Massachusetts 2011 Baseline Study of Single-family Residential New Construction

Final Report
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Executive Summary

The 2011 Baseline study was conducted with several objectives in mind. The primary objective is to provide a baseline study of the characteristics of single-family homes recently completed across Massachusetts and permitted under the 2009 International Energy Conservation Code (IECC) that did not participate in the Massachusetts New Homes with ENERGY STAR® Program (Program) that can be used to update User Defined Reference Home (UDRH) assumptions used in calculating Program savings. Secondary objectives are:

- Providing a comparison of measure-specific prescriptive compliance for the 2011 baseline homes, built at the beginning of the 2009 IECC code cycle, and the 50 homes built at the end of the 2006 IECC code cycle that were audited with findings reported in the Mini Baseline Study[1].
- Providing a comparison of the characteristics of the 2011 baseline homes to the characteristics of homes inspected in the 2005, 2001 and 1999 baseline studies
- Providing a comparison of 2011 baseline homes to single-family homes completed through the 2011 Program

Throughout this Executive Summary there are links to sections of the report that provide more detail on the information being presented. Readers may place the cursor on the link and use control/click to go directly to the section of the report that provides more detail.

Background

Audits of 100 homes were conducted from late July through early November of 2011; HERS (Home Energy Rating System) ratings were performed on all 100 homes and HVAC performance testing was done at 35 homes. Manual J assessments were done for all inspected homes. The REM/Rate™ software used for the HERS ratings provided 2009 IECC code compliance reports for multiple compliance paths for each home. The owners of audited homes were asked to complete a short survey while their homes were being inspected. The survey addressed, among other things, how the home was purchased, the importance of getting an energy-efficient home, who specified various home components, and owners' perceptions of the overall energy-efficiency of their home and its various components.

The sampling plan matched the percentage of on-site inspections conducted in a county to the percentage of state level permits issued in that county and targeted a mix of custom and spec built homes that would reflect the mix of custom and spec single-family homes participating in the Program. Later, study sponsors decided to weight study results to reflect the mix of single-family detached and attached homes participating in the Program (49.2% attached homes and

[1] Massachusetts Mini Baseline Study of Homes Built at the End of the 2006 IECC Cycle, Final Report, Submitted to Massachusetts Residential New Construction Program Administrators by NMR Group, Inc. KEMA, Inc. and Dorothy Conant. June 2012.

50.8% detached homes). Both unweighted and weighted results are provided throughout this report, with the emphasis on weighted results. See Section 2 Sampling Methodology.

The remainder of this Executive Summary summarizes the UDRH inputs estimated; comparisons with individual 2009 IECC prescriptive insulation requirements; potential compliance rates under various compliance paths based on the compliance reports available from the REM/Rate software used to produce HERS ratings; and the results of the Manual J assessments and HVAC performance testing. Also addressed are findings from the comparison of the 50 Mini Baseline Study homes built at the end of the 2006 IECC code cycle and the 2011 baseline homes, the comparison of 2011 baseline homes to 2011 Program homes, and the on-site survey completed by the owners of inspected homes. These are very high level summaries that include links to the report sections that provide more detailed information.

Preliminary UDRH Inputs

Table ES 1 on the next page compares 2011 Baseline Study findings to selected UDRH inputs from the 2005 Baseline Study, 2010 UDRH inputs, and 2011 Hybrid UDRH inputs.[2,3] The 2011 Baseline UDRH inputs are preliminary estimates based on study findings weighted to reflect the mix of single-family detached and attached housing in the 2011 Program. See Section 3 Preliminary UDRH Inputs for detailed tables showing the data used to develop the preliminary estimates of UDRH inputs. Program Administrators will review these preliminary UDRH estimates and develop a final set of UDRH inputs that incorporates additional information based on experience administering the Program as well as information on specific measures that were found in either none or very few of the audited baseline homes. The final UDRH inputs will be provided as an Addendum to this report.

As shown, the 2011 baseline preliminary estimated UDRH inputs suggest that the current UDRH assumptions may underestimate the efficiency of some current building practices or equipment. Examples include most types of heating systems, gas water heaters, and air infiltration, where the average efficiencies from the 2011 Baseline Study are higher than the current UDRH assumptions. In other cases, study findings suggest current UDRH inputs may overestimate the efficiency of current building practices. Examples are U-values for floors over unconditioned spaces and exterior walls.

[2] Going forward, the 2011 Hybrid UDRH inputs will be referred to as the current UDRH inputs. The 2010 UDRH inputs are the same as the 2005 UDRH inputs. The 2011 Hybrid (current) UDRH inputs incorporate interim changes that were made to address adoption of the 2009 IECC until 2011 Baseline Study results became available. The interim changes addressed wall, ceiling, floor, slab, foundation wall, window, duct insulation and duct leakage inputs.

[3] Several UDRH inputs are U-values. U-values are the overall heat transfer coefficient for the entire wall, floor or ceiling assembly, not just the insulation. The lower the U-value is, the more energy efficient the assembly. U-values calculated using REM/Rate software account for the R-value of framing members, the R-value of other components such as air barriers and drywall, the R-value of the insulation, and the quality of the insulation installation. If insulation is compressed, or there are gaps, the energy efficiency of the assembly is lower and the U-value is higher.

Table ES 1: Comparison of 2005, 2010, 2011 Hybrid and Preliminary Estimated 2011 Baseline UDRH Inputs

Building Characteristic	2005 Baseline UDRH	2010 UDRH	2011 Hybrid UDRH (current)	2011 Baseline Study Preliminary Estimated UDRH Inputs[4]
Wall U-value	Grade II U=.082 Grade III U=.089	Grade II U=.082 Grade III U=.089	U=.066	U=.072
Flat Ceiling U-value	U=0.058	U=0.058	U=0.041	U=0.041
Slab Insulation R-value		R=0.10	R=10	R=1.67
Floor over Unconditioned Space U-value	U=0.063	U=0.063	U=0.038	U=.048
Foundation Wall Insulation R-value (conditioned basements)	R=11.1	R=11.1 (cavity)	R=10.4 (continuous)	R=16.6*
Window U-value	U=0.37	U=0.366	U=0.35	U=0.34***
	SHGC=0.35	SHGC=0.346	SHGC=0.346	SHGC=0.291
Air Infiltration ACH50	6.72 ACH50	6.72 ACH50	6.72 ACH50	4.88 ACH50
Gas Furnace Efficiency (AFUE)**	89.2%	89.2%	89.2%	91.5%
Gas Boiler Efficiency (AFUE)**	81.7%	81.7%	81.7%	89.8%
Oil Furnace Efficiency (AFUE)	83.9%	83.9%	83.9%	82.7%
Oil Boiler Efficiency (AFUE)	84.4%	84.4%	84.4%	85.9%
Gas Domestic Stand Alone Storage Tank Water Heater Energy Factor**	0.58 EF	0.58 EF	0.58 EF	0.64 EF
Cooling Efficiency (SEER)	13	13	13	13.7
Duct Leakage (CFM25/100 Sq. Ft.)	21.7	21.7	12.0	11.9
Duct Insulation—Attic Supply Ducts	R=4.66	R=4.66	R=6.5	R=6.5
Duct Insulation—non Attic Ducts in Unconditioned Space	R=4.37****	R=4.37****	R=5	R=5.5

*Based on 20 homes—17 with interior cavity insulation and three with continuous insulation

**Gas includes both natural gas and propane equipment.

***Based on secondary information.

****Includes all ducts in unconditioned space, including attic ducts.

Comparison to Individual 2009 IECC Prescriptive Insulation Requirements

There are three types of 2009 IECC requirements: mandatory, prescriptive and performance. Examples of mandatory requirements are air and duct sealing and equipment sizing. Prescriptive compliance path requirements address insulation, fenestration and lighting. Performance

[4] As explained earlier, Program Administrators will review these preliminary UDRH estimates and develop a final set of UDRH inputs that incorporates additional information based on experience administering the Program as well as information on specific measures that were found in either none or very few of the audited baseline homes. The final UDRH inputs will be provided as an Addendum to this report.

compliance path requirements are based on a home's performance using a simulation model, such as REM/Rate. This study does not attempt to assess whether or not individual homes complied with current building codes or assess code enforcement. Details on the compliance path utilized by each of the audited homes would be necessary to conduct such an evaluation, and this information was not pursued. Throughout this report, 2009 IECC prescriptive path code requirements are simply used as reference points for comparison, with the percentages of inspected homes that meet or fail to meet prescriptive requirement levels presented. Comparing what was observed in inspected homes to specific prescriptive insulation requirements serves as a tool for assessing how many homes, regardless of what compliance path they followed, meet those requirements.

Almost all inspected homes, 93%, have at least one instance where the R-value of installed insulation is below 2009 IECC prescriptive insulation requirements or mandatory duct insulation requirements:[5]

- Wood framed wall insulation of R-20 or R-13 cavity insulation plus R-5 insulated sheathing
- Conditioned basement foundation wall insulation R-10 continuous or R-13 cavity
- Ceiling insulation R-38 (Allows up to 500 square feet of vaulted ceiling area to be R-30)
- Floor insulation over unconditioned spaces of R-30 or framing cavity filled
- Attic supply duct insulation of R-8 and all other ducts in unconditioned space insulated to R-6

Table ES 2 on the following page categorizes inspected homes by what applicable prescriptive insulation levels the homes do not meet. As shown, 22% of detached and 29% of attached homes, for a weighted average of 25%, do not meet wall and duct insulation prescriptive requirement levels; 12% of detached and 14% of attached homes, for a weighted average of 13%, do not meet wall, ceiling and duct insulation prescriptive requirement levels. Twelve homes (all detached homes) meet all applicable prescriptive requirement insulation levels except for walls. Only seven homes, six detached (7%) and one attached (14%), for a weighted average of 10%, meet all applicable prescriptive requirement insulation levels (See Appendix B Comparison to 2009 IECC Prescriptive Insulation Requirements by Site for a list of the insulation requirements applicable to each home, which requirements the home met, and which the home failed to meet.)

Throughout this Executive Summary there are links to sections of the report that provide more detail on the information being presented. Readers may place the cursor on the link and use control/click to go directly to the section of the report that provides more detail.

[5] Note that two building components are not addressed here—windows and slab floors. Documented U-value and SHGC information for windows was available for a limited number of homes where the original NFRC (National Fenestration Rating Council) sticker was visible. Auditors were unable to observe underneath the slabs and, therefore, were able neither to confirm the existence nor record the R-values of slab floor insulation in most homes.

Table ES 2: Applicable 2009 IECC Prescriptive Insulation Requirements Not Met

Applicable 2009 IECC Prescriptive Insulation Requirements Homes Did Not Meet	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Wall & Duct	22 (22%)	20 (22%)	2 (29%)	25%
Wall, Ceiling & Duct	12 (12%)	11 (12%)	1 (14%)	13%
Wall	12 (12%)	12 (13%)	0 (0%)	7%
Wall, Ceiling, Floor & Duct	6 (6%)	5 (5%)	1 (14%)	10%
Wall, Floor & Duct	6 (6%)	5 (5%)	1 (14%)	10%
Wall & Ceiling	6 (6%)	6 (6%)	0 (0%)	3%
Duct	6 (6%)	6 (6%)	0 (0%)	3%
Ceiling & Duct	5 (5%)	4 (4%)	1 (14%)	9%
Wall & Floor	4 (4%)	4 (4%)	0 (0%)	2%
Ceiling & Floor	4 (4%)	4 (4%)	0 (0%)	2%
Ceiling	4 (4%)	4 (4%)	0 (0%)	2%
Wall, Ceiling & Floor	2 (2%)	2 (2%)	0 (0%)	1%
Floor & Duct	2 (2%)	2 (2%)	0 (0%)	1%
Ceiling, Floor & Duct	1 (1%)	1 (1%)	0 (0%)	1%
Floor	1 (1%)	1 (1%)	0 (0%)	1%
None: Met All Applicable Prescriptive Insulation Requirements	**7 (7%)**	**6 (6%)**	**1 (14%)**	**10%**

REM/Rate Assessments of Code Compliance

The REM/Rate software was used to assess how inspected homes would have likely performed under three different compliance paths. In addition, one compliance path, the prescriptive path, was assessed outside of REM/Rate. The four compliance paths are the Prescriptive, Home Energy Rating, Annual Energy Cost, and Overall Building UA compliance paths. The Home Energy Rating, Annual Energy Cost, and Overall Building UA compliance paths were all assessed using reports and calculations available through the REM/Rate software. This approach allowed the evaluation team to leverage the REM/Rate files that were compiled for other pieces of this report and utilize those files for this analysis. Again, it should be noted that the purpose of this study is not to assess code compliance for each inspected home, nor is it to evaluate code enforcement. Details on the compliance path utilized by each of the audited homes would be necessary to conduct such an evaluation, and this information was not pursued. Therefore, the results presented in this report are not indicative of actual code compliance but serve as a tool for assessing specific prescriptive measure compliance and how homes would likely perform under different performance based compliance paths.

The compliance analysis shows that homes are likely to achieve the highest compliance using the Home Energy Rating path (32% of all homes), followed by the Annual Energy Cost path (22% of all homes), the Prescriptive path (7% of all homes), and finally the Overall Building UA path

(3% of all homes). Overall Building UA compliance was assessed using REM/Rate, not the more commonly used REScheck™ software. REM/Rate, unlike REScheck, accounts for the quality of the insulation installation when calculating overall UA values. For this reason it is much more difficult to achieve compliance using the REM/Rate UA approach as opposed to using REScheck. More details on code compliance can be found in the code compliance section of this report. See Section 7 Code Compliance

Manual J Assessments and HVAC Performance

REM/Rate was used to assess heating and cooling system sizing. Results show most heating and cooling systems are oversized. The average heating equipment size ratio is 1.92, indicating that the average installed heating system rated capacity is 1.92 times the properly sized system capacity. For cooling systems, the average size ratio is 1.67, indicating that the average installed cooling system rated capacity is 1.67 times the properly sized system capacity. See Section 10.4 Heating and Cooling Equipment Sizing–Manual J.

In-field measurements were performed to calculate the actual cooling capacities and efficiencies of a sample of residential central air conditioning (CAC) systems throughout the state.[6] Thirty-five systems were ultimately included in the analysis; the average operating capacity was found to be 21.9% less than the rated capacity while the operating efficiency was found to be 3% less than the rated efficiency. These differences are likely due to some combination of poor heat transfer through evaporator and/or condenser coils, improper refrigerant charge, and low air flow. More details on the HVAC performance testing analyses can be found in Section 10.3 HVAC Performance Testing and Appendix F HVAC Performance Testing.

Comparison to 2011 Program Single-Family Homes

Selected building characteristics of 2011 baseline homes are compared to the characteristics of single-family homes completed through the 2011 Program.[7] Average flat ceiling R-values and U-values, cathedral ceiling U-values, unconditioned basement foundation wall R-values, duct insulation R-values, air infiltration, duct leakage and HERS indices are all significantly less energy efficient in baseline homes; all these differences are statistically significant at the 90% confidence level. Differences in average conditioned/ambient wall R-values and U-values, cathedral ceiling R-values, floor R-values and U-values, and conditioned basement foundation wall R-values between Program and baseline homes are not statistically significant at the 90% confidence level. See Section 4 Comparison to 2011 Program Single-Family Homes

[6] Central heat pumps were included in the sample, but only the cooling performance of such systems was considered. Some homes used window air conditioning units, which were not included in the CAC analysis.
[7] Data on the characteristics of 2011 Program single-family homes were extracted from the REM/Rate files of all single-family homes completed through the 2011 Program.

Comparison to Mini Baseline Study Homes

Selected building characteristics of the 50 Mini Baseline Study homes completed at the end of the 2006 IECC code cycle are compared to the characteristics of the 2011 baseline homes completed at the beginning of the 2009 IECC code cycle. Compared to the Mini Baseline Study homes, 2011 baseline homes are smaller, and the average HERS Index is significantly lower (better) in 2011 baseline homes (HERS 79) than in Mini Baseline Study homes (HERS 83); the difference in HERS indices is statistically significant at the 90% confidence level.

One of the important aspects of this report is to compare compliance with prescriptive requirements at the end of the 2006 IECC code cycle to the compliance at the beginning of the 2009 IECC code cycle. Two key prescriptive requirements changed from 2006 to 2009 IECC. The prescriptive insulation requirement for exterior wood-framed walls increased from R-19 in 2006 IECC to R-20 in 2009 IECC. The compliance rate dropped from 84% of homes meeting 2006 IECC prescriptive wall insulation requirements at the end of the 2006 IECC cycle to 30% of homes meeting 2009 IECC prescriptive wall insulation requirements at the beginning of the 2009 IECC code cycle. Requirements for insulating ducts in unconditioned space were relaxed in 2009 IECC. 2006 IECC required ducts to have a minimum of R-8 insulation. 2009 IECC requires only supply ducts located in attics to be insulated to R-8, while all other ducts located in unconditioned space must be insulated to R-6. Only 10% of Mini Baseline Study homes met 2006 IECC insulation requirements for ducts in unconditioned spaces, but 31% met 2009 IECC requirements, approximately the same as the 27% of 2011 baseline homes meeting 2009 IECC requirements. See Section 5 Comparison with Mini Baseline Homes

On-site Homeowner Survey

Homeowners were asked to complete a short survey during the on-site inspections. Homeowners are a diverse group with representation across an array of education, age, and income levels. Survey findings indicate homeowners are not very good at assessing the energy efficiency of their homes. They may have no idea whether or not they have 2 x 6 framing let alone the importance of air sealing and insulation. Or, they may think any home with 2 x 6 framing is energy efficient. They may simply take the builder's word that a home is energy efficient. Over three-quarters (76%) of homeowners said that they had seen or heard of a newly constructed home being referred to as an ENERGY STAR home. However, findings suggest making potential homebuyers aware of ENERGY STAR homes is not enough to get them to act on that awareness when they look for a home or a builder to build a custom home. Only 15 of the 66 owners (23%) who did not build their own home and who said they had seen or heard of a newly constructed home being referred to as an ENERGY STAR home said they asked their builder or sales agent about ENERGY STAR homes. See Section 8 Homeowner On-Site Survey.

Lessons Learned

Every baseline study attempts to address lessons learned in previous studies and finds there are new lessons to be learned. Listed below are examples of lessons learned conducting the 2011 Baseline Study:

- Identifying and recruiting owners of newly constructed homes is always time consuming. Targeting only homes permitted under 2009 IECC turned out to be particularly challenging and time consuming because it required verifying with town building departments what code homes were permitted under and cooperation from building departments varied widely.
- Home inspections started only about a year after the 2009 IECC became mandatory for building permits drawn. Identifying spec built homes that were permitted under 2009 IECC, finished, sold, and owner occupied was another challenge, especially given the still slow housing market.
- It is impossible to assess whether or not a home complies with code without knowing what compliance path the home followed. If the goal is to assess whether or not an individual home meets code, information on the compliance path is critical. Getting this information can be very time consuming and, therefore, expensive.
- If at all possible, all involved parties should finalize a sampling approach identifying the types of homes to target before recruiting begins. The original sampling plan called for recruiting a mix of spec and custom single-family homes that matched the mix of those homes in the 2011 Program. After the audits were completed, it was decided that it was more important to look at the mix of attached versus detached single-family homes in the 2011 Program. Only seven attached homes were inspected. The low number of attached homes in the sample forces the study to rely heavily on the few cases of attached homes and proper weighting means these few cases have a disproportionate importance on the final results.

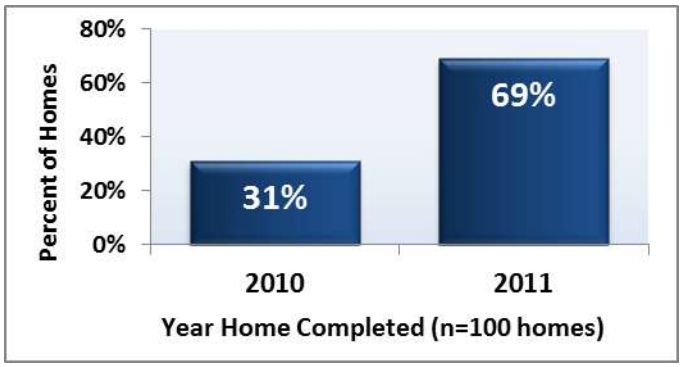
Remainder of the Report

Detailed information supporting the findings presented in this Executive Summary is provided in the body of the report. In addition, the report includes a comparison of the characteristics of the 2011 baseline homes to the characteristics of homes inspected in 2005, 2001 and 1999 baseline studies. Appendix D Insulation Grades and Appendix E Building Practices—Examples from the Site Visits address how insulation installations were graded and provide examples of good and bad building practices observed during the site visits.

1 Introduction

Auditors conducted on-site audits at 100 recently completed non-ENERGY STAR-qualified single-family homes across Massachusetts. Figure 1-1 shows 31% of inspected homes were completed in 2010 and 69% in 2011.

Figure 1-1: Year Homes Completed



Homes were inspected from late July through early November of 2011 with four primary objectives in mind:

- Providing a baseline study of 100 single-family non-ENERGY STAR-qualified homes recently completed across Massachusetts and permitted under 2009 IECC that can be used to update baseline home assumptions used in calculating energy savings for the Massachusetts Program.
- Conducting a full HERS rating for each home using REM/Rate software.
- Providing a comparison of the characteristics of the 100 inspected homes to the characteristics of 1) homes inspected in the 2005, 2001 and 1999 baseline studies; 2) homes inspected in the Mini Baseline Study, and 3) homes completed through the 2011 Program.
- Providing a comparison of measure-specific prescriptive compliance for the 100 inspected homes, built at the beginning of the 2009 IECC code cycle, and the 50 Mini Baseline Study homes, built at the end of the 2006 IECC code cycle.

1.1 General Characteristics of Inspected Homes

The most popular style of the homes inspected is colonial (52% of inspected homes) followed by contemporary (14%), cape (13%), and ranch (7%). Auditors classified a further 5% of homes as townhouses, 4% as modular, and the remaining 5% as various other styles. The majority of homes (93%) are detached single-family homes; 7% are attached single-family homes. With the exception of one home that is occupied seasonally (during summers), all homes are primary residences. The majority of inspected homes (62%) are two stories; 32% are one to one and one-half stories and 6% are two and one-half to three and one-half stories. The smallest home

inspected is 959 square feet and the largest is 5,080 square feet. Figure 1-2 shows examples of the different sizes of homes inspected and Figure 1-3 graphs the Conditioned Floor Area[8] (CFA) of inspected homes.

Figure 1-2: Examples of Inspected Homes

Figure 1-3: Conditioned Floor Area

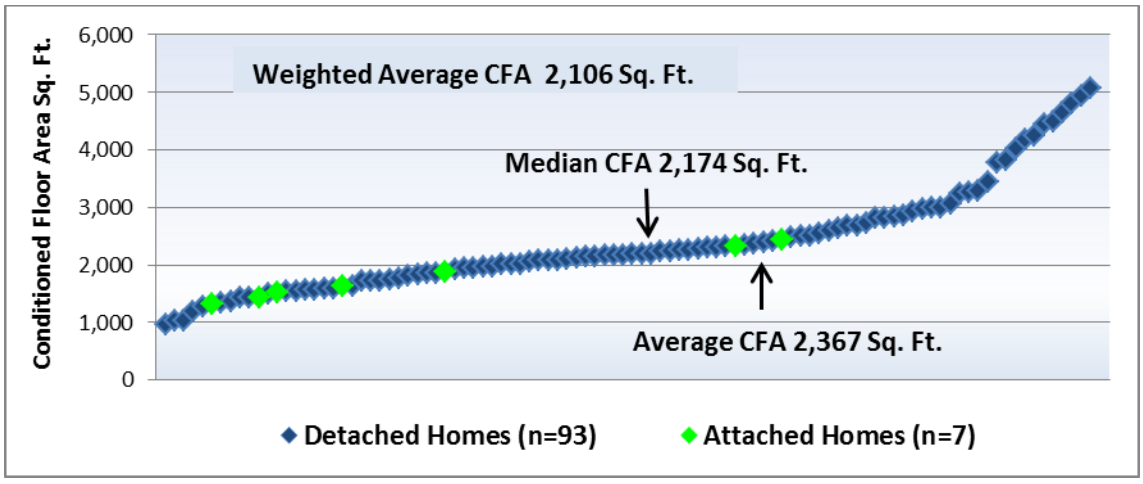


Table 1-1 shows Conditioned Floor Area (CFA) statistics for baseline and 2011 Program homes. As shown, inspected baseline homes are smaller than 2011 Program homes. The average weighted CFA for all inspected homes is 2,106 square feet, which is 417 square feet less than the average 2011 Program single-family home (2,523 square feet CFA). The average detached baseline home is smaller than the average 2011 Program single-family detached home (2,410 versus 2,984 square feet CFA) and this difference is statistically significant at the 90% confidence level. The average attached baseline home is smaller than the average 2011 Program

[8] RESNET definition of conditioned floor area (CFA): "CFA includes all finished space that is within the (insulated) conditioned space boundary (that is, within the insulated envelope), regardless of HVAC configuration. CFA includes unfinished spaces that are directly conditioned, that is, they have "fully ducted" intentional HVAC supply (or other intentional heat source). CFA does not include spaces such as insulated basements or attics that are unfinished, if there is no intentional HVAC supply, or minimal supply (inadequate to be considered directly conditioned space. CFA does not include heated garages."
Source: http://www.resnet.us/standards/Floor_Area_Interpretation.pdf

single-family attached home (1,792 versus 1,963 CFA), but this difference is not statistically significant at the 90% confidence level.

Table 1-1: Baseline and 2011 Program Home Square Footage

Home Square Feet Conditioned Floor Area (CFA)	Baseline Homes Weighted* (Detached/ Attached)	All 2011 Program Homes (n=1,187)	Baseline Detached Homes (n=93)	Program Detached Homes (n=651)	Baseline Attached Homes (n=7)	Program Attached Homes (n=536)
Minimum CFA	959	459	959	720	1,319	459
Maximum CFA	5,080	10,987	5,080	10,987	2,439	5,015
Average CFA	**2,106**	**2,523**	**2,410****	**2,984****	**1,792**	**1,963**
Median CFA	2,174	2,255	2,184	2,614	1,638	1,924

*Only the average is weighted.
**Significantly different at the 90% confidence level.

1.2 On-Site Data Collection

An on-site data collection form that contained the inputs required to conduct a full HERS rating was developed. The data collection form was broken up into five primary sections that are detailed in Table 1-2. (See 0)

Table 1-2: Data Collection Form Inputs

General Information	Insulation/Shell Measures	Mechanical Equipment	Test Results	Lighting & Appliances
• House type • Area of conditioned space • Volume of conditioned space • Primary heating fuel • Stories • Bedrooms • Thermostat type • Builder type • Own/Rent • Evaluation region	• Exterior walls • Ceilings • Frame floors • Rim/Band joists • Windows • Skylights • Doors • Slab Floors • Foundation walls • Mass walls • Sunspaces	• Heating equipment • Water heating equipment • Cooling equipment • Duct insulation • Renewables	• Blower door results • Duct blaster results	• CFL fixtures • Incandescent or Halogen fixtures • Fluorescent tube fixtures • LED fixtures • Ceiling Fans • Refrigerators • Dishwashers

One of the challenges of inspecting completed homes is that several building envelope components are not accessible or visible. Specifically, three components are difficult to verify in a post-occupancy inspection: slab insulation, exterior foundation wall insulation, and window efficiencies. Slab insulation is almost never visible once the slab has been poured. Similarly, if exterior foundation wall insulation does not extend above grade then it is very difficult to visually verify in a post-occupancy inspection. Finally, window U and SHGC values are difficult to verify in occupied homes as most homeowners have removed the National Fenestration Rating

Council (NFRC) labels from the windows in their home and typically do not retain a copy. For all three measures auditors may be able to estimate the efficiency related characteristics based on building plans or discussions with homeowners.

Framing was relatively easy to determine based on the depth of the wall, which was determined either by looking at the width of a door frame or window, or by removing an electrical outlet cover and measuring the depth of the wall. Insulation levels and the quality of installation were harder to verify. Floor insulation type, R-value and installation grade were almost always verifiable, as insulated frame floors are rarely enclosed except when located between conditioned space and a garage or conditioned space and the outside. Wall insulation characteristics were frequently verifiable in the basement or attic knee walls, although the installation grade was sometimes reported as not observable because the walls were enclosed.

The default assumptions for the level of insulation were R-19 for 2x6 stud walls and R-11 for 2x4 stud walls; these are common insulation values for these size walls. The default assumption for the type of insulation was fiberglass batts if that was the type of insulation visible in other areas of the home. It is possible, using these assumptions, that the prevalence of fiberglass batts may be overestimated and the prevalence of other insulation types may be underestimated. However, given the verification of fiberglass batts in so many homes, this does seem to be a reasonable approach to estimating the insulation type in unobservable components. Throughout this report, the percentage of homes in which auditors were able to visually inspect insulation is reported.

In order to conduct a full HERS rating, auditors were required to assign an installation grade to each of the insulation components in the home. Per RESNET standards there are three insulation installation grades: Grade I, Grade II, and Grade III. In general, Grade I is a "perfect" installation, Grade II is a "pretty good" installation, and Grade III is a "sloppy" installation. (See Appendix D Insulation Grades for full definitions of Grade I, II and III installations and pictures of insulation installations observed in inspected homes.) If the insulation installation was visible, then auditors applied the RESNET definitions to determine the installation grade. When the insulation was not visible (e.g. an enclosed wall cavity) auditors used what was observed in other areas of the home to help estimate the installation grade for that particular component. For example, if exterior wall insulation was visible in an unconditioned walk-out basement and assigned a Grade II installation, then the above grade walls for that home were also assigned a Grade II installation.

Figure 1-4 shows a Grade I and a Grade III floor insulation installation.

Figure 1-4: Example of Grade I and Grade III Floor Insulation Installation

Wall insulation (where visible) was predominantly fiberglass batts and was typically assigned either a Grade II or Grade III installation. Frame floor insulation was also predominantly fiberglass batts and typically assigned a Grade III installation as the insulation was often out of contact with the subfloor. In general, Grade I applications were reserved for spray foam insulation and blown-in insulation (i.e. cellulose and fiberglass) in attics.

Duct sealing was almost always unobservable as insulation was covering the ducts, preventing visual verification of duct sealing. Similarly, it was often impossible to verify that building cavities were not being used as supply ducts, as most building cavities are enclosed once construction is complete.

2 Sampling Methodology

The sampling methodology involved developing a sampling plan based on the number of building permits for homes in one to four unit residential buildings issued in each Massachusetts county in 2010 while also taking into account the proportion of permits issued in cities and towns that adopted the stretch code in 2010 and the mix of spec and custom built homes in the program. The homes matching the sampling plan criteria were selected from utility new residential permanent service requests and additional information collected from the city and town building departments about new homes that had been permitted under 2009 IECC.

2.1 Sampling Plan

The sampling plan, shown in Table 2-1, was based on the number of building permits for homes in one to four unit residential buildings issued in stretch code and non-stretch code communities in each Massachusetts county in 2010.

Table 2-1: Sampling Plan

County	Permit Data under Stretch Code	Permit Data not under Stretch Code	Targeted Total On-Site Inspections	Targeted On-Site Inspections in Non-Stretch Code Communities	Targeted On-Site Inspections in Stretch Code Communities
Barnstable	42	340	6	5	1
Berkshire	48	84	2	1	1
Bristol	21	464	8	8	0
Dukes	18	95	2	2	0
Essex	106	468	10	8	2
Franklin	31	27	1	0	1
Hampden	73	223	5	4	1
Hampshire	77	156	4	3	1
Middlesex	677	704	23	12	11
Nantucket	0	53	1	1	0
Norfolk	83	462	9	8	1
Plymouth	81	550	10	9	1
Suffolk	57	0	1	0	1
Worcester	181	923	18	15	3
Total	**1,495**	**4,549**	**100**	**76**	**24**

In addition to the specified number of on-site inspections by county and stretch/non-stretch code community, the study attempted to maintain a mix of 74% spec and 26% custom built homes. This split reflects the spec/custom split in one- to four-unit buildings that participate in the Program. Spec and custom built homes were defined according to the homeowner's response to the following screening question:

How did you purchase your home?

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

Homes were classified as custom built if the homeowner chose responses 1, 2, or 6; if the home owner chose responses 3, 4, or 5, the home was classified as spec built.

There was also a goal to perform no more than one on-site inspection in each community; the reasoning is that new residential construction in each city and town would come under the same building inspection department and may thus have similar rates of code compliance.

