating System (HERS) ratings by various categories and shows the associated performance-based compliance within those groups. HERS ratings are produced by the REM/Rate software and provide a metric for assessing overall building performance. Note, this information is only meant to provide a comparison between HERS ratings and performance-based compliance. HERS scores had no impact on the weatherization status of a given home. For more background on HERS ratings see Section 3.5.

HERS scores can range from less than zero to well over 100, with a lower score indicating lower energy use.[15] Homes heated by oil and other fuels have a lower (better) average HERS rating (115.9) when compared to homes heated by natural gas (123.0) and homes heated by electricity (123.3). The overall average HERS rating, across all homes, was 118.6. As shown, electrically heated homes have the highest compliance rate, but do not have the lowest (best) HERS ratings. The primary reason for this is that the HERS reference home compares electric resistance heat (which the majority of electrically heated homes in the sample had) to a heat pump.[16] As a result, electrically heated homes generally have higher HERS ratings than homes heated by other fuels with similar characteristics.

Table ES-8: HERS Ratings and Performance-Based Compliance

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil and Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Average HERS Rating	116	123	123	125	117	119
Homes Meet or Exceed Wx Standard	25%[a]	22%[b]	50%[a,b]	15%[c]	29%[c]	26%
Homes Below Wx Standard	75%[a]	78%[b]	50%[a,b]	85%[c]	71%[c]	74%

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

Figure ES-4 graphs the HERS ratings of all 180 homes. The blue diamonds are homes that fall below the weatherization standard, while the red diamonds are homes that meet or exceed the weatherization standard. Most of the homes with the lowest HERS indices do indeed meet or exceed the standard. That said, there are a number of homes with low HERS indices that do not meet or exceed the standard, and there are a number of homes with higher HERS indices that do meet or exceed the standard.

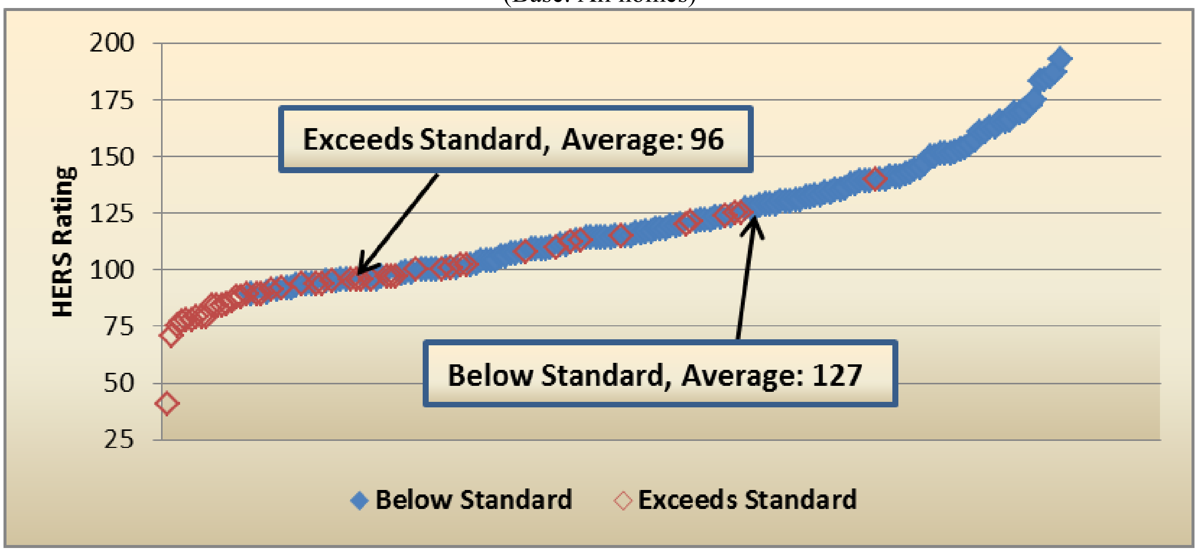
[15] A score of 100 indicates that a home was built to the specifications of the 2004 IECC (with 2006 IECC modifications), while a score of zero indicates a net zero energy home. A score of less than zero indicates a home with negative energy consumption.

[16] Residential Energy Services Network, "Mortgage Industry National Home Energy Rating System Standards", Submitted to RESNET Board of Directors, January 1, 2013.

This figure illustrates that the weatherization standard, as currently defined, is not directly correlated with overall home performance. There are a number of reasons for this, but the most obvious is that the weatherization standard does not currently account for the efficiency of mechanical equipment (i.e., heating, cooling, and hot water heating equipment). Mechanical equipment efficiencies are major drivers of overall home performance (and subsequent HERS scores) and that is likely the primary reason that some less efficient homes are compliant with the standard and some more efficient homes are not. Other drivers of overall home performance that are not included in the weatherization standard are lighting, appliances, solar orientation, and renewable energy.

Figure ES-4: HERS Ratings by Performance-Based Compliance*

(Base: All homes)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

Conclusions and Recommendations

The following conclusions and recommendations are focused on possible ways to increase performance-based compliance with the current weatherization standard; some of the recommendations overlap but each stems from a unique conclusion of the baseline study. The Team makes only limited recommendations regarding the HES or HES-IE programs, as this effort did not involve impact or process analyses of those programs.[17] However, the Team believes the information contained in the report will be of vital importance in assessing more substantial changes that could be made to HES in order to help the state meet the 80%

[17] From here on, both of these programs will be referred to as HES.

weatherization goal.[18] To that end, it is important to note that the 18 homes visited for this study that had previously participated in the HES program are only somewhat more likely to meet the weatherization requirements than the 162 homes that had not participated (39% and 25%, respectively). While the sample size of HES homes is small, the results suggest that HES participation alone does not ensure that homes will meet the weatherization standard. Therefore, several of the following recommendations focus on deeper savings opportunities that go beyond the core program measures (which include air sealing and duct sealing, among others) that the HES program can target in order to help homes meet the weatherization standard.

Weatherization Standard

Conclusion: The current weatherization standard does not address multifamily buildings, which account for approximately 36% of the housing units in the State of Connecticut.

> ***Recommendation:*** The EEB should develop a weatherization standard specific to multifamily buildings. After a multifamily standard has been developed, the EEB should consider conducting a weatherization baseline assessment of the multifamily housing stock in Connecticut.

Conclusion: Classifying basements as "conditioned" or "unconditioned" can be challenging in existing homes and as a result is often left to the discretion of the auditor. The final classification can have a significant impact on the compliance of homes with the weatherization standard as multiple measures address basement insulation and the designation of a basement as "conditioned" or "unconditioned" influences the results of diagnostic tests (i.e., air and duct leakage tests).

> ***Recommendation:*** The EEB should consider the best way to address basements in the weatherization standard. The current standard suggests that homeowners should insulate the frame floor separating a conditioned first floor from an unconditioned basement. In some cases, this suggestion may be contradictory to sound building science; there may be limited cost-effective savings from insulation retrofits in these cases as the temperature change is typically not that dramatic between a first floor and a basement. Moreover, insulation installation in these applications can be challenging due to wiring, plumbing penetrations, and access stairways. Finally, accurately defining a basement as conditioned or not influences the results of air and duct leakage testing which are components of the weatherization standard.

Conclusion: It is nearly impossible for an auditor to verify the presence, type, and R-value of slab insulation in existing homes.

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[18] The Residential Evaluation Team is currently engaged in an impact evaluation of HES and HES-IE that relies on billing analyses to estimate measure-specific and overall program energy savings. The Team is working with the EEB Evaluation Consultant to plan HES and HES-IE process evaluations that address concerns about depth of savings. Depending on the results of these studies, they may result in concrete suggestions on ways to increase program savings as well as achievement of the 80% weatherization goal.

> ***Recommendation:*** The EEB should consider removing the slab insulation requirement that exists in the current draft weatherization standard. The majority of homes in the State are older homes that likely lack documentation on the presence and level of slab insulation. As a result, any assessment of slab insulation, when addressing progress towards the 80% weatherization requirement, will likely be based on general assumptions as opposed to visual verification.

Conclusion: Compliance is high for certain measures (e.g, 82% for windows and 81% for attic duct insulation) and low for others (15% for frame floor over unconditioned basements and 34% for flat ceiling insulation).

> ***Recommendation:*** The EEB should review the current standard definition and consider revisions to the efficiency levels required by the standard based on the study results. Although the EEB should review the entire standard, the Team suggests paying particular attention to basements and frame floors. The information provided in the main body of the report will assist this review and potential revision.

Conclusion: The current standard only addresses frame floor insulation over unconditioned basements and excludes frame floors located over other unconditioned spaces such as garages and ambient conditions.[19] Additionally, the current standard does not address rim joist insulation which is an important component of building envelopes.

> ***Recommendation:*** The EEB should consider adding details to the current standard that address all frame floor locations that are located over unconditioned space (e.g., conditioned to garage frame floor locations, conditioned to ambient frame floor locations, etc.). Similarly, the EEB should consider adding a requirement to the standard that addresses rim joists.

Program Opportunities

Conclusion: Statistical modeling (Appendix K) reveals that participation in the HES program, the age of homes, and whether homes are heated primarily by electricity are the most significant predictors of whether or not homes meet the weatherization standard. Of these three, the age of home serves as the strongest predictor of weatherization status.

> ***Recommendation:*** The HES program should target non-electrically heated homes built prior to 1980, regardless of household income. The program should prioritize those homes that have not yet taken part in the program.[20] Targeting non-electrically heated homes is the best way to increase state-level compliance with the weatherization

[19] Note, the Team included all locations in their assessment of the weatherization standard based on discussions with the EEB evaluation technical consultant. See Appendix F for additional details.
[20] The Team does not take a stance on whether the HES program should continue its current practice of not allowing homes to participate in HES more than once. The forthcoming process evaluation may address this issue.

standard, but HES should continue to pursue energy saving opportunities (e.g., heat pumps replacing electric resistance heat) in the electrically heated homes that do take part in the program even if these opportunities will not greatly increase compliance with the weatherization standard. The current study suggests that a greater proportion of electrically heated homes already meets the weatherization standard, so serving them will not move forward state-level compliance; however, adoption of electric-efficiency measures in electrically heated homes will meet the other critical objectives of increasing electricity and demand savings in Connecticut.

Conclusion: One out of every five homes (20%) that heat primarily with natural gas have uninsulated exterior walls.

Recommendation: The Companies should ensure that HES vendors are discussing wall insulation upgrades with homeowners, particularly in homes with uninsulated wall cavities. The Companies may want to consider whether the current incentive and financing options adequately induce adoption of wall insulation upgrades by households with by natural gas.[21]

Conclusion: Air leakage, flat ceiling insulation, and conditioned to ambient wall insulation are significantly less efficient in performance-based non-compliant homes than in compliant homes.

Recommendation: The Companies should continue to focus on air infiltration reductions during initial HES visits and continue to have HES vendors offer flat ceiling and wall insulation upgrades where applicable. Likewise, the Companies may want to consider whether the current incentive and financing options adequately induce adoption of these measures.

Conclusion: Inadequate basement insulation—primarily conditioned to unconditioned basement frame floor insulation—and foundation wall insulation are contributing factors to the low performance-based compliance with the weatherization standard.

Recommendation: Increasing basement insulation, specifically conditioned to unconditioned basement frame floor insulation, will likely increase compliance with the *current* weatherization standard. The Companies could consider increasing the focus on basement insulation during initial HES visits and encourage homeowners to insulate their basement at either the foundation walls or the frame floor if increasing compliance with the current standard definition is a priority[22].

[21] In addition to offering substantial incentives for insulation projects in the past, the Companies have also offered low-interest financing packages for such projects.

[22] The Companies recently added conditioned to unconditioned basement frame floor insulation to the list of measures eligible for HES incentives.

Conclusion: The use of infrared cameras would help vendors with their retrofit efforts, particularly when it comes to air sealing.

> ***Recommendation:*** The Companies should consider requiring and/or recommending that HES vendors utilize infrared cameras during HES visits. The use of these cameras would likely increase air infiltration reductions and help increase compliance with the weatherization standard.

Other

Conclusion: Among the 180 homes visited as part of this study, 9% (16 homes) have asbestos or vermiculite present and an additional 4% (7 homes) have mold present.

> ***Recommendation:*** The Companies previously helped address these issues through the healthy homes initiative and health impact assessments. The Companies should continue to work with other agencies to address these issues. The EEB and DEEP may also want to consider the appropriateness of offering financing to HES households and HES-IE landlords and rebates to HES-IE homeowners to fund abatement of these problems with the understanding the recipient would then adopt more energy-savings measures such as insulation or air sealing. It is the opinion of the evaluation team that meeting the 80% weatherization requirement by 2030 without increasing the efficiency of homes with these concerns will be difficult.

Conclusion: The labor required to fully populate a REM/Rate model is significant. REM/Rate requires users to perform intensive area and volume calculations in order to properly populate the model. Additionally, REM/Rate accounts for more variables than many other software options. The result is a thorough and accurate energy consumption estimate for any given model (and the option to analyze a large selection of data).

> ***Recommendation:*** The EEB should consider the pros and cons of various software options for assessing compliance using the performance-based approach. REM/Rate is a robust modeling tool that produces accurate energy consumption estimates, but it may not be a viable software option if the EEB expects HES vendors to calculate the weatherization status for HES participating homes. Other options such as the DOE Home Energy Score software or a customized spreadsheet based model may be more applicable. There would undoubtedly be a tradeoff of time/cost vs. accuracy should a less robust model be adopted, but these tradeoffs are something the Team believes the EEB should consider.

1 Introduction

In 2011, the State of Connecticut passed Public Act 11-9, *An Act Concerning the Establishment of the Department of Energy and Environmental Protection [DEEP] and Planning for Connecticut's Energy Future,*[23] which specifies that the Conservation and Load Management Plan should propose how 80% of the residential units in Connecticut could be weatherized by 2030. As a result of this legislation, the Connecticut Energy Efficiency Board (EEB), over several months and with considerable stakeholder input, developed a draft weatherization standard[24] for single-family homes[25] (from here on referred to as the "weatherization standard" or just "the standard") that defines the term *weatherization* (see Appendix L).

In order to assess future progress toward this goal, DEEP and the EEB determined that they must first establish the baseline of homes that currently meet the weatherization standard. As a result, the primary objective of this study is to determine the percentage of single-family residential units in Connecticut currently meeting the weatherization standard. Although, Public Act 11-9 encompasses multifamily residential units as well as single-family units. At the request of DEEP and the EEB, multifamily units are not included in this study and all results are for single-family residential units only. The study included both single-family detached (i.e., stand-alone) and single-family attached (e.g., duplex or townhouse) homes.

Secondary research objectives in this report include the following:

- Detail what percentage of single-family homes with different characteristics (e.g., low income vs. non-low income, fuel oil vs. natural gas heated homes, etc.) fall above and below the weatherization threshold.
- Characterize the weatherization-related features of single-family homes in Connecticut.
    - Detail the characteristics of homes' thermal envelopes (wall insulation, ceiling insulation, air infiltration, duct leakage, etc.), including visual inspection with infrared cameras.
    - Detail the characteristics of homes' heating, cooling, and water heating equipment.
    - Detail the characteristics of other energy-related features (e.g., appliances).

NMR Group, Inc., served as the primary contractor on this study and is referred to as "the evaluators" or "the Team" throughout the report. The evaluators performed the onsite visits in partnership with the Home Energy Solutions (HES) vendors.

[23] http://www.cga.ct.gov/2011/act/pa/pdf/2011PA-00080-R00SB-01243-PA.pdf
[24] Connecticut Energy Efficiency Board, "Public Act 11-80 Weatherization Definition and Determination," Memo provided to Department of Energy and Environmental Protection, June 10, 2012.
[25] At this point there is no weatherization standard for multi-family buildings.

1.1 Description of Table Format

Throughout this report, many tables are presented with the following format (Table 1-1). The left side of the table presents data broken down by the primary heating fuel in each home. There are three categories of primary heating fuel in the table: oil and other fuels, natural gas, and electricity.[26] The "oil and other fuels" category is predominantly fuel oil, but it does include a few homes heated with propane, pellet fuel, or wood.[27] The middle of the table presents results by household income level, which the Team defined similarly to the Low Income Heating Energy Assistance Program (LIHEAP). Specifically, low-income households are those with household income at or below 60% of the state median for their family size and non-low-income are those households above the 60% state median for their family size. The far right column of the table presents data weighted to the statewide population of single-family homes (more detail on the weighting scheme can be found in the Sampling Methodology section). Note, data in all other columns are unweighted; similarly, throughout the report, data are not weighted unless they are specified as being weighted.

Table 1-1: Example Table

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*xx*	*xx*	*xx*	*xx*	*xx*	*xx*
Variable 1	%[a]	%[a]	%	%[c]	%[c]	%
Variable 2	%	%[b]	%[b]	%	%	%

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

Within each applicable table, the Team identified statistically significant results at the 90% confidence level using letters of the alphabet in superscript; in other words, there is 90% probably that the compared results are truly different from each other, but only a 10% probability that observed differences happened by chance. In the example above, an a superscript *a* would indicate statistically significant results between the oil and other fuels and natural gas categories for variable 1, a superscript *b* would indicate significant results between the natural gas and electricity categories for variable 2, and a superscript *c* would indicate significant results between the low-income and non-low-income categories for variable 1.

Throughout the report, many tables present percentage-based results. In these tables, any variable with a sample size of less than 10 is presented as a sample size count and the associated percentage in parentheses. For example, if the electricity category in Table 1-1 had an overall

[26] Of the homes heated primarily by electricity, 75% have electric resistance heat, 31% have air source heat pumps, and 6% have ground source heat pumps (Table 6-2). These values add to more than 100% because many homes had more than one type of heating system.

[27] Specifically, 111 homes were heated primarily by fuel oil, four by propane, two by pellet stoves, and one by wood. Together, these homes comprise the "other fuel" category.

sample size of eight and each variable had a sample size of four, then the data for both variable 1 and variable 2 would be presented as 4 (50%).

1.2 Summary of Terms

Below is a brief summary of terms commonly used throughout this report.

Conditioned Space: The Team defined *conditioned space*, which includes conditioned floor area (CFA) and conditioned volume, using RESNET's formal interpretation of conditioned floor area.[28] The following spaces are considered conditioned floor area:

- Any directly conditioned space.
- Any finished space within the thermal envelope of the building.
- Any unfinished space that is directly conditioned (i.e., directly heated via ducts or other distribution sources).

In addition to conditioned floor area, conditioned space also includes conditioned volume. Conditioned volume, for the purposes of this study, includes the following spaces:

- Any space considered conditioned floor area.
- Any indirectly conditioned and unfinished space located within the thermal envelope of the building.

Ambient: In building science, ambient refers to outdoor conditions. For example, a conditioned to ambient wall is a wall separating the interior of a home from outdoor conditions (an exterior wall).

Frame Floor: Frame floor is a term that is commonly used in the building science industry to describe a floor that separates a conditioned space from an unconditioned space. For example, the floor separating an unconditioned basement from a conditioned first floor is often referred to as a conditioned to unconditioned basement frame floor. In reality, this "frame floor" is the basement ceiling. Similarly, a floor separating an unconditioned garage from a conditioned bonus room above would be considered a conditioned to garage frame floor.

Insulation Installation Grade: In order to conduct a HERS rating, auditors must assign an installation grade, consistent with the Residential Energy Services Network (RESNET) standards,[29] to each building component with cavity insulation. There are three installation grades, which range from Grade I to Grade III. Grade I installation is generally considered to be "perfect," while Grade II is considered "pretty good" and Grade III is "sloppy" (see Appendix B for more detail).

[28] http://www.resnet.us/standards/Floor_Area_Interpretation.pdf

[29] Residential Energy Services Network (2006), *2006 Mortgage Industry National Home Energy Rating Systems Standards*, Oceanside, CA: Residential Energy Services Network.

ACH50: Air Changes per Hour at 50 Pascals. This term is associated with air leakage testing results. When testing homes for air leakage, they are pressurized or depressurized to a pressure of 50 Pascals. Air leakage results are commonly normalized by the conditioned volume of the house and presented as the number of air changes per hour that occur at 50 Pascals of pressurization or depressurization.

CFM25 per 100 sq. ft.: Cubic feet per Minute at 25 Pascals per 100 square feet of conditioned floor area. This term is associated with duct leakage testing results. When testing ducts for leakage they are typically pressurized to 25 Pascals. Duct leakage results are commonly normalized by the conditioned floor area they serve and are presented as the flow (cubic feet per minute) of leakage, at 25 Pascals, per 100 square feet of conditioned floor area.

R-value: R-value is, generally speaking, a measure of insulation's ability to resist heat travelling through it. A higher R-value means the insulation is more resistive to heat transfer.

AFUE: Annual Fuel Utilization Efficiency. This is a common measure of efficiency for mechanical equipment (e.g., furnaces and boilers).

EF: Energy Factor. This is a common measure of efficiency for various appliances (e.g., dishwashers) and water heaters.

SEER: Seasonal Energy Efficiency Ratio. This is a common measure of efficiency for air conditioning equipment.

1.3 On-site Data Collection

As part of this study, the Team visited 180 single-family homes throughout the State of Connecticut between September, 2012 and January, 2013. At the request of the EEB, the Team performed the onsite visits in partnership with the HES vendors. At most sites, a team of three to four people was used for data collection: one member of the evaluation team and two to three members from a participating HES vendor firm. Upon arrival, the evaluation team member typically began collecting information on the size and configuration of the home. At the same time, HES vendor team members began setting up equipment for diagnostic tests (e.g., blower doors and duct blasters). After gathering information on the size and configuration of the home, evaluation team members worked with HES vendors to gather information on air and duct leakage. Once these tests were complete, evaluation team members began collecting a wide range of information independent of the HES vendors (e.g., insulation levels, mechanical equipment make and model, infrared images, appliance make and model, etc.). While evaluation team members collected this information, HES vendors began simultaneously performing their "core" services; these services include air sealing, duct sealing, installing hot water pipe insulation, installing efficient light bulbs, and installing water-saving measures such as low-flow showerheads and faucet aerators. The site visits ranged from two to six hours in length, averaging approximately four hours. Homeowners were provided with free HES core services, a

$100 incentive for their participation, and the chance to win one of three iPads after all of the site visits were completed.

An on-site data collection form with inputs mimicking those required by REM/Rate™ was developed for this study.[30] REM/Rate is a residential energy analysis software that is commonly used to model the performance of residential buildings; the software is most notably used by the ENERGY STAR® Homes program and in Connecticut's Residential New Construction Program. It includes fields for the following information:

- General information, including house type and year of construction, conditioned floor area, conditioned volume, foundation type, primary heating fuel, number of stories, number of bedrooms, thermostat type, and ownership status;
- Basement information, detailing a basement's characteristics to aid in categorizing a space as within or outside the buildings conditioned space;
- Building shell measures that fall into two types:
    - Insulation location, area, type, R-value, and installation grade for walls, floors, ceilings, joists, foundation walls, and slabs,
    - Framing description where applicable;
- Window type, location, area, U-value, and SHGC values;
- Door type, location, area, and insulation;
- Mechanical equipment, including make, model, type, age, location, efficiency, and capacity of heating, cooling, and water heating units;
- Appliances, including make, model, age, location, energy usage in kWh/yr., and Energy Factor where applicable;
- Lighting, including number of fixtures by type and location;
- Diagnostic testing, including building envelope air leakage in cubic feet per minute at 50 Pascals (CFM50) and duct leakage, both total and to the outside of the envelope, in cubic feet per minute at 25 Pascals (CFM25);
- Duct information, including type of duct, location in the home, location on the supply or return portion of the system, insulating material, and R-value;
- Ventilation, including attic ventilation; Energy Recovery and Heat Recovery Ventilation Systems (ERV/HRV) make, model, rate, and recovery efficiency; and bathroom fan control type;
- Renewable technologies, including the size, type, and efficiency of solar thermal, photovoltaic, and wind technologies; and
- Auditor rankings, wherein auditors record the level of opportunity for improving energy efficiency in the home on a scale of 1 (low) to 5 (high) and rank the energy features of the home by greatest savings opportunity.

[30] This form was created in Microsoft Access and could not be attached to this report.

One challenge associated with conducting HERS ratings on existing homes is that some building shell components are not accessible or visible. Some components such as frame floors over basements or foundation walls in unconditioned space have readily identifiable characteristics. However, other components—particularly conditioned to ambient[31] wall insulation, vaulted ceiling insulation, slab insulation, exterior foundation wall insulation, and window U-values and Solar Heat Gain Coefficients (SHGC) values—are more difficult to verify. Auditors used a variety of methods to collect and verify building shell information while on site.

While infrared imaging can confirm the presence and installation grade of insulation in most shell measures, auditors periodically must infer its type and R-value based upon insulation observed elsewhere in the house, construction plans, or homeowner testimony. In the case of walls, auditors commonly probe through an existing opening – such as to the side of an electrical outlet box – to determine the type and thickness of the insulation, and then calculate an R-value. The auditors recorded information regarding whether a given insulation R-value was verified or assumed.

In order to conduct a HERS rating, auditors must assign an installation grade, consistent with the Residential Energy Services Network (RESNET) standards[32], to each building component with cavity insulation. There are three installation grades, which range from I to III. Grade I installation is generally considered to be "perfect," while Grade II is considered "pretty good" and Grade III is "sloppy" (see Appendix A for more detail). When the insulation was not visible, as in an enclosed wall or ceiling cavity, auditors used either infrared cameras (when possible) or the insulation grades that were observed in other areas of the home to estimate the installation grade for that component.

Defining a basement as either within or outside the conditioned volume of the house is a critical step in conducting a HERS rating. In homes with poorly defined thermal boundaries, it is sometimes not immediately apparent whether a basement should be considered part of the conditioned space or not. For the purposes of this study, unfinished basements with neither foundation wall[33] nor frame floor insulation were generally considered unconditioned, as this is the guideline used by contractors in the Connecticut HES program. After some discussion with the EEB Evaluation Technical Consultant, it was decided that the audits performed for this study should be consistent with the HES program where appropriate so that the study results are as informative as possible for the EEB moving forward.

[31] Ambient locations refer to building shell locations that abut outside air.
[32] Residential Energy Services Network (2006), *2006 Mortgage Industry National Home Energy Rating Systems Standards,* Oceanside, CA: Residential Energy Services Network.
[33] Adding to the challenge of defining basements as conditioned is the fact that exterior foundation wall and slab insulation are extremely difficult to verify in existing buildings.

In some homes, these poorly defined unconditioned spaces[34] could not be separated from the conditioned space for the purposes of air leakage testing. Therefore, in order to obtain a more accurate measurement of building envelope air leakage, these spaces were included in the conditioned volume despite otherwise being defined as existing outside the building's finished space.[35]

[34] An example of this would be a home with a fully unconditioned basement (e.g., no foundation wall insulation and not directly heated) that had no door separating the conditioned first floor from the basement.
[35] Parts of 29 basements were considered conditioned volume only (not CFA and conditioned volume). Many of these 29 homes only had small spaces, such as mechanical rooms, defined as conditioned volume, while others had the entire basement defined as such.

2 Methodology

This section summarizes a variety of research components that affected the results of the study. Specifically, the section addresses methodologies surrounding the following areas: sampling, weighting, calculating average R-values, modeling performance-based compliance, estimating air leakage levels, telephone survey results, insulation grades, room air conditioners, and portable space heaters.

2.1 Sampling and Weighting Methodology

2.1.1 Sampling Plan

As noted earlier, the study focused exclusively on single-family homes, both detached (stand-alone homes) and attached (side-by-side duplexes and townhouses that have a wall dividing them from attic to basement and that pay utilities separately). Multifamily units—even smaller ones with two to four units—were excluded from the study due to the complexity and concomitant added costs of including them in the evaluation. Specifically, multifamily units would be difficult to recruit for this study as these units have a higher proportion of renters; the need to secure landlord permission—and the difficulties in doing so—reduced the likelihood that the team would have permission to enter such buildings to perform a weatherization assessment. Additionally, it can be challenging to assess the efficiency of the buildings without having access to all of the units. From a logistics perspective, it would be quite difficult to coordinate participation of multiple tenants (renters or condominium owners) within the same building in order to achieve the most reliable study results. All of these factors lend themselves to a more expensive study, and the EEB and DEEP directed the Team to exclude them for this reason. The evaluators relied on a disproportionately stratified design that aimed to achieve 10% sampling error or better at the 90% confidence level across all of Connecticut and also for several subgroups of interest (Table 2-1, shaded cells). This level of precision means that one can be 90% confident that the results are a reasonably (±10% or less) accurate description of all the single-family homes in Connecticut. All precisions are based on a coefficient of variation of 0.5.[36]

[36] The coefficient of variation measures the dispersion of data in a series of data points; it is commonly used to estimate sampling error when measuring the efficiency of measures installed in weatherization efforts.

Table 2-1: Sample Design Planned and Actual, with Sampling Error

Single-family Segment	Planned Sample Size	Actual Sample Size	Precision
Overall	180	180	**6%**
Low-income	68	34	14%
Non-low-income	76	146	**7%**
Income eligibility not identified	36*	0*	n/a
Fuel oil heat	109	111	**8%**
All other heating fuels	71**	69**	**10%**
Own	159	177	**6%**
Rent	21	3	47%

*The survey approach for identifying household income asked respondents if their income was above or below a certain amount based on their family size. This unobtrusive approach meant that the evaluators were able to identify the income status for all participants in the onsite study.

**The evaluators planned for 47 of these homes to heat with natural gas, and 46 of the homes in the final sample actually did so.

The final sample, however, did not achieve 90/10 precision for low-income households—although the sampling error of 14% is close to the desired 10%—and sampled fewer than expected renters (although the evaluators had not expected to achieve 90/10 precision for renters). These are traditionally difficult groups to sample,[37] but three factors directly related to this study further limited the evaluators' ability to achieve 90/10 precision for the low-income households and to visit the expected number of rental households. Two of these factors stem from the HES requirement that renters receive permission from their landlords before receiving HES services. First, when recruiting for the study, the evaluators informed possible participants that they would have to get landlord approval before taking part in the study; at that point, many renters indicated they did not want to take part in the study. Second, renters that did originally express interest in the study were ultimately unable or unwilling to secure landlord permission prior to the onsite visit. Because a disproportionately high number of households that rent single-family homes also qualify as low-income, the difficulty in securing participants who rent also limited the evaluators' ability to sample as many low-income households as designed. A third reason for the lower than expected renter and low-income participation relates to the structure of buildings: When scheduling onsite visits, the evaluators discovered that many interested survey respondents who had originally indicated that they lived in single-family attached homes actually lived in multifamily homes or attached homes that were not completely separate units (i.e., they were not separated from attic to basement or they shared utilities).

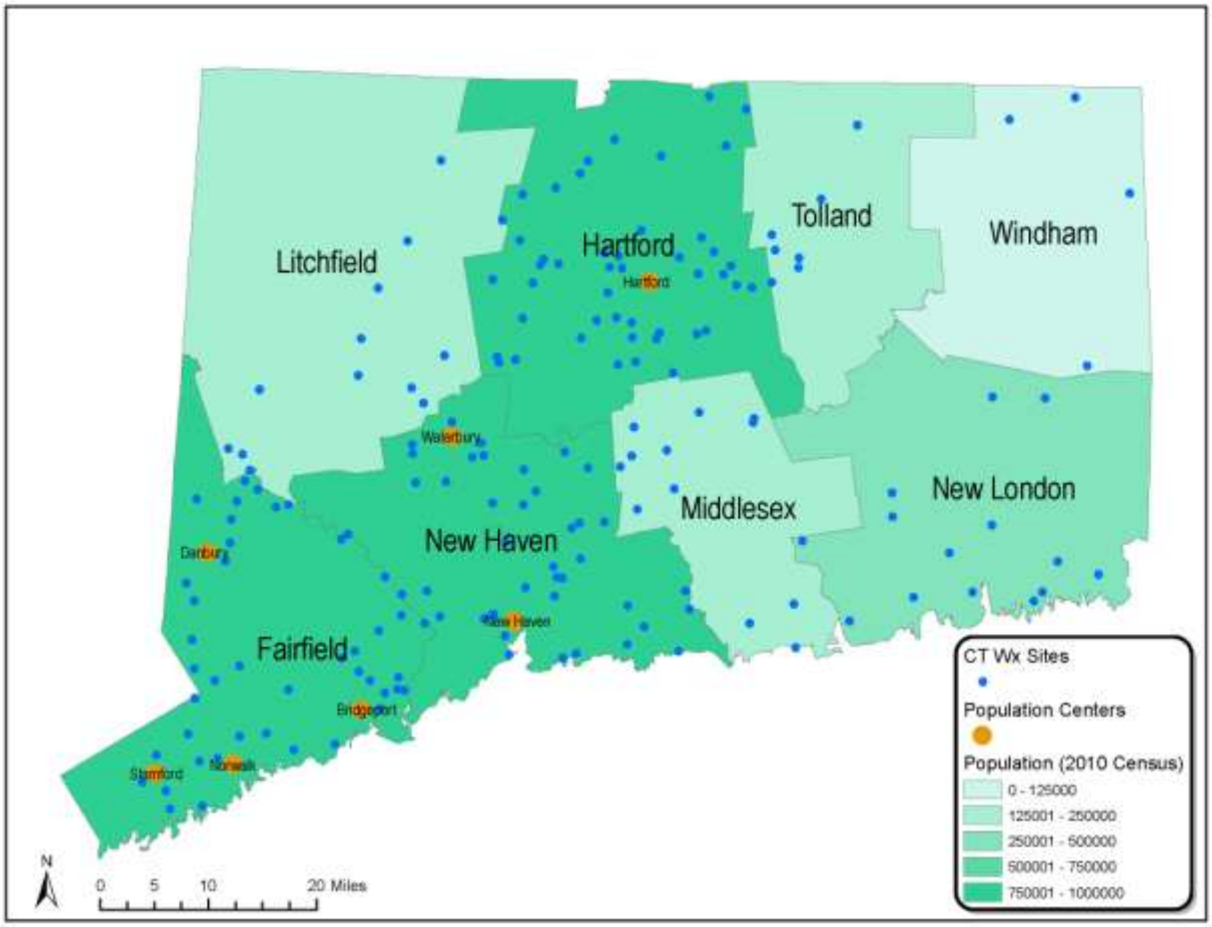
[37] Underrepresentation of renters and low-income respondents is common in telephone surveys. For example, see Galesic, M., R. Tourangeau, M.P. Couper (2006), "Complementing Random-Digit-Dial Telephone Surveys with Other Approaches to Collecting Sensitive Data," *American Journal of Preventive Medicine*, Volume 35, Number 5.

Despite the fact that these circumstances limited the evaluators' ability to achieve the desired completions for low-income and renter households, Appendix I, which summarizes demographic and household characteristics of telephone survey respondents and final onsite participants, demonstrates that the final onsite sample closely resembles single-family homes in Connecticut on most critical characteristics.

It is also the case that the sample design implemented by the Team achieved 90/10 precision for oil-heated households and for households of all other fuel types combined. This reflects the fact that about 62% of single-family homes in Connecticut are heated with oil, and the Team could not promise—and did not achieve—90/10 precision for any other single heating fuel type with a sample size of 180 (the size chosen by the EEB and DEEP from a list of options provided by the evaluators). However, because of the heating fuel-oriented structure of the HES and Home Energy Solutions Income Eligible (HES-IE) programs, which will most likely be vital components of any effort to achieve 80% weatherization by 2030, this report presents results for natural gas and electric heated households as well as oil and other fuel types to provide information in the manner most conducive to future program planning. Likewise, the weighting scheme, discussed next, also takes the different fuel types into account.

Figure 2-1 maps the distribution of sites that took part in the study.

Figure 2-1: Distribution of Site Visits



2.1.2 Weighting

The onsite data in this analysis were proportionally weighted based on the site's primary heating fuel type and whether or not the household qualifies as low-income. The Team weighted the data to a count of Connecticut households, gathered from the American Community Survey 2008-2010 three-year estimates, and broken out by fuel type and low-income status as described above.[38] Two categories of primary heating fuel type served as the basis for this weighting

[38] Because the study limited participation to single-family households and defined low-income based on 2012 Low-income Heating Energy Assistance Program (LIHEAP) eligibility requirements for income and household size, the evaluators used the Census Bureau's Data Ferret search function, which allows for greater manipulation of raw ACS data than the commonly used American FactFinder website. However, Data Ferret does not extrapolate "missing data," meaning that the resulting sample sizes listed in Table 2-2 fall below those reported elsewhere for the state. In particular, the number of households drawn from Data Ferret in Table 2-2 sums to 892,598, but the ACS puts that number at 951,715 (a difference of 59,117). Most of the missing data stems from ACS respondents who refused to provide their income on that government survey.

scheme: (1) oil, propane, and other fuel types, and (2) gas and electricity. By combining the income and primary heating fuel categories, the evaluators established four weighting categories: (1) low income with oil, propane, or miscellaneous fuel; (2) low income with gas or electricity; (3) not low income with oil, propane, or miscellaneous fuel; and (4) not low income with gas or electricity. The four weighting categories resulted in baseline weights that were very close to one for all four categories, suggesting that the sample closely resembled the population even prior to weighting the data (Table 2-2).

Table 2-2: Onsite Baseline Proportional Weights

Weighting Category (Income Level: Primary Heating Fuel)	Connecticut Population from ACS	Sample	Proportional Weight
Low Income: Oil, Propane, or Miscellaneous	128,495	20	1.296
Low Income: Gas or Electric	72,766	14	1.048
Not Low Income: Oil, Propane, or Miscellaneous	475,295	98	0.978
Not Low Income: Gas or Electric	216,042	48	0.908

The weighting scheme depicted in Table 2-2 is termed the baseline weighting scheme because it represents the scheme used when the analysis applied to all homes in the sample. However, a number of variables in the onsite sample had missing values due to the variable of interest not being present in a household (e.g., duct systems, gas boilers, oil furnaces, etc.). In such situations, the baseline sample did not appropriately represent the population of the subset of households that had these measures. To adjust the weighting scheme for variables with missing values, the Team developed adjusted weighting schemes specific to the variable under examination. The adjustments created new weighting schemes that reflected the actual portion of the overall population with these measures. Table 2-3 provides an example of revised weights for building shell air leakage.[39]

Table 2-3: Revised Weights Example—Air Changes per Hour at 50 Pascals*

(Base: All homes where air leakage was tested)

Weighting Category (Income Level: Primary Heating Fuel)	Connecticut Population from ACS	Sample	Proportional Weight
Low Income: Oil, Propane, or Miscellaneous	128,495	15	1.497
Low Income: Gas or Electric	72,766	12	1.06
Not Low Income: Oil, Propane, or Miscellaneous	475,295	88	0.944
Not Low Income: Gas or Electric	216,042	41	0.921

[39] Note that the sample size for this table is less than 180 because blower door tests were not conducted at all 180 homes. See the Diagnostics section of this report for more details.

2.2 Building Science Methodology

2.2.1 Calculating Average R-values

The Team derived the average R-value for a given building shell component—e.g., conditioned to ambient walls or vaulted ceilings—using the UA (U-value*area) equation. Unlike simply taking the mean of all R-values observed in a given house, the UA equation accounts for the surface areas of shell components insulated to different levels and in this way accounts for the fact that heat transfer follows the path of least resistance; therefore, the effective average R-value of an assembly is not simply an area-weighted average of nominal R-values. For example, a house with walls that are 75% R-19 and 25% R-11 would have an area-weighted average R-value of R-17. The same assembly using the UA approach would have R-12.3 walls, on average. Using the UA approach is standard practice in the building science industry when calculating average R-values.

2.2.2 Insulation Grades

As part of the auditing process, auditors applied insulation grades to all insulation locations. In order to conduct a HERS rating, auditors must assign an installation grade to each building component with cavity insulation. There are three installation grades, which range from Grade I to Grade III. A Grade I installation is generally considered to be "perfect," while Grade II is considered "pretty good" and Grade III is "sloppy" (see Appendix B for more detail). When the insulation was not visible, as in an enclosed wall or ceiling cavity, auditors used either infrared cameras (when possible) or the insulation grades that were observed in other areas of the home to estimate the installation grade for that component.

Insulation grades were not factored into the R-values statistics throughout the report. These statistics are based on the R-values identified during the site visits, without accounting for insulation grades.

Prior to modeling performance-based compliance, the Team and the EEB technical consultant decided that all insulation would be modeled as a Grade II installation in the "weatherized" REM/Rate model. This means that homes with Grade I installations (high quality) were given additional credit when assessing performance-based compliance and homes with Grade III installations (low quality) were penalized.[40]

[40] The Team explored the influence of insulation grades by looking at R-19 wood-framed walls in REM/Rate. A Grade I installation with R-19 insulation has an effective U-value of .059, a Grade II installation has an effective U-value of .063, while a Grade III installation has an effective U-value of .070.

2.2.3 Estimating Air Leakage

The Team was unable to conduct blower door tests at 24 sites due primarily to the presence of asbestos, vermiculite, or mold.[41] Similarly, the Team was only able to conduct duct leakage tests at 73 out of 97 homes with duct systems.

In order to model each of the 180 homes in REM/Rate, the evaluators had to estimate air leakage for each of the 24 homes in which blower door tests were not conducted.[42] The Team did this by leveraging data from the homes for which it did have blower door measurements and the results of a model previously developed by Lawrence Berkeley National Laboratory (LBNL). Beginning in 2006, and updated in 2011, LBNL developed a statistical model to determine which characteristics (e.g., floor area, building age, income status, etc.) influence building shell leakage.[43, 44] The model suggests that income status, participation in an energy efficiency program, building age, and building floor area were the characteristics with the most significant impact on air leakage.

Section 7.1 describes this process in more detail, but, in summary, the Team created eight unique bins, two for low-income households and six for non-low-income households, based on home age and building size in order to apply air leakage estimates to each of the 24 sites that did not receive blower door tests. Based on these analyses, the leakage estimates ranged from 10.5 to 22.1 ACH50 for low-income homes and 6.9 to 16.0 ACH50 for non-low-income homes. The Team applied these estimates to the 24 homes lacking blower door measurements based on income status, building age, and, where applicable, building size.

The evaluators conducted secondary research in an attempt to estimate duct leakage values for the 24 sites that had ducts but where a duct blaster test could not be conducted. Unfortunately, the Team could not find any studies that would help develop such estimates.

2.3 Modeling "As-Built" and "Weatherized" Homes

In order to assess compliance with the weatherization standard's performance approach, the evaluators developed a User-Defined Reference Home (UDRH) script in REM/Rate that compared each audited (or "as built") home to the same home (with the same configuration, conditioned floor area, volume, etc.) modeled with the prescriptive efficiency specifications listed in the weatherization standard (considered the "weatherized" home). Any REM/Rate

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[41] The Team did not try to determine the cause of mold, and instead only documented its presence.

[42] REM/Rate does not have default values for air leakage. In order to produce the outputs required to assess the weatherization status of each home, it was necessary to estimate air leakage values for these sites.

[43] Lawrence Berkeley National Laboratory. *Development of a Mathematical Air-Leakage Model from Measured Data*. By Jennifer McWilliams and Melanie Jung. LBNL-59041 (Washington, D.C: United States Government Printing Office, 2006).

[44] Lawrence Berkeley National Laboratory. *Preliminary Analysis of U.S. Residential Air Leakage Database v.2011*. By Wanyu R. Chan and Max H. Sherman. LBNL-5552E (Washington, D.C: United States Government Printing Office, 2011).

inputs not included in the weatherization standard (e.g., mechanical equipment) remained the same in both the “as-built” and “weatherized” REM/Rate models.

2.4 Telephone Survey

In order to identify households to take part in the onsite visits, the Team conducted a recruitment survey to gather information about the demographic and social characteristics of the household and the home in which they lived. The survey also allowed the evaluators to screen out households living in multifamily structures. Appendix I details the results of the telephone recruitment survey while Appendix J offers a comparison of self-reported telephone survey data and data that were verified onsite. The Team found that the self-reported data corresponded closely to the data that were verified onsite.

2.5 Inspecting Room Air Conditioners and Space Heaters

As stated previously, the Team conducted site visits between September, 2012 and January, 2013. Given the timing of the site visits, room air conditioners and portable space heaters were often not in use at the time of the visits. Auditors asked homeowners about the presence and location of room air conditioners and portable space heaters during the site visits and subsequently inspected them, regardless of whether or not they were installed at the time.

3 Weatherization Assessment

The Team assessed compliance with the weatherization standard using both the prescriptive and performance paths described in the memorandum issued by the EEB on June 10, 2012.[45] As described in that document, in order to comply with the prescriptive approach a home must meet all of the criteria listed in Table 3-1 (more details on prescriptive compliance can be found in Section 3.2: Prescriptive Weatherization Assessment). In order to comply with the performance approach, a home must demonstrate modeled energy usage that is equal to or less than the same home built according to the criteria listed in Table 3-1. As shown, all of the items listed in the weatherization standard, with the exception of duct leakage and duct insulation, relate to the building envelope. DEEP and the EEB excluded mechanical equipment from the standard for the following reasons: it can be difficult to induce early retirement, mechanical equipment is covered through non-weatherization related program activities, and much of the mechanical equipment currently in use will be replaced with new equipment[46] by 2030, when compliance with the standard is expected to be 80%.

Table 3-1: Weatherization Prescriptive Checklist and Performance Modeling Inputs

Building Element	Prescriptive Requirements and Modeling Inputs for Performance Approach
Above Grade Walls	R-11
Flat Ceilings	R-30
Cathedral Ceilings	R-19
Unconditioned Basements & Crawlspaces	Floor separating basement from conditioned space above is insulated to R-13
Conditioned Basements & Crawlspaces	Interior walls fully insulated to R-5
Slab on Grade	R-5 four feet below grade; assume to proper depth if present
Windows	U-0.50 (Double pane or single pane with storm)
Air Leakage	9 ACH @ 50 Pascals based on HES program data
Duct Leakage for ducts outside conditioned space	16 CFM @ 25 Pascals per 100 sq. ft. of conditioned space based on HES program data
Duct Insulation: Unconditioned Basements	R-2
Duct Insulation: Unconditioned Attics and Crawlspaces	R-4.2

The evaluators used REM/Rate software to model each of the 180 homes audited as part of this study. In order to assess performance-based compliance, each site was modeled once with the energy efficiency characteristics that were identified onsite (considered the "as built" model) and

[45] Connecticut Energy Efficiency Board, "Public Act 11-80 Weatherization Definition and Determination," Memo provided to Department of Energy and Environmental Protection, June 10, 2012.
[46] New equipment will also come with higher efficiencies as federal standards increase.

once using the efficiency specifications provided in Table 3-1.[47] Appendix F provides more details related to the modeling inputs.

3.1 Performance-Based Weatherization Assessment Results

Statewide, just over one-quarter of the sampled homes (26%) comply with the performance path of the weatherization standard (Table 3-2). Non-low-income homes (29%) are much more likely to be compliant with the standard that low-income homes (15%). Similarly, the 16 homes heated primarily by electricity (50%) are much more likely than homes heated by natural gas (22%) and homes heated by oil and other fuels (25%) to be compliant with the standard.

Table 3-2: Weatherization Compliance Rate
(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Homes Meet or Exceed Wx Standard	25%[a]	22%[b]	50%[a,b]	15%[c]	29%[c]	26%
Homes Below Wx Standard	75%[a]	78%[b]	50%[a,b]	85%[c]	71%[c]	74%

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

Table 3-3 shows the confidence intervals associated with the various compliance estimates listed in Table 3-2. For example, with 90% confidence, the statewide weatherization rate is estimated to fall between 21% and 31%.

Table 3-3: Lower and Upper Bounds for Weatherization Compliance Estimate at 90% Confidence Level
(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Lower Bound of the Wx Compliance Estimate at 90% C.L.	18%	12%	29%	5%	23%	21%
Wx Compliance Estimate	25%	22%	50%	15%	29%	26%
Upper Bound of the Wx Compliance Estimate at 90% C.L.	32%	32%	71%	25%	35%	31%

[47] A User Defined Reference Home (UDRH) script was written in order to model each home with prescriptive weatherization requirements.

Table 3-4 shows the level at which homes either exceed or fall below the weatherization standard when comparing the heating and cooling energy consumption of the "as built" energy model and the model built to the prescriptive weatherization requirements. The majority of homes that comply with the standard (94%) do so by a margin of 25% or less, while just 6% comply by a margin of more than 25%. Distance from the prescriptive baseline among non-compliant homes is more varied, with roughly one-third of homes (36%) falling below the standard by 25% or less, while the other two-thirds of homes (65%) fall below the standard by 26% or more. Essentially, most homes that do comply with the standard do so by a relatively small margin (within 0% to 25% of the baseline energy consumption). In contrast, homes that do not meet the standard fall on a broader spectrum of non-compliance. On average, homes that comply with the standard exceed the standard by 13%, while homes that do not comply fall below the standard by 48% (Figure ES-2). See Figure A-10 in Appendix A for additional details on the level at which homes either exceed or fall below the weatherization standard.

Table 3-4: Distance from Baseline of the Performance-Based Standard by Heating and Cooling Energy Consumption

(Base: All homes)

	Statewide Weighted			
	0-10%	**11-25%**	**26-50%**	**>50%**
n	*20*	*25*	*3*	--
Homes Meet or Exceed Standard	43%	51%	6%	--
n	*23*	*25*	*39*	*45*
Homes Below Standard	17%	19%	30%	35%

Table 3-5 shows compliance with the weatherization standard by county, although small sample sizes in the less populous counties limit the generalizability of some of the results. Of the counties where ten or more onsites were performed, homes located in New London county (57%) are the most likely to meet the weatherization requirements, while homes in Fairfield and New Haven counties (20%) are the least likely to meet the requirements. The three largest counties in the state—Fairfield, Hartford, and New Haven—all have very similar compliance results, with approximately one out of every five homes complying with the standard.

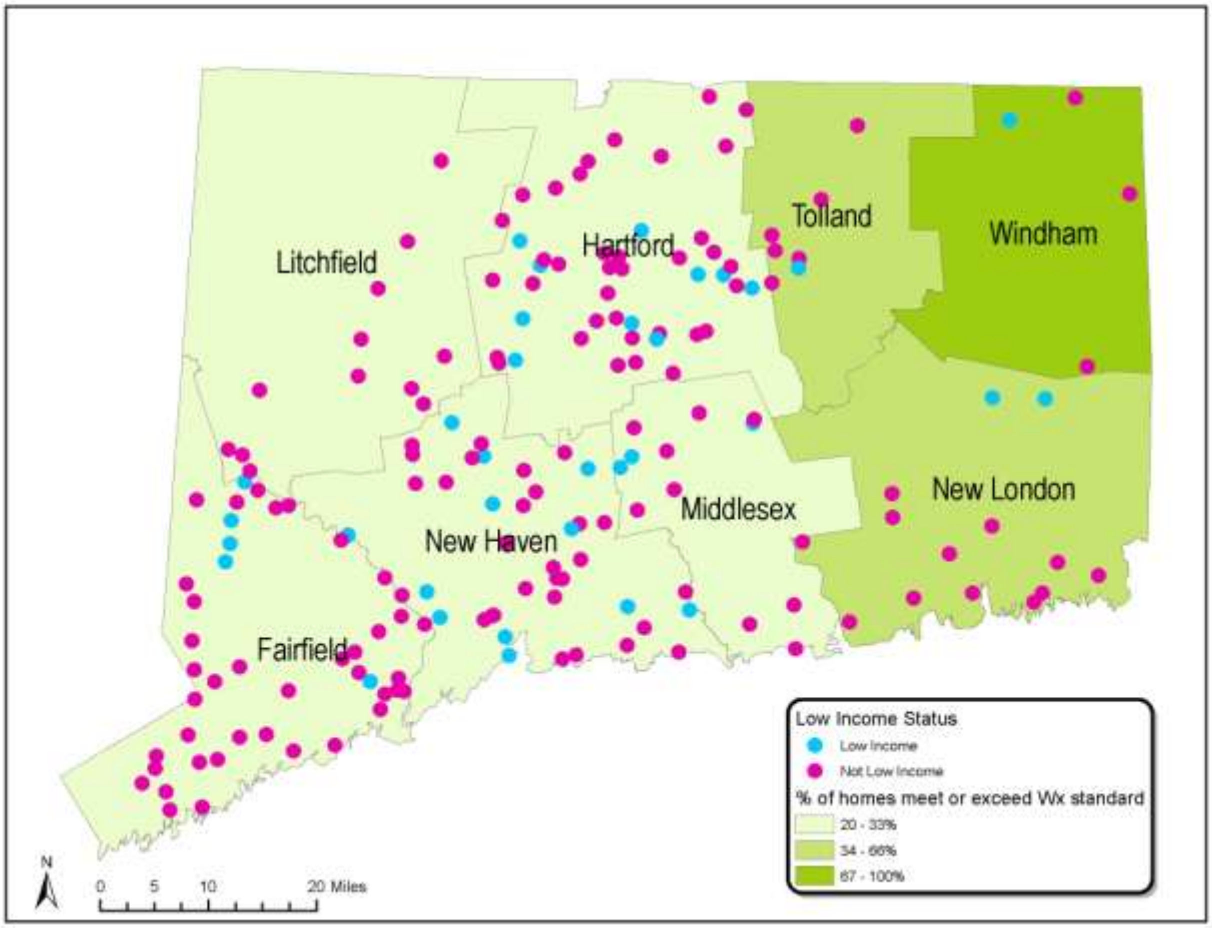
Table 3-5: Weatherization Assessment by County

(Base: All homes)

County	n	Statewide Weighted	
		Homes Meet or Exceed Wx Standard	Homes Below Wx Standard
Fairfield	45	20%	80%
Hartford	46	22%	78%
Litchfield	12	25%	75%
Middlesex	12	33%	67%
New Haven	40	20%	80%
New London	14	57%	43%
Tolland	7	43%	57%
Windham	4	75%	25%
Statewide	**180**	**26%**	**74%**

Figure 3-1 displays the distribution of site visits, by household income, overlaying the weatherization compliance range for each county. As shown, low-income households appear to be evenly distributed across the counties and compliance with the standard is highest in the eastern most counties of the State.

Figure 3-1: Weatherization Assessment by County and Household Income



Ten percent of the 180 homes visited for this study were found to have participated in the HES program, which is similar to the historical program participation rate for the broader population. As shown in Table 3-6, the homes that had previously participated in the HES program are more likely to meet the weatherization requirements than homes that have not participated in the HES program (39% and 25%, respectively); however, the difference is not significant at the 90% confidence level. Note, however, that simply because a household took part in HES does not mean that the household adopted measures that would meet the weatherization standard; many HES participants receive only the core services[48] and either are not eligible to receive or choose not to adopt the deeper measures outlined in the standard. For example, many homeowners may need above grade wall insulation but choose not to adopt the measure for any one of a number of reasons. Similarly, homes with no basement insulation, until recently, were not eligible for such insulation rebates as they were not offered by the HES program.

Table 3-6: Weatherization by HES Participation
(Base: All homes)

	Statewide Weighted	
	Participant	**Non-Participant**
n	*18*	*162*
Homes Meet or Exceed Wx Standard	39%	25%
Homes Below Wx Standard	61%	75%

[48] Core services, at the time of the study, included efficient light bulbs, air sealing, duct sealing, hot water pipe insulation, and low-flow water saving fixtures.

Table 3-7 shows that newer homes are significantly more likely to meet the weatherization requirements than older homes. Homes built between 1980 and 1989 (48%) are significantly more likely to meet the standard than are homes built in 1939 or earlier (7%), homes built from 1940 to 1959 (6%), or homes built from 1960 to 1969 (16%). This jump is likely due to the fact that the State began enforcing energy code requirements around 1980. As stated by the Department of Energy when referring to Connecticut residential energy codes, "In 1979, legislation was passed requiring that the State Building and Fire Safety Code promote and ensure the design and construction of energy-conserving buildings and the use of renewable resources."[49] In Connecticut, many more homes were built prior to 1980 than afterwards; as a result, the sample sizes for homes built in 1980 or later are substantially smaller than those built prior to 1980. Keeping the small sample in mind, these homes show a steady increase in compliance with the standard after 1980. Similar to the significant increase in compliance beginning in the 1980s, increases in the 1990s and 2000s are likely due to continued energy code adoption and enforcement. The overall sample of the audited homes accurately reflects the ages of homes in the actual population (see Appendix I, Table I-5).

Table 3-7: Weatherization by Home Age

(Base: All homes)

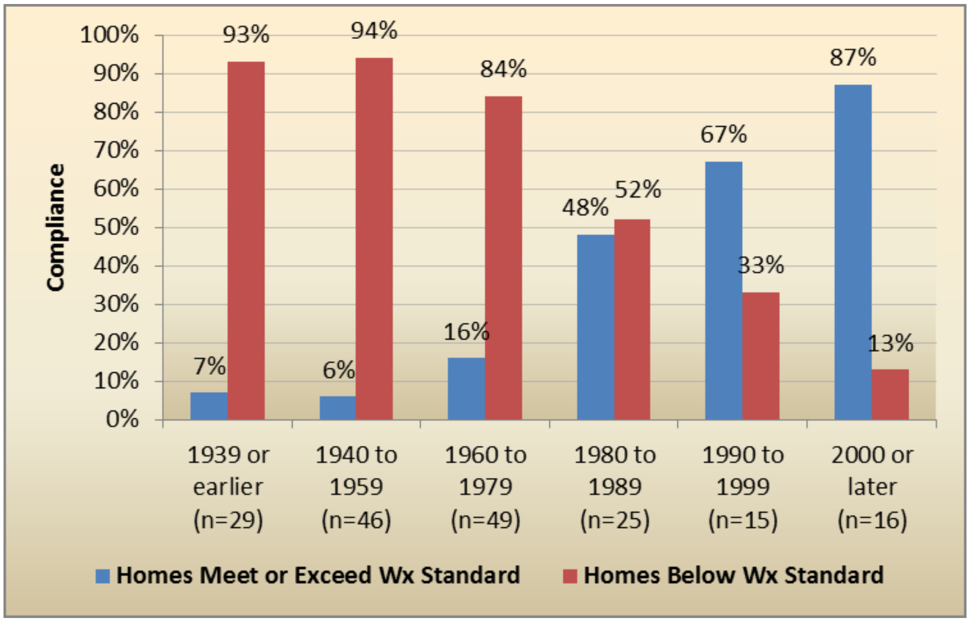
	Statewide Weighted					
	1939 or earlier	**1940 to 1959**	**1960 to 1979**	**1980 to 1989**	**1990 to 1999**	**2000 or later**
n	*29*	*46*	*49*	*25*	*15*	*16*
Percent of Single-Family Homes in Sample	16%	26%	27%	14%	8%	9%
Percent of Single-Family Homes Statewide	18%	27%	27%	12%	8%	8%
Homes Meet or Exceed Wx Standard	7%[a,b,c]	6%[d,e,f]	16%[g,h,i]	48%[a,d,g,j]	67%[b,e,h]	87%[c,f,i,j]
Homes Below Wx Standard	93%[a,b,c]	94%[d,e,f]	84%[g,h,i]	52%[a,d,g,j]	33%[b,e,h]	13%[c,f,i,j]

[a,b,c,d,e,f,g,h,i,j] Statistically significant difference at the 90% confidence level.

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

Figure 3-2 presents the same information as Table 3-7 in a chart format.

Figure 3-2: Weatherization by Home Age
(Base: All homes)



Homes heated primarily by fuel oil (22%) and natural gas (21%) have very similar compliance results and represent 88% of the sites visited as part of this study (Table 3-8). That said, homes heated primarily by electricity composed only 9% of the sample (16 homes) and show significantly higher compliance (50%) than homes heated by fuel oil and natural gas.

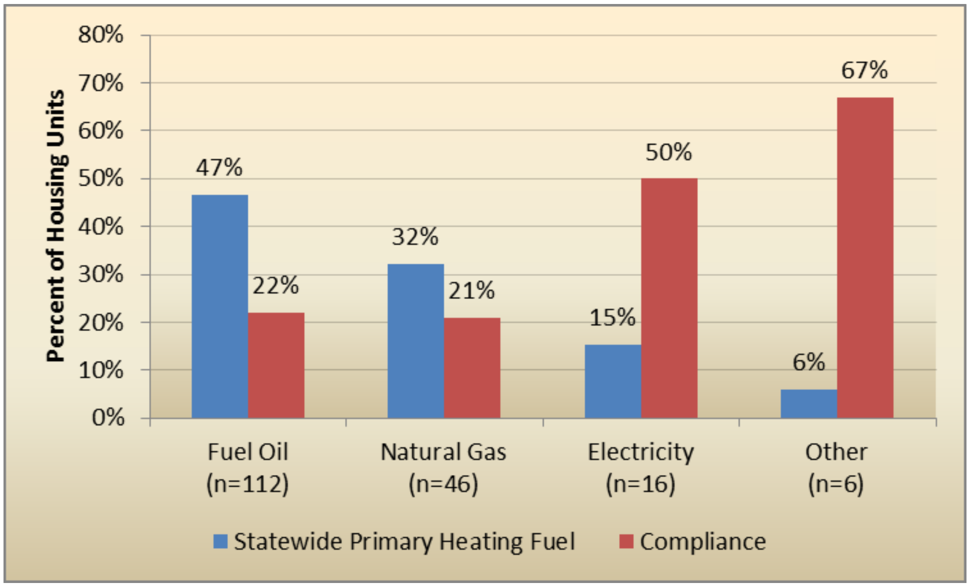
Table 3-8: Weatherization by Primary Heating Fuel
(Base: All homes)

	Statewide Weighted			
	Fuel Oil	**Natural Gas**	**Electricity**	**Other***
n	*112*	*46*	*16*	*6*
Homes Meet or Exceed Wx Standard	22%[a,b]	21%[c,d]	50%[a,c]	67%[b,d]
Homes Below Wx Standard	78%[a,b]	79%[c,d]	50%[a,c]	33%[b,d]

*Propane, pellet, and wood
[a,b,c,d] Statistically significant difference at the 90% confidence level.

Building from Table 3-8, Figure 3-3 displays a comparison of performance-based compliance by fuel type and the number of housing units (including multifamily), statewide, that are primarily heated by each fuel. As shown, while homes heated primarily by electricity and other fuels do show higher compliance (50% and 67%, respectively) they represent small portion of the statewide housing units (21%).

Figure 3-3: Statewide Primary Heating Fuel by Performance-Based Compliance



Single-family detached homes (26%) show slightly higher compliance with the standard than single-family attached homes (23%), though the difference is not statistically significant at the 90% confidence interval (Table 3-9).

Table 3-9: Weatherization by House Type
(Base: All homes)

	Statewide Weighted	
	Detached	**Attached**
n	*167*	*13*
Homes Meet or Exceed Wx Standard	26%	23%
Homes Below Wx Standard	74%	77%

A series of advanced statistical modeling approaches (logit models, the calculation of odds ratios, population attributable risk models, and a statically-informed Venn diagram) demonstrated that age of home serves as the most important factor driving weatherization (see Appendix K for more details). In fact, these models show that homes built in or after 1980 were nearly 17 times more likely to meet the weatherization standard than those built prior to 1950. Had all the homes in the sample been built in or after 1980s, the models predict that an *additional* 52% would have met the weatherization standard. Together, this information suggests that future efforts designed to help the State achieve 80% weatherization should target older homes (i.e., those build prior to 1980).

While paling in comparison to the potential impact of targeting older homes, the same analysis also suggests that the HES program should target non-electrically heated homes and homes that have not previously taken part in HES in efforts to boost the number of homes meeting the weatherization standard. Targeting non-electrically heated homes is the best way to increase compliance with the weatherization standard. That said, there are lots of energy saving opportunities in electrically heated homes that the HES program could pursue (e.g., heat pumps replacing electric resistance heat), but these opportunities are not as likely to increase compliance with the weatherization standard. Similarly, targeting low-income homes would not lead to substantial increases in the number of homes meeting the weatherization standard, although doing so provides numerous other energy- and non-energy benefits.

3.2 Prescriptive Weatherization Assessment

While, for the purposes of this study, compliance with the weatherization standard is primarily assessed using the performance approach, the evaluators also analyzed compliance with the prescriptive approach. In order to comply with the prescriptive approach, a home must meet all of the requirements listed in Table 3-10. As is shown, compliance with the individual measures listed in the standard ranged from 15% for floors over unconditioned basements to 82% for windows. Overall, compliance with the prescriptive approach is only 5%—substantially lower than the 26% compliance with the performance approach (Table 3-10). In other words, only 5% of the sampled homes comply with all applicable prescriptive requirements. The difference between performance- and prescriptive-based compliance is not surprising, as the performance approach allows for trade-offs that the prescriptive approach does not. For example, if a home has ceiling insulation exceeding the prescriptive requirement of R-30, then the home is credited for that additional insulation through the modeling process in the performance approach. Under the prescriptive approach, the home simply meets one of the requirements and is given no additional credit, regardless of how much it exceeds the prescriptive requirement. If the same home failed to meet any other prescriptive requirement, it would not be considered weatherized. Appendix A shows the distribution of efficiency levels, in the form of histograms, for most of the measures with efficiency requirements in the weatherization standard.

Table 3-11 shows how measure-level prescriptive compliance would change if different efficiency requirements were incorporated into the weatherization standard. For each measure the Team looked at low and high efficiency requirements relative to what the current standard references. This information—together with additional information presented in later sections—may be valuable to the EEB if they decide to revise the standard requirements for any of the current components.

Table 3-10: Compliance with Prescriptive Weatherization Requirements

(Base: All homes)

Measure or Characteristic	Requirement	Primary Heating Fuel: Oil & Other Fuels	Primary Heating Fuel: Natural Gas	Primary Heating Fuel: Electricity	Household Income: Low Income	Household Income: Non-Low Income	Statewide (Weighted)
*n**		*118*	*46*	*16*	*34*	*146*	*180*
Above Grade Walls (conditioned/ambient)	R-11	53%	54%	50%	41%	56%	53%
Flat Ceilings	R-30	35%	32%	47%	19%[d]	39%[d]	34%
Cathedral Ceilings	R-19	66%[a]	44%[a,b]	86%[b]	56%	64%	62%
Floors Over Unconditioned Basements & Crawlspaces (conditioned/unconditioned basement)	R-13	17%[a,c]	3%[a,b]	50%[b,c]	5%[d]	18%[d]	15%
Walls in Conditioned Basements & Crawlspaces	R-5[1]	41%	55%	67%	63%	43%	48%
Slab on Grade[2]	R-5[3]	DK	DK	DK	DK	DK	DK
Windows	U-0.50[4]	83%	74%[b]	94%[b]	79%	82%	82%
Air Leakage[5]	9 ACH50	39%	35%	56%	29%	42%	39%
Duct Leakage to the Outside	16 CFM25/100 sq. ft.	63%	50%	25%	22%[d]	63%[d]	54%
Duct Insulation: Unconditioned Basements	R-2	55%[a,c]	29%[a,b]	100%[b,c]	36%	51%	47%
Duct Insulation: Unconditioned Attics & Crawlspaces	R-4.2	90%[a]	59%[a]	75%	100%[d]	80%[d]	81%
Overall[6]	--	6%	2%	6%	3%	5%	5%

[*] These are maximum sample sizes as not every characteristic is present in each home.

[1] Interior walls must be fully insulated.

[2] Inspectors were unable to verify the presence, type, and R-value of slab insulation for all homes with on-grade slabs.

[3] Insulated to four feet below grade. Insulation is assumed to be the proper depth if present.

[4] Alternatively any double pane window or single pane with a storm window is considered compliant.

[5] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.

[6] Includes compliance with all applicable wall and floor locations (e.g., conditioned/garage walls, conditioned/ambient frame floors, etc.).

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

Table 3-11: Prescriptive Compliance Under Difference Scenarios
(Base: All homes)

Measure or Characteristic	Requirement*	n	Statewide (Weighted)
Above Grade Walls (conditioned/ambient)	R-5	180	81%
	R-11		53%
	R-13		24%
Flat Ceilings	R-19	174	63%
	R-30		34%
	R-38		13%
Cathedral Ceilings	R-11	107	78%
	R-19		62%
	R-30		20%
Floors Over Unconditioned Basements & Crawlspaces	R-11	120	23%
	R-13		15%
	R-19		11%
Walls in Conditioned Basements & Crawlspaces[1]	R-2.5	97	55%
	R-5		48%
	R-11		29%
Windows	Single-Pane or Better	180	100%
	U-0.50[2]		82%
	Double-Pane or Better		65%
Air Leakage[3]	12 ACH50	180	67%
	9 ACH50		39%
	7 ACH50		19%
Duct Leakage to the Outside	22 CFM25/100 sq. ft.	73	74%
	16 CFM25/100 sq. ft.		54%
	7 CFM25/100 sq. ft.		22%
Duct Insulation: Unconditioned Basements	Uninsulated	47	100%
	R-2		47%
	R-4.2		27%
Duct Insulation: Unconditioned Attics & Crawlspaces	R-2	63	91%
	R-4.2		81%
	R-6		5%

*Gray shaded cells represent the current weatherization standard requirements and associated compliance levels.

[1] Interior walls must be fully insulated.

[2] Alternatively any double pane window or single pane with a storm window is considered compliant.

[3] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.

3.3 Comparing Performance and Prescriptive Compliance Results

Table 3-12 displays the prescriptive measure-level compliance for homes that meet and do not meet the performance-based weatherization standard. As shown, homes that meet or exceed the weatherization standard using the performance path are significantly more likely than non-compliant homes to meet the measure level prescriptive requirements for the following measures: all above-grade wall locations, flat ceilings, vaulted ceilings, all frame floor locations (except conditioned to ambient floors), conditioned foundation walls, windows, air leakage, and duct insulation in unconditioned basements.

A few measures exhibit substantial declines in average efficiency when comparing compliant homes to non-compliant homes. These measures include conditioned to ambient wall insulation (R-15.1 vs. R-7.6, respectively)[50], flat ceiling insulation (R-32.5 vs. R-17.2, respectively), conditioned to unconditioned basement frame floor insulation (R-9.9[51] vs. R-2.6, respectively), conditioned to garage frame floor insulation (R-22.4 vs. R-13.2, respectively), air leakage (6.6 ACH50 vs. 13.2 ACH50, respectively), and duct leakage to the outside (13.7 CFM25/100 sq. ft. vs. 19.8 CFM25/100 sq. ft., respectively). All of these differences are significant at the 90% confidence level. Three measures—air leakage, flat ceiling insulation, and conditioned to ambient wall insulation—appear to present the largest opportunities in non-compliant homes; this is due to the fact that these measures are found in nearly all homes (it is possible for a home to have no flat ceiling insulation, but very rare) and, as mentioned above, have significantly lower average efficiency levels than in compliant homes.

Table 3-13 shows prescriptive measure-level compliance and statistics of all performance-based non-compliant homes broken down by primary heating fuel. In general, prescriptive measure-level compliance and average efficiency values do not vary much by fuel type among non-compliant homes.

Table 3-14 shows prescriptive measure-level compliance and statistics of all performance-based non-compliant homes broken down by household income. Non-compliant low-income households (15.2 ACH50) have significantly higher air leakage levels than non-low-income households (12.2 ACH50), though compliance with the prescriptive weatherization requirement

[50] This is largely a function of cavity size. Seventy percent of homes with 2x6 wall framing comply with the overall weatherization standard, while only 18% of homes with 2x4 wall framing comply with the standard. Newer homes are more likely to comply with the standard and are more likely to have 2x6 wall framing. As a result, homes that comply with the standard have significantly more wall insulation than homes that do not.

[51] Even in complying homes the average conditioned to unconditioned basement frame floor insulation R-value is below the current weatherization standard requirement of R-13. Connecticut's New Construction Baseline Study, which was finalized in 2012 shows that new homes in Connecticut have an average conditioned to unconditioned basement insulation R-value of R-20.5, well above the current standard requirement. This suggests that conditioned to unconditioned basement insulation is more of an issue in older homes, which dominated the weatherization baseline sample. The baseline study can be found here: http://energizect.com/sites/default/files/ConnecticutNewResidentialConstructionBaseline-10-1-12_0.pdf

is not significantly different. In addition, non-compliant low-income households (25%) have significantly lower compliance with the prescriptive duct leakage requirement than non-low-income households (60%), though the average duct leakage to the outside is not significantly different between the two samples.

Table 3-12: Prescriptive Compliance and Efficiencies by Performance-Based Compliance Results*

(Base: All Homes)

Measure or Characteristic	Requirement (and Units)	Statewide Weighted: Homes Meet or Exceed Performance Wx Standard: *n*	% Prescriptive Compliance	Average Value	Homes Below Performance Wx Standard: *n*	% Prescriptive Compliance	Average Value
Conditioned to Ambient Walls	R-11	*48*	96%[a]	15.1[b]	*132*	42%[a]	7.6[b]
Conditioned to Garage Walls	R-11	*40*	92%[a]	13.5[b]	*80*	61%[a]	8.4[b]
Conditioned to Attic Walls	R-11	*27*	85%[a]	12.7[b]	*74*	49%[a]	7.8[b]
Conditioned to UC Basement Walls	R-11	*30*	43%[a]	6.5[b]	*81*	19%[a]	2.5[b]
Flat Ceilings	R-30	*45*	75%[a]	32.5[b]	*129*	21%[a]	17.2[b]
Vaulted Ceilings	R-19	*27*	96%[a]	26.0[b]	*80*	51%[a]	15.4[b]
Conditioned to UC Basement Frame Floor	R-13	*31*	31%[a]	9.9[b]	*89*	10%[a]	2.6[b]
Conditioned to Garage Frame Floor	R-13	*29*	89%[a]	22.4[b]	*43*	59%[a]	13.2[b]
Conditioned to Ambient Frame Floor	R-13	*22*	62%	16.6[b]	*54*	52%	11.5[b]
Conditioned to Enclosed Crawl Frame Floor	R-13	*2*	100%[a]	29.0[b]	*23*	26%[a]	9.1[b]
Walls in Conditioned Basements & Crawlspaces	R-5[1]	*29*	71%[a]	8.3[b]	*68*	40%[a]	4.1[b]
Windows	U-0.50[2]	*48*	93%[a]	DK**	*132*	78%[a]	DK**
Air Leakage[3]	9 ACH50	*48*	96%[a]	6.6[b]	*132*	19%[a]	13.2[b]
Duct Leakage to the Outside	16 CFM25/100 sq. ft.	*20*	63%	13.7[b]	*53*	51%	19.8[b]
Duct Insulation: Unconditioned Basements	R-2	*16*	71%[a]	3.8[b]	*31*	38%[a]	1.8[b]
Duct Insulation: Unconditioned Attics & Crawlspaces	R-4.2	*19*	89%	4.8	*44*	77%	4.4

[1] Interior walls must be fully insulated.

[2] Alternatively any double pane window or single pane with a storm window is considered compliant.

[3] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.

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

*Slab on grade is a prescriptive requirement, but is not presented here because inspectors were unable to verify the presence, type, and R-value of slab insulation for all homes with on-grade slabs.

**Auditors were unable to determine the U-value of windows in the majority of the inspected homes.

Table 3-13: Prescriptive Compliance and Statistics for Performance-Based Non-Compliant Homes by Primary Heating Fuel*

(Base: All Performance-Based Non-Compliant Homes)

Measure or Characteristic	Requirement (and Units)	Oil & Other Fuels			Natural Gas			Electricity		
		n	% Prescriptive Compliance	Average Value	*n*	% Prescriptive Compliance	Average Value	*n*	% Prescriptive Compliance	Average Value
Conditioned to Ambient Walls	R-11	*88*	42%	7.8	*36*	44%	7.0	*8*	38%	7.8
Conditioned to Garage Walls		*56*	59%	8.3	*18*	72%	9.4	*6*	50%	8.7
Conditioned to Attic Walls		*48*	52%	8.4	*22*	41%	6.5	*4*	50%	8.0
Conditioned to UC Basement Walls		*54*	22%	2.8	*24*	13%	1.6	*3*	33%	5.7
Flat Ceilings	R-30	*86*	22%	17.3[e]	*35*	17%	15.1[f]	*8*	25%	25.3[e,f]
Vaulted Ceilings	R-19	*56*	55%[a]	16.5[d]	*19*	32%[a,c]	11.5[d,f]	*5*	80%[c]	18.1[f]
Conditioned to UC Basement Frame Floor	R-13	*60*	12%[a]	2.7[d,e]	*25*	0%[a,c]	0.8[d,f]	*4*	50%[c]	15.6[e,f]
Conditioned to Garage Frame Floor		*29*	55%	12.2[e]	*9*	67%	13.5	*5*	80%	17.4[e]
Conditioned to Ambient Frame Floor		*36*	56%	12.7	*12*	42%	7.9	*6*	50%	11.6
Conditioned to Enclosed Crawl Frame Floor		*14*	29%	9.6	*7*	29%	8.6	*2*	50%	15.0
Walls in Conditioned Basements & Crawlspaces	R-5[1]	*49*	33%	3.6	*15*	53%	5.8	*4*	50%	3.2
Windows	U-0.50[2]	*88*	81%	DK**	*36*	67%	DK**	*8*	88%	DK**
Air Leakage[3]	9 ACH50	*88*	20%	13.2	*36*	17%	12.6	*8*	13%	12.6
Duct Leakage to the Outside	16 CFM25/100 sq. ft.	*36*	58%[b]	16.2	*15*	53%[c]	24.6	*2*	0%[b,c]	42.7
Duct Insulation: Unconditioned Basement	R-2	*20*	45%	2.2	*10*	20%	1.0[f]	*1*	100%	2.9[f]
Duct Insulation: Unconditioned Attics & Crawlspaces	R-4.2	*31*	90%[a,b]	4.6[d,e]	*11*	36%[a,c]	3.5[d,f]	*2*	100%[b,c]	5.5[e,f]

[1] Interior walls must be fully insulated.

[2] Alternatively any double pane window or single pane with a storm window is considered compliant.

[3] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.

[a,b,c,d,e,f] Statistically significant difference at the 90% confidence level.

*Slab on grade is a prescriptive requirement, but is not presented here because inspectors were unable to verify the insulation characteristics for most slabs.

**Auditors were unable to determine the U-value of windows in the majority of the inspected homes.

Table 3-14: Prescriptive Compliance and Statistics for Performance-Based Non-Compliant Homes by Household Income*

(Base: All Performance-Based Non-Compliant Homes)

Measure or Characteristic	Requirement	Low Income			Non-Low Income		
		n	% Prescriptive Compliance	Average Value	*n*	% Prescriptive Compliance	Average Value
Conditioned to Ambient Walls	R-11	*29*	38%	6.8	*103*	44%	7.8
Conditioned to Garage Walls		*13*	54%	6.9	*67*	63%	8.9
Conditioned to Attic Walls		*17*	47%	7.3	*57*	49%	7.9
Conditioned to UC Basement Walls		*14*	14%	1.6	*67*	21%	2.8
Flat Ceilings	R-30	*28*	14%	17.3	*101*	23%	17.2
Vaulted Ceilings	R-19	*17*	53%	16.2	*63*	51%	15.2
Conditioned to UC Basement Frame Floor	R-13	*17*	6%	1.1[b]	*72*	11%	3.2[b]
Conditioned to Garage Frame Floor		*6*	50%	13.2	*37*	62%	13.1
Conditioned to Ambient Frame Floor		*10*	40%	9.0	*44*	55%	12.1
Conditioned to Enclosed Crawl Frame Floor		*4*	0%[a]	4.4	*19*	37%[a]	10.9
Foundation Walls in Conditioned Basements & Crawlspaces	R-5[1]	*13*	54%	5.1	*55*	35%	3.8
Windows	U-0.50[2]	*29*	79%	DK**	*103*	77%	DK**
Air Leakage[3]	9 ACH50	*29*	17%	15.8[b]	*103*	19%	12.2[b]
Duct Leakage to the Outside	16 CFM25/100 sq. ft.	*8*	25%[a]	22.5	*45*	60%[a]	19.0
Duct Insulation: Unconditioned Basement	R-2	*6*	33%	1.5	*25*	40%	1.9
Duct Insulation: Unconditioned Attics & Crawlspaces	R-4.2	*2*	100%[a]	4.9	*42*	76%[a]	4.4

[1] Interior walls must be fully insulated.

[2] Alternatively any double pane window or single pane with a storm window is considered compliant.

[3] Compliance results include estimated air leakage levels at 24 sites where blower door tests were not conducted.

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

*Slab on grade is a prescriptive requirement, but is not presented here because inspectors were unable to verify the presence, type, and R-value of slab insulation for all homes with on-grade slabs.

**Auditors were unable to determine the U-value of windows in the majority of the inspected homes.

3.4 As-Built vs. Weatherized Energy Loads, Consumption, and Cost

Table 3-16 displays average measure-level energy loads and associated costs for the "as-built" and corresponding "weatherized" energy models.[52] As-built loads reflects the energy loads (in MMBtu) of the modeled homes as they were found during the site visits—accounting for all of the efficiency levels identified during the site visits. Weatherized loads reflect the same homes modeled to the prescriptive weatherization standard requirements listed in Table 3-1. As shown, as-built models display significantly higher heating-season energy loads than the weatherized models for almost all of the critical shell measures addressed by the current weatherization standard. These measures include roofs (accounting for both flat and cathedral ceilings), above grade walls, foundation walls, frame floors over unconditioned basements or crawlspaces, air infiltration, and ducts (accounting for both duct insulation and duct leakage). Interestingly, the weatherized models actually show significantly higher cooling season energy loads than the as-built models. This happens for two reasons: 1) the as-built models actually have more efficient windows than the weatherized models and windows have a significant impact on cooling-season energy loads in the models, and 2) REM/Rate is a seasonal calculation tool which sometimes estimates average outdoor temperatures below the set point of the building in the cooling season; in these cases some components, particularly those with low efficiencies (e.g., low insulation levels, high air leakage) will actually reduce the cooling load.[53]

The rates used to estimate energy costs for as-built and weatherized homes are outlined in Table 3-15.[54]

Table 3-15: Fuel Rates Used for REM/Rate Models

Fuel	Rate
Electricity	$.172/kWh
Natural Gas	$13.83/MCF
Propane	$3.46/Gallon
Fuel Oil	$4.16/Gallon
Wood	$230/Cord

[52] Unfortunately, REM/Rate does not export data on measure-level energy consumption, which is different than the measure-level energy loads (though they are similar).
[53] Rob Salcido (Architectural Energy Corporation), email message to author, December 3, 2013.
[54] Rate information was predominantly taken from 2011 and 2012 published by the Energy Information Administration.

Table 3-16: As-Built vs. Weatherized Average Measure-Level Energy Loads (MMBtu) and Associated Costs ($)

(Base: All homes)

Measure or Characteristic	Season Type	Statewide Weighted				
		n	As-Built		Weatherized	
			MMBtu	Costs ($)	MMBtu	Costs ($)
Roofs	Heating Season	180	14.8[a]	388.1[b]	9.6[a]	257.1[b]
	Cooling Season	147	0.8[a]	40.0[b]	0.5[a]	27.2[b]
Above Grade Walls	Heating Season	180	24.0[a]	633.5[b]	19.8[a]	535.0[b]
	Cooling Season	147	-0.3[a]	-13.4	-0.2[a]	-11.4
Foundation Walls	Heating Season	101	11.3[a]	311.3[b]	7.4[a]	211.0[b]
	Cooling Season	84	-1.5[a]	-76.0[b]	-1.0[a]	-50.6[b]
Windows	Heating Season	180	9.5[a]	257.3	10.8[a]	291.7
	Cooling Season	147	12.4[a]	624.9[b]	13.8[a]	695.0[b]
Frame Floors Over Garage or Ambient Conditions	Heating Season	102	4.1	116.6	3.5	101.0
	Cooling Season	88	-0.5	-26.6	-0.4	-22.2
Frame Floors Over Unconditioned Basement or Crawlspace	Heating Season	128	11.0[a]	273.0[b]	6.7[a]	171.8[b]
	Cooling Season	102	-1.9[a]	-96.0[b]	-1.1[a]	-55.9[b]
Slabs	Heating Season	120	7.3[a]	206.0[b]	4.6[a]	130.5[b]
	Cooling Season	101	-1.5[a]	-76.0[b]	-1.2[a]	-58.2[b]
Air Infiltration	Heating Season	180	31.4[a]	840.6[b]	27.5[a]	738.3[b]
	Cooling Season	147	-2.0	-100.7	-2.1	-104.1
Ducts	Heating Season	68	24.2[a]	617.6[b]	18.4[a]	472.8[b]
	Cooling Season	77	4.4	219.3	4.5	228.5
*Total**	*Heating Season*	*180*	*98.3*[a]	*2,600.5*[b]	*77.6*[a]	*2,085.2*[b]
	Cooling Season	*147*	*17.0*[a]	*853.3*[b]	*18.7*[a]	*941.0*[b]

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

*Total loads are greater than the sum of individual components as not all homes had each component and not all components are included in this table.

Table 3-17 displays as-built and weatherized end-use energy costs and consumption. The energy data presented here is in fact consumption, not design loads as presented in the previous table. For this reason the heating and cooling costs in Table 3-17 do not align perfectly with those in Table 3-16. As-built models show significantly higher heating, cooling, and overall energy costs when compared to weatherized models. Water heating and lights and appliances end uses are nearly identical between the models. This is expected as the current weatherization standard does not address either of these end uses. Overall, the models show that as-built homes have average annual energy costs of $5,118 compared to $4,504 for the weatherized homes (a 12% decrease in annual energy costs). As-built homes have an average energy consumption, for heating and cooling end uses, of 125.7 MMBtu and average costs of $3,393, while weatherized homes have an average energy consumption of 100.4 MMBtu and costs of $2,784. These differences result in a 20% decrease for energy consumption and an 18% decrease for energy costs when comparing weatherized homes to as-built homes.

Table 3-17: As-Built vs. Weatherized End Use Energy Consumption (MMBtu) and Costs ($)*

(Base: All homes)

End Use	Statewide Weighted				
	n	As-Built		Weatherized	
		MMBtu	Costs ($)	MMBtu	Costs ($)
Heating	180	120.1[a]	$3,113[b]	94.3[a]	$2,475[b]
Cooling	147	5.6[a]	$280[b]	6.1[a]	$309[b]
Water Heating	180	19.3	$568	19.3	$569
Lights and Appliances	180	25.4	$1,241	25.4	$1,241
*Total**	*180*	*168.6*[a]	*$5,118*[b]	*143.3*[a]	*$4,504*[b]

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

*Total cost is not equal to the sum of the end uses as not all homes had each end use and not all end uses (i.e., photovoltaics) are included in the table.

Additional tables detailing as-built vs. weatherized energy loads, energy consumption, and energy costs by primary heating fuel type and income status can be found in Appendix C.

3.5 HERS Ratings by Compliance with Weatherization Standard

Table 3-18 presents the average Home Energy Rating System (HERS) ratings by various categories and shows the associated performance-based compliance within those groups. HERS Ratings are produced by the REM/Rate software and provide a metric for assessing overall building performance. Note, this information is only meant to provide a comparison between HERS ratings and performance-based compliance. HERS scores had no impact on the weatherization status of a given home.

The HERS Index compares homes to the 2004 International Energy Conservation Code (IECC) with some modifications reflecting the 2006 IECC.[55,56] Scores can range from less than zero to well over 100. A score of 100 indicates that a home was built to the specifications of the 2004 IECC (with 2006 IECC modifications), while a score of zero indicates a net zero energy home. According to the Residential Energy Services Network (RESNET), "Each 1-point decrease in the HERS Index corresponds to a 1% reduction in energy consumption compared to the HERS Reference Home."[57]

Among the homes in the sample, those heated by oil and other fuels have a lower average HERS rating (115.9) compared to homes heated by natural gas (123.0) and homes heated by electricity (123.3)(Table 3-18). The overall average HERS rating, across all homes, was 118.6. As shown, electrically heated homes have the highest compliance rate, but do not have the lowest (best) HERS ratings. The primary reason for this is that the HERS reference home compares electric resistance heat (which the majority of electrically heated homes in the sample had) to a heat pump.[58] As a result, electrically heated homes generally have higher HERS ratings than homes heated by other fuels with similar characteristics.

Table 3-18: HERS Ratings and Performance-Based Compliance

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Average HERS Rating	116	123	123	125	117	119
Homes Meet or Exceed Wx Standard	25%[a]	22%[b]	50%[a,b]	15%[c]	29%[c]	26%
Homes Below Wx Standard	75%[a]	78%[b]	50%[a,b]	85%[c]	71%[c]	74%

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

[55] There is conflicting information regarding the HERS Reference Home. Some sources state the reference home is based on the 2006 IECC, while others state it is based on the 2004 IECC. The evaluators confirmed that the reference home is based on the 2004 IECC through communications with Architectural Energy, the developers of REM/Rate.

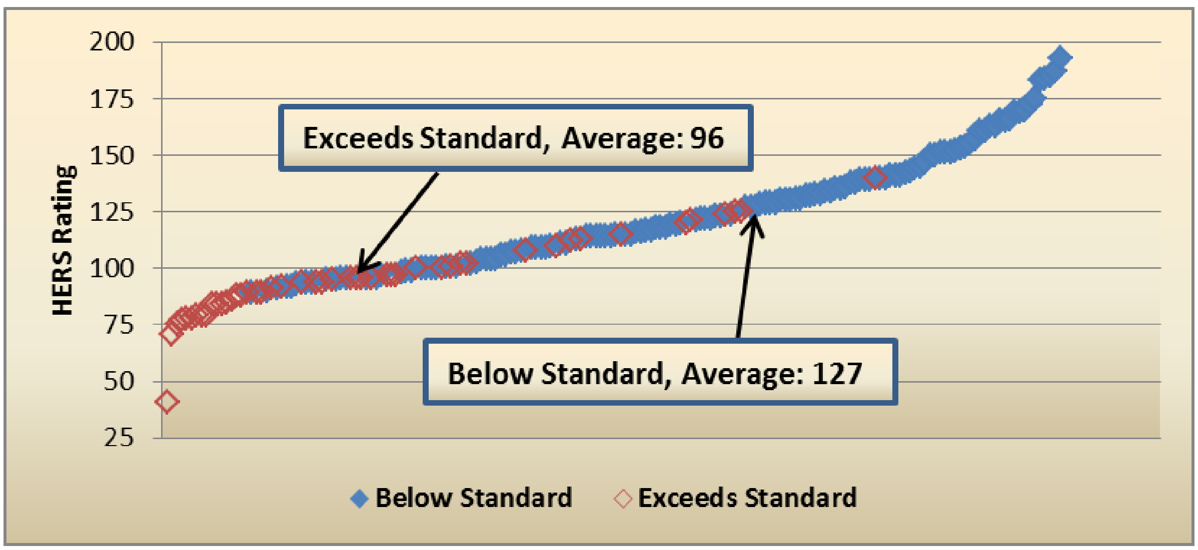
[56] Brian Christensen (Architectural Energy Corporation), email message to author, May 15, 2012.

[57] http://www.resnet.us/professional/rater/what-is-a-hers

[58] Residential Energy Services Network, "Mortgage Industry National Home Energy Rating System Standards", Submitted to RESNET Board of Directors, January 1, 2013.

Figure 3-4 graphs the HERS ratings of all 180 homes. The blue diamonds are homes that fall below the weatherization standard, while the red diamonds are homes that meet or exceed the weatherization standard. Most of the homes with the lowest HERS indices do indeed meet or exceed the standard. That said, there are a number of homes with low HERS indices that do not meet or exceed the standard, and there are a number of homes with higher HERS indices that do meet or exceed the standard. This figure illustrates the fact that the weatherization standard, as currently defined, is not directly correlated with overall home performance (the standard does correlate with thermal performance, as shown in Section 3.4). There are a number of reasons for this, but the most obvious is that the weatherization standard does not currently account for the efficiency of mechanical equipment. Mechanical equipment efficiencies are major drivers of overall home performance, and that is likely the primary reason that some less efficient homes are compliant with the standard and some more efficient homes are not. Other drivers of overall home performance that are not included in the weatherization standard are lighting, appliances, and renewable energy.

Figure 3-4: HERS Ratings by Performance-Based Compliance*
(Base: All homes)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

4 General Home Characteristics

This section presents information on the general characteristics of all 180 audited homes. Note that the information presented in this section was verified onsite and may differ from the self-reported results of the telephone survey (see Appendix I for details on the telephone survey results). A comparison of the information verified onsite and the self-reported telephone survey results can be found in Appendix J.

Table 4-1 displays the most common result for key general home characteristics presented in this section; the characteristics listed in this table are not directly related. For example, the average conditioned floor area of 2,484 sq. ft. for homes heated by oil and other fuels is the average conditioned floor area across all homes heated by these fuels, not just homes built between 1940 and 1959.

Table 4-1: Summary of General Home Characteristics

Characteristics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
House Type: Single-family detached	97%[a]	83%[a]	88%	82%[b]	95%[b]	93%
# of Stories: Two stories	73%[a]	61%	50%[a]	59%	70%	67%
# of Bedrooms: Three bedrooms	51%	41%	63%	26%[c]	55%[c]	48%
Year Built: 1940-1959*	13%	17%	31%	41%[b]	22%[b]	27%
Home Size: Average conditioned floor area	2,484	2,241	2,089	1,773	2,529	2,364
Foundation Type: More than one type**	48%	43%	25%	24%	50%	44%
Type of Thermostat: Manual	46%[a]	41%[b]	75%[a,b]	50%	47%	47%

*Homes built from 1960-1979 also represent 27% of the overall sample.

**Homes that had two or more foundation types were recorded as *More than one type*.

Statewide, 93% of the audited homes are single-family detached homes (Table 4-2). Among the homes visited, low-income homes (18%) are significantly more likely than non-low-income homes (5%) to be single-family attached homes. Homes heated primarily by natural gas (17%) are significantly more likely than homes primarily heated by oil and other fuels (3%) to be single-family attached homes.

Table 4-2: Types of Homes

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Single-family detached	97%[a]	83%[a]	88%	82%[b]	95%[b]	93%
Single-family attached	3%[a]	17%[a]	13%	18%[b]	5%[b]	7%

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

Figure 4-1 provides a few examples of the types of homes that were visited as part of this study.

Figure 4-1: Examples of Homes Visited

Statewide, about two-thirds of the inspected homes (67%) are two stories in height (Table 4-3).

Table 4-3: Number of Stories per Home

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
One story	17%	20%	13%	26%	15%	18%
Two Stories	73%[a]	61%	50%[a]	59%	70%	67%
Three or more	10%[a]	20%	38%[a]	15%	15%	14%

[a] Statistically significant difference at the 90% confidence level.

Statewide, about one-half of all homes (48%) have three bedrooms and about one-third (36%) have four or more bedrooms (Table 4-4).

Table 4-4: Number of Bedrooms per Home

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
One	2%	0%	0%	3%	1%	1%
Two	7%[a]	26%[a]	19%	41%[c]	6%[c]	14%
Three	51%	41%	63%	26%[c]	55%[c]	48%
Four	30%[b]	26%	13%[b]	18%	29%	27%
Five or more	11%	7%	6%	12%	9%	9%

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

Table 4-5 displays the age of homes that were visited as part of the study. The period between 1960-1979 was a particularly busy time for home-building, accounting for just over half (56%) of homes that heat with oil and other fuels and one-quarter of homes that heat with natural gas (24%) or electricity (25%). Homes that heat with electricity are, on average, younger than homes that heat with natural gas or other fuel types, which may be one of the contributing factors to higher compliance with the standard for electrically heated homes.

Table 4-5: When Home was Built

(Base: All homes)

	Oil &Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	Statewide (Weighted)
n	*118*	*46*	*16*	*34*	*146*	*180*
1939 or earlier	6%[a]	26%[a]	14%	15%	16%	16%
1940-1959	13%	17%	31%	41%[b]	22%[b]	27%
1960-1979	56%[ac]	24%[a]	25%[c]	35%	25%	27%
1980-1989	25%[a]	13%[a]	13%	6%[b]	16%[b]	13%
1990-1999	0%[a]	7%[a]	10%	0%[b]	10%[b]	8%
2000 or later	0%[a]	13%[a]	8%	3%[b]	10%[b]	9%
Average Age (years)	52	57[d]	44[d]	58	51	48
Median Age (years)	49	46	40	54	44	53

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

Among all of the homes visited, the average conditioned floor area (CFA) is 2,364 square feet and the median is 2,211 square feet (Table 4-6). Non-low-income homes have an average CFA that is 1.4 times larger than that of low-income homes. Comparing average CFA by fuel type, homes that primarily heat with oil and other fuels (2,484 sq. ft.) are larger than those that heat primarily with natural gas (2,241 sq. ft.) or electricity (2,089 sq. ft.).

Table 4-6: Square Feet of Conditioned Area

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Minimum	630	776	1,208	630	776	630
Maximum	7,362	4,897	4,019	3,704	7,362	7,362
Average	2,484	2,241	2,089	1,773	2,529	2,364
Median	2,340	1,941	1,783	1,607	2,437	2,211

Table 4-7 displays the percentage of homes by basement type. Statewide, the most common basement types are more than one type[59] (44%), unconditioned basements (29%), and conditioned basements (20%).[60] When comparing household income, basements found in low-income homes are significantly more likely to be unconditioned (44%) than basements in non-low-income homes (25%).

Table 4-7: Basement Type

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Conditioned basement	19%	15%[a]	38%[a]	26%	18%	20%
Conditioned crawl space	1%	0%	0%	0%	1%	1%
Enclosed crawl space	2%	2%	0%	3%	1%	2%
More than one type*	48%	43%	25%	24%	50%	44%
Slab on-grade	4%	7%	6%	3%	5%	5%
Unconditioned basement	26%	33%	31%	44%[b]	25%[b]	29%

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

* Homes that had two or more foundation types were recorded as *More than one type*.

[59] Homes with two or more foundation types (e.g., conditioned and unconditioned basement, slab on grade and enclosed crawl space, etc.) were recorded as *More than one type*.

[60] As mentioned in the Summary of Terms section, basements were defined using RESNET's definition of conditioned space.

Table 4-8 displays the type and number of thermostats found in inspected homes. Homes that heat primarily with electricity are significantly more likely to have manual thermostats (75%) than homes that heat primarily with natural gas (41%) or other fuel types (46%). Conversely, homes that heat primarily with natural gas (57%) are more likely to have programmable thermostats than homes that heat primarily with electricity (25%) or other fuel types (41%). Weighted results show that two-thirds of homes (65%) have either one or two thermostats. Homes that heat with electricity are more likely to have four or more thermostats (67%) than homes that heat with natural gas (7%) or oil and other fuels (11%) because each baseboard is controlled by an individual thermostat. One home had zero thermostats because it heated with a pellet stove.

Table 4-8: Number of Thermostats

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Type of Thermostat						
Manual	46%[a]	41%[b]	75%[a,b]	50%	47%	47%
Programmable	41%[c]	57%[c,b]	25%[b]	44%	43%	43%
Both	13%[a,c]	2%[c]	0%[a]	3%	10%	9%
None	1%	0%	0%	3%	0%	1%
Number of Thermostats						
Zero*	1%	0%	0%	3%	0%	>1%
One	28%[ac]	46%[c,b]	6%[a,b]	53%[d]	25%[d]	32%
Two	36%	30%	19%	21%[d]	36%[d]	33%
Three	24%[a]	17%	6%[a]	15%	22%	21%
Four or more	11%[a]	7%[b]	[b]	9%	16%	14%

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

*Home heats with a pellet stove and as a result does not have a thermostat.

Room air conditioners are present in just over four out of ten homes (41%) statewide (Table 4-9). Onsite visits were conducted between September, 2012 and January, 2013, which led to room air conditioners being installed for only a fraction of the site visits. That said, at all sites auditors asked homeowners if they had room air conditioners and inspected them even if they were not installed at the time of the visit. Homes that heat with natural gas are the least likely to have room air conditioners (33%) compared to homes that primarily heat with electricity (50%) or other fuel types (42%). Room air conditioners are significantly more common in low-income (56%) than in non-low-income (37%) homes. One reason for this, as shown in the Cooling Systems section of this report (Table 6-13), is that non-low-income homes are significantly more likely than low-income homes to have central air conditioning systems.

Table 4-9: Room Air Conditioners

(Base: All homes)

RAC Present	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Present	42%	33%	50%	56%[a]	37%[a]	41%
Not Present	58%	67%	50%	44%[a]	63%[a]	59%

[a] Statistically significant difference at a 90% confidence level.

Before conducting any diagnostic tests, auditors inspected homes for the presence of asbestos and vermiculite[61]. These are extremely hazardous substances when airborne, so auditors did not conduct diagnostic tests if either was present during the site visits. Just under one out of every ten homes audited (9%) contained asbestos or vermiculite (Table 4-10). Homes that heated with natural gas (7%) were the least likely to contain asbestos or vermiculite when compared to homes that heat with oil and other fuels (9%) or electricity (13%).

Table 4-10: Presence of Asbestos or Vermiculite

(Base: All homes)

Asbestos or Vermiculite Present	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Yes	9%	7%	13%	9%	9%	9%
No	91%	93%	88%	91%	91%	91%

[61] The Team also inspected homes for the presence of mold. The Team did not try to determine the cause of mold, and instead only documented its presence.

The majority of the fireplaces (88%) in inspected homes burned wood as opposed to natural gas (6%) or propane (6%) (Table 4-11). Similarly, the majority of stoves were heated by either wood (71%) or pellets (26%). Finally, of all the space heaters (both portable and permanently-installed) identified during the site visits, 95% were electric resistance space heaters and 5% were fueled by propane. As was the case with room air conditioners, auditors asked homeowners at all site visits if they had space heaters and recorded information on space heaters regardless of whether or not they were in use during the site visits.

Table 4-11: Fuel source for Fireplace, Stove, and Space Heater

(Base: All fireplaces, stoves, and space heaters)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Fireplace—n	*85*	*37*	*13*	*12*	*123*	*135*
Wood	91%	76%	100%	92%	87%	88%
Natural Gas	0%	24%	0%	0%	7%	6%
Propane	9%	0%	0%	8%	6%	6%
Stove—n	*33*	*3*	*4*	*8*	*32*	*41*
Wood	79%	1 (33%)	2 (50%)	4 (50%)	78%	71%
Pellet	21%	2 (67%)	1 (25%)	4 (50%)	19%	26%
Propane	--	--	1 (25%)	--	1%	2%
Space Heater—n	*21*	*12*	*8*	*10*	*31*	*40*
Electric	95%	100%	7 (88%)	9 (90%)	97%	95%
Propane	5%	--	1 (13%)	1 (10%)	3%	5%

5 Building Envelope

This section presents details on the building envelope of the audited homes. Note that throughout this section, unless otherwise specified, the units of analyses are homes in the sample (as opposed to the wall entries in the sample or window entries in the sample).

5.1 Calculating Average R-value

The average R-value for a given building shell component—e.g., conditioned to ambient walls or vaulted ceilings—was derived using the UA (U-value*area) equation. Unlike simply taking the mean of all R-values observed in a given house, the UA equation accounts for the surface areas of shell components insulated to different levels and in this way accounts for the fact that heat transfer follows the path of least resistance; therefore, the effective average R-value of an assembly is not simply an area-weighted average of nominal R-values. For example, a house with walls that are 75% R-19 and 25% R-11 would have an area-weighted average R-value of R-17. The same assembly using the UA approach would have R-12.3 walls, on average. This is standard practice in the building science industry when calculating average R-values. Auditors identified insulation installation grades for all insulation locations. Insulation installation grades do not factor into the average R-values reported in this section. Insulation installation grades were only used for modeling purposes when assessing compliance with the weatherization standard using the performance-based compliance approach (see Appendix F for details).

5.2 Above-Grade Walls

5.2.1 Conditioned to Ambient Walls

More than one-half of houses (53%) statewide have conditioned to ambient walls insulated to at least R-11, which is the weatherization standard for above-grade wall insulation (Table 5-1). There are no statistically significant differences in these R-values across fuel types. In contrast, these walls are significantly less insulated in low-income houses than they are in houses with non-low-income occupants (average R-7.6 vs. R-9.6, respectively).

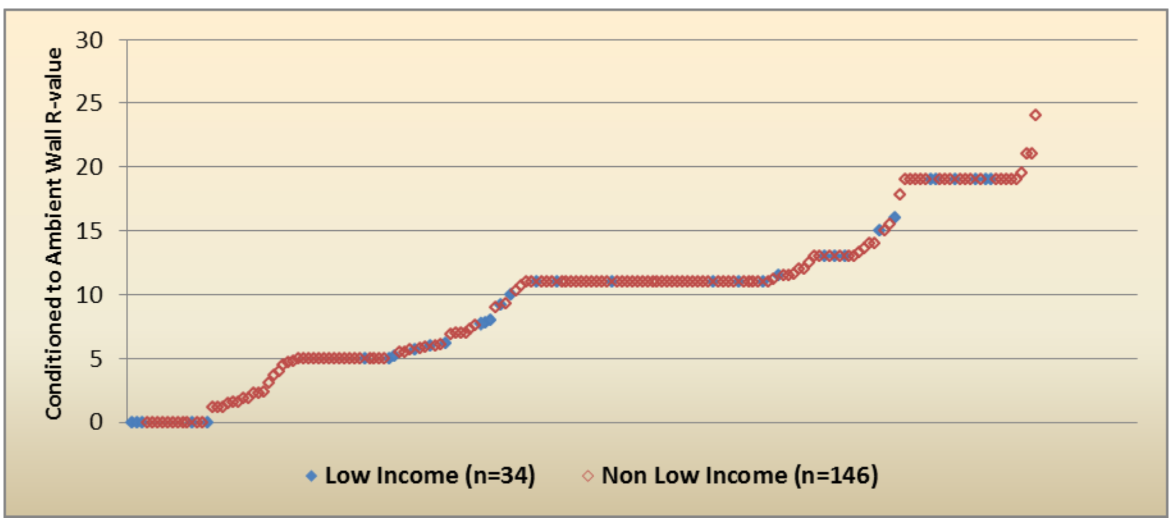
Table 5-1: Conditioned to Ambient Walls – R-value Statistics
(Base: All homes)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Min	0.0	0.0	5.0	0.0	0.0	0.0
Max	21.0	24.0	19.0	19.0	24.0	24.0
Average	9.8	9.1	9.9	7.6[a]	9.6[a]	9.5
Median	11.0	11.0	11.0	9.6	11.0	11.0
Compliance with Above Grade Wall Weatherization Standard (R-11)						
Homes Equal to or Exceeding Wx Standard	53%	54%	50%	41%	56%	53%
Homes Below Wx Standard	47%	46%	50%	59%	44%	47%

[a] Statistically significant difference at the 90% confidence level.

Figure 5-1 graphs average R-values in conditioned to ambient walls for all 180 homes inspected.

Figure 5-1: Conditioned to Ambient Wall R-value by Income Status*
(Base: All homes)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

Fiberglass is the predominant insulation type in conditioned to ambient walls. The fiberglass that was observed over the course of the onsite inspections, however, ranged significantly in age and quality. Low-income homes (71%) are statistically less likely to be insulated with fiberglass than non-low-income homes (86%). Conversely, houses heated with natural gas (67%) are statistically less likely to be insulated with fiberglass as well as statistically more likely to be uninsulated (20%) than are homes heated with oil and other fuels (88% fiberglass and 6%

uninsulated). Statewide, about one of ten homes (9%) have uninsulated conditioned to ambient walls (Table 5-2).

Table 5-2: Type of Cavity Insulation in Conditioned to Ambient Walls
(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Fiberglass batts or rock wool	88%[b]	67%[b]	94%	71%[a]	86%[a]	83%
Another material	2%	9%	6%	6%	3%	4%
Fiberglass batts and another material	4%	4%	0%	9%	3%	4%
Uninsulated	6%[b]	20%[b]	0%	15%	8%	9%

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

Over three-quarters of houses (76%) statewide have 2x4x16" framing in their conditioned to ambient walls, which was standard building practice from the early years of the 20th century until the mid-1990s. Another 6% have a combination of 2x4 and 2x6 framing. Homes heated with electricity are statistically more likely to have been built with 2x4 framing than homes using another fuel; similarly, homes heated with oil and other fuels are more likely to have a combination of framing types. Low-income homes are significantly less likely than non-low-income homes to have been built with 2x6 framing (Table 5-3).

Table 5-3: Conditioned to Ambient Walls – Framing Description*
(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
2 x 4 x 16" o.c.	75%[b]	74%[c]	94%[b,c]	79%	75%	76%
2 x 6 x 16" o.c.	15%	20%	6%	6%[a]	18%[a]	15%
2 x 4 & 2 x 6 x 16" o.c.	8%[d]	2%[d]	0%	6%	6%	6%
Another framing type	3%	4%	0%	9%	1%	3%

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

In a HERS rating, the quality of insulation installation is graded on a scale of I to III, with a grade of I representing a high quality installation without gaps or compression. Unlike insulation R-value, installation grade can be determined using infrared imaging. The auditors verified that 97% of homes have conditioned to ambient wall insulation graded either II or III (Table 5-4). In Table 5-4, and other tables detailing insulation grades, "verified" entries are entries where the insulation grade was confirmed via visual inspection or infrared imaging. The insulation grade was estimated for all other entries.

Table 5-4: Conditioned to Ambient Walls – Insulation Installation Grade & Verification
(Base: All homes with insulation in conditioned to ambient walls)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Verified entries only-n	*74*	*26*	*10*	*16*	*94*	*110*
Grade I only	3%	4%	0 (0%)	0%	3%	3%
Grade II only	54%	69%	7 (70%)	56%	60%	58%
Grades II & III	1%	0%	0 (0%)	0%	1%	1%
Grade III only	42%	27%	3 (30%)	44%	36%	38%
All entries-n	*110*	*37*	*16*	*28*	*135*	*163*
Grade I only	2%	3%	0%	0%	2%	2%
Grades I & II	3%	0%	0%	4%	2%	2%
Grade II only	52%[a]	65%	75%[a]	50%	59%	57%
Grades II & III	12%	5%	6%	7%	10%	10%
Grade III only	32%	27%	19%	39%	27%	30%

[a] Statistically significant difference at the 90% confidence level.