2.2 Sample Development

The sample of homes for the on-site inspections was initially developed from new residential permanent service requests collected by the four investor owned electric utilities in Massachusetts: National Grid, NSTAR, Unitil, and Western Massachusetts Electric. New permanent service requests have been used to identify newly constructed homes in Massachusetts over the past several years for baseline studies and new home buyer surveys. However, the tight timeframe for completing inspections of homes permitted under 2009 IECC necessitated repeated contacts with various building departments to ascertain that the homes identified by the new service requests had indeed been permitted under 2009 IECC and to identify additional homes that had been recently permitted under the new code, completed construction, and, in the case of spec homes, were no longer owned by the builders. In total, information was obtained from 250 municipal building departments for recruitment of the 100 homes.[9]

[9] This includes 11 building departments that were contacted but reported that no homes had been built under 2009 IECC.

2.3 Data Cleaning

The sample for the on-site inspections was initially drawn from permanent new service requests received by the utilities from July 1, 2010 through approximately the first three months of 2011, depending on when each utility drew the data requested. These dates were chosen to target homes built under the 2009 IECC code in Massachusetts; building permits drawn starting on July 1, 2010 had to come under the new building code. The new service requests were cleaned to remove addresses where:

- The home had participated in the Program.
- The housing unit was obviously part of a building with five or more units.
- There was only the builder's name on the utility record.

After the initial cleaning, the addresses were checked through the local building departments to ensure that the home had been permitted under 2009 IECC; the checks with the building departments also meant that new service requests that did not involve new home construction, such as those involving additions to existing homes or major renovations, could be screened out at this stage. At the end of this stage, there were 1,056 possible addresses identified for the on-site inspections.

2.4 Sample Selection

Sample selection involved pre-recruitment of both the homeowners identified through the utility permanent new service requests and building department records of homes permitted under 2009 IECC.

2.4.1 Pre-Recruitment

Pre-recruitment for the on-site inspections was initially coordinated with a telephone survey of recent purchasers of newly constructed homes.[10] Each homeowner at the 1,056 addresses identified was mailed a letter, with the Program Sponsors' logos, explaining the purpose of the study, what the on-site inspections would be like, and the incentives of $150 to $200 offered for participation. Homeowners were also informed that some of them would be recruited for the on-sites at the end of a fifteen minute telephone survey.

Homeowners who expressed an interest in participating in the on-sites at the end of the telephone survey were told that they would possibly receive a call to schedule a visit. Once the quota of telephone surveys was completed, homeowners were simply pre-recruited through a short phone call asking them how they had purchased their homes (so that their address could be classified as spec or custom) and if they were interested in participating in the on-sites. A total of 270 homes were pre-recruited through this effort.

Since the number of pre-recruited homes was not judged to be adequate to fulfill the sampling

[10] NMR Group Inc. and Dorothy Conant, Massachusetts Residential New Construction Home Buyer Survey, Final Report, 12/1/2011.

plan described above, municipal building departments were again contacted and asked to provide any information on homes that had been permitted under 2009 IECC, completed construction, and, in the case of spec homes, were no longer owned by the builders. A total of 1,631 additional addresses considered possible candidates for the on-sites were identified at this stage. Since there were no phone numbers available for these addresses, they were mailed the letter with the Program Sponsors' logos explaining the purpose of the study along with a postcard they could return with a phone number. A total of 134 postcards were returned; added to the 270 homes pre-recruited through the telephone surveys, they brought the pre-recruited sample to 404 homes.

2.4.2 Sample Disposition

The sampling plan targeting a certain number of on-sites in each county along with the goal of one inspection per community and the spec/custom mix meant that some of the pre-recruited sample could not be used. Of the 404 names, 177 were considered not eligible because the quota of inspections in a particular county was reached or an inspection had already taken place in their city or town. This meant a valid sample of 227 homes. Table 2-2 summarizes the disposition of the sample.

Table 2-2: Sample Disposition

Sample Description	Number	Percent
Sample	404	
Sample considered not eligible	177	
Valid Sample	227	
Completed on-site inspections	102[11]	45%
Refusals	32	14%
Not reached	93	41%

It is important to note that the overwhelming majority of the valid sample not reached consists of messages left for homeowners that had no follow-up because the desired number of on-site inspections was reached. Of the homeowners who were reached, there were more than three times as many acceptances (102) than refusals (32), likely due to the pre-recruitment efforts.

2.5 Completed On-Site Inspections

Table 2-3 shows the completed on-site inspections followed the sampling plan shown in Table 2-1 and the desired stretch code/non-stretch code and spec/custom mixes fairly closely. The study has a mix of 77% spec built and 23% custom built homes. Coincidentally, 77% of the on-site inspections took place in non-stretch code communities and 23% took place in communities that have adopted the stretch code. However, only a few, if any, of the inspected homes were built under the stretch code.[12] Of the 23 inspected homes in stretch code communities, 16 homes were completed before the stretch code was in effect; 3 under 3,000 square feet spec homes in

[11] Two homes were completed and subsequently dropped because they had gone through the Program.
[12] In MA towns that adopted the stretch code, the code has not gone into effect until 6 to 20 months after adoption.

stretch code communities were completed fewer than nine months after the stretch code went into effect and have HERS indices too high (over 76) to meet the stretch code requirement[13] of HERS 70 for homes less than 3,000 square feet; and one over 3,000 square feet custom home in a stretch code community was completed six months after the stretch code went into effect and has a HERS index of 69, which is higher than the stretch code requirement of HERS 65 or lower for homes 3,000 square feet or larger. This leaves only three inspected homes that could, possibly, have been built under the stretch code; two over 3,000 square feet homes with HERS indices of 50 and 62 completed six months after the stretch code went into effect and one under 3,000 square feet home with a HERS index of 73[14] completed four months after the stretch code went into effect.

Table 2-3: Completed On-Site Inspections

County	Total On-Site Inspections	Stretch Code Community	Non-Stretch Code Community	Spec Built	Custom Built
Barnstable	9	1	8	3	6
Berkshire	2	1	1	2	0
Bristol	8	0	8	5	3
Dukes	0	0	0	0	0
Essex	12	0	12	11	1
Franklin	1	1	0	1	0
Hampden	5	1	4	4	1
Hampshire	3	1	2	1	2
Middlesex	22	11	11	20	2
Nantucket	0	0	0	0	0
Norfolk	9	1	8	7	2
Plymouth	11	3	8	10	1
Suffolk	0	0	0	0	0
Worcester	18	3	15	13	5
Total	100	23	77	77	23

Moreover, the inspections took place in 74 cities and towns across Massachusetts; there was only one inspection done in 56 communities, two inspections done in each of 20 communities, and four inspections done in one community. The 74 communities covered are shown in Figure 2-1.

[13] MA stretch code requires a HERS index of 65 or less for new homes of 3,000 square feet or above, and 70 or less for new homes below 3,000 square feet (this includes multi-family units in buildings of 3 stories or less). Source: http://www.mass.gov/eopss/docs/dps/inf/summary-of-the-ma-building-code-appendix-120.doc

[14] This home is being treated as a possible stretch code home to allow for a few point difference between the HERS rating performed by the rater who observed the home during construction and the HERS rating performed post occupancy for the baseline study.

Figure 2-1: On-Site Inspections

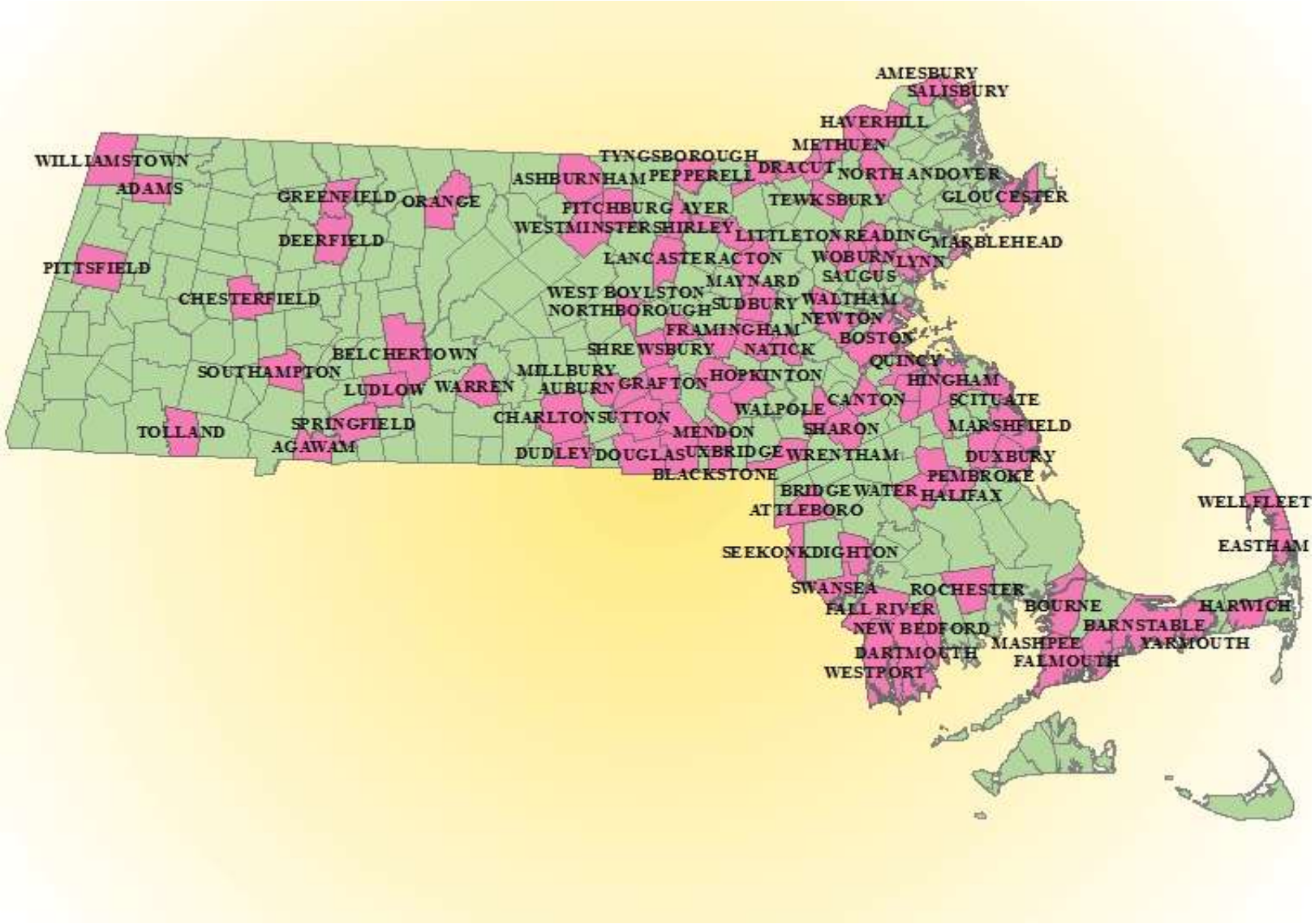


Table 2-4 presents summary economic characteristics by county. More than three-fifths of on-sites (63%) were conducted in counties where the median value of owner-occupied housing units is above the statewide median; however, 58% of on-sites were conducted in counties were the median household income is below the statewide median.

Table 2-4: Economic Characteristics by County

County	Completed On-Site Inspections	Median Value of Owner-Occupied Units*	Median Household Income*
Barnstable	9	$399,900	$56,991
Berkshire	2	$202,700	$44,061
Bristol	8	$315,900	$54,048
Essex	12	$380,000	$62,758
Franklin	1	$216,500	$48,993
Hampden	5	$197,200	$46,646
Hampshire	3	$252,500	$56,263
Middlesex	22	$427,400	$77,762
Norfolk	9	$414,900	$79,548
Plymouth	11	$368,000	$70,447
Worcester	18	$285,000	$62,885
Total Massachusetts	100	$357,600	$64,057

*http://quickfacts.census.gov/qfd/states/09/09001.html; median home values are for the years 2005 through 2009; median income is for the year 2009

There is considerable variation in economic characteristics among the cities and towns within each county, so Table 2-5 examines the median housing values and incomes in the communities with on-sites. At a community level, there were slightly fewer on-sites in communities with housing values above the statewide median and slightly more on-sites in communities with incomes above the statewide median. However, since these data were lacking for more than four out of ten communities, these numbers warrant caution in interpretation.

Table 2-5: Economic Characteristics by Community

	Median Value of Owner-Occupied Units*	Median Household Income*
On-Sites in Communities Above State Median	26%	31%
On-Sites in Communities Below State Median	33%	28%
On-Sites in Communities Without Data	41%	41%

*http://www.city-data.com/; data is for 2009

2.6 Weighting

While the completed on-site inspections matched the spec/custom split in one- to four-unit buildings that participate in the Program fairly closely, there was a much higher proportion of detached versus attached single family homes audited than the mix in the Program. The baseline audits included 93 detached and 7 attached single-family homes; in order to reflect the mix in the Program, the baseline data are weighted by 49.2% for attached homes and 50.8% for detached homes. See Table 2-6.

Table 2-6: Weighting Factor Calculation

Weighting Factors	Number of 2011 Program Homes	Percent of 2011 Program Homes (Weighting Factors)
All 2011 Program Single-Family Homes	1,282	100.0%
2011 Program Single-Family Detached homes	**651**	**50.8%**
2011 Program Single-Family Attached Homes	**631**	**49.2%**

The low number of attached homes in the sample forces the study to rely heavily on the few cases of attached homes found in the sample. For now, proper weighting means these few cases have a disproportionate importance in the final results; the result of which is lower precision for estimates.

The tables in this report generally show the unweighted data from all 100 audited homes, the unweighted data from the detached homes audited, the unweighted data from the attached homes audited, and the weighted average of attached and detached homes. Statistically significant differences at the 90% confidence level between detached and attached homes are noted in the appropriate tables.

2.7 Sampling Error

In developing the on-site sample design, the evaluation team drew from experience in similar studies to estimate a coefficient of variation (CV) and a sample size that would provide a precision of ± 10% at the 90% confidence level. Assuming a coefficient of variation of 0.49, the team estimated that a sample size of at least 64 homes would be adequate to produce a final precision of ± 10% at the 90% confidence level. As a result of this study the evaluation team is able to utilize actual coefficients of variation to estimate the final precision levels of key home characteristics.

The coefficient of variation is of central importance to determining the final precision levels. A primary objective of this study is to document the existing building and equipment status of new single-family homes by feature. Some features are far more variable than others. In the current

study, duct leakage and air infiltration are the most variable, and HVAC system efficiencies the least variable.

Table 2-7 shows the coefficients of variation and relative precisions at the 90% confidence level for several key building components and measurements that influence a home's energy efficiency. Based on these coefficients of variation, relative precision ranges from ± 1.0% for all fossil-fuel fired heating system efficiencies to ± 13.6% for duct leakage. The HERS index, which is the one measurement that addresses multiple building components, has a coefficient of variation of 0.12 and a very good relative precision of ± 2.0% at the 90% confidence level.

Table 2-7: Coefficients of Variation and Relative Precision for Key Residential Construction Measurements

Parameter	Sample Size	Coefficient of Variation	Relative Precision
All Fossil-Fuel Fired Heating System AFUE	121	0.07	±1.0%
Central Air Conditioning SEER	119	0.10	±1.5%
Conditioned/Ambient Wall Insulation R Value	100	0.17	±2.8%
HERS Index	100	0.12	±2.0%
Cathedral Ceiling Insulation R-Value	65	0.12	±2.4%
Flat Ceiling Insulation R-Value	97	0.14	±2.3%
Air Infiltration—Air Changes per Hour at 50 Pascals	73	0.36	±6.9%
Duct Leakage—CFM25/100 Sq. Ft.	69	0.69	±13.6%

3 Preliminary UDRH Inputs

The 2011 Baseline UDRH inputs are preliminary estimates based on study findings weighted to reflect the mix of single-family detached and attached housing in the 2011 Program. This section presents detailed tables showing the data used to develop UDRH inputs. Note that weighted averages and cases where the difference between detached and attached homes is statistically significant at the 90% confidence level (far right column) are in red text.

Program Administrators will review these preliminary UDRH estimates and develop a final set of UDRH inputs.

WATER HEATING UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
ALL TYPE, SIZES, EXTRA INSULATION AND LOCATIONS ARE THE SAME AS THE RATED HOME	Current Inputs	All Systems (n)	Weighted Average EF*	All Homes Average EF (Raw Data)	Systems in Detached Homes (n)	Average EF	Systems in Attached Homes (n)	Average EF*	Attached/ Detached Difference
Conventional (Natural Gas)	.58 EF .65 RE	**45**	**0.64**	**0.63**	40	0.63	5	0.65	**Significant**
Conventional (Propane)	.58 EF .65 RE	**7**	**0.64**	**0.64**	7	0.64	0	n/a	n/a
Conventional (Natural Gas & Propane)		**52**	**0.64**	**0.63**	47	0.63	5	0.65	**Significant**
Conventional (Oil)	.61 EF .65 RE	**No Baseline Homes**							
Conventional (Electric)	.86 EF .98 RE	**20**	**0.90**	**0.89**	19	0.89	1	0.90	n/a
Instantaneous converted to conventional (Natural Gas)	.58 EF .76 RE	**8**	**0.88***	**0.84**	7	0.82	1	0.95*	n/a
Instantaneous converted to conventional (Propane)	.58 EF .76 RE	**4**	**0.83**	**0.83**	4	0.83	0	n/a	n/a
Instantaneous Natural Gas & Propane		**12**	**0.88***	**0.83**	11	0.82	1	0.95*	n/a
Instantaneous converted to conventional (Oil)	.61 EF .65 RE	**No Baseline Homes**							
Instantaneous converted to conventional (Electric)	.86 EF .98 RE	**No Baseline Homes**							
Weighted Avg. Nat. Gas and Propane Conventional and Instantaneous (weighting based on percent of conventional and instantaneous systems)		**64**		**0.67**					
Integrated (Natural Gas)	.75 EF .76 RE	**6**	**0.84**	**0.84**	6	0.84	0	n/a	n/a
Integrated (Propane)	.75 EF .76 RE	**5**	**0.85**	**0.85**	5	0.85	0	n/a	n/a
Integrated (Oil)	.69 EF .76 RE	**6**	**0.79**	**0.79**	6	0.79	0	n/a	n/a
Heat Pump Converted to Conventional (Electric)	.86 EF .98 RE	**No Baseline Homes**							
Ground Source Heat Pump Converted to Conventional (Electric)	.86 EF .98 RE	**No Baseline Homes**							

*There are only seven attached homes in the sample and only one of them has an instantaneous water heater—a very high 0.95 EF Navien America system. There are 850 models on the current EPA product list for ENERGY STAR Qualified Whole-Home Gas Tankless Water Heaters and the average EF of these ENERGY STAR-qualified systems is 0.85. The ENERGY STAR criteria are EF 0.67 for high efficiency gas conventional systems and EF 0.82 for gas instantaneous systems. The 0.95 EF instantaneous water heater in the attached home is clearly an outlier and should not be weighted to represent the average efficiency of instantaneous water heaters in attached housing.

HEATING UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
ALL TYPE, SIZES, AUXILARY POWER AND LOCATIONS ARE THE SAME AS THE RATED HOME		All Systems (n)	Weighted Average AFUE	All Homes Average AFUE (Raw Data)	Systems in Detached Homes (n)	Average AFUE	Systems in Attached Homes (n)	Average AFUE	Attached/ Detached Difference
Fuel fired, air distribution (natural gas)	89.2 AFUE	78	91.6	92.0	69	92.2	9	91.0	Not Significant
Fuel fired, hydronic distribution (natural gas)	81.7 AFUE	6	86.8	86.8	6	86.8	0	n/a	n/a
Fuel fired, air distribution (propane)	89.2 AFUE	22	92.0	92.0	22	92.0	0	n/a	n/a
Fuel fired, hydronic distribution (propane)	81.7 AFUE	1	87.2	87.2	1	87.2	0	n/a	n/a
Fuel fired, air distribution (oil)	83.9 AFUE	10	84.1	84.1	10	84.1	0	n/a	n/a
Fuel fired, hydronic distribution (oil)	84.4 AFUE	3	84.5	84.5	3	84.5	0	n/a	n/a
Combined appliance (natural gas)	.817 CAafue, .75 CAef	No Baseline Homes							
Combined appliance (propane)	.817 CAafue, .75 CAef	No Baseline Homes							
Combined appliance (oil)	.844 CAafue, .69 CAef	No Baseline Homes							
Air Source Heat Pump	7.7 HSPF	No Baseline Homes							
Ground Source Heat Pump (converted to an Air Source Heat Pump)	7.7 HSPF (2.26 COP)	6	14.4 HSPF (4.22 COP)	14.4 HSPF (4.22 COP)	6	14.4 HSPF (4.22 COP)	0	n/a	n/a
Dual Fuel Heat Pump	7.7 HSPF, 87.4 AFUE	No Baseline Homes							
All Gas Furnaces Natural Gas & Propane		93	91.5	92.0	84	92.1	9	91.0	Not Significant
Non-Attic Gas Furnaces Nat & Propane		72	94.0	93.8	65	93.8	7	94.2	Not Significant
Attic Gas Furnaces Nat & Propane		21	83.1	85.6	19	86.1	2	80.0	n/a
All Oil Furnaces		7	82.7	82.7	7	82.7	0	n/a	n/a
Gas Boilers Nat. Gas & Propane		14	89.8	89.8	14	89.8	0	n/a	n/a
Oil Boilers		6	85.9	85.9	6	85.9	0	n/a	n/a

COOLING UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
ALL TYPE, SIZES AND LOCATIONS SAME AS RATED HOME		All Systems (n)	Weighted Average SEER or EER	All Homes Average SEER or EER (Raw Data)	System in Detached Homes (n)	Average SEER Or EER	Systems in Attached Homes (n)	Average SEER Or EER	Attached/ Detached Difference
Air Conditioner	13 SEER	118	**13.7**	13.60	109	13.6	9	13.8	Not Significant
Air Source Heat Pump	13 SEER	1	**14.0**	14.00	1	14.0	0	n/a	n/a
Ground Source Heat Pump	12.26 EER	6	**21.90**	21.90	6	21.90	0	n/a	n/a

WALL UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
Wall Type		All Homes (n)	Weighted Average U-factor	All Homes Average U-factor (Raw Data)	Detached Homes (n)	Average U-factor	Attached Homes (n)	Average U-factor	Attached/ Detached Difference
Above Grade Wall (Conditioned/Ambient)	Uo= .066	100	**0.072**	0.069	93	0.069	7	0.075	Not Significant
FLOOR UDRH INPUTS		**Weighted Sample Results (49.2% Attached 50.8% Detached)**							
Floor Type		All Homes (n)	Weighted Average U-factor	All Homes Average U-factor (Raw Data)	Detached Homes (n)	Average U-factor	Attached Homes (n)	Average U-factor	Attached/ Detached Difference
Frame Floor over Unconditioned Basement	Uo= .038	60	**0.048**	0.053	57	0.054	3	0.042	**Significant**
CEILING UDRH INPUTS		**Weighted Sample Results (49.2% Attached 50.8% Detached)**							
Ceiling Type		All Homes (n)	Weighted Average U-factor	All Homes Average U-factor (Raw Data)	Detached Homes (n)	Average U-factor	Attached Homes (n)	Average U-factor	Attached/ Detached Difference
Attic	Uo= .041	97	**0.041**	0.044	90	0.044	7	0.039	Not Significant
Vaulted	Uo= .0422	65	**0.043**	0.042	62	0.042	3	0.044	Not Significant

FOUNDATION WALL & SLAB UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
		All Homes (n)	Weighted Average R-Value	All Homes Average R-value (Raw Data)	Detached Homes (n)	Average R-Value	Attached Homes (n)	Average R-Value	Attached/ Detached Difference
Foundation Wall: Unconditioned Basement	10" thick concrete or stone walls with R-3.1 cavity insulation, Grade 3, 2x4 studs at 16" O.C.	79	0.02	0.04	74	0.04	5	0	Not Significant
Foundation Wall: Conditioned Basement	8" solid concrete or stone walls with R-10.4 continuous insulation, Grade 1, no studs	20	16.6	12.74	19	12.30	1	21.0	n/a
Unheated Slab On Grade	R-10 under slab (2ft), no perimeter insulation	7	0.42	0.71	6	0.83	1	0	n/a
Heated Slab On Grade	R-15 under slab (2ft), no perimeter insulation	No Baseline Homes							
Unheated Slab Below Grade	R-10 under slab (2ft), no perimeter insulation	12	1.67	1.67	12	1.67	0	n/a	n/a
Heated Slab Below Grade	R-15 under slab (2ft), no perimeter insulation	No Baseline Homes							

DUCT UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
THE LOCATION IS THE SAME AS THE RATED HOME EXCEPT WHERE NOTED		All Homes (n)	Weighted Average R-Value	All Homes Average R-value (Raw Data)	Detached Homes (n)	Average R-Value	Attached Homes (n)	Average R-Value	Attached/ Detached Difference
Unconditioned Attic (supply only)	R-6.5	60	6.5	6.5	54	6.5	6	6.5	Not Significant
All other unconditioned spaces	R-5	85	5.5	5.8	78	5.9	7	5.1	Significant

WINDOW UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
		All Homes (n)	Weighted Average U- or SHGC Value	All Homes Average U- or SHGC Value	Detached Homes (n)	Average U-Value	Attached Homes (n)	Average U-Value	Attached/ Detached Difference
Equally Distributed	U= .35	31	0.32*	0.31	29	0.30	2	0.35	n/a
Equally Distributed	SHGC= .346	30	0.291	0.29	28	0.287	2	0.295	n/a

* Documented U-value and SHGC information was available for 18 homes where the original NFRC (National Fenestration Rating Council) sticker was visible. Auditors had access to the U-value and/or SHGC, or to information with which they could estimate the U-value and/or SHGC (such as the window manufacturer and series listed in a home's plans) for an additional 13 homes. Of the 31 homes with U-value data, argon fill was confirmed in 24 homes. Given the relatively small sample size of homes with verified window U-values and feedback from several window manufacturers and lumber stores, the recommendation is to use a more conservative UDRH U-value of 0.34.

DUCT LEAKAGE UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
		All Homes (n)	Weighted Average CFM25/ 100 sq. ft.	All Homes Average CFM25/ 100 sq. ft. (Raw Data)	Systems in Detached Homes (n)	Average CFM25/ 100 sq. ft.	Attached Homes (n)	Average CFM25/ 100 sq. ft.	Attached/ Detached Difference
DISTRIBUTION LOSS IS FOR DUCTED HOMES ONLY	12 CFM per 100 sq. ft. @25Pa	69*	11.9	12.4	64	12.5	5	11.2	Not Significant

*Excludes any conditioned volume basement systems where the ducts ran into the attic as well. If all ducts were located in the basement and the basement was considered conditioned volume for testing, total leakage was used as a proxy for leakage to the outside. The logic behind using total leakage as a proxy for leakage to outside only applies if all of the ducts are in the basement.

AIR INFILTRATION UDRH INPUTS		Weighted Sample Results (49.2% Attached 50.8% Detached)							
ACH50		All Homes (n)	Weighted Average ACH50	All Homes Average ACH50 (Raw Data)	Detached Homes (n)	Average ACH50	Attached Homes (n)	Average ACH50	Attached/ Detached Difference
shelter class 4	6.72 ACH50	99	**4.77**	4.49	92	4.44	7	5.11	Not Significant
shelter class 4	6.72 ACH50	73*	**4.88**	4.78	67	4.76	6	5.01	Not Significant
shelter class 4	6.72 ACH50	26*	**4.64**	3.67	25	3.59	1	5.72	n/a

* The data for 73 homes includes only homes with basements that were finished and conditioned space or fully unconditioned and the basement area was NOT considered conditioned volume in the testing. The data for the 26 homes includes only those homes with unconditioned walkout basements and the basement was considered conditioned volume (not conditioned floor area) for testing.

4 Comparison to 2011 Program Single-Family Homes

This section compares selected building characteristics in 2011 baseline homes and single-family homes completed through the 2011 Program; the 2011 Program homes exclude those that failed to meet Program requirements. Comparisons address:

- Conditioned/Ambient Walls
- Flat Ceilings
- Cathedral Ceilings
- Conditioned/Basement Floors
- Foundation Walls
- Duct Insulation
- Duct Leakage
- Air Infiltration
- HERS Indices

For conditioned/ambient walls, ceilings and floors both R-values and U-values are addressed. U-values are the overall heat transfer coefficient for the entire wall, floor or ceiling assembly, not just the insulation. The lower the U-value is, the more energy efficient the assembly. U-values calculated using REM/Rate software account for the R-value of framing members, the R-value of other components such as air barriers and drywall, the R-value of the insulation, and the quality of the insulation installation. If insulation is compressed, or there are gaps, the energy efficiency of the assembly is lower and the U-value is higher.

The following differences between 2011 baseline and Program homes are statistically significant at the 90% confidence level:

- The average R-value of flat ceiling insulation is higher in Program homes.
- The average U-value of flat ceilings is lower (more energy efficient) in Program homes.
- The average U-value of cathedral ceilings is lower (more energy efficient) in Program homes.
- The average R-value of foundation wall insulation in unconditioned basements is higher in Program homes.
- The average R-value of attic supply duct insulation is higher in Program homes.
- The average R-value of duct insulation on ducts installed in non-attic, unconditioned space is higher in Program homes.
- Average duct leakage and air infiltration are lower in Program homes.
- Program homes have a lower (better) average HERS index.

In Table 4-1, the first column of data is the unweighted average over all inspected homes, which reflects the mix of single-family spec and custom homes in the 2011 Program; the second column is the average over all single-family homes that were completed through the 2011 Program—this excludes homes that failed to meet Program requirements; the third column is the current UDRH input; and the fourth column is the raw data for attached and detached baseline homes weighted to reflect the mix of single-family attached and detached homes in the 2011 Program, which is typically also the preliminary weighted UDRH input estimate.

Table 4-1: Comparison of 2011 Baseline and 2011 Program Homes

Baseline Compared to 2011 Program Homes	MA Baseline 2011	MA 2011 Program	Current UDRH Input	Baseline Weighted & Preliminary UDRH Input
Average Conditioned/Ambient Wall Insulation R-value	19.4	19.0	n/a	18.5
Average Conditioned/Ambient Wall Insulation U-value	0.069	0.068	0.066	0.072
Average Flat Ceiling Insulation R-value	36.8*	40.6*	n/a	36.3
Average Flat Ceiling Insulation U-value	0.044*	0.030*	0.041	0.041
Average Cathedral Ceiling Insulation R-value	35.5	35.8	n/a	35.4
Average Cathedral Ceiling Insulation U-value	0.0417*	0.0345*	0.0422	0.0429
Average Conditioned/Basement Floor Insulation R-value	26.5	27.1	n/a	28.1
Average Conditioned/Basement Floor Insulation U-value	0.053	0.048	0.038	0.048
Foundation Wall Insulation - Conditioned Basements R-value	12.7	14.1	10.4	16.6
Foundation Wall Insulation - Unconditioned Basements R-value	0.04*	0.5*	3.1	0.02
Duct Insulation - Attic Supply R-value	6.5*	7.4*	6.5	6.5
Duct Insulation - All other Unconditioned Spaces	5.8*	6.8*	5.0	5.5
Average Duct Leakage--CFM25/100 sq. ft.	12.44*	3.32*	12.0	11.9
Air Infiltration—Average ACH50	4.78*	3.85*	6.72	4.88
Average HERS Index	79*	63*	n/a	80

*Significantly different at the 90% confidence level.

Conditioned/Ambient Walls

The average R-value of insulation in conditioned/ambient walls is slightly higher in 2011 baseline homes than in 2011 Program homes. This is not surprising since all of the 2011 baseline homes were permitted under 2009 IECC, where the prescriptive requirement for conditioned/ambient wall insulation is R-20, and most of the 2011 Program homes were permitted under 2006 IECC when the prescriptive requirement was R-19. However, the weighted average baseline R-value of R-18.5 (weighted to reflect the mix of single-family attached and detached housing in the 2011 Program) is lower than the 2011 Program average of R-19.0. Looking at U-values, the average unweighted and weighted U-values for 2011 baseline homes are both higher (less efficient) than for 2011 Program homes.

Ceilings

The average R-value of flat ceiling insulation is lower and the average U-value higher in 2011 baseline homes than in 2011 Program homes; these differences are statistically significant. The average R-value of cathedral ceiling insulation is virtually the same in 2011 baseline homes (R-35.5 unweighted and R-35.4 weighted) and 2011 Program homes (R-35.8). However, the average cathedral ceiling U-value is much higher (less energy efficient) in 2011 baseline homes; this difference is statistically significant.

Conditioned/Basement Floors

The unweighted average R-value of conditioned/basement floor insulation in 2011 baseline homes is slightly lower (R-26.5) and the weighted average slightly higher (R-28.1) than in 2011 Program homes (R-27.1). The unweighted 2011 baseline home average U-value for conditioned/basement floors of U-0.053 is higher than the average U-value of U-0.048 in 2011 Program homes, but the weighted average U-value for 2011 baseline homes is the same as the average for 2011 Program homes. All of these U-values are higher than the current UDRH input of U-0.038.

Foundation Walls

The average unweighted foundation wall insulation level is R-12.7 in 2011 baseline homes with conditioned basements, which is lower than the average R-value of 14.1 in 2011 Program homes, but the weighted average R-value of 16.6 in 2011 baseline homes is higher. The average R-value of foundation wall insulation in homes with unconditioned basements is lower in 2011 baseline homes than in 2011 Program homes; this difference is statistically significant. However, average foundation wall insulation R-values are below R-1 for both 2011 baseline homes (weighted and unweighted) and 2011 Program homes. Building code does not require these foundation walls to be insulated.

Duct Insulation

The average R-value of duct insulation on attic supply ducts is lower in 2011 baseline homes (both weighted and unweighted averages are R-6.5) than in 2011 Program homes (R-7.4); this difference is statistically significant. The average of R-6.5 in 2011 baseline homes is the same as the current UDRH input. Average attic supply duct insulation levels in both 2011 baseline and 2011 Program homes fall short of the 2009 IECC R-8 requirement for attic supply ducts. Average duct insulation levels for ducts in other unconditioned spaces are also lower in 2011 baseline homes than in 2011 Program homes; this difference is statistically significant. The average R-value of 6.8 for 2011 Program homes exceeds the 2009 IECC requirement of R-6; neither the unweighted average (R-5.8) or the weighted average (R-5.5) for 2011 baseline homes meet 2009 IECC requirements.

Duct Leakage

Duct leakage is much higher in 2011 baseline homes than in 2011 Program homes; the difference is statistically significant. The weighted average duct leakage of 11.9 CFM25 per 100 square feet of conditioned floor space in 2011 baseline homes is virtually the same as the current UDRH input assumption of 12.0 CFM25 per 100 square feet of conditioned floor space. In comparison, average duct leakage in 2011 Program homes is only 3.3 CFM25 per 100 square feet of conditioned floor space.

Air Infiltration—ACH50

Average air infiltration is also lower in 2011 Program homes, but the difference is not as great as the difference in duct leakage; the difference is statistically significant. Average air leakage in both 2011 baseline homes (unweighted average 4.78 ACH50 and weighted average 4.88 ACH50) and 2011 Program homes (3.85 ACH50) is lower than the current UDRH input assumption of 6.72 ACH50.

HERS Indices

Average HERS indices show a clear difference in the overall energy efficiency of 2011 baseline and 2011 Program homes. The average HERS index for 2011 Program homes of 63 is much lower (more energy efficient) than the unweighted average 79 HERS index for 2011 baseline homes: this difference is statistically significant. The weighted average HERS index for 2011 baseline homes is 80.

5 Comparison to Mini Baseline Study Homes

This section compares the results of the Mini Baseline Study of 50 homes completed at the end of the 2006 IECC code cycle to the results of the 2011 Baseline Study of 100 homes completed at the beginning of the 2009 IECC code cycle. A key purpose of the Mini Baseline Study was to provide a point of comparison between compliance with IECC prescriptive requirements at the end of the 2006 IECC code cycle and the beginning of the 2009 IECC code cycle.

The homes addressed in the Mini Baseline Study are the same homes inspected for the Massachusetts Energy Code Pilot Report.[15] The objective of the Code Pilot Report was to field test the protocol developed by Pacific Northwest National Laboratory (PNNL), as part of the US Department of Energy (DOE) Building Energy Code Program (BECP), for verifying energy code compliance. The core of the PNNL protocol is a checklist designed to be completed during on-site inspections at various construction stages. The 2006 IECC checklist developed by PNNL was completed for two groups of homes: 50 non-ENERGY STAR-qualified homes completed at the end of the 2006 IECC code cycle in Massachusetts and 50 ENERGY STAR-qualified homes certified in the 2010 Program.

The samples of 50 non-ENERGY STAR-qualified homes inspected for the Mini Baseline Study and 100 non-ENERGY STAR-qualified homes inspected for the 2011 Baseline Study report both reflect the mix of spec and custom homes in the 2011 Program; the 50 home Mini Baseline Study sample is 24% custom homes, the 100 home 2011 Baseline Study sample is 23% custom homes, and the 2011 Program homes are 23% custom. Because the make-up of both the Mini Baseline Study and 2011 baseline home samples reflect the mix of custom and spec homes in the 2011 Program, the comparisons presented here compare Mini Baseline Study results to unweighted 2011 baseline results.

When comparing compliance with specific IECC prescriptive requirements it is important to remember that a home not complying with a specific prescriptive requirement is not an indication that the home failed to comply with state building code—homes may meet code requirements by following a non-prescriptive compliance path that allows trade-offs, such as REScheck or the Home Energy Rating compliance path.

Table 5-1 shows that the average Mini Baseline Study home has 244 more square feet of conditioned floor area than the average 2011 baseline home and a higher (not as good) HERS Index of 83 compared with the average HERS Index in 2011 baseline homes (HERS 79). The difference in size is not statistically significant, but the difference in HERS indices is statistically significant at the 90% confidence level. The only statistically significant difference in home sizes between Mini Baseline Study and 2011 Baseline Study homes is that the average size of spec

[15] Massachusetts Energy Code Pilot Report. Submitted to Massachusetts Residential New Construction Program Administrators, Massachusetts Department of Energy Resources and Northeast Energy Efficiency Partnerships by NMR Group, Inc., KEMA, Inc. and Dorothy Conant. . July 2011.

homes in the Mini Baseline Study is significantly larger than the average size of spec homes in the 2011 Baseline Study.

Table 5-1: Home Sizes and HERS Indies

Conditioned Floor Area and HERS Index	2011 Program Homes (n=1,187)	Mini Baseline Homes (n=50)	2011 Baseline Homes (n=100)	2011 Baseline Detached Homes (n=93)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Average Area sq. ft.	2,523	2,611	2,367	2,410	1,792	2,106
Average HERS Index	**63****	**83****	**79****	**79**	**81**	**80**

**Differences between HERS indices statistically significant at the 90% confidence level.

5.1.1 Comparison to Specific IECC Prescriptive Requirements

Table 5-2 through Table 5-6 display a comparison of measure-specific compliance for the Mini Baseline Study and 2011 baseline homes. These tables do not include a comparison for slab insulation or window U-factors.[16] These measures are very difficult to verify in a post-occupancy audit and therefore have been excluded from the comparative analysis; slab insulation is nearly impossible to visually confirm after the foundation has been poured, and window U-factors are often only verifiable if the NFRC label is still on the window—most homeowners remove these labels after they move in leaving little documentation on window U-factors available to auditors.

The prescriptive requirement for exterior wood-framed walls increased from R-19 in 2006 IECC to R-20 in 2009 IECC. Table 5-2 shows the average conditioned/ambient wall insulation level increased from R-17.9 in Mini Baseline Study homes to R-19.4 in 2011 baseline homes; this difference is statistically significant at the 90% confidence level. Most (84%) of the 50 Mini Baseline Study homes built at the end of the 2006 IECC code cycle met the 2006 IECC R-19 wall insulation requirement. Just under a third of 2011 baseline homes (30%), completed at the beginning of the 2009 IECC cycle, met the 2009 IECC R-20 wall insulation requirement.

Table 5-2: Conditioned/Ambient Walls

Conditioned/Ambient Exterior Walls	Mini Baseline Homes (n=50)	2011 Baseline Homes (n=100)	2011 Baseline Detached Homes (n=93)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Average R-value	**17.9***	**19.4***	**19.5**	**17.6**	**18.5**
Comparison to 2006 IECC (R-19)					
R-19 or Higher	42 (84%)				
Comparison to 2009 IECC (R-20 or R-13 + 5)					
R-20 or R-13+5 or Higher	**3 (6%)***	**30 (30%)***	28 (30%)	2 (29%)	29%

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

[16] Under both 2006 and 2009 IECC there is no SHGC requirement in climate zone 5.

Duct insulation requirements also changed from 2006 IECC to 2009 IECC. 2006 IECC required ducts located in unconditioned space to have a minimum of R-8 insulation. In the 2009 IECC, duct insulation requirements were relaxed—only supply ducts located in attics must be insulated to R-8, while all other ducts located in unconditioned space must be insulated to R-6. Table 5-3 shows that the average duct insulation R-value in unconditioned spaces is R-6.0 for Mini Baseline Study homes and R-5.9 for 2011 baseline homes. Only 10% of Mini Baseline Study homes met 2006 IECC insulation requirements for ducts in unconditioned spaces, but 31% of these homes met 2009 IECC requirements, approximately the same as the 27% of 2011 baseline homes meeting 2009 IECC requirements.

Table 5-3: Duct Insulation in Unconditioned Spaces

Duct Insulation Level All Ducts in Unconditioned Spaces	Mini Baseline Homes (n=39)	2011 Baseline Homes (n=85)	2011 Baseline Detached Homes (n=78)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Average R-value	6.0	5.9	6.0	5.4	5.7
Comparison to 2006 IECC (R-8)					
R-8 or Higher	10% (4 of 39)				
Comparison to 2009 IECC (supply-attic R-8, all other R-6)					
Supply-Attic ≥ R-8, All Other ≥ R-6	31% (12 of 39)	27% (23 of 85)	28% (22 of 78)	14% (1 of 7)	22%

Table 5-4 summarizes prescriptive insulation requirements that did not change from 2006 IECC to 2009 IECC. As shown, 2011 baseline homes were more likely than Mini Baseline homes to meet prescriptive requirement insulation levels for flat ceilings, cathedral ceilings and floors over unconditioned basements; differences in the percentages of 2011 study and Mini Baseline Study homes meeting prescriptive requirement insulation levels in flat ceilings and floors over unconditioned basements are statistically significant at the 90% confidence level.

Table 5-4: Summary of Compliance with Insulation Requirements where 2006 and 2009 Requirements the Same

2006 and 2009 IECC Prescriptive Code Requirement	Percent of Mini Baseline Homes Meeting IECC 2006 & 2009 Prescriptive Requirements	Percent of 2011 Baseline Homes Meeting IECC 2006 & 2009 Prescriptive Requirements
Flat Ceiling Insulation R-38	**22% (11 of 50)***	**63% (61 of 97)***
Cathedral Ceiling Insulation R-38 (Allows up to 500 sq. ft. R-30)	67% (8 of 12)	83% (54 0f 65)
Floors over Unconditioned Basements R-30 or Fills Cavity—Min R-19	**28% (13 of 46)***	**69% (59 of 85)***
Foundation Wall Insulation R10/13 (Conditioned basement space bounded by foundation walls)	73% (13 of 18)	60% (12 of 20)

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

These large increases in the percentage of homes meeting prescriptive insulation requirements occurred within two years; see Figure 5-1 showing that 92% of Mini Baseline Study homes were completed in 2009 or 2010 and 31% of 2011 baseline homes were completed in 2010 and 69% in 2011. Whether these increases are simply naturally occurring or were influenced by the increased level of training available to builders in the last two years on 2009 IECC and stretch code requirements is not known. One exception is the percentage of homes meeting prescriptive requirements for insulation in foundation walls that bound conditioned space, which is lower in 2011 baseline homes (60%) than in Mini Baseline Study homes (73%), but this difference is not statistically significant at the 90% confidence level.

Figure 5-1: Year Homes Completed

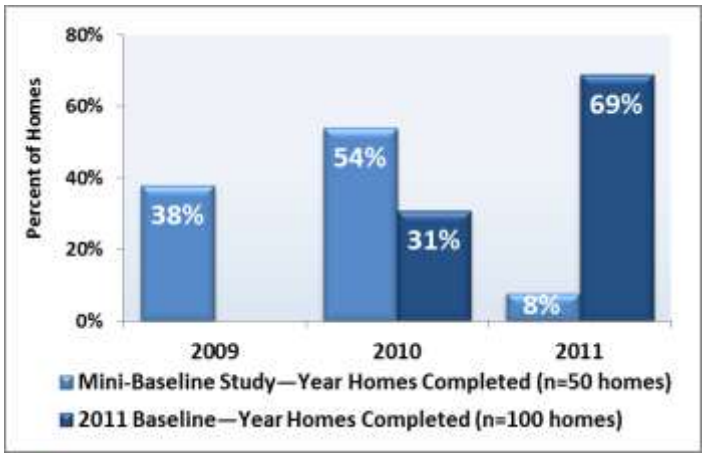


Table 5-5 provides more detailed information on ceiling insulation. As shown, the average R-values of both flat and cathedral ceiling insulation are higher in 2011 baseline homes than in Mini Baseline Study homes; these differences are statistically significant at the 90% confidence level.

Table 5-5: Ceilings and Floors

Flat (Attic) Ceilings	Mini Baseline Homes (n=50)	2011 Baseline Homes (n=97)	2011 Baseline Detached Homes (n=90)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Average R-value	32.0*	36.8*	36.9	35.7	36.3
Comparison to 2006 & 2009 IECC (R-38)					
R-38 or Higher	11 (22%)*	61 (63%)*	57 (63%)	4 (57%)	60%
Cathedral (Vaulted) Ceilings	**Mini Baseline Homes (n=12)**	**2011 Baseline Homes (n=65)**	**2011 Baseline Detached Homes (n=62)**	**2011 Baseline Attached Homes (n=3)**	**2011 Weighted Average (Detached/ Attached)**
Average R-value	28.8*	35.5*	35.5	35.3	35.4
Comparison to 2006 & 2009 IECC (R-38—Allows up to 500 sq. ft. R-30)					
R-38 or Higher or Not More Than 500 sq. ft. Lower Than R-38	8 (67%)	54 (83%)	51 (82%)*	3 (100%)*	89%

*Significantly different at 90% confidence level.

Table 5-6 provides more detailed information on floor and foundation wall insulation. As shown, the average R-value of floor insulation is higher in 2011 baseline homes than in Mini Baseline Study homes and the average R-value of foundation wall insulation is lower in 2011 baseline homes than Mini Baseline Study homes; these differences are statistically significant at the 90% confidence level.

Table 5-6: Floors and Foundation Walls

Floors over Unconditioned Basements	Mini Baseline Homes (n=46)	2011 Baseline Homes (n=85)	2011 Baseline Detached Homes (n=80)	2011 Baseline Attached Homes (n=5)	2011 Weighted Average (Detached/ Attached)
Average R-value	21.0*	26.7*	26.8	25.6	26.2
Comparison to 2006 & 2009 IECC (R-30 or Fills Cavity—Min R-19)					
R-30 or Higher or Fills Cavity—Min R-19	13 (28%)*	59 (69%)*	56 (71%)	3 (60%)	65%
Foundation Wall Insulation Level	**Mini Baseline Homes (n=18)**	**2011 Baseline Homes (n=20)**	**2011 Baseline Detached Homes (n=19)**	**2011 Baseline Attached Homes (n=1)**	**2011 Weighted Average (Detached/ Attached)**
Average R-value	15.6*	12.7*	12.3	21.0	16.6
Comparison to 2006 & 2009 IECC (R-10/13)					
R-10/13 or Higher	13 (73%)	12 (60%)	11 (58%)	1 (100%)	79%

*Significantly different at 90% confidence level

5.1.2 Glazing

In most Mini Baseline Study and 2011 baseline homes the U-value of the windows could not be verified because the NFRC stickers were no longer available.[17] The average U-values of windows in the 2 Mini Baseline Study homes and the 31 baseline homes where the U-values could be documented are both 0.31. Based on the portion of homes for which U-value data were available and discussions with staff personnel at two large lumber yards that sell windows to builders of new homes and with five major window companies exhibiting at Build Boston (Andersen, Harvey, JELD-WEN, Marvin and Pella) the estimated average U-value of windows in both Mini Baseline Study and 2011 baseline homes is 0.34. See Section 9.4 Windows for more detailed information.

Table 5-7 shows that the average percent of glazing (percent of conditioned/ambient wall area) and the average percent of south-oriented glazing is virtually the same in Mini Baseline Study and 2011 baseline homes.

Table 5-7: Percent Glazing and Southern Exposure

Percent Glazing Percent of Conditioned/Ambient Wall Area	Mini Baseline Homes (n=50)	2011 Baseline Homes (n=100)	2011 Baseline Detached Homes (n=93)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Average Percent Glazing	16%	16%	16%	15%	**15%**
Average Percent South Glazing	38%	39%	39%	46%	**42%**

[17] Documented U-value and SHGC information was available for only two homes in the Mini Baseline Study. The original NFRC sticker was visible at one home. Window performance information for one modular home was provided in the specifications provided on the modular home company's website. In both cases the windows are Low-E with argon. For two other homes, building specifications included the manufacturer of the windows and, in one case, the window series; one specified Andersen 400 series windows and one specified Pella windows. Information available on the manufacturer's web sites indicates the windows in both homes are Low-E with argon. Documented U-value and SHGC information was available for 18 of the 2011 baseline homes where the original NFRC sticker was visible. Auditors had access to the U-value and/or SHGC, or to information with which they could estimate the U-value and/or SHGC for an additional 13 homes. Of the 31 homes with U-value data, argon fill was confirmed in 24 homes.

5.1.3 Mechanicals—Heating, Cooling, and Water Heating Systems

Table 5-8 shows that heating system efficiencies tend to be slightly higher in 2011 baseline homes than in Mini Baseline Study homes, but none of the differences are statistically significant at the 90% confidence level.

Table 5-8: Heating System Efficiency

Average Heating System Efficiencies	Mini Baseline Heating Systems (n=62)	2011 Baseline Heating Systems (n=126)*	2011 Baseline Detached Home Heating Systems (n=117)	2011 Baseline Attached Home Heating Systems (n=9)	2011 Weighted Average (Detached/ Attached)
All Gas Furnaces (AFUE)	91.3(n=47)	92.0 (n=93)	92.1 (n=84)	91.0 (n=9)	91.5
Non-Attic Gas Furnaces (AFUE)	93.6 (n=35)	93.8 (n=72)	93.8 (n=65)	94.2 (n=7)	94.0
Attic Gas Furnaces (AFUE)	84.7 (n=12)	85.6 (n=21)	86.1 (n=19)	80.0 (n=2)	83.1
Oil Furnaces (AFUE)	81.0 (n=3)	82.7 (n=7)	82.7 (n=7)	n/a	82.7
Gas Boilers (AFUE)	91.1 (n=5)	89.8 (n=14)	89.8 (n=14)	n/a	89.8
Oil Boilers (AFUE)	85.7 (n=6)	85.9 (n=6)	85.9 (n=6)	n/a	85.9
Ground Source Heat Pump (HSPF & COP)	14.7 HSPF 4.3 COP (n=1)	14.4 HSPF 4.22 COP (n=6)	14.4 HSPF 4.22 COP (n=6)	n/a	14.4 HSPF 4.22 COP

*Does not include one 92 AFUE Pellet Boiler

Table 5-9 shows the average SEER of central air conditioning systems is 13.08 in Mini Baseline Study homes and 13.62 in 2011 baseline homes; this difference is statistically significant at the 90% confidence level. However, the majority of central air conditioning systems in both Mini Baseline Study homes and 2011 baseline homes are SEER 13.0, the federal minimum efficiency standard.

Table 5-9: Central Air Conditioning SEER

Central Air Conditioning SEER (CAC Units with SEER Data)	All CAC Units in Mini Baseline Homes (n=37)*	All CAC Units in 2011 Baseline Homes (n=119)	CAC Units in 2011 Baseline Detached Homes (n=100)	CAC Units in 2011 Baseline Attached Homes (n=9)	2011 Weighted Average (Detached/ Attached)
Average	**13.08***	**13.62***	**13.60**	**13.83**	**13.72**

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

Table 5-10 shows that water heaters, like heating systems, tend to be somewhat higher efficiency in 2011 baseline homes than in Mini Baseline Study homes, but the differences are not statistically significant at the 90% confidence level.

Table 5-10: Water Heaters

Average Water Heater Energy Factors	Mini Baseline Homes (n=46)	2011 Baseline Homes (n=100)	2011 Baseline Detached Homes (n=93)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
Instantaneous Natural Gas & Propane	0.82 (n=6)	0.83 (n=12)	0.82 (n=11)	0.95 (n=1)	0.88
Integrated With Tank Natural Gas, Propane & Oil	0.81 (n=8)	0.83 (n=17)	0.83 (n=17)	n/a	0.83
Conventional Storage Tank Electric	0.89 (n=11)	0.89 (n=20)	0.89 (n=19)	0.90 (n=1)	0.90
Conventional Storage Tank Natural Gas & Propane	0.62 (n=22)	0.63 (n=52)	0.63 (n=47)	0.65 (n=5)	0.64
Tankless Coil Oil	0.53 (n=2)	n/a (n=0)	n/a (n=0)	n/a	n/a

5.1.4 Duct Leakage and Air Infiltration

Table 5-11 and Table 5-12 on the next page show that both duct leakage and air infiltration are lower in 2011 baseline homes than in Mini Baseline Study homes and that these differences are statistically significant at the 90% confidence level. 2009 IECC requires duct leakage to the outside, tested post construction, to be 8 CFM25 per 100 square feet of conditioned floor area. As shown, 39% of 2011 baseline homes and 25% of Mini Baseline Study homes had duct leakage of 8 CFM25 per 100 square feet of conditioned floor area or lower; the difference in the percentages of homes is not statistically significant at the 90% confidence level.

Table 5-11: Duct Leakage

Duct Leakage	Mini Baseline Homes (n=40)	2011 Baseline Homes (n=69)	2011 Baseline Detached Homes (n=64)	2011 Baseline Attached Homes (n=5)	2011 Baseline Weighted4 (Detached/ Attached)
Average CFM25/100 sq. ft.	**17.2***	**12.4***	12.5	11.2	11.9
8 CFM25/100 sq. ft. or lower	10 (25%)	28 (39%)	25 (38%)	3 (60%)	49%

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

Table 5-12: Air Infiltration—ACH50

Air Infiltration ACH50	Mini Baseline Homes (n=40)*	2011 Baseline Homes (n=73)	2011 Baseline Detached Homes (n=67)	2011 Baseline Attached Homes (n=6)	2011 Baseline Weighted (Detached/ Attached)
Average ACH50	**5.79***	**4.78***	4.76	5.01	4.88

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

5.1.5 Lighting and Appliances

As shown in Table 5-13, the use of energy-efficient lighting is low in both Mini Baseline Study and 2011 baseline homes. 2011 baseline homes are significantly more likely to have 10% or less of their fixtures contain energy-efficient bulbs than Mini Baseline Study homes, though this is not an exact comparison since the Mini Baseline Study counted bulbs and the 2011 baseline counted fixtures with energy-efficient bulbs. Only 12% of 2011 baseline homes (19% when weighted by the number of attached and detached homes) are in compliance with the IECC 2009 requirement for 50% or more energy-efficient lighting for homes complying under a prescriptive approach compared to 16% of Mini Baseline Study homes, but this difference is not statistically significant.

Table 5-13: Lighting

Percent of Fixtures with Energy-Efficient Bulbs in the Home**	Mini Baseline Homes (n=49)	2011 Baseline Homes (n=99)	2011 Baseline Detached Homes (n=92)	2011 Baseline Attached Homes (n=7)	2011 Weighted Average (Detached/ Attached)
10% or less	**23 (46%)***	**60 (61%)***	55 (60%)	5 (71%)	65%
11% to 30%	9 (18%)	15 (15%)	15 (16%)	0 (0%)	8%
30% to 49%	9 (18%)	12 (12%)	12 (13%)	0 (0%)	7%
Compliance with 2009 IECC (50% or more energy efficient)					
50% to 74%* **	6 (12%)	8 (8%)	7 (8%)	1 (14%)	11%
75% to 100%* **	2 (4%)	4 (4%)	3 (3%)	1 (14%)	8%

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.
**Mini Baseline figures represent the percentage of energy-efficient bulbs in the home while 2011 baseline figures represent the percentages of fixtures with energy-efficient bulbs.
***The Mini Baseline figures represent 50% to 79% and 80% to 100%.

Table 5-14 and Table 5-15 show fairly high saturations for ENERGY STAR refrigerators and dishwashers. There are significantly more ENERGY STAR refrigerators in 2011 baseline homes (86%) than in Mini Baseline Study homes (73%). Dishwasher saturations are over four out of five homes in both baselines.

Table 5-14: ENERGY STAR Status for Refrigerators

Status	Mini - Baseline Homes (n=49)	2011 Baseline Homes (n=97)	2011 Baseline Detached Homes (n=91)	2011 Baseline Attached Homes (n=6)	2011 Weighted Average (Detached/ Attached)
ENERGY STAR	**36 (73%)***	**83 (86%)***	78 (86%)	5(83%)	85%
Not ENERGY STAR	**13 (27%)***	**14 (14%)***	13 (14%)	1 (17%)	15%

*2011 baseline is significantly different from Mini Baseline at 90% confidence level.

Table 5-15: ENERGY STAR Status for Dishwashers

Status	Mini Baseline Homes (n=45)	2011 Baseline Homes (n=96)	2011 Baseline Detached Homes (n=90)	2011 Baseline Attached Homes (n=6)	2011 Weighted Average (Detached/ Attached)
ENERGY STAR	40 (89%)	83 (86%)	78 (87%)	5(83%)	85%
Not ENERGY STAR	5 (11%)	13 (14%)	12 (13%)	1 (17%)	14%

6 Comparison to Previous Baseline Studies

This section compares 2011 Baseline Study findings to previous baseline study findings. Before discussing how construction practices have changed from one study to another it is important to discuss the homes inspected in these studies. Wherever possible, 2011 Baseline Study findings are compared to three previous studies. The earliest is a 1999 study of Massachusetts and Rhode Island homes.[18] The second is a 2001 study prepared for the Massachusetts Board of Building Regulations and Standards (BBRS).[19] The third is the 2005 Baseline Study[20] submitted to the JMC (Joint Management Committee). The following descriptions of the homes inspected in the previous studies clearly show the sample homes were selected differently in each study. However, even though the samples of homes may not be directly comparable, there are enough years between the studies so that the comparisons show clear and reasonable trends in building characteristics and mechanical equipment efficiencies.

1999 Baseline Study

- Seventy-five single-family homes constructed in 1996, 1997 and 1998
    - Fifty inspections conducted in 1998 on gas-heated homes in Boston Gas Company service territory
    - Twenty-five inspections conducted in 1999 in Massachusetts (16) and Rhode Island (9)—all types of heating systems

2001 BBRS Study

- Designed to reflect statewide building practices
- Random sample of 186 single- and two-family homes constructed in 1999 and 2000
- Homes selected geographically in proportion to 1999 building permits issued
- Two to seven homes in each of 30 towns
- Recruited homes through homeowners--percentage of custom homes likely higher than in the population of new homes in Massachusetts

[18] ENERGY STAR® Homes Program – Market Assessment and Baseline Study for Massachusetts and Rhode Island, Final Report, Prepared for The Joint Management Committee by the Delta Technologies Group, LLC, Marietta, Georgia. September 1999.

[19] Impact Analysis of The Massachusetts 1998 Residential Energy Code Revisions, Prepared for the Massachusetts Board of Building Regulations and Standards (BBRS) Boston, Massachusetts by XENERGY Inc., Portland, Oregon. May 14, 2001.

[20] Massachusetts ENERGY STAR® Homes: 2005 Baseline Study Part I: Inspection Data Analysis, Final Report, Prepared for The Joint Management Committee by Nexus Market Research and Dorothy Conant. May 2006.

2005 Baseline Study

- Inspected 144 non-ENERGY STAR single-family homes in 110 towns across the state
- Number of homes inspected in each area proportional to the number of single-family building permits issued in 2004
- All homes completed in 2004 or 2005
- Recruited homes through homeowners--percentage of custom homes likely higher than in the population of new homes in Massachusetts

The comparisons presented in this section are based on raw data to be consistent with the how previous study data were presented.

Table 6-1 shows that the average area of conditioned space in new homes increased each study year from 2,511 square feet in the 1999 study to 2,672 square feet in the 2005 study, but then dropped to 2,367 square feet in the 2011 study – the smallest average conditioned space area of all four studies. Table 6-1 also shows that unconditioned basements predominate across the various studies, although more homes in the 2005 and 2011 studies have full or partially conditioned basements than in the 2001 study.

Table 6-1: Conditioned Space and Basements

Conditioned Space and Basements	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Average Area of Conditioned Space				
Number of Homes	100	144	186	75
Average Area sq. ft.	**2,367**	**2,672**	**2,538**	**2,511**
Type of Basement				
Number of Homes	100	144	186	
Unconditioned Basement	78%	74%	86%	
Conditioned Basement	12%	13%	7%	
More Than one Type*	8%	9%	5%	
Slab on Grade	1%	2%	2%	
Crawl Space	1%	1%	0%	
No basement	0%	1%	n/a	

* Homes with partial conditioned basements.

Table 6-2 shows a consistent trend of increasing insulation levels in conditioned/ambient walls. The average R-value increased from R-14.1 in the 1999 study to R-19.4 in the 2011 study. This change is consistent with a much higher percentage of 2011 homes having 2 x 6 framed walls and changes in building codes over the years requiring higher wall insulation levels. Average flat ceiling insulation levels changed little from the 1999 study to the 2005 study and then climbed from R-31.5 in the 2005 study to R-36.8 in the 2011 study. Likewise, average cathedral ceiling insulation levels climbed from R-31 in the 2005 study to R-35.5 in the 2011 study.

Table 6-2: Walls, Ceilings and Floors

Walls, Ceilings and Floors	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Wall Insulation – Trends in Average R-Value				
Number of Homes	100	144	186	75
Average R-Value	19.4	16.3	14.1	14.1
Trends in Average R-Value by Framing Type				
2 x 4 Framing				
Number of Homes	7	58		52
Average R-value	14.5	12.7		11.9
2 x 6 Framing				
Number of Homes	93	82		23
Average R-value	19.7	19.1		19
Ceiling Insulation – Trends in R-Value*				
Flat Ceilings–Number of Homes	97	137	186	75
Average Flat Ceiling R-Value	36.8	31.5	31.5	30.5
Cathedral Ceilings–Number of Homes	65	65	24	n/a
Average Cathedral Ceiling R-Value	35.5	31	29.7	n/a
Floor Insulation over Unconditioned Basements – Trends in R-Value				
Number of Homes	85	117**	183***	61****
Average R-value	26.7	18.5	18.6	19.4

*Although unclear, it is likely that the results in the 1999 study include both flat and cathedral ceilings.

** Includes all homes without floor insulation over unconditioned basements to increase comparability to the BBRS study. However, homes with floors over conditioned basements are not included.

*** Data include floors over conditioned as well as unconditioned basements, likely understating the efficiency of floor insulation over unconditioned basement areas (because floors above conditioned areas do not need insulation and are often not insulated).

**** Data exclude homes lacking floor insulation but include floors over conditioned as well as unconditioned basements. Because homes with no insulation are excluded, the average likely overstates the efficiency of floor insulation over unconditioned basement areas.

Table 6-3 shows that, over the years, windows in homes have consistently become more efficient. The average U-value decreased from 0.41 in the 1999 study to 0.34 in the 2011 study. Table 6-3 also shows that there has not been any upward or downward trend in foundation wall insulation levels over time. The average R-value of foundation wall insulation in homes with foundation wall insulation increased from R-12.1 in the 1999 study to R-15.5 in the 2005 study, but then dropped to its lowest level in the 2011 study (R-11.7).

Table 6-3: Windows and Foundation Walls

Windows and Foundation Wall Insulation	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Window Efficiency – Trends in U-value				
Number of Homes	100	144	75	186
Average U-value	0.34*	0.36	0.39	0.41
Foundation Wall Insulation – Trends in R-Value**				
All Homes with Basements				
Number of Homes	99	138	174	72
Average R-Value	2.6	4.5	0.6	6.7
All Homes with Foundation Wall I Insulation				
Number of Homes	22	47	8	40
Average R-value	11.7	15.5	12.8	12.1

*This value is not a calculation but an estimate based on the portion of homes for which data were available, and discussions with staff personnel at two large lumber yards that sell windows to builders of new homes and with five major window companies exhibiting at Build Boston (Andersen, Harvey, JELD-WEN, Marvin and Pella).

**The 1999 and 2001 studies did not differentiate between foundation walls in conditioned and unconditioned basements and did not include homes with no foundation wall insulation in their calculations of average R-values; therefore, the only comparisons that can be made with the current and 2005 studies' findings are between the averages of foundation wall insulation in all homes with basements, with or without foundation wall insulation, and the averages of foundation wall insulation in all homes with foundation wall insulation, whether or not the walls bound conditioned space.

Table 6-4 shows that, over the years, the percentage of homes with oil heating systems has fallen from 46% in the 2001 study to 13% in the 2011 study. At the same time, the percentage of homes with propane heating systems has grown from 4% in the 2001 study to 21% in 2011 and the percentage of natural gas heating systems has grown from 50% to 62%. Three percent of the homes in the 2011 study have ground source heat pumps—no homes in the previous studies had ground source heat pumps. The overall average AFUE of fossil fuel heating systems has increased from 85.6 in the 2001 study to 90.9 in the 2011 study.