One way to increase the R-value of conditioned to ambient walls beyond what their framing can accommodate is to install rigid foam insulation on the exterior of the house underneath the siding. Statewide, about 8% of houses have this kind of insulation installed (Table 5-5).

Table 5-5: Type of Continuous Insulation* on Conditioned to Ambient Walls
(Base: All homes)

	Statewide (Weighted)
n	*180*
No continuous insulation	92%
Expanded polystyrene**	2%
Extruded polystyrene	4%
Polyisocyanurate	2%

*In three cases, this insulation is continuous on the interior, between the framing and drywall rather than under the siding. In the remaining cases, it is under the siding.
**In one case, the polystyrene is much thinner and less rigid than what one would normally associate with expanded polystyrene.

5.2.2 Other Wall Locations

Among all wall locations, conditioned to garage walls are insulated most consistently to the weatherization standard, with 69% of houses containing a wall between the living space and the garage having an R-value of 11 or greater (Table 5-6). Walls between living space and attic space, which are common on the second floors of Cape-style homes, are insulated to at least R-11 in fewer houses than are garage walls (57%), but they maintain a median R-value of R-11 statewide. Walls situated between conditioned space and unconditioned basements, however, are insulated only about a third of the time, and insulated to at least R-11 in fewer than one-quarter of homes (24%).

Table 5-6: Other Wall Locations—R-value Statistics

(Base: All homes with applicable wall locations)

Statistics	Statewide Weighted		
	Conditioned to Attic	**Conditioned to Garage**	**Conditioned to U.C. Basement***
n	*101*	*120*	*111*
Min	0.0	0.0	0.0
Max	30.0	19.5	19.0
Average	9.0	10.1	3.5
Median	11.0	11.0	0.0
Compliance with Above Grade Wall Weatherization Standard (R-11)			
Homes Equal to or Exceeding Wx Standard	57%	69%	24%
Homes Below Wx Standard	44%	31%	76%

*Conditioned to unconditioned basement walls refer to a stud wall separating a conditioned space from an unconditioned basement (e.g., the walls separating a mixed-use basement that has a finished conditioned space and an unfinished mechanical room), not foundation wall insulation.

Fiberglass is the most common type of insulation used in above-grade walls, regardless of location. The installation quality of this insulation rarely reaches a grade of I; grade II installation is most common, followed by grade III. Like conditioned to ambient walls, walls to attics, garages, and basements tend to be constructed with 2x4 stud framing (Table 5-7).

Table 5-7: Other Wall Locations-Insulation Type, Insulation Grade, and Wall Framing
(Base: All homes with applicable wall locations)

	Statewide Weighted		
	Conditioned to Attic	**Conditioned to Garage**	**Conditioned to U.C. Basement**
Insulation Type-n	*101*	*120*	*111*
Fiberglass batts or rock wool	76%	87%	32%
Another material	2%	3%	3%
Fiberglass batts and another material	5%	2%	1%
Uninsulated	18%	9%	64%
Insulation Installation Grade-n*	*83*	*111*	*41*
Grade I only	5%	3%	12%
Grades I & II	1%	0%	0%
Grade II only	49%	64%	54%
Grades II & III	5%	2%	0%
Grade III only	41%	31%	34%
Framing Description-n	*101*	*120*	*111*
2 x 4 x 16” o.c.	86%	87%	90%
2 x 6 x 16” o.c.	11%	12%	5%
Another framing type	3%	1%	5%

*Sample size is less than corresponding insulation type and framing description sample sizes because uninsulated walls do not receive insulation grades.

5.2.3 Opportunities and Barriers to Increasing Wall Insulation

Opportunities

- Low-income homes have an average conditioned to ambient wall R-value of R-7.6, meaning there is room for improvement to work toward the weatherization standard of R-11.
- Conditioned to unconditioned basement walls have an average R-value of R-3.5. These walls are subject to the same R-11 requirement, meaning there is significant room for improvement in this particular wall location.

Barriers

- While opportunities exist to increase wall insulation in many homes, it will be difficult to do so in homes that fall just below the standard due to diminishing returns. For example, it is much less likely be cost-effective for homeowners to increase insulation from R-9 to R-11 than it is for homeowners to move from uninsulated to R-11. In fact, cost-effectiveness tests for a program such as HES may not identify such insulation in this scenario as a recommended measure. As a result, achieving high compliance with the prescriptive measure may be difficult.

5.3 Ceilings

About one-third of houses (34%) statewide meet the weatherization standard for flat ceiling R-value (R-30) (Table 5-8). The average statewide flat ceiling R-value of 21.1 is well below the standard, and the median of R-19 suggests that a few high values are skewing the average up. Just 19% of low-income homes have flat ceiling insulation of R-30 or higher. Statistically, mid- to high-income homes and homes heated with electricity are better insulated than other categories of homes.

Table 5-8: Flat Ceilings – R-value Statistics

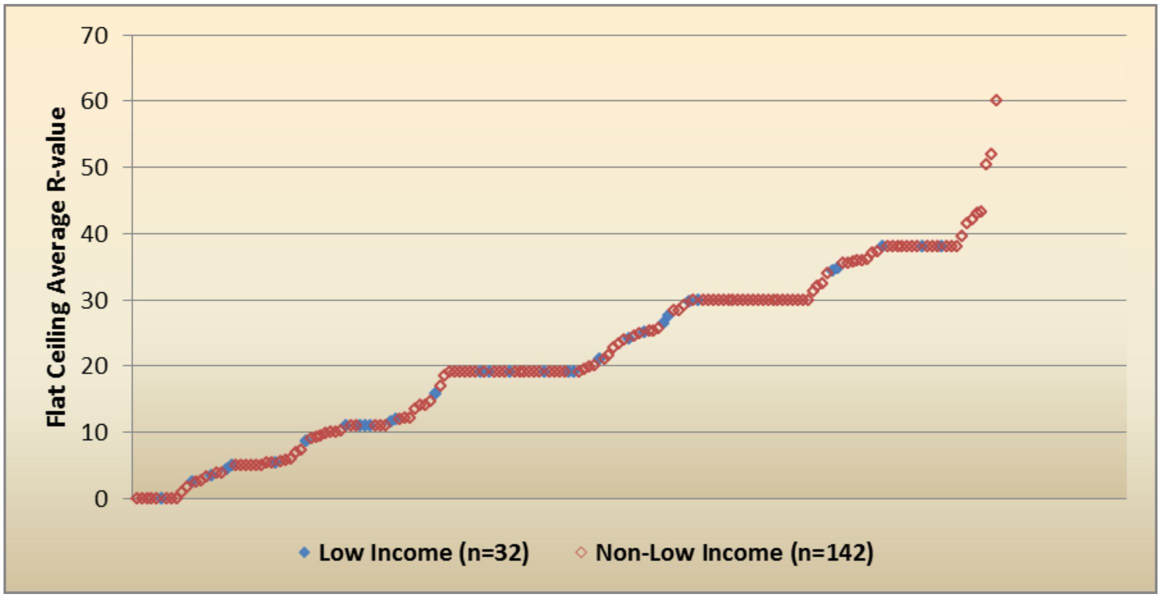
(Base: All homes with flat ceilings)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*115*	*44*	*15*	*32*	*142*	*174*
Min	0.0	0.0	14.0	0.0	0.0	0.0
Max	60.0	52.0	43.0	38.0	60.0	60.0
Average	20.8[b]	19.9[c]	28.2[b,c]	18.6[a]	21.8[a]	21.1
Median	19.0	19.0	25.7	19.0	19.7	19.0
Compliance with Flat Attic Ceiling Weatherization Standard (R-30)						
Homes Equal to or Exceeding Wx Standard	35%	32%	47%	19%[a]	39%[a]	34%
Homes Below Wx Standard	65%	68%	53%	81%	61%	66%

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

Figure 5-2 graphs average R-values in flat ceilings for all 174 homes where they were observed.

Figure 5-2: Flat Ceiling R-value by Income Status*
(Base: All homes with flat ceilings)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

The weatherization standard for vaulted ceiling R-value is R-19, and a much larger percentage of vaulted ceilings statewide are insulated to the weatherization standard (62%) compared to flat ceilings (Table 5-9). Homes heated with natural gas, however, have a relatively low compliance rate (44%) with respect to the weatherization standard. Vaulted ceilings in homes heated with electricity have a statistically higher R-value than those in homes using oil and other fuels, which in turn have a statistically higher R-value than vaulted ceilings in homes heated with natural gas.

Table 5-9: Vaulted Ceilings – R-value Statistics

(Base: All homes with vaulted ceilings)

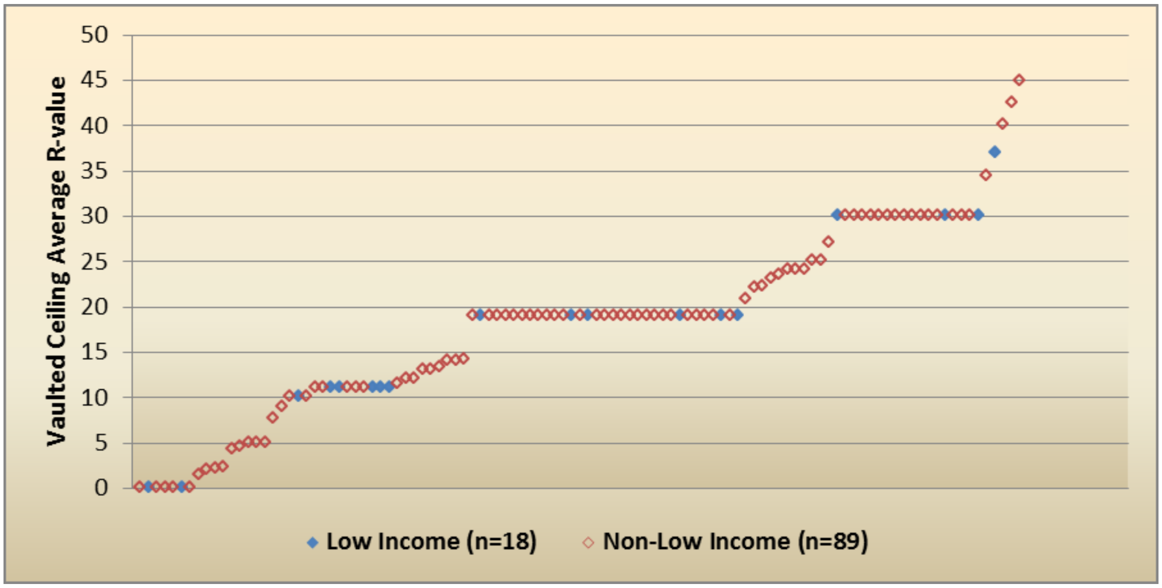
Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*77*	*23*	*7*	*18*	*89*	*107*
Min	0.0	0.0	11.4	0.0	0.0	0.0
Max	44.8	30.0	34.3	37.0	44.8	44.8
Average	18.9[a]	14.2[a,b]	21.7[b]	17.0	18.3	17.9
Median	19.0	13.3	19.0	19.0	19.0	19.0
Compliance with Vaulted Ceiling Weatherization Standard (R-19)						
Homes Equal to or Exceeding Wx Standard	66%[a]	44%[a,b]	6 (86%)[b]	56%	64%	62%
Homes Below Wx Standard	34%	57%	1 (14%)	44%	36%	38%

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

Figure 5-3 graphs average R-values in vaulted ceilings for all 107 homes where they were observed.

Figure 5-3: Vaulted Ceiling R-value by Income Status*

(Base: All homes with vaulted ceilings)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

The area of flat ceilings in the sample far exceeds the area of vaulted ceilings. On average, single-family homes have 1,171.4 square feet of flat ceiling, compared to less than half that amount for vaulted ceilings (550.3 square feet). Overall, more than three-quarters (77.2%) of ceiling area in the state is flat, while the remaining 22.8% is vaulted.

Fiberglass batts are the most common insulation type in all flat ceilings (56%), but blown-in insulation (14% alone or 11% with fiberglass batts), which can be a convenient method of installing insulation in an open attic, is also relatively common in flat ceilings (Table 5-10). About one-fifth of flat ceilings are not insulated (18%). There is some variation in installation quality, but grades II and III are most common.

Table 5-10: Summary of Other Ceiling Attributes
(Base: All homes with applicable ceiling locations)

	Statewide Weighted	
	Flat Ceilings	**Vaulted Ceilings**
Insulation Type—n	*174*	*107*
Fiberglass batts or rock wool	56%	77%
Blown-in fiberglass or cellulose	14%	6%
Another material	1%	3%
Fiberglass batts and blown-in or another material	11%	8%
Uninsulated	18%	7%
Insulation Installation Grade—n*	*161*	*100*
Grade I only	14%	8%
Grades I & II	3%	1%
Grades I & III	3%	0%
Grade II only	46%	62%
Grades II & III	8%	4%
Grade III only	25%	26%
Grades I, II, & III	1%	0%
Framing Description—n	*174*	*107*
2 x 4 x 16” o.c.	9%	11%
2 x 6 x 16” o.c.	44%	25%
2 x 8 x 16” o.c.	14%	27%
2 x 10 x 16” o.c.	8%	14%
2 x 12 x 16” o.c.	0%	6%
Other single joist type	11%	13%
More than one joist type	13%	5%

*Sample size is less than corresponding insulation type and framing description sample sizes because uninsulated walls do not receive insulation grades.

Framing type is a more important consideration in vaulted ceilings than flat ceilings. While flat ceilings nearly always lead to an open attic which could conceivably be insulated to well above the weatherization standard of R-30 (the equivalent of 8 to 12 inches of insulation depending on the material used), vaulted ceilings lead directly to the outside. In order to insulate a vaulted ceiling to the standard of R-19 using common insulating materials, that ceiling must have a stud depth of at least 5.5 inches (2x6 construction); at least 71% of the vaulted ceilings have this capability (Table 5-10). Eleven percent of homes with vaulted ceilings have a 3.5-inch stud depth (2x4 construction), which can only accommodate an R-value of R-9 to R-13.

5.3.1 Opportunities and Barriers to Increasing Ceiling Insulation

Opportunities

- There is substantial room for improvement with regard to increasing flat attic insulation as only 34% of homes statewide currently meet the prescriptive weatherization requirement of R-30.
- Increasing attic insulation (both flat ceiling and vaulted[62]) is one of the easier retrofits for existing homes.

Barriers

- Eleven percent of homes with vaulted ceilings have 2x4 framing. In these cases it is very difficult to achieve the standard requirement of R-19 with retrofit cavity insulation.

5.4 Floors

Just 15% of homes with floors over unconditioned basements meet the standard with an average R-value of R-4.4 (Table 5-11). This is the lowest level of compliance among all the prescriptive measures listed in the weatherization standard and is a contributing factor of the 26% performance-based compliance rate.

Low-income homes (5%) are less likely than non-low-income homes (18%) to have insulation meeting the floor insulation standard. Similarly, homes heated with oil and other fuels (17%) are statistically more likely to meet the standard than homes using natural gas (3%) and, despite small sample sizes, homes with electric heating (50% of the eight homes) are the most likely to meet the standard for this building component.

[62] Insulating vaulted ceilings, while more difficult than insulating open attics, is still a relatively easy retrofit as insulation can be blown into framing cavities similar to exterior wall insulation retrofits.

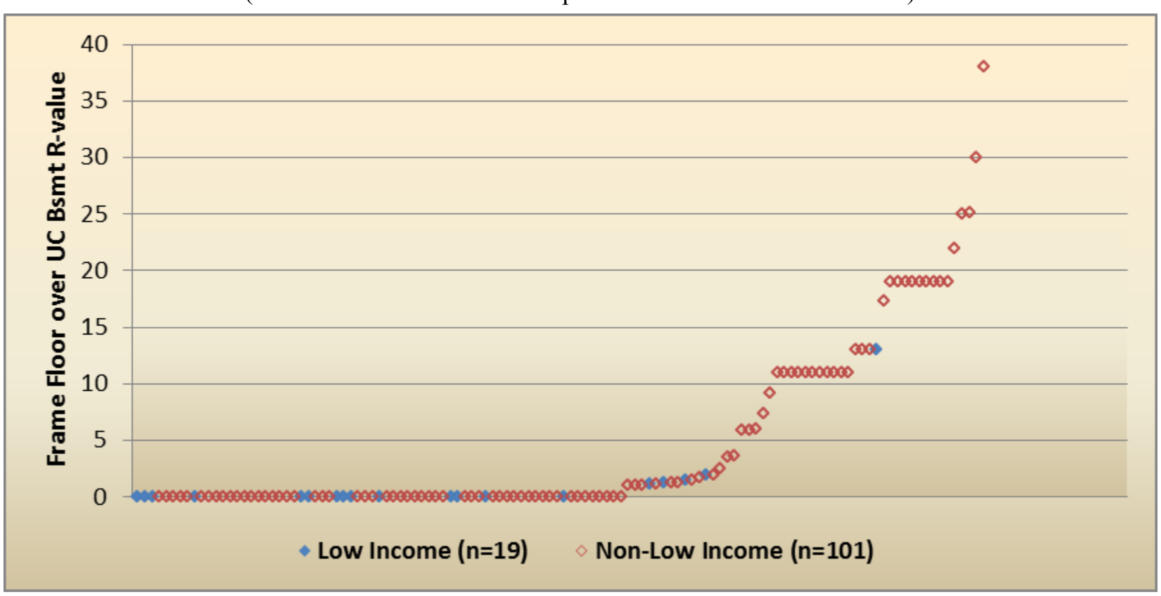
Table 5-11: Frame Floors Over Unconditioned Basements – R-value Statistics
(Base: All homes with full or partial unconditioned basements)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*81*	*31*	*8*	*19*	*101*	*120*
Min	0.0	0.0	0.0	0.0	0.0	0.0
Max	38.0	13.0	30.0	13.0	38.0	38.0
Average	4.8[b,c]	1.8[b,d]	14.7[c,d]	1.0[a]	5.4[a]	4.4
Median	0.0	0.0	15.0	0.0	0.0	0.0
Compliance with Frame Floor over Unconditioned Space Weatherization Standard (R-13)						
Homes Equal to or Exceeding Wx Standard	17%[b,c]	3%[b,d]	4 (50%)[c,d]	5%[a]	18%[a]	15%
Homes Below Wx Standard	83%	97%	4 (50%)	95%	82%	85%

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

Figure 5-4 graphs average R-values in frame floors over unconditioned basements for all 120 homes where they were observed.

Figure 5-4: Frame Floor Over Unconditioned Basement R-values by Income Status
(Base: All homes with full or partial unconditioned basements)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

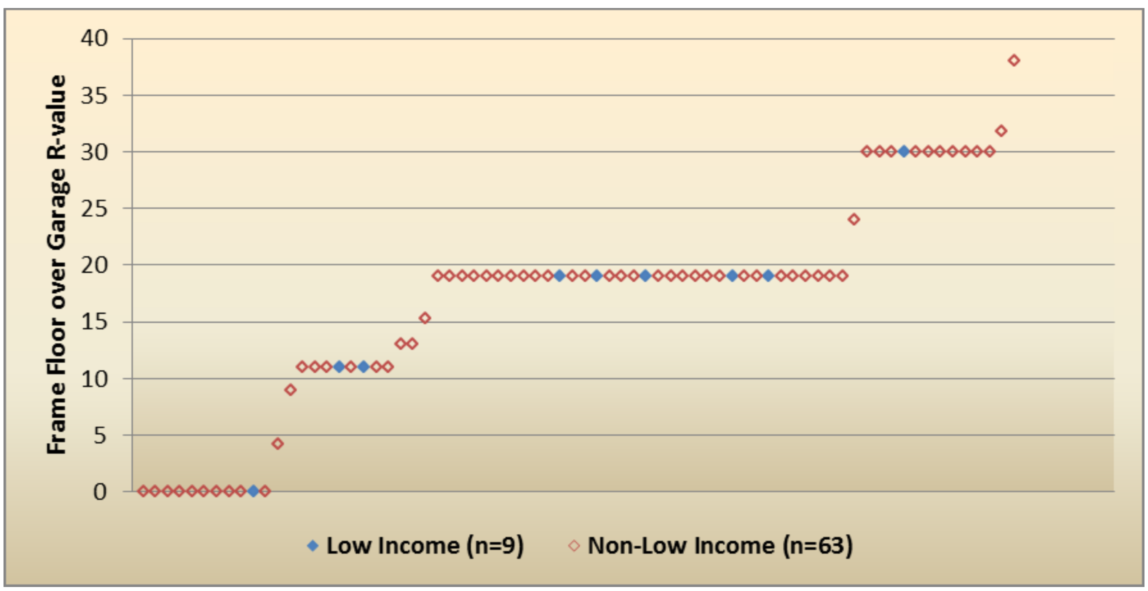
Seventy-two of the homes in the sample (40%) had conditioned space over the garage. Frame floors associated with these spaces were, on the whole, much more well-insulated than floors over unconditioned basements; 70% met the R-13 weatherization standard (Table 5-12).

Table 5-12: Frame Floors Over Garages – R-value Statistics
(Base: All homes with conditioned space over a garage)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*47*	*15*	*10*	*9*	*63*	*72*
Min	0.0	0.0	11.0	0.0	0.0	0.0
Max	38.0	30.0	31.8	30.0	38.0	38.0
Average	16.8	15.7	18.7	16.3	16.9	16.8
Median	19.0	19.0	19.0	19.0	19.0	19.0
Compliance with Frame Floor over Unconditioned Space Weatherization Standard (R-13)						
Homes Equal to or Exceeding Wx Standard	70%	67%	8 (80%)	6 (67%)	71%	70%
Homes Below Wx Standard	30%	33%	2 (20%)	3 (33%)	29%	30%

Figure 5-5 graphs average R-values in frame floors over garages for all 72 homes where they were observed.

Figure 5-5: Frame Floor Over Garage R-values by Income Status*
(Base: All homes with conditioned space over a garage)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

Just over one-half of homes (54%) with floors over ambient conditions have insulation in those floors that meets the weatherization standard of R-13 (Table 5-13). Floors over unconditioned, enclosed crawlspaces are insulated to the weatherization standard 36% of the time.

Table 5-13: Other Frame Floors – R-value Statistics

(Base: All homes with applicable floor locations)

Statistics	Over Enclosed Crawlspace*	Over Ambient Conditions (Weighted)
n	*25*	*76*
Min	0.0	0.0
Max	36.0	32.1
Average	11.3	12.9
Median	0.0	17.8
Compliance with Frame Floor over Unconditioned Space Weatherization Standard (R-13)		
Homes Equal to or Exceeding Wx Standard	36%	54%
Homes Below Wx Standard	64%	46%

* Unweighted due to low sample size.

As in other building shell components, the most commonly found insulation type in all floors is fiberglass batts. The majority of floors have been constructed using either 2x8 or 2x10 framing (Table 5-14). Notably, the installation quality of insulation in floors over unconditioned basements and crawlspaces is more commonly grade III than grade II. Fiberglass insulation that hangs over an open space is prone to sagging; installers will therefore often compress the fiberglass up into the floor cavity, which leads to a decreased effective R-value. This is not as much of an issue for floors over garages or ambient conditions due to the frequent presence of sheetrock, which holds the insulation in place. It should be noted that even with sheetrock holding insulation in place it is still possible to have poor insulation installation. In order to achieve full effectiveness insulation must fill the cavity; often insulation in garage ceilings and floors over ambient conditions will not fill the cavity and will have a gap above the insulation, reducing its effectiveness.

Table 5-14: Summary of Other Frame Floor Attributes

(Base: All homes with applicable floor locations)

	Over U.C. Basement (Weighted)	Over Garage (Weighted)	Over Enclosed Crawlspace*	Over Ambient Conditions (Weighted)
Insulation Type—n	*120*	*72*	*25*	*76*
Fiberglass batts or rock wool**	42%	85%	40%	69%
Another material	0%	0%	4%	0%
Fiberglass batts and another material	0%	0%	4%	1%
Uninsulated	58%	15%	52%	30%
Insulation Installation Grade—n*	*51*	*61*	*12*	*53*
Grade I only	0%	0%	8%	0%
Grade II only	40%	69%	42%	82%
Grades II & III	2%	0%	0%	0%
Grade III only	58%	31%	50%	18%
Framing Description—n	*120*	*72*	*25*	*76*
2 x 6 x 16” o.c.	6%	7%	12%	9%
2 x 8 x 16” o.c.	36%	38%	48%	47%
2 x 10 x 16” o.c.	36%	41%	24%	36%
2 x 12 x 16” o.c.	6%	6%	0%	3%
Other single joist type	12%	5%	16%	2%
More than one joist type	5%	2%	0%	5%

* Unweighted due to low sample size.

** Includes some cases where insulation is partial.

***Sample size is less than corresponding insulation type and framing description sample sizes because uninsulated walls do not receive insulation grades.

5.4.1 Opportunities and Barriers to Increasing Frame Floor Insulation

Opportunities

- Statewide, homes have an average R-value of R-4.4 in floors over unconditioned basements, falling well below the standard requirement of R-13. Low-income homes have an average R-value of R-1 in floors over unconditioned basements. Overall, compliance with this requirement is only 15%, suggesting most homes with floors over unconditioned basements have room for improvement.
- In general, adding insulation to a floor over an unconditioned basement is easily done as these floors are usually accessible.

Barriers

- A handful of homes with floors located over unconditioned space have R-11 insulation in the cavity (a common R-value for standard fiberglass batts). Achieving the standard requirement of R-13 in these homes may offer little benefit in terms of energy savings.
- While adding insulation to floors over unconditioned basements is a relatively easy retrofit it can be difficult to ensure quality installations due to wire protrusions, plumbing protrusions, and the lack of sheetrock to hold insulation in place.

5.5 Foundation Walls

Slightly less than one-half of homes (48%) with foundation walls in conditioned space have insulation in those walls that meets the weatherization standard of R-5 (Table 5-15). Accordingly, the median statewide R-value for these walls is R-4.2, just shy of the standard.

Table 5-15: Foundation Walls in Conditioned Spaces – R-value Statistics*

(Base: All homes with foundation walls abutting conditioned space)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*68*	*20*	*9*	*16*	*81*	*97*
Min	0.0	0.0	0.0	0.0	0.0	0.0
Max	19.0	19.0	12.5	13.0	19.0	19.0
Average	4.7	6.9	6.5	5.8	5.2	5.4
Median	3.1	7.5	5.0	5.0	3.6	4.2
Compliance with Foundation Wall in Conditioned Space Weatherization Standard (R-5)						
Homes Equal to or Exceeding Wx Standard	41%	55%	6 (67%)	63%	43%	48%
Homes Below Wx Standard	59%	45%	3 (33%)	38%	57%	52%

* Includes all conditioned spaces (basements and crawlspaces).

Two-thirds of foundation walls (66%) in conditioned space are insulated. Fiberglass batts are the most common insulation type. Various kinds of rigid foam, spray foam, and cellulose were also observed. Similar to other shell components, the most common cavity installation quality was grade II (Table 5-16).

Table 5-16: Summary of Other Foundation Wall Attributes

(Base: All homes with foundation walls abutting conditioned space)

	Conditioned Space (Weighted)
Insulation Type—n	*97*
Fiberglass batts	49%
Another material	14%
Fiberglass batts and another material	3%
Uninsulated	34%
Insulation Installation Grade—n	*55*
Grade I	5%
Grade II	59%
Grade III	36%

5.5.1 Improvement Opportunities for Basement Insulation

More than one-half of homes (51%) with an unconditioned basement or crawlspace lack insulation on both the frame floor and the foundation wall associated with that space; 82% are either uninsulated or have inadequate basement insulation (Table 5-17). For these homes, the prescriptive requirements for weatherization can be satisfied either by insulating the foundation wall to R-5 or by insulating the frame floor to R-13. Homes heated primarily by natural gas (6%) are significantly less likely than homes heated by oil and other fuels (20%) to have either foundation walls or frame floors in basements be insulated to the weatherization standard. Low-income homes (5%), similarly, are significantly less likely than non-low-income homes (22%) to have basement or crawlspace insulation that meets the standard. Addressing thermal boundaries in basements, either at the foundation walls or at the frame floor level, could contribute to increasing compliance with the weatherization standard.

Table 5-17: Homes In Need of Basement/Crawlspace Insulation
(Base: All homes with an unconditioned basement or crawlspace)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*85*	*35*	*8*	*22*	*106*	*128*
Completely uninsulated*	46%[a]	74%[a]	0 (0%)	64%	48%	51%
Insulated, but not to Wx standard	34%	20%	3 (38%)	32%	30%	31%
Insulated to Wx standard	20%[a,b]	6%[a,c]	5 (63%)[b,c]	5%[d]	22%[d]	18%

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

*Homes with unconditioned basements and neither frame floor insulation nor foundation wall insulation. Includes enclosed crawlspace entries. Note that there are no foundation walls associated with open crawlspaces, so that case is excluded from this analysis.

5.6 Slabs

Nine of the 180 homes in the sample (5%) have a slab on-grade foundation type, indicating that there is no basement or crawlspace present. However, 62% of homes have some kind of slab present; these are (1) homes with conditioned basements or crawlspaces, for which the slab below the basement is the thermal boundary, or (2) homes that rest partially on a slab and partially over a basement.

It is nearly impossible for an auditor to verify the presence, type, and R-value of slab insulation in existing homes. In six cases, however, construction specs or homeowner testimony provided information regarding slab insulation. Among those six homes, the average slab insulation R-value is R-6.3 and, in the four cases where it is known, the insulation type is polystyrene or polyisocyanurate.

5.7 Rim and Band Joist Insulation

One hundred sixty-four out of the 180 homes (91%) contain rim or band joists between conditioned and ambient space (Table 5-18). Insulation R-values across all categories range from R-0 to R-31. When comparing home heating fuel type, homes that heat primarily with electricity (R-7.4) have the lowest average insulation R-value, and homes that heat with natural gas have the highest average (R-9.4). Statewide, 37% of homes with conditioned to ambient joists are uninsulated. Homes that heat primarily with oil and other fuels or natural gas (37% each) are significantly more likely than homes that heat with electricity (14%) to have uninsulated joists. Fiberglass batts are the predominant insulation type for rim/band joists. Over one-half of homes (58%) have a grade II insulation installation.

Table 5-18: Summary of Conditioned to Ambient Rim/Band Joists

(Base: All homes with conditioned to ambient joists)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
R-Value Statistics—n	*107*	*42*	*15*	*30*	*134*	*164*
Minimum	0	0	0	0	0	0
Maximum	31	30	19	30	31	31
Average	8.2	9.4	7.4	9.4	8.2	8.3
Median	11	12	11	11	11	11
Insulation type—n	*107*	*42*	*15*	*30*	*134*	*164*
Cellulose	2%	6%	9%	6%	2%	3%
Spray foam	2%	0%	0%	0%[a]	2%[a]	2%
Fiberglass batts	56%	52%	73%	48%	59%	56%
Other	3%[b,c]	0%[b]	0%[c]	0%	3%	2%
None	37%[c]	37%[d]	14%[c,d]	47%	33%	37%
Insulation Installation Grade*--n	*73*	*32*	*10*	*24*	*91*	*115*
Grade I only	4%[bc]	0%[b]	0 (0%)[c]	0%[a]	4%[a]	3%
Grade I & II	0%	0%	1 (6%)	0%	1%	1%
Grade II only	55%	55%	6 (63%)	51%[a]	57%[a]	58%
Grade II & III	6%[c]	8%	0 (0%)[c]	12%	4%%	5%
Grade III only	35%	38%	3 (31%)	37%	35%	34%

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

*Sample size is less than corresponding insulation type and framing description sample sizes because uninsulated walls do not receive insulation grades.

Table 5-19 displays the insulation type, grade, and R-value for insulation found on conditioned to garage, conditioned to attic, conditioned to unconditioned (UC) basement, and UC basement to ambient joist locations. Average R-values range from R-3.8 for conditioned to UC basement joists to R-9.8 for conditioned to garage joists.

Table 5-19: Summary of Other Rim/Band Joist Locations
(Base: All homes with applicable joist locations)

	Statewide Weighted			
	Conditioned to Garage	**Conditioned to Attic**	**Conditioned to UC Basement**	**UC Basement to Ambient**
R-Value Statistics—n	*39*	*20*	*5*	*84*
Minimum	0	0	0	0
Maximum	21	19	19	19
Average	9.8	5.2	3.8	6.3
Median	11	0	0	0
Insulation type—n	*39*	*20*	*5*	*84*
Cellulose	0%	0%	0 (0%)	0%
Spray foam	3%	0%	0 (0%)	4%
Fiberglass batts	61%	47%	1 (20%)	31%
Fiberglass batts and none	9%	0%	0 (0%)	9%
Other	0%	53%	4 (80%)	3%
None	28%	0%	0 (0%)	54%
Insulation Installation Grade—n*	*28*	*9*	*1*	*37*
Grade I	4%	0 (0%)	0 (0%)	19%
Grade II	56%	4 (40%)	0 (0%)	32%
Grade III	36%	5 (60%)	1 (100%)	49%
Grade II & III	4%	0 (0%)	0 (0%)	0%

*Sample size is less than corresponding insulation type and framing description sample sizes because uninsulated walls do not receive insulation grades.

5.8 Windows and Skylights

Auditors recorded the area, frame material, and number of panes for all windows. They verified the presence of low-E coatings with a lighter or flashlight test.[63] There is no standard field test or indicator to identify argon-filled windows, so windows are identified as argon-filled only where additional documentation or confirmation from the homeowner was available. Likewise, window U-values and solar heat gain coefficient (SHGC) ratings cannot be determined in the field, so

[63] It is standard industry practice to use a small point source of light, like a lighter or flashlight, to determine whether a low-E coating is present.

auditors recorded values only where National Fenestration Rating Council (NFRC) labels were still present on the windows or retained by the occupant.[64]

The prescriptive checklist of the weatherization standard requires windows to have a maximum U-value of 0.50, which is assumed to include all double pane and single pane with storm windows. Statewide, 82% of homes meet this requirement (Table 5-20). That is, 82% of homes in the sample have 100% of their windows on conditioned exterior walls in compliance with the weatherization standard. If homes with 95% or higher compliant windows by area are included, 92% of homes statewide meet the window standard. A significantly higher share of homes with electricity as the primary fuel (94%) had standard-compliant windows compared to homes with natural gas as the primary fuel (74%).

Table 5-20: Homes with All Exterior Windows Meeting Weatherization Standard

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)[65]
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Homes Equal to or Exceeding Wx Standard	83%	74%[a]	94%[a]	79%	82%	82%
Homes Below Wx Standard	17%	26%	6%	21%	18%	18%

[a] Statistically significant difference at the 90% confidence level.

[64] Auditors recorded U-values and SHGC ratings at 14 sites. At these sites, confirmed U-values ranged from 0.29 to 0.49. SHGC ratings ranged from 0.24 to 0.60.

[65] 92% of homes statewide (weighted) have 95% or greater compliant windows by area.

Double pane clear windows are the most common glazing type, present in 69% of homes (Table 5-21). Fifty-six percent of homes have double pane windows with low-E coatings installed. Over one-third of homes (35%) have single pane windows present. Twenty-seven percent have single pane windows with storm windows and 18% have single pane windows with no storm windows. Auditors conclusively identified double pane low-E windows with argon fill in 9% of homes, though this likely under-represents windows of this type for reasons discussed above. Triple pane windows are the least common, present in only 2% of homes. Single pane windows are significantly more common in low-income homes than in non-low-income homes. Homes heated primarily by electricity are significantly more likely than homes heated by oil and other fuels to have double pane clear windows. Double pane windows with low-E coatings are significantly more prevalent in non-low-income homes than they are in low-income homes.

Table 5-21: Types of Windows by Percent of Homes*

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Single Pane	32%	44%	25%	53%[a]	30%[a]	35%
*w/storm***	*25%*	*35%*	*19%*	*41%*	*23%*	*27%*
*no storm***	*17%*	*26%*	*6%*	*21%*	*18%*	*18%*
Double Pane (clear)	65%[b]	70%[c]	88%[b,c]	77%	66%	69%
Double Pane Low-E	60%	50%	50%	41%[a]	60%[a]	56%
Double Pane Low-E w/Argon	9%	7%	13%	12%	8%	9%
Triple Pane	1%	2%	6%	0%	2%	2%

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

*Numbers add to more than 100% because each home may have several types of windows present. The percentages presented in this table only represent the fact that homes had at least one window with the characteristic in question.

**Combined these percentages represent the 35% of homes with single pane windows. The numbers add to more than 35% because some homes had more than one type of single pane window.

Double pane clear windows represent 41% of window area statewide (Table 5-22). Thirty-eight percent of window area is double pane low-E glazing; another 5% is confirmed argon-filled. Single pane windows are 15% by area, while triple-pane windows are less than 1%. Homes heated primarily by natural gas have a significantly higher proportion of single pane windows than homes heated primarily by electricity or oil and other fuels. Non-low-income homes have a significantly greater proportion of double pane low-E windows than low-income homes. Among homes with single pane windows, 86% of these windows, by area, have storm windows installed.

Table 5-22: Types of Windows by Percent of Window Area

(Base: All homes)

	Primary Heating Fuel			**Household Income**		**Statewide (Weighted)**
	Oil & Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**	
n	*118*	*46*	*16*	*34*	*146*	*180*
Single Pane	14%[a]	21%[a,b]	3%[b]	21%	14%	15%
w/storm	*12%*[a]	*18%*[a,b]	*3%*[b]	*18%*	*12%*	*13%*
no storm	*2%*	*3%*	*0%*	*3%*	*2%*	*2%*
Double Pane (clear)	44%	44%	61%	47%	41%	41%
Double Pane Low-E	30%	30%	29%	23%[c]	41%[c]	38%
Double Pane Low-E w/Argon	5%	5%	6%	9%	4%	5%
Triple Pane	<1%	0%	1%	0%	<1%	<1%

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

5.9 Infrared Imaging

As part of the onsite inspections, Team auditors utilized infrared (IR) cameras to aid in the assessment of each site's thermal envelope. Specifically, IR cameras were used to identify insulation gaps and voids, insulation compression, and air leaks in the building envelope. Appendix E of the report presents a sample of the images taken during the site visits. These images are representative of the other photos taken during the site visits and are meant to provide qualitative results that inform readers about the thermal envelope of the sites visited as part of this study.

Infrared imaging was not always possible because IR cameras only begin to provide meaningful results with an indoor-outdoor temperature differential of at least ten degrees,[66] with at least a twenty degree differential providing the best results.[67] In total, the evaluators used IR cameras at 107 sites (59%), as shown in Table 5-23.

Table 5-23: Percentage of Sites with Infrared Photos

Infrared Photos Taken	Statewide (Weighted)
n	*180*
Yes	59%
No	41%

5.9.1 Recommendations Based on Infrared Images

After using IR cameras and working with HES vendors at the majority of sites, it is clear that these cameras would help vendors with their retrofit efforts, particularly when it comes to air sealing. As shown in the first part of Appendix E (see Examples of Air Leakage Using IR), these cameras are valuable for identifying air leaks. Therefore, vendors may be able to improve their air sealing efforts, and ultimately CFM reductions, by utilizing IR cameras when running blower door tests and searching for sources of air leakage. This would ultimately help more homes going through the HES program to achieve the weatherization standard, particularly when using the performance-based approach.

As shown in the other parts of Appendix E, these cameras are also very useful at identifying missing insulation, degraded insulation, and moisture damage. Infrared cameras could help HES vendors identify uninsulated shell components that may present significant savings, such as uninsulated floors over garages, uninsulated floors over ambient conditions, and uninsulated exterior walls. Note that, in many cases, the IR cameras would help auditors find small issues in the shell of a home that would be good to fix and certainly useful for homeowners to be aware of, but the issues may not always be large enough to present significant savings opportunities. Examples of these types of issues include small sections of missing insulation and poor insulation installation.

In summary, IR cameras are beneficial and would certainly be useful for vendors in the HES programs. However, these cameras are very expensive[68] (even though their cost has decreased significantly over the years), and that should be accounted for when considering whether or not to recommend or require their use for programs such as HES and HES-IE.

[66] Useful results can be achieved with a ten-degree temperature differential and a high quality IR camera.
[67] http://www.energysavers.gov/your_home/energy_audits/index.cfm/mytopic=11200
[68] Cameras typically used for building science applications range in price from ~$2,000 to $8,000.

6 Mechanical Equipment

This section presents detailed information on the mechanical equipment that was present in each of the 180 audited homes. Mechanical equipment, while not a part of the weatherization standard, was included in the data collection efforts as it is required to populate a REM/Rate model and was of interest to the various stakeholders involved in the planning process for the study. Having this information could be valuable for future planning efforts related to the weatherization standard or various building efficiency programs.

6.1 Heating Systems

6.1.1 Primary Heating Fuel

Statewide, 64% of sampled homes use oil as the primary heating fuel, 24% use natural gas, 8% use electricity, 2% use propane, 1% use pellets, and 1% use wood (Table 6-1). Note that these percentages may differ slightly from those self-reported by respondents to the telephone survey (Appendix I), as the data here have been verified by the auditors while onsite.

Table 6-1: Homes in Each Primary Fuel Category and Income Level

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Oil	95%	--	--	53%	64%	64%
Natural Gas	--	100%	--	35%	23%	24%
Electric	--	--	100%	6%	10%	8%
Propane	3%	--	--	3%	1%	2%
Pellet	2%	--	--	3%	1%	1%
Wood	1%	--	--	0%	1%	1%

6.1.2 Types of Heating Systems

Most homes in the sample have boilers (62%), followed by furnaces (30%), and then electric resistance heat (19%), as Figure 6-1 shows. These figures include primary and supplemental heating systems. Air source heat pumps (ASHP) are less common; only about 4% of sampled homes (8 homes) have these systems as heating sources. In addition, two homes have solar-assisted heating systems,[69] two have propane-fired ductless direct vent heaters, and one has a ground source heat pump (GSHP). There are five steam boilers in the sample, one of which is attached to a solar panel to pre-heat the water.[70][71]

Figure 6-1 also shows a breakdown of how many of these homes have each type of heating system as their primary heating system as opposed to a secondary heating system. (This chart ignores any homes using stoves as a primary heating system.) Boilers and furnaces are overwhelmingly primary heating systems; all of the boilers in the sample are primary heating system, and furnaces are the primary heating system in 94% homes that have furnaces installed. Electric resistance heating, the next most common type of heating system found in homes, is the primary heating system in only 30% of homes sampled. Of the eight homes with ASHPs, only three of these homes have ASHPs as their primary heating system.

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[69] These two solar-assisted systems are markedly different from one another. In one house, solar panels had been added to an old steam boiler from 1952; the solar panels preheated the water for the boiler. In the other home, a solar hydronic heating unit had been installed in an air handler cabinet and was used in conjunction with an ASHP and a hydro-air boiler.

[70] Some homes have more than one permanently installed heating system. Ignoring stoves, few homes have more than one of the same type of heating system. Three homes have two ASHPs, and seven homes have two furnaces. Otherwise, homes with more than one non-stove heating system have different system types installed.

[71] This is a low incidence of steam boilers. This could be due to random sampling error or to an actual decrease in steam systems in single-family homes.

Figure 6-1: Percent of Homes with Each Type of Heating System

(Base: All homes)

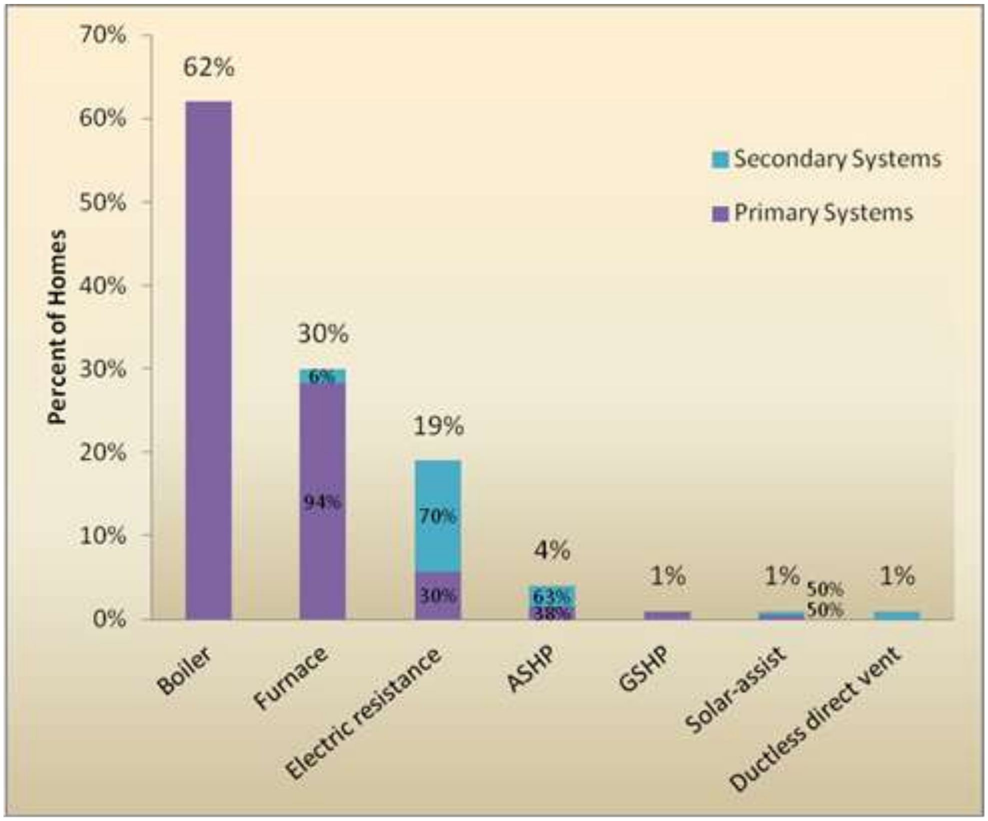


Table 6-2 provides a more detailed breakdown of the types of heating systems found in sampled homes, with information on how the system types vary depending on the home's primary heating fuel and household income. Homes with natural gas as the primary heating fuel have a roughly even split between boilers and furnaces: 52% have boilers and 52% have furnaces (two homes have both). In comparison, boilers are more prevalent in homes in the oil and other fuels category: 73% of those homes have boilers, and only 26% have furnaces. Homes with natural gas heat are also significantly less likely than homes in the oil and other fuels category to have electric resistance backup heat (only 4% vs. 17% of homes in the oil and other fuels category).

Table 6-2: Percent of Homes with Each Type of Heating System Present

(Base: All homes*)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Boiler	73%[a,b]	52%[a,c]	6%[b,c]	65%	61%	62%
Furnace	26%[a,b]	52%[a,c]	0%[b,c]	26%	32%	30%
Electric resistance	17%[a,b]	4%[a,c]	75%[b,c]	15%	20%	19%
ASHP	3%[a,b]	0%[a,c]	31%[b,c]	0%[d]	5%[d]	4%
GSHP	0%	0%	6%	0%	1%	1%
Solar-assist	1%	0%	6%	0%	1%	1%
Ductless direct vent heater	1%	0%	6%	0%	1%	1%

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

*Categories add up to more than 100% because many homes had more than one type of heating system.

6.1.3 Heating System Efficiency

It is important to note that, in existing homes, obtaining efficiency data for heating systems of varying ages can be a complex process. Whenever possible, auditors reported the Air-Conditioning, Heating, and Refrigeration Institute (AHRI)-based efficiency.[72] In other cases, auditors recorded efficiency data as reported by manufacturers, or calculated the efficiency by dividing the energy input by the heating capacity[73] (when applicable). In some cases, however, no efficiency data were available, in which case auditors recorded the age-based default

[72] http://www.ahridirectory.org/ahridirectory/pages/home.aspx

[73] Some boilers and furnaces do not have rated AFUE values, but they may be labeled with both an energy input and a heating capacity (or output), both in units of BTU/hr. Dividing the output value by the input value approximates the AFUE. For example, a boiler with a 93,000-BTU/hr. output and 100,000-BTU/hr. input would have a calculated AFUE of 0.93. Please note that calculating efficiencies in this manner only captures steady-state efficiency as it does not account for various energy losses (off-cycle, jacket, and stack losses) that take place and are accounted for in standard AFUE calculations. As a result, the AFUE's reported in this manner will over-state the efficiency of a given unit.

efficiencies from the Residential Energy Services Network (RESNET) standards, as noted in the bottom row of the tables below.

Table 6-3 shows the rated Heating Seasonal Performance Factor (HSPF) efficiency statistics of the 11 ASHPs in sampled homes (these 11 units were found in 8 homes). The mean HSPF of these 11 systems is 8.8 (this includes ducted and ductless systems).

Table 6-3: ASHP Efficiency (HSPF)

(Base: All ASHPs Used for Heating)

	HSPF
n	*11*
Min	6.8
Max	10.0
Average	8.8
Median	8.7
Count of systems using age-based defaults	0

Table 6-4 shows the Annual Fuel Utilization Efficiency (AFUE) statistics for boilers. The mean AFUE of all boilers is 81.6, with a median of 83.1. Oil boilers in the sample have a slightly higher—but not statistically higher—efficiency (82.1) than natural gas boilers (79.7).

Table 6-4: Boiler AFUE by Fuel Type

(Base: All boilers)

	Natural Gas	Oil (Weighted)[1]	Pellet	Propane	All Boilers (Weighted)
n	*25*	*84*	*1*	*2*	*112*
Min	60.0	60.0	92.2	82.0	60.0
Max	90.0	87.5	92.2	87.0	92.2
Average	79.7[a]	82.1[b]	92.2	84.5	81.6
Median	81.3	83.8	92.2	84.5	83.1
% of Units with AFUE ≥ 90.0	12% (n=3)	0%	100% (n=1)	0%	4% (n=4)
Count of systems using age-based defaults[2]	3	1	0	1	5

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

[1] Note that one of the oil boilers has water pre-heated by solar panels. The AFUE included in these averages is the rated AFUE of that boiler, not accounting for the solar benefit.

[2] These are included in the above counts and statistics.

Table 6-5 shows the same AFUE statistics for furnaces in the sampled homes. The mean AFUE of furnaces sampled is 83.7, with a median of 81.9. Natural gas furnaces have a mean AFUE of 85.1, higher than the 82.4 for oil furnaces; these differences are statistically significant at the 90% confidence level.

Table 6-5: Furnace AFUE by Fuel Type

(Base: All furnaces)

	Natural Gas	Oil (Weighted)	Propane	All Furnaces (Weighted)
n	*28*	*32*	*2*	*62*
Min	63.5	77.0	92.1	63.5
Max	95.0	86.5	95.0	95.0
Average	85.1[a,b]	82.4[a,c]	93.6[b,c]	83.7
Median	85.9	81.6	93.6	81.9
% of Units with AFUE ≥ 90.0	50% (n=14)	0%	100% (n=2)	20% (n=16)
Count of systems using age-based defaults[1]	1	2	0	3

[1]These are included in the above counts and statistics.

Table 6-6 shows how the sampled AFUE of boilers and furnaces varies based on income status. In the sample, boilers in non-low-income homes are slightly more efficient (82.3) than in low-income homes (80.0). That is switched for furnaces, which are slightly more efficient in low-income homes (84.7) than non-low-income homes (83.8). However, these are minor differences, and not statistically significant at the 90% confidence level.

Table 6-6: Mean Boiler and Furnace AFUE by Income Level

(Base: All boilers and furnaces*)

	Household Income		Statewide (Weighted)
	Low Income	Non-Low Income	
Boilers	80.0 (n=22)	82.3 (n=90)	81.6 (n=112)
Furnaces	84.7 (n=9)	83.8 (n=53)	83.7 (n=62)

*This includes one boiler with a supplemental solar system. The AFUE included in these averages is the rated AFUE of that boiler, not accounting for the solar benefit.

There is only one GSHP in the sample (COP of 3.8), and two propane-fired direct-vent ductless heaters (both have a rated AFUE of 77.0) (Table 6-7).

Table 6-7: Efficiencies of Other Heating Systems

(Base: All homes)

Heating System Type	*n*	Units	Efficiency
GSHP	*1*	COP	3.8
Propane ductless direct vent heater	*2*	AFUE	77.0

Appendix G provides more detailed breakdowns of heating system efficiencies by system type, household income, and primary heating fuel in Table G- and Table G-2.

6.1.4 Heating System Age

The following discussion of heating system ages excludes stoves and electric resistance heating systems, where the age of the system is less important when considering the efficiency of the heating systems.

Table 6-8 shows the average age of sampled ASHPs. The mean age of ASHPs is 10.4 years. This includes several types of ASHPs, including ducted split systems, ductless mini-splits, and one wall-mounted packaged unit.

Table 6-8: ASHP Age

(Base: All ASHPs)

	All ASHP
n	*11*
Min	0
Max	30
Average	10.4
Median	10.0

Table 6-9 shows the average age of sampled boilers. The mean age in years is 17.7, with a median of 13 years. The oldest system found is 64 years old. The natural gas boilers in the sample are older than the oil boilers on average, and the difference is statistically significant at the 90% confidence level (22.6 years vs. 15.7 years, respectively).

Table 6-9: Boiler Age by Fuel Type (age in years)

(Base: All boilers)

	Natural Gas	Oil (Weighted)	Pellet	Propane	All Boilers (Weighted)
n	*25*	*84*	*1*	*2*	*112*
Min	1	0	4	11	0
Max	52	64	4	15	64
Average	22.6[a,b,c]	15.7[a,d]	4[b,d,e]	13.0[c,e]	17.7
Median	23.0	12.0	4	13.0	13.0

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

Table 6-10 shows age statistics for sampled furnaces. The mean age is 15.5 years, and the median is 14.5. The oldest furnace is 40 years. Natural gas furnaces in the sample are younger on average than oil furnaces: 13.3 and 17.5 years, respectively. These differences are statistically significant at the 90% confidence level. This may also help explain the fact that AFUE values of natural gas furnaces in the sample are higher than those for oil furnaces, as shown in Table 6-5.

Table 6-10: Furnace Age by Fuel Type

(Base: All furnaces)

	Natural Gas	Oil (Weighted)	Propane	All Furnaces (Weighted)
n	*28*	*32*	*2*	*62*
Min	1	2	1	1
Max	30	40	3	40
Average	13.3[a,b]	17.5[a,c]	2.0[b,c]	15.5
Median	13.5	16.0	2.0	14.5

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

Table 6-11 shows how the age of boilers and furnaces varies in the sample based on the income status. In the sample, boilers in low-income homes appear older (21 years) than those in non-low-income homes (16 years), on average, while furnaces are slightly newer in sampled low-income homes (14 years) than in non-low-income units (15.4 years). Neither of these differences, however, is statistically significant.