Table 6-4: Space Heating

Space Heating	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Space Heating Type and Fuel				
Number of Homes	100	144	186	
All Natural Gas Systems	**62%**	**47%**	50%	
Natural Gas Furnace	**53%**	**28%**	31%	
Natural Gas Hot Water Boiler	**6%**	**13%**	16%	
Natural Gas Hydro-Air Boiler	3%	6%	2%	
All Oil Systems	**13%**	**42%**	46%	
Oil Furnace	**7%**	**2%**	10%	
Oil Hydro –Air	**3%**	**13%**	4%	
Oil Hot Water Boiler	**2%**	**27%**	32%	
Oil Steam Boiler	1%	0%	0%	
All Propane Systems	**21%**	**10%**	4%	
Propane Furnace	**16%**	**3%**	3%	
Propane Hydro-air	4%	3%	0.50%	
Propane Hot Water Boiler	1%	4%	0.50%	
Pellet Hot-Water Boiler	**1%**	**0%**	**0%**	
Electric Resistance	**0%**	**1%**	**0%**	
Electric GSHP	**3%**	**0%**	**0%**	
Overall AFUE (Fossil Fuel Systems)*	**90.9**	**86.0**	**85.6**	

*The 100 homes in the 2011 study have 121 fossil fuel heating systems; the overall AFUE of fossil fuel systems is based on the 121 systems.

Table 6-5 shows that, consistent with heating systems, the percentage of homes with oil water heating systems decreased from 37% in the 2001 study to 6% in the 2011 study while the percentages of natural gas and propane water heating systems increased; natural gas systems increased from 52% to 58% of homes and propane systems from 4% to 16% of homes. Also, the percentage of electric water heaters grew sharply from 7% of homes in the 2001 study to 20% in the 2011 study. With respect to the types of water heaters, the biggest changes over time are that homes inspected in 2011 are much more likely to have an electric water heater or a natural gas or propane instantaneous water heater, and less likely to have an indirect water heater integrated with a boiler.

Table 6-5 also shows that the water heater types with the biggest Energy Factor increases are natural gas and propane conventional storage water heaters. The overall average Energy Factor has climbed from 0.59 in the 2001 study to 0.75 in the 2011 study; a large part of this increase reflects the increase in the penetration of electric water heaters, which have very high Energy Factors, from 7% to 20%, and the increase in the penetration of natural gas and propane instantaneous water heaters, which also have high Energy Factors, from 1% to 12%.

Table 6-5: Water Heating

Water Heating	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Trends in Water Heating Fuel, Systems and Efficiency				
Water Heating Type and Fuel				
Number of Homes	100*	144	186	
All Natural Gas Systems	**58%**	**47%**	**52%**	
Nat. Gas – Conventional Storage	44%	33%	42%	
Natural Gas – Integrated	6%	14%	8%	
Natural Gas – Instantaneous	8%	0%	0%	
Natural Gas – Tankless Coil	0%	0%	2%	
All Oil Systems	**6%**	**41%**	**37%**	
Oil – Conventional Storage	0%	1%	5%	
Oil – Integrated	6%	32%	13%	
Oil – Tankless Coil	0%	8%	19%	
All Propane Systems	**16%**	**10%**	**4%**	
Propane – Conventional Storage	7%	3%	3%	
Propane – Integrated	5%	6%	1%	
Propane – Instantaneous	4%	1%	0%	
Electric	**20%**	**1%**	**7%**	
Water Heating Average Energy Factors				
Number of Homes	102*	144	186	
All Natural Gas Systems	**0.69**	**0.64**	**0.59**	
Nat. Gas – Conventional Storage	0.63	0.58	0.56	
Natural Gas – Integrated	0.84	0.78	0.77	
Natural Gas – Instantaneous	0.84	n/a	n/a	
Natural – Gas Tankless	n/a	n/a	0.48	
All Oil Systems	**0.79**	**0.71**	**0.59**	
Oil – Conventional Storage	n/a	0.61	0.59	
Oil – Integrated	0.79	0.78	0.76	
Oil – Tankless	n/a	0.44	0.48	
All Propane Systems	**0.75**	**0.74**	**0.61**	
Propane – Conventional Storage	0.64	0.63	0.54	
Propane – Integrated	0.85	0.79	0.8	
Propane – Instantaneous	0.83	0.79	n/a	
Electric	**0.89**	**0.89**	**0.86**	
Average Energy Factors (All Systems)	**0.75**	**0.68**	**0.59**	

*Two homes have two water heaters each. The average Energy Factors for the 2011 Baseline Study are based on the 102 water heating systems observed.

Table 6-6 shows that the percentage of homes with central air conditioning increased from study to study; from 56% in the 1999 study to 89% in the 2011 study. The average SEER increased to over 13 SEER in the 2011 study. This reflects an increase in the minimum federal efficiency standard to SEER 13 in early 2006. Average SEER values in all baseline studies are close to the minimum federal efficiency standard in place at the time of the study.

Table 6-6: Cooling Systems

Cooling Systems	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Type of Air Conditioning Installed				
Number of Homes	100	144	186	75
Central Air Conditioning	89%	63%	58%	56%
Window/Portable	1%	21%	n/a*	n/a
No Air Conditioning	10%	17%	n/a	n/a
Trends in Central Air Conditioning Efficiency and Size				
Number of Homes	87**	90	42	108
Average SEER	13.6	10.6	10.2	10.2
Average Tons/Home	4.0	5.2	n/a	4.5
Conditioned Space per Ton of Cooling				
Study	2011 Study	2005 Study	2003 HERS Study[21]	2001 BBRS Study
Number of Homes	87**	90	35	108
Square Feet Of Conditioned Space Per Ton Of Cooling	638	618	816	604

*The BBRS study collected information on the number of room air conditioners in the homes that were surveyed. However, this information was averaged over all 174 homes for which inspectors noted the number of units, ranging from zero through two. Therefore, we are unable to determine the number of homes that actually had window units installed. The average for all 174 homes was 0.2 units.

**89 homes will have central air conditioning, but in two homes the systems were not yet installed--efficiency and capacity information for the units to be installed were not available.

[21] A 2004 HERS rating study of non-ENERGY STAR-certified homes built in 2003. HERS Rating Analysis of Non-ENERGY STAR Homes in Massachusetts GDS Associates, Inc., May 2004.

Table 6-7 shows a declining trend in homes having ducts used only for air conditioning, from a high of 50% of air conditioned homes with hot water boiler heating systems in 2001 to only 2% in 2011. Additionally, the percentage of homes with no ducts located in unconditioned space being insulated has steadily declined from 4% in the 2001 study to 0% in the current study. Average R-values for duct insulation in all unconditioned locations decreased between the 2001 and 2005 studies, but rebounded to reach their highest level in the 2011 study among all study years with duct insulation R-value data. Ducts located in attics have consistently been the most highly insulated across all study years, and duct wrap continues to be the insulation of choice among builders.

Table 6-7: Duct Insulation

Duct Insulation	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Duct Insulation				
Number of Homes	100	144	186	75
Percent of Air Cond. Homes with Boiler Heating System	2%	16%	50%	24%
Number of Homes with Duct Systems in Uncond. Space	**85**	**84**	**123**	**47**
Percent of Homes Where All Ducts Insulated	74%	67%	76%	83%*
Percent of Homes Where Some Ducts Insulated	26%	31%	20%	
Percent of Homes Where No Ducts Insulated	0%	2%	4%	n/a
Overall Average R-Value of Duct Insulation	R-5.9	R-4.0	R-4.5	n/a
Average R-Value of Attic Duct Insulation	R-6.4	R-4.6	R-4.7	n/a
Average R-Value of Basement Duct Insulation	R-5.6	R-3.5	R-4.4	n/a
Most Common Type of Duct Insulation	Duct Wrap	Duct Wrap	Duct Wrap	Duct Wrap

*The 1999 study simply reported that 39 of the 47 homes with duct work had insulated ducts in unconditioned space and that all but one of these homes used fiberglass duct wrap. There is nothing reported on the other eight homes, so it is impossible to know if the ducts in these eight homes were in conditioned or unconditioned space or if any of the ducts were insulated.

Table 6-8 shows that average duct leakage and air infiltration in 2011 are much lower than in the 2005 Baseline Study.

Table 6-8: Duct Leakage and Air Infiltration

Duct Leakage and Air Infiltration	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Average Duct Leakage to the Outside (CFM25)				
Number of Homes with Ducts in Unconditioned Space	69	89	22	
CFM25 per 100 Square Feet of Conditioned Space	12.4	21.7	n/a	
Natural Infiltration Rate – Trend Over Time				
Number of Homes	100	144	184	
ACHnat	0.27	0.43	0.5	

Table 6-9 shows that, over the past ten years, there has been a dramatic increase in the proportion of energy-efficient lighting in homes from practically no energy-efficient bulbs in 2001 to less than one in twenty bulbs in 2005 to more than one in five in 2011. The average number of energy-efficient bulbs per home rose from close to zero in 2001 to close to two in 2005 to over nine fixtures with energy-efficient bulbs in 2011. Thus, as expected, most of the increase in the saturation of energy-efficient lighting took place between 2005 and 2011 likely due to better technologies, lower prices, and code requirements.

Table 6-9: Lighting

Overall Lighting	2011 Baseline	2005 Baseline	2001 BBRS	1999 Baseline
Number of Homes	99	144	186	
Number of Bulbs*	4,506	5,973	7,394	
Percent Qualifying	20.2%	4.6%	0.1%	
Percent Not Qualifying	79.8%	95.4%	99.9%	
Average Qualifying per home	9.2	1.9	<0.1	
Average Non-qualifying per home	36.3	40	40	

*The 2011 Baseline counted fixtures with energy-efficient bulbs rather than bulbs.

7 Code Compliance

IECC 2009 code compliance for inspected homes was assessed using four different compliance paths. The four compliance paths are the Prescriptive, Home Energy Rating, Annual Energy Cost, and Overall Building UA compliance paths. The Home Energy Rating, Annual Energy Cost, and Overall Building UA compliance paths were all assessed using reports and calculations available through the REM/Rate software. This approach allowed the evaluation team to leverage the REM/Rate files that were compiled for other pieces of this report and utilize those files for this analysis. It should be noted that the purpose of this study is not to assess code compliance for each inspected home, nor is it to evaluate code enforcement. Details on the compliance path utilized by each of the audited homes would be necessary to conduct such an evaluation, and this information was not available. Therefore, the results presented here are not indicative of actual code compliance but serve as a tool for assessing specific prescriptive measure compliance and how homes would likely perform under different performance based compliance paths.

7.1 Compliance Paths

7.1.1 Prescriptive Compliance Path

The Prescriptive path refers to a compliance path under which various aspects of a home are inspected individually to determine compliance with prescriptive requirements. Under the prescriptive path, items are typically assessed in one of two ways:

1) The item does not meet, meets, or exceeds a minimum value provided for it (e.g., wall insulation R-value)
2) The item either is, or is not, compliant on a yes/no basis (e.g., floor insulation installation quality)

In this report, compliance under the prescriptive path is assessed by looking only at the 2009 IECC prescriptive insulation requirements. Compliance is assessed looking at the percent of homes that meet each prescriptive insulation requirement and the percent of applicable prescriptive insulation requirements met in each home. Three prescriptive requirements—slab insulation, window U-factors, and skylight U-factors—were not addressed in this analysis. Auditors were unable to verify the insulation and/or fenestration values for these measures and therefore they were excluded from the prescriptive compliance analysis.

7.1.2 Home Energy Rating Compliance Path (Performance)

HERS ratings are performed using REM/Rate, where REM/Rate compares the "design" or "as-built" home to the "reference" home. The current reference home is based on the 2004 IECC.[22] To calculate a HERS index, REM/Rate models the reference home to be configured similar to

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

the as-built home (e.g., size, shape, orientation), but with the reference home efficiency measures based on the 2004 IECC prescriptive requirements. A home built to 2004 IECC prescriptive code requirements should score a HERS index of roughly 100; a home that is more energy efficient will have a HERS index less than 100. Several states allow for compliance under the Home Energy Rating Path, with varying HERS scores being considered compliant. For example, in Massachusetts, while 2006 IECC was still in effect, homes were considered compliant with the energy code if they achieved a HERS rating of 100 or less. For homes built to 2009 IECC, Massachusetts requires a HERS index of 75 or lower for 1-4 unit residential buildings and 70 or lower for residential buildings with five or more units.[23]

7.1.3 Annual Energy Cost Compliance Path (Performance)

The Annual Energy Cost compliance path is based on REM/Rate models and compares the as-built home to the 2009 IECC reference home. That is, the as-built home is compared to an identical home built to the 2009 IECC prescriptive requirements. The Annual Energy Cost compliance path only compares the as-built and reference homes for heating, cooling, and domestic water heating costs. This compliance path does not consider other factors that are typically modeled in REM/Rate. Examples of measures not addressed are lighting, appliances, and photovoltaics.

7.1.4 Overall Building UA Compliance Path (Trade-off)

The Overall Building UA trade-off path is an approach that compares the overall UA-value of the as-built home to the overall UA-value of an identical home built to meet the 2009 IECC prescriptive requirements. The overall UA-value of a home is calculated by summing the UA-values for the primary shell measures of the home (e.g., ceilings, above-grade walls, frame floors, etc.). This analysis was conducted using REM/Rate. Although the basic calculations are similar to the REScheck software developed by the Department of Energy and the Building Energy Codes Program (BECP)[24] there are several key differences between the REM/Rate Overall Building UA approach and REScheck. These differences include, but are not limited to, different approaches used to calculate insulation U-factors and different framing inputs for the respective software. Ultimately, these differences make it much more difficult to achieve compliance using the REM/Rate UA approach as opposed to using REScheck.

7.2 Compliance Results

Table 7-1 displays the minimum, maximum, average, and median compliance results under the prescriptive and REM/Rate compliance paths for the 100 inspected homes. The first half of the table displays code compliance results from checks of up to nine prescriptive requirements. On average, inspected homes meet or exceed 55% of the 2009 IECC prescriptive requirements applicable to the home. The Annual Energy Cost and the Overall Building UA trade-off

[23] http://www.mass.gov/eopss/docs/dps/inf/780-8th-51.pdf
[24] http://www.energycodes.gov/REScheck/download.stm

compliance path results are presented as a percentage above or below code. A positive percentage represents homes meeting or exceeding code, while a negative percentage represents homes below code. This does not represent the percent of homes that pass or fail, but the degree to which the average of the sample falls short of or exceeds the code. Weighted results indicate compliance is 10% below code using the Annual Energy Cost compliance path, and 19% below code using the Overall Building UA trade-off approach. In other words, on average, annual energy costs are 10% higher than the 2009 IECC reference home and overall UA values are 19% higher than the 2009 IECC reference home.[25] Weighted results show 19% compliance under the Annual Energy Cost compliance path and only 2% compliance under the Overall Building UA trade-off path. Finally, the weighted compliance rate is 37% under the HERS rating path.

Table 7-1: Prescriptive and REM/Rate Compliance Results

Statistic	Prescriptive			REM/Rate Compliance		
	Applicable Criteria	Criteria Met/Exceeded	Percent of Criteria Met	HERS Index*	Energy Cost Compliance	UA Compliance
Minimum	3.0	0.0	0%	50	-50%	-55%
Maximum	8.0	7.0	100%	116	25%	7%
Un-Weighted Average	5.3	3.0	55%	79	-10%	-16%
Weighted Average	5.3	3.0	55%	80	-10%	-19%
Median	5.5	3.0	57%	79	-8%	-17%
Percent of Homes Compliant				32%	22%	3%
Weighted Compliance Percent				37%	19%	2%

*The lower the HERS index the more energy efficient.

7.2.1 Prescriptive Compliance Detailed Results

Nine insulation requirements were considered for the prescriptive compliance analysis. Table 7-2 shows the percentage of inspected homes that comply with applicable 2009 IECC prescriptive insulation requirements. Weighted results show 29% compliance with 2009 IECC wood frame wall R-value requirements, 22% compliance with the 2009 IECC requirement of R-8 for attic supply ducts and R-6 for all other ducts, and 68% compliance with the 2009 IECC floor R-value requirements. While the percent of homes compliant with an individual requirement ranges from 22% to 91%, only 10% of homes comply with all applicable prescriptive requirements.

[25] Lower UA values typically result in higher compliance under the UA trade-off approach.

Table 7-2: Compliance with IECC Prescriptive Insulation Requirements

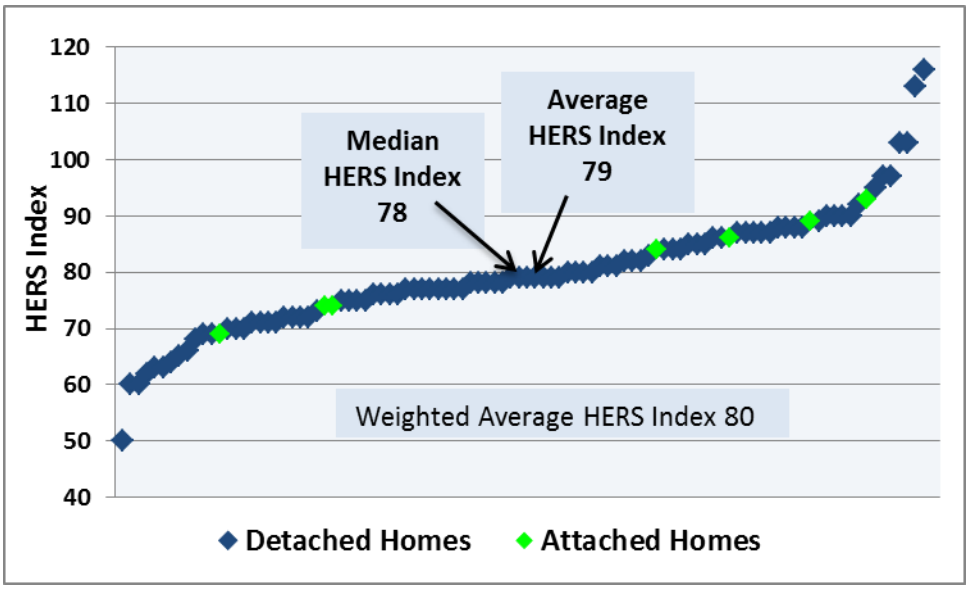
Measure or Characteristic	IECC 2009 Prescriptive Requirements	n	All Homes	Detached Homes	Attached Homes	Weighted Data
Wood Framed Wall Insulation	R-20	100	30 (30%)	28 (30%)	2 (29%)	29%
Foundation Wall	R-10/R-13 (cont./cavity)	20	12 (60%)	11 (58%)	1 (100%)	79%
Duct Insulation	R-8 attic supply ducts. R-6 all other ducts	83	23 (28%)	22 (29%)	1 (14%)	22%
Flat Ceiling Insulation	R-38	97	61 (63%)	57 (63%)	4 (57%)	60%
Cathedral Ceiling Insulation	R-38 (R-30 for ceilings less than 500 sq. ft.	65	54 (83%)	**51 (82%)***	**3 (100%)***	91%
All Ceiling Insulation Requirements		**100**	**60 (60%)**	**56 (60%)**	**4 (57%)**	**59%**
Floors Over Unconditioned Space Insulation R-Value (basement)	R-30 or cavity filled	85	60 (71%)	57 (71%)	3 (60%)	66%
Floors Over Unconditioned Space Insulation R-Value (garage)	R-30 or cavity filled	51	36 (71%)	33 (70%)	3 (75%)	73%
Floors over unconditioned space (outside)	R-30 or cavity filled	28	20 (71%)	19 (76%)	1 (33%)	55%
Floors over unconditioned space (crawlspace)	R-30 or cavity filled	2	1 (50%)	1 (50%)	n/a	50%
All Floors Over Unconditioned Space Prescriptive Requirement	**R-30**	**90**	**63 (70%)**	**59 (70%)**	**4 (67%)**	**68%**
Met All Applicable IECC 2009 Requirements		**100**	**7 (7%)**	**6 (6%)**	**1 (14%)**	**10%**

*Significantly different at the 90% confidence level.

7.2.2 HERS Compliance Detailed Results

Three out of seven attached homes and 29 of 93 detached homes achieved a HERS index of 75 or lower, producing a weighted HERS compliance rate of 37%. The weighted average HERS index is 80, suggesting that many homes are likely to have HERS ratings slightly above the Massachusetts compliance threshold of 75. Figure 7-1 shows the distribution of HERS scores, broken out by detached and attached homes.

Figure 7-1: Distribution of HERS Scores



7.2.3 Annual Energy Cost Compliance Path (Performance) Detailed Results

As shown in Table 7-3, 19% of the inspected homes were compliant under the Annual Energy Cost Compliance approach with overall annual energy costs lower than the 2009 IECC reference home.

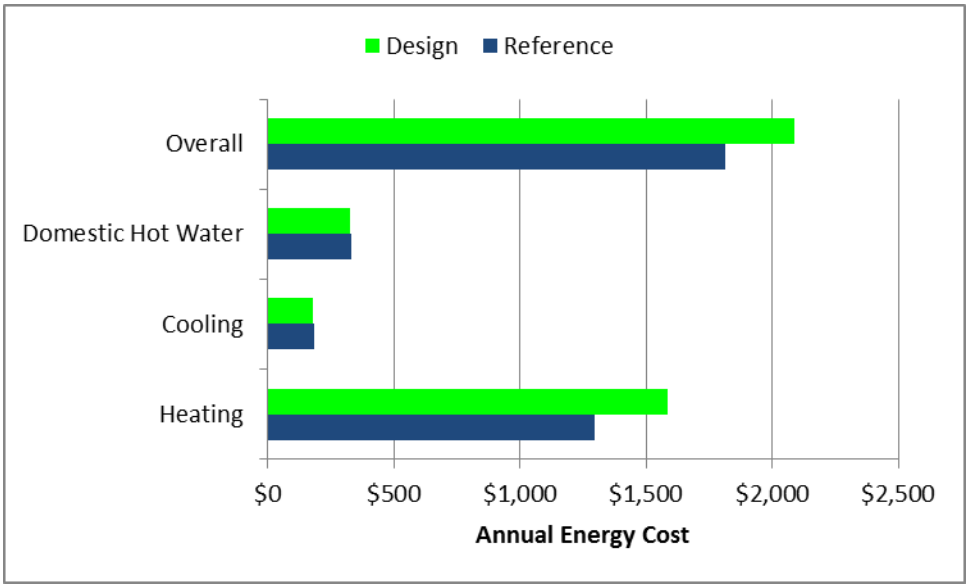
Table 7-3: Energy Cost Compliance Path Results

End Use	All Homes (n = 100)	Detached Homes (n = 93)	Attached Homes (n = 7)	Weighted (Detached/Attached)
Heating	20 (20%)	19 (20%)	1 (14%)	17%
Cooling	66 (66%)	62 (67%)	4 (57%)	62%
Domestic Hot Water	98 (98%)	91 (98%)	7 (100%)	99%
Overall	**22 (22%)**	**21 (23%)**	**1 (14%)**	**19%**

Overall compliance is driven down by the low compliance for the heating end use. For the cooling and water heating end uses, the weighed results show 62% and 99% compliance

respectively. On average, these two end-uses combine to account for only 26% of the total annual energy costs considered for the energy cost compliance approach. Heating accounts for the remaining 74% of total annual energy costs considered, and weighted results show only 17% compliance with this end use. On average, weighted results show 19% compliance using the Annual Energy Cost compliance path. Figure 7-2 shows the weighted average annual energy costs, by end use, for the 2009 IECC reference home and inspected homes.

Figure 7-2: End Use Energy Cost Comparison



7.2.4 Overall Building UA Compliance Path (Trade-Off) Detailed Results

Table 7-4 shows the percent of homes where the calculated UA value complies with the 2009 IECC requirement by component. Note, these results in no way reflect what compliance might be, via the UA trade-off approach, assessed using REScheck software as opposed to REM/Rate. Three measures—skylights, windows and doors, and slab floors—are excluded from the table as values for these measures were rarely verified onsite and default values were typically used in the REM/Rate models; while these values are excluded from the table they are still part of the overall UA value and therefore feed into the overall UA-tradeoff compliance. Weighted results show two-percent compliance with 2009 IECC via the UA trade-off path. Key shell measures such as above grade walls (2%), frame floors over unconditioned basements (0%), and frame floors over garages (0%) show little to no compliance. This is not to say that these components never meet prescriptive requirements. UA compliance, when calculated in REM/Rate, accounts for compression and gaps in insulation, effectively lowering any given assembly R-value (or raising the U-value). These adjustments lead to component specific non-compliance under the UA trade-off path. For example, weighted results show that frame floors over unconditioned basements comply with the prescriptive requirement two-thirds (66%) of the time (Table 7-2), but 0% comply under the UA trade-off approach. Most of these floors had R-30 insulation (the

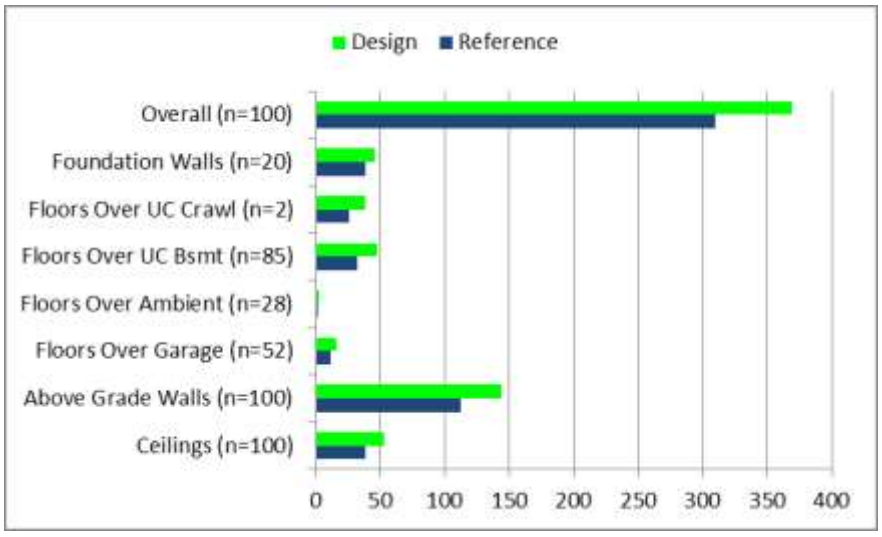
prescriptive requirement), but they were often assigned a Grade II or Grade III installation and therefore the UA value for the assembly falls below that of the 2009 IECC reference home. Ceilings (18%) and foundation walls (55%) show some of the highest compliance rates among the measures for which auditors were able to record reliable data.

Table 7-4: UA Compliance by Surface

Component	n	All Homes	Detached	Attached	Weighted (Detached/ Attached)
Ceilings	100	21 (21%)	20 (22%)	1 (14%)	18%
Above Grade Walls	100	3 (3%)	3 (3%)	0 (0%)	2%
Floors Over Garage	51	0 (0%)	0 (0%)	0 (0%)	0%
Floors Over Ambient	28	3 (11%)	3 (12%)	0 (0%)	6%
Floors Over UC Basement	85	0 (0%)	0 (0%)	0 (0%)	0%
Floors Over UC Crawlspace	2	1 (50%)	1 (50%)	n/a	50%
Foundation Walls	20	3 (15%)	2 (11%)	1 (100%)	55%
Overall	**100**	**3 (3%)**	**3 (3%)**	**0 (0%)**	**2%**

Figure 7-3 compares average UA values from the sample (design) to the 2009 IECC reference home's UAs by component and overall.[26] It should be noted that under the UA compliance path, and in Figure 7-3, a home is considered to be in compliance if its UA value is less than that of the reference home.

Figure 7-3: UA Comparison



[26] As is the case with Table 7-4, this figure excludes skylights, windows and doors, and slab floors although these values still feed into the overall UA value.

7.2.5 Variability in Compliance Based on Approach

This section refers to unweighted data in order to reflect the actual compliance percentages under the various compliance paths.

Compliance of the inspected homes was lowest when determined using the REM/Rate Overall Building UA trade-off approach. On average, the inspected homes are estimated to be 16% below code using this approach and only 3% of the inspected homes are compliant with 2009 IECC.

When assessed using the performance compliance methods (i.e., the Home Energy Rating path and the Annual Energy Cost compliance path), compliance rates were determined to be better. Using the Annual Energy Cost compliance path, 22% of the homes were determined to comply with the code, although the average compliance was found to be 10% below code. The Home Energy Rating path gave even higher compliance rates—32% of the homes comply using this method. There are a number of reasons for the jumps in compliance using the performance paths versus the prescriptive and UA trade-off paths. The performance paths allow homes to be assessed as a system. This allows for whole building tradeoffs with respect to efficiency and energy usage. Also, key inputs such as low air and duct leakage are considered in a performance approach and including such factors typically results in higher compliance rates.

Again, it is important to remember that it is not the purpose of this study to report how many of the inspected homes complied with code. Without knowing what compliance path a home was permitted under it is impossible to accurately assess whether or not the home complies with code. In addition, the REM/Rate software compliance assessments are not necessarily consistent with the tools code officials and builders use to assess compliance. For example, there are significant differences between the REM/Rate Overall UA approach and the commonly accepted and used REScheck software, and compliance under the REM/Rate UA approach will always be lower than when using REScheck.

8 Homeowner On-Site Survey

The owners of the 100 inspected homes were asked to complete a brief survey during the on-site audits. A total of 96 surveys were completed by homeowners. The survey addressed:

- How home was purchased
- Comfort of home
- Complaints about home
- If energy efficiency was discussed between the homeowner and the real estate agent or builder
- Importance of buying an energy-efficient home
- Who specified various building components, HVAC equipment, and appliances (homeowner or builder)
- Homeowner perception of the energy efficiency of their home and various components
- Awareness of the ENERGY STAR label on homes
- Homeowner demographics including:
    - First time home buyer or previously owned home
    - How long expect to stay in home
    - Education
    - Age
    - Income

Combining information collected during the inspections with information provided by homeowners provides insight on how aware homeowners are of the building materials and mechanical equipment in their homes, and whether or not homeowners who think they have energy-efficient homes and mechanical equipment really do. The results presented in this section are unweighted. As a result, the results are biased towards buyers of larger, detached homes and likely reflect the opinions of wealthier and older buyers.

8.1 How Homes Were Purchased

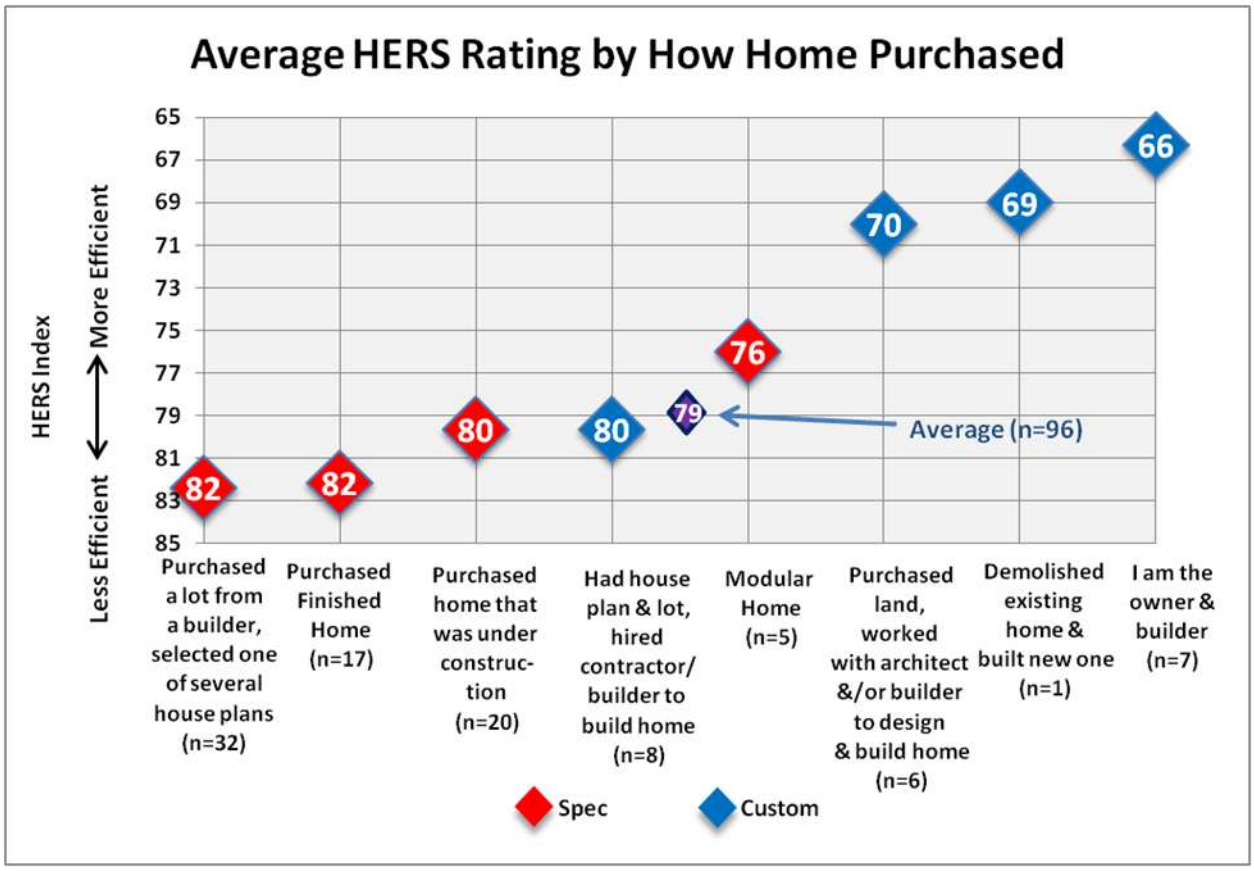
Table 8-1 displays the various ways the homes were purchased and divides them into two major categories: custom homes and spec homes. Custom homes include all cases in which the homeowner had a building lot and initiated the home-building process. Spec homes include all homes where the builder owned the land and either offered potential buyers a choice of several home plans or started construction without a buyer involved. Just over three-quarters (77%) of the homes are spec homes, and just under one-quarter (23%) are custom homes. The most commonly cited method of purchasing a new home is to purchase a lot from a builder and select one of several house plans offered by the builder (32%), followed by purchasing a home that was under construction (20%), and purchasing a finished home (17%). The owner was the builder for seven (7%) of the 100 homes.