Table 6-11: Mean Boiler and Furnace Age by Income Level

(Base: All boilers and furnaces)

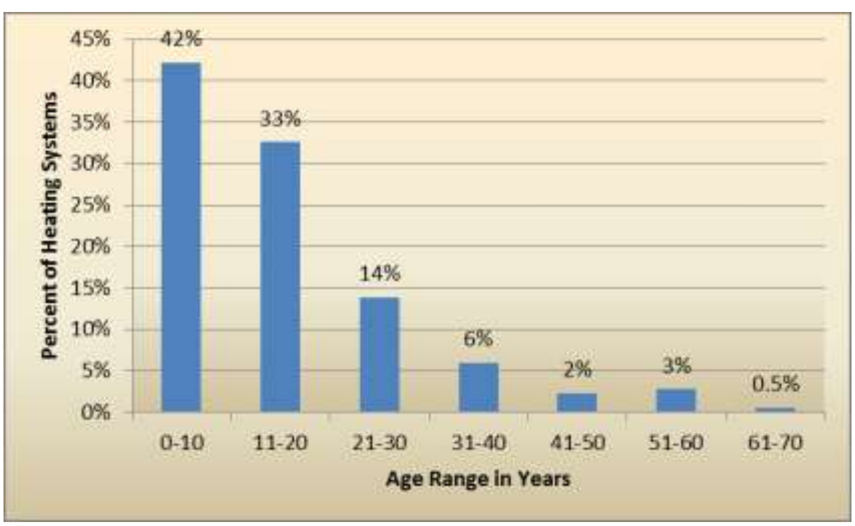
	Household Income		Statewide (Weighted)
	Low Income	Non-Low Income	
Boilers	21.0 (n=22)	16.0 (n=90)	17.7 (n=112)
Furnaces	14.0 (n=9)	15.4 (n=53)	15.5 (n=62)

The one GSHP system is two years old, as is the solar-assist system installed in an air handler. The two ductless direct vent propane furnaces are seven and eight years old. Appendix G provides more detailed breakdowns of heating system ages by system type, household income, and primary heating fuel in Table G-3 and Table G-4.

Figure 6-2 groups heating systems by their age in 10-year increments (excluding electric resistance heating systems and stoves). While 42% of heating systems are 10 years of age or newer, it is interesting to note that a full 25% of sampled heating systems are more than 20 years old. Just under a quarter of heating systems statewide (23%) are five years old or less, as the underlying data for this table shows in Appendix G, Table G-5.

Figure 6-2: Heating System Age Ranges (10-Year Increments)

(Base: All heating system types excluding stoves and electric resistance)



6.2 Cooling Systems

Statewide, 88% of homes have some kind of air conditioning (AC) system—central AC, window units, or heat pumps (Table 6-12 and Table 6-13). The percentage of sampled homes with AC is higher in non-low-income homes (90%) than low-income homes in the sample (79%), but these differences are not statistically significant at the 90% confidence level. Auditors recorded information about all AC systems present in homes, whether or not they were installed at the time of the visit. If homeowners used room air conditioners, but they were not installed at the time of the site visits, auditors asked the homeowners about the units and their locations and inspected them as if they were installed.

Table 6-12: Percent of Homes with Any Type of AC System

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Have AC	90%	83%	94%	79%	90%	88%
No AC	10%	17%	6%	21%	10%	12%

Table 6-13: Percent of Homes with Each Type of AC System Present

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Central AC	47%[a]	48%[b]	6%[a,b]	24%[c]	48%[c]	43%
Room AC	42%	33%	50%	56%[a]	37%[a]	41%
ASHP	8%[a]	4%[b]	38%[a,b]	0%[c]	12%[c]	9%
GSHP	0%	0%	6%	0%	1%	1%
No AC	10%	17%	6%	21%	10%	12%

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

It is common to have multiple room AC units: 29% of sampled homes have more than one (Table 6-14). This includes window units, through-wall units, and portable units. Only one home contains seven room AC units, the maximum found.[74]

[74] There is an expanded version of this table in Appendix G, Table G-8, that provides the same information based on a home's primary heating fuel as well.

Table 6-14: Number of Room Air Conditioning Units, by Income[75]

(Base: All homes)

		Household Income		Statewide (Weighted)
		Low Income	Non-Low Income	
Number of Homes		*34*	*146*	*180*
No room AC		44%[a]	63%[a]	59%
Have at least one unit		56%[a]	37%[a]	41%
# of RAC units in each house:	One	24%[a]	10%[a]	13%
	Two	12%	8%	9%
	Three	18%	12%	13%
	Four	0%[a]	5%[a]	4%
	Five	3%	0%	1%
	Six	0%	1%	1%
	Seven	0%	1%	1%

[a] Statistically significant difference at the 90% confidence level.

6.2.1 Capacity of Cooling Systems

Table 6-15 shows the capacity statistics of the cooling systems found in homes in tons. The mean system capacity for central AC is 2.9 tons, for room AC units is 0.64 tons (about 7,700 BTU/hr.), and for ASHPs is 1.7 tons.[76]

Table 6-15: AC System Capacity (tons)

(Base: All AC systems with known capacities)

	Central AC (Weighted)	Room AC (Weighted)	ASHP (Ducted Systems)**	ASHP (Ductless)**	GSHP
n	*92*	*158*	*8*	*17*	*1*
Min	1.0	0.42	1.5	0.5	3.7
Max	5.0	1.50	6.0	2.6	3.7
Average	2.9	0.64	2.7	1.3	3.7
Median	3.0	0.50	2.0	1.0	3.7
Counts of systems of unknown size*	2	22	0	0	0

*The counts for unknown values are not includes in the sample sizes and data in the rest of the table.
Not tested for significance because system sizes are not comparable across system type.
**The count of ASHP's here is higher than it is in the heating section of this report because some homeowners were only using ASHP's for cooling purposes.

[75] The number of room air conditioning units is not dependent on or related to the primary heating fuel of a home. Therefore, we do not display the differences in room AC counts based on primary heating fuel—only on income.

[76] Confirming the size of room AC units could be difficult at times, because they were, for example, sometimes inaccessible or missing labels.

6.2.2 Efficiency of Cooling Systems

In most cases, auditors recorded AC efficiency data provided by AHRI or the manufacturer, or AHAM for room air conditioners. When those values were not available, auditors used RESNET's age-based default efficiency values. Counts for the number of systems where auditors relied on age-based efficiencies are provided in the efficiency tables.

Table 6-16 shows efficiency statistics of the AC systems in sampled homes. The SEER of central AC systems ranges from 7.4 to a high of 16.0, with a mean of 11.3 and a slightly lower median of 10.4. Room AC units have EER values ranging from 6.1 to 11.1, with a mean and median of 9.7. The mean SEER of the ducted split ASHP systems is 11.9, with a range from 10 to 18 SEER. For the ductless ASHP systems with SEER ratings, the mean SEER is 17.7, with a wide range from 10 to 26 SEER. (The two ductless ASHPs whose manufacturers provide EER ratings only are 10.0 and 11.7 EER.[77]) There is one GSHP in the sample with an overall EER of 17.9.

Table 6-16: AC Efficiency by System Type
(All AC systems with known efficiencies)

	Central AC (SEER) (Weighted)	Room AC (EER) (Weighted)	ASHP-Ducted Systems (SEER)	ASHP-Ductless[78]		GSHP (EER)
				SEER	EER	
n	*94*	*172*	*8*	*15*	*2*	*1*
Min	7.4	6.1	10.0	10.0	10.0	17.9
Max	16.0	11.1	18.0	26.0	11.7	17.9
Average	11.3	9.7	11.9	17.7	10.9	17.9
Median	10.4	9.7	10.0	18.0	10.9	17.9
Count of systems using age-based defaults*	9	37	0	0	0	0
Count of systems with unknown efficiency**	0	8	0	0	0	0

*These are included in the above counts and statistics.
**These are *not* included in the above counts and statistics.

[77] ASHPs are split into SEER and EER because manufacturers of some systems provide only one or the other type of rating.
[78] Ductless ASHPs were all ductless mini-splits except for one packaged system.

Table 6-17 shows that the efficiency of central and room AC systems does not significantly vary between low-income and non-low-income households in the sample, bearing in mind that the sample size of low-income central AC systems is quite small (9 systems) compared to the 85 in non-low-income homes.[79,80]

Table 6-17: Mean Central and Room AC Efficiency by Income Level

(Base: All AC systems with known efficiencies)

	Units	Household Income		Statewide (Weighted)	Count of Systems with Unknown Eff.*
		Low Income	Non-Low Income		
Central AC	SEER	11.3 (n=9)	11.3 (n=85)	11.3 (n=94)	0
Room AC	EER	9.8 (n=39)	9.7 (n=133)	9.7 (n=172)	8

*These are *not* included in the counts and statistics in the rest of the table.

6.2.3 Age of Cooling Systems

Table 6-18 describes the ages of the different types of AC systems in the sample. On average, central AC systems are older than room AC units—11.4 and 8.5 years old, respectively. This is only a difference of about two years, but it is statistically significant at the 90% confidence level. The age range for central AC systems and room AC units is comparable; the oldest of each is around 40 years old, while the oldest ASHP is an original system from a home built in 1982 (30 years old). The one GSHP in the sample is relatively new, only two years old.

Table 6-18: AC Age (age in years)

(Base: All AC systems with known ages)

	Central AC (Weighted)	Room AC (Weighted)	ASHP	GSHP
n	*88*	*158*	*24*	*1*
Min	0	0	0	2
Max	38	42	30	2
Average	11.4[a,b]	8.5[a]	8.2[b]	2
Median (Unweighted)	10.0	8.0	7.0	2.0
Count of systems with unknown age**	6	22	1	0

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

*The counts for unknown values are not included in the sample sizes and data in the rest of the table.

[79] Heat pumps are not included in this table because there are no heat pumps in the sampled low-income homes.

[80] An expanded version of this table can be found in Appendix G (Table G-11), which shows the variation in AC efficiency by the home's primary heating fuel and by household income.

Table 6-19 shows how the age, like the efficiency, of central and room AC systems does not significantly vary between low-income and non-low-income households, again bearing in mind that the sample size of low-income central AC systems is small.[81,82]

Table 6-19: Mean AC System Age by Income Level (age in years)

(Base: All AC systems with known ages)

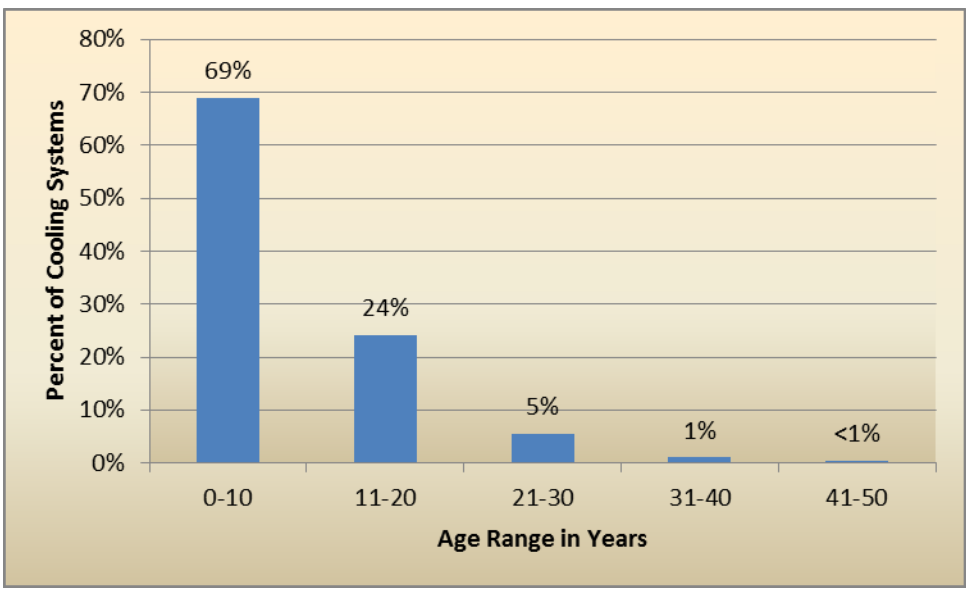
	Household Income		Statewide (Weighted)	Count of systems with unknown age*
	Low Income	Non-Low Income		
Central AC	14.3 (n=7)	11.1 (n=81)	11.4 (n=88)	6
Room AC	8.3 (n=37)	8.6 (n=121)	8.5 (n=158)	22

*The counts for unknown values are not includes in the sample sizes and data in the rest of the table.

Figure 6-3 groups AC systems by their age in 10-year increments. Of all AC systems in the sample, 69% are 10 years old or less, 24% are between 10 and 20 years, and the remaining 7% are more than 20 years old. Just under a third of all air conditioners (32%) are five years old or less, as shown in Appendix G in Table G-13, which includes the more detailed data underlying Figure 6-3.

Figure 6-3: Cooling System Age Ranges

(Base: All AC systems)



[81] The 25 ASHPs and 1 GSHP used for cooling are only in non-low-income homes, and are not included in this table.

[82] An expanded version of this table can be found in Appendix G (Table G-12), which shows the variation in AC system age by the home's primary heating fuel.

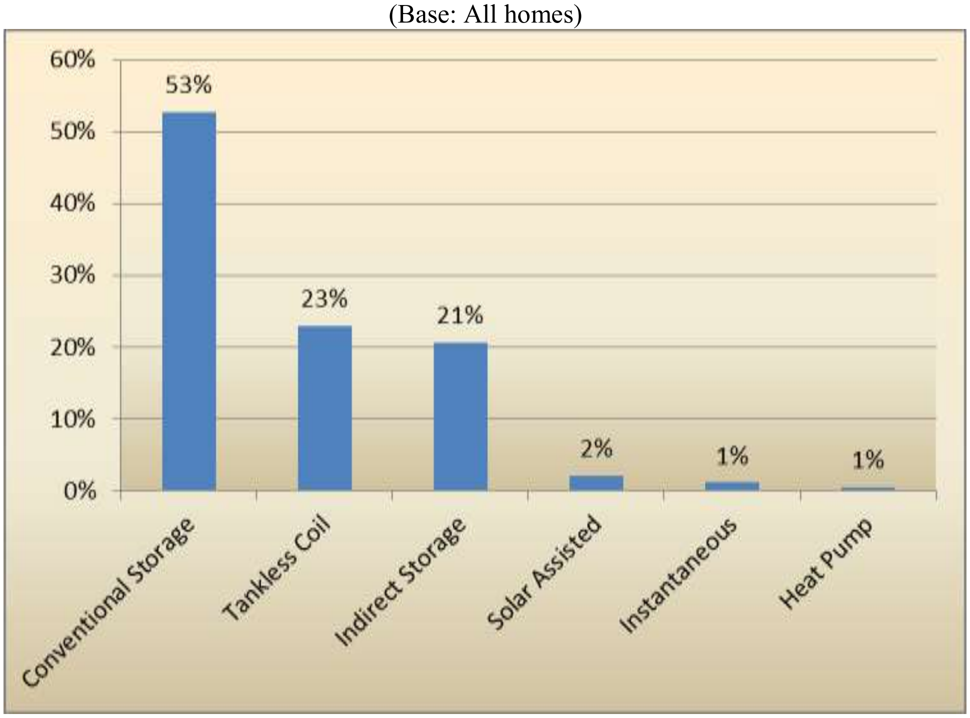
6.3 Water Heating

6.3.1 Types of Water Heaters

Most homes in the sample (176 of 180) have just one water heater installed. Figure 6-4 shows the percentage of homes with each type of water heater found: 53% of homes have conventional storage tank water heaters, 23% have boiler heating systems with tankless coil water heating, 21% have indirect storage tank systems that use the home's boiler heating system to heat water, and the remaining 4% includes four solar-assisted water heaters[83] (2%), two instantaneous water heaters (1%), and a single heat pump water heater (less than 1%).

Figure 6-4: Percent of Homes with Each Type of Water Heater

(Base: All homes)



[83] This is a category for any solar-assisted system, of which there were multiple types. However, in all four cases, the solar-assisted system was the only hot water system.

Table 6-20 provides a more detailed breakdown of the types of water heating systems found in sampled homes, with information on how the system types vary depending on the home's primary heating fuel and household income. The type of water heater in a home varies significantly depending on the home's primary heating fuel. For example, homes with natural gas or electricity as the primary heating fuel have a much higher percentage of conventional storage water heaters (91% and 81%, respectively) compared to only 35% of homes in the oil and other fuels category.[84] Homes in the oil and other fuels category tend to have a more even distribution between the three top water heater types: conventional storage tanks (35%), tankless coils (33%), and indirect storage tanks (28%); these differences across primary heating fuel are statistically significant at the 90% confidence interval. The difference in water heater types is less dramatic between low-income and non-low-income homes; 62% of low-income homes have conventional storage tanks compared to 51% in non-low-income homes, but these differences are not statistically significant at the 90% confidence level.

Table 6-20: Percent of Homes with Each Type of Water Heater, by Primary Heating Fuel and Income

(Base: All homes)

	Primary Heating Fuel*			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Conventional Storage	35%[a,b]	91%[a]	81%[b]	62%	51%	53%
Tankless coil	33%[a,b]	2%[a]	0%	21%	23%	23%
Indirect Storage	28%[a,b]	7%[a,c]	0%[b,c]	18%	21%	21%
Solar Assisted	2%	0%	13%	0%[d]	3%[d]	2%
Instantaneous	2%	0%	0%	0%	1%	1%
Heat Pump	0%	0%	6%	0%	1%	1%

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

* There were 39 conventional electric storage tank water heaters found in the sample; 24 of these were found in homes in the "Other Fuels" primary heating fuel category. Twelve were found in electric-heat homes, and only three were in homes with natural gas as the primary heating fuel.

Table 6-21, on the other hand, provides more information about the water heaters themselves, by providing counts of each system type found, and the percentage of each type fueled by either natural gas, propane, oil, or electricity. Among the 184 water heaters found (in the 180 sampled homes), 50% were oil-fired, 23% each were electric and fired by natural gas, and only 4% were propane-fired. Among the conventional storage tanks, 46% were electric. In addition, 98% of the

[84] This difference may be partially explained by the fact that oil heated homes are more likely to have boilers than homes heated by natural gas and electricity. As a result, homes heated by oil are more likely to have indirect storage tank water heaters or tankless coil water heaters.

tankless coil water heaters were located within oil-fired boilers, and 86% of indirect storage tanks were also connected to oil-fired boilers.

Table 6-21: Water Heater Fuel by System Type
(Base: All DHW Systems)

	Conventional Storage (Weighted)	Tankless Coil (Weighted)	Indirect Storage (Weighted)	Solar Assisted	Instant	Heat Pump	All Water Heaters (Weighted)
n	*100*	*40*	*37*	*4*	*2*	*1*	*184*
Natural gas	24%	2%	9%	0 (0%)	0 (0%)	0 (0%)	23%
Propane	5%	0%	5%	0 (0%)	2 (100%)	0 (0%)	4%
Oil	25%	98%	86%	2 (50%)	0 (0%)	0 (0%)	50%
Electric	46%	0%	0%	2 (50%)	0 (0%)	1 (100%)	23%
Total	100%	100%	100%	100%	100%	100%	100%

Table 6-22 describes the type and fuel source of all water heaters found in the sample (184 systems). In the rows it shows the percentage of water heaters that are powered by each fuel type (natural gas, propane, oil, and electricity), and in the columns it shows the percentage of each type of water heating system found (conventional storage, tankless coils, and so forth). Just over half (54%) of the water heaters in the sample were conventional storage tank water heaters, tankless coils were 22% of the sample, indirect storage tanks were 21%, and solar, instantaneous, and heat pump water heaters combined make up the small remainder (about 4%). By far, the four most common system types found were: 1) electric storage tank water heaters (22% of the sampled units), 2) oil-fired tankless coils (22%), 3) natural gas-fired storage tanks (21%), 4) oil-fired indirect storage tanks (18%), and 5) oil-fired conventional storage tanks (9% of systems). The other individual system types (natural gas-fired indirect tanks, propane instantaneous systems, etc.) each made up no more than 2% of all water heaters found.

Table 6-22: All Water Heaters, by Fuel and System Type
(Base: All DHW systems; all percentages weighted)

		Conventional Storage	Tankless Coil	Indirect Storage	Solar Assisted	Instant	Heat Pump	Total (All Water Heaters)
	n	*100*	*40*	*37*	*4*	*2*	*1*	***184***
Natural gas	44	21%	1%	2%	0 (0%)	0 (0%)	0 (0%)	**23%**
Propane	7	2%	0%	1%	0 (0%)	1 (1%)	0 (0%)	**4%**
Oil	91	9%	22%	18%	2 (1%)	0 (0%)	0 (0%)	**50%**
Electric	42	22%	0%	0%	2 (1%)	0 (0%)	1 (1%)	**23%**
Total	**184**	**54%**	**22%**	**21%**	**2%**	**1%**	**1%**	**100%**

6.3.2 Water Heater Tank Size

Most inspected water heating systems (141 out of 184) have storage tanks. This includes conventional storage tank water heaters, but also indirect tanks, solar heating systems with tanks, and a single heat-pump water heater. The most common tank sizes are 40 gallons (27%) and 50 gallons (29%). Table 6-23 shows that 23% of water heaters with tanks are between 20 and 39 gallons, 32% are 40 to 45 gallons, 29% are 50 gallons, 14% are 60 to 81 gallons, and the remaining 2% are 100 to 135 gallons.

Table 6-23: Volume of Water Heater Tanks (gallons)

(Base: All water heaters with storage tanks)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n – number of DHW systems in each category	*80*	*45*	*16*	*28*	*113*	*141*
20-39	30%[a,b]	9%[a,c]	0%[b,c]	21%	19%	23%
40-45	29%[a,b]	51%[a,c]	0%[b,c]	50%[d]	28%[d]	32%
50	28%[a]	22%[b]	69%[a,b]	18%[c]	34%[c]	29%
60-81	13%	16%	25%	11%	16%	14%
100-135	1%	2%	6%	0%[a]	3%[a]	2%

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

Table 6-24 breaks down conventional, storage tank water heaters into the same size categories as identified above (Table 6-21) and by the fuel of the water heater itself. (The previous table includes all storage tank systems, including solar-assisted systems, indirect tanks, etc.; this table is conventional tanks only.)

Table 6-24: Volume of Conventional Storage Tank Water Heaters (gallons)

(Base: All conventional storage tank water heaters)

	Natural Gas (Weighted)	Propane	Oil	Electric (Weighted)
n	*40*	*4*	*17*	*39*
20-39	10%	1 (25%)	59%	3%
40-45	59%	0 (0%)	0%	24%
50	20%	2 (50%)	35%	52%
60-81	10%	1 (25%)	6%	21%
100-135	2%	0 (0%)	0%	0%

The U.S. federal government updated the required energy efficiency standards for water heaters, and these will take effect in 2015. The efficiency requirements are based on the size and fuel of the water heater. Table 6-25 (natural gas- and propane-fired water heaters), Table 6-26 (oil-fired), and Table 6-27 (electric) group the conventional tank water heaters found in the study into size categories that correspond to those 2015 federal standards.

Table 6-25: Natural Gas and Propane Conventional Storage Tank Water Heater Size, Grouped by 2015 Federal Appliance Standard Size Categories[85]
(Base: All natural gas and propane-fired conventional storage tank water heaters)

	Natural Gas (Weighted)	Propane
n	*40*	*4*
≤55 gallons	88%	3 (75%)
>55 gallons	12%	1 (25%)

Table 6-26: Oil Conventional Storage Tank Water Heater Size, Grouped by 2015 Federal Appliance Standard Size Categories
(Base: All oil-fired conventional storage tank water heaters)

	Oil
n	*17*
≤50 gallons	94%
>50 gallons	6%

Table 6-27: Electric Conventional Storage Tank Water Heater Size, Grouped by 2015 Federal Appliance Standard Size Categories
(Base: All electric conventional storage tank water heaters)

	Electric (Weighted)
n	*39*
≤55 gallons	79%
>55 gallons and ≤120 gallons	21%

6.3.3 Water Heater Energy Factor

Like with heating systems and air conditioners, obtaining the energy factor (EF) of water heaters in existing homes can involve consulting multiple sources. Auditors typically used AHRI or manufacturer data. Some commercial and large water heaters do not have rated energy factors; auditors used the RESNET Energy Factor Calculator for Commercial DHW Tanks[86] to estimate it in those rare cases. If no efficiency ratings were available, auditors recorded the age-based default efficiencies from RESNET standards, as noted in the bottom of the following tables.

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85 Available at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/27#standards.

86 Available here: http://www.resnet.us/uploads/documents/standards/Commercial_Hot_Water_EF_Calculator_12-10.xls; accessed May 23, 2013.

Most of the conventional storage tank water heaters in the sample are either natural gas-fired (40 out of 100), or electric (39 out of 100). Table 6-28 shows the energy factor statistics of conventional storage tank water heaters, separated by fuel type. The fossil fuel fired conventional storage tank water heaters all have similar mean energy factors (0.58 for natural gas, 0.61 for the four propane systems, and 0.57 for oil).

Table 6-28: Conventional Storage Tank Water Heater Energy Factor by Fuel Type

(Base: All conventional storage tank water heaters)

	Natural Gas (Weighted)	Propane	Oil	Electric (Weighted)
n	*40*	*4*	*17*	*39*
Min	0.48	0.54	0.47	0.86
Max	0.65	0.65	0.63	0.93
Average	0.58	0.61	0.57	0.89
Median	0.59	0.62	0.56	0.90
Count of systems using age-based defaults*	2	0	3	3

*These are included in the above counts and statistics.

Of the 37 indirect tank water heaters, all but four are attached to oil-fired boilers. The average energy factor of all indirect tank water heaters is 0.77 (Table 6-29). The energy factor of an indirect tank water heater is a function of the AFUE of the boiler to which it is attached; the energy factor is calculated by multiplying the boiler AFUE by 0.92. The fuel in the following table represents the fuel of the boiler to which the indirect tank is attached.

Table 6-29: Indirect Tank Energy Factor by Fuel Type

(Base: All indirect DHW tank systems)

	Natural Gas	Propane	Oil (Weighted)	All Indirect w/Tank DHW (Weighted)
n	*3*	*1*	*33*	*37*
Min	0.76	0.80	0.60	0.60
Max	0.83	0.80	0.81	0.83
Average	0.79	0.80	0.76	0.77
Median	0.78	0.80	0.77	0.78
Count of systems using age-based defaults*	0	0	3	3

*These are included in the above counts and statistics.

The average energy factor of boilers providing domestic hot water through tankless coils in the sample is 0.51 (Table 6-30). The fuel listed in the table below represents the fuel of the boiler in which the tankless coil is located; 39 of the 40 tankless coil systems are in oil boilers. Consistent with the NEHERS manual, the energy factor for tankless coil water heating systems is estimated based on the potential occupancy of the home (number of bedrooms plus one): 0.45 for three occupants, 0.50 for four occupants, 0.55 for five occupants, 0.60 for six occupants, and 0.65 for seven occupants.

Table 6-30: Tankless Coil EF by Fuel Type, based on Occupancy

(Base: All tankless coil DHW systems)

	Natural Gas	Oil (Weighted)	All Tankless Coils (Weighted)
n	*1*	*39*	*40*
Min	0.50	0.45	0.45
Max	0.50	0.60	0.60
Average	0.50	0.51	0.51
Median	0.50	0.50	0.50

Table 6-31 describes the energy factor of the only two instantaneous water heaters in visited homes; both are propane-fired.

Table 6-31: Instantaneous Water Heater EF

(Base: All instantaneous DHW systems)

	Propane
n	*2*
Min	0.80
Max	0.82
Average	0.81
Median	0.81
Count of systems using age-based defaults	0

There is also one heat-pump water heater attached to an electric storage tank. Auditors estimated its energy factor at 2.0, based on RESNET default efficiencies for heat pump water heaters.

Auditors did not calculate energy factors for the four solar-assisted water heaters. They are all different from one another and uniquely designed.

Table 6-32 shows how, in most cases, the efficiency of common water heater types does not vary significantly depending on the home's household income level.[87]

Table 6-32: Mean Water Heater Energy Factor by Income Level

(Base: Common water heater types)[88]

	Household Income		Statewide (Weighted)
	Low Income	Non-Low Income	
Conventional Storage (non-electric)	0.58 (n=12)	0.58 (n=49)	0.58 (n=61)
Conventional Storage (electric)	0.90 (n=10)	0.89 (n=29)	0.89 (n=39)
Indirect Storage	0.76 (n=6)	0.77 (n=31)	0.77 (n=37)

6.3.4 Age of Water Heaters

Table 6-33 compares the age statistics of different types of water heaters in sampled homes. The mean water heater age is 11 years. Tankless coils are the oldest water heaters; the oldest is 64 years old, and the next oldest is a solar-assisted tankless coil, at 60 years old. The most common water heater type, conventional storage tanks, is just over nine years old on average, and the oldest is 38 years.

Table 6-33: Water Heater Age by System Type (age in years)

(Base: All DHW systems)

	Conventional Storage (Weighted)	Tankless Coil (Weighted)	Indirect Storage (Weighted)	Solar Assisted	Instantaneous	Heat Pump	All Water Heaters (Weighted)
n	*93*	*40*	*34*	*4*	*2*	*1*	*174*
Min	0	3	1	2	3	12	0
Max	38	64	18	60	10	12	64
Average	9.3[a,b]	16.9[a,c,d]	9.0[c,e]	23.5[b,e,f]**	6.5[d,f]	12	11.0
Median	8.0	11.5	8.0	16	6.5	12	9.0
Count of systems with unknown age*	7	0	3	0	0	0	10

[a,b,c,d,e,f] Statistically significant difference at the 90% confidence level.

*The counts for unknown values are not included in the sample sizes and data in the rest of the table.

**Mean value is high due to one 60-year-old system. Without that one old boiler, the mean would be around 11 years old.

[87] An expanded version of this table can be found in Appendix G (Table G-16), which shows the variation in water heater age by the home's primary heating fuel.

[88] This table excludes instantaneous, heat pump, and solar systems, which do not exist in more than one of each of the categories being compared. Tankless coils are also excluded because their EF is a function of occupancy, not system performance.

Table 6-34 provides a detailed breakdown of the mean age of different types of water heaters and compares these values across household income levels. There are no statistically significant differences in mean ages for low-income and non-low-income systems when they are compared at this detailed level.

Table 6-34: Mean Water Heater Age by Income Level (age in years)

(Base: All DHW system types found in low- and non-low-income homes[89])

	Household Income		Statewide	Count of systems with unknown age*
	Low Income	Non-Low Income		
Conventional Storage	7.9 (n=18)	9.0 (n=75)	9.3 (n=93) (Weighted)	7
Indirect Storage	9.7 (n=6)	8.7 (n=28)	9.0 (n=34) (Weighted)	3
Tankless coil	13.3 (n=4)	17.0 (n=30)	16.9 (n=40) (Weighted)	0

[a] Statistically significant difference at the 90% confidence level.

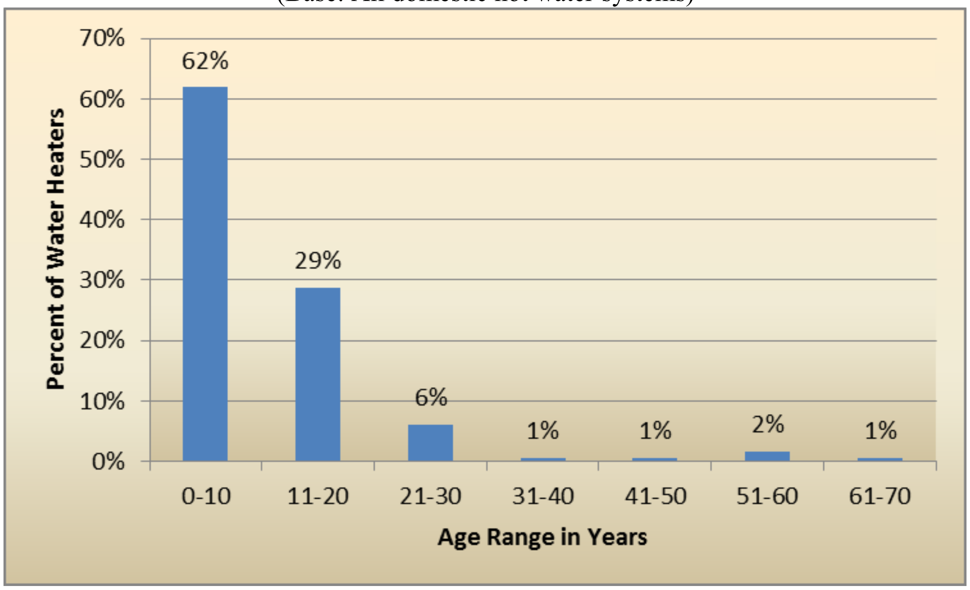
Appendix G provides slightly more detailed breakdowns of water heater ages by system type, household income, and primary heating fuel. Table G-15 provides a detailed breakdown of the mean age of different types of water heaters and compares these values across primary heating fuels and household income levels.

[89] Instantaneous, heat pump, and solar-assisted water heaters are not included in this table because, in the sample, these types of systems are only found in non-low-income homes. Statewide average ages for these systems can be found in Table 6-33.

Figure 6-5 groups water heaters by their age in 10-year increments. Of all water heaters in the sample, 62% are ten years old or less, 29% are between 10 and 20 years, and the remaining 9% are more than 20 years old. Just under one-third of water heaters statewide (32%) are five years old or less, as shown Table G-16.

Figure 6-5: Water Heater Age Ranges (10-Year Increments)

(Base: All domestic hot water systems)



7 Diagnostics

The Team, together with the HES vendors, performed two different types of diagnostic tests—air leakage and duct leakage. They successfully measured air leakage at 156 of the 180 site visits, but the evaluators were unable to conduct blower door tests at 24 sites due primarily to the presence of asbestos, vermiculite, or mold. Similarly, the Team was only able to conduct duct leakage tests at 73 out of 97 homes with duct systems. The presence of asbestos and/or mold and unreachable registers were the primary reasons that duct blasters were not conducted at 24 sites with duct work.

7.1 Estimating Air Leakage

In order to model each of the 180 homes in REM/Rate, the evaluators had to estimate air leakage for each of the 24 homes in which blower door tests were not conducted.[90] The Team did this by leveraging data from the homes for which it did have blower door measurements and the results of a model previously developed by Lawrence Berkeley National Laboratory (LBNL). Beginning in 2006, and updated in 2011, LBNL developed a statistical model to determine which characteristics (e.g., floor area, building age, income status, etc.) influence building shell leakage.[91,92] The model suggests that income status, participation in an energy efficiency program, building age, and building floor area were the characteristics with the most significant impact on air leakage.

Based on the findings of the LBNL study, the Team created a number of bins to summarize the leakage results for 142 of the 156 sites where blower door tests were conducted.[93] Ultimately, the evaluators created eight unique bins, two for low-income households and six for non-low-income households, based on home age and building size in order to apply air leakage estimates to each of the 24 sites that did not receive blower door tests. Given the small sample sizes in the low-income bins, the evaluators decided to base the estimates on building age alone, as breaking the data down by home age and building size resulted in sample sizes that were too small. Table 7-1 shows the bins and estimated air leakage values for low-income homes and Table 7-2 shows the same information for non-low-income homes. Each table, from left to right, presents the key variables in each bin, the number of observations that went into each bin, the number of homes

[90] There are no default values for air leakage in REM/Rate. In order to produce the outputs required to assess the weatherization status of each home, it was necessary to estimate air leakage values for these sites.

[91] Lawrence Berkeley National Laboratory. *Development of a Mathematical Air-Leakage Model from Measured Data*. By Jennifer McWilliams and Melanie Jung. LBNL-59041 (Washington, D.C: United States Government Printing Office, 2006).

[92] Lawrence Berkeley National Laboratory. *Preliminary Analysis of U.S. Residential Air Leakage Database v.2011*. By Wanyu R. Chan and Max H. Sherman. LBNL-5552E (Washington, D.C: United States Government Printing Office, 2011).

[93] The evaluators removed the 14 households with blower door tests that had previously taken part in HES because most of the homes lacking blower door tests had not taken part in the HES program; leaving them in would have created a biased model that did not represent most of the homes that lacked blower-door tests.

that the estimates apply to (out of the 24 sites with missing information), and the estimated average leakage values. As shown, the leakage estimates ranged from 10.5 to 22.1 ACH50 for low-income homes and 6.9 to 16.0 ACH50 for non-low-income homes. The Team applied these estimates to the 24 homes lacking blower door measurements based on income status, building age, and, where applicable, building size.

Table 7-1: Estimated Air Leakage for Low-Income Homes—Inputs and Outputs

Building Age	# of Homes with Blower Door Measurements	# of Homes Estimate Applied To (without Blower Door Measurement)	Average ACH50 Value
1880-1910	7	5	22.1
1911-2007	19	2	10.5

Table 7-2: Estimated Air Leakage for Non-Low-Income Homes—Inputs and Outputs

Building Age	Building Size (s.f.)	# of Homes with Blower Door Measurements	# of Homes Estimate Applied To (without Blower Door Measurement)	Average ACH50 Value
1820-1920	All sizes	10	5	16.0
1922-1960	776-1,544	20	7	13.7
	2,574-3,479	9	2	9.2
1962-1999	776-1,544	31	2	10.9
	2,574-3,479	31	1	8.1
2000-2009	All sizes	15	0	6.9

7.2 Air Leakage Results

The auditors developed two separate sets of results for air leakage. One set of results includes only the 156 homes at which the Team performed blower door tests; the second set of results also includes the 24 homes for which the Team estimated ACH50.

In order to comply with the prescriptive air leakage requirements of the current weatherization standard, homes must have nine or fewer air changes per hour at 50 Pascals (ACH50). Forty-four percent of the 156 homes where blower door tests were conducted complied with the weatherization prescriptive requirement (Table 7-3). Homes heated with electricity as a primary fuel were significantly more likely to comply with the standard than homes heated with either natural gas or oil and other fuels were (69% for electricity vs. 40% for natural gas and 44% for oil and other fuels, respectively). Electrically heated homes are less likely than homes heated by other fuels to have certain penetrations (e.g., duct work or boiler pipes running from conditioned to unconditioned space) that tend to increase air leakage. Additionally, electrically heated homes were found to be significantly younger than homes that heat with natural gas (44 years old vs. 57 years old, respectively), which may also contribute to lower leakage levels (Table 4-5). Homes with low-income occupants had significantly higher ACH50 levels than homes with non-low-income homeowners (13.3 and 10.2 ACH50, respectively).

Table 7-3: Envelope Leakage Statistics — Air Changes per Hour at 50 Pascals
(Base: All sites where air leakage was tested)

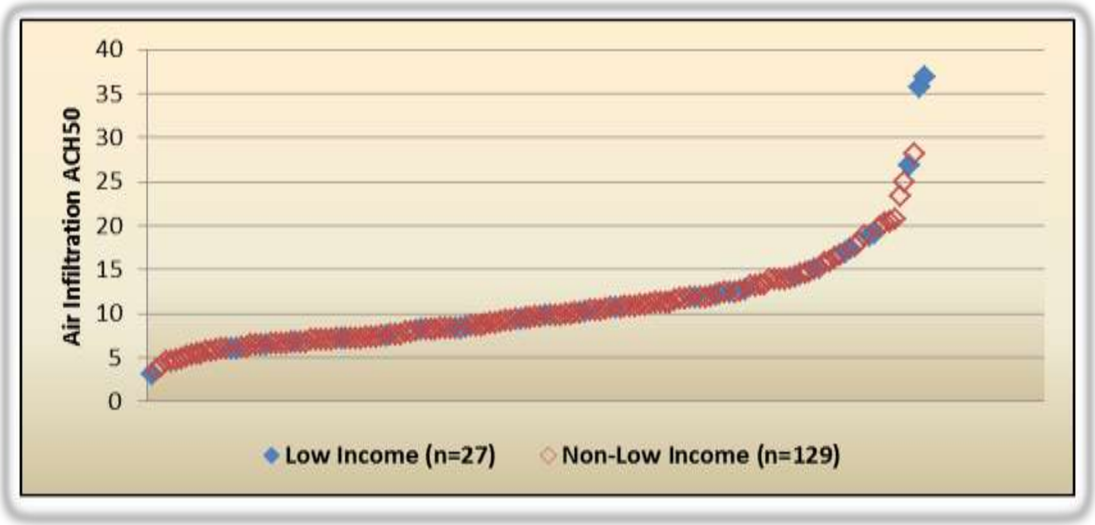
Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*103*	*40*	*13*	*27*	*129*	*156*
Min	3.1	4.0	5.4	3.1	3.6	3.1
Max	36.9	20.8	18.0	36.9	28.2	36.9
Average	11.0	10.6	9.0	13.3[a]	10.2[a]	11.0
Median	9.7	9.9	7.2	10.7	9.5	9.7
Compliance with Weatherization Standard Air Leakage Requirement (9 ACH50)						
Homes Meet or Exceed Wx Standard	44%[b]	40%[c]	69%[b,c]	37%	47%	44%
Homes Below Wx Standard	56%[b]	60%[c]	31%[b,c]	63%	53%	56%

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

Figure 7-1 graphs the ACH50 results for all low-income and non-low-income homes where blower door tests were conducted.

Figure 7-1: Air Changes per Hour at 50 Pascals—Low-Income vs. Non-Low-Income Homes*

(Base: All sites where air leakage was tested)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

As previously mentioned, the Team estimated air leakage values for the 24 homes where blower door tests were not conducted (see Estimating Air Leakage). Table 7-4 presents the air leakage results for all homes, including the 24 sites for which the evaluators had to estimate air leakage. When including the estimated air leakage in the calculations, the average air leakage statewide increases from 11.0 to 11.5 ACH50. Similarly, the statewide compliance with the prescriptive air leakage requirement decreases from 44% to 39%. This is primarily due to the fact that most of the homes missing air leakage results were older homes that had higher than average leakage estimates applied to them (see Table 7-1 and Table 7-2). As is the case when excluding estimated air leakage values, low-income homes have significantly higher air leakage levels than non-low-income homes (14.4 and 10.6 ACH50, respectively).

Table 7-4: Envelope Leakage Statistics — Air Changes per Hour at 50 Pascals

(Base: All sites, includes estimated air leakage values for 24 sites)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Min	3.1	4.0	5.4	3.1	3.6	3.1
Max	36.9	22.1	18.0	36.9	28.2	36.9
Average	11.5	11.3	9.7	14.4[a]	10.6[a]	11.5
Median	10.4	10.2	8.4	11.9	9.8	10.4
Compliance with Weatherization Standard Air Leakage Requirement (9 ACH50)						
Homes Meet or Exceed Wx Standard	39%	35%	56%	29%	42%	39%
Homes Below Wx Standard	61%	65%	44%	71%	58%	61%

[a] Statistically significant difference at the 90% confidence level.

Table 7-5 shows air leakage results by home age for all 180 homes (including the 24 homes with estimated leakage results). As shown, the average air leakage consistently increases as home age increases. This is not surprising, as awareness regarding the energy efficiency of homes has increased over time, particularly with regard to energy-efficient building codes. When comparing average air leakage across all home age groups, all of the differences are statistically significant at the 90% confidence level with the exception of 1980-1989 vs. 1990-1999 and 1990-1999 vs. 2000 or later. Similarly, compliance with the air leakage requirement in the weatherization standard steadily decreases as home age increases.

Table 7-5: Envelope Leakage Statistics by Home Age
(Base: All sites, includes estimated air leakage values for 24 sites)

Statistics	Statewide Weighted					
	1939 or earlier	**1940 to 1959**	**1960 to 1979**	**1980 to 1989**	**1990 to 1999**	**2000 or later**
n	*29*	*46*	*49*	*25*	*15*	*16*
Min	6.8	3.1	3.6	4.6	4.5	4.0
Max	35.7	36.9	19.1	18.0	11.9	14.0
Average	17.5	13.4	10.2	8.8[1]	7.8[1,2]	6.9[2]
Median	16.0	12.1	10.5	8.2	8.1	6.6
Compliance with Weatherization Standard Air Leakage Requirement (9 ACH50)						
Homes Meet or Exceed Wx Standard	17%[3]	20%[3]	35%	58%[1]	64%[1]	93%
Homes Below Wx Standard	83%	80%	65%	42%	36%	7%

[1,2,3] No statistically significant difference at the 90% confidence level. All other comparisons are statistically significant at the 90% confidence level.

7.3 Duct Leakage Results

Overall, 54% of the homes visited (97 homes) have ducts. Auditors conducted duct blaster tests at 73 sites during the onsite inspections. There were 24 additional sites where duct blaster tests could not be conducted for a variety of reasons ranging from presence of asbestos to unreachable vents.[94] The remaining 83 homes did not have duct work. As shown in Table 7-6, the average statewide duct leakage to the outside was 18.3 cubic feet per minute at 25 pascals per 100 square feet (CFM25/100 sq. ft.). Statewide compliance with the prescriptive weatherization standard requirement (16 CFM25/100 sq. ft.) is 54%. Low-income homes (22%) have a significantly lower compliance rate than non-low-income homes (63%).

Table 7-6: Duct Leakage to the Outside Statistics—CFM25/100 sq. ft.*

(Base: All sites where duct leakage to the outside tests were conducted)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*49*	*21*	*4*	*9*	*64*	*73*
Min	0.0	0.0	3.0	3.7	0.0	0.0
Max	37.3	66.7	67.3	45.0	67.3	63.3
Average	15.2	22.7	27.6	21.9	17.4	18.3
Median	14.2	16.5	20.1	18.6	14.4	15.3
Compliance with Weatherization Standard Duct Leakage to the Outside Requirement (16 CFM25/100 sq. ft.)						
Homes Meet or Exceed Wx Standard	63%	50%	25%	22%[a]	63%[a]	54%
Homes Below Wx Standard	37%	50%	75%	78%[a]	38%[a]	46%

*In cases where two or more duct systems were present the leakage values and the area served by the various duct systems were summed together to come up with one leakage value per home.

[a] Statistically significant difference at the 90% confidence level.

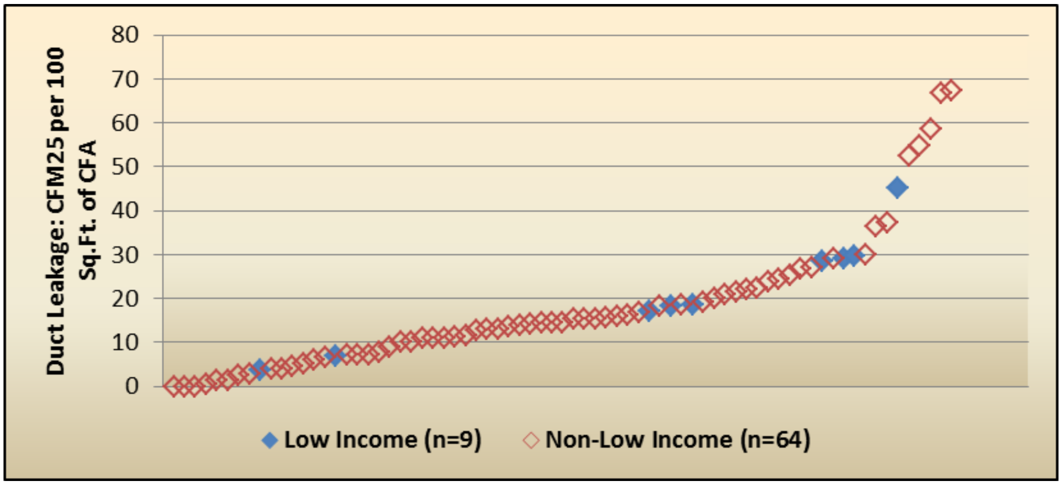
The evaluators conducted secondary research in an attempt to estimate duct leakage values for the 24 sites that had ducts but where a duct blaster test could not be conducted. Unfortunately, the Team could not find any studies that would help develop such estimates. Similarly, given that the mean leakage results across the various strata presented in Table 7-6 are not significantly different, the Team did not feel it would be appropriate to estimate leakage values based on these results.

[94] These 24 homes are not the same 24 homes that were excluded from air leakage testing, though there is some overlap. Not all of the homes with asbestos and/or mold issues had ducts, and there were some sites where the Team was able to conduct an air leakage test but unable to conduct a duct blaster test for reasons other than health concerns (e.g., unreachable vents).

Figure 7-2 graphs duct leakage to the outside for low-income and non-low-income homes where duct blaster tests were conducted.

Figure 7-2: Duct Leakage to the Outside CFM25/100 sq. ft.—Low-Income vs. Non-Low-Income Homes*

(Base: All sites where duct leakage to the outside tests were conducted)



* The x-axis in this figure was formatted to rank the homes and show trends in the y-axis variable.

Table 7-7 shows duct leakage to the outside by home age. Unlike air leakage, there is not a consistent trend in duct leakage when compared to home age. In fact, homes built from 1940 to 1959 have the lowest average duct leakage (14.1 CFM25/100 sq. ft.) across all age groups, though the average is not significantly different from newer homes (homes built in 1990 or later). Compliance with the weatherization standard ranges from 33% for homes built from 1980-1989 to 62% for homes built from 1960-1979.

Table 7-7: Duct Leakage to the Outside Statistics by Home Age

(Base: All sites where duct leakage to the outside tests were conducted)

Statistics	Statewide Weighted					
	1939 or earlier	1940 to 1959	1960 to 1979	1980 to 1989	1990 to 1999	2000 or later
n	*6*	*18*	*21*	*9*	*8*	*11*
Min	3.0	0.0	0.4	1.5	4.1	0.0
Max	66.7	29.2	54.9	67.3	27.1	36.4
Average	28.4	14.1[a]	18.3	27.4[a,b]	15.0[b]	16.0
Median	21.7	14.4	14.5	23.4	15.0	14.8
Compliance with Weatherization Standard Duct Leakage to the Outside Requirement (16 CFM25/100 sq. ft.)						
Homes Meet or Exceed Wx Standard	50%	52%	62%	33%	57%	60%
Homes Below Wx Standard	50%	48%	38%	67%	43%	40%

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

Table 7-8 shows duct leakage results broken down by the end use of the system. As shown, systems that support only cooling systems have significantly lower duct leakage (15.1 CFM25/100 sq. ft.) than systems that support both heating and cooling systems (21.6 CFM25/100 sq. ft.). This may be attributable to the fact that duct systems supporting only cooling systems are often retrofit into older homes, but are themselves newer systems that may have been installed using efficient technologies and techniques (e.g., duct mastic, installing ducts in conditioned space, etc.).

Table 7-8: Duct Leakage to the Outside Statistics by Duct System End Use

(Base: All duct systems tested for leakage to the outside)*

Statistics	Statewide Weighted		
	Heating Only	**Cooling Only**	**Both Heating and Cooling**
n	*11*	*25*	*52*
Min	0.0	0.0	0.0
Max	66.7	54.9	84.0
Average	17.9	15.1[a]	21.6[a]
Median	12.7	13.4	17.1
Compliance with Weatherization Standard Duct Leakage to the Outside Requirement (16 CFM25/100 sq. ft.)			
Homes Meet or Exceed Wx Standard	64%	68%[a]	46%[a]
Homes Below Wx Standard	36%	32%[a]	54%[a]

[a] Statistically significant difference at the 90% confidence level.

8 Duct Insulation

Fifty-four percent of the homes visited have ducts. Statewide, supply ducts are most likely found exposed in attics (36%), conditioned spaces (28%), or an unconditioned basement (28%) (Table 8-1). Sixty-three percent of supply ducts are insulated with fiberglass wrap, while 33% are uninsulated. Metal (56%) and flexible ducts (40%) are the two most common supply duct types. Supply duct insulation R-values range from R-0 to R-8.3 with an average R-value of R-3.3 and median R-value of R-4.0.

Like supply ducts, return ducts are most commonly found in conditioned spaces (37%), unconditioned basements (35%), and exposed in attics (19%). Fifty percent of return ducts are insulated with fiberglass wrap, while 44% are uninsulated. Metal (69%) and flexible ducts (23%) are the two most common return duct types. Return duct insulation R-values range from R-0 to R-8.3, with an average R-value of R-2.6 and median R-value of R-2.6.

Table 8-1: Characteristics of Ducts and Duct Insulation

(Base: All homes with ducts)

	Statewide Weighted	
	Supply	**Return**
Number of Homes with Ducts	*97*	*97*
R-Value Statistics		
Minimum	0.0	0.0
Maximum	8.3	8.3
Average	3.3[a]	2.6[a]
Median	4.0	2.6
Location		
Attic, exposed	36%[a]	19%[a]
Attic, under insulation	4%	3%
Conditioned Space	28%	37%
Unconditioned basement	28%	35%
Other unconditioned spaces	5%	5%
Insulation Type		
Fiberglass Wrap	61%[a]	50%[a]
Bubble Wrap	2%	3%
Other	5%	4%
Uninsulated	33%	44%
Duct Type		
Metal	56%[a]	69%[a]
Flexible Duct	40%[a]	23%[a]
Duct Board	4%	4%
Other	0%	3%

[a] Statistically significant difference at the 90% confidence level.

The weatherization standard for ducts located in an unconditioned basement is a minimum of R-2. Of the heating fuel types, homes that heat with electricity (100%) are most likely to meet the weatherization standard, though the sample size is small (Table 8-2). Of the homes that have ducts in unconditioned basements, more than one-half that heat with oil and other fuels (55%) and about three out of ten that heat with natural gas (29%) comply with the standard. Statewide, 47% of homes with ducts in an unconditioned basement meet the weatherization standard. The weatherization standard for ducts located in unconditioned attics and crawlspaces is a minimum of R-4.2. Of the heating fuel types, homes that heat with oil and other fuels (90%) are significantly more likely than homes that heat with natural gas (59%) to meet the standard. Statewide, 81% of homes with ducts in unconditioned attics and crawlspaces meet the weatherization standard.

Table 8-2: Ducts compared to Weatherization Standards

(Base: All homes with ducts in unconditioned basements, unconditioned attics, and crawlspaces)

	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	Statewide
Compliance with Weatherization Standard Duct Insulation in Unconditioned Basement Requirement (R-2)						
n	*31*	*14*	*2*	*6*	*41*	*47**
Homes Equal to or Exceeding Wx Standard	55%[a,b]	29%[a,c]	2 (100%)[b,c]	2 (36%)	51%	47%
Homes Below Wx Standard	45%[a,b]	71%[a,c]	0 (0%)[b,c]	4 (64%)	49%	53%
Compliance with Weatherization Standard Duct Insulation in Unconditioned Attics and Crawlspaces Requirement (R-4.2)						
n	*42*	*17*	*4*	*3*	*60*	*63***
Homes Equal to or Exceeding Wx Standard	90%[a]	59%[a]	3 (75%)	3 (100%)[d]	80%[d]	81%
Homes Below Wx Standard	10%[a]	41%[a]	1 (25%)	0 (0%)[d]	20%[d]	19%

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

*Weighted

**Unweighted due to small sample size within weighting strata

Table 8-3 displays duct work broken down by supply and return compared to the weatherization standard statewide. The weatherization standard for ducts in an unconditioned basement is R-2. Supply ducts (62%) are significantly more likely to meet or exceed the weatherization standard than return ducts (37%) in basements. The weatherization standard for duct work located in unconditioned attics/crawlspaces is R-4.2. Once again, supply ducts (83%) are more likely than return ducts (71%) to meet or exceed the weatherization standard, but the difference is not statistically significant at the 90% confidence level.

Table 8-3: Supply and Return Ducts Compared to Weatherization Standards

(Base: All homes with supply and return ducts in unconditioned basements, unconditioned attics, and crawl spaces)

	Supply (Weighted)	Return (Weighted)
Compliance with Weatherization Standard Duct Insulation in Unconditioned Basement Requirement (R-2)		
n	*47*	*46*
Homes Equal to or Exceeding Wx Standard	62%[a]	37%[a]
Homes Below Wx Standard	38%[a]	63%[a]
	Supply (Unweighted)	**Return (Unweighted)**
Compliance with Weatherization Standard Duct Insulation in Unconditioned Attics and Crawlspaces Requirement (R-4.2)		
n	*63*	*62*
Homes Equal to or Exceeding Wx Standard	83%	71%
Homes Below Wx Standard	17%	29%

[a] Statistically significant difference at a 90% confidence level.

9 Ventilation

The study investigated the presence of whole house fans and bathroom ventilation. The evaluators also searched for heat recovery/energy recovery ventilation systems (HRV/ERV), but did not find any of these systems in the 180 homes that were part of the study. Whole house fans were present at just over one out of every ten homes (12%) (Table 9-1).[95]

Table 9-1: Whole House Fan Presence

(Base: All homes)

	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	Statewide (Weighted)
n	*118*	*46*	*16*	*34*	*146*	*180*
Present	14%	7%	13%	15%	11%	12%
Not Present	86%	93%	88%	85%	89%	88%

Of all the bathroom fans (separate from the whole house fans mentioned previously) identified during the site visits (316 fans), only one was controlled by a timer. All other bathroom fans were controlled by a standard local switch.

[95] The Team did not collect details on the controls of whole house fans.

10 Renewables

Renewable generation systems such as photovoltaic and wind turbines were not commonly found at homes that participated in the study. Only four out of the 180 inspected homes have a solar-assisted water heating system, and two have photovoltaic (PV) systems installed. One PV system is 4.9 kW in size and the second is 7.2 kW. None of the homes visited has wind turbines.

11 Appliances

Table 11-1 presents the saturation levels of various appliances. All homes have at least one refrigerator and an oven/range. Nearly every home has a clothes washer and dryer (present in 99% and 98% of homes, respectively). Non-low-income homes are significantly more likely to have a clothes dryer than low-income homes. Ninety-one percent of homes statewide have dishwashers. Low-income homes are significantly less likely to have a dishwasher than non-low-income homes. Homes with electricity as the primary heating fuel are significantly more likely to have a dishwasher than homes in the other two heating fuel categories. Thirty-five percent of homes have a separate freezer, with low-income homes significantly more likely to have a separate freezer than non-low-income homes. Second refrigerators are present in 31% of homes. One percent of homes have a third refrigerator.

Table 11-1: Appliance Saturations

(Base: All homes)

Appliance	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Refrigerator	100%	100%	100%	100%	100%	100%
Oven / Range	100%	100%	100%	100%	100%	100%
Clothes washer	98%	100%	100%	94%	100%	99%
Clothes dryer	98%	98%	100%	91%[a]	100%[a]	98%
Dishwasher	94%[b]	85%[c]	100%[b,c]	74%[a]	97%[a]	91%
Separate Freezer	36%	24%	44%	50%[a]	30%[a]	35%
Second Refrigerator	32%	26%	31%	35%	30%	31%

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

11.1 ENERGY STAR® Appliances

Auditors designated appliances as ENERGY STAR® qualified if they found the ENERGY STAR logo on the appliance, found the model on a current or historical list of ENERGY STAR appliances, or determined, based on data available for the model, that it would have qualified for the then-current ENERGY STAR standard at the time of manufacture. Through this process the Team was able to determine the ENERGY STAR status for the majority of applicable appliances.[96] Statewide, 35% of refrigerators, 4% of freezers, 63% of dishwashers, and 52% of clothes washers were ENERGY STAR qualified at the time of manufacture (Table 11-2).

Table 11-2: ENERGY STAR-Qualified Appliances

(Base: ENERGY STAR qualified at time of manufacture; all appliances with ENERGY STAR data)

	Statewide Weighted			
	Refrigerators	**Freezers**	**Dishwashers**	**Clothes Washers**
n	*223*	*50*	*140*	*167*
ENERGY STAR	35%	4%	63%	52%
Non-ENERGY STAR	65%	96%	37%	48%

Table 11-3: ENERGY STAR-Qualified Appliances by Income Category

(Base: ENERGY STAR qualified at time of manufacture; all appliances with ENERGY STAR data)

	Refrigerators		**Freezers**		**Dishwashers**		**Clothes Washers**	
	Low Income	**Non-Low Income**	**Low Income**	**Non-Low Income**	**Low Income**	**Non-Low Income**	**Low Income**	**Non-Low Income**
n	*45*	*178*	*11*	*39*	*20*	*120*	*28*	*139*
ENERGY STAR	40%	34%	0%	5%	55%	68%	43%	55%
Non-ENERGY STAR	60%	66%	100%	95%	45%	33%	57%	45%

[96] In a few instances, the Team was unable to obtain any sort of efficiency information based on the model number collected onsite. As a result, a handful of appliances were not included in ENERGY STAR determinations.

11.2 Refrigerators

There is an average of 1.3 refrigerators per home statewide. Four percent of non-primary refrigerators at the audited sites were not plugged in. Second refrigerators are present in 31% of homes. One percent of homes have a third refrigerator. The largest share of refrigerators, 27%, were manufactured between 2006 and 2010, with large shares manufactured from 2001-2005 (25%) and 1996-2000 (20%) (Table 11-4). A minimum of 6% were manufactured before the first implementation of the National Appliance Energy Conservation Act (NAECA) standards in 1987.[97]

Table 11-4: Year of Manufacture for Refrigerators

(Base: All refrigerators with age data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*46*	*190*	*237*
2011-present	20%	10%	12%
2006-2010	22%	28%	27%
2001-2005	22%	25%	25%
1996-2000	20%	20%	20%
1991-1995	7%	4%	5%
1986-1990	4%	7%	7%
1981-1985	0%	3%	2%
1976-1980	2%	2%	2%
1970-1975	2%	1%	1%
Pre-1970	2%	0%	1%

[97] http://www1.eere.energy.gov/buildings/appliance_standards/history.html

Table 11-5 displays consumption information for refrigerators using verified data based on refrigerator model number and manufacturer reported consumption values. Table 11-6 presents refrigerator consumption data using verified data as well as age-based defaults for refrigerators when consumption data were unavailable. Age-based defaults are based on data from the Association of Home Appliance Manufacturers (AHAM), who provide unit energy consumption estimates for refrigerators and freezers based on vintage.[98,99,100] Consumption data are more difficult to locate for older refrigerators. Older refrigerators also tend to have higher consumption values, so limiting the analysis to refrigerators with verified consumption data results in a lower average. With verified data and age-based defaults, the statewide average consumption value is 671.1 kWh/year, with a median of 576.5 kWh/year. Using only the verified consumption data, the average is 642.5 kWh/year, with a median of 571.9 kWh/year. For reference, the average energy use for a typical refrigerator on the current ENERGY STAR list is 428 kWh/year.[101]

Table 11-5: Electricity Consumption of Refrigerators: Verified Data (kWh/year)

(Base: All refrigerators with consumption data)

Statistics	Low Income	Non-Low Income	Statewide Weighted
n	*39*	*165*	*204*
Min	253.0	316.0	253.0
Max	867.0	1,978.0	1,978.0
Average	567.6[a]	662.8[a]	642.5
Median	547.0	572.0	571.9

[a] Statistically significant difference at the 90% confidence level.

Table 11-6: Electricity Consumption of Refrigerators: Verified Data and Age-Based Defaults (kWh/year)

(Base: All refrigerators with consumption and/or age data)

Statistics	Low Income	Non-Low Income	Statewide Weighted
n	*46*	*190*	*236*
Min	253.0	316.0	253.0
Max	1,680.5	1,978.0	1,978.0
Average	651.6	675.2	671.1
Median	577.5	571.5	576.5

[98] AHAM (2010). *Trends in Energy Efficiency 2009*. July 6th, 2010.
[99] AHAM (2003). *Refrigerators Energy Efficiency and Consumption Trends*. May 23rd, 2003.
[100] http://www.nwcouncil.org/energy/rtf/meetings/2010/0629/ResFrigRecycle_FY10v2_1.zip
[101] Average energy use value for 19-21 cu. ft. refrigerators of all configurations with automatic defrost and without through-the-door ice service for the June 2013 list of approved ENERGY STAR refrigerators.

11.3 Separate Freezers

Statewide, 35% of homes have a separate freezer. Three percent of homes have two separate freezers. Four percent of separate freezers at the audited sites were not plugged in. The largest share of freezers were manufactured between 2001 and 2005 (29%) (Table 11-7). Another 25% were manufactured after 2005. There is a much larger share of separate freezers manufactured in 1990 or before (31%) than any of the other appliances examined in this study, with 20% manufactured in 1980 or before. This is notable because refrigerators and freezers manufactured before the first implementation of NAECA standards in 1993 are much less efficient than more recent models.[102]

Table 11-7: Year of Manufacture for Separate Freezers

(Base: All freezers with age data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*14*	*46*	*60*
2011-present	14%	11%	12%
2006-2010	14%	13%	13%
2001-2005	29%	28%	29%
1996-2000	14%	7%	9%
1991-1995	7%	7%	6%
1986-1990	7%	9%	8%
1981-1985	7%	2%	3%
1976-1980	0%[a]	9%[a]	7%
1970-1975	7%	11%	10%
Pre-1970	0%	4%	3%

[a] Statistically significant difference at the 90% confidence level.

[102] "Refrigerators," Energy Efficiency Standards Group of Lawrence Berkeley National Laboratory, accessed April 17, 2013, http://ees.ead.lbl.gov/projects/past_projects/refrigerators

As with refrigerators, the Team calculated consumption figures for separate freezers first using confirmed values only and then with age-based default values for freezers where consumption data were unavailable. The statewide average consumption for freezers is 683.8 kWh/year, with a median of 621.0 kWh/year when age-based default values are included (Table 11-8). The average consumption decreases to 567.6 kWh/year (median 588.5 kWh/year) when only confirmed consumption values are included in the calculations (Table 11-9). For reference, the average energy use for a typical freezer on the current ENERGY STAR list is 528 kWh/year.[103]

Table 11-8: Electricity Consumption of Separate Freezers: Verified Data and Age-Based Defaults (kWh/year)

(Base: all freezers with consumption data and/or age data)

Statistics	Low Income	Non-Low Income	Statewide Weighted
n	*16*	*44*	*60*
Min	196.0	209.0	196.0
Max	1412.5	1,460.0	1,460.0
Average	580.2	716.5	683.8
Median	522.0	665.4	621.0

Table 11-9: Electricity Consumption of Separate Freezers: Verified Data (kWh/year)

(Base: all freezers with consumption data)

Statistics	Low Income	Non-Low Income	Statewide Weighted
n	*13*	*26*	*39*
Min	196.0	209.0	196.0
Max	1,059.0	1,059.0	1,059.0
Average	507.2	592.5	567.6
Median	480.0	621.0	588.5

[103] Average energy use value for 8-24.9 cu. ft. freezers (either upright or chest configuration) without through-the-door ice service for the June 2013 list of approved ENERGY STAR freezers.

11.4 Dishwashers

Dishwashers are present in 91% of homes. The majority of dishwashers were manufactured between 2006 and 2010 (28%) or 2001 and 2005 (27%) (Table 11-10). Equal shares of dishwashers (19%) were manufactured during or after 2011 and between 1996 and 2000. Dishwashers have the largest share of recently manufactured (2011-present) units of the appliances examined in this study.

Table 11-10: Year of Manufacture for Dishwashers

(Base: All dishwashers with age data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*23*	*139*	*162*
2011-present	30%	17%	19%
2006-2010	26%	28%	28%
2001-2005	22%	28%	27%
1996-2000	17%	19%	19%
1991-1995	4%	2%	3%
1986-1990	0%[a]	3%[a]	2%
1981-1985	0%	1%	1%
1976-1980	0%	1%	1%
1970-1975	0%	1%	1%

[a] Statistically significant difference at the 90% confidence level.

11.5 Clothes Washers

Clothes washers are present in 99% of homes. The largest share, 34%, of clothes washers were manufactured between 2006 and 2010 (Table 11-11). Another 28% were manufactured between 2001 and 2005. Twelve percent of clothes washers were manufactured in or after 2011 and 12% between 1996 and 2000.

Table 11-11: Year of Manufacture for Clothes Washers

(Base: All clothes washers with age data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*32*	*146*	*178*
2011-present	11%	12%	12%
2006-2010	34%	34%	34%
2001-2005	22%	30%	28%
1996-2000	9%	12%	12%
1991-1995	9%	6%	6%
1986-1990	3%	3%	3%
1981-1985	3%	4%	4%
1976-1980	3%	0%	1%

Statewide, 59% of clothes washers are top load models as opposed to front load models (Table 11-12). Front load clothes washers tend to be more energy efficient, although there are also ENERGY STAR qualified top load models.[104]

Table 11-12: Types of Clothes Washers

(Base: All clothes washers)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*32*	*147*	*179*
Top load	72%[a]	56%[a]	59%
Front load	28%[a]	44%[a]	41%

[a] Statistically significant difference at the 90% confidence level.

11.6 Clothes Dryers

Ninety-eight percent of homes have a clothes dryer. Thirty percent of clothes dryers were manufactured between 2001 and 2005, with nearly the same share (29%) manufactured between 2006 and 2010 (Table 11-13).

Table 11-13: Year of Manufacture for Clothes Dryers

(Base: All clothes dryers with age data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*28*	*140*	*168*
2011-present	21%	8%	11%
2006-2010	14%[a]	34%[a]	29%
2001-2005	29%	30%	30%
1996-2000	11%	14%	14%
1991-1995	7%	4%	5%
1986-1990	4%	7%	6%
1981-1985	7%	2%	4%
1976-1980	7%	0%	2%
1970-1975	0%	1%	1%

[a] Statistically significant difference at the 90% confidence level.

[104] "Clothes Washers," ENERGY STAR, accessed April 17, 2013, http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=CW

A large majority of clothes dryers (88%) are electric (Table 11-14).

Table 11-14: Clothes Dryer Fuel

(Base: All clothes dryers with fuel type data)

	Low Income	Non-Low Income	Statewide (Weighted)
n	*31*	*145*	*176*
Electric	88%	88%	88%
Natural Gas	13%	10%	10%
Propane	0%	2%	2%

12 Auditor Rankings of Homes and Energy Features

For each home, auditors recommended four energy features that, in each auditor's assessment, present the largest opportunity for energy savings. Auditors ordered the recommendations from the largest opportunity (#1) to the least opportunity (#4). The energy features were chosen based on the state of the home when the auditor arrived, disregarding any improvements that may have been made during the visit by the auditor or the HES vendors. Among homes that are below the weatherization standards for performance-based compliance, the auditors most often chose air leakage as the worst energy feature (33% statewide) (Table 12-1). Ceiling insulation R-value was cited as the worst feature in 28% of this subset of homes and above-grade wall insulation R-value in 13%. Many of the sites visited for the sample were done in conjunction with an HES audit. For these sites, the HES technicians were often able to substantially improve air sealing in the home. As noted before, the auditor-chosen energy features were based on the state of the home prior to any HES improvements.

Table 12-1: Number One Worst Rated Energy Feature for Homes Below Weatherization Standard

(Base: Homes below Wx standard for performance-based compliance)

	Primary Heating Fuel			Household Income		Homes Below Wx Standard (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*88*	*36*	*8*	*29*	*103*	*132*
Air Leakage	34%	31%	3 (38%)	28%	35%	33%
Ceiling Insulation (R-value)	28%	33%	0 (0%)	31%	27%	28%
Above Grade Wall Insulation (R-value)	16%	8%	0 (0%)	17%	12%	13%
Frame Floor Insulation (R-value)	6%	8%	0 (0%)	7%	6%	6%
Duct Leakage	1%	11%	1 (13%)	7%	4%	5%
Heating System Efficiency	3%	3%	2 (25%)	0%	6%	5%
Ceiling Insulation Installation	1%	3%	0 (0%)	3%	1%	2%
Lighting-Interior	3%	0%	0 (0%)	0%	3%	2%
Foundation Wall Insulation (R-value)	2%	0%	0 (0%)	3%	1%	2%
Appliances	1%	0%	1 (13%)	0%	2%	2%
Frame Floor Insulation Installation	0%	3%	0 (0%)	0%	1%	1%
Heating System Installation Quality	1%	0%	0 (0%)	0%	0%	1%
Rim/Band Joist Insulation (R-value)	1%	0%	0%	0%	1%	1%
Window Quality	1%	0%	0%	0%	1%	1%
Heating System Type	0%	0%	1 (13%)	3%	0%	1%

Among homes that are below the weatherization standard for performance-based compliance, auditors ranked ceiling insulation (64%) and air leakage (35%) as the number one worst energy feature for HES participants and non-participants, respectively (

Table 12-2). This suggests that homeowners, who had previously participated in the HES program but did not comply with the standard, had not increased their ceiling insulation through the HES program.

Table 12-2: Number One Worst Rated Energy Feature for Homes Below Weatherization Standard by HES Participation

(Base: Homes below Wx standard for performance-based compliance)

	Participant	Non-Participant
n	*11*	*121*
Ceiling Insulation (R-value)	64%	25%
Air Leakage	18%	35%
Above Grade Wall Insulation (R-value)	18%	12%
Frame Floor Insulation (R-value)	0%	7%
Duct Leakage	0%	5%
Heating System Efficiency	0%	5%
Lighting-Interior	0%	3%
Appliances	0%	2%
Ceiling Insulation Installation	0%	2%
Foundation Wall Insulation (R-value)	0%	2%
Frame Floor Insulation Installation	0%	1%
Heating System Installation Quality	0%	1%
Heating System Type	0%	1%
Window Quality	0%	1%
Rim/Band Joist Insulation (R-value)	0%	1%

Table 12-3 shows the number one worst rated energy feature for non-compliant homes by year built. As shown, ceiling insulation was most commonly cited as the worst energy feature for homes built before 1960. Interestingly, ceiling insulation was not the worst rated feature beginning in 1980 as air leakage and duct leakage became the worst rated features for homes built from 1980-1989.

Table 12-3: Number One Worst Rated Energy Feature for Homes Below Weatherization Standard by Year Built

(Base: Homes below Wx standard for performance-based compliance)

	1939 or earlier	1940-1959	1960-1979	1980-1989	1990-1999	2000 or later
n	*27*	*44*	*41*	*13*	*5*	*2*
Ceiling Insulation (R-value)	41%	89%	66%	8%	1 (20%)	0 (0%)
Air Leakage	33%	52%	46%	39%	0 (0%)	1 (50%)
Above Grade Wall Insulation (R-value)	15%	16%	15%	0%	0 (0%)	0 (0%)
Duct Leakage	4%	0%	5%	23%	0 (0%)	0 (0%)
Frame Floor Insulation Installation	4%	0%	0%	0%	0 (0%)	0 (0%)
Heating System Installation Quality	4%	0%	0%	0%	0 (0%)	0 (0%)
Frame Floor Insulation (R-value)	0%	96%	10%	8%	2 (40%)	0 (0%)
Foundation Wall Insulation (R-value)	0%	93%	0%	0%	0 (0%)	0 (0%)
Ceiling Insulation Installation	0%	0%	68%	0%	0 (0%)	0 (0%)
Heating System Efficiency	0%	0%	7%	0%	1 (20%)	0 (0%)
Heating System Type	0%	0%	2%	0%	0 (0%)	0 (0%)
Lighting-Interior	0%	0%	2%	8%	0 (0%)	1 (50%)
Rim/Band Joist Insulation (R-value)	0%	0%	2%	0%	0 (0%)	0 (0%)
Window Quality	0%	0%	2%	0%	0 (0%)	0 (0%)
Appliances	0%	0%	0%	8%	1 (20%)	0 (0%)

Table 12-4 shows that the number one worst rated energy feature was not heavily influenced by the location of homes. Air leakage, ceiling insulation, and above grade wall insulation were still three most common worst features.

Table 12-4: Number One Worst Rated Energy Feature for Homes Below Weatherization Standard by County

(Base: Homes below Wx standard for performance-based compliance)

	Fairfield	Hartford	Litchfield	Middlesex	New Haven	New London	Tolland	Windham
n	*42*	*37*	*6*	*8*	*28*	*6*	*4*	*1*
Air Leakage	38%	27%	3 (50%)	4 (50%)	21%	3 (50%)	2 (50%)	0 (0%)
Ceiling Insulation (R-value)	24%	35%	1 (17%)	2 (25%)	29%	1 (17%)	1 (25%)	1 (100%)
Above Grade Wall Insulation (R-value)	10%	19%	0 (0%)	1 (13%)	18%	0 (0%)	0 (0%)	0 (0%)
Frame Floor Insulation (R-value)	10%	8%	0 (0%)	0 (0%)	0%	0 (0%)	1 (25%)	0 (0%)
Heating System Efficiency	7%	3%	0 (0%)	0 (0%)	0%	2 (33%)	0 (0%)	0 (0%)
Ceiling Insulation Installation	2%	0%	0 (0%)	0 (0%)	4%	0 (0%)	0 (0%)	0 (0%)
Foundation Wall Insulation (R-value)	2%	0%	0 (0%)	0 (0%)	4%	0 (0%)	0 (0%)	0 (0%)
Frame Floor Insulation Installation	2%	0%	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0 (0%)
Heating System Type	2%	0%	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0 (0%)
Window Quality	2%	0%	0 (0%)	0 (0%)	0%	0 (0%)	0 (0%)	0 (0%)
Duct Leakage	0%	5%	1 (17%)	0 (0%)	11%	0 (0%)	0 (0%)	0 (0%)
Appliances	0%	3%	0 (0%)	0 (0%)	4%	0 (0%)	0 (0%)	0 (0%)
Lighting-Interior	0%	0%	1 (17%)	0 (0%)	7%	0 (0%)	0 (0%)	0 (0%)
Heating System Installation Quality	0%	0%	0 (0%)	0 (0%)	4%	0 (0%)	0 (0%)	0 (0%)
Rim/Band Joist Insulation (R-value)	0%	0%	0 (0%)	1 (13%)	0%	0 (0%)	0 (0%)	0 (0%)

As previously mentioned, among all homes below the weatherization standard, auditors again most often chose air leakage (33%), ceiling insulation R-value (28%), and above-grade wall insulation R-value (13%) as the worst energy feature (Table 12-5). These three features, plus frame floor insulation R-value and duct leakage, were the most common second worst energy feature. Above-grade wall insulation R-value (14%), heating system efficiency (13%), and frame floor insulation R-value (10%) were the most common third worst energy feature. Auditors most often chose heating system efficiency (9%), above-grade wall insulation R-value (8%), foundation wall insulation R-value (8%), window U-value (8%), DHW system efficiency (8%), and pipe insulation (8%) as the fourth worst energy feature.

Table 12-5: Worst Energy Features by Ranking

(Base: Homes below Wx standard for performance-based compliance)

Worst Energy Feature	Homes Below Wx Standard (Weighted)			
	First	Second	Third	Fourth
n	*132*	*132*	*132*	*132*
Air Leakage	33%	20%	8%	3%
Ceiling Insulation (R-value)	28%	18%	7%	1%
Above Grade Wall Insulation (R-value)	13%	14%	14%	8%
Frame Floor Insulation (R-value)	6%	12%	10%	3%
Heating System Efficiency	5%	5%	13%	9%
Duct Leakage	5%	11%	3%	3%
Lighting-Interior	2%	1%	5%	5%
Ceiling Insulation Installation	2%	2%	3%	2%
Appliances	2%	3%	4%	6%
Foundation Wall Insulation (R-value)	2%	5%	5%	8%
Frame Floor Insulation Installation	1%	0%	1%	2%
Rim/Band Joist Insulation (R-value)	1%	3%	5%	10%
Window Quality	1%	1%	1%	4%
Heating System Type	1%	0%	0%	0%
Heating System Installation Quality	1%	0%	0%	0%
Window U-Value	0%	2%	3%	8%
DHW System Efficiency	0%	2%	7%	8%
Lighting-Exterior	0%	0%	1%	2%
Pipe Insulation	0%	1%	2%	8%
Above Grade Wall Insulation Installation	0%	0%	2%	3%
Rim/Band Joist Insulation Installation	0%	1%	2%	1%
Central Cooling System Efficiency	0%	0%	2%	2%
Slab Insulation	0%	0%	1%	0%
Duct Insulation (R-value)	0%	0%	2%	2%
Duct Insulation Installation	0%	0%	1%	2%
Foundation Wall Insulation Installation	0%	0%	1%	1%
Other	0%	0%	0%	1%

13 Inspection and Data Collection Challenges

This section discusses several key research issues that affected the data collection and analysis conducted for this study.

13.1 Data Collection Methods

Collecting information on the thermal envelope of an existing home is extremely challenging for a number of reasons. First, key envelope areas such as exterior walls and floors separating conditioned space from a garage are typically enclosed on all sides. As a result, it is difficult to assess the level and type of insulation in these components.[105] Other components, such as slab insulation and occasionally exterior foundation wall insulation, may be impossible to verify, as they are buried during construction. In these instances, auditors have to either make assumptions or utilize other sources (e.g., building plans, homeowner knowledge, etc.) to estimate the level and type of insulation present.

13.2 Time Constraints

Auditors typically had to complete two audits in a day. HERS raters who evaluate buildings during construction will often make multiple visits to the site, which allows time to review data and correct mistakes or answer questions on a return visit. It was difficult for schedulers and auditors to judge the complexity of rating a given home in advance. Time constraints due to travel, additional appointments, and the expectations of the occupant often forced auditors to move more swiftly than they typically would. Auditors still collected all of the required data in these situations, but they had to sacrifice some level of detail. For example, auditors may have taken photos of mechanical equipment and appliance model numbers as opposed to entering the information into the data collection form directly onsite. Taking photos allowed auditors to move more quickly through the home, but extended the amount of time required to complete the data collection forms in the office, as make and model information had to be transcribed from photos to the form.

13.3 Appliance Data

There are multiple, but incomplete, sources of specification data for appliances. The evaluation Team most often used the California Energy Commission Appliance Database, appliance energy data from the Federal Trade Commission, and data from ENERGY STAR. While extensive, these sources do not all include the same appliances or data items. There were some appliances that the evaluation Team could not locate in any of these sources.

[105] Infrared cameras aided in the determination of the presence of insulation for these components, but it is still challenging to assess the level and type of insulation.

13.4 Mechanical Equipment Data

Specifications for HVAC and water heating equipment are generally easier to access than appliance data thanks to the standardized AHRI Directory. This database is not comprehensive, however, especially in the case of older models. HVAC system elements that are important in determining capacity and efficiency, such as indoor coils of central A/C systems and the firing rate for burners on oil boilers, are often difficult to access or unlabeled. If efficiency specifications were not available online, auditors reached out to manufacturers (via email or a phone call) to fill in the missing specifications. This worked most of the time. That said, the evaluators still could not identify detailed efficiency specifications on some equipment, in which case auditors applied specifications from the Residential Energy Services Network (RESNET) age-based defaults for mechanical equipment.

13.5 Window U-factor and SHGC values

The U-factor and SHGC values for a window are important determinants of its efficiency. Without an NFRC rating sticker from the window, these specifications are impossible to determine in the field. This reduces the accuracy of window ratings. Auditors did not attempt to estimate these values; instead, they gathered information on the number of window panes, the framing material of the window, the presence of storm windows, and the presence of low-e coatings to aid in the assessment of window efficiency. These components all contribute to overall window efficiency and help auditors apply default U-factor and SHGC values to windows for modeling purposes.

13.6 Field Protocols and Assumptions

Nearly every home visited by the auditors raised questions of interpretation for modeling. Not all of these questions could be determined in advance of the project, so the Team developed protocols and guidance for addressing these situations based on their field experience and in consultation with the EEB evaluation and implementation consultants. The best example of interpretation has to do with defining the thermal boundary for modeling purposes. Thermal boundaries, particularly in existing homes, are not always well defined and require auditors to make judgment calls and determine the best way to collect and report on the results of a given home. For example, homes with no frame floor insulation over an unheated basement and no foundation wall insulation have a poorly defined thermal boundary. Within the building science community, there are various accepted ways to define these spaces (e.g., call the basement fully conditioned space, call the basement fully unconditioned space, etc.). For the purposes of this study, the Team developed protocols in consultation with the EEB evaluation and implementation consultants to assure consistent data collection with useful results in these questionable areas.

13.7 Occupant Behavior

The evaluation Team did not incorporate data on occupant behavior, such as utility bills, thermostat settings, line drying of clothes, etc., into the weatherization analysis. Including this information could reveal relationships between the weatherization status of a home and how the occupants use it, or the relative impact of behavior changes versus weatherization upgrades.

14 Conclusions and Recommendations

The following conclusions and recommendations are focused on possible ways to increase performance-based compliance with the current weatherization standard; some of the recommendations overlap but each stems from a unique conclusion of the baseline study. The Team makes only limited recommendations regarding the HES or HES-IE programs, as this effort did not involve impact or process analyses of those programs.[106] However, the Team believes the information contained in the report will be of vital importance in assessing more substantial changes that could be made to HES in order to help the state meet the 80% weatherization goal.[107] To that end, it is important to note that the 18 homes visited for this study that had previously participated in the HES program are only somewhat more likely to meet the weatherization requirements than the 162 homes that had not participated (39% and 25%, respectively). While the sample size of HES homes is small, the results suggest that HES participation alone does not ensure that homes will meet the weatherization standard. Therefore, several of the following recommendations focus on deeper shell-related savings opportunities that go beyond the core program measures (which include air sealing and duct sealing, among others) that the HES program can target in order to help homes meet the weatherization standard.

14.1 Weatherization Standard

Conclusion: The current weatherization standard does not address multifamily buildings, which account for approximately 36% of the housing units in the State of Connecticut.

> ***Recommendation:*** The EEB should develop a weatherization standard specific to multifamily buildings. After a multifamily standard has been developed, the EEB should consider conducting a weatherization baseline assessment of the multifamily housing stock in Connecticut.

Conclusion: Classifying basements as "conditioned" or "unconditioned" can be challenging in existing homes and as a result is often left to the discretion of the auditor. The final classification can have a significant impact on the compliance of homes with the weatherization standard as multiple measures address basement insulation and the designation of a basement as "conditioned" or "unconditioned" influences the results of diagnostic tests (i.e., air and duct leakage tests).

[106] From here on, both of these programs will be referred to as HES.

[107] The Residential Evaluation Team is currently engaged in an impact evaluation of HES and HES-IE that relies on billing analyses to estimate measure-specific and overall program energy savings. The Team is working with the EEB Evaluation Consultant to plan HES and HES-IE process evaluations that address concerns about depth of savings. Depending on the results of these studies, they may result in concrete suggestions on ways to increase program savings as well as achievement of the 80% weatherization goal.

> ***Recommendation:*** The EEB should consider the best way to address basements in the weatherization standard. The current standard suggests that homeowners should insulate the frame floor separating a conditioned first floor from an unconditioned basement. In some cases, this suggestion may be contradictory to sound building science. Additionally, there may be limited cost-effective savings from insulation retrofits in these cases as the temperature change is typically not that dramatic between a first floor and a basement. Moreover, insulation installation in these applications can be challenging due to wiring and plumbing penetrations.

Conclusion: It is nearly impossible for an auditor to verify the presence, type, and R-value of slab insulation in existing homes.

> ***Recommendation:*** The EEB should consider the best way to address basements in the weatherization standard. The current standard suggests that homeowners should insulate the frame floor separating a conditioned first floor from an unconditioned basement. In some cases, this suggestion may be contradictory to sound building science; there may be limited cost-effective savings from insulation retrofits in these cases as the temperature change is typically not that dramatic between a first floor and a basement. Moreover, insulation installation in these applications can be challenging due to wiring, plumbing penetrations, and access stairways. Finally, accurately defining a basement as conditioned or not influences the results of air and duct leakage testing which are components of the weatherization standard.

Conclusion: Compliance is high for certain measures (e.g, 82% for windows and 81% for attic duct insulation) and low for others (15% for frame floor over unconditioned basements and 34% for flat ceiling insulation).

> ***Recommendation:*** The EEB should review the current standard definition and consider revisions to the efficiency levels required by the standard based on the study results. Although the EEB should review the entire standard, the Team suggests paying particular attention to basements and frame floors. The information provided in the main body of the report will assist this review and potential revision.

Conclusion: The current standard only addresses frame floor insulation over unconditioned basements and excludes frame floors located over other unconditioned spaces such as garages and ambient conditions.[108] Additionally, the current standard does not address rim joist insulation which is an important component of building envelopes.

> ***Recommendation:*** The EEB should consider adding details to the current standard that address all frame floor locations that are located over unconditioned space (e.g., conditioned to garage frame floor locations, conditioned to ambient frame floor locations,

[108] Note, the Team included all locations in their assessment of the weatherization standard based on discussions with the EEB evaluation technical consultant. See Appendix F for additional details.

etc.). Similarly, the EEB should consider adding a requirement to the standard that addresses rim joists.

14.2 Program Opportunities

Conclusion: Statistical modeling (Appendix K) reveals that participation in the HES program, the age of homes, and whether homes are heated primarily by electricity are the most significant predictors of whether or not homes meet the weatherization standard. Of these three, the age of home serves as the strongest predictor of weatherization status.

> ***Recommendation:*** The HES program should target non-electrically heated homes built prior to 1980, regardless of household income. The program should prioritize those homes that have not yet taken part in the program.[109] Targeting non-electrically heated homes is the best way to increase state-level compliance with the weatherization standard, but HES should continue to pursue energy saving opportunities (e.g., heat pumps replacing electric resistance heat) in the electrically heated homes that do take part in the program even if these opportunities will not greatly increase compliance with the weatherization standard. The current study suggests that a greater proportion of electrically heated homes already meets the weatherization standard, so serving them will not move forward state-level compliance; however, adoption of electric-efficiency measures in electrically heated homes will meet the other critical objectives of increasing electricity and demand savings in Connecticut.

Conclusion: One out of every five homes (20%) that heat primarily with natural gas have uninsulated exterior walls.

> ***Recommendation:*** The Companies should ensure that HES vendors are discussing wall insulation upgrades with homeowners, particularly in homes with uninsulated wall cavities. The Companies may want to consider whether the current incentive and financing options adequately induce adoption of wall insulation upgrades by households with by natural gas.[110]

Conclusion: Air leakage, flat ceiling insulation, and conditioned to ambient wall insulation are significantly less efficient in performance-based non-compliant homes than in compliant homes.

> ***Recommendation:*** The Companies should continue to focus on air infiltration reductions during initial HES visits and continue to have HES vendors offer flat ceiling and wall

[109] The Team does not take a stance on whether the HES program should continue its current practice of not allowing homes to participate in HES more than once. The forthcoming process evaluation may address this issue.
[110] In addition to offering substantial incentives for insulation projects in the past, the Companies have also offered low-interest financing packages for such projects.

insulation upgrades where applicable. Likewise, the Companies may want to consider whether the current incentive and financing options adequately induce adoption nof these measures.

Conclusion: Inadequate basement insulation—primarily conditioned to unconditioned basement frame floor insulation—and foundation wall insulation are contributing factors to the low performance-based compliance with the weatherization standard.

Recommendation: Increasing basement insulation, specifically conditioned to unconditioned basement frame floor insulation, will likely increase compliance with the *current* weatherization standard. The Companies could consider increasing the focus on basement insulation during initial HES visits and encourage homeowners to insulate their basement at either the foundation walls or the frame floor if increasing compliance with the current standard definition is a priority.

Conclusion: The use of infrared cameras would help vendors with their retrofit efforts, particularly when it comes to air sealing.

Recommendation: The Companies should consider requiring and/or recommending that HES vendors utilize infrared cameras during HES visits. The use of these cameras would likely increase air infiltration reductions and help increase compliance with the weatherization standard.

14.3 Other

Conclusion: Among the 180 homes visited as part of this study, 9% (16 homes) have asbestos or vermiculite present and an additional 4% (7 homes) have mold present.

Recommendation: The Companies previously helped address these issues through the healthy homes initiative and health impact assessments. The Companies should continue to work with other agencies to address these issues. The EEB and DEEP may also want to consider the appropriateness of offering financing to HES households and HES-IE landlords and rebates to HES-IE homeowners to fund abatement of these problems with the understanding the recipient would then adopt more energy-savings measures such as insulation or air sealing. It is the opinion of the evaluation team that meeting the 80% weatherization requirement by 2030 without increasing the efficiency of homes with these concerns will be difficult.

Conclusion: The labor required to fully populate a REM/Rate model is significant. REM/Rate requires users to perform intensive area and volume calculations in order to properly populate the model. Additionally, REM/Rate accounts for more variables than many other software options. The result is a thorough and accurate energy consumption estimate for any given model (and the option to analyze a large selection of data).

> ***Recommendation:*** The EEB should consider the pros and cons of various software options for assessing compliance using the performance-based approach. REM/Rate is a robust modeling tool that produces accurate energy consumption estimates, but it may not be a viable software option if the EEB expects HES vendors to calculate the weatherization status for HES participating homes. Other options such as the DOE Home Energy Score software or a customized spreadsheet based model may be more applicable. There would undoubtedly be a tradeoff of time/cost vs. accuracy should a less robust model be adopted, but these tradeoffs are something the Team believes the EEB should consider.

Appendix A Weatherization Histograms

This appendix presents histograms for 9 of the 11 measures listed in the weatherization standard. Histograms were not created for windows or slabs as the data collected for these measures during the site visits does not lend itself to the presentation of a histogram. A histogram showing the amount by which homes either exceed or fall below the weatherization standard when comparing the energy consumption (in MMBtu) of the "as built" and "weatherized" energy models has also been included. For each histogram, red lines denote either mean or median values, while green lines denote the current efficiency level specified by the standard.

Figure A-1: Distribution of Conditioned to Ambient Wall R-Values

(Base: All homes)

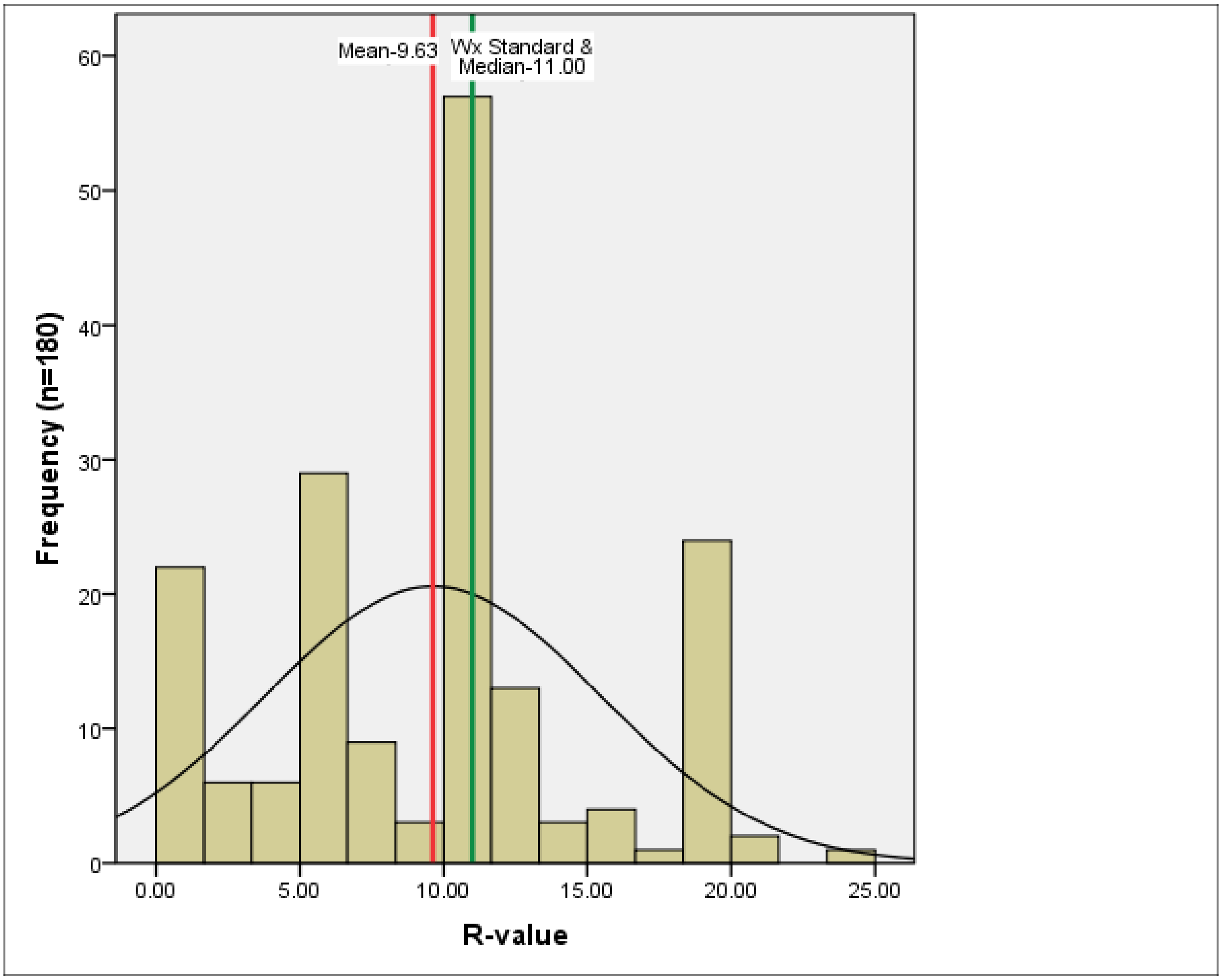


Figure A-2: Distribution of Flat Ceiling R-values
(Base: All homes with flat ceiling insulation)

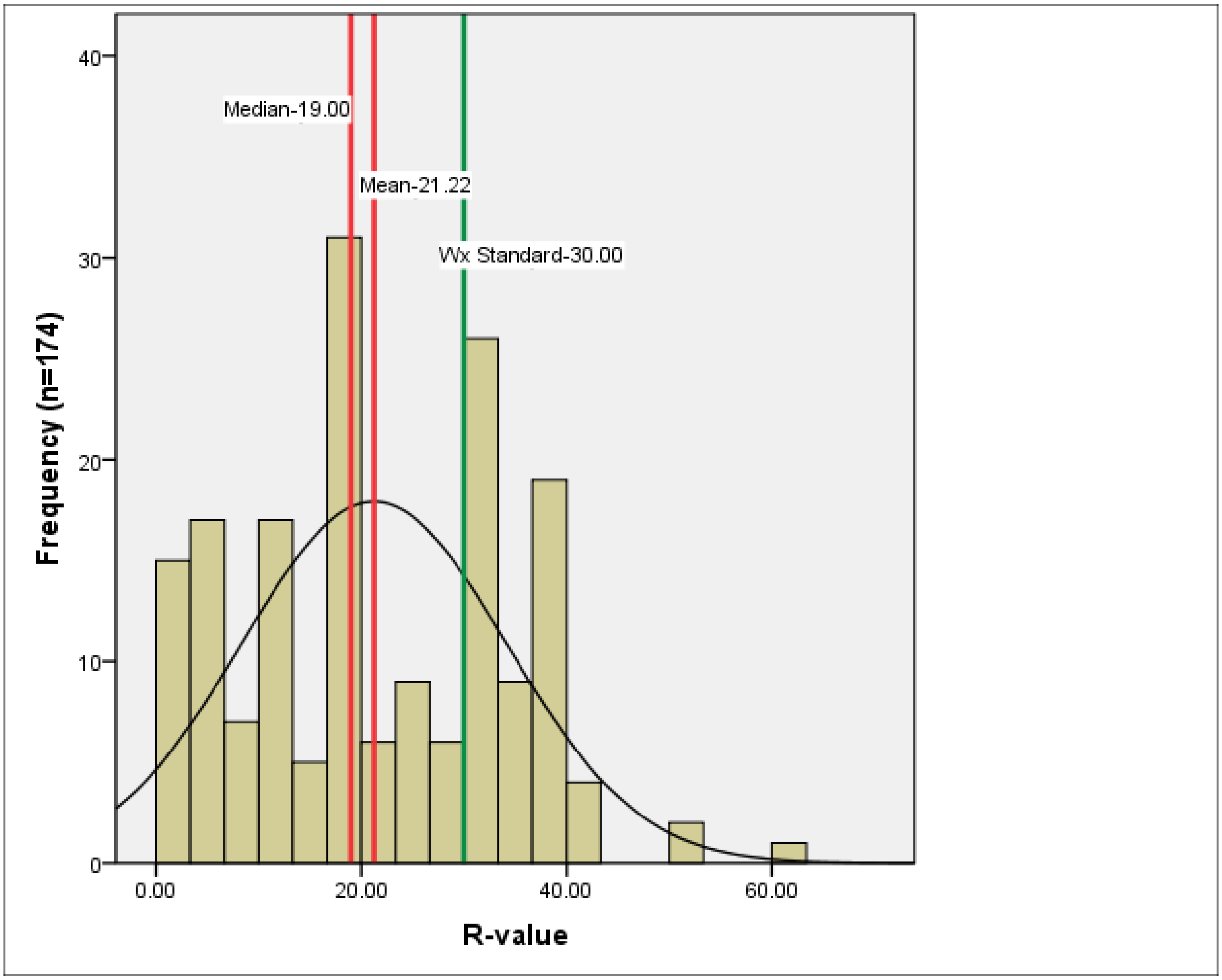


Figure A-3: Distribution of Vaulted Ceiling R-Values
(Base: All homes with vaulted ceilings)

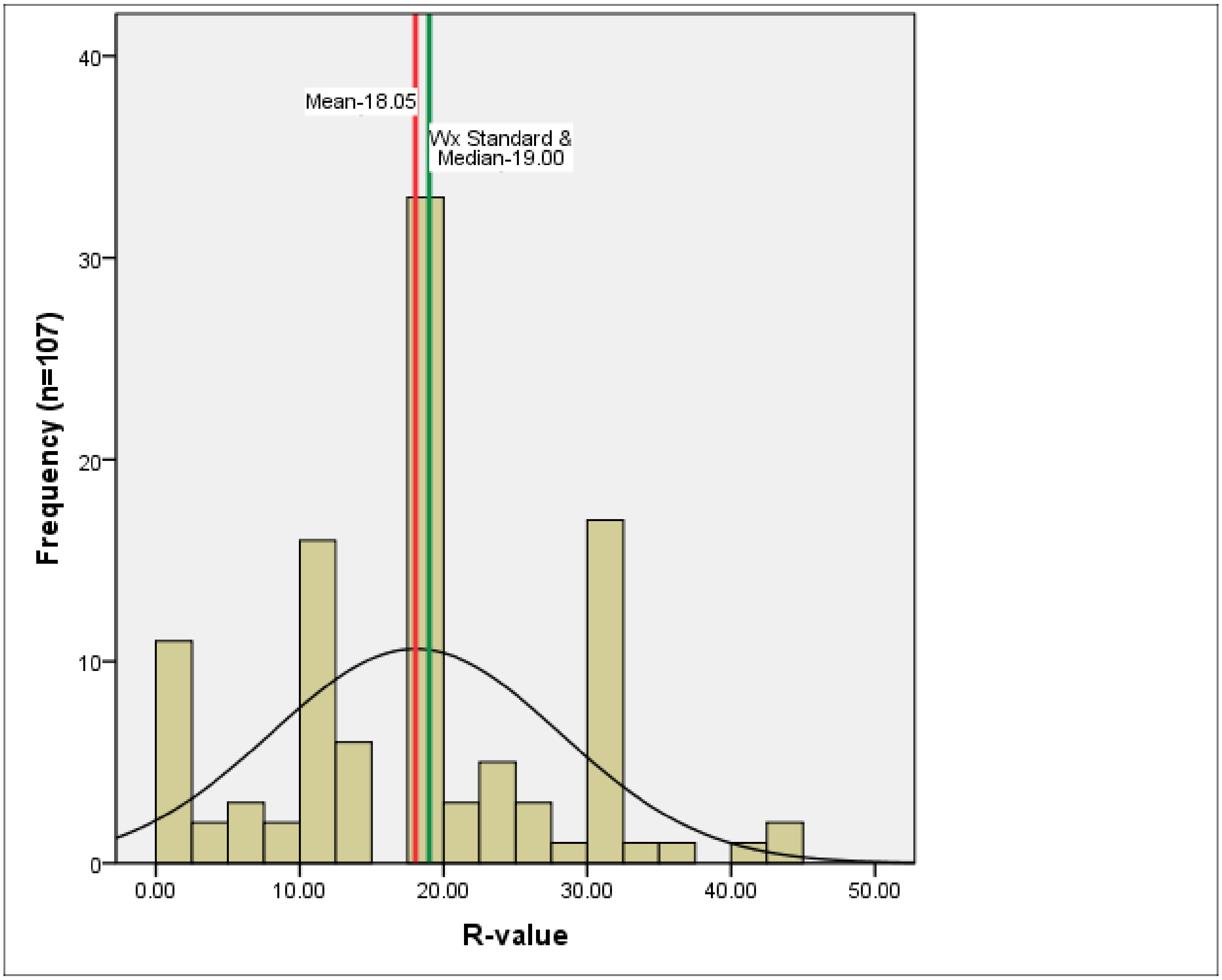


Figure A-4: Distribution of Conditioned to Unconditioned Basement Frame Floor R-Values

(Base: All homes with conditioned to unconditioned basement frame floors)

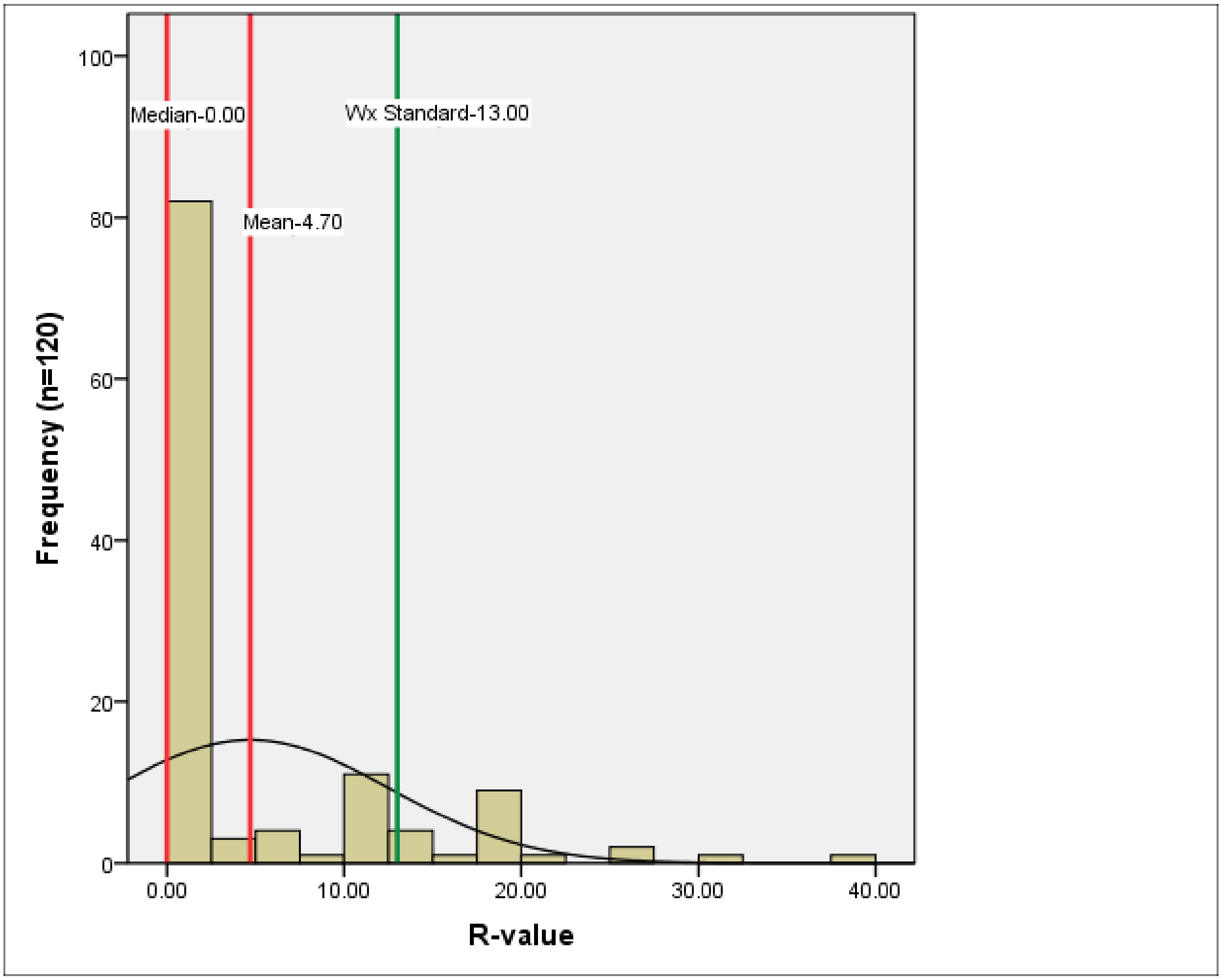


Figure A-5: Distribution of Foundation Wall R-values
(Base: All homes with foundation walls abutting conditioned space)