Table 8-1: How Home Was Purchased

How Home Was Purchased	Number of Homes	Percent of Homes
Spec Homes		
Purchased a lot from a builder, selected one of several house plans offered by builder	32	32%
Purchased a home that was under construction	20	20%
Purchased a finished home	17	17%
Modular Home	5	5%
No Response	3	3%
Subtotal Spec Homes:	77	77%
Custom Homes		
Had a house plan and a lot and hired a contractor/builder to build the home	8	8%
I am the owner and builder	7	7%
Purchased land and worked with an architect and/or builder to design and build the home	6	6%
Demolished existing home and built a new one	1	1%
No Response	1	1%
Subtotal Custom Homes:	23	23%

Figure 8-1 displays the average HERS rating for homeowners by the various ways the homes were purchased. The average HERS rating across all 96 homes of owners who completed the survey is 79. On average, homeowners who were also the builder or general contractor for their home have the most energy-efficient homes (average HERS rating of 66), while homeowners who purchased a finished home or purchased a lot from a builder and selected one of several house plans offered by the builder have the least energy-efficient homes (average HERS rating of 82).

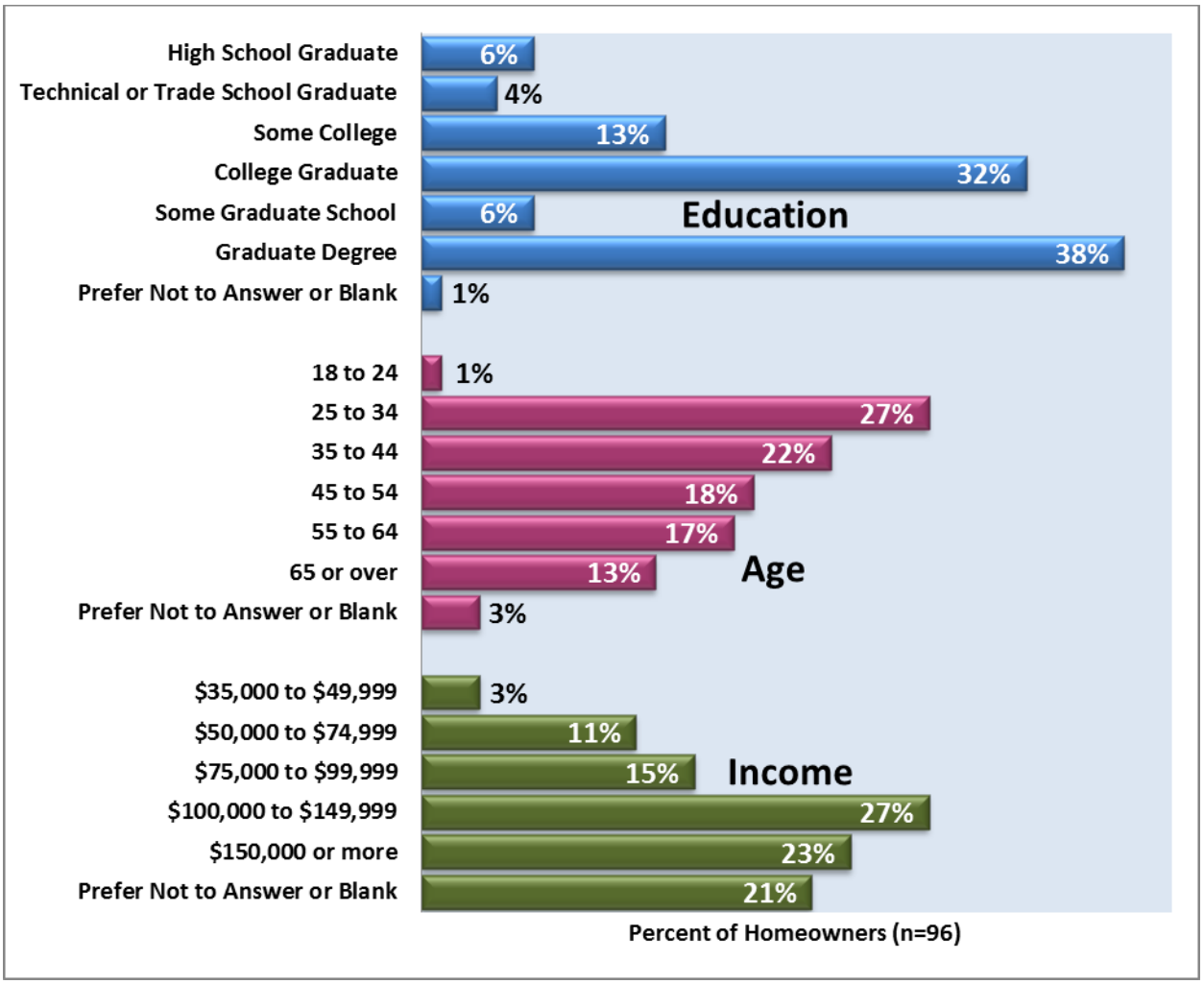
Figure 8-1: Average HERS Rating by How Home Purchased



8.2 Homeowner Demographics

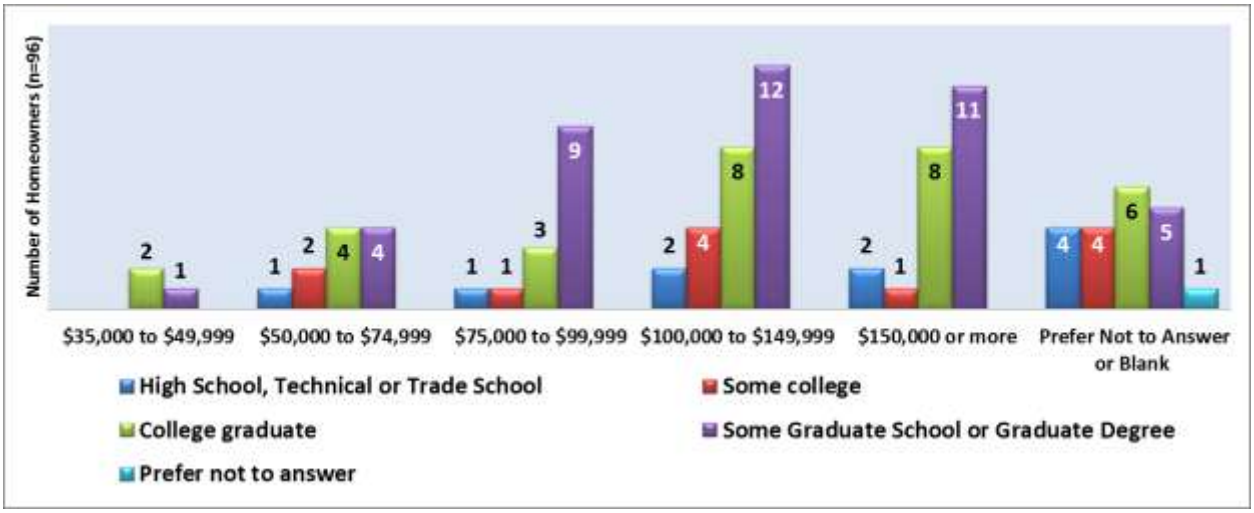
The homeowners are a diverse group with representation across an array of education, age, and income levels. Figure 8-2 shows the percentage of the 96 homeowners who completed the survey that fall into each education, age, and income level category. The homeowners tend to be well-educated, young, and have higher incomes than the average household. The majority of homeowners (76%) are college graduates, with nearly two out of five homeowners (38%) having completed a graduate degree. Over one-quarter of the homeowners (28%) are under the age of 35, and nearly one-half (49%) are between the ages of 25 and 44. Over one-fifth (21%) of the homeowners did not provide income information. However, well over one-half (63%) of the homeowners who did provide income information have an annual income of $100,000 or more.

Figure 8-2: Homeowner Education, Age, and Income



Over two out of five homeowners (42%) are college graduates aged 25 to 44. As shown in Figure 8-3, nearly every income level includes homeowners from each educational attainment level. The exception is the lowest income level ($35,000 to $49,999): this income level contains only college graduates and lacks representation from high school, technical, or trade school graduates. One of the two high school graduates with annual incomes over $150,000 is a builder/owner.

Figure 8-3: Homeowner Education by Income



Almost one-third (29%) of the homeowners are aged 25-44 with annual incomes greater than $100,000. As shown in Figure 8-4, over one-third (35%) of homeowners with annual incomes of $100,000 to $149,999 are aged 25-34. Additionally, nine out of 22 homeowners (41%) with annual incomes of $150,000 or more are aged 35-44.

Figure 8-4: Homeowner Age by Income

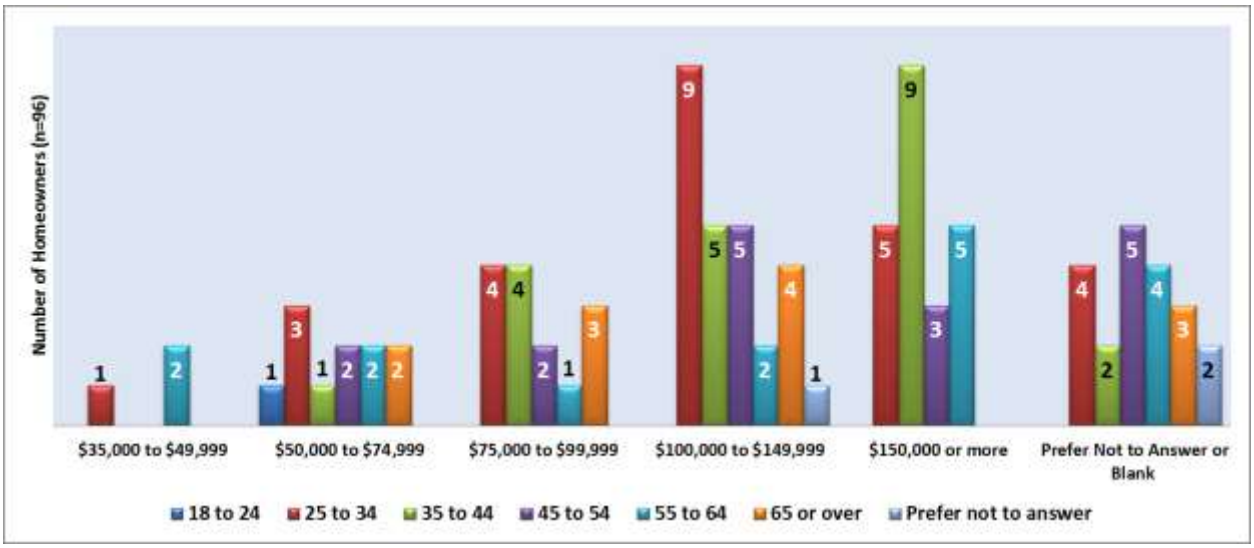
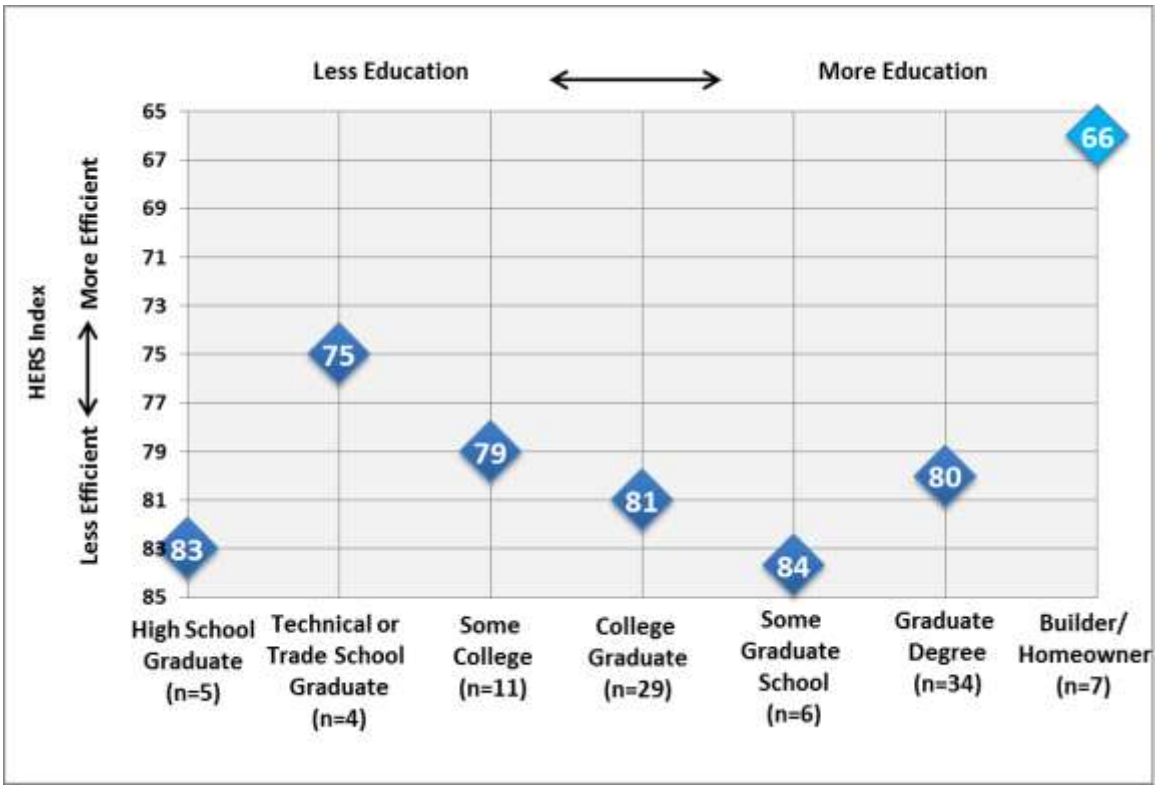


Figure 8-5 displays the average HERS rating for homeowners of each educational attainment level. The seven homeowners who were also the builder or general contractor for their homes have educational attainment levels ranging from high school graduate to graduate degree. However, they have been grouped together due to their specialized knowledge about new home construction, and because the average HERS rating for this group (HERS 66) is more efficient than the average HERS rating for the rest of the homeowners (HERS 80).[27] After the seven builder/owners, homeowners with a technical or trade school degree own the most efficient homes, while homeowners with some graduate school own the least efficient homes.

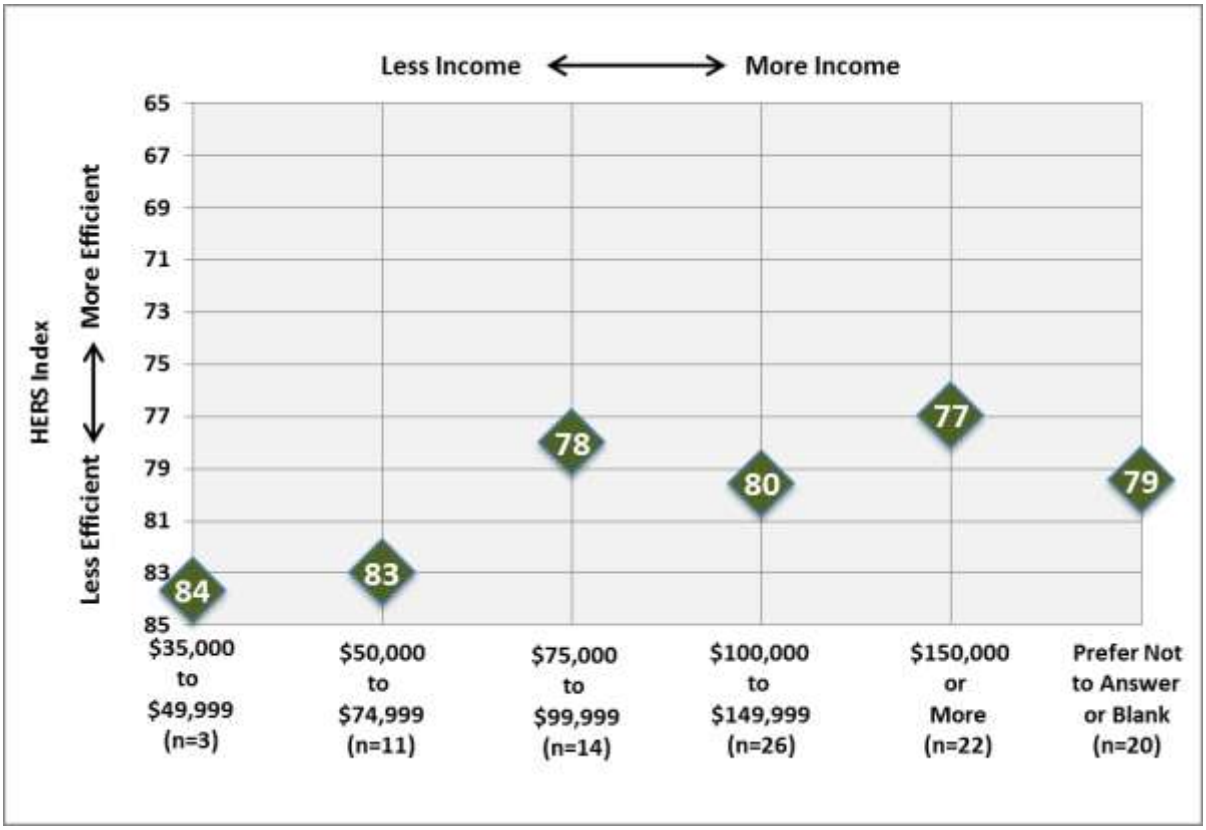
Figure 8-5: Homeowner Education by HERS Score



[27] This difference is statistically significant at the 90% confidence level.

Figure 8-6 displays the average HERS rating for homeowners of each income level. As shown, homeowners with annual incomes greater than $150,000 have, on average, the most efficient homes, while those with annual incomes less than $75,000 have the least efficient homes. Most (four out of six) of the builder/owners who provided income information have incomes ranging from $100,000 to $149,999. These four builder/owners have an average HERS rating of 66, and removing these four values from the average calculation for homeowners in this income category results in a less efficient average HERS rating of 82. Looking at the HERS ratings, how the home was purchased, and income data shows that builder/owners tend to have relatively high incomes and the most efficient homes.

Figure 8-6: Homeowner Income by Average HERS Score



Fewer than one in five homeowners (19%) said that this was their first time buying a home. Most (15 out of 18, or 83%) of the first-time homebuyers are under the age of 34. Only one of the seven builder/owners reported being a first-time homebuyer. The majority of homeowners (76%) plan to stay in their new home for at least ten years. As might be expected, homeowners aged 65 or over were the most likely to say they plan to stay in their home indefinitely (9 out of 12, or 75%), followed by homeowners aged 55 to 64 (9 out of 16, or 56%). Six of the seven builder/owners plan to stay in their new home indefinitely.

Table 8-2: First-Time Home Buyer?

First-Time Home Buyer? (n=96)	
Already owned home	81%
First-time home buyer	19%
How Long Do You Expect to Stay in Your New Home? (n=96)	
Indefinitely/the Rest of My Life	45%
More Than Ten Years	31%
Six to Ten Years	18%
Two to Three Years	1%
Don't Know	5%

8.3 Comfort and Complaints

Homeowners were asked to describe the comfort of their home by indicating if it was "very comfortable," "somewhat comfortable," "somewhat uncomfortable," or "very uncomfortable." Most homeowners (89%) said their home is very comfortable; 11% said their home is somewhat comfortable. None of the 96 homeowners who completed the survey said that their home is uncomfortable. These results are virtually the same as those for the same question asked on the 2005 homebuyer survey, at which time 89% of homeowners said their home is very comfortable, and 10% said their home is somewhat comfortable.

Next, homeowners were given the opportunity to provide comments about the comfort of their new home and to describe any complaints they have about the home. A little over one-fifth of the homeowners (22) described a total of 25 complaints about their homes. Homeowners who said their home is somewhat comfortable were more likely to mention a complaint than those who described their home as very comfortable. Over one-half (7 out of 11) of homeowners who described their home as somewhat comfortable mentioned a complaint, compared to fewer than one in five (15 out of 85) of the homeowners describing their home as very comfortable.

Figure 8-7 displays the types of complaints submitted by homeowners and the number of complaints within each category. The majority of homeowner complaints pertain to heating and cooling issues, including six complaints regarding uneven or insufficient heating or cooling distribution throughout the home, one complaint regarding the home heating fuel type, a complaint that the home does not have multiple heating/cooling zones, and a complaint that the

home was "extremely expensive to heat last winter." Not surprisingly, the average HERS score for homeowners with heating/cooling complaints is less efficient (82) than the average HERS score for all homeowners who completed the survey (79). The second most commonly mentioned type of complaint pertains to the quality of specific components in the home and/or general construction quality (7 complaints). For example, two homeowners had complaints about their windows, one homeowner had a complaint about the toilets, and one homeowner stated that the roof leaked. A fifth homeowner lamented that the builder cleared too many trees, a sixth, owner of a modular home complained that components were omitted prior to the home's arrival at the site, and the seventh homeowner simply commented "builder flaws." Three homeowners each had complaints regarding water heating (including two comments that it takes too long for hot water to get to the faucets and one complaint that the builder installed electric water heating instead of gas), and space issues (e.g. home is too small, not enough closets, no room for dining area). Homeowners describing their home as somewhat comfortable were most likely to complain about heating and cooling issues, whereas homeowners describing their homes as very comfortable were most likely to complain about the quality of components or general construction quality.

Figure 8-7: Homeowner Complaints about New Home

*Other complaints include a home break-in, road noise, and smell/taste of water from faucets.

8.4 Discussed Energy Efficiency with Builder or Sales Agent

Nearly two-thirds (64%) of homeowners said their builder or sales agent talked to them about energy efficiency or the benefits of energy-efficient windows, heating and cooling equipment, insulation, etc.[28] Owners of custom homes were more likely than owners of spec homes to say that their builder or sales agent talked about energy efficiency—77% of custom homeowners compared to 59% of spec homeowners. Over one-half (60 or 63%) of homeowners said they asked their builder or the sales agent about energy efficiency.

Table 8-3 shows that almost one-third (29%) of homeowners who said that their builder or sales agent did not talk to them about energy efficiency, or they do not remember, said they asked about energy efficiency. In addition, most (80%) homeowners who said their builder or sales agent talked to them about energy efficiency also said they asked about energy efficiency.

Table 8-3: Homeowners Who Discussed Energy Efficiency

	Number (%) of Homeowners	Number of Homeowners Who Asked About Energy Efficiency	Percent of Homeowners Who Asked About Energy Efficiency
Builder or Sales Agent Talked About Energy Efficiency (Includes Builder/owners)	61 (64%)	49	80%
Builder or Sales Agent Did NOT Talk About Energy Efficiency or Homeowner Does Not Remember	34 (35%)	10	29%
Blank	1 (1%)	1	100%
Total Homeowners:	96	60	63%

8.5 Importance of Getting an Energy-Efficient Home

Most homeowners reported that getting an energy-efficient home was relatively important in their decision to buy or build their home. However, homeowners who assigned a high importance rating to energy efficiency did not necessarily get energy-efficient homes. One possible explanation is that some owners may have started out wanting the most energy-efficient options, but when budget limitations came into play the first things to go were the less visible energy-efficient options in favor of high-end appearance options such as granite countertops. It may also be that some owners said energy efficiency was important only because they were

[28] Homeowners who are also the builder did not respond consistently to questions about whether or not their builder or sales agent talked to them about energy efficiency and whether or not they asked their builder or sales agent about energy efficiency. Some of these homeowners simply identified themselves as the builder, some said they do not remember or left the question blank, and some said their builder talked to them about energy efficiency and/or that they asked their builder or sales agent about energy efficiency. It seems reasonable to assume that those who identified themselves as the builder considered energy efficiency in their role as builder—several of the homeowners who were also the builder commented that this was the case. Therefore homeowners who identified themselves as the builder are counted as homeowners who say they talked to their builders or sales agents about energy efficiency or asked about energy efficiency.

participating in a program to assess the energy efficiency of their home and felt they should say energy efficiency was important.

Using a scale of zero (one of the least important features) to ten (one of the most important features), homeowners rated the importance of getting an energy-efficient home in their decision to buy or build their home. The average rating is eight. Figure 8-8 shows that very few homeowners rated energy efficiency below five, and about two-thirds (68%) rated energy efficiency eight or higher.

Figure 8-8: Importance of Getting an Energy-Efficient Home

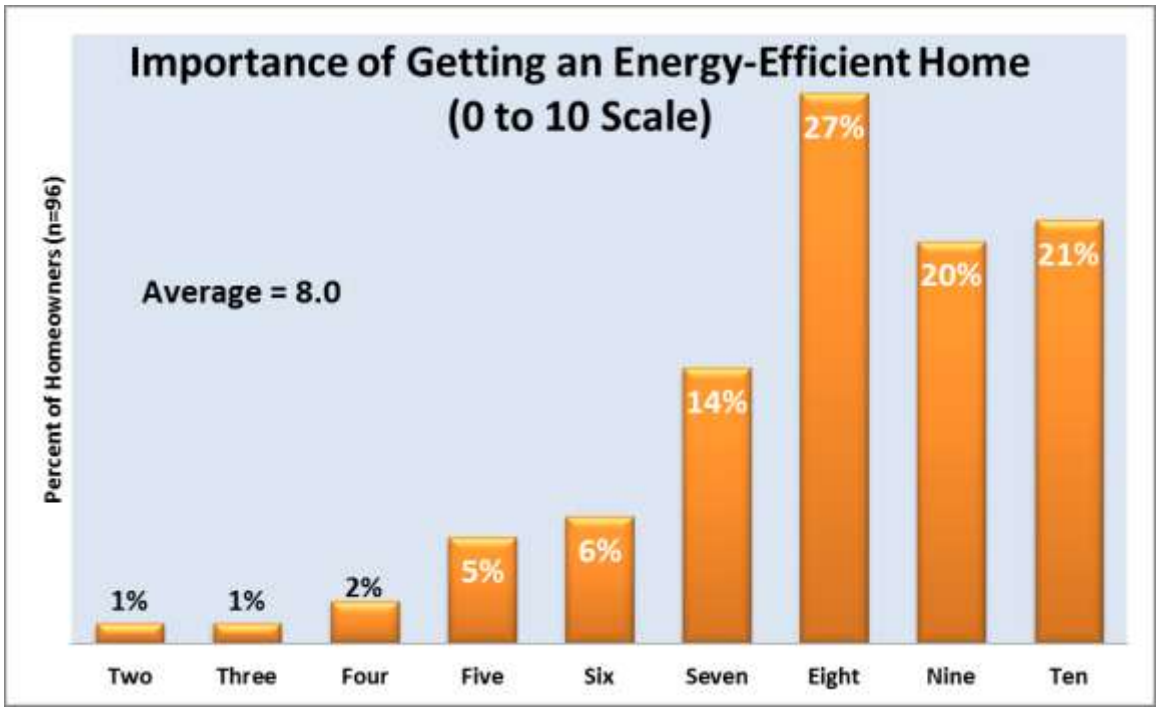


Figure 8-9 displays homeowners' ratings of the importance of getting an energy-efficient home by the homes' HERS ratings. Homeowners who assigned the highest importance rating (10) to getting an energy-efficient home own homes that have an average HERS rating of 75, which is more efficient than the average HERS rating of 82 for homeowners who assigned a lower importance rating of 5 to getting an energy-efficient home. However, looking at the six least efficient homes, four of the six homeowners assigned a high importance rating (8-10) to getting an energy-efficient home. Additionally, the average HERS rating for all homeowners who assigned a high importance rating (8-10) to getting an energy-efficient home is 78, which is only one HERS index point lower (more efficient) than the average HERS rating of 79 across all 96 homes of owners who completed the survey.

Figure 8-9: Importance of Getting an Energy-Efficient Home by HERS Rating

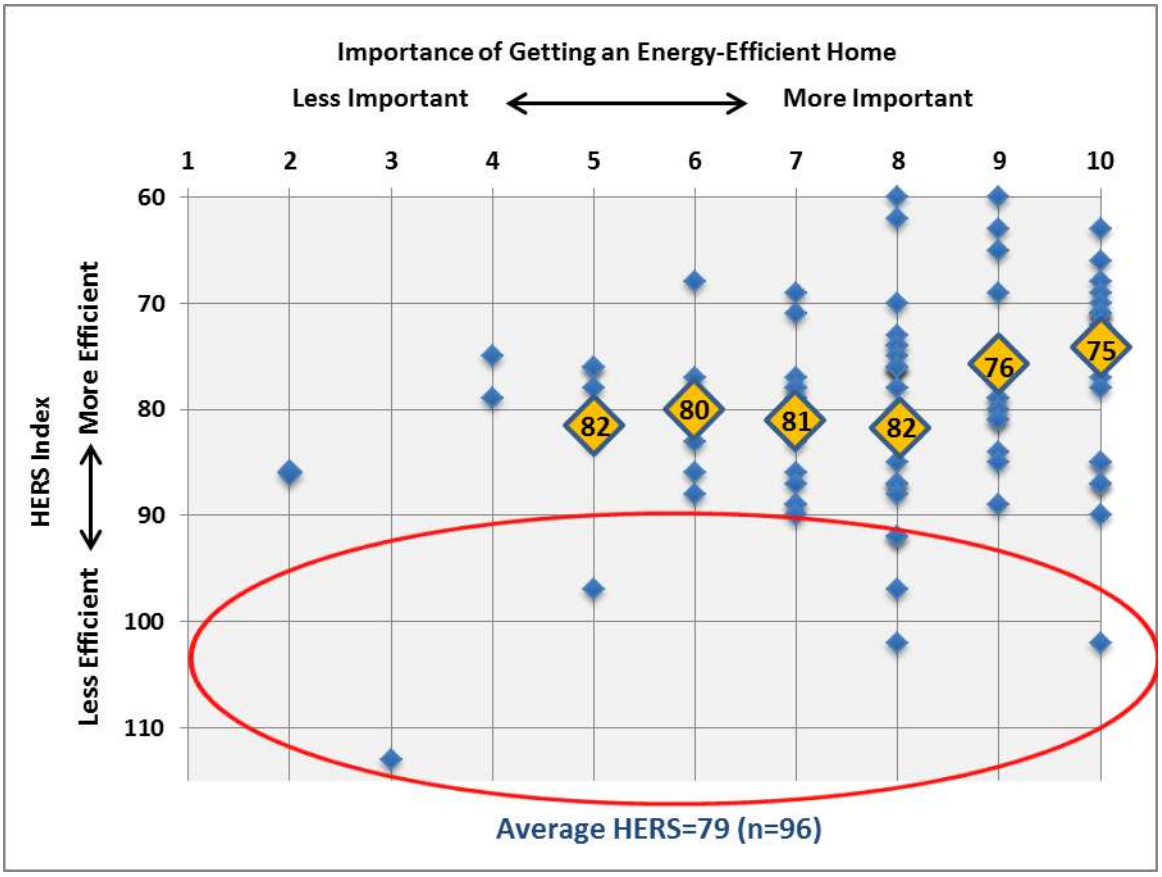
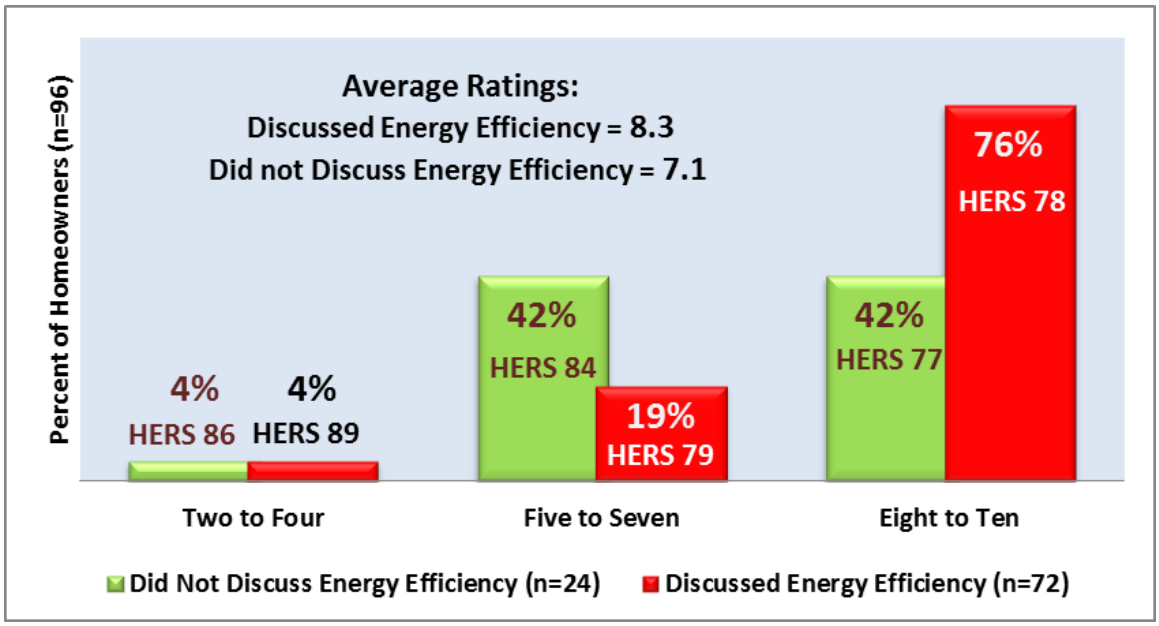


Figure 8-10 displays homeowners' ratings of the importance of getting an energy-efficient home by whether or not the homeowner talked with the builder or sales agent about energy efficiency. Nearly three-quarters (72) of the homeowners said that either their builder or sales agent talked to them about energy efficiency, or they asked their builder/sales agent about energy efficiency. The average rating for homeowners who said they talked to their builder or sales agent about energy efficiency is 8.3; the average rating for homeowners who said they did not talk to their builder/sales agent about energy efficiency is 7.1. More than two out of five homeowners (42%) who did not discuss energy efficiency with their builder or sales agent still assigned a high rating (from eight to ten) to the importance of getting an energy-efficient home.