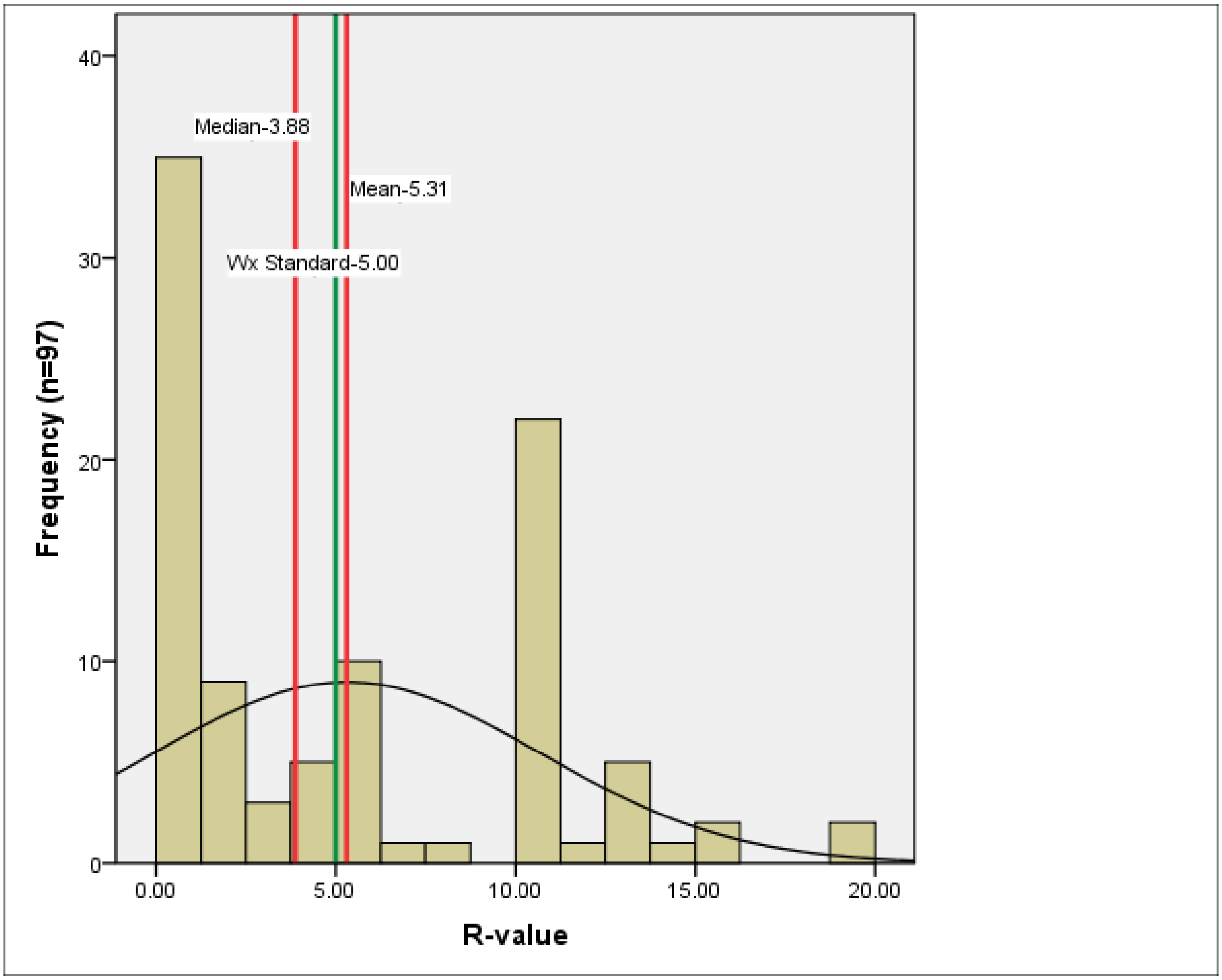


Figure A-6: Distribution of Air Leakage Results (ACH50)
(Base: All homes)

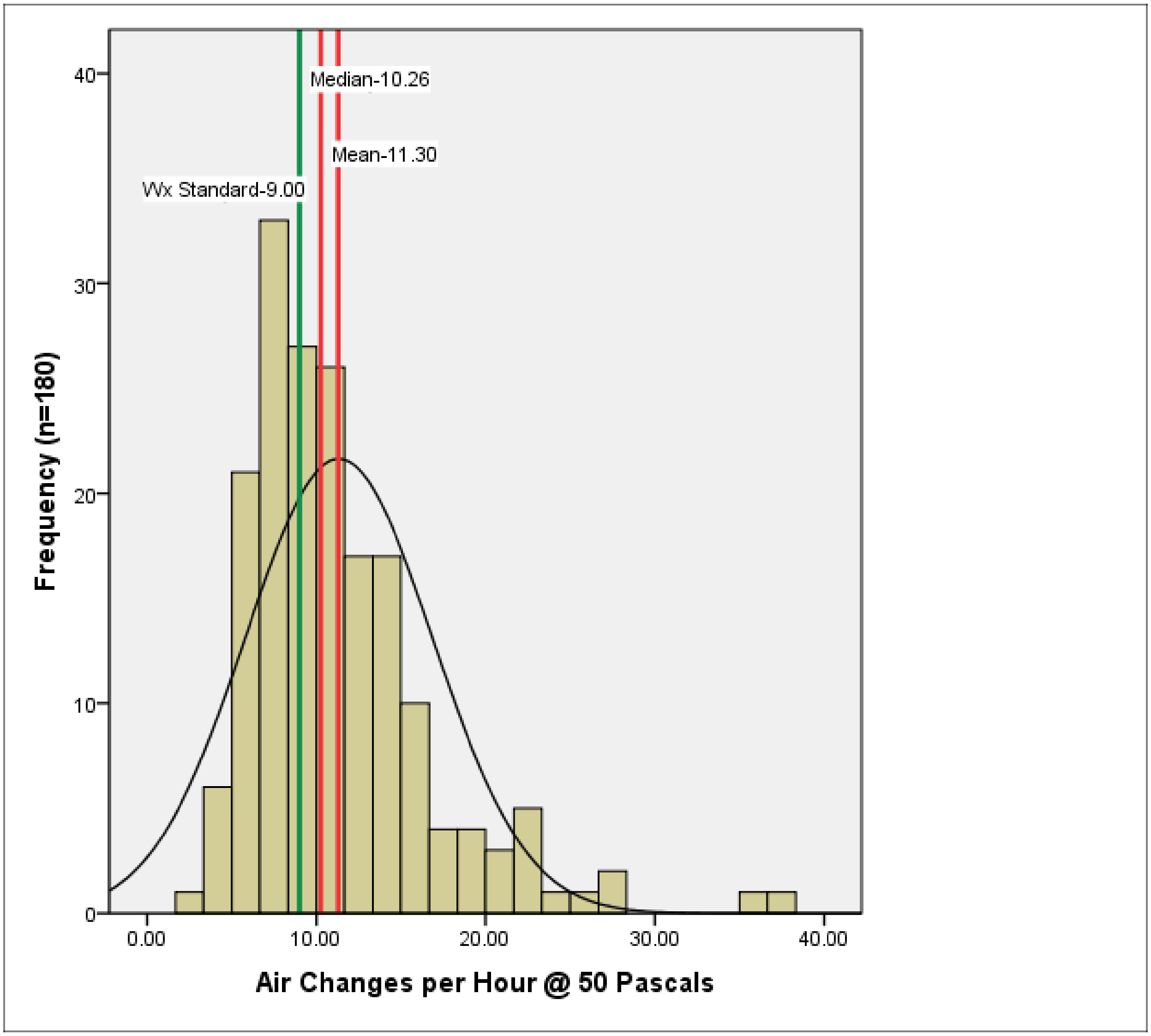


Figure A-7: Distribution of Duct Leakage to the Outside Results (CFM25/100 sq. ft.)
(Base: All homes where duct leakage to the outside was tested)

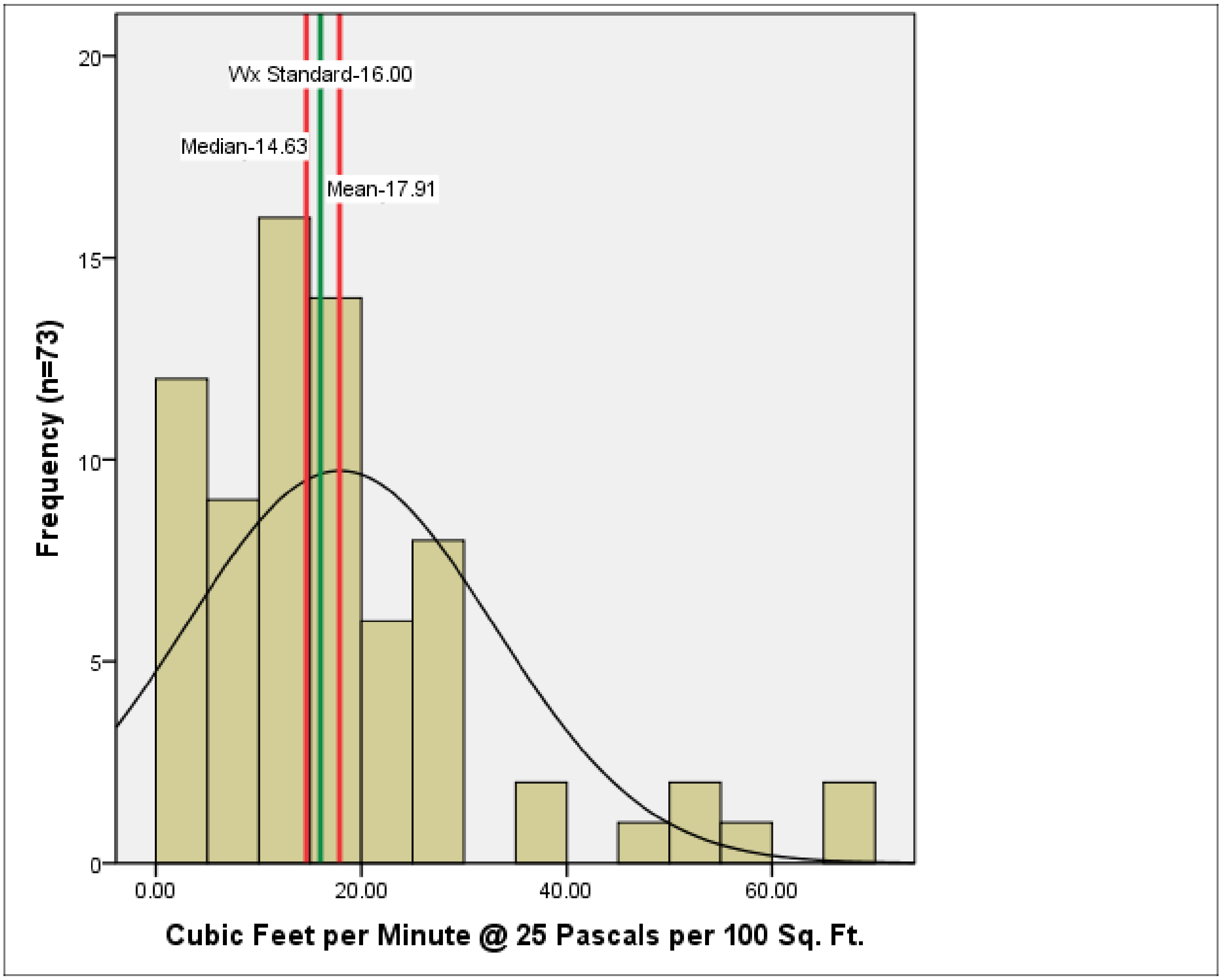


Figure A-8: Distribution of Duct Insulation R-Values in Unconditioned Basements
(Base: All homes with ducts in unconditioned basements)

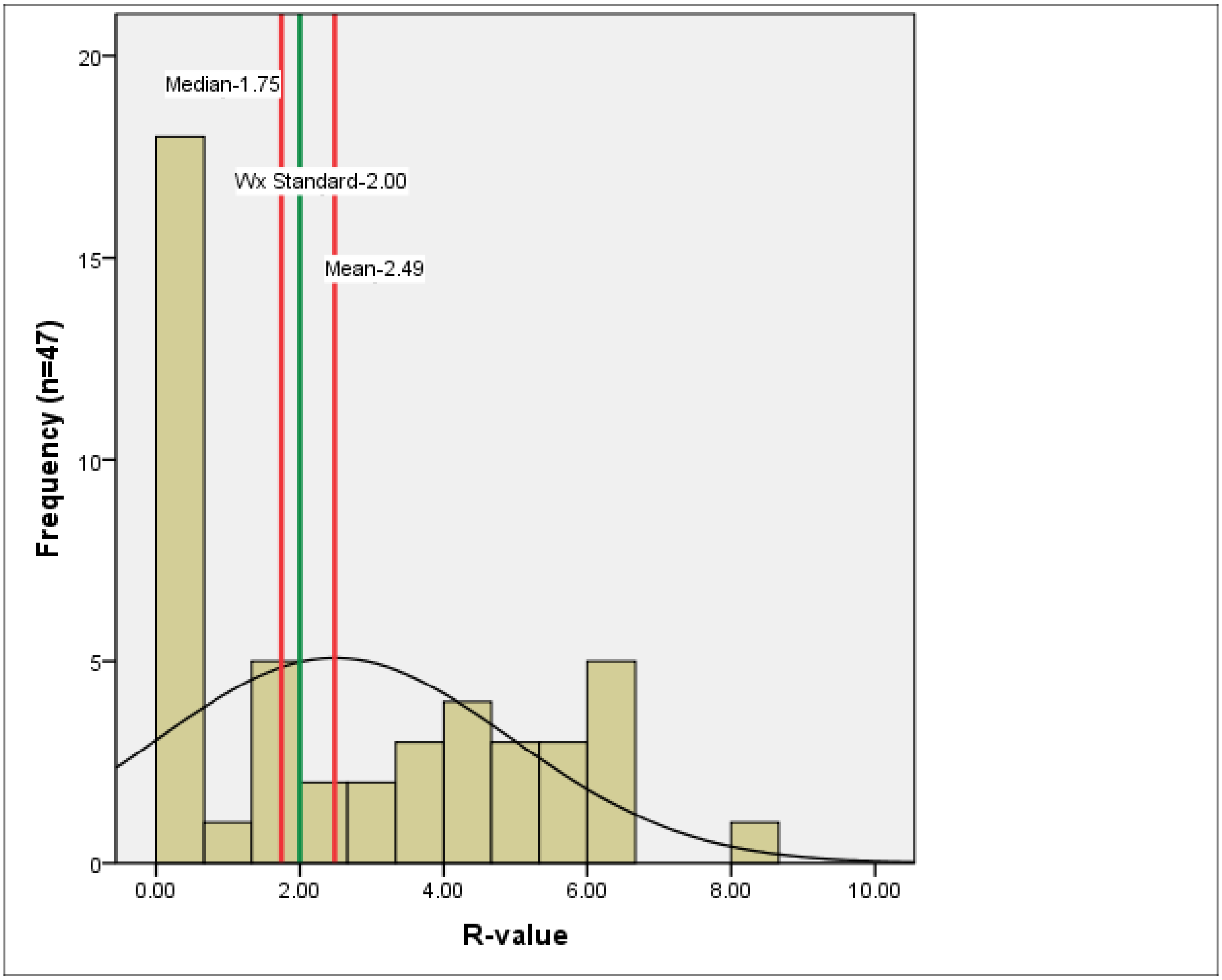


Figure A-9: Distribution of Duct Insulation R-Values in Attics and Crawlspaces
(Base: All homes with ducts in attics or crawlspaces)

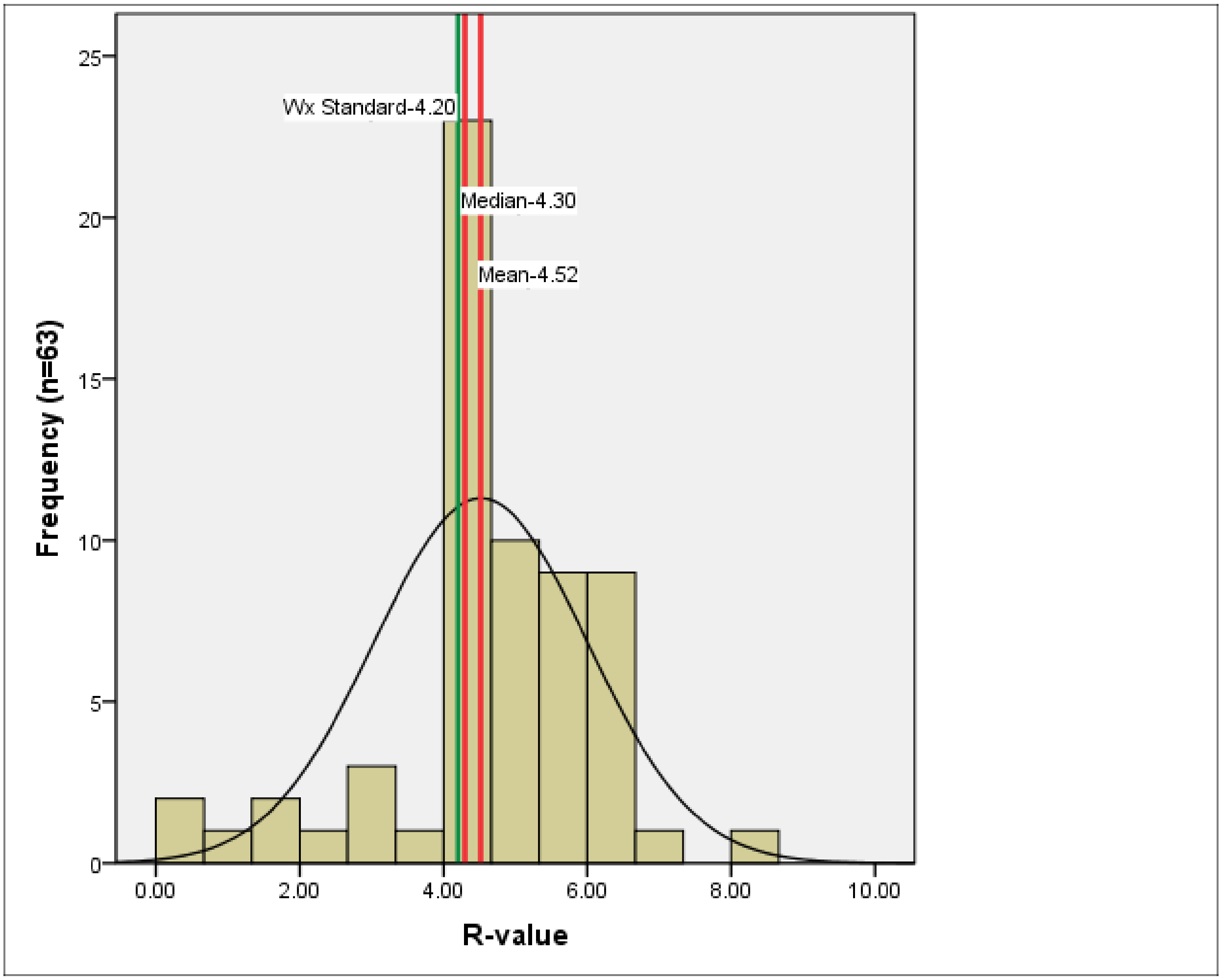
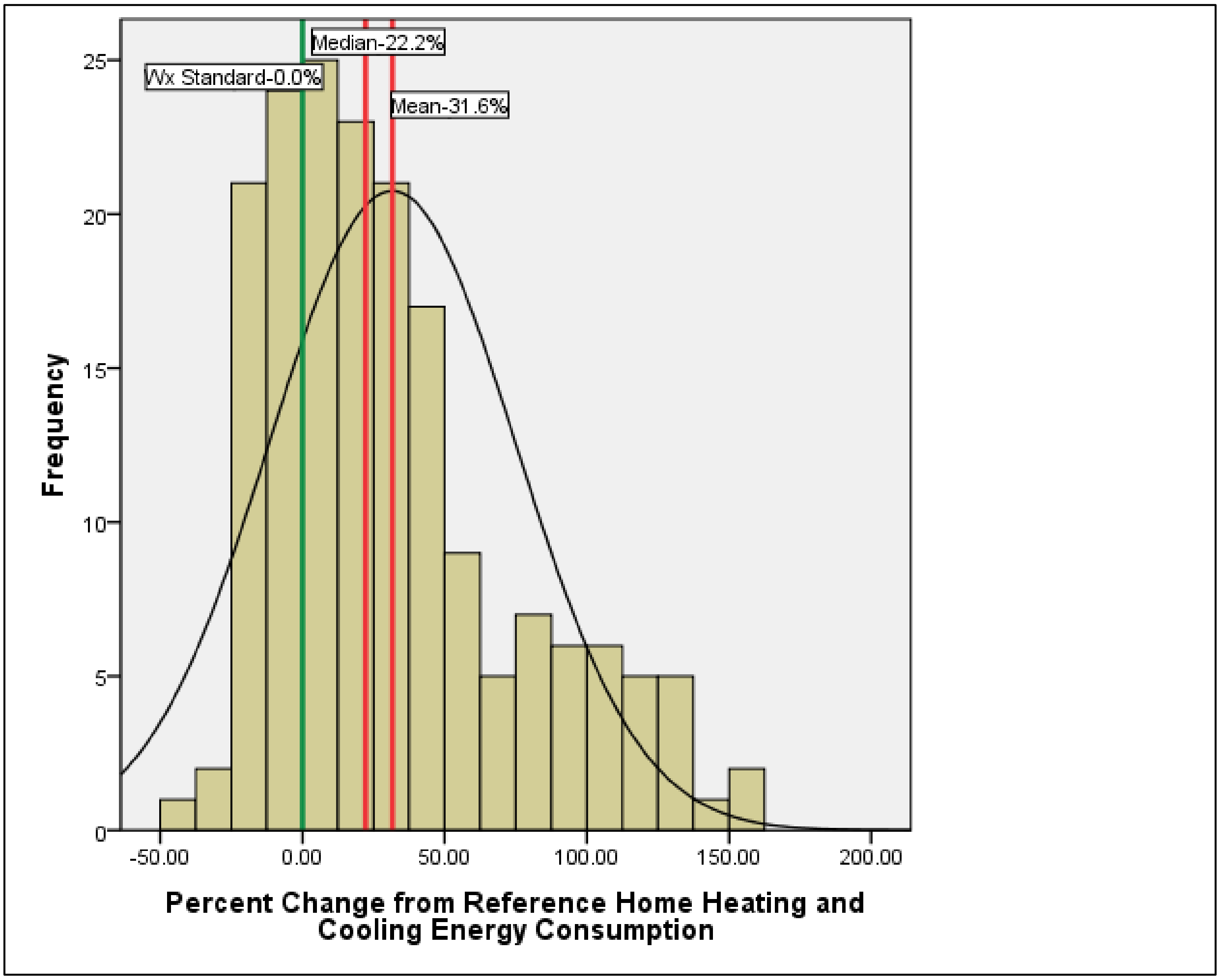


Figure A-10: Distribution of Percent Change from Reference Home Heating and Cooling Energy Consumption

(Base: All homes)



Appendix B Insulation Grades

The Residential Energy Services Network (RESNET) provides guidelines and definitions for defining the quality of insulation installation. As stated on its website, "RESNET is a recognized national standards-making body for building energy efficiency rating and certification systems in the United States."[111] RESNET has specified three grades for designating the quality of insulation installation; the grades range from Grade I (the best) to Grade III (the worst). The RESNET definitions of Grade I, Grade II, and Grade III installation are provided below.[112]

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.

[111] http://www.resnet.us/about/what-is-resnet

[112] Residential Energy Services Network (2006), *2006 Mortgage Industry National Home Energy Rating Systems Standards*, Oceanside, CA: Residential Energy Services Network.

Figure B-1 shows a conditioned attic with closed cell spray foam applied to the walls. This installation received a Grade I installation, as the closed cell spray foam has few to no gaps, has no compression, and the cavity is enclosed on all six sides.[113]

Figure B-1: Grade I Closed Cell Spray Foam—Exterior Walls

Figure B-2 shows a Grade II installation of unfaced fiberglass batts in a conditioned basement.[114] 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 (in most places), warranting a Grade II designation.

Figure B-2: Grade II Fiberglass Batts—Basement Walls

[113] 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.
[114] The basement in this case was considered conditioned volume, not conditioned floor area.

Figure B-3 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 B-3: Grade III Fiberglass Batts—Attic Kneewalls

Figure B-4 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, as it has substantial gaps and compression.

Figure B-4: Grade II Fiberglass Batts—Frame Floor

Figure B-5 shows frame floor insulation that received a Grade III designation. The insulation has gaps, substantial compression in places, and is severely sagging in other places. The sagging insulation creates an air space between the insulation and the subfloor, which ultimately diminishes the insulating characteristics of the fiberglass batts.

Figure B-5: Grade III Fiberglass Batts—Frame Floor

Figure B-6 shows a Grade I installation of blown fiberglass in an attic. This received a Grade I designation because the fiberglass 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 B-6: Grade I Blown Fiberglass—Attic

Appendix C As-Built vs. Weatherized Loads, Consumption, and Costs—Additional Tables

This appendix presents a detailed breakdown of the results that are summarized in Section 3.4.

Table C-1: As-Built vs. Weatherized Average Measure-Level Energy Loads by Primary Heating Fuel Type (MMBtu)

Measure or Characteristic	Season Type	Oil & Other Fuels			Natural Gas			Electricity		
		n	As-Built	Weatherized	*n*	As-Built	Weatherized	*n*	As-Built	Weatherized
Roofs	Heating Season	*118*	15.7[a]	10.3[a]	*46*	14.9[b]	8.4[b]	*16*	7.2	7.3
	Cooling Season	*96*	0.8[a]	0.6[a]	*37*	0.9[b]	0.5[b]	*14*	0.4	0.4
Above Grade Walls	Heating Season	*118*	24.1[a]	20.5[a]	*46*	25.1[b]	18.6[b]	*16*	19.1	18.3
	Cooling Season	*96*	-0.3	-0.3	*37*	-0.2	-0.1	*14*	-0.2	-0.2
Foundation Walls	Heating Season	*71*	11.6[a]	7.4[a]	*20*	11.0[b]	6.9[b]	*10*	9.5	8.4
	Cooling Season	*59*	-1.6[a]	-1.0[a]	*17*	-1.4	-0.9	*8*	-1.3	-1.2
Windows	Heating Season	*118*	9.9	11.3	*46*	9.0	9.9	*16*	7.9	8.8
	Cooling Season	*96*	13.1	14.6	*37*	11.1	12.2	*14*	10.9	12.3
Frame Floors Over Garage or Ambient Conditions	Heating Season	*67*	4.2	3.6	*21*	4.0	3.0	*14*	4.2	3.8
	Cooling Season	*56*	-0.5	-0.4	*20*	-0.5	-0.4	*12*	-0.5	-0.4
Frame Floors Over Unconditioned Basement or Crawlspace	Heating Season	*85*	10.7[a]	6.7[a]	*35*	12.4[b]	6.9[b]	*8*	8.3	6.1
	Cooling Season	*68*	-1.9[a]	-1.2[a]	*26*	-2.1[b]	-1.1[b]	*8*	-1.1	-0.8
Slabs	Heating Season	*82*	7.8[a]	4.8[a]	*27*	6.1	4.0	*11*	6.5	4.5
	Cooling Season	*70*	-1.6[a]	-1.2[a]	*22*	-1.3	-1.0	*9*	-1.4	-1.1
Air Infiltration	Heating Season	*118*	32.2[a]	28.2[a]	*46*	31.5	26.2	*16*	24.9	25.3
	Cooling Season	*96*	-2.0	-2.1	*37*	-2.1	-2.0	*14*	-1.6	-1.9
Ducts	Heating Season	*39*	24.2[a]	19.4[a]	*21*	26.0[b]	17.8[b]	*5*	16.4	12.3
	Cooling Season	*50*	4.3	4.7	*21*	4.6	4.5	*6*	3.7	3.4
Total	*Heating Season*	*118*	*100.4*[a]	*80.1*[a]	*46*	*101.4*[b]	*73.8*[b]	*16*	*71.3*	*67.4*
	Cooling Season	*96*	*17.5*	*19.4*	*37*	*16.2*	*17.7*	*14*	*15.0*	*15.9*

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

Table C-2: As-Built vs. Weatherized Average Measure-Level Energy Loads by Income Status (MMBtu)

Measure or Characteristic	Season Type	Low Income			Non-Low Income		
		n	As-Built	Weatherized	*n*	As-Built	Weatherized
Roofs	Heating Season	*34*	12.4[a]	7.3[a]	*146*	15.5[b]	10.2[b]
	Cooling Season	*25*	0.7	0.4	*122*	0.8[b]	0.6[b]
Above Grade Walls	Heating Season	*34*	20.0[a]	14.4[a]	*146*	25.1[b]	21.4[b]
	Cooling Season	*25*	-0.2	-0.1	*122*	-0.3	-0.3
Foundation Walls	Heating Season	*16*	11.9[a]	7.8[a]	*85*	11.2[b]	7.3[b]
	Cooling Season	*12*	-1.7[a]	-1.1[a]	*72*	-1.5[b]	-1.0[b]
Windows	Heating Season	*34*	5.9	6.6	*146*	10.6[b]	12.0[b]
	Cooling Season	*25*	8.5	9.3	*122*	13.4[b]	15.0[b]
Frame Floors Over Garage or Ambient Conditions	Heating Season	*16*	2.8	2.4	*86*	4.4	3.7
	Cooling Season	*14*	-0.4	-0.3	*74*	-0.6	-0.5
Frame Floors Over Unconditioned Basement or Crawlspace	Heating Season	*22*	13.4[a]	7.3[a]	*106*	10.4[b]	6.6[b]
	Cooling Season	*14*	-2.3[a]	-1.1[a]	*88*	-1.8[b]	-1.1[b]
Slabs	Heating Season	*18*	5.5	3.7	*102*	7.7[b]	4.8[b]
	Cooling Season	*15*	-1.3	-1.0	*86*	-1.6[b]	-1.2[b]
Air Infiltration	Heating Season	*34*	27.1[a]	18.8[a]	*146*	32.7	30.0
	Cooling Season	*25*	-1.3	-1.3	*122*	-2.2	-2.3
Ducts	Heating Season	*8*	24.2[a]	13.6[a]	*57*	24.2[b]	19.3[b]
	Cooling Season	*8*	3.1	3.2	*69*	4.5	4.7
Total	*Heating Season*	*34*	*81.4*[a]	*54.4*[a]	*146*	*103.2*[b]	*84.3*[b]
	Cooling Season	*25*	*12.2*	*13.5*	*122*	*18.2*[b]	*20.1*[b]

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

Table C-3: As-Built vs. Weatherized Average Measure-Level Energy Costs by Primary Heating Fuel Type* ($)

Measure or Characteristic	Season Type	Oil & Other Fuels			Natural Gas			Electricity		
		n	As-Built	Weatherized	*n*	As-Built	Weatherized	*n*	As-Built	Weatherized
Roofs	Heating Season	*118*	457.0[a]	296.6[a]	*46*	214.4[b]	123.2[b]	*16*	331.4	324.4
	Cooling Season	*96*	41.0[a]	29.0[a]	*37*	44.4[b]	24.3[b]	*14*	20.8	21.4
Above Grade Walls	Heating Season	*118*	702.2[a]	593.3[a]	*46*	370.6[b]	278.2[b]	*16*	839.7	809.2
	Cooling Season	*96*	-15.7	-13.4	*37*	-8.2	-6.9	*14*	-9.9	-8.6
Foundation Walls	Heating Season	*71*	333.4[a]	214.3[a]	*20*	163.4[b]	102.8[b]	*10*	438.3	403.2
	Cooling Season	*59*	-78.3[a]	-51.0[a]	*17*	-72.0	-44.1	*8*	-66.1	-61.4
Windows	Heating Season	*118*	291.5	333.2	*46*	132.0	144.7	*16*	344.2	381.9
	Cooling Season	*96*	659.1	734.1	*37*	557.1	613.4	*14*	545.9	616.2
Frame Floors Over Garage or Ambient Conditions	Heating Season	*67*	119.9	104.2	*21*	59.6	44.4	*14*	185.1	169.8
	Cooling Season	*56*	-27.2	-23.2	*20*	-26.5	-20.2	*12*	-23.7	-20.8
Frame Floors Over Unconditioned Basement or Crawlspace	Heating Season	*85*	300.7[a]	190.9[a]	*35*	186.1[b]	102.0[b]	*8*	335.6	260.9
	Cooling Season	*68*	-95.9[a]	-58.0[a]	*26*	-108.1[b]	-53.9[b]	*8*	-55.5	-42.3
Slabs	Heating Season	*82*	228.6[a]	141.9[a]	*27*	88.5	59.7	*11*	313.1	213.4
	Cooling Season	*70*	-80.0[a]	-60.5[a]	*22*	-64.8	-51.7	*9*	-69.5	-54.8
Air Infiltration	Heating Season	*118*	936.7[a]	812.4[a]	*46*	464.8	389.6	*16*	1,152.1	1,151.9
	Cooling Season	*96*	-102.3	-106.4	*37*	-104.1	-100.5	*14*	-79.7	-95.9
Ducts	Heating Season	*39*	717.0[a]	573.8[a]	*21*	382.1[b]	262.7[b]	*5*	759.0	551.9
	Cooling Season	*50*	218.7	236.4	*21*	229.3	224.5	*6*	188.3	169.2
*Total**	*Heating Season*	*118*	*2,921.6*[a]	*2,324.7*[a]	*46*	*1,487.8*[b]	*1,092.5*[b]	*16*	*3,225.0*	*3,028.8*
	Cooling Season	*96*	*879.6*	*977.7*	*37*	*816.3*	*888.9*	*14*	*752.5*	*801.6*

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

*Costs are based on the design loads of the various components as REM/Rate does not export consumption information in this level of detail

Table C-4: As-Built vs. Weatherized Average Measure-Level Energy Costs by Income Status* ($)

Measure or Characteristic	Season Type	Low Income			Non-Low Income		
		n	As-Built	Weatherized	*n*	As-Built	Weatherized
Roofs	Heating Season	*34*	317.0^a	190.9^a	*146*	408.8^b	276.3^b
	Cooling Season	*25*	33.7	19.8	*122*	41.7^b	29.1^b
Above Grade Walls	Heating Season	*34*	493.3^a	363.4^a	*146*	674.3^b	585.0^b
	Cooling Season	*25*	-10.1	-6.7	*122*	-14.2	-12.6
Foundation Walls	Heating Season	*16*	318.9^a	216.9^a	*85*	309.5^b	209.6^b
	Cooling Season	*12*	-84.3^a	-54.0^a	*72*	-74.3^b	-5.56^b
Windows	Heating Season	*34*	154.6	174.8	*146*	287.3^b	325.8^b
	Cooling Season	*25*	429.1	467.2	*122*	675.2^b	753.5^b
Frame Floors Over Garage or Ambient Conditions	Heating Season	*16*	74.7	66.3	*86*	126.4	109.2
	Cooling Season	*14*	-18.5	-15.8	*74*	-28.5	-23.8
Frame Floors Over Unconditioned Basement or Crawlspace	Heating Season	*22*	326.4^a	179.5^a	*106*	259.2^b	169.9^b
	Cooling Season	*14*	-113.7^a	-54.2^a	*88*	-92.4^b	-56.3^b
Slabs	Heating Season	*18*	158.2	105.0	*102*	216.5^b	136.1^b
	Cooling Season	*15*	-63.1	-50.5	*86*	-78.9^b	-59.9^b
Air Infiltration	Heating Season	*34*	690.9^a	479.5^a	*146*	884.2	813.7
	Cooling Season	*25*	-65.6	-63.6	*122*	-109.8	-114.5
Ducts	Heating Season	*8*	611.1^a	328.7^a	*57*	618.8^b	497.1^b
	Cooling Season	*8*	156.2	161.1	*69*	228.5	238.3
*Total**	*Heating Season*	*34*	*2,074.1*^{a}	*1,399.8*^{a}	*146*	*2,753.9*^{b}	*2,284.9*^{b}
	Cooling Season	*25*	*614.5*	*676.6*	*122*	*914.7*^{b}	*1,009.0*^{b}

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

*Costs are based on the design loads of the various components as REM/Rate does not export consumption information in this level of detail

Table C-5: As-Built vs. Weatherized End Use Energy Consumption by Primary Heating Fuel Type (MMBtu)

Measure or Characteristic	Oil & Other Fuels			Natural Gas			Electricity		
	n	As-Built	Weatherized	*n*	As-Built	Weatherized	*n*	As-Built	Weatherized
Heating	*118*	124.9[a]	99.6[a]	*46*	126.3[b]	91.7[b]	*16*	62.6	58.5
Cooling	*96*	5.7[a]	6.6[a]	*37*	5.4	5.9	*14*	4.9	5.2
Water Heating	*118*	19.9	20.0	*46*	20.0	20.2	*16*	11.8	11.8
Lights and Appliances	*118*	26.1	26.1	*46*	24.6	24.6	*16*	22.4	22.4
Total	*118*	*174.9*[a]	*150.1*[a]	*46*	*174.6*[b]	*140.5*[b]	*16*	*99.2*	*95.3*

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

Table C-6: As-Built vs. Weatherized End Use Energy Consumption by Income Status (MMBtu)

Measure or Characteristic	Low Income			Non-Low Income		
	n	As-Built	Weatherized	*n*	As-Built	Weatherized
Heating	*34*	104.0[a]	69.6[a]	*146*	124.8[b]	101.5[b]
Cooling	*25*	4.1	4.5	*122*	6.0	6.6
Water Heating	*34*	18.7	18.8	*145*	19.5	19.5
Lights and Appliances	*34*	21.3	21.3	*146*	26.6	26.6
Total	*34*	*145.4*[a]	*111.4*[a]	*146*	*175.4*[b]	*152.6*[b]

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

Table C-7: As-Built vs. Weatherized End Use Energy Costs by Primary Heating Fuel Type ($)

Measure or Characteristic	Oil & Other Fuels			Natural Gas			Electricity		
	n	As-Built	Weatherized	*n*	As-Built	Weatherized	*n*	As-Built	Weatherized
Heating	*118*	3,607.2[a]	2,865.3[a]	*46*	1,851.8[b]	1,356.4[b]	*16*	2,748.7	2,542.6
Cooling	*96*	287.4[a]	318.9[a]	*37*	273.0	296.3	*14*	247.3	264.0
Water Heating	*118*	664.9	665.8	*46*	307.8	309.9	*16*	580.1	580.8
Lights and Appliances	*118*	1,290.1	1,290.1	*46*	1,150.6	1,150.6	*16*	1,097.2	1,097.2
Total	*118*	*5,766.6*[a]	*5,051.2*[a]	*46*	*3,495.1*[b]	*3,020.4*[b]	*16*	*4,545.8*	*4,355.1*

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

Table C-8: As-Built vs. Weatherized End Use Energy Costs by Income Status ($)

Measure or Characteristic	Low Income			Non-Low Income		
	n	As-Built	Weatherized	*n*	As-Built	Weatherized
Heating	*34*	2,600.2[a]	1,750.9[a]	*146*	3,262.3[b]	2,685.5[b]
Cooling	*25*	205.9	227.1	*122*	299.6	329.6
Water Heating	*34*	547.9	550.2	*145*	578.1	578.9
Lights and Appliances	*34*	1,032.0	1,032.0	*146*	1,301.3	1,301.3
Total	*34*	*4,251.8*[a]	*3,420.4*[a]	*146*	*5,370.3*[b]	*4,819.4*[b]

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

Appendix D Building Envelope—Additional Details

This section presents additional information on the characteristics of the thermal envelopes for all of the audited homes.

D.1 Windows and Skylights

Windows with wood frames are the most common by area statewide at 48% (Table D-1). Vinyl frame windows are nearly as common at 43%. Metal and fiberglass frames are relatively rare, representing 6% and 3% of window area, respectively. Metal windows are significantly less common in homes with electricity as the primary fuel than they are in homes in the oil and other fuels category.

Table D-1: Types of Window Frames by Percent of Window Area

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Wood	49%	46%	43%	47%	48%	48%
Vinyl	41%	47%	56%	49%	42%	43%
Metal	7%[a]	4%	1%[a]	3%	6%	6%
Fiberglass	3%	3%	1%	1%	3%	3%

[a] Statistically significant difference at the 90% confidence level.

Table D-2 displays the glazing percentage of exterior walls. The statewide average and median value is 14%, with a range from 7% to 34%. Homes with electricity as the primary fuel have a significantly lower glazing percentage than homes with natural gas or oil and other fuels as the primary heat source. Non-low-income homes have a significantly greater glazing percentage than low-income homes.

Table D-2: Glazing Percentage of Exterior Wall Area

(Base: All homes)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Min	7%	9%	8%	7%	7%	7%
Max	34%	27%	19%	22%	34%	34%
Average	15%[a]	15%[b]	13%[a,b]	12%[c]	15%[c]	14%
Median	14%	14%	13%	11%	14%	14%

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

South-facing windows allow for greater passive solar heating, particularly in the winter when the sun is lower in the sky. The average home statewide has 35% of its window area facing south, southwest, or southeast, with a median value of 33% (Table D-3). Values for south-facing glazing range from 0% to 100%.

Table D-3: Percent of South-Facing Glazing on Exterior Walls

(Base: All homes; includes SE, S, and SW facing windows)

Statistics	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Min	0%	0%	0%	0%	0%	0%
Max	80%	100%	79%	100%	80%	100%
Average	34%	35%	40%	36%	35%	35%
Median	33%	29%	43%	32%	35%	33%

Skylights are present in 29% of homes statewide (Table D-4).

Table D-4: Skylights

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
Skylight(s) present	32%	20%	38%	21%	32%	29%

D.2 Doors

Wood is the most common material for exterior doors statewide at 41%, followed by steel (32%) and fiberglass (27%) (Table D-5). Wood doors are significantly more common in homes in the oil and other fuels category than in homes where natural gas or electricity is the primary fuel. Steel doors are significantly more common in low-income versus non-low-income homes and in natural gas homes versus homes heated with oil and other fuels. Fiberglass doors are significantly more prevalent in non-low-income homes than in low-income homes.

Statewide, 55% of exterior doors are insulated, 54% have a storm door, and 79% have glass. Homes that heat primarily with natural gas are significantly more likely to have insulated doors and doors with glass than homes in the oil and other fuels category.

Table D-5: Exterior Doors

(Base: All homes; includes only exterior doors on conditioned walls)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Door Material—n (doors)	*236*	*87*	*27*	*69*	*281*	*350*
Wood	46%[a,b]	30%[a]	30%[b]	41%	41%	41%
Steel	28%[a]	41%[a]	37%	41%[c]	30%[c]	32%
Fiberglass	27%	29%	33%	19%[c]	30%[c]	27%
Door Features--n (doors)*	*236*	*87*	*27*	*69*	*281*	*350*
Insulated	51%[a]	67%[a]	63%	49%	57%	55%
with Storm Door	56%	47%	52%	59%	52%	54%
with Glass	83%[a]	69%[a]	74%	71%	80%	79%

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

*Totals are greater than 100% because doors may have more than one of the listed features.

Appendix E Infrared Imaging Details and Examples

Throughout this appendix, all of the IR photos are presented with the same color scale. In this scale, yellow and orange represent warmer surfaces, while purple and black represent cooler surfaces. When interpreting infrared photos it is important to understand whether the image was taken from the inside or outside of the home, and also whether the photo was taken during the winter or the summer. All of the photos presented in this section were taken in the winter and the majority were taken from inside homes. The bullets below provide examples of how to interpret infrared photos in various situations.

- Scenario 1: The auditor takes a photo of a well-insulated wall from the interior of the home during the heating season. In this case, one would expect the wall cavity to be a lighter color (yellow or orange) than the wood studs in the wall because the well-insulated cavity will conduct heat to the outside more slowly than wood studs.
- Scenario 2: The same scenario as above, except this time the auditor takes the photo from outside the home. In this case, one would expect the wall cavity to be darker than the wood studs because not as much heat is conducting through the cavity compared to the studs. The studs are heating up more quickly (from the inside to the outside) and, as a result, will appear to be a lighter color in the infrared image than the well-insulated wall cavity.
- Scenario 3: The auditor takes an infrared photo of an attic hatch from inside a home during a blower door test. In this case, one would expect to see dark spots surrounding the attic hatch. These dark spots would represent cold air being drawn into the home from the attic during the blower door test.

E.1 Examples of Air Leakage Using IR

All of the photos showing air leakage were taken while auditors were simultaneously running a blower door test. Using an infrared camera while running a blower door test can reveal air leaks that are difficult to identify using more basic techniques, such as a trying to feel air leaks with the back of your hand.

E.1.1 Air Leaks at Top Plates, Exterior Walls, and Ceilings[115]

Figure E-1shows a photo of a newer home that is very leaky. The images show a hallway in the middle of the home located below the attic. The photo on the left reveals substantial air leakage at the top plate, indicated by the black and purple areas on the ceiling and wall that represent cool air leaks being pulled into the house through the attic.

Figure E-1: Air Leakage at Attic Top Plate

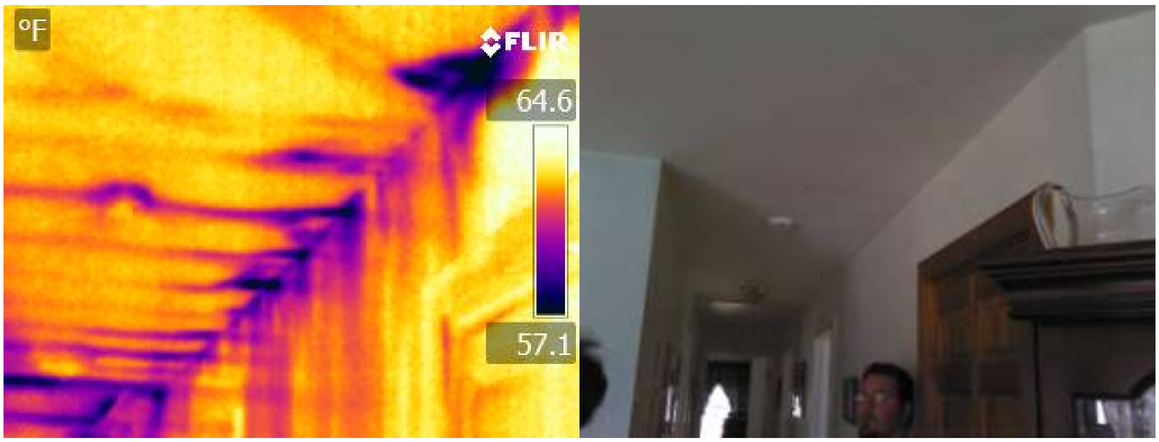


Figure E-2 shows a significant amount of air leakage through a structural beam that is part of a vaulted ceiling assembly. In this home, one can see the gap under the beam with the naked eye, typically a clear sign of a significant air leak.

Figure E-2: Air Leakage through Ceiling Framing

[115] A top plate is the upper framing member of a stud wall on which the platform for the next story or the ceiling and roof assembly rest and are attached.

Figure E-3 shows an example of air leakage taking place at the top plate and through studs of an exterior wall in one home. The black and dark purple areas of the photo are where the blower door is drawing cold air in from the outside or where the cold air that was drawn in has washed over the surface.

Figure E-3: Air Leakage at Top Plate of Exterior Wall

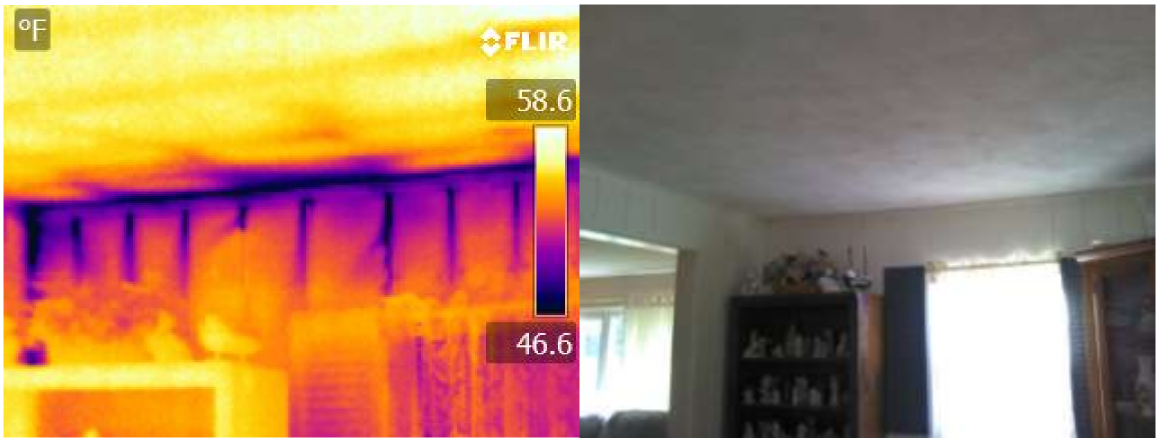
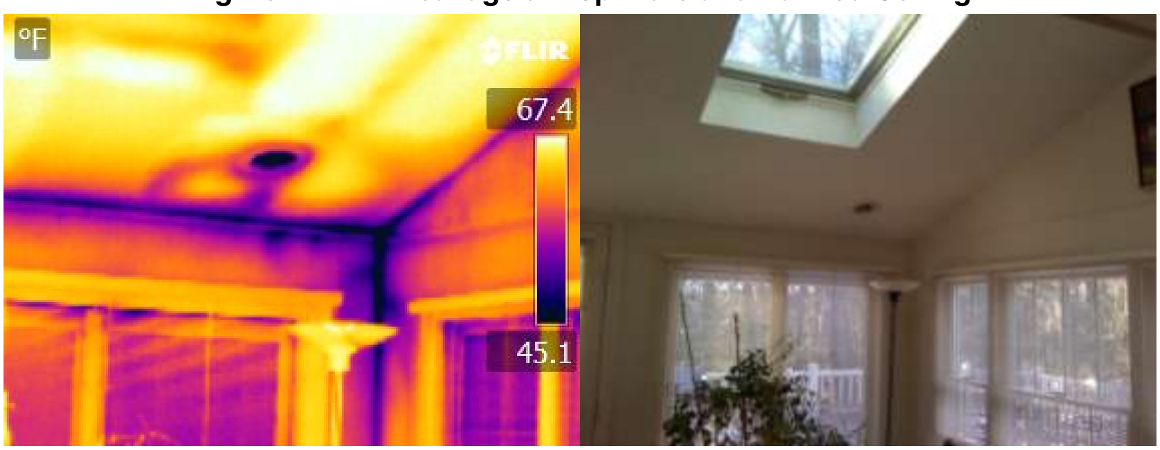


Figure E-4 shows another example of leakage at the top plate. As shown, the corner framing members where the wall meets the roof are leaking considerably. This was a common trend across the audited homes.

Figure E-4: Air Leakage at Top Plate and Vaulted Ceiling



E.1.2 Air Leaks at Attic Hatches, Windows, Doors, and Baseboard

Figure E-5 shows a significant amount of air leakage coming through the door frame in one home during the blower door test. Doors and door frames are common areas for preventable air leakage.

Figure E-5: Air Leakage at an Exterior Door

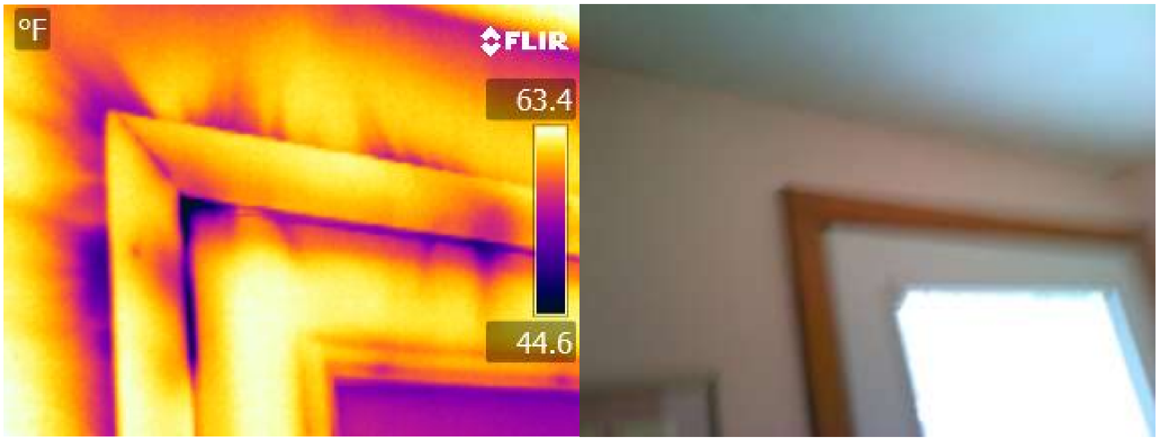


Figure E-6 and Figure E-7 show leakage under the baseboard trim at two different homes. Both photos were taken during blower door tests and indicate that there is preventable air leakage occurring at baseboard trim in a number of homes.

Figure E-6: Air Leakage at Baseboard Trim

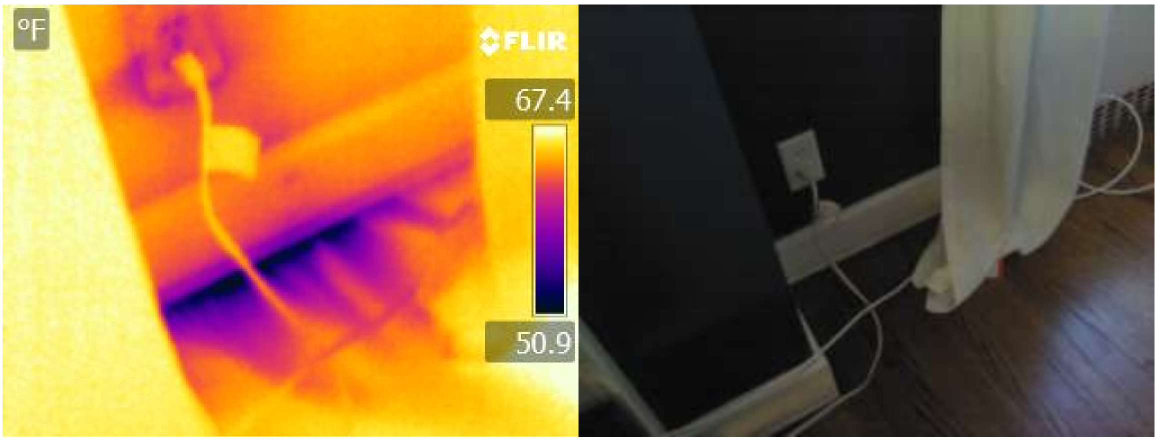


Figure E-7: Air Leakage through Baseboard and Outlet

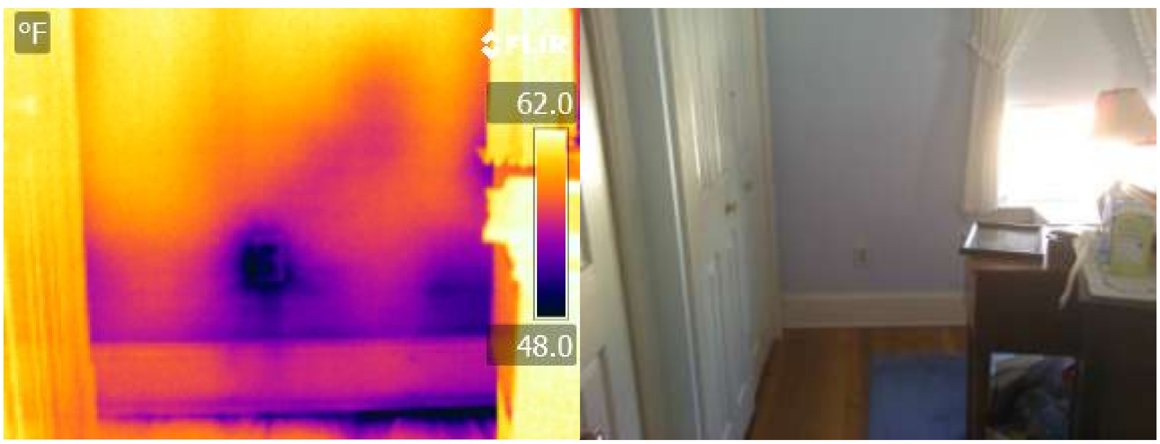


Figure E-8 shows a substantial amount of air leakage coming through an attic hatch. Attic hatches are notorious for air leaks, and auditors found many leaky hatches during the site visits.