Figure 8-10: Importance of Getting an Energy-Efficient Home by Talked to Builder/Agent about Energy Efficiency



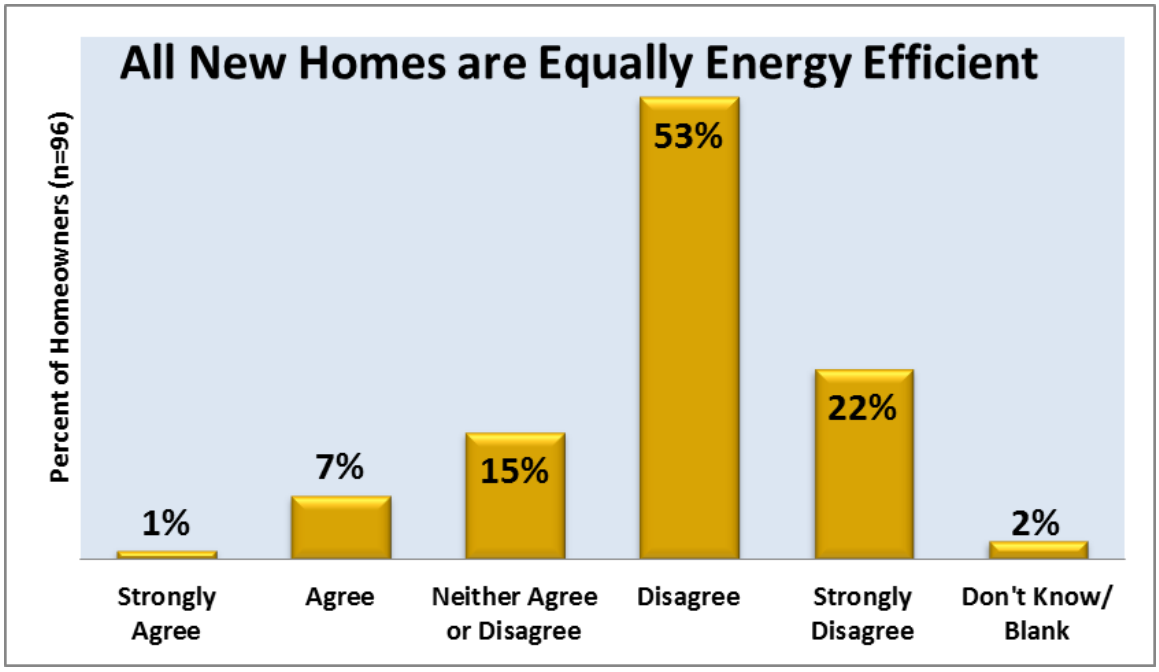
8.6 Homeowner Perception of Energy Efficiency of New Homes

Homeowners are generally aware that the energy efficiency of new homes varies from one home to another. However, they are not very good at assessing the energy efficiency of their homes. They may think any home with 2 x 6 framing is energy efficient and not consider the importance of air sealing and insulation levels or they may simply take the builder's word that a home is energy efficient. The following example looks at the most and least energy-efficient homes inspected, based on HERS ratings. The four most energy-efficient homes, with HERS indices of 50 to 60, are custom homes; two of these homes were built by owners. The four least energy-efficient homes, with HERS indices of 102 to 116, are spec homes; two are homes where the owner purchased a lot from a builder, selected one of several house plans offered by the builder and selected from various available upgrade options; one is a home that was already under construction when purchased and the owner could choose upgrade options, and one was a finished home when sold. As different as these two groups of homes are in terms of energy

efficiency, the owners do not seem to be aware. Seven of the eight owners of these homes rated the importance of getting an energy-efficient home in their decision to buy or build their new home an 8, 9, or 10 on a scale of zero (not important) to 10 (very important). Six of the eight owners of these homes think their homes are somewhat more energy efficient than other new homes—three of the four owners of the most efficient and three of the four owners of the least energy-efficient homes. One owner of a very energy-efficient home thinks his home is much more efficient than other new homes, and one owner of one of the least energy efficient thinks his home is about as energy efficient as other new homes. Two of the four owners of the most energy-efficient homes and three of the four owners of the least energy-efficient homes said they had heard of or seen an ENERGY STAR home, but only one of these owners, an owner of one of the most energy-efficient homes, said he talked with his builder about ENERGY STAR homes.

Homeowners were asked to indicate the extent to which they agree with the statement "all new homes are equally energy efficient." Figure 8-11 shows that the majority of homeowners (75%) disagree with this statement. Two of the seven homeowners who were also the builder or general contractor for their homes neither agree nor disagree with this statement, two disagree, and three strongly disagree.

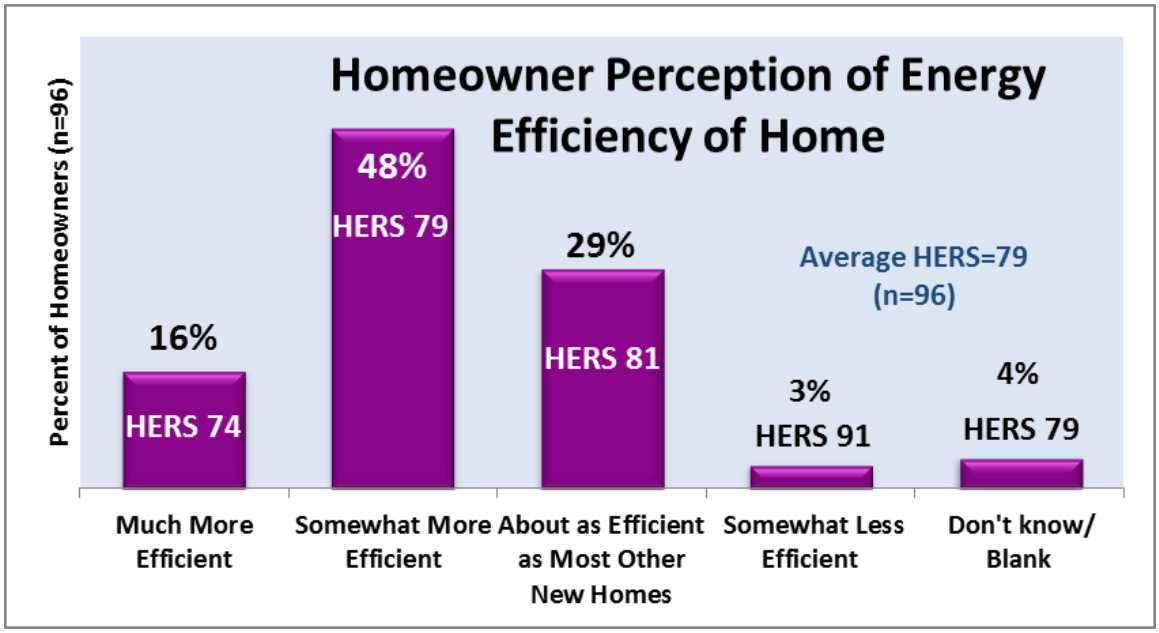
Figure 8-11: All New Homes are Equally Energy Efficient



Relative to other new homes, homeowners on average tend to believe that their home is more efficient than it actually is. Figure 8-12 shows that most homeowners think their home is somewhat more energy efficient than most other new homes (48%), or about as energy efficient (29%). The average HERS rating for homeowners who believe their home is somewhat more energy-efficient than most other new homes is 79, which equals the average HERS rating across all 96 homes of owners who completed the survey. Homeowners who believe their home is about

as efficient as most other new homes have homes that are, on average, 2 HERS index points higher (less efficient) than the sample average.[29] Those who believe their home is much more efficient than most other new homes have homes that are, on average, 5 HERS index points lower (more efficient) than the sample average.

Figure 8-12: Homeowner Perception of Energy Efficiency of Home Compared to Other New Homes



Custom homeowners were more likely than spec homeowners to say that their home is more efficient than other new homes—91% of custom homeowners said that their home is somewhat or much more efficient than other new homes compared to 57% of spec homeowners. On average, the custom homeowners who completed the survey do have more efficient homes (average HERS rating of 72) compared to the spec homes (average HERS rating of 81). Four of the seven builder/owners believe their home is somewhat more energy-efficient than most other new homes, and the rest believe their home is much more efficient.

Almost two-thirds (66) of the homeowners commented on why they believe their home is more, about the same, or less energy efficient than other new homes. Both of the two homeowners who believe their home is somewhat less efficient than other new homes explained why. One of these two homeowners explained the "builder did not use any energy-efficient products." This home, which has a HERS rating of 92, is heated by an 80.3 AFUE oil furnace – one of the least efficient heating systems among the sample sites. Additionally, nearly all of the light bulbs – which are among the most visible energy-efficiency related products to homeowners – are incandescent bulbs. The other homeowner who believes his home is somewhat less efficient commented,

[29] A home built to the specifications of the HERS Reference Home (based on the 2004 International Energy Conservation Code) scores a HERS Index of 100, while a net zero energy home scores a HERS Index of 0. Each one-point decrease in the HERS Index corresponds to a 1% reduction in energy consumption compared to the HERS Reference Home.

"Comparatively speaking, it seems as though this house is more expensive to heat (not cool) than other new homes." This home, which has a HERS rating of 90, has a very efficient heating system (AFUE 95), but the auditors assigned an insulation installation grade of III in most areas of the home, noting that most insulation in the home "was pretty sloppy" and that the blower door test results indicated that the home was "very drafty."

Figure 8-13 displays the numbers and categories of reasons homeowners gave as to why they believe their home is about as energy efficient as most other new homes. The most frequently mentioned reason is that the home has standard efficiency building components and/or that the homeowner did not opt for any energy-efficient upgrades. Additionally, three homeowners each stated that their home is built to code or that the home is built with modern components.

Figure 8-13: Why Homeowners Think their Home is About as Energy Efficient as Other New Homes

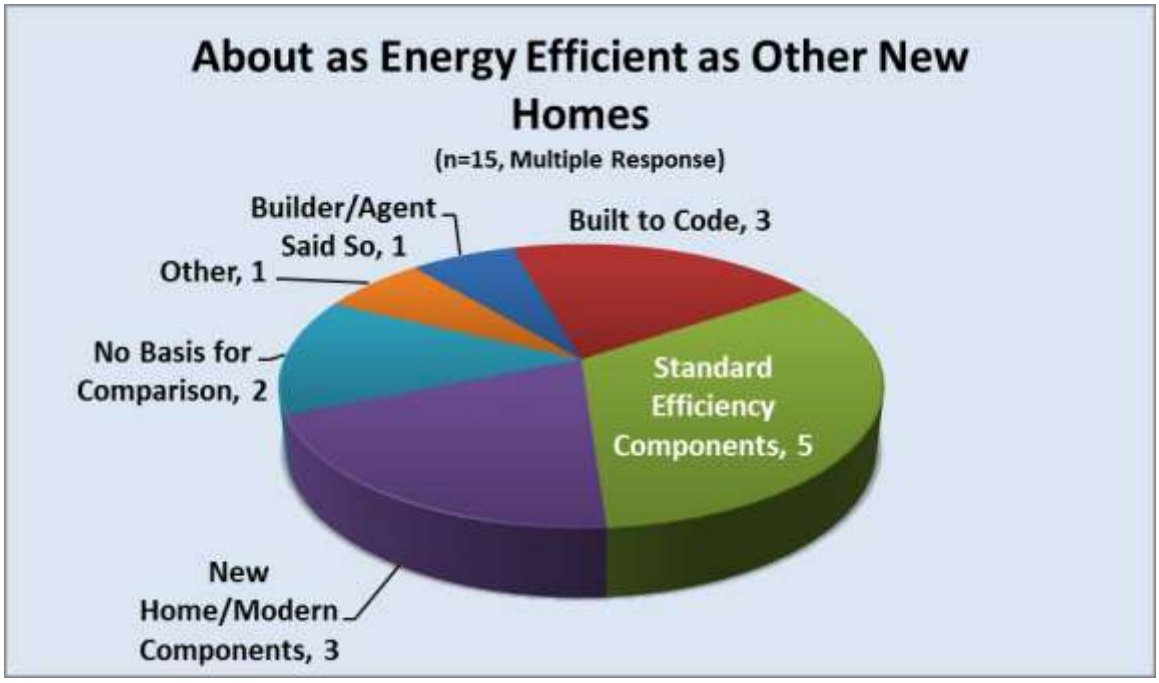
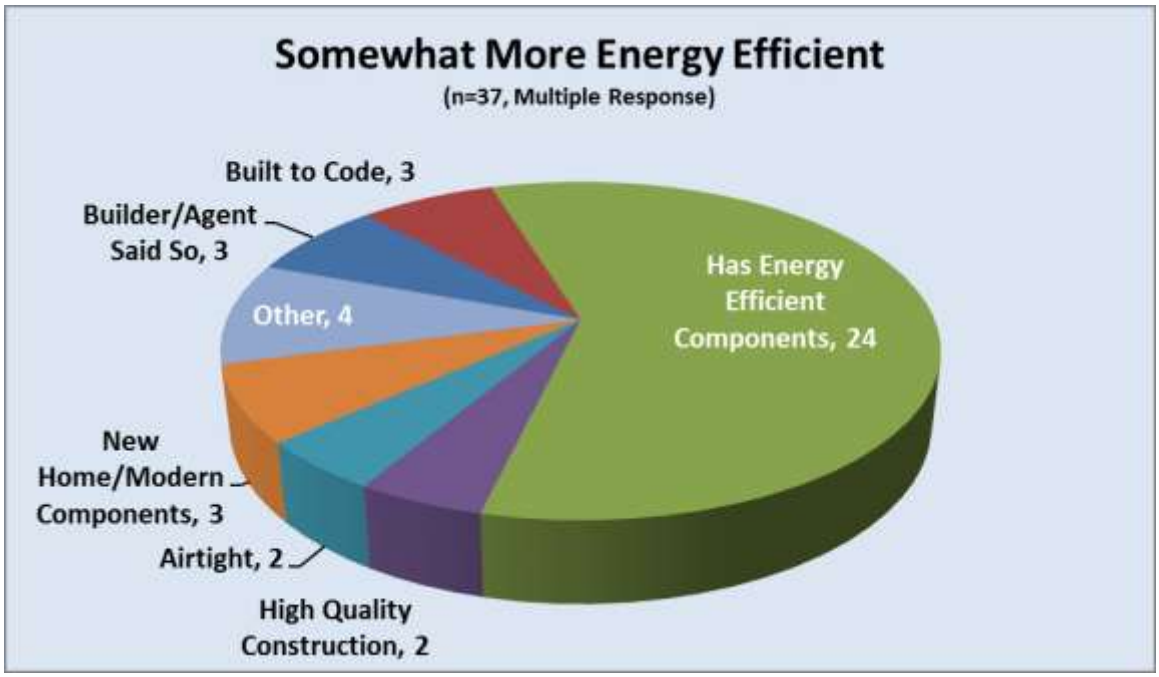


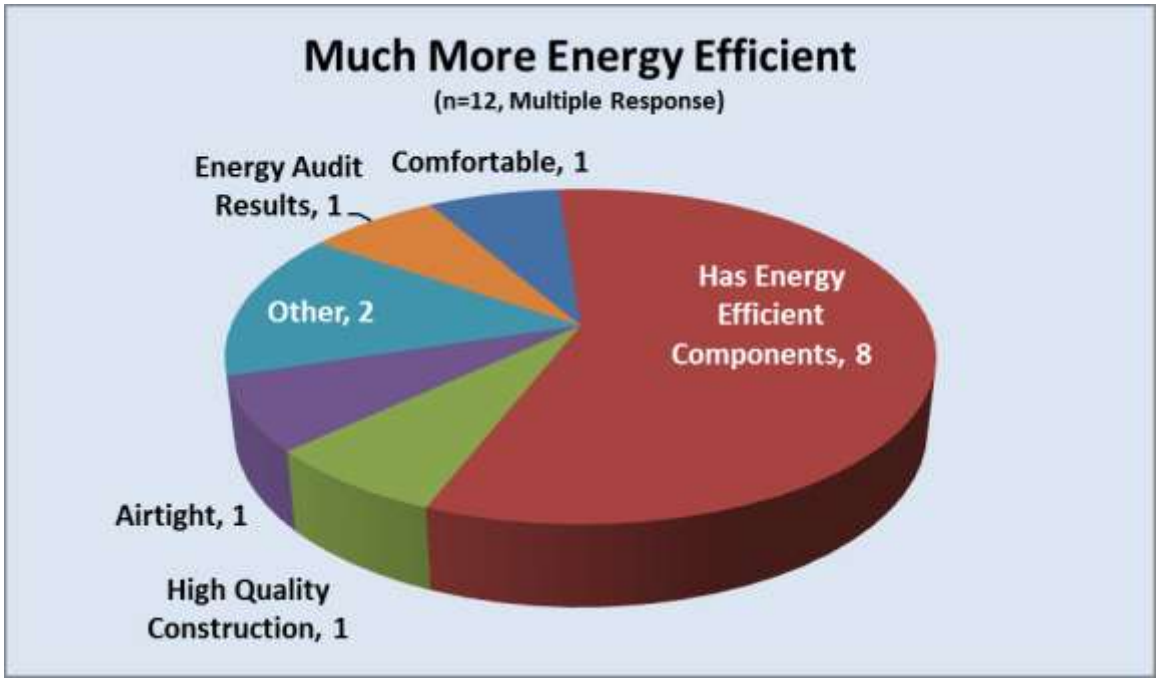
Figure 8-14 shows that most homeowners who think their home is somewhat more energy efficient than most other new homes attribute this to specific building components they believe to be energy efficient. For example, homeowners frequently mentioned having "above average" or "efficient" windows, insulation, appliances, and/or HVAC components. Additionally, three homeowners mentioned that their home was built to what they perceive to be higher efficiency code requirements, including one homeowner who commented, "As I understand it, Natick building codes are more stringent than state codes." Three homeowners simply mentioned that their home is new, one of whom added, "I am assuming that a new home would have had energy efficiency in mind."

Figure 8-14: Why Homeowners Think their Home is Somewhat More Energy Efficient than Other New Homes



Homeowners who think their home is much more energy efficient than most other new homes also attribute this to specific building components (Figure 8-15). These homeowners mentioned 2x6 construction, geothermal heating (mentioned twice, both times by a builder/owner), and energy-efficient windows, doors, appliances, and insulation.

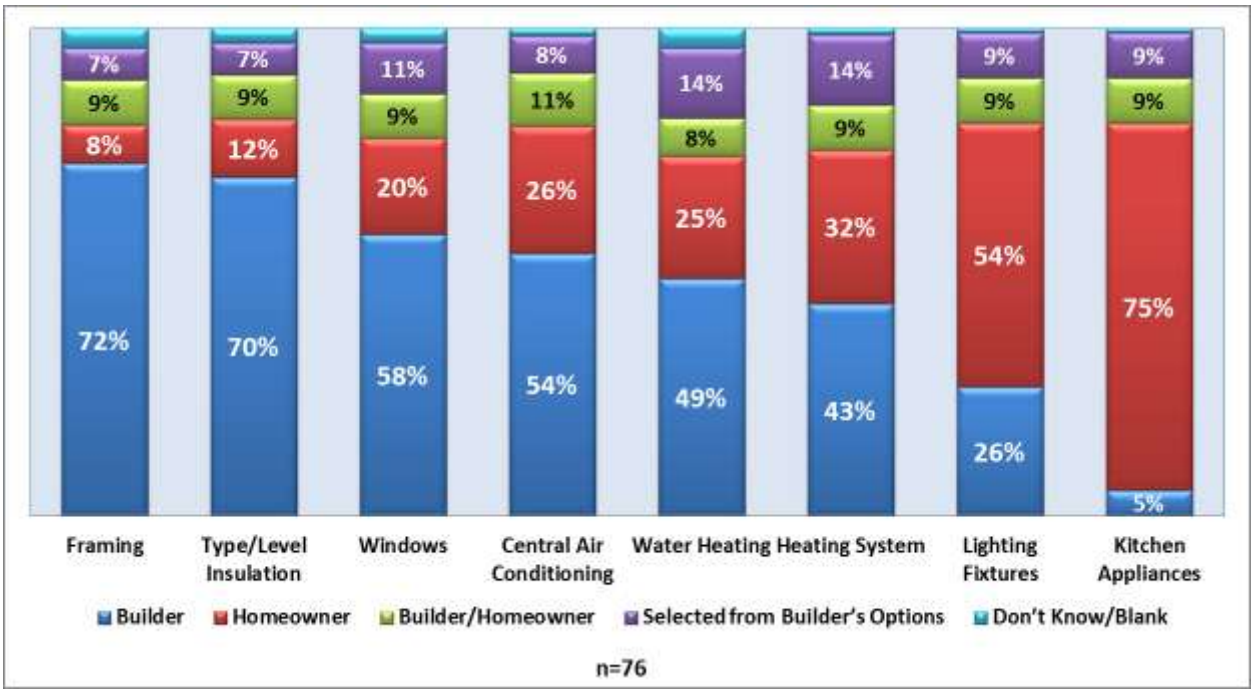
Figure 8-15: Why Homeowners Think their Home is Much More Energy Efficient than Other New Homes



8.7 Homeowner Awareness of Equipment and Building Components

Homeowners who had the opportunity to choose various options for their home (those who had a custom home built or purchased a home before it was completed) were asked to indicate who was responsible for selecting numerous energy efficiency related components in their homes. Almost three-quarters (55 out of 74) of the spec homeowners and nearly all (21 out of 22) of the custom homeowners indicated that they had had the opportunity to choose various options for their home. Figure 8-16 shows that builders are most likely to specify framing, insulation, windows, heating and cooling equipment, and water heaters, while homeowners are most likely to specify kitchen appliances and lighting fixtures. Homeowners who built or acted as the general contractor for their home are characterized as builder/homeowners in Figure 8-16, and in almost all cases these homeowners say they made all the decisions.

Figure 8-16: Who Specified Building Components

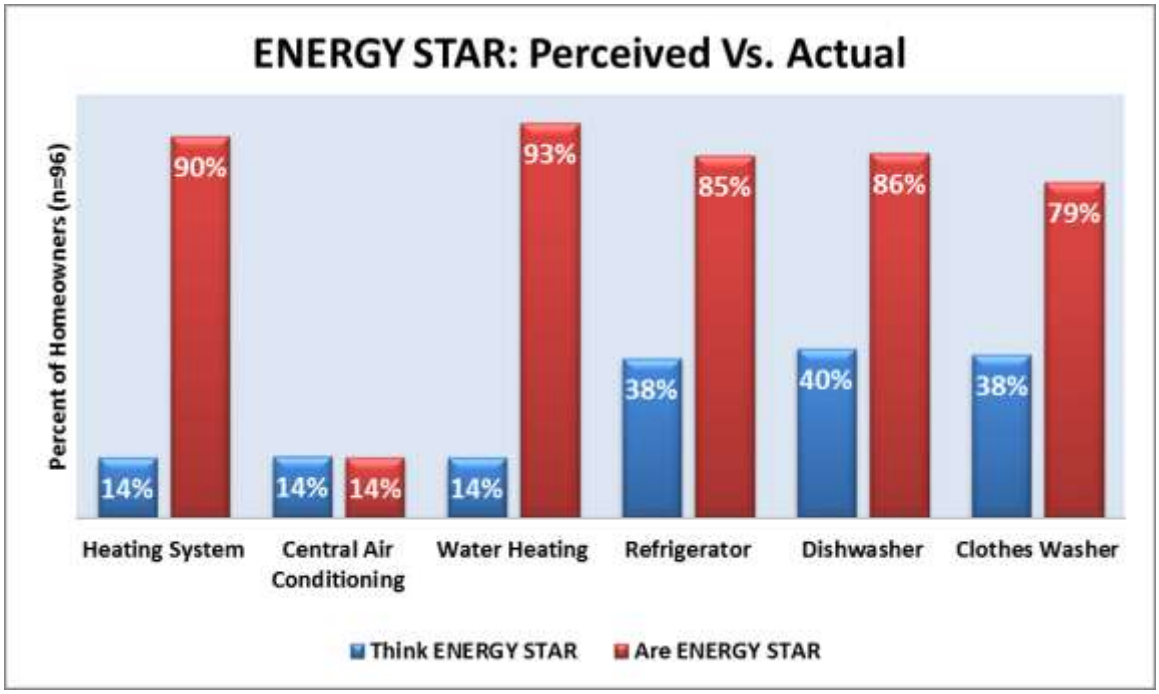


*Percentages for central air conditioning are percentages of homes with central air conditioning.

Homeowners were asked to indicate whether certain components in their homes are ENERGY STAR labeled. Figure 8-17 displays the percentage of homeowners who think components of their home are ENERGY STAR and the percentage of homes where the component really is ENERGY STAR. Less than half of the homeowners who have ENERGY STAR refrigerators, dishwashers, and clothes washers are aware that they have ENERGY STAR labeled appliances. Additionally, less than one-sixth of the homeowners who have ENERGY STAR heating systems and water heaters are aware that they have ENERGY STAR labeled components. Twelve homeowners (14%) think they have ENERGY STAR labeled central air conditioning, and twelve homeowners actually do have ENERGY STAR labeled central air conditioning. However, seven of the twelve homeowners who think their central air conditioning systems are ENERGY STAR

labeled are mistaken; only five of the 12 homeowners who said they have ENERGY STAR labeled central air conditioning systems actually do, and the other seven do not. These findings indicate that homeowners are an unreliable source of information for the prevalence of ENERGY STAR-qualified HVAC systems, water heaters, and appliances in homes.

Figure 8-17: ENERGY STAR Components – Perceived versus Actual



*Percentages for central air conditioning, dishwashers, and clothes washers are percentages of homes with central air conditioning, dishwashers, and clothes washers. Percentages for water heaters are percentages of ENERGY STAR eligible water heaters (gas instantaneous or storage) that qualify under either current ENERGY STAR criteria or ENERGY STAR criteria ending 8/31/2010.

8.8 Awareness of ENERGY STAR Homes

Over three-quarters (76%) of homeowners said that they had seen or heard of a newly constructed home being referred to as an ENERGY STAR Home, including all seven of the builder/owners. However, only one in five homeowners (20%) said that their builder or agent brought up the subject of ENERGY STAR Homes, indicating that builders and real estate agents are not a primary source of program awareness. Almost one in five homeowners (19%) said that they asked their builder or agent about ENERGY STAR Homes while making plans for building or buying a home. (Table 8-4)

Table 8-4: Homeowner Awareness of ENERGY STAR Homes

n=96	Heard of ENERGY STAR Homes?	Builder/Agent Talked About ENERGY STAR Homes	Asked About ENERGY STAR Homes
Yes	76%	20%	19%
No	20%	52%	63%
Don't Know/Blank	4%	28%	19%

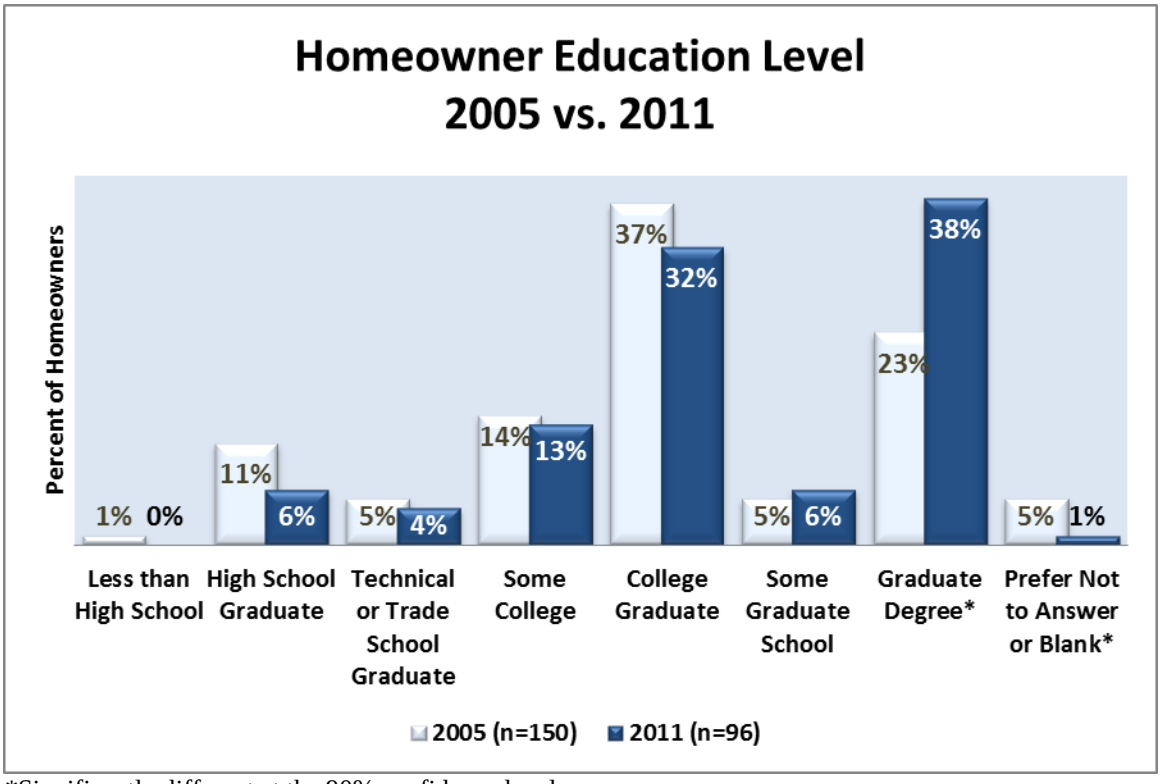
Survey findings suggest making potential homebuyers aware of ENERGY STAR homes is not enough to get them to act on that awareness when they look for a home or a builder to build a custom home. Only 15 of the 66 owners (23%) who did not build their own home and who said they had seen or heard of a newly constructed home being referred to as an ENERGY STAR home said they asked their builder or sales agent about ENERGY STAR homes.

8.9 Comparison to Previous Homebuyer Survey Findings

Compared to the 2005 homeowners, 2011 homeowners tend to have higher educational attainment levels, higher incomes, and are more likely to be under 35 or over 55. The 2011 homeowners were more likely to be aware of ENERGY STAR-labeled homes and to have discussed energy efficiency with their builders or real estate agents. Fewer 2011 homeowners thought that their heating systems, cooling systems, and appliances are ENERGY STAR-labeled than 2005 homeowners.

Figure 8-18 compares the educational attainment levels of the 2011 homeowner survey respondents to those of the 2005 homeowner survey respondents. More of the 2011 homeowners have a graduate degree than the 2005 homeowners—38% of 2011 homeowners compared to 23% of 2005 homeowners. This difference is statistically significant at the 90% confidence level.

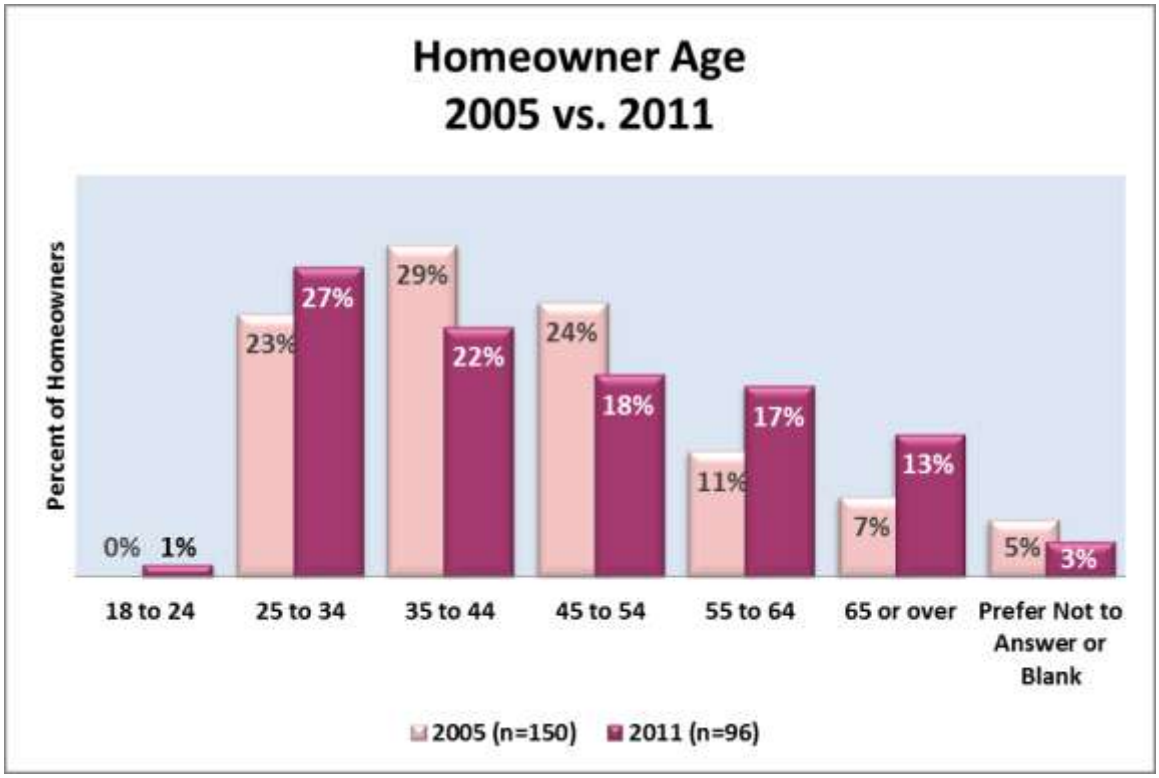
Figure 8-18: Homeowner Education - 2011 Compared to 2005



*Significantly different at the 90% confidence level.

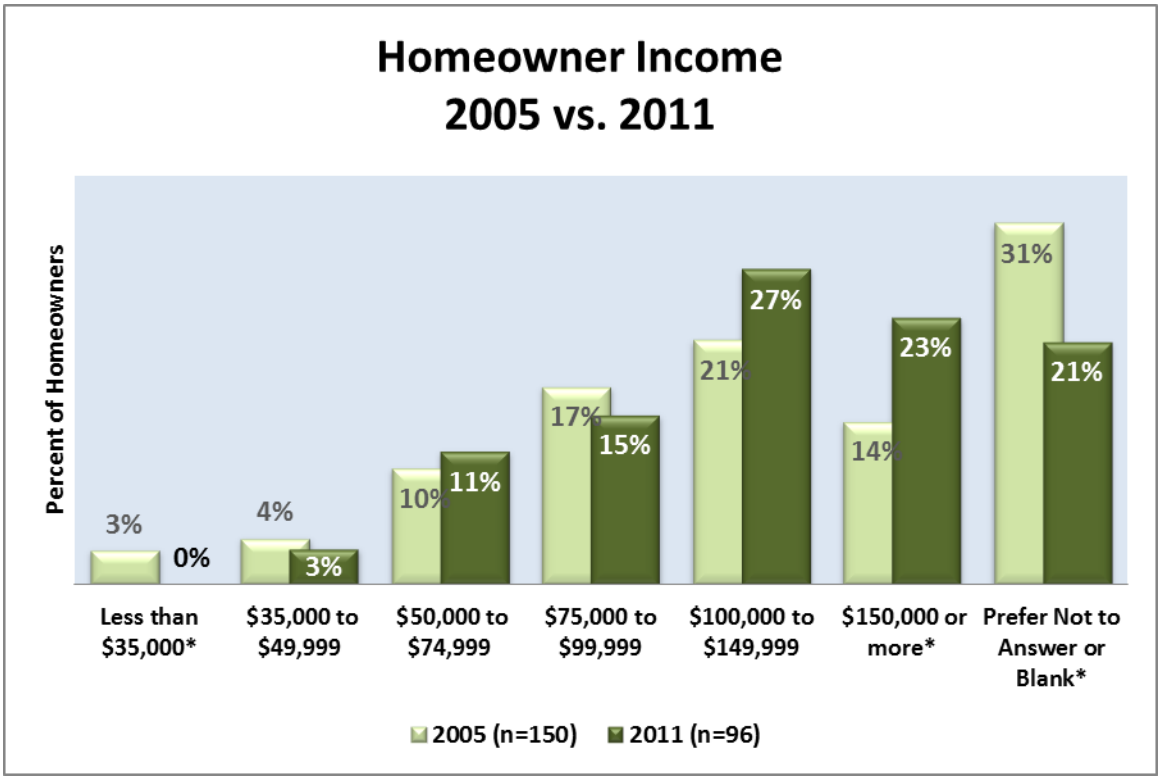
Figure 8-19 compares the ages of the 2011 homeowner survey respondents to those of the 2005 homeowner survey respondents. The 2011 sample contains a higher percentage of homeowners under 35 and over 55; however, these differences are not statistically significant at the 90% confidence level.

Figure 8-19: Homeowner Age - 2011 Compared to 2005



Almost one-quarter (23%) of the 2011 homeowners reported earning over $150,000 annually, compared to 14% of the 2005 homeowners. Unlike the 2005 sample, none of the 2011 homeowners reported earning less than $35,000. The differences between the 2011 and 2005 samples at these two extreme income categories are statistically significant at the 90% confidence level. Caution should be used in interpreting these differences since nearly one-third (31%) of the 2005 homeowners and over one-fifth (21%) of the 2011 homeowners did not provide income information. However, it does seem reasonable given the poor economy and depressed market for new housing in 2010 and 2011 that those in the market to purchase a new home would likely be higher income buyers with job security.

Figure 8-20: Homeowner Income - 2011 Compared to 2005



*Significantly different at the 90% confidence level.

The proportions of 2011 and 2005 first-time homebuyers are similar. Figure 8-21 shows that 19% of homeowners in 2011 and 16% of homeowners in 2005 said they were first-time homebuyers.

Figure 8-21: Percentage of First-Time Homebuyers – 2011 Compared to 2005

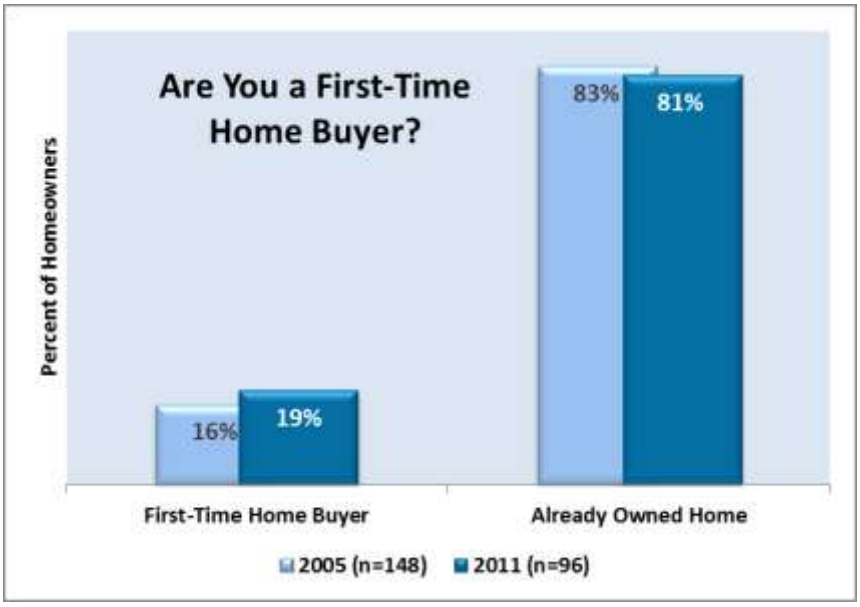
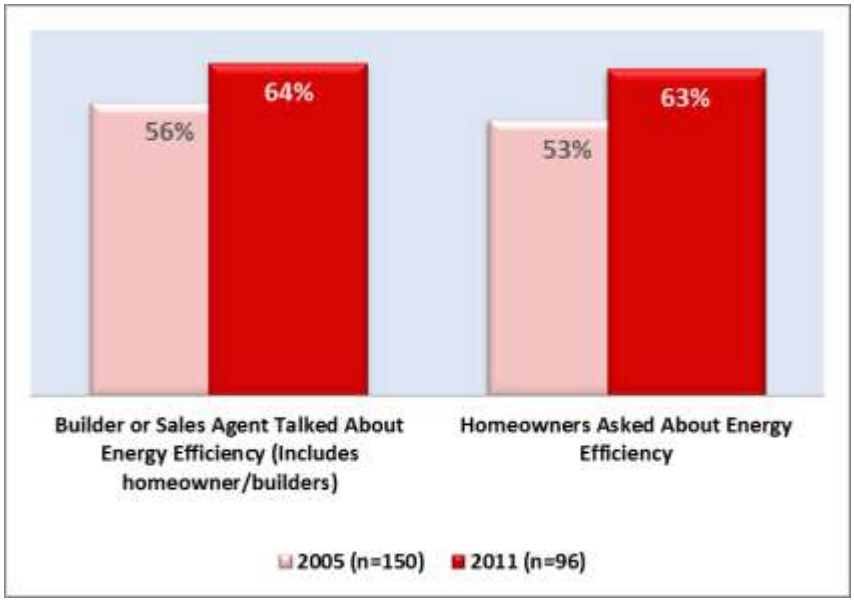


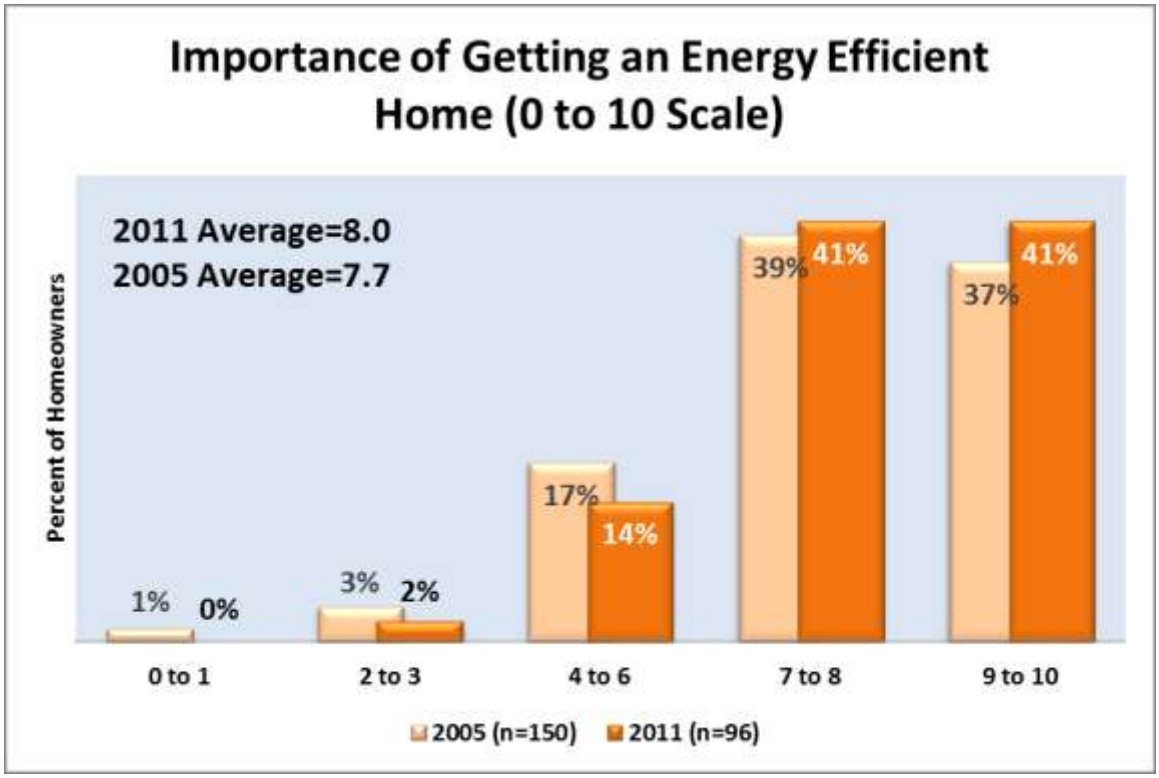
Figure 8-22 shows the percentage of homeowners stating that their builder or sales agent talked to them about energy efficiency and the percentage of homeowners stating that they asked their builder or sales agent about energy efficiency. A greater percentage of 2011 homeowners discussed energy efficiency with their builder or agent than 2005 homeowners; however, these differences are not statistically significant at the 90% confidence level.

Figure 8-22: Homeowners Who Discussed Energy Efficiency – 2011 Compared to 2005



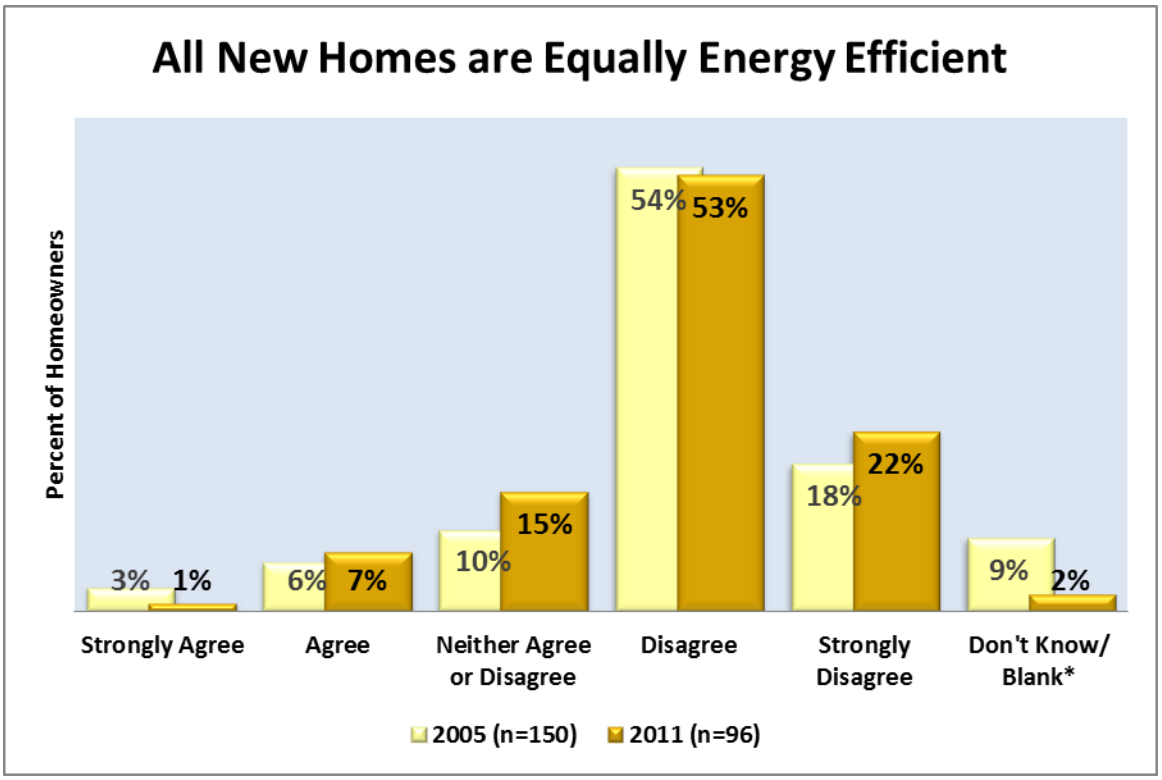
The 2011 and 2005 homeowners assigned similar ratings to the importance of getting an energy-efficient home. As shown in Figure 8-23, the average rating for 2011 homeowners is 8.0 as compared to an average rating of 7.7 among the 2005 homeowners.

Figure 8-23: Importance of Getting an Energy-Efficient Home – 2011 Compared to 2005



Homeowner perception of the energy efficiency of new homes in general did not change between the 2011 and 2005 studies. The majority of both the 2011 homeowners (75%) and 2005 homeowners (72%) disagree with the statement that "all new homes are equally energy efficient." The only statistically significant difference between the two groups is the proportion of homeowners who answered "don't know" or did not respond. (Figure 8-24)

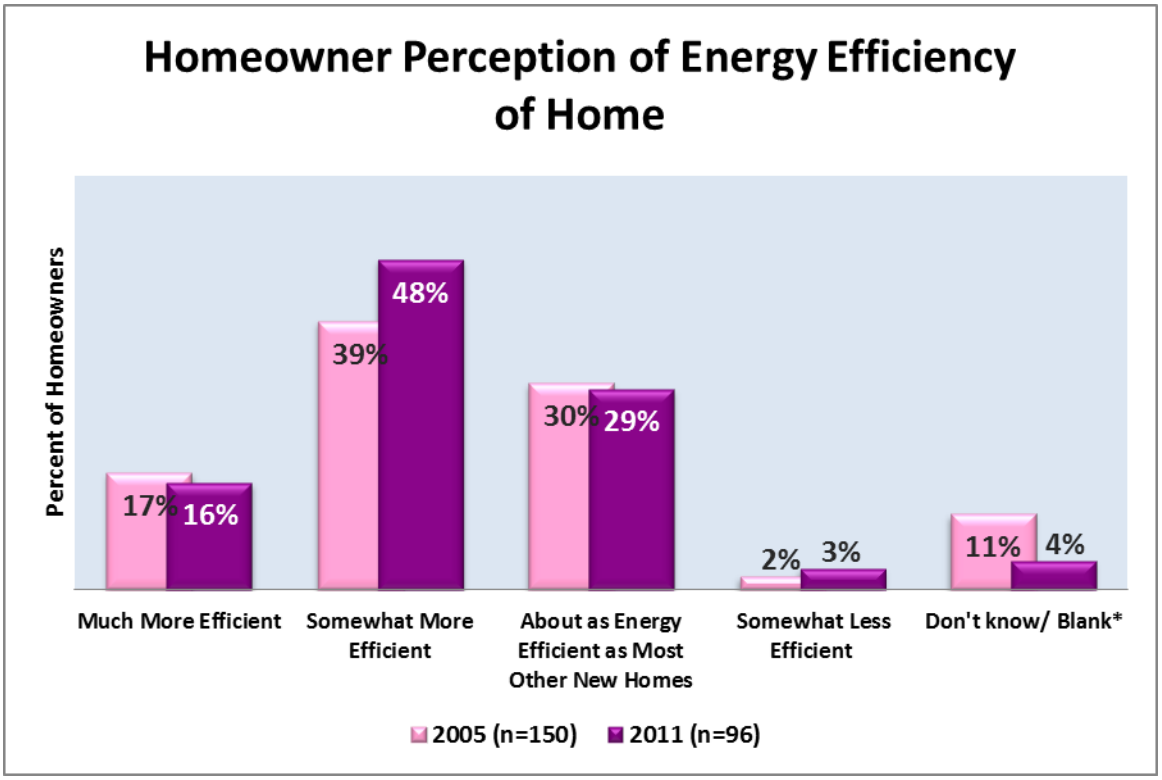
Figure 8-24: Homeowner Perception of Energy Efficiency of New Homes in General – 2011 Compared to 2005



*Significantly different at the 90% confidence level.

Homeowner perception of the energy efficiency of their own, new home also did not change between the 2011 and 2005 studies. The majority of both the 2011 homeowners (64%) and 2005 homeowners (56%) believe that their home is more energy efficient than most other new homes. Almost one-third of both the 2011 homeowners (29%) and 2005 homeowners (30%) believe that their home is about as energy efficient as other new homes. Again, the only statistically significant difference between the two groups is the proportion of homeowners who answered "don't know" or did not respond. (Figure 8-25)

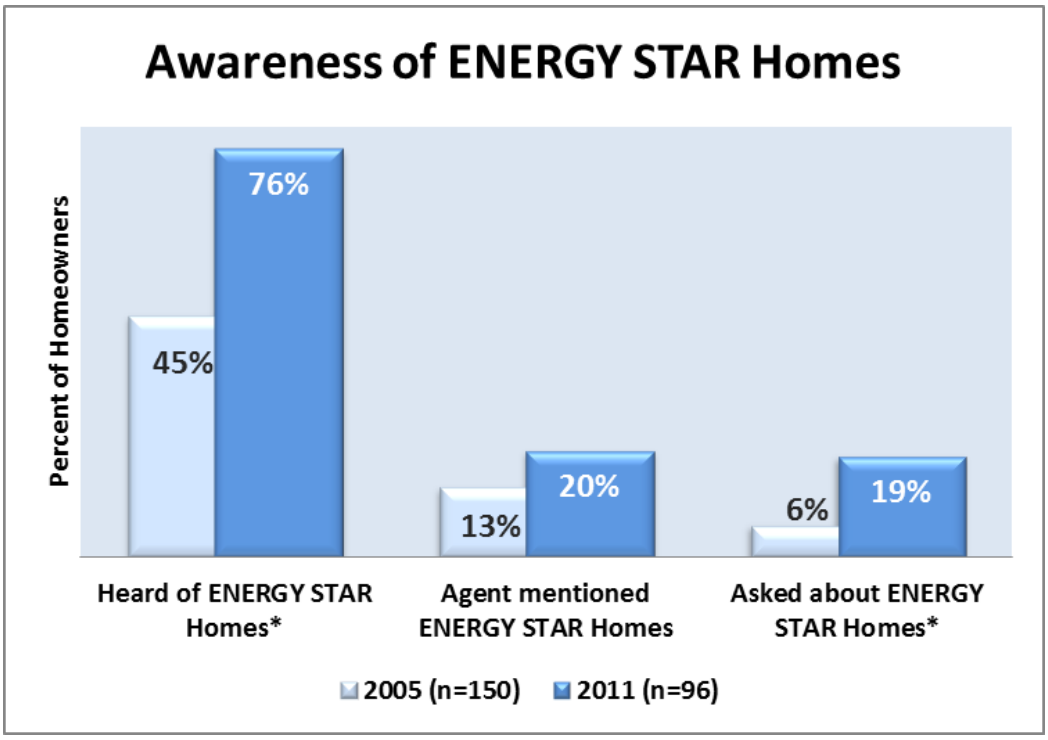
Figure 8-25: Homeowner Perception of Energy Efficiency of Their Home – 2011 Compared to 2005



*Significantly different at the 90% confidence level.

Awareness of ENERGY STAR-labeled homes increased between the 2011 and 2005 studies (Figure 8-26). Over three-quarters (76%) of the 2011 homeowners said that they had seen or heard of a newly constructed home being referred to as an ENERGY STAR Home, compared to less than one-half (45%) of the 2005 homeowners. In addition, nearly one in five (19%) of the 2011 homeowners said they asked their builder or real estate agent about ENERGY STAR Homes during the home buying process. In comparison, fewer than one in ten (6%) of the 2005 homeowners said they asked their builder or real estate agent about ENERGY STAR Homes. These results are statistically significant at the 90% confidence level. While the proportion of homeowners who said their builder or real estate agent talked about ENERGY STAR Homes increased from 13% in 2005 to 20% in 2011, this change is not statistically significant at the 90% confidence level.

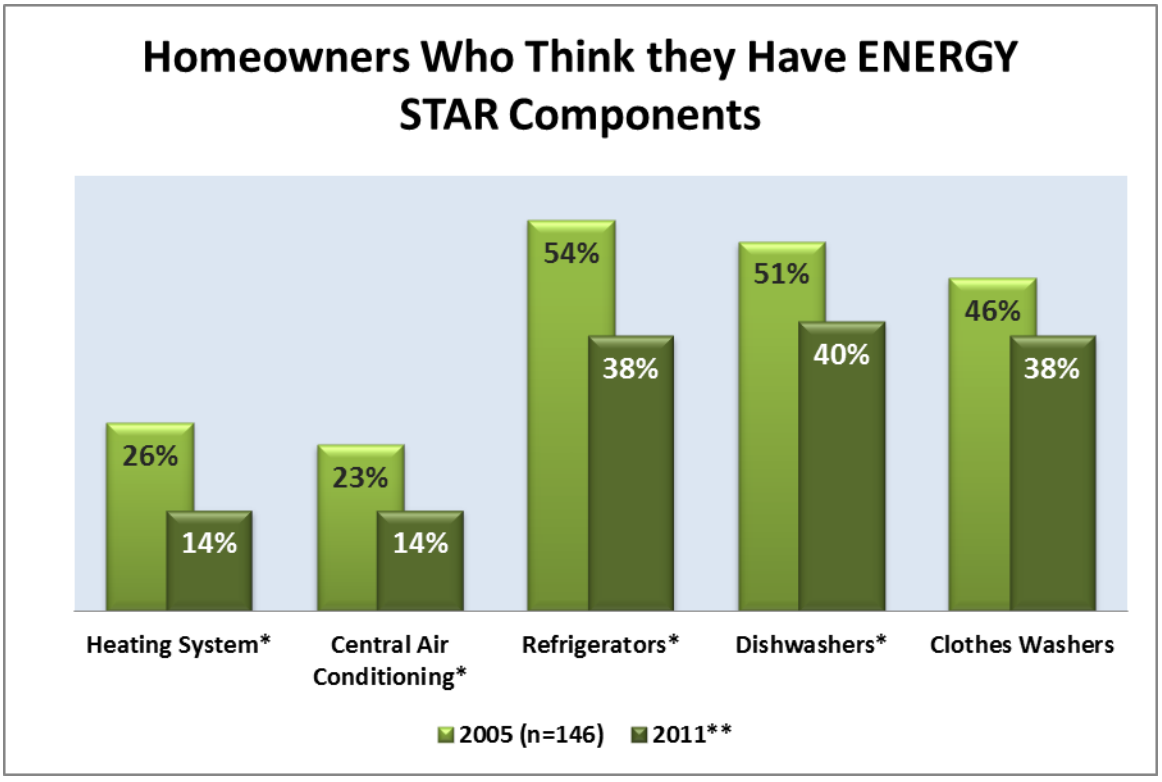
Figure 8-26: Homeowner Awareness of ENERGY STAR Homes – 2011 Compared to 2005



*Significantly different at the 90% confidence level.

Figure 8-27 displays the percentage of 2011 homeowners who think they have certain ENERGY STAR labeled components to those in the 2005 homeowner sample. The percentage of homeowners who said they have ENERGY STAR labeled heating systems, central air conditioning systems, refrigerators, dishwashers, and clothes washers decreased between the two studies. This change is statistically significant at the 90% confidence level for all of these components except clothes washers.

Figure 8-27: Homeowners Who Think they Have ENERGY STAR Components – 2011 Compared to 2005



*Significantly different at the 90% confidence level.

**n=96 except for central air conditioning (n=84), dishwashers (n=93), and clothes washers (n=86).

9 Building Envelope

9.1 Wall Insulation

Auditors recorded insulation information for all walls on the thermal boundary of homes. This includes conditioned/ambient, conditioned/garage, conditioned/unconditioned basement, and conditioned/attic walls. Information was also recorded for adiabatic walls (walls shared with an adjoining housing unit) and unconditioned basement/garage walls. Auditors described how each wall was framed and the type, R-value and grade of the insulation installation. Table 9-1 through Table 9-6 show the characteristics of each wall type for all inspected homes, detached homes, attached homes and weighted data reflecting the mix of single-family detached and attached housing in the 2011 Program.

Fiberglass batt insulation is clearly dominant—weighted percentages for walls insulated with only fiberglass batt insulation are 83% or higher for every wall category. Weighted average insulation levels range from R-12.4 in conditioned/unconditioned basement walls to R-19.2 in unconditioned basement/garage walls. Weighted framing data show 2 x 6 16 inch-on-center framing is predominant in all wall types except conditioned/unconditioned basement walls, where 2 x 4 16 inch-on-center framing predominates. Weighted data show insulation is most likely to be observable, or verifiable, in conditioned/attic walls and least likely in conditioned/garage walls. Auditors assigned a Grade I rating (the best rating) to insulation installation in only a few homes. For all but conditioned/attic walls, both raw and weighted data show Grade II installations are the most common. Weighted results for conditioned/attic walls are 1% Grade I, 46% Grade II, and 53% Grade III.

Table 9-1: Characteristics of Conditioned/Ambient Walls

Conditioned/Ambient Walls	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Average R-value	19.4	19.5	17.6	18.5
Framing				
2 x 4 16" On Center	7 (7%)	5 (5%)	2 (29%)	17%
2 x 6 16" On Center	92 (92%)	87 (94%)	5 (71%)	83%
2 x 6 24" On Center	1 (1%)	1 (1%)	0 (0%)	1%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	22 (22%)	21 (23%)	1 (14%)	18%
Grade I Installation	9 (9%)	8 (9%)	1 (14%)	11%
Grade II Installation	56 (56%)	52 (56%)	4 (57%)	57%
Grade III Installation	35 (35%)	33 (35%)	2 (29%)	32%
Only Fiberglass Batt	92 (92%)	86 (92%)	6 (86%)	89%

Table 9-2: Characteristics of Conditioned/Garage Walls

Conditioned/ Garage Walls	All Homes (n=71)	Detached Homes (n=66)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Average R-value	18.1	18.2	16.6	17.4
Framing				
2 x 4 16" On Center	15 (21%)	13 (20%)	2 (40%)	30%
2 x 6 16" On Center	55 (77%)	52 (79%)	3 (60%)	70%
2 x 6 24" On Center	1 (1%)	1 (2%)	0 (0%)	1%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	13 (18%)	13 (20%)*	0 (0%)*	10%
Grade I Installation	5 (7%)	5 (8%)*	0 (0%)*	4%
Grade II Installation	44 (62%)	41 (62%)	3 (60%)	61%
Grade III Installation	22 (31%)	20 (30%)	2 (40%)	35%
Fiberglass Batt	67 (94%)	62 (94%)*	5 (100%)*	97%

* Significantly different at the 90% confidence level.

Table 9-3: Characteristics of Conditioned/Attic Walls

Conditioned/Attic Walls	All Homes (n=64)	Detached Homes (n=59)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Average R-value	17.2	17.3	16.2	16.8
Framing				
2 x 4 16" On Center	21 (33%)	19 (32%)	2 (40%)	36%
2 x 6 16" On Center	41 (64%)	38 (64%)	3 (60%)	62%
2 x 6 & 2 x 4 x 16" On Center	2 (3%)	2 (3%)	0 (0%)	2%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	28 (44%)	28 (47%)*	0 (0%)*	24%
Grade I Installation	1 (2%)	1 (2%)	0 (0%)	1%
Grade II Installation	22 (34%)	19 (32%)	3 (60%)	46%
Grade III Installation	41 (64%)	39 (66%)	2 (40%)	53%
Fiberglass Batt	60 (94%)	55 (93%)*	5 (100%)*	97%

* Significantly different at the 90% confidence level.

Table 9-4: Characteristics of Conditioned/Unconditioned Basement Walls

Conditioned/ Unconditioned Basement Walls	All Homes (n=59)	Detached Homes (n=56)	Attached Homes (n=3)	Weighted (Detached/ Attached)
Average R-value	13.0	13.0	11.7	12.4
Framing				
2 x 4 16" On Center	49 (83%)	46 (82%)*	3 (100%)*	91%
2 x 6 16" On Center	9 (15%)	9 (16%)*	0 (0%)*	8%
2 x 6 24" On Center	1 (2%)	1 (2%)	0 (0%)	1%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	15 (25%)	15 (27%)*	0(0%)*	14%
Grade I Installation	2 (3%)	2 (4%)	0(0%)	2%
Grade II Installation	42 (71%)	39 (70%)*	3 (100%)*	85%
Grade III Installation	14 (24%)	14 (25%)*	0(0%)*	13%
Fiberglass Batt	57 (97%)	54 (96%)	3 (100%)	98%

* Significantly different at the 90% confidence level.