Figure E-8: Air Leakage through an Attic Hatch

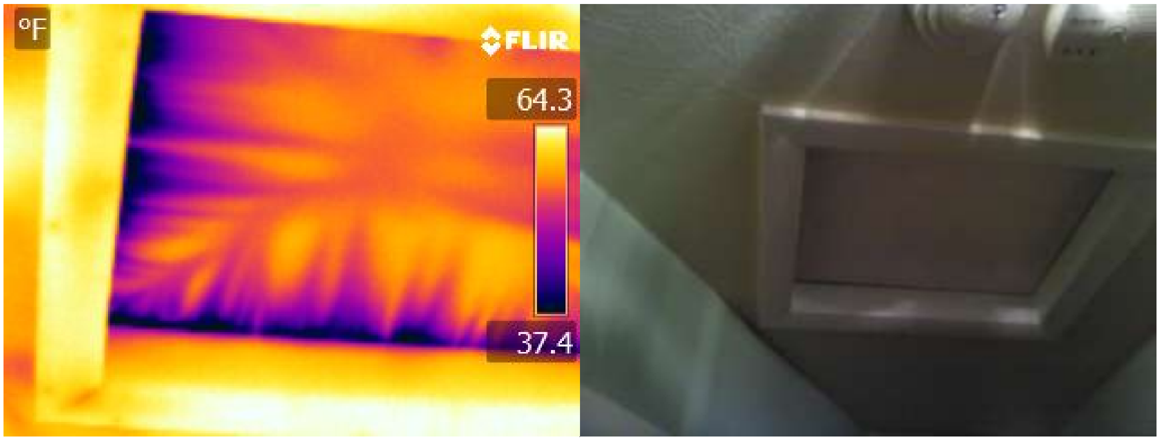


Figure E-9 and Figure E-10 show leakage from the trim located around windows. These types of leaks can easily be rectified by running a bead of caulk around the trim of the window.

Figure E-9: Air Leakage at Framing around Window

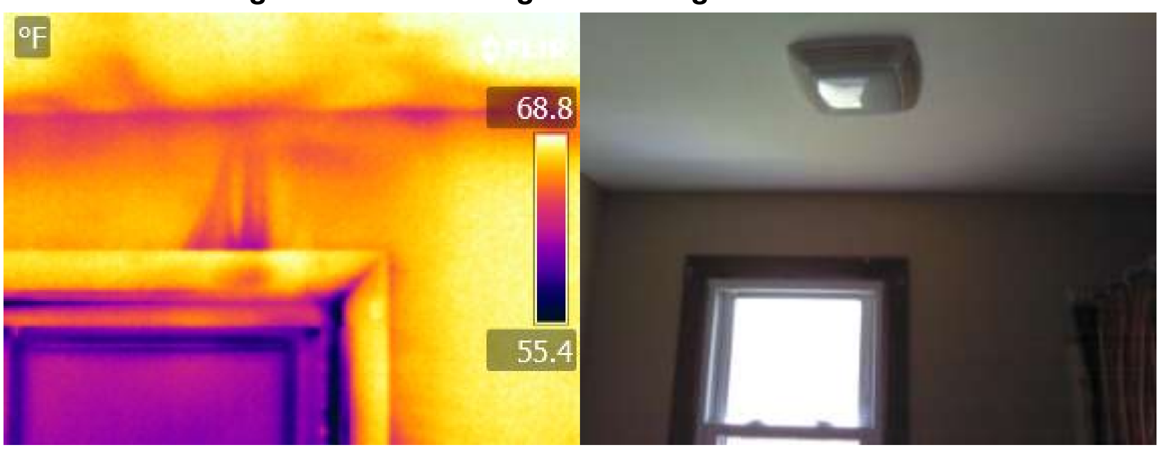
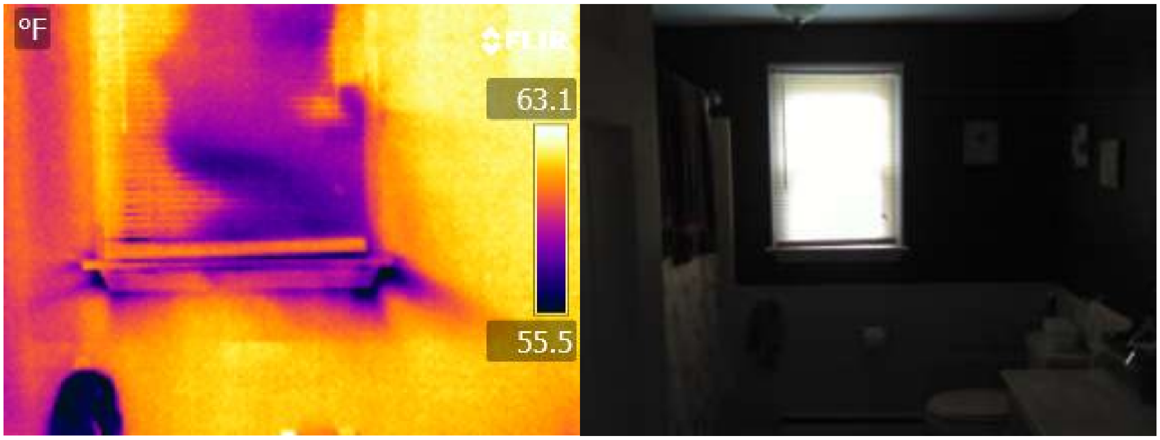


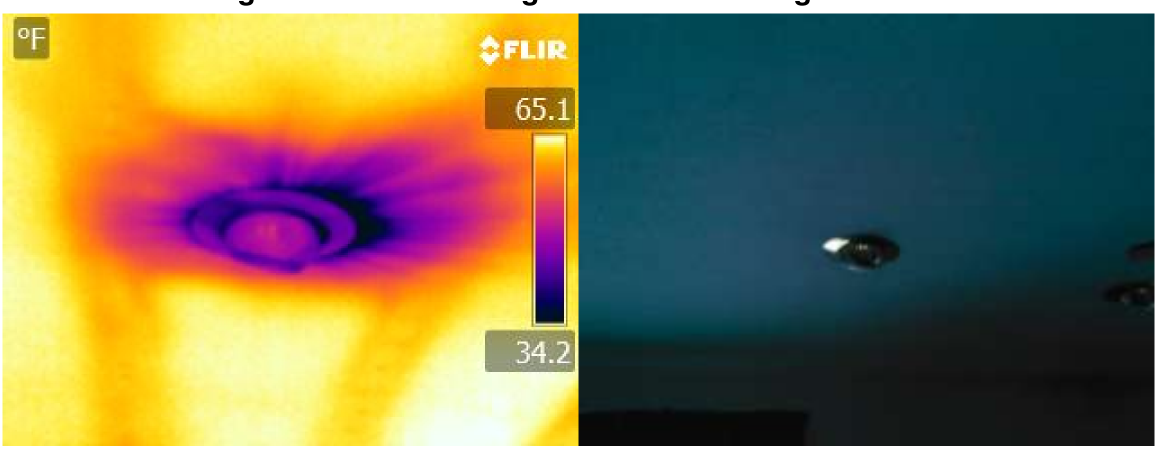
Figure E-10: Air Leakage at Framing around Bathroom Window



E.1.3 Air Leaks at Recessed Lighting Fixture

Figure E-11 shows air leakage at a recessed light fixture. In this photo, the blower door is pulling air from the attic through the recessed can and into the house. Recessed cans, particularly in older homes, are common sources of considerable air leakage.

Figure E-11: Air Leakage at a Recessed Light Fixture



E.2 Examples of Insulation Assessment Using IR

This section presents examples of insulation and moisture damage assessment using an IR camera.

Figure E-12 shows a home where a large piece of fiberglass insulation was falling down off of the knee wall, causing a significant thermal bridge in the knee wall area. Specifically, the large black spot in the middle of the infrared image is where the insulation was falling down. In the other dark areas, the insulation was either compressed or not touching the sheetrock and, as a result, was not working to its full potential as a thermal break.

Figure E-12: Missing Knee Wall Insulation

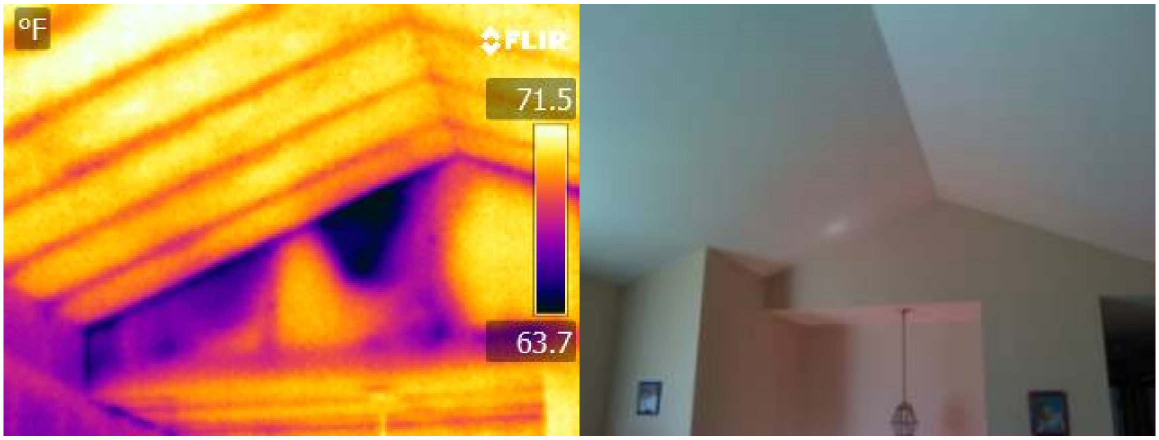


Figure E-13 shows a large patch of missing attic insulation. According to the auditor who took the photo, a contractor had been in the attic to access a vent and at the time had moved some of the insulation around. As shown in the image, the contractor never put the insulation back, resulting in a large section of uninsulated attic.

Figure E-13: Missing Attic Insulation

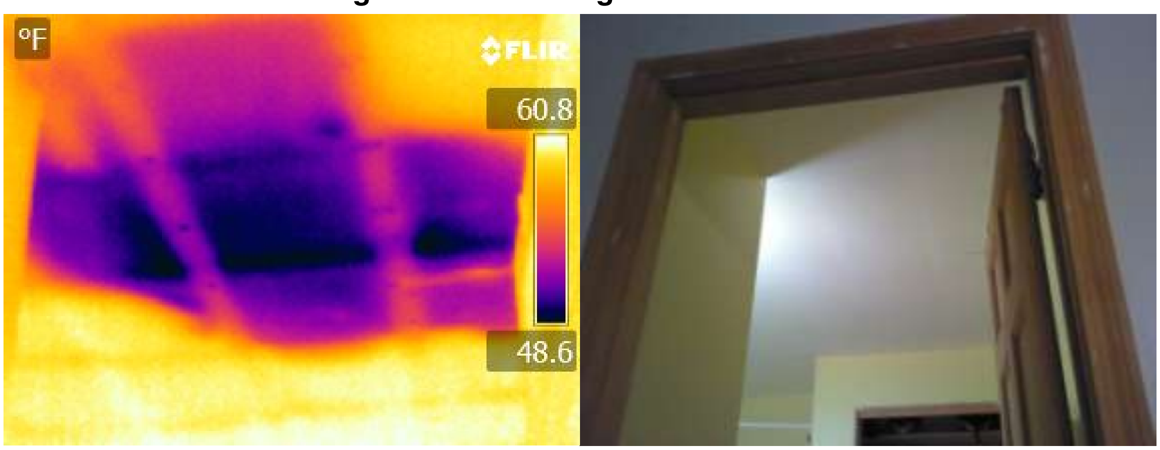


Figure E-14 shows a wall that is missing insulation where two windows used to exist. In this home, the homeowners had added a garage to this side of the home and consequently had removed two windows and installed drywall over the window areas. Unfortunately, when the homeowners installed the drywall they neglected to insulate the window cavities first, resulting in these uninsulated spaces.

Figure E-14: Missing Wall Insulation

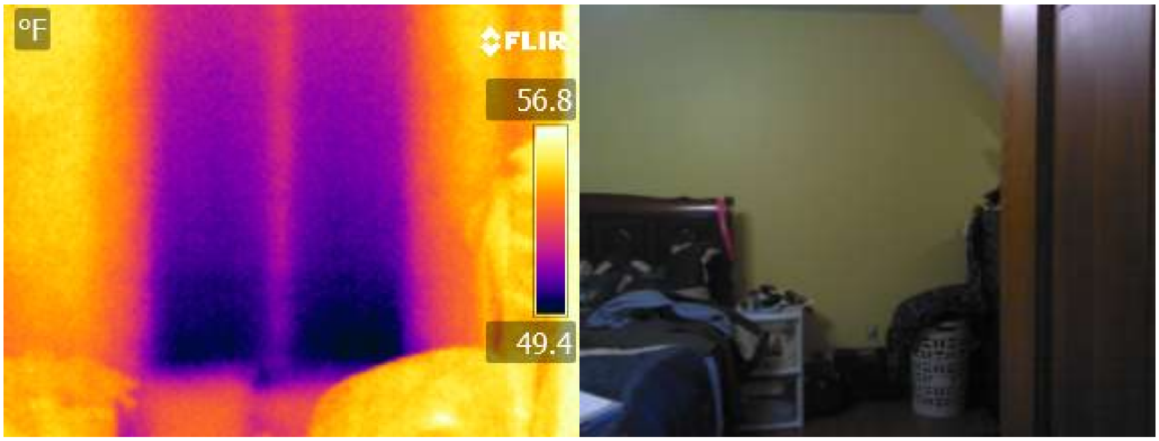


Figure E-15 shows slight settling of blown-in cellulose in a wall separating a garage from conditioned space. In the photo on the right, if one looks closely, one can see approximately six holes that were drilled (above the shovels) where the cellulose was blown in. Looking at the photo on the left, one can see that the top of the wall cavities (essentially above the holes) are a light yellow while the bottom of the wall cavities are a purple color. This photo was taken from the garage (the cold side of the wall); thus, in an insulated wall, cooler colors (purple) are preferable because that means the heat is conducting through the walls very slowly. If the wall were totally uninsulated, one would expect to see a yellow color, such as the studs, as that would mean the heat from the interior were conducting through the wall more quickly. In this case, the yellow color at the top of the wall cavities indicates that there is less blown-in cellulose than in the lower part of the cavities, which is likely due to settling. This is a common problem with blown-in cellulose as a retrofit wall insulation measure.

Figure E-15: Settling of Blown-In Cellulose Insulation

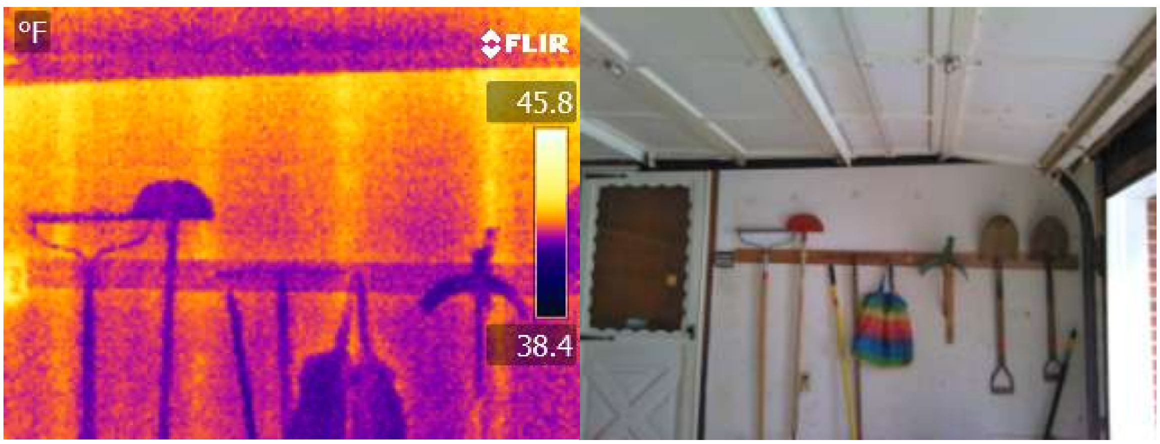


Figure E-16 shows an attic that had blown-in fiberglass insulation and many patches of ceiling that were uninsulated. This is not uncommon in homes with blown-in attic insulation, as installers often do not install the insulation consistently across the attic and homeowners may disturb the insulation over time for a variety of reasons. It is important to make sure insulation is installed evenly in ceilings, as this ultimately increases the overall average R-value of the attic compared to having peaks and valleys of insulation. The reason for this is that heat takes the path of least resistance. As a result, having inconsistent levels of insulation allows more overall heat transfer than having evenly distributed insulation.

Figure E-16: Missing Attic Insulation

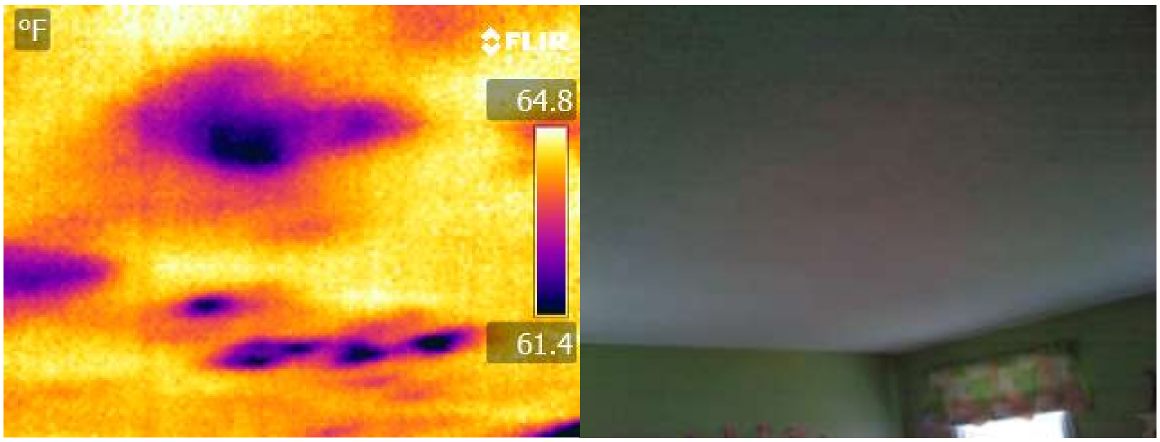


Figure E-17 shows an uninsulated band joist in a large open foyer. The dark band in the middle of the infrared image shows the uninsulated beam in the middle of two wall sections. If this beam were insulated (as it should be), it would look similar to the orange wall sections above and below.

Figure E-17: Uninsulated Band Joist

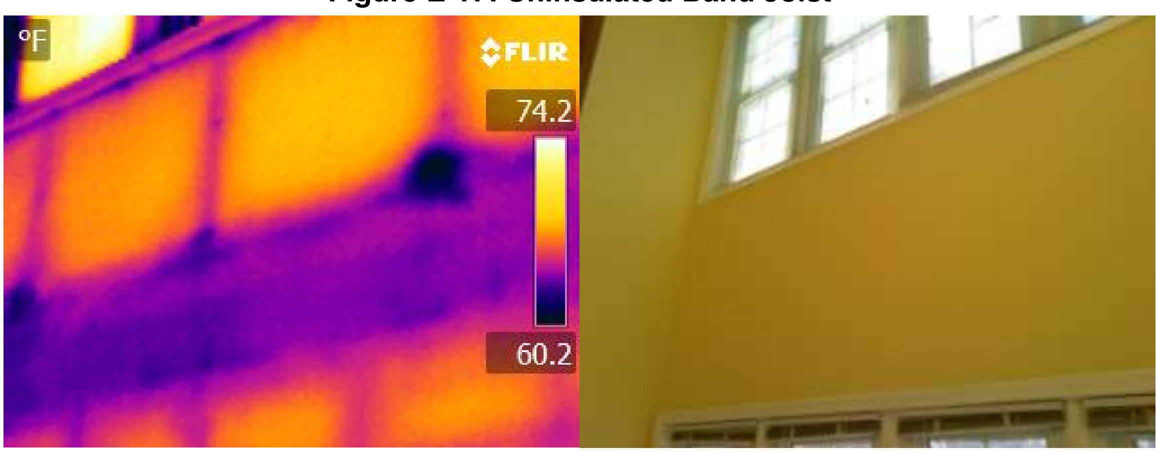


Figure E-18 shows a bathroom where there appears to be moisture damage. The marbled look of the wall indicates that moisture may linger in the bathroom after showers and baths, eventually saturating the sheetrock and insulation on the other side. The darker areas of the infrared photo, on the left, indicate areas that may be moist. This is concerning, as the moisture may eventually turn into mold, which poses a health concern.

Figure E-18: Likely Moisture Damage in Bathroom

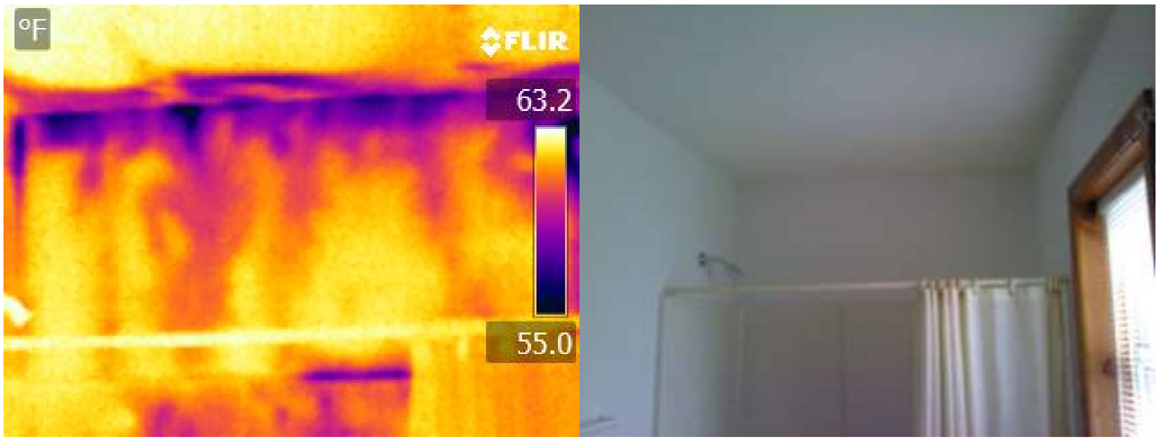


Figure E-19 shows vaulted ceiling insulation that was at least 50 years old in a house built in the 1800s. The image on the left shows dark patches in the middle of some of the cavities. Over time, the effectiveness of insulation can degrade for a variety of reasons, and that is evidenced in this photo. The dark patches in these cavities could be due to compression of insulation, some sort of sagging, or rodents creating patches. It could also be due to some other reason, such as moisture damage. IR images, while valuable, can only tell part of the story. They can identify a problem, but more investigative work may be required to figure out what caused the problem.

Figure E-19: Old, Inconsistent Vaulted Ceiling Insulation

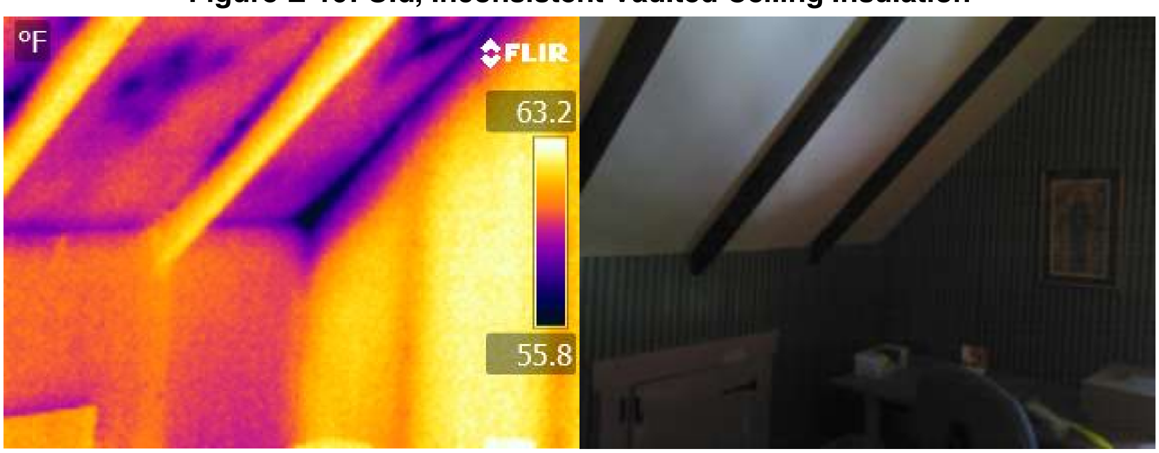
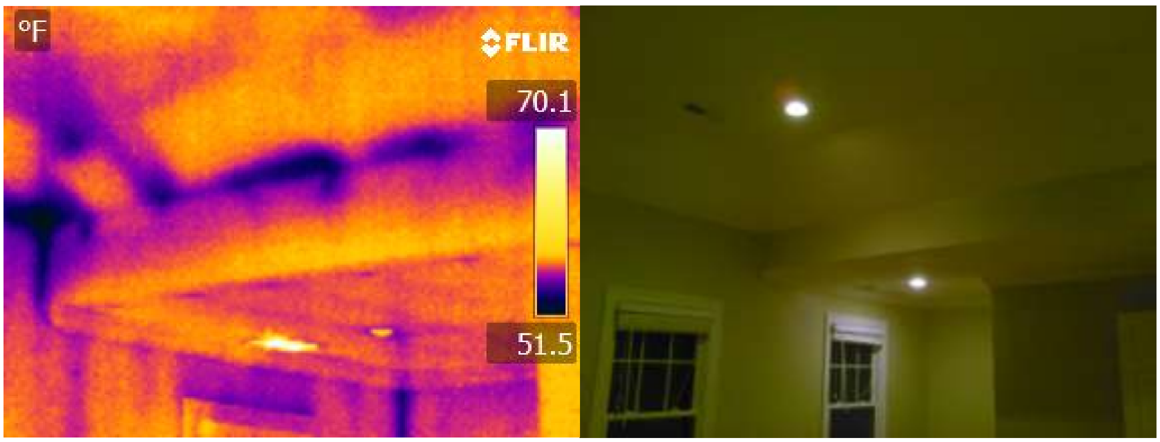


Figure E-20 shows poor insulation installation around a tray ceiling[116] in a newer home. This photo is representative of many areas where there are numerous angles around which to insulate. Using a standard insulation material such as fiberglass batts, it is extremely difficult to properly insulate around these various angles. In the image below, the dark areas represent spots where the insulation is either compressed or missing. All of the dark spots are on seams where the tray ceiling meets the flat ceiling or the small section of wall directly below the vaulted part of the tray ceiling.

Figure E-20: Poor Insulation Installation in Tray Ceiling



[116] A tray ceiling is a piece of ceiling that is inverted or recessed and is most commonly used as a design feature.

E.3 Good Practices Identified Using IR

This section provides a few examples of good practices and how they may be identified using infrared imaging.

Figure E-21 shows a spray-foamed vaulted ceiling and attic wall. Looking at the infrared image on the left, one can see that most of the spray foam is one color (there is very little darker colored insulation), indicating that the vaulted ceiling and the attic wall are a similar temperature. This represents an example of a good installation of insulation.

Figure E-21: Spray Foam Vaulted Ceiling and Attic Wall

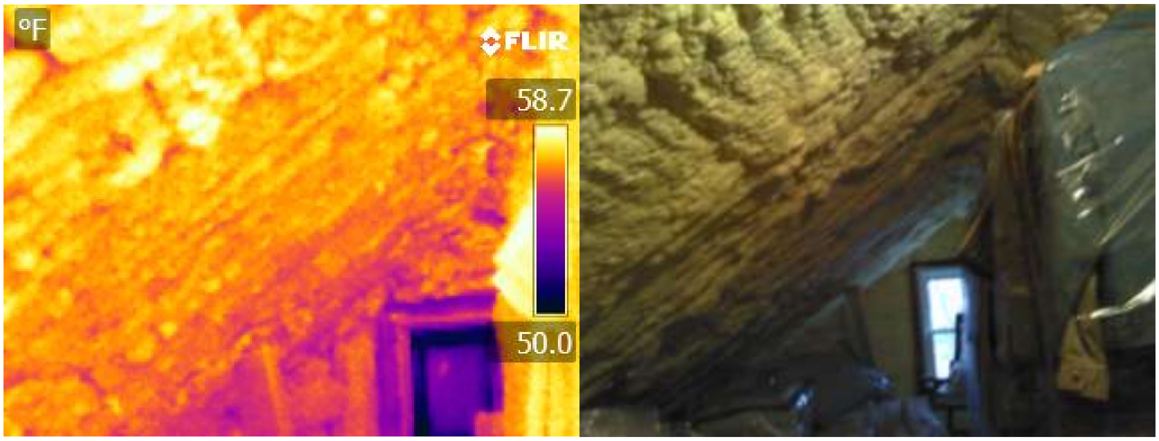
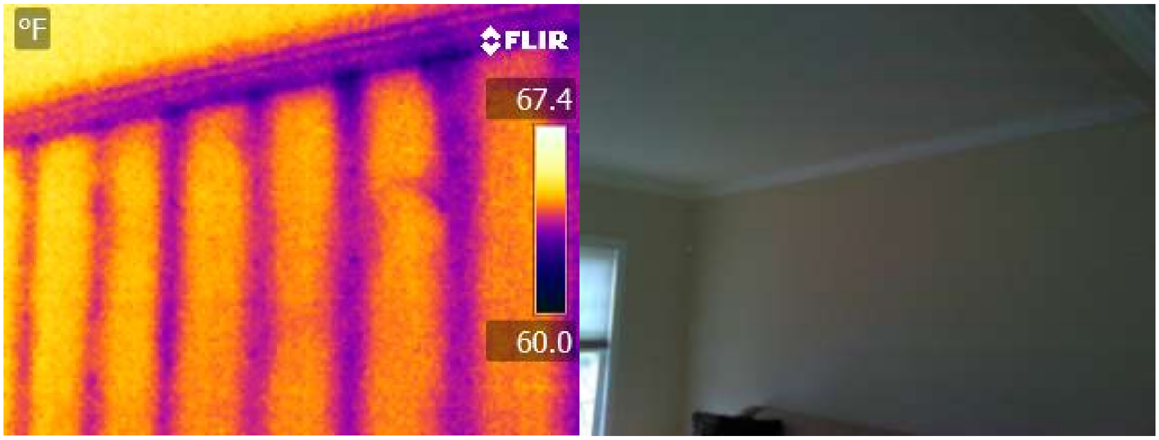


Figure E-22 shows a wall that has well installed insulation. This is an exterior wall; the photo was taken from the interior. The light color within the cavities indicates that the insulation in the cavities is effective at keeping the heat inside the home (the studs, by comparison, are purple and cold due to the fact that heat is conducting through them quickly, leaving them cooler than the cavity). Also, this image shows that the cavities are nearly all one color, indicating that the installers have done a good job of consistently filling wall cavities with insulation.

Figure E-22: Well Installed Wall Insulation



Appendix F Modeling Details

This appendix provides additional details on the approach that was taken to model all 180 homes as part of the performance-based compliance analysis. In order to assess compliance with the weatherization standard's performance approach, the evaluators developed a User-Defined Reference Home (UDRH) script that compared each audited (or "as built") home to the same home (with the same configuration, conditioned floor area, volume, etc.) modeled with the prescriptive efficiency specifications listed in the weatherization standard.

The bullet list below displays the requirement for each of the measures listed in the weatherization standard and the modeling approach that was applied to each measure.

- **Above-Grade Walls—R-11 requirement**
  - All above-grade walls in all locations (conditioned to ambient, conditioned to garage, conditioned to unconditioned basement, etc.) were compared to a wall with R-11, grade II cavity insulation.
- **Flat Ceilings—R-30 requirement**
  - All flat attics were compared to a flat attic with R-30, grade II cavity insulation.
- **Vaulted Ceilings—R-19 requirement**
  - All vaulted ceilings were compared to a vaulted ceiling with R-19, grade II cavity insulation.
- **Unconditioned Basements & Crawlspaces—R-13 requirement**
  - All floors over unconditioned spaces in all locations (conditioned to unconditioned basement, conditioned to garage, conditioned to ambient, etc.) were compared to a floor with R-13, grade II cavity insulation.[117]
- **Conditioned Basements & Crawlspaces—Interior walls fully insulated to R-5**
  - All foundation walls within conditioned space and abutting unconditioned space were compared to foundation walls with interior continuous R-5 insulation.
- **Slab on Grade—R-5 four feet below grade; assume to proper depth if present**
  - All on-grade slabs in conditioned space were compared to a slab insulated with R-5 continuous perimeter insulation that extends to a depth of four feet.[118]
- **Windows—U-0.50 (Double pane or single pane with storm)**
  - All windows were compared to a window with a U-value of U-0.50 and an SHGC value of U-0.60.[119]

[117] The EEB evaluation technical consultant agreed to include other floor locations (e.g., conditioned to garage) in the analysis even though they are not specified in the weatherization standard.

[118] Note that slabs are very difficult to inspect onsite and it is also difficult to determine the presence of slab insulation. For this reason, any home built in 2000 or later with a slab on grade in conditioned space was assumed to meet the weatherization standard requirement of R-5. On grade slabs in homes built before 2000 were assumed to be uninsulated unless auditors had sufficient information to make an alternative assumption (e.g., access to building plans, homeowner information, etc.).

- **Air Leakage—9 ACH @ 50 pascals**
  - All homes were compared to the same home with an overall air leakage of 9 ACH50.
- **Duct Leakage for Ducts Outside Conditioned Space—16 CFM at 25 Pascals per 100 sq. ft. of conditioned floor area**
  - All duct systems were compared to a duct system with leakage to the outside of 16 CFM25/100 sq. ft.
- **Duct Insulation—R-2 insulation in unconditioned basements and R-4.2 insulation in unconditioned attics and crawlspaces**
  - All ducts in unconditioned basements were compared to the same ducts with R-2 insulation. Similarly, all ducts in unconditioned attics and crawlspaces were compared to the same ducts insulated to R-4.2.[120,121]

F.1 Insulation Grades

Prior to modeling performance-based compliance, the Team and the EEB technical consultant decided that all insulation would be modeled as a Grade II installation in the "weatherized" REM/Rate model. This means that homes with Grade I installations (high quality) would be given additional credit when assessing performance-based compliance and homes with Grade III installations (low quality) would be penalized.

F.2 Air and Duct Leakage Estimates

In order to calculate performance-based compliance, it was first necessary to estimate building envelope air leakage levels for the 24 homes where blower door tests were not conducted. The presence of asbestos and/or mold were the primary reasons that blower door tests were not conducted. These estimates were required to accurately complete the REM/Rate models that were used for these analyses (more detail on these estimates can be found in the Estimating Air Leakage section of this report). Similarly, there were 24 homes where ducts were present but could not be tested for a variety of reasons (e.g., presence of asbestos, unreachable registers, etc.). For these sites, REM/Rate default values were used as duct leakage inputs to the models. The weatherization results presented in this report exclude the impact of duct leakage requirements for these 24 sites; because they were unable to estimate leakage values for these duct systems, the evaluators believe it is inappropriate to compare default values to the weatherization standard. In other words, the impact of the prescriptive duct leakage requirement on performance- (and prescriptive-) based weatherization compliance was neutralized for these

[119] Any double pane window or single pane window with a storm was modeled with the same specifications as the prescriptive standard in the baseline or "as is" model.
[120] Ducts in other unconditioned spaces (e.g., garages) were not compared to either prescriptive requirement.
[121] Supply and return ducts were both compared to the standard requirements.

24 sites. That said, the Team believes that the aforementioned building envelope air leakage estimates are indeed accurate and therefore have compared those leakage values to the weatherization standard and included them in the weatherization results throughout this report.

Appendix G Mechanical Equipment—Additional Details

This section presents additional information on the mechanical equipment that was inspected during the site visits.

G.1 Appendix – Heating

Table G-1 and Table G-2 show a detailed breakdown of heating system efficiencies by system type, fuel, and household income. Several types of heating systems, such as ASHPs, GSHPs, pellet and propane boilers, and direct-vent ductless heaters are only found in non-low-income homes in the sample.[122]

Table G-1: Mean Heating System Efficiency by Income Level

(Base: All heating systems with known efficiencies)

Heating System Type	Units	Low Income	Non-Low Income
Natural Gas Boilers	AFUE	78.0 (n=8)	80.9 (n=17)
Natural Gas Furnaces	AFUE	85.5 (n=4)	85.1 (n=24)
Oil Boilers	AFUE	80.7 (n=13)	82.5 (n=71)
Oil Furnaces	AFUE	84.0[a] (n=5)	82.0[a] (n=27)
ASHP	HSPF	--	8.8 (n=11)
GSHP	COP	--	4.6 (n=1)
Pellet boiler	AFUE	--	92.2 (n=1)
Propane boiler	AFUE	87.0 (n=1)	82.0 (n=1)
Propane furnace	AFUE	--	93.6 (n=2)
Propane ductless direct vent heater	AFUE	--	77.0 (n=2)

[a] Statistically significant difference at the 90% confidence level.

[122] Of the system types in **Error! Reference source not found.**1, when separated by fuel, only oil furnaces have a statistically significant difference (at the 90% confidence level) between the AFUEs found in low-income (84.0) and non-low-income homes (82.0), taking into account the fact that these are small sample sizes and relatively small differences.

Table G-2: Mean Heating System Efficiency by Primary Heating Fuel and Income Level

(Base: All heating system types excluding stoves and electric resistance)

	Units	Primary Heating Fuel			Household Income		Statewide
		Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Boilers	AFUE	82.4[a,b] (n=87)	79.5[a,c] (n=24)	90.0[b,c] (n=1)	80.0 (n=22)	82.3 (n=90)	81.6 (n=112) (Weighted)
Furnaces	AFUE	83.0 (n=34)	85.1 (n=28)	--	84.7 (n=9)	83.8 (n=53)	83.7 (n=62)
ASHP	HSPF	10.0 (n=4)	--	8.1 (n=7)	--	8.8 (n=11)	8.8 (n=10)
GSHP	COP	--	--	4.6 (n=1)	--	4.6 (n=1)	4.6 (n=1)
Propane ductless direct vent heater	AFUE	77.0 (n=1)	--	77.0 (n=1)	--	77.0 (n=2)	77.0 (n=2)

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

*This excludes electric resistance heat and the single solar system that was not paired to a boiler, for which the Team does not report efficiency. The other solar system paired with a boiler was just reported with its rated AFUE, excluding any solar benefit.

Table G-3 and Table G-4 provide a detailed breakdown of the mean age of different types of heating systems and compare these values across household income levels. There are no statistically significant differences in mean ages for low-income and non-low-income systems when they are compared at this detailed level.

Table G-3: Heating System Average Age by Income Level (age in years)

(Base: Heating systems*)

Heating System Type	Low Income	Non-Low Income
Natural Gas Boilers	26 (n=8)	21 (n=17)
Natural Gas Furnaces	14 (n=4)	13 (n=24)
Oil Boilers	18 (n=13)	15 (n=71)
Oil Furnaces	14 (n=5)	18 (n=27)
ASHP	--	10.4 (n=11)
GSHP	--	2 (n=1)
Pellet boiler	--	4 (n=1)
Propane boiler	15 (n=1)	11 (n=1)
Propane furnace	--	2 (n=2)
Propane ductless direct vent heater	--	7.5 (n=2)

*This excludes electric resistance heat and the solar-assist system.

Table G-4: Mean Heating System Age by Primary Heating Fuel and Income Level

(Base: All heating system types excluding stoves and electric resistance)

	Primary Heating Fuel			Household Income		Statewide (weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Boilers	15.4 (n=87)	23.5 (n=24)	2 (n=1)	21.0 (n=22)	16.0 (n=90)	17.7 (n=112) (Weighted)
Furnaces	16.7 (n=34)	13.3 (n=28)	--	14.0 (n=9)	15.4 (n=53)	15.5 (n=62) (Weighted)
ASHP	3.0[a] (n=4)	--	14.6[a] (n=7)	--	10.4 (n=11)	10.4 (n=11)
GSHP	--	--	2 (n=1)	--	2 (n=1)	2 (n=1)
Propane ductless direct vent heater	8 (n=1)	--	7 (n=1)	--	7.5 (n=2)	7.5 (n=2)

[a] Statistically significant difference at the 90% confidence level.

Table G-5 shows the same age range information as Figure 6-2, but with five-year increments for the heating systems that are less than 30 years old, to be able to see greater detail in the collected age data.

Table G-5: Heating System Age Ranges

(Base: All heating system types excluding stoves and electric resistance)

	Primary Heating Fuel			**Household Income**		**Statewide (Weighted)**
	Oil & Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**	
n – number of heating systems in each category	*126*	*52*	*11*	*31*	*158*	*189*
0 to 5 years	21%	21%	45%	29%	21%	23%
6 to 10 years	24%[a]	13%[a]	9%	10% [b]	22% [b]	20%
11 to 15 years	18%	13%	27%	10%	19%	17%
16 to 20 years	17%[a]	13%[b]	0%[a,b]	16%	15%	15%
21 to 25 years	7%[a]	13%[b]	0%[a,b]	10%	8%	8%
26 to 30 years	3%	8%	18%	6%	5%	5%
31 to 40 years	4%[a]	12%[b]	0%[a,b]	6%	6%	6%
41 to 50 years	2%	4%	0%	6%	1%	2%
51 to 60 years	3%[a]	2%	0%[a]	6%	2%	3%
61 to 70 years	1%	0%	0%	0%	1%	<1%

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

The performance of heating systems can be affected by whether they are installed in unconditioned or conditioned spaces. Of those system types that could be installed in either location, 71% of systems are located in unconditioned space, and 29% are in conditioned space. Most systems in unconditioned space are in basements (65% of all systems) (Table G-6).

Table G-6 also shows the minor differences in the sample of heating system location according to the home's primary heating fuel and household income. Sampled homes with natural gas as the primary heating fuel have a slightly higher percentage of heating systems in unconditioned space than do homes in the oil and other fuels category. The differences based on household income are minor.

Table G-6: Location of Heating System

(Base: Heating systems that could be located in conditioned or unconditioned space; excludes stoves, electric resistance, and similar*)

	Primary Heating Fuel			Household Income		Statewide (weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n – number of heating systems in each category	*121*	*52*	*9*	*31*	*151*	*182*
Systems in Conditioned Space	**30%**	**23%**	**4 (44%)**	**32%**	**28%**	**29%**
Systems in Unconditioned Space	**70%**	**77%**	**5 (56%)**	**68%**	**72%**	**71%**
Uncond. basement	68%[a]	65%[b]	3 (33%)[a,b]	65%	66%	65%
Attic	0%[a]	6%[a]	2 (22%)	0%[c]	3%[c]	3%
Garage	2%	4%	0 (0%)	3%	3%	3%
Crawl space	0%	2%	0 (0%)	0%	1%	1%

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

*This table includes boilers, furnaces, GSHPs, ASHPs (except for ductless mini-splits or packaged window units), and solar-assisted systems. It does not include stoves, electric resistance heat, ductless mini-splits, packaged ASHPs, of ductless direct vent heaters.

Statewide, 64% of homes with hydronic heat have no insulation on their space heating water lines; 36% have at least some insulation, but only 13% of homes have fully insulated space heating water lines (Table G-7). These percentages do not change significantly depending on whether or not a household is low-income or on its primary heating fuel.

Table G-7: Hydronic Heat Pipe Insulation

(Base: Homes with hydronic lines for space heating)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity (Counts only)	Low Income	Non-Low Income	
n	*86*	*24*	*2*	*86*	*24*	*112*
No insulation	67%	63%	0	55%	68%	64%
At least some insulation	33%	38%	2	45%	32%	36%
Mostly uninsulated	7%	13%	0	14%	7%	8%
Mostly insulated	13%	17%	0	14%	13%	14%
Fully insulated	13%	8%	2	18%	12%	13%

No statistically significant differences at the 90% confidence level.

G.2 Appendix – AC

Table G-8 expands on Table 6-14 by providing counts of room AC units based on primary heating fuel.

Table G-8: Number of Room Air Conditioning Units, by Primary Heating Fuel and Income

(Base: All homes)

		Primary Heating Fuel			Household Income		Statewide (Weighted)
		Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Number of Homes		*118*	*46*	*16*	*34*	*146*	*180*
No room AC		58%	67%	50%	44%[a]	63%[a]	59%
Have at least one unit		42%	33%	50%	56%[a]	37%[a]	41%
# of RAC units in each house:	One	12%	11%	19%	24%[a]	10%[a]	13%
	Two	10%	4%	13%	12%	8%	9%
	Three	14%	13%	6%	18%	12%	14%
	Four	3%	4%	13%	0%[a]	5%[a]	4%
	Five	2%	0%	0%	3%	1%	1%
	Six	1%	0%	0%	0%	1%	1%

[a] Statistically significant difference at the 90% confidence level.

The air handlers of ducted cooling systems (traditional central AC, ASHP, and GSHP systems) can be installed in unconditioned or conditioned spaces.[123] There are 103 such ducted cooling systems in the 180 sampled homes. Of these ducted systems, 26% have air handlers in conditioned space and 74% are located in unconditioned space (mostly in basements and attics). At the 90% confidence level, there are no statistically significant differences in the location of air handler system by household income (Table G-9).

Table G-9: Location of Indoor Coil for Cooling System

(Base: All ducted central and heat pump AC systems)

	Household Income		**Statewide (Weighted)**
	Low Income	**Non-Low Income**	
n – number of heating systems in each category	*9*	*94*	*103*
Systems in Conditioned Space	3 (33%)	24%	26%
Systems in Unconditioned Space	6 (67%)	76%	74%
Uncond. basement	3 (33%)	37%	37%
Attic	2 (22%)	36%	35%
Garage	1 (11%)	2%	3%

Table G-10 expands on the information provided in Table G-9 by also showing where ducted AC systems are located in homes with different primary heating fuels, household incomes, and in the state as a whole. At the 90% confidence level, there are no statistically significant differences across primary heating fuel except in the amount of AC systems installed in attics: homes with natural gas as their primary heating fuel have a smaller percentage of AC systems in the attic than homes in the “other fuel” category.

[123] The cooling coils of window units, through-wall units, portable units, and ductless mini-splits are always installed in conditioned space, and are therefore excluded from this table.

Table G-10: Location of Indoor Coil for Cooling System, by Primary Heating Fuel and Household Income

(Base: All ducted central and heat pump AC systems)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**	
n – number of heating systems in each category	*68*	*27*	*8*	*9*	*94*	*103*
Systems in Conditioned Space	21%	33%	3 (38%)	3 (33%)	24%	26%
Systems in Unconditioned Space	79%	67%	5 (63%)	6 (67%)	76%	74%
Uncond. basement	38%	37%	2 (25%)	3 (33%)	37%	37%
Attic	40%[a]	22%[a]	3 (38%)	2 (22%)	36%	35%
Garage	1%	7%	0 (0%)	1 (11%)	2%	3%

[a] Statistically significant difference at the 90% confidence level.

Table G-11 shows how AC efficiency varies for each system type across homes with different types of primary heating fuel.

Table G-11: Mean AC System Efficiency, by Primary Heating Fuel and Income Level

(Base: All AC systems with known efficiencies)

	Units	Primary Heating Fuel			Household Income		Statewide	Count of Systems with Unknown Eff.*
		Oil & Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**		
Central AC	SEER	11.3[a] (n=68)	11.3 (n=25)	12.0[a] (n=1)	11.3 (n=9)	11.3 (n=85)	11.3 (n=94) (Weighted)	0
Room AC	EER	9.7 (n=119)	9.6 (n=35)	9.8 (n=18)	9.8 (n=39)	9.7 (n=133)	9.7 (n=172) (Weighted)	8
ASHP	SEER**	17.7[a,b] (n=14)	10.0[a,c] (n=2)	13.2[b,c] (n=7)	--	15.7 (n=23)	15.7 (n=23)	0
GSHP	EER	--	--	22.8 (n=1)	--	22.8 (n=1)	22.8 (n=1)	0

[a,b,c] Statistically significant difference at the 90% confidence level.
*These are *not* included in the above counts and statistics.
**The 23 ASHPs counted here do not include two more EER-only systems, one 10 EER, and the other 11.7 EER.

Following this pattern, Table G-12 provides a similar breakout for AC system age, including comparisons across homes' primary heating fuel.

Table G-12: Mean AC System Age by Primary Heating Fuel and Income Level (age in years)

(Base: All AC systems with known ages)

	Primary Heating Fuel			Household Income		Statewide	Count of systems with unknown age*
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income		
Central AC	10.8[a] (n=64)	12.9[b] (n=23)	18[a,b] (n=1)	14.3 (n=7)	11.1 (n=81)	11.4 (n=88) (Weighted)	6
Room AC	8.9 (n=108)	7.6 (n=32)	8.2 (n=18)	8.3 (n=37)	8.6 (n=121)	8.6 (n=158) (Weighted)	22
ASHP	5.0[a] (n=14)	7.0 (n=2)	13.8[a] (n=8)	--	8.2 (n=24)	8.2 (n=24)	1
GSHP	--	--	2 (n=1)	--	2 (n=1)	2 (n=1)	0

*The counts for unknown values are not includes in the sample sizes and data in the rest of the table.
[a,b] Statistically significant difference at the 90% confidence level.

Table G-13 provides a detailed breakdown of the data in Figure 6-3, including how the AC age ranges vary depending on the primary heating fuel and income level.

Table G-13: AC System Age Ranges

(Base: All AC systems)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n – number of AC systems in each category	*186*	*57*	*28*	*44*	*227*	*271*
0 to 5 years	29%	40%	36%	39%	31%	32%
6 to 10 years	40% [a]	28% [a]	29%	34%	37%	36%
11 to 15 years	20%	12%	18%	14%	19%	18%
16 to 20 years	5%	11%	4%	7%	6%	6%
21 to 25 years	3%	2%	7%	5%	3%	3%
26 to 30 years	1%	5%	7%	2%	2%	2%
31 to 40 years	1%	2%	0%	0%	1%	2%
41 to 50 years	1%	0%	0%	0%	<1%	<1%
Counts of systems with unknown age*	24	5	0	4	25	29

*The counts for unknown values are not includes in the sample sizes and data in the rest of the table.

[a] Statistically significant difference at the 90% confidence level.

G.3 Appendix – Water Heaters

Table G-14 expands on Table 6-32 by including how water heater efficiency varies for each common system type across homes with different types of primary heating fuels.

Table G-14: Mean Water Heater EF by Primary Heating Fuel and Income Level

(Base: Common water heater types)[124]

	Primary Heating Fuel			Household Income		Statewide
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
Conventional Storage (non-electric)	0.58[a] (n=21)	0.58[b] (n=39)	0.63[a,b] (n=1)	0.58 (n=12)	0.58 (n=49)	0.58 (n=61) (Weighted)
Conventional Storage (electric)	0.89 (n=24)	0.89 (n=3)	0.89 (n=12)	0.90 (n=10)	0.89 (n=29)	0.89 (n=39) (Weighted)
Indirect Storage	0.77 (n=34)	0.79 (n=3)	--	0.76 (n=6)	0.77 (n=31)	0.77 (n=37) (Weighted)

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

Table G-15 provides a detailed breakdown of the mean age of different types of water heaters and compares these values across primary heating fuels and household income levels. There are no statistically significant differences in mean ages for low-income and non-low-income systems when they are compared at this detailed level.

[124] This table excludes instantaneous, heat pump, and solar systems, which do not exist in more than one of each of the categories being compared. Tankless coils are also excluded because their EF is a function of occupancy, not system performance.

Table G-15: Mean Water Heater Age by Region and Income Level (age in years)

(Base: All DHW systems)

	Primary Heating Fuel			Household Income		Statewide	Count of systems with unknown age*
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income		
Conventional Storage	10.1[a] (n=43)	7.8 (n=38)	7.0[a] (n=12)	7.9 (n=18)	9.0 (n=75)	9.3 (n=93) (Weighted)	7
Indirect Storage	9.2[a] (n=32)	4.0[a] (n=2)	--	9.7 (n=6)	8.7 (n=28)	8.9 (n=34) (Weighted)	3
Tankless coil	15.6[a] (n=33)	46[a] (n=1)	--	13.3 (n=4)	17.0 (n=30)	16.9 (n=40) (Weighted)	0
Instantaneous	6.5 (n=2)	--	--	--	6.5 (n=2)	6.5 (n=2)	0
Heat Pump	--	--	12 (n=1)	--	12 (n=1)	12 (n=1)	0
Solar Assisted	32.5 (n=2)	--	14.5 (n=2)	--	23.5 (n=4)	23.5 (n=4)	0

[a] Statistically significant difference at the 90% confidence level.

Table G-16 shows the same age range information described in Figure 6-5, with five-year increments for the water heating systems that are less than 30 years old, to reveal greater detail in the collected age data. Just under one-third of water heaters statewide (32%) are five years old or less. The table also shows the modest differences in water heater age ranges based on the home's primary heating fuel and household income.

Table G-16: Water Heater Age Ranges

(Base: All DHW systems)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n – number of DHW systems in each category	*118*	*41*	*15*	*31*	*143*	*174*
0 to 5 years	29%	39%	40%	39%	31%	32%
6 to 10 years	28%	37%	27%	23%	31%	29%
11 to 15 years	19%	17%	20%	23%	17%	19%
16 to 20 years	13%[a]	2%[a]	7%	13%	9%	10%
21 to 25 years	6%[a,b]	0%[a]	0%[b]	3%	4%	4%
26 to 30 years	2%	2%	7%	0%[c]	3%[c]	2%
31 to 40 years	1%	0%	0%	0%	1%	1%
41 to 50 years	0%	2%	0%	0%	1%	1%
51 to 60 years	3%[a,b]	0%[a]	0%[b]	0%[c]	2%[c]	2%
61 to 70 years	1%	0%	0%	0%	1%	1%
Counts of systems with unknown age*	4	5	1	4	6	10

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

*The counts for unknown values are not includes in the sample sizes and data in the rest of the table.

Statewide, only 9 of the 88 water heater tanks have tank insulation (7% when weighted) (Table G-17). Of these 9 water heater tanks, eight are conventional storage tank water heaters, seven are electric, one is propane, and one is natural gas-fired; the ninth is an indirect storage tank attached to an oil-fired boiler. In addition, one boiler with a tankless coil water heater system is covered with fiberglass R-10 insulation; this insulated boiler is not included in the table below.

Table G-17: Water Heater Tank Wrap Insulation

(Base: All homes)

	Statewide (Weighted)
*Number of Tank Water Heaters**	*88*
Percent with insulation wrap	7%

*Includes conventional tanks, indirect tanks, the one heat pump water heater, and the solar-assisted systems using tanks.

Statewide, 56% of homes have no insulation on their domestic hot water lines; 44% have at least some insulation, but only 15% of homes have fully insulated domestic hot water lines. These percentages do not change dramatically depending on whether or not a household is low-income, though homes with electricity as their primary heating fuel do have a greater percentage of insulated water lines; 31% of electric homes have fully insulated hot water lines compared to 9% for natural gas homes or 15% for "other fuel" homes (Table G-18).

Table G-18: Homes with Water Heater Pipe Insulation

(Base: All homes)

	Primary Heating Fuel			Household Income		Statewide (Weighted)
	Oil & Other Fuels	Natural Gas	Electricity	Low Income	Non-Low Income	
n	*118*	*46*	*16*	*34*	*146*	*180*
No insulation	59%	52%	38%	53%	56%	56%
At least some insulation	41% [a]	48%	63% [a]	47%	44%	44%
Mostly uninsulated	14%	22%	25%	26%	14%	17%
Mostly insulated	12%	17%	6%	12%	13%	13%
Fully insulated	15%	9% [b]	31% [b]	9%	16%	15%

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

Only one home has two different types of DHW systems: an indirect storage tank and a conventional storage tank. That home is split between the “conventional storage” and “indirect” categories in the below graphic and table. Three other homes have multiple DHW systems, but in all three cases each home has two conventional storage tank water heaters.

The four solar-assisted water heaters are not all the same type of system. Two include indirect storage tanks that are fed by boilers and solar panels working in conjunction. One is a stand-alone tank fed by solar panels, but with an electric backup. The last one is a steam boiler from 1952 that provides hot water from an internal tankless coil, but the whole boiler is fed pre-heated water from the solar array.

Table G-19 shows that most water heaters are in unconditioned space (68%) and only 32% are in conditioned space. It also shows the differences in heating system location according to the home's primary heating fuel and household income. Sampled homes with natural gas as the primary heating fuel have a slightly higher percentage of water heaters in unconditioned space (78%) than do homes in the oil and other fuels category (68%) or the electric category (44%).[125] Low-income homes have a lower percentage of water heaters in unconditioned space (63%) than do non-low-income homes (70%), but this is not a statistically significant difference. Most water heaters in unconditioned space are installed in basements, with a handful in garages.

Table G-19: Location of Water Heater

(Base: All water heaters)

	Primary Heating Fuel			**Household Income**		**Statewide (Weighted)**
	Oil & Other Fuels	**Natural Gas**	**Electricity**	**Low Income**	**Non-Low Income**	
n – number of DHW systems in each category	*122*	*46*	*16*	*35*	*149*	*184*
Systems in conditioned space	32%	22%[a]	56%[a]	37%	30%	32%
Systems in unconditioned space	68%	78%[a]	44%[a]	63%	70%	68%

[a] Statistically significant difference at the 90% confidence level.

[125] Only the differences between natural gas and electricity categories are statistically significant at the 90% confidence level, however.

Appendix H Additional Maps of Site Visit Distribution

This section presents a few additional maps that plot the location of all 180 homes visited as part of this study.

Figure H-1 shows the distribution of site visits by town. As indicated by the legend in the map, the different colors indicate varying numbers of audits per town. No more than five audits were conducted in any one town.

Figure H-1: Distribution of Site Visits by Town

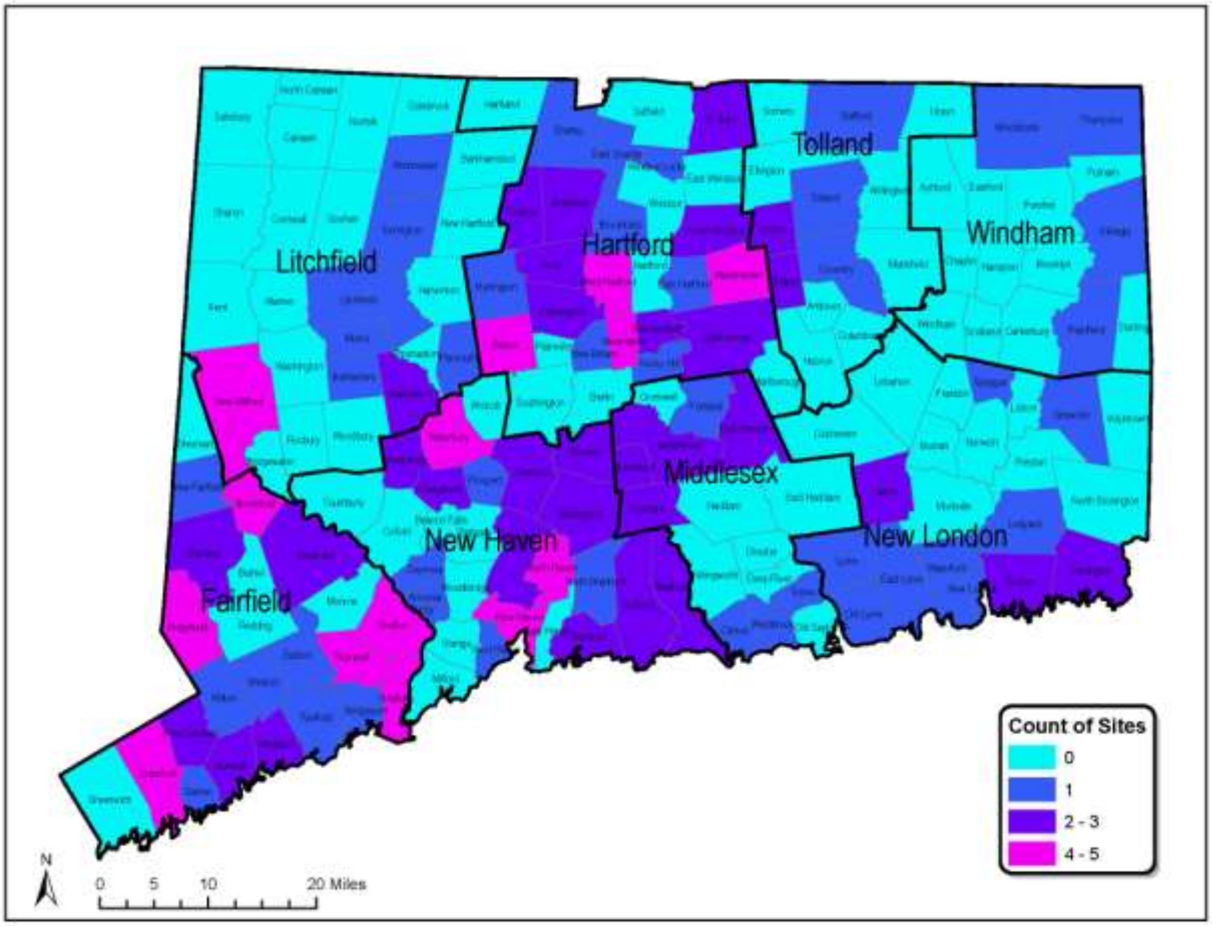


Figure H-2 plots all of the 180 audited homes by county. Blue dots indicate households that were designated as low-income, while pink dots represent households that were designated as non-low-income. As shown, there was a fairly even distribution of site visits by county.

Figure H-2: Site Visit Distribution by County and Income Status

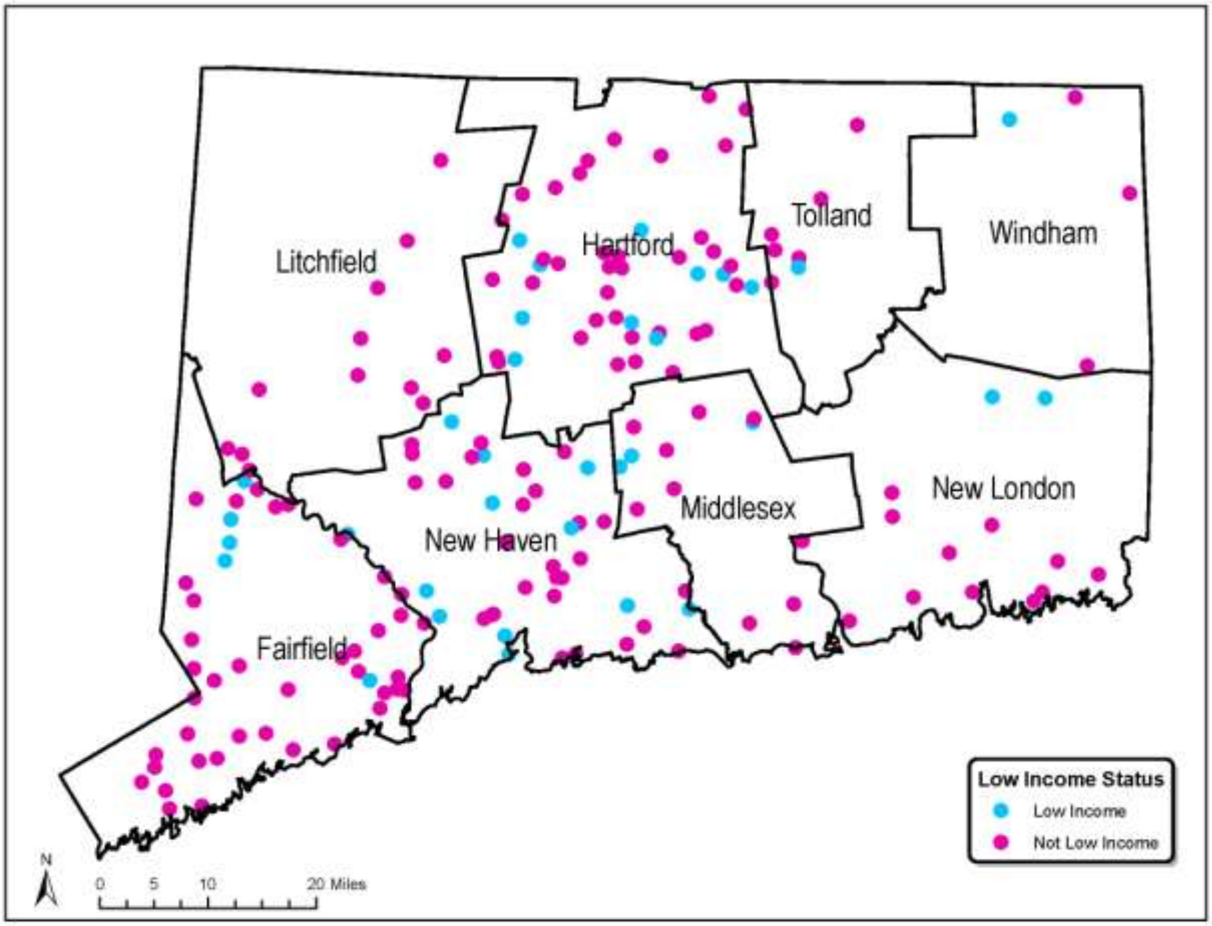
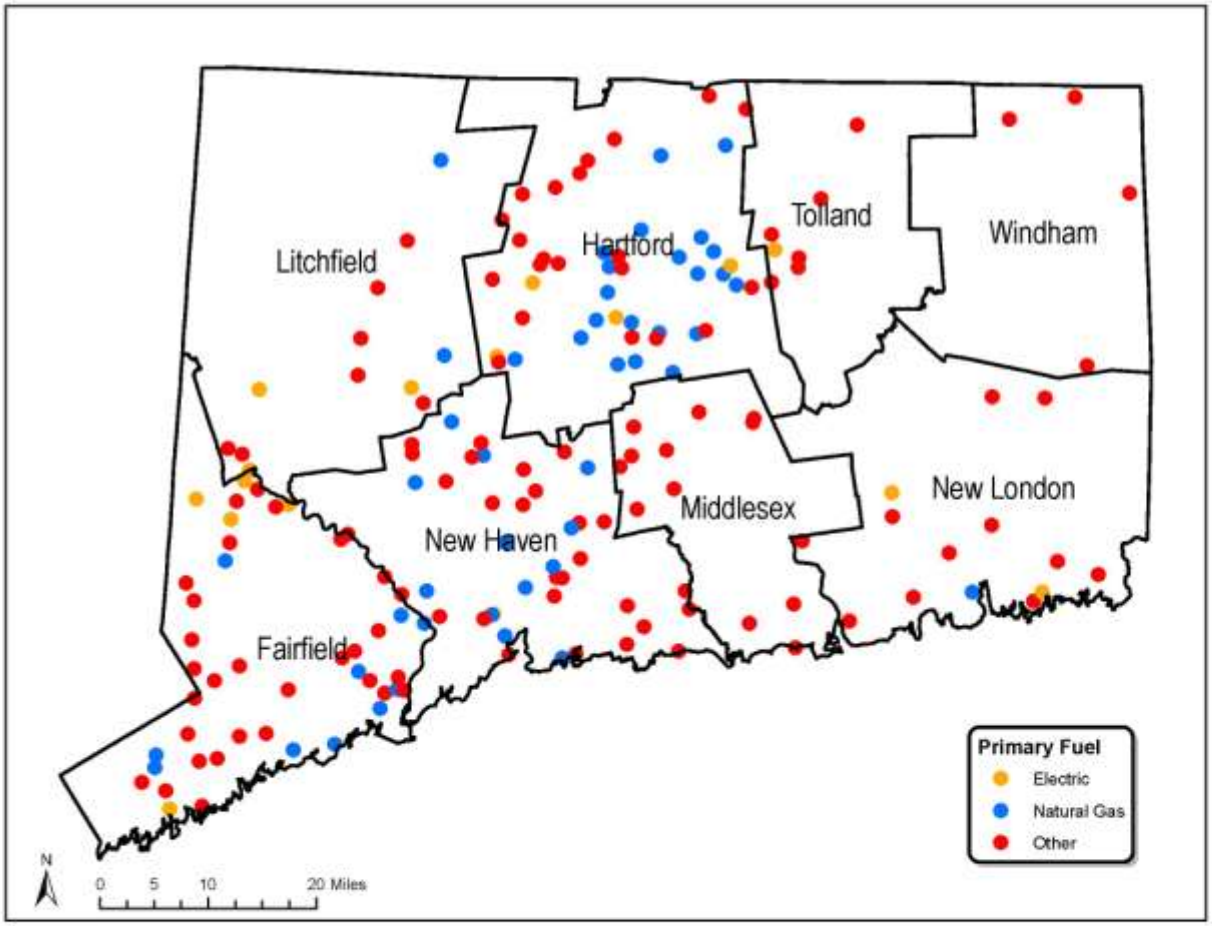


Figure H-3 plots all 180 audited homes by county. Orange dots indicate homes where the primary heating fuel was electric, blue dots indicate homes where the primary heating fuel was natural gas, and red dots indicate homes where the primary heating fuel was categorized as oil and other fuels (predominantly fuel oil). As shown, homes heated by natural gas are generally found in only Hartford, New Haven, and Fairfield counties. Homes heated primarily by oil and other fuels are evenly distributed across the state.

Figure H-3: Site Visit Distribution by County and Primary Heating Fuel



Appendix I Telephone Recruitment Survey Results

In order to identify households to take part in the onsite visits, the Team conducted a recruitment survey to gather information about the demographic and social characteristics of the household and the home in which they lived. The survey also allowed the evaluators to screen out households living in multifamily structures. This appendix compares Census data for Connecticut to the self-reported characteristics of all 1,413 respondents who answered the survey (total), the 288 respondents who initially expressed interest in the study but ultimately did not take part in the onsite visits (interested non-participants), the 1,006 households who said they did not want to take part in the study (not interested), and the 179 participants who did take part in the study (participants).[126] Note that the Team identified one household when the HES vendor and NMR auditor became confused about which of their appointments that day was to take part in the weatherization study. Because this household met all of the eligibility requirements, the EEB evaluation consultant approved inclusion of this 180th home. Overall, the results presented in this appendix demonstrate how closely the onsite sample represents the state of Connecticut.

The Team sampled study participants from all eight counties in Connecticut, as shown in Table I-1. By design, participation by county was similar to the distribution of single-family households by county. Interest in the study by county—including those who eventually did not participate—generally mirrored the distribution of households in the state.

Table I-1: Study Interest by County
(Base: Recruitment survey respondents)

County	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Fairfield	21%	23%	19%	25%	24%
Hartford	22%	25%	21%	25%	24%
Litchfield	9%	5%	11%	6%	7%
Middlesex	7%	5%	8%	7%	6%
New Haven	23%	22%	24%	23%	23%
New London	9%	7%	10%	7%	8%
Tolland	4%	7%	3%	4%	5%
Windham	5%	6%	5%	2%	3%

The majority of participants (98%) were homeowners (Table I-2). The Team achieved participation rates that were similar to Connecticut's overall demographics, where 92% of single-family households own the home they live in. Twenty percent of interested non-participants rent

[126] Actual characteristics of the home (e.g., whether it was really a single-family structure) may differ from what the respondents reported during the recruitment survey.

or lease their homes, versus only 2% of study participants and 8% of single-family households in the state. The difference between study interest and participation is due largely to the Team's effort to oversample renters. Ultimately, renters were not oversampled for three reasons: 1) during scheduling, the evaluators found that some households misidentified their home as a duplex or townhome but were instead typical multifamily homes; 2) renters were unwilling or unable to secure landlord permission, which is required for HES services; and 3) tenants were less likely to return phone calls to schedule an appointment.

Table I-2: Study Interest by Ownership
(Base: Recruitment survey respondents)

Ownership	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Own	89%	80%	89%	98%	92%
Rent or Lease	11%	20%	11%	2%	8%
Occupy Without Rent Payment	<1%	<1%	<1%	<1%	n/a
Other	<1%	<1%	<1%	<1%	n/a
Don't Know/Refused	<1%	<1%	<1%	<1%	n/a

The study was limited to single-family detached (stand-alone) and attached (e.g., townhouse) homes. Most single-family homes in the state are detached (92%), and the Team achieved a similar percentage of participants who live in detached single-family homes (Table I-3). Twenty percent of interested non-participants live in attached homes, versus only 6% of study participants and 8% of single-family households in the state. Thus, the Team had no shortage of interested households in single-family attached homes, but, as discussed in Section 2.1.1, confusion among participants about the structure of their building and difficulties securing landlord permission limited the inclusion of these households in the final sample. Moreover, in the final sample, 43% of respondents living in a townhouse or duplex rented, versus only 5% of parties living in stand-alone homes.

Table I-3: Study Interest by House Type
(Base: Recruitment survey respondents)

Home Type	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Stand Alone or Detached Single-Family	85%	77%	85%	93%	92%
Townhouse or Duplex	12%	20%	11%	6%	8%
Other	3%	3%	4%	1%	

Table I-4 shows study interest by primary heating fuel. There are small differences in the fuel used by participants and by overall single-family households in Connecticut. A slightly lower percentage of participants use fuel oil as their primary heating fuel (55% vs. 61%), and a slightly higher percentage of participants use electricity as their primary heating fuel (11% vs. 6%).

Table I-4: Study Interest by Primary Heating Fuel
(Base: Recruitment survey respondents)

Primary Heating Fuel	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Natural Gas From Underground Pipes	24%	26%	23%	26%	25%
Fuel Oil	57%	50%	58%	55%	61%
Electricity	11%	15%	10%	11%	6%
Propane or Gas in a Tank	4%	4%	4%	2%	3%
Wood	3%	4%	3%	3%	3%
Other	1%	1%	1%	3%	<1%
Don't Know/Refused	1%	1%	1%	<1%	n/a

Table I-5 shows study interest by home age. Across the participation spectrum, study interest by the approximate age of the home mimics Connecticut census data.

Table I-5: Study Interest by Year Home was Built
(Base: Recruitment survey respondents)

Year Built	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
1950 and Before[1]	26%	22%	27%	27%	25%
1951 to 1989[2]	54%	56%	54%	55%	58%
1990 and After	16%	16%	15%	17%	16%
Don't Know/Refused	4%	6%	4%	1%	n/a

[1] Census data are from 1949 and before.
[2] Census data are from 1950 to 1989.

Table I-6 shows that participants (10%) were far less likely to reside in small homes[127] compared to all single-family households in the state (20%), interested non-participants (27%), and those not interested in the study (22%). Again, the challenges of securing renters and duplexes/townhouses likely explains these differences.

Table I-6: Study Interest by House Size
(Base: Recruitment survey respondents)

Number of Bedrooms	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
0	n/a	n/a	n/a	n/a	<1%
1	4%	6%	4%	1%	2%
2	17%	21%	18%	9%	18%
3	46%	36%	47%	50%	48%
4	27%	32%	25%	33%	25%
5	4%	3%	4%	5%	5%
6	1%	2%	1%	2%	<1%
7 or More	1%	<1%	1%	1%	1%
Don't Know/Refused	<1%	<1%	<1%	<1%	n/a

Households that took part in the onsites were slightly more likely to have four or more people in them (36%) compared to all single-family households in the state (29%), which is likely tied to the slightly larger home-size and fewer attached homes included in the sample (Table I-7).

Table I-7: Study Interest by Household Size
(Base: Recruitment survey respondents)

Number of Household Residents	Total	Interested – Non Participant	Not Interested	Participant	CT Census[1]
n	*1,413*	*228*	*1006*	*179*	*900,039*
1	18%	18%	19%	13%	19%
2	39%	32%	41%	36%	35%
3	16%	13%	17%	17%	18%
4	18%	25%	15%	25%	18%
5	6%	7%	5%	7%	7%
6	2%	4%	1%	2%	2%
7	1%	1%	<1%	1%	1%
8 or More	1%	1%	1%	1%	<1%
Don't Know/Refused	1%	<1%	1%	<1%	n/a

[1] Excluding vacant houses.

[127] One or two bedrooms.

Participant age is comparable to statewide age distribution for single-family households; however, respondents who were not interested in the study were more likely to be older than interested respondents (Table I-8). Thirty-nine percent of seniors[128] were not interested in the study, compared to only one-quarter of interested non-participants (25%), participants (26%), and statewide (24%). The Team is not certain why seniors were less interested in the study, but it could have to do with fears that the study was a "scam" of some sort, as seniors are more often the target of such activities than other households.[129]

Table I-8: Study Interest by Age
(Base: Recruitment survey respondents)

Age	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Under 65	62%	73%	58%	74%	76%
65 or Older	35%	25%	39%	26%	24%
Refused	3%	1%	4%	<1%	n/a

Just under one-fifth of participants are low-income (19%), mirroring the percentage of single-family households in the state (Table I-9). The percentage of low-income participants is lower than that of interested non-participants (32%) because, as noted previously, the Team purposely attempted to oversample renters, and renters are more likely to be low-income than are homeowners.

Table I-9: Study Interest by Income Level
(Base: Recruitment survey respondents)

Income Level	Total	Interested – Non Participant	Not Interested	Participant	CT Census
n	*1,413*	*228*	*1006*	*179*	*956,941*
Low Income	31%	32%	33%	19%	19%
Non-Low Income	67%	67%	65%	81%	81%
Don't Know/Refused	2%	1%	3%	<1%	n/a

The main body of this report provides more detail on the homes visited for the study and relevant information regarding the energy efficiency of these homes. The Team anticipates that the additional information will help in understanding the nature of the baseline weatherization conditions and ways in which future energy efficiency program activity in Connecticut could help the state achieve its 80% weatherization goal.

[128] Aged 65 or above.
[129] For example, http://www.nbcconnecticut.com/news/local/State-Warns-of-Utility-Scam-169336676.html

Appendix J Comparison of Onsite and Telephone Survey Results

This appendix presents a comparison of self-reported telephone survey data and data that was verified onsite. As shown, the self-reported data are very similar to the data that were verified onsite.

Table J-1: Comparison of Primary Heating Fuel

Primary Heating Fuel	Telephone Survey	Onsite
n	*179*	*180*
Natural Gas From Underground Pipes	26%	24%
Fuel Oil	55%	64%
Electricity	11%	8%
Propane or Gas in a Tank	2%	2%
Wood	3%	1%
Other	3%	1%
Don't Know/Refused	<1%	--

Table J-2: Comparison of Ownership Status

Ownership	Telephone Survey	Onsite
n	*179*	*180*
Own	98%	98%
Rent or Lease	2%	2%
Occupy Without Rent Payment	<1%	--
Other	<1%	--
Don't Know/Refused	<1%	--

Table J-3: Comparison of House Type

Home Type	Telephone Survey	Onsite
n	*179*	*180*
Stand Alone or Detached Single-Family	93%	93%
Townhouse or Duplex	6%	7%
Other	1%	--

Table J-4: Comparison of Home Age

Year Built	Telephone Survey	Onsite
n	*179*	*180*
1950 and Before[1]	27%	24%
1951 to 1989[2]	55%	58%
1990 and After	17%	17%
Don't Know/Refused	1%	--

Table J-5: Comparison of Number of Bedrooms

Number of Bedrooms	Telephone Survey	Onsite
n	*179*	*180*
0	--	--
1	1%	1%
2	9%	13%
3	50%	49%
4	33%	27%
5	5%	7%
6	2%	2%
7 or More	1%	1%
Don't Know/Refused	<1%	--

Appendix K Targeting Homes to Increase Weatherization

The Team's initial analysis pointed to the importance of household income, age and location of home, primary heating fuel, and HES participation in the likelihood of meeting the weatherization standard. Specifically, this analysis suggested that the following types of homes were significantly less likely to meet the weatherization standard:

- Low income homes
- Older homes (built before 1980)
- Homes heated by means other than electricity

The likelihood of meeting the weatherization standard also varied by the county in which the home was located and by HES program participation, although not always to a statistically significant degree.

In order to determine the specific characteristics that should be targeted to increase the number of homes reaching the weatherization standard, the Team considered all of these factors in one statistical model. Many homes had a number of these characteristics, and only by considering them collectively could the Team understand the unique influence of each. As a result, a logistic regression model determined which household characteristics were most important in homes that did *not* reach the weatherization standard. Specifically, the Team fit the following model:

$$logit(Y) = \beta_0 + \beta_1 HES + \beta_2 DateBuilt + \beta_3 LowIncome + \beta_4 ElecHeat + \beta_5 County2 + \cdots + \beta_{11} County8$$

The model is specified as follows:

- ***Y*** is the indicator for whether a household fell below the weatherization standard ($Y = 1$ if a house was below the standard)
- ***HES*** is the indicator for whether a house was enrolled in a HES program
- ***DateBuilt*** is a continuous variable indicating the year each house was built (see below for analysis treating this variable as categorical)
- ***LowIncome*** is an indicator for whether a household was a low income household
- ***ElecHeat*** is an indicator for whether a house was heated by electricity or by another means
- ***County[j]*** was an indicator variable for one of the 8 counties in the study.

The model identified HES participation, age of home, and electric heating as the significant predictors of meeting the weatherization standard. Homes that previously participated in the HES program were more likely to meet the standard than those that had not participated, newer homes were more likely to meet the standard than older homes, and homes with electric heating were more likely to meet the standard than homes heated by other fuels.

To make meaningful comparisons between homes of different ages, the Team fit an analogous model to the one above, but with the *DateBuilt* variable made categorical. The categories were: built before 1950, built between 1950 and 1979, and built in 1980 or later. Results from the logistic regression with the age of home variable categorized are summarized in Table K-1 below. The displayed odds ratios represent the odds of meeting the weatherization standard for one level of the specified variable compared to another level of that same variable. For example, the odds of meeting the weatherization standard were almost 100 times higher for homes built in or after 1980 (97.84) compared to homes built before 1950, this translates to a relative rate of just under 17, meaning homes built after 1980 were almost 17 times more likely to meet the weatherization standard than homes built before 1950.

Table K-1: Input Variables with Accompanying Odds Ratio and Relative Rate

Variable	Odds Ratio	Relative Rate[130]
Year Built (After 1980 vs. Before 1950)	97.84*	16.75*
Electric Heat (Yes vs. No)	6.95*	2.84*
HES participation (participants vs. non-participants)	4.80*	2.46*
Year Built (1950-1979 vs. Before 1950)	4.00	3.48

* Results are statistically significant at the 90% confidence level.

To further aid in the comparison of these odds ratios, the Team calculated the population attributable fraction (PAF).[131,132] The PAF estimates the percent reduction in the prevalence of a particular variable if certain factors could be lowered to hypothetical baseline levels. The PAF estimates are used to determine which factors for a particular dependent variable should be targeted to help reduce or increase the dependent variable's prevalence—in the case of this study, weatherization. Ideally, household factors with the largest PAF would be targeted first, as reductions or increases in the prevalence of those factors would yield the largest gains in terms of reducing or increasing the prevalence of meeting the weatherization standard. While circumstances do not allow for direct intervention on some of these risk factors (e.g. the year a house was built cannot be changed) the Team was able to calculate the PAF to determine which demographic and building characteristics future programs should be tailored to target.

[130] Zhang J., Yu K.F. "What's the Relative Risk? A Method of Correcting the Odds Ratio in Cohort Studies of Common Outcomes." Journal of the American Medical Association 280 (1998): 1690-1691.
[131] Greenland S., Drescher K. "Maximum Likelihood Estimation of the Attributable Fraction from Logistic Models." Biometrics 49 (1993): 865-872.
[132] Rockhill B., Newman B., Weinberg C. "Use and Misuse of Population Attributable Fractions." American Journal of Public Health 88 (1998): 15-19.

Table K-2 below summarizes the PAF for the statistically significant predictors in our model, as calculated using STATA.[133] For HES homes, the Team calculated the PAF under the hypothetical scenario of everyone being enrolled in the HES program compared to what was actually observed in our sample. Similarly, the Team calculated the PAF for electric heat under the hypothetical scenario of every household in the sample having an electric heating system and for age of home under the hypothetical scenario of every household in the sample being built in 1980 or later.

Table K-2: Input Variables and PAF and CI

Variable	Population Attributable Fraction	90% Confidence Interval
Year Built	0.52	(0.38, 0.63)
Electric Heat (Yes vs. No)	0.30	(0.07, 0.47)
HES Participation (Yes vs. No)	0.23	(0.01, 0.41)

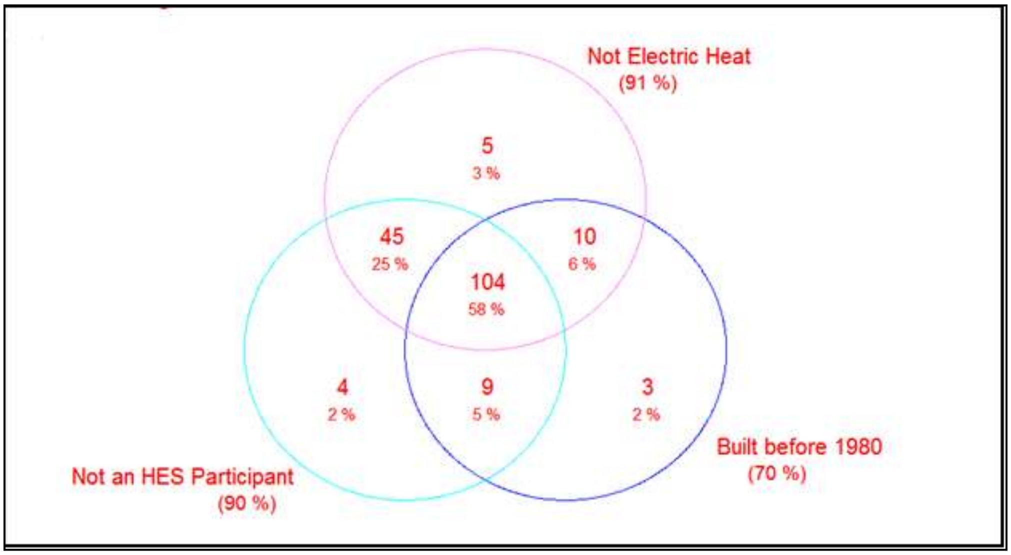
Holding all other variables constant, the number of homes meeting the weatherization standard would increase by more than one-half (52%) if all homes had been built in 1980 or later, by 30% if all homes had electric heat, and by 23% if all homes participated in the HES program. These results suggest that future programs should target older homes (particularly those built before 1980) and encourage HES participation. The PAF for electric heat may be an artifact of when such homes were built (largely in the 1970s through 1990s) and, of course, the Team does not encourage the construction of new homes with electric heat or the conversation of existing homes heating with fuel oil or natural gas to electricity. However, the finding does suggest that targeting homes that heat with fuel oil or natural gas may be more effective than targeting those with electric heat. Of particular note in this analysis was that when controlling for all other factors, household income status was *not* a significant predictor of homes meeting the weatherization standard. Thus, the Team does not recommend utilizing household income to target specific homes unless future work (ideally with a larger sample size) demonstrates that income level is significantly associated with meeting the weatherization standard.

[133] Newson R. "PUNAF: Stata Module to Compute Population Attributable Fractions for Cohort Studies." Statistical Software Components S457193, Boston College Department of Economics.

In order to narrow in on homes to target for weatherization efforts and to further explore the relationship between the predictor variables negatively associated with the odds of a home being weatherized, the Team created a set of Venn diagrams to classify the most common combinations of predictors.

Figure K-1 includes all the signifciant predictors associated with odds of a home being weatherized. Counting homes without electric heat, that were built before 1980, and in which the homeowner had not participated in HES, the analysis shows that the most common combination of the predictors was the combination of all three predictors (representing 58% of the total sample). The next largest combination of factors is non-HES homes and homes without electric heat, accounting for 25% of the sample.

Figure K-1: Diagram of Predictors Associated with Reduced Odds of Weatherization



Appendix L Draft Weatherization Standard

Draft Memo

To: Department of Energy and Environmental Protection

From: Connecticut Energy Efficiency Board

CC: Glenn Reed, Richard Faesy, Jeff Schlegel, and Kim Oswald

Date: 6/10/2012

Re: Public Act 11-80 Weatherization Standard and Determination

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Summary

Public Act 11-80 *An Act Concerning the Establishment of the Department of Energy and Environmental Protection and Planning for Connecticut's Energy Future* specifies that the electric Companies' Conservation and Load Management Plan propose how eighty percent of residential units in Connecticut be weatherized by 2030:

Such plan shall include steps that would be needed to achieve the goal of weatherization of eighty per cent of the state's residential units by 2030

However, the Act does not define the term "weatherization".

Based on input from the utility Companies, Home Energy Solutions (HES) income eligible and non-income eligible vendors, and other interested parties, the EEB proposes the following recommendation of a weatherization standard for single family and low-rise multifamily dwellings with up to four dwelling units. These dwelling units represent 82 percent of residences in Connecticut based on 2010 Census data. For larger multifamily buildings - most of which will need to be treated as more complex commercial structures - we recommend that DEEP work with the EEB to develop an appropriate standard for these dwellings at a later date.

Two approaches are recommended to determine compliance with the proposed weatherization standard.

For the **prescriptive** compliance approach, a home would have to meet all of the requirements listed in Table 1. For the **performance** compliance approach a home would need to demonstrate modeled energy usage equal to or less than the same home built to the criteria listed in Table 1. It is expected that the Companies' new HES Field Service Tool will be able to make such a

determination. A performance approach allows for trade-offs between building elements. For example, a home in a historic district with single pane windows may still be defined as weatherized if there is additional attic insulation or duct leakage performance to compensate for the inefficient windows. It is expected that for the majority of homes the use of the prescriptive checklist in Table 1 will be sufficient to determine weatherization status.

The current HES Programs, with small modifications, will offer an ideal avenue by which to assess the conformity of an individual home to the weatherization standard, and for homes that do not meet the standard, to offer its occupant a clear path for improvement. The recommendations below presume that some enhanced version of the current HES/HES-IE Program is the principal means to assess, deliver, and track the state's efforts to attain its legislatively mandated weatherization goal. The tools that will need to be put in place to implement the performance approach will also provide a foundation for a future building rating and labeling system.

Table 1

Weatherization Prescriptive Checklist and Performance Modeling Inputs

Building Element	Prescriptive Requirements and Modeling Inputs for Performance Approach
Above Grade Walls	R-11
Flat Ceilings	R-30
Cathedral ceilings	R-19
Unheated Basements & Crawlspaces	Floor separating basement from conditioned space above is insulated to R-13
Heated Basements & Crawlspaces	Interior walls fully insulated to R-5
Slab on Grade	R-5 four feet below grade; assume to proper depth if present
Windows	U 0.50 (Double pane or single pane with storm)
Air Leakage	9 ACH @ 50 Pascals based on HES program data
Duct leakage for ducts outside conditioned space	16 cfm at 25 Pascals per 100 sq. feet of conditioned space based on HES program data
Duct Insulation: Unheated Basements	Minimum R-2
Duct Insulation: Unheated Attics and Crawlspaces	Minimum R-4.2

The above requirements are meant to provide a balance between energy efficiency and attainability. For some homes, higher levels of thermal integrity might be appropriate and cost-effective, e.g., higher levels of ceiling insulation. This would depend on the existing level of insulation or air or duct leakage rates as well as the heating fuel used and the presence of air conditioning. HES participants would continue to be encouraged to implement all cost-effective efficiency that can be captured, even when it would exceed the above minimums.

Improvements to heating, cooling and hot water equipment will also continue to be encouraged through the HES Program, but are not recommended to be a component of the weatherization standard. This recognizes the cost and difficulty of convincing consumers to replace functional HVAC and DHW equipment. Further, improved federal standards, e.g., the 2013 federal furnace standard, will address some significant portion of this opportunity during the normal equipment replacement cycle of approximately 10-25 years.

A detailed residential existing homes onsite baseline study is currently being planned for Connecticut. The details as to sample size and other study parameters are now being considered by the Board's Evaluation Committee with input from DEEP staff. One of the primary goals of this study is to determine the current percentage of homes that are weatherized. All newly weatherized homes would be considered incremental additions to this baseline as the State works to meet the legislative 80 percent goal. The Companies and EEB will track progress towards the weatherization goal through the HES program.

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<u>Detailed Discussion</u>

Defining and Determining if a Home is Weatherized: Prescriptive and Performance Approach Options

Described below are the two proposed approaches to defining and determining if a home is weatherized. The general consensus that emerged after multiple stakeholder engagements is that a weatherized home is one that has at a minimum:

- All accessible building shell elements insulated to reasonable levels of thermal efficiency, e.g., above grade walls insulated to a minimum of R-11, attic floors insulated to a minimum of R-30, etc. See Table 1 for detailed levels.
- Air leakage tested to be at or below prescribed levels. See Table 1 for detailed levels.
- Duct leakage tested when some portion of the ducts are outside of the thermal envelope to be at or below prescribed levels. See Table 1 for detailed levels.
- Double pane windows or single pane with storms

The prescriptive approach is generally straightforward and requires that all accessible building elements meet or exceed prescribed levels. Note that testing of air leakage and of duct leakage outside of the thermal envelope is required in both approaches. The performance approach requires that building modeling be performed to determine if the home's heating and cooling energy use does not exceed consumption equivalent to what it would be if constructed to the minimum prescriptive standards in Table 1.

Prescriptive Approach

The values in Table 1 will serve as a checklist by which a home would be determined to be weatherized. All visible and accessible building components would have to meet the specified values. In situations where the insulation is not visible, e.g., slab on grade or exterior basement foundation insulation, the building element would be assumed to meet the required level. Note that for some homes and for some building elements higher levels of thermal efficiency above those in the Table 1 may be appropriate depending on current levels of insulation, insulation type, projected energy costs, and customer payback criteria. The prescriptive levels in Table 1 should not be viewed as a cap to what consumers and the Companies' efficiency programs would encourage residents to install.

Performance Approach

The description below details the proposed approach to determining compliance with the proposed weatherization using a performance approach. This approach will require that the thermal efficiency of a residence be modeled and compared to that of the same home built to the minimum prescriptive requirements in Table 1. The overall thermal efficiency of the residence must be as good if not better than the same home modeled to the minimum prescriptive requirements in Table 1.

The steps to make this determination follow.

1. **A given home's annual energy use Performance Metric would be calculated assuming typical operating conditions**

   The expected annual heating and cooling energy consumption for each home would be estimated based on existing insulation levels and air and duct leakage rates. Average annual consumption would be modeled assuming typical operating conditions, i.e., number of occupants (based on number of bedrooms), pre-determined default temperature set points and HVAC equipment efficiencies, etc.

   Note that collecting the necessary data to perform these calculations may require some additional time beyond what HES vendors currently spend doing a home assessment. The data requirements, and time spent to collect the data, of any energy model employed to assess weatherization will need to be considered. This will be addressed as part of the Companies' plans to enhance their HES Field Service Tool (FST) in 2012.

2. **The home's estimated energy use Threshold Value would be calculated on a house specific basis by the Field Service Tool (FST)**

   For each home the estimated annual heating and cooling consumption would be calculated using the values in Table 1 and the same operational default values used to calculate the Performance Metric for the home. It is assumed that as the Companies enhance the capabilities of the FST in 2012 that they will add the ability to calculate the Threshold Value for a specific home at the same time the Performance Metric is calculated.

3. **If the home's energy Performance Metric is equal to or less than the corresponding Threshold Value the home is considered weatherized**

Note that even if the home is deemed "weatherized" there may still be opportunities for further cost-effective energy reductions. These would continue to be pursued by the HES vendor as would any HVAC and DHW equipment upgrades.

Using HES Program Services to Make the Necessary Improvements to Homes Not Meeting the Weatherization Standard

While the HES Program may not be the only means to determine if a home is weatherized, it will likely be the principal one, particularly in the near term. Not only can the HES Program determine if a home is weatherized, for those homes that do not meet the standard the Program offers a variety of services to help the homeowner identify and make improvements to improve its performance and exceed the weatherization standard.

The HES FST will continue to provide guidance as to which measures the dwelling owner should pursue based on their savings, costs, and payback period.

In a small number of homes the cost to meet the proposed weatherization standard may be prohibitive. This might be the case where asbestos or knob and tube wiring is present or where the payback is very long, e.g., basement wall insulation. DEEP and others may want to consider whether such homes should be treated any differently as to the weatherization standard. However, the inability of such homes to meet the full definition of weatherized would not likely be a serious impediment to Connecticut meeting its 80 percent weatherization goal by 2030

The HES/HES-IE Programs will track which measures are installed for homes not initially meeting the Threshold Value. If the "improved" dwelling meets the weatherization standard due to subsequent measure installations the home will be deemed weatherized.

Determining the Current Percentage of Homes Already Meeting the Weatherization Standard

The EEB and Companies are planning to proceed with a study to characterize the efficiency and building characteristics of existing homes in Connecticut. This study will include on-site surveys and the modeling of the homes' energy usage. The on-site surveys and modeling will be used to determine which homes meet the proposed weatherization standard and by how much. From this analysis the study will develop a baseline estimate of the percentage of homes already weatherized in Connecticut. Any subsequent homes identified as weatherized will be considered incremental additions to this baseline as the state works to reach the 80 percent weatherization goal.

Results from this study will also provide an indication as to what percentages of homes meet the weatherization standard through the prescriptive vs. performance approaches. The study may also provide insight into possible refinements to the values in Table 1.

This planned study will provide information on not only progress towards the weatherization goal, but also critical data on appliance and HVAC equipment saturations and efficiencies, insulation levels, air leakage rates, and duct locations, insulation and leakage rates. These data will be used to help further refine HES Program offerings and vendor training. The data will also help inform planning for the Companies' Retail Products Program.

In the Future the Implementation of a Home Labeling system in Connecticut would Support and Complement Connecticut's Weatherization Goal.

Labeling homes with an energy rating score will enable future buyers to compare the efficiency of the home to others, allow appraisers and lenders to value energy efficiency in future real estate transactions, and document compliance with Act 11-80. Presentation of the results should be expressed in either MMBtu/year or MMBtu/yr – square foot, or could be tied to the U.S.DOE's Home Energy Score (HES) 1-10 scale to potentially make them more accessible and understandable. Note that DOE's HES is based on source and not site usage, and is not fully normalized to home size, which might not be as suitable for Connecticut, which has a relatively wide range of home sizes and heating fuels.

Another alternative consistent with the above would be to use a HERS scoring system to establish both the home's Performance Metric, in this case the HERS score or index, and the required Threshold Value. However, generating a HERS score or index for an existing home is expensive and would require RESNET certification of HES vendors, though this approach could be used by the Companies' residential new construction program.

Establishing a home building label is a recommended longer term goal for Connecticut. To develop a viable statewide home label in Connecticut may take some time. To date, no state has yet to implement a statewide home label. Therefore, efforts to address the weatherization requirements of Public Act 11-80 should move forward absent agreement on a home labeling approach.

Appendix M Onsite Data Collection Form

General Information

Site ID
Address
Auditor 1
Customer Name
City
Auditor 2
Date
County
Auditor 3
Auditor 4

House Type
House Style
# of Stories
Foundation Type
Bedrooms
Foundation Type Notes:
Year Built (Range)
Year Built (Exact Date)
Year Built Notes:
Own or Rent

Conditioned Floor Area (CFA)
Conditioned Volume

Primary Heating Fuel
Ambient Temperature
Type of Thermostat
Indoor Temperature
# of Thermostats

Fireplace #1 Fuel
Stove #1 Fuel
Space Heater #1 Fuel
Fireplace #2 Fuel
Stove #2 Fuel
Space Heater #2 Fuel
Fireplace #3 Fuel
Stove #3 Fuel
Space Heater #3 Fuel

	% Load	Capacity		% Load	Capacity		% Load	Capacity
Fireplace #1 Fuel			Stove #1 Fuel			Space Heater #1 Fuel		
Fireplace #2 Fuel			Stove #2 Fuel			Space Heater #2 Fuel		
Fireplace #3 Fuel			Stove #3 Fuel			Space Heater #3 Fuel		

Ask Homeowner: Do you have any room air conditioners? If yes, record information in mechanical section. If it is uninstalled ask homeowner where it is and try to get nameplate information.

Room A/C

Asbestos or Vermiculite Present?

Do Blower Door?
Do Duct Blaster?
IR Imaging?

Items Installed Onsite

# of standard mini-twist CFLs
# of A-line CFLs
# of 100 watt equivalent CFLs
# of shower heads
# of aerators

General Notes

s

Basement Details

Area	Included in CFA and Conditioned Volume	Included in only Conditioned Volume	Fully Unconditioned	Finished Space	Directly Conditioned
	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐
	☐	☐	☐	☐	☐

Basment Notes

Foundation Wall Properties

Wall Type	Location	Length (ft)	Height (ft)	Height A.G.(ft)	Insulation Height	Insulation Type	R-value	Cavity Grade

Insulation Location

Insulation Location Notes:

Foundation Wall Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1	☐	☐	☐	☐	☐	☐
Entry 2	☐	☐	☐	☐	☐	☐
Entry 3	☐	☐	☐	☐	☐	☐
Entry 4	☐	☐	☐	☐	☐	☐
Entry 5	☐	☐	☐	☐	☐	☐
Entry 6	☐	☐	☐	☐	☐	☐
Entry 7	☐	☐	☐	☐	☐	☐
Entry 8	☐	☐	☐	☐	☐	☐
Entry 9	☐	☐	☐	☐	☐	☐
Entry 10	☐	☐	☐	☐	☐	☐

Slab Properties

	Slab Location	Area	Depth BG	Full perimeter	Total exposed perimeter	On-grade exposed perimeter
Entry 1:						
Entry 2:						
Entry 3:						

	Insulation Location	Insulation Type	R-value	Grade
Entry 1:				
Entry 2:				
Entry 3:				

Radiant Floor: ☐

Slab Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1:	☐	☐	☐	☐	☐	☐
Entry 2:	☐	☐	☐	☐	☐	☐
Entry 3:	☐	☐	☐	☐	☐	☐

Frame Floor Properties

Joist Description	Location	Area	Insulation Type	Cavity R-value	Cont. R-value	Cavity Grade

Frame Floor Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1						
Entry 2						
Entry 3						
Entry 4						
Entry 5						

Rim/Band Joist Properties

Joist Description	Location	Area	Insulation Type	Cavity R-value	Cont. R-value	Cavity Grade	Rim/Band

Rim/Band Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1	☐	☐	☐	☐	☐	☐
Entry 2	☐	☐	☐	☐	☐	☐
Entry 3	☐	☐	☐	☐	☐	☐
Entry 4	☐	☐	☐	☐	☐	☐

Above Grade Wall Properties

Framing Description	Location	Area	Insulation Type 1	Insulation Type 2	Cavity R-value	Cont. R-value	Cavity Grade

Above Grade Wall Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1	☐	☐	☐	☐	☐	☐
Entry 2	☐	☐	☐	☐	☐	☐
Entry 3	☐	☐	☐	☐	☐	☐
Entry 4	☐	☐	☐	☐	☐	☐
Entry 5	☐	☐	☐	☐	☐	☐
Entry 6	☐	☐	☐	☐	☐	☐
Entry 7	☐	☐	☐	☐	☐	☐
Entry 8	☐	☐	☐	☐	☐	☐

Window Properties

Type of Glass	Storm	U-value	SHGC	Location	Area	OH Depth	OH to Top	OH to Bottom	Orientation

Window Notes

Door Properties

Material	Insulated	Storm	Type of Glass	Gross Door Area	Glass Area	Location

Door Notes

Ceiling Properties

Framing Description	Location	Area	Insulation Type 1	Insulation Type 2	Cavity R-value	Cont. R-value	Cavity Grade

Attic Hatch

Area	Hatch Insulation Type	R-value

Ceiling Notes

	Insulation Type		R-value		Grade	
	Verified	Assumed	Verified	Assumed	Verified	Assumed
Entry 1	☐	☐	☐	☐	☐	☐
Entry 2	☐	☐	☐	☐	☐	☐
Entry 3	☐	☐	☐	☐	☐	☐
Entry 4	☐	☐	☐	☐	☐	☐
Entry 5	☐	☐	☐	☐	☐	☐

Skylight Properties

Type of Glass	U-value	SHGC	Area	Orientation	Pitch (?/12)

Skylight Notes

Mechanical Equipment Properties

Heating Equipment

	Make	Model	Type	Age	Fuel	Location	Output Capacity	Efficiency	Units
1									
2									
3									
4									

For Electric Baseboard Only

Watts per Baseboard	Number of baseboard units	Linear feet of baseboard

Water Heating Equipment

Make	Model	Type	Age	Fuel	Location	Gallons	Energy Factor	Exterior Tank Wrap R

Cooling Equipment

	Make	Outdoor Model	Indoor Model	Type	Age	Location	Output Capacity	Efficiency SEER	Efficiency EER	Efficiency COP
1										
2										
3										
4										

Heating Pipes Insulated	R-value (if insulated)	DHW Pipes Insulated	R-value (if insulated)	CAC Referigrant Lines Insulated	R-value (if insulated)

Mechanical Equipment Notes

Duct Properties

Supply/Return	Material	Location	Insulation Type	R-value	% of System Duct Area	Htg System	Clg System

Number of Returns

Duct Insulation Notes

Diagnostic Results

Air Leakage

Measure 1 @ 50 Pascals		*OPTIONAL: Measure 2 @ 50 Pascals*		*OPTIONAL: Measure 3 @ 50 Pascals*	
Baseline Pressure (Pa)		Baseline Pressure (Pa)		Baseline Pressure (Pa)	
Ring		Ring		Ring	
CFM50 Leakage		CFM50 Leakage		CFM50 Leakage	

Duct Leakage

	System 1 @ 25 Pascals		*System 2 @ 25 Pascals*	
	Total Leakage	Leakage to Outside	Total Leakage	Leakage to Outside
Ring				
CFM25 Leakage				
Heating System				
Cooling System				
CFA Served				

	System 3 @ 25 Pascals		*System 4 @ 25 Pascals*	
	Total Leakage	Leakage to Outside	Total Leakage	Leakage to Outside
Ring				
CFM25 Leakage				
Heating System				
Cooling System				
CFA Served				

Diagnostic Notes

Lighting Properties

	No. of CFL Fixtures	No. of Incand/Halogen Fixtures	No. of Fluorescent Tube Fixtures	No. of LED Fixtures	No. of Ceiling Fans
Bedroom 1					
Bedroom 2					
Bedroom 3					
Bedroom 4					
Bedroom 5					
Bedroom 6					
Bedroom 7					
Kitchen 1					
Kitchen 2					
Living Space 1					
Living Space 2					
Living Space 3					
Living Space 4					
Living Space 5					
Dining Room					
Bathroom 1					
Bathroom 2					
Bathroom 3					
Bathroom 4					
Bathroom 5					
Bathroom 6					
Bathroom 7					
Hallways					
Stairways					
Office					
Utility Room					
Mud Room					
Foyer					
Garage					
Outdoor					
UC Bsmt/Crawl					
Cond Bsmt/Crawl					

Lighting Notes

Sunspace

	Area	R-value
Roof		
Exterior Walls		
Subgrade Walls		
Interior Walls		
Frame Floor		

Auto Fan Coupling	Fan Flow (CFM)

	Exposed Perimeter	Depth BG	Thickness	R-value
Slab Floor				

Windows

Type of Glass	Storm	U-value	SHGC	Location	Area	OH Depth	OH to Top	OH to Bottom	Orientation

Skylights

Type of Glass	U-value	SHGC	Area	Orientation	Pitch (?/12)

Interior Mass

Type	Location	Area	Thickness

Sunroom/Mass Notes

Appliance Properties

	Make	Model	Type	Cu. Ft.	kWh/yr	Location	ENERGY STAR	Age
Primary Refrigerator								
Secondary Refrigerator								
Extra Refrigerator								
Freezer								

	Make	Model	Type	Cu. Ft.	kWh/yr	MEF	Location	ENERGY STAR	Age
Clothes Washer									

	Make	Model	Type	Fuel	Efficiency Factor	Location	Moisture Sensing	Age
Dryer								

	Make	Model	Energy Factor	kWh/yr	ENERGY STAR	Age	Size
Dishwasher							

	Fuel	Induction Range	Convection Oven	Age
Range/Oven				

	Plugged In		Plugged In
Secondary Refrigerator		Other Refrigerator	

Appliance Notes

ENERGY STAR Status Confirmed?

Primary Refrigerator	Secondary Refrigerator	Freezer	Clothes Washer	Dishwasher

Ventilation Properties

Bath Fans Control Type

Entry 1

Entry 2

Entry 3

Entry 4

Entry 5

ERV/HRV

Make	Model	Sensible Recovery Efficiency	Total Recovery Efficiency	Rate (CFM)	Hours/Day	Fan Watts

Whole House Fan

Attic Ventilation

Ventilation Notes

Renewables

Solar for Heating/DHW

System Type

Collector Loop Type

Collector Type

Collector Orientation

Collector Area

Collector Tilt (degrees)

Storage Volume (cu. ft. or gal)

Photovoltaics

Array Orientation

Array Area

Peak Power (watts)

Array Tilt (degrees)

Inverter Eff.

Wind Power

# of Turbines

Total Watts

Renewable Notes

Auditor Ratings

Recommendations for Energy Improvements

What is the level of opportunity for improving energy efficiency in this home? Use a scale of 1 (low) to 5 (high).

Ranking Energy Features

Please make recommendations for the four energy features that present the largest savings opportunities in this home. Rank these in order from #1 (largest opportunity) to #4 (least opportunity).

#1 Feature with Savings Opportunities

#2 Feature with Savings Opportunities

#3 Feature with Savings Opportunities

#4 Feature with Savings Opportunities

Auditor Rating Notes

Mechanical Equipment References

Heating Equipment

	Make	Model	AHRI Reference # or Source
1			
2			
3			
4			

Water Heating Equipment

Make	Model	AHRI Reference # or Source

Cooling Equipment

	Make	Outdoor Model	Indoor Model	AHRI Reference # or Source
1				
2				
3				
4				

Appliances

Primary Refrigerator		Clothes Washer	
Secondary Refrigerator		Dryer	
Extra Refrigerator		Dishwasher	
Freezer		Range/Oven	

Reference Notes