Table 9-5: Characteristics of Unconditioned Basement/Garage Walls

Unconditioned Basement/Garage Walls	All Homes (n=14)	Detached Homes (n=13)	Attached Homes (n=1)	Weighted (Detached/ Attached)
Average R-value	17.7	17.5	21.0	19.2
Framing				
2 x 4 16" On Center	4 (29%)	4 (31%)	0(0%)	16%
2 x 6 16" On Center	10 (71%)	9 (69%)	1 (100%)	84%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	4 (29%)	4 (31%)	0 (0%)	16%
Grade II Installation	10 (71%)	9 (69%)	1 (100%)	84%
Grade III Installation	4 (29%)	4 (31%)	0(0%)	16%
Fiberglass Batt	14 (100%)	13 (100%)	1 (100%)	100%

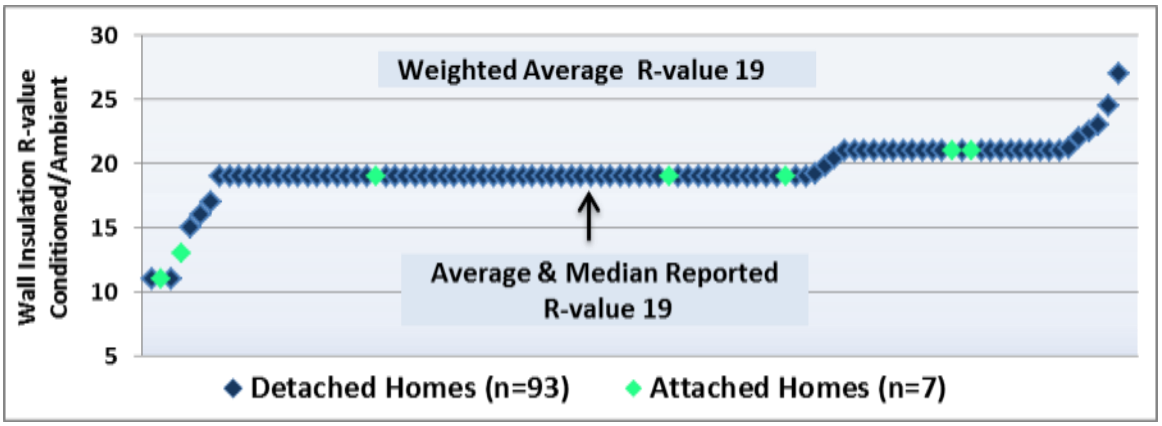
Table 9-6: Characteristics of Adiabatic Walls

Adiabatic Walls R-value	All Homes (n=6)	Detached Homes (n=0)	Attached Homes (n=6)	Weighted (Detached/ Attached)
Average R-value	16.7		16.7	16.7
Framing				
2 x 4 16" On Center	2 (33%)		2 (33%)	2 (33%)
2 x 6 16" On Center	4 (67%)		4 (67%)	4 (67%)
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	1 (17%)		1 (17%)	17%
Grade I Installation	1 (17%)		1 (17%)	17%
Grade II Installation	4 (67%)		4 (67%)	67%
Grade III Installation	1 (17%)		1 (17%)	17%
Fiberglass Batt	5 (83%)		5 (83%)	83%

9.1.1 Conditioned/Ambient Walls

Because of their greater importance in overall home energy efficiency, the remainder of this section focuses on the efficiency of conditioned/ambient walls. As reported above, the average recorded insulation level in conditioned/ambient walls is R-19.4 and the weighted average is R-18.5 (rounds to R-19). Figure 9-1 graphs the individual recorded R-values in conditioned/ambient walls for all 100 inspected homes.

Figure 9-1: Recorded R-Value for Conditioned/Ambient Wall Insulation



As described earlier, fiberglass batts continue to be the insulation of choice and in a large majority of the 100 inspected homes (83%) conditioned/ambient wall framing is 2 x 6 studs 16 inch-on-center. Table 9-7 shows the average R-value is higher in detached homes (R-19.5) than in attached homes (R-17.6), but this difference is not significant at the 90% confidence level; the weighted average is R-18.5. With respect to prescriptive insulation requirements, 30 of the 100 inspected homes meet or exceed the 2009 IECC prescriptive insulation requirement: the weighted percentage is 29%.

Table 9-7: Conditioned/Ambient Wall Statistics

Conditioned/Ambient Wall Statistics	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted* (Detached/ Attached)
Minimum R-value	11.0	11.0	11.0	11.0
Maximum R-value	27.0	27.0	21.0	27.0
Average R-value	**19.4**	**19.5**	**17.6**	**18.5**
Median R-value	19.0	19.0	19.0	19.0
Comparison to 2009 IECC (R-20)				
Less Than R-20 or R-13+5	70 (70%)	65 (70%)	5 (71%)	71%
R-20 or R-13+5	0 (0%)	0 (0%)	0 (0%)	0%
More Than R-20 or R-13+5	30 (30%)	28 (30%)	2 (29%)	29%

*Only the average is weighted.

9.1.2 Who Specified Framing and Insulation

Ninety-four homeowners completed the on-site survey, but not all owners responded to all questions. Therefore, the numbers of responses on which presented results are based vary. The on-site homeowner survey asked who specified the framing and insulation. The choices were:

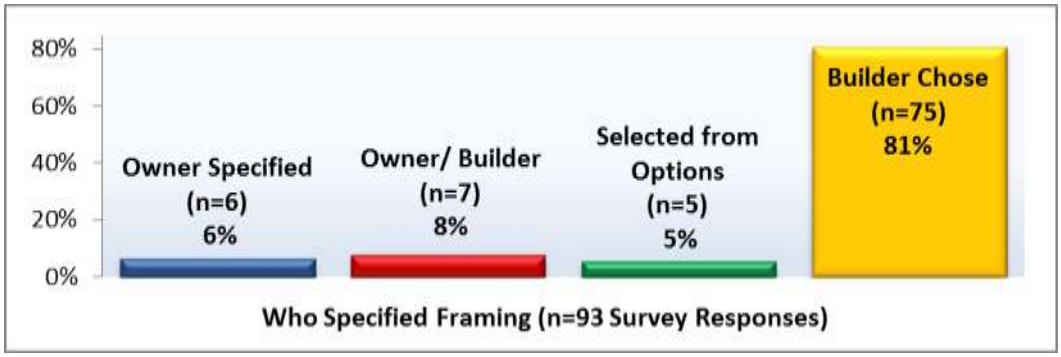
- I specified (Note that owners who are also the builder are treated as a separate category in this section.)
- Builder chose
- Selected from options offered by the builder
- Do not remember or do not know

Homeowners were not asked what type of framing was used or what type or level of insulation was installed. If they responded that they specified the insulation, they were asked, "Do you remember what you specified?" If they remembered, they were asked to check all options that applied; the two options were "Type of Insulation" and "Level of Insulation."

Framing

Figure 9-2 shows builders chose the type of framing for most homes (81%). Thirteen owners, including seven who built their own homes, say they specified the type of framing for their home, and five owners say they selected from framing options offered by their builder. The actual type of framing does not vary by who specified the framing; all but six homes have 2 x 6 framing. Six homes have 2 x 4 framing. Builders specified the framing in these six homes, which include three homes that were purchased as finished homes (two detached and one attached), two detached homes in developments where the owner purchased a lot from the builder and selected a home plan, and one attached home that was purchased while under construction.

Figure 9-2: Who Specified Framing



Insulation

Figure 9-3 shows builders chose the type of insulation for most homes (78%). Nine owners say they specified the insulation for their home; four of these owners also say they specified the framing for their home. Of the nine owners who say they specified the insulation for their home,

four say they specified only the type of insulation and five say they specified both the type and level of insulation. The same seven owner/builders who say they specified the framing for their home say they specified the insulation. Five owners say they selected from insulation options offered by their builder.

Figure 9-3: Who Specified Insulation

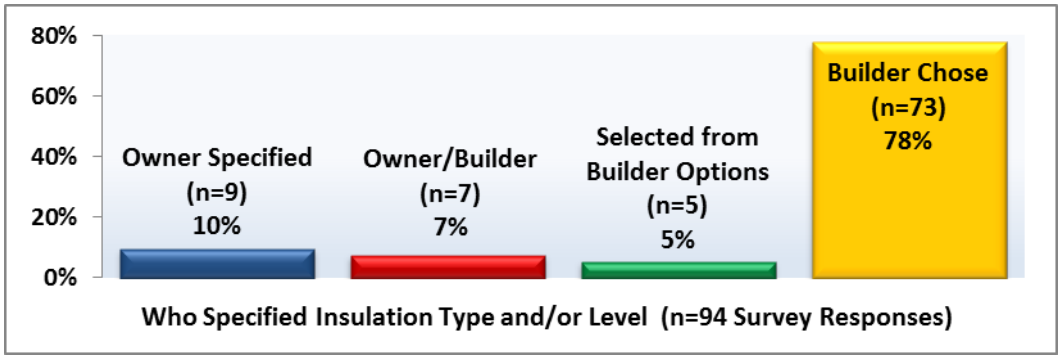


Figure 9-4 shows the average wall insulation R-value by who specified the insulation. As shown, R-values vary only slightly depending on who specified the insulation—from R-19.1 to R-20.5. However, the highest average R-values are for homes where the owner or owner/builder specified the insulation and the lowest average R-value is for homes where the builder specified the insulation without input from the owner.

Figure 9-4: Average Wall Insulation R-value by Who Specified

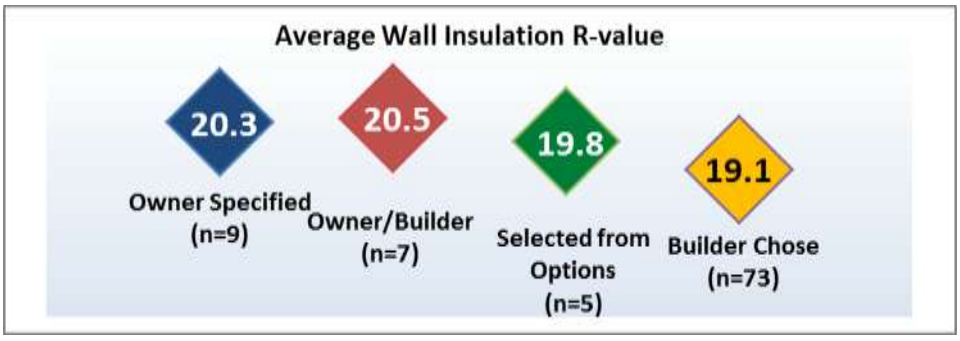
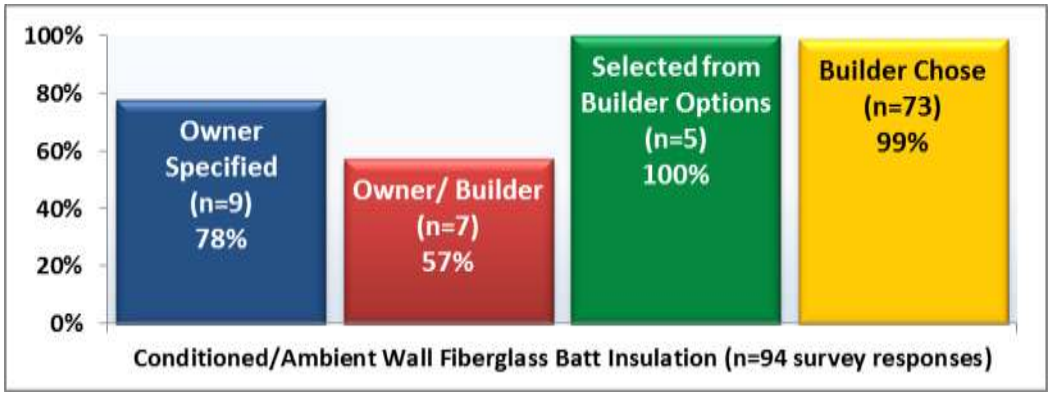


Figure 9-5 shows the incidence of fiberglass batt conditioned/ambient wall insulation by who specified the insulation. Owner/builders were least likely to specify fiberglass batt insulation; of the seven owner/builders who specified the insulation for their homes, four have homes with fiberglass batt insulation and three have homes with spray foam insulation in conditioned/ambient walls. Of the nine owners who specified the insulation for their home, seven have fiberglass batt insulation, one has spray foam insulation, and one has a combination of spray foam and fiberglass batt insulation in conditioned/ambient walls. All homes where owners selected insulation from options offered by the builder and all but one home where the builder

specified the insulation have fiberglass batt insulation in conditioned/ambient walls. In one home where the builder specified the insulation, conditioned/ambient walls are insulated with a combination of fiberglass batts and rigid foam.

Figure 9-5: Incidence of Fiberglass Batt Insulation by Who Specified



Owners were asked to rate the energy efficiency of the type and the level of insulation in their homes. The choices were:

- Not Energy Efficient
- Average
- Very Energy Efficient
- ENERGY STAR Labeled
- Do Not Know

Figure 9-6 shows how owners perceive the energy efficiency of the type of insulation used in their home and Figure 9-7 shows the average conditioned/ambient wall R-value by how owners perceive the energy efficiency of the type of insulation used in their home. As shown, most owners think the type of insulation used in their home is average or very energy efficient. Of the four owners who think the type of insulation in their homes is ENERGY STAR labeled, two have R-19 fiberglass batt, one has R-21 fiberglass batt and one has R-22.5 spray foam insulation.

Figure 9-6: Perceived Energy Efficiency of Type of Insulation

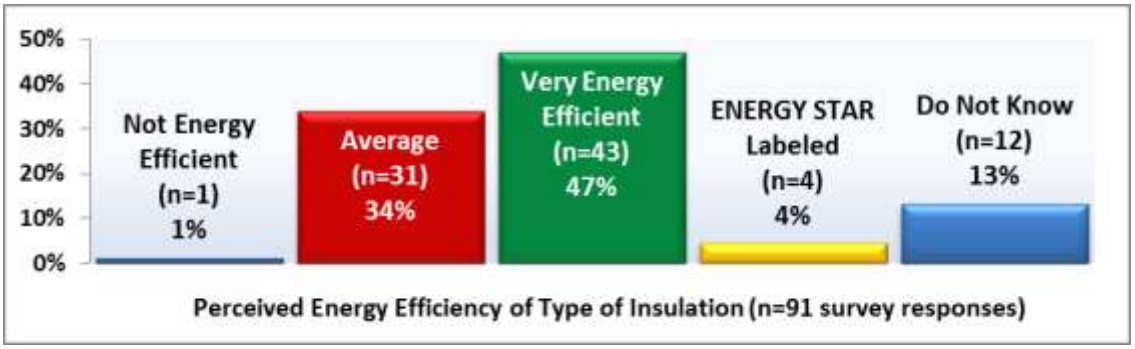


Figure 9-7 shows that average R-values vary only slightly depending on how energy efficient owners think the type of insulation used in their home is—from R-19.0 to R-20.4—except for the one owner who thinks the insulation in his home is not energy efficient and whose home has 2 x 4 framing insulated with R-11 fiberglass batts. Two other survey respondents have homes with 2 x 4 framed walls insulated with R-11 fiberglass batts; one of these owners thinks the type of insulation in his home is average and one thinks it is very energy efficient.

Figure 9-7: Average Wall Insulation R-value by Perceived Energy Efficiency of Type of Insulation

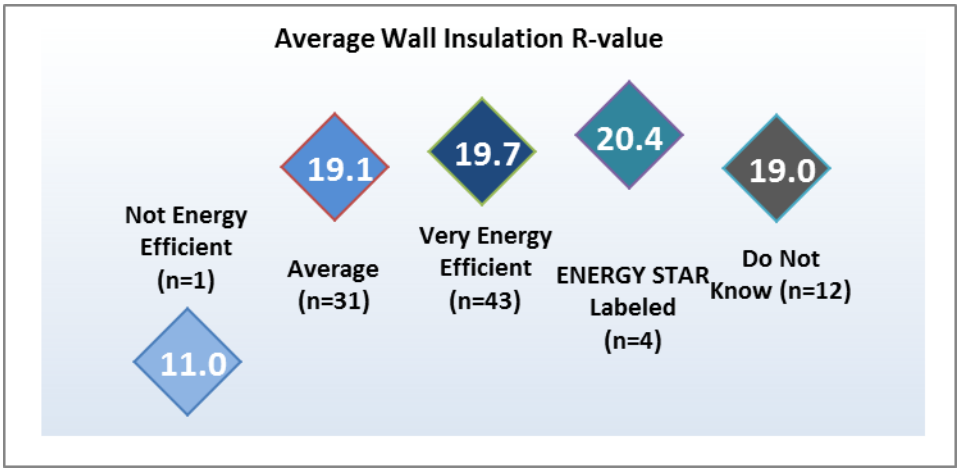


Figure 9-8 shows how owners perceive the energy efficiency of the level of insulation installed in their home and Figure 9-9 shows the average conditioned/ambient wall R-value by how owners perceive the energy efficiency of the level of insulation installed in their home.. As shown, most owners think the level of insulation installed in their home is average or very energy efficient.

Figure 9-8: Perceived Energy Efficiency of Level of Insulation

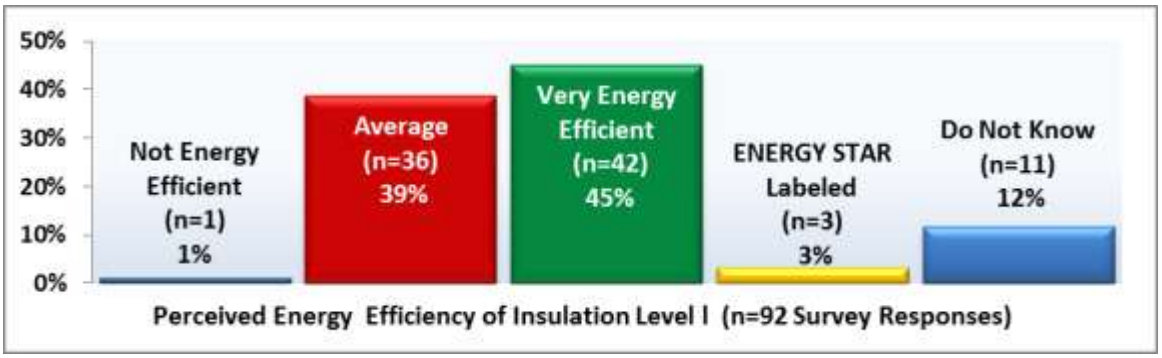
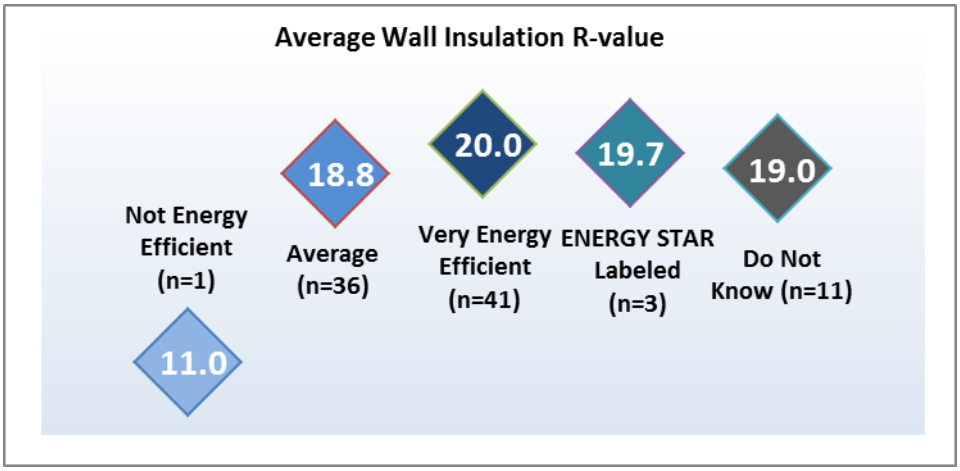


Figure 9-9 shows, once again, that average R-values vary only slightly depending on how energy efficient owners think the level of insulation installed in their home is—from R-18.8 to R-20.0—except for the one owner who thinks the insulation in his home is not energy efficient and whose home has 2 x 4 framed walls insulated with R-11 fiberglass batts. Both of the two other owners with 2 x 4 framed walls and R-11 fiberglass batts think the level of insulation in their home is average.

Figure 9-9: Average Wall Insulation R-value by Perceived Energy Efficiency of Level of Insulation



9.2 Ceiling Insulation

Auditors reported data for flat and cathedral (vaulted) attic insulation; 97 inspected homes have flat ceiling areas and 65 have cathedral ceiling areas. Table 9-8 and Table 9-9 show the characteristics of flat and cathedral ceilings for all inspected homes, detached homes, attached homes and weighted data reflecting the mix of single-family detached and attached housing in the 2011 Program. Auditors were able to verify the insulation in flat ceilings more often than in cathedral ceilings: the weighted averages of verified insulation installations are 89% for flat and 36% for cathedral ceilings. Weighted average insulation levels are R-36.3 for flat ceilings and R-35.4 for cathedral ceilings. The most common framing for both flat and cathedral ceilings is 2 x 10 16 inch-on-center, followed by 2 x 8 16 inch-on-center. The weighted percentage of 2 x 10 and 2 x 8 16 inch-on-center framing is 78% for flat and 94% for cathedral ceilings.

Once again, fiberglass batt insulation dominates. Weighted results are 92% for cathedral ceilings and 52% for flat ceilings. Grade I installations are reported for flat ceilings in 36 homes and for cathedral ceilings in 10 homes; none of the Grade I installations are for homes where only fiberglass batts were used.[30] Weighted results for flat ceilings are 40% Grade I, 42% Grade II and 18% Grade III and for cathedral ceilings 8% Grade I, 61% Grade II, and 31% Grade III.

[30] Auditors typically rated a ceiling insulation installation as Grade I if the insulation was a blown-in product that filled the cavity with no compression or if the ceiling insulation was some form of spray foam.

Table 9-8: Flat Ceiling Characteristics

Flat Ceilings	All Homes (n=97)	Detached Homes (n=90)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Average R-value	36.8	36.9	35.7	36.3
Framing				
2 x 4 x 24	5 (5%)	4 (4%)	1 (14%)	9%
2 x 6 x 16	4 (4%)	4 (4%)*	0 (0%)*	2%
2 x 8 x 16	28 (29%)	26 (29%)	2 (29%)	29%
2 x 10 x 16	41 (42%)	37 (41%)	4 (57%)	49%
2 x 12 x 16	7 (7%)	7 (8%)*	0 (0%)*	4%
Truss	5 (5%)	5 (6%)*	0 (0%)*	3%
Other	7 (7%)	7 (8%)*	0 (0%)*	4%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	78 (80%)	71 (79%) *	7 (100%)*	89%
Grade I Installation	36 (37%)	33 (37%)	3 (43%)	40%
Grade II Installation	40 (41%)	37 (41%)	3 (43%)	42%
Grade III Installation	21 (22%)	20 (22%)	1 (14%)	18%
Only Fiberglass Batt	58 (60%)	55 (61%)	3 (43%)	52%
Fiberglass Batts & Blown in Fiberglass	12 (12%)	11 (12%)	1 (14%)	13%
Blown-in Fiberglass	11 (11%)	10 (11%)	1 (14%)	13%
Cellulose	8 (8%)	6 (7%)*	2 (29%)*	17%
Other	8 (8%)	8 (8%)	0 (0%)	5%

* Significantly different at the 90% confidence level.

Table 9-9: Cathedral Ceiling Characteristics

Cathedral Ceilings	All Homes (n=65)	Detached Homes (n=62)	Attached Homes (n=3)	Weighted (Detached/ Attached)
Average R-value	35.5	35.5	35.3	35.4
Framing				
2 x 8 x 16	11 (17%)	10 (16%)	1 (33%)	25%
2 x 10 x 16	46 (71%)	44 (71%)	2 (67%)	69%
2 x 12 x 16	7 (11%)	7 (11%)*	0 (0%)*	6%
Truss	1 (2%)	1 (2%)	0 (0%)	1%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	25 (38%)	24 (39%)	1 (33%)	36%
Grade I Installation	10 (15%)	10 (16%)*	0 (0%)*	8%
Grade II Installation	36 (55%)	34 (55%)	2 (67%)	61%
Grade III Installation	19 (29%)	18 (29%)	1 (33%)	31%
Only Fiberglass Batt	55 (85%)	52 (84%)*	3 (100%)*	92%
Spray Foam	6 (9%)	6 (10%)*	0 (0%)*	5%
Blown-in Fiberglass	1 (2%)	1 (2%)	0 (0%)	1%
Cellulose	1 (2%)	1 (2%)	0 (0%)	1%
Blown in cellulose & Rigid Foam	1 (2%)	1 (2%)	0 (0%)	1%
Icynene & Rigid Foam	1 (2%)	1 (2%)	0 (0%)	1%

* Significantly different at the 90% confidence level.

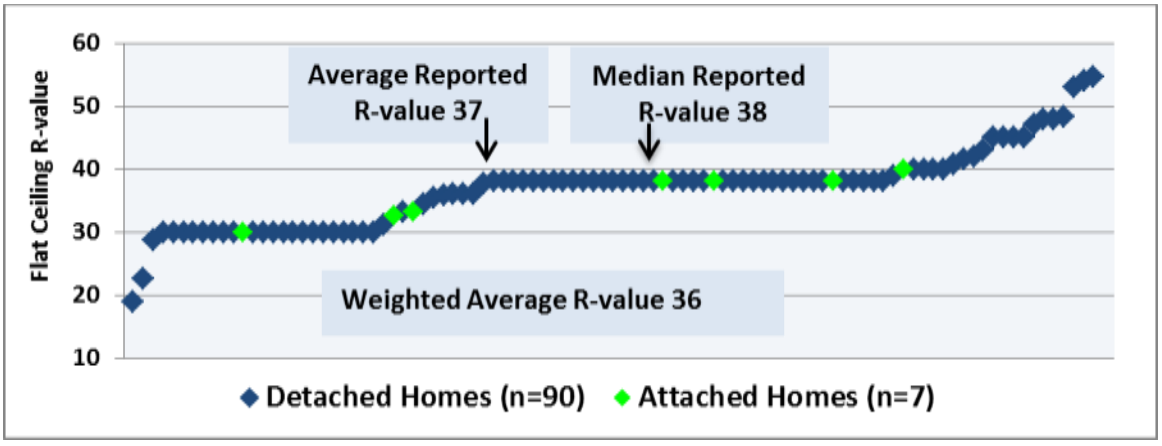
Table 9-10 and Table 9-11 show weighted average insulation levels of R-36.3 for flat ceilings and R-35.4 for cathedral ceilings. Reported flat ceiling insulation levels range from R-19.0 to R-54.6 in detached homes and from R-30 to R-40 in attached homes. With respect to prescriptive insulation requirements, 61 of the 97 inspected homes with flat ceiling areas meet or exceed the 2006 and 2009 IECC prescriptive insulation requirement of R-38 insulation in flat ceilings; the weighted percentage is 60%. Figure 9-10 graphs the individual recorded flat ceiling insulation R-values for all 97 inspected homes with flat ceiling areas.

Table 9-10: Flat Ceiling Insulation Statistics and Compliance

Flat Ceiling Insulation R-value Statistics	All Homes (n=97)	Detached Homes (n=90)	Attached Homes (n=7)	Weighted* (Detached/ Attached)
Minimum R-value	19.0	19.0	30.0	19.0
Maximum R-value	54.6	54.6	40.0	54.6
Average R-value	**36.8**	**36.9**	**35.7**	**36.3**
Median R-value	38.0	38.0	38.0	38.0
Comparison to 2006 & 2009 IECC (R-38 in Flat Ceilings)				
Less Than R-38	36 (37%)	33 (37%)	3 (43%)	40%
R-38	40 (41%)	37 (41%)	3 (43%)	42%
More Than R-38 and Not More Than 500 sq. ft. Lower Than R-38	21 (22%)	20 (22%)	1 (14%)	18%

*Only the average is weighted.

Figure 9-10: Recorded Flat Ceiling Insulation R-values



For cathedral ceilings, both 2006 and 2009 IECC allow for R-30 insulation in up to 500 square feet of ceiling area without attic spaces, where the design of the roof/ceiling assembly does not allow sufficient space for R-38 insulation. Factoring this allowance into the percentage of homes meeting prescriptive insulation requirements, 54 of the 65 inspected homes with cathedral ceiling areas meet or exceed the 2006 and 2009 IECC prescriptive insulation level requirement for

cathedral ceilings; the weighted percentage is 91%. Figure 9-11 graphs the individual recorded cathedral ceiling insulation R-values for all 65 inspected homes with cathedral ceilings.

Table 9-11: Cathedral Ceiling Insulations Statistics

Cathedral Ceiling Insulation R-value Statistics	All Homes (n=65)	Detached Homes (n=62)	Attached Homes (n=3)	Weighted** (Detached/ Attached)
Minimum R-value	24.0	24.0	30.0	24.0
Maximum R-value	48.5	48.5	38.0	48.5
Average R-value	**35.5**	**35.5**	**35.3**	**35.4**
Median R-value	38.0	38.0	38.0	38.0
Comparison to 2006 & 2009 IECC (R-38 or R-30 in not more than 500 Square Feet of Cathedral Ceiling Area)				
Less Than R-38 and/or More Than 500 sq. ft. Lower Than R-38	11 (17%)	**11 (18%)***	**0 (0%)***	9%
R-38 and/or Not More Than 500 sq. ft. Lower Than R-38	51 (78%)	**48 (77%)***	**3 (100%)***	89%
More Than R-38 and/or Not More Than 500 sq. ft. Lower Than R-38	3 (5%)	**3 (5%)***	**0 (0%)***	2%

* Significantly different at the 90% confidence level.
**Only the average is weighted.

Figure 9-11: Recorded Cathedral Ceiling R-values

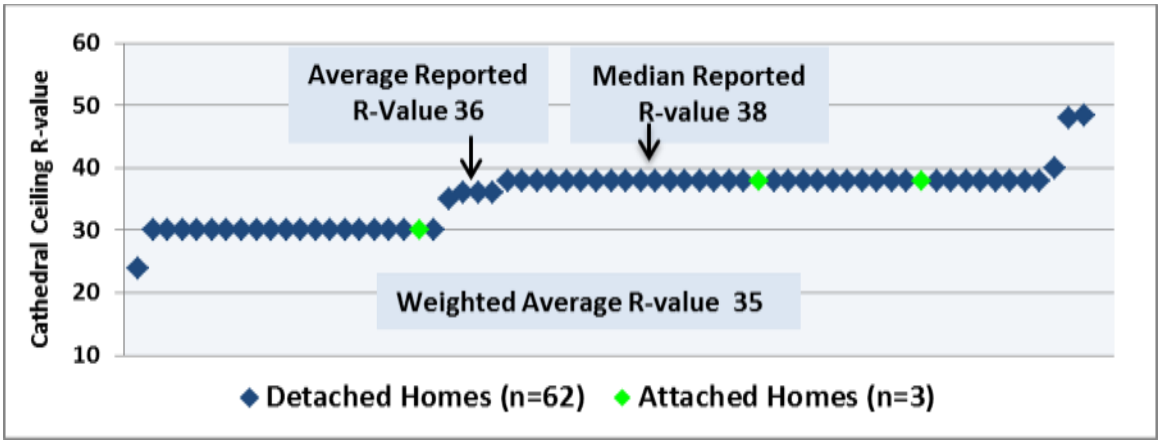


Table 9-12 shows overall how many inspected homes meet 2009 IECC prescriptive requirements for ceiling insulation. In this table, meeting requirements means both flat and cathedral ceiling areas in a home meet prescriptive requirements. The percentages of homes meeting requirements are lower than when looking at just flat or just cathedral ceilings; the weighted percentage is 58%.

Table 9-12: Overall Ceiling Insulation Statistics

Flat & Cathedral Ceiling Insulation Comparison to 2009 IECC Prescriptive Requirements	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Comparison to 2006 & 2009 IECC (R-38 in Flat Ceilings and R-30 in not more than 500 Square Feet of Cathedral Ceiling Area)				
Flat < R-38 and/or Cathedral > 500 sq. ft. < R-38	40 (40%)	37 (40%)	3 (43%)	41%
R-38 Flat and Cathedral ≤ 500 sq. ft. < R-38	49 (49%)	46 (49%)	3 (43%)	46%
Flat > R-38 and ≤ 500 sq. ft. < R-38	11 (11%)	10 (11%)	1 (14%)	12%

9.3 Floor Insulation

Auditors recorded data on floor insulation between conditioned spaces and unconditioned basements, crawl spaces, garages and outside air. Table 9-13 through Table 9-15 show the characteristics of each floor type, except conditioned/crawl space floors[31], for all inspected homes, detached homes, attached homes and weighted data reflecting the mix of single-family detached and attached housing in the 2011 Program. Weighted insulation levels are R-26.2 for conditioned/basement, R-27.2 for conditioned/garage, and R-25.0 for conditioned/ambient (outside air) floors.

Auditors were able to visually verify floor insulation, or the lack of insulation, for almost all floors over unconditioned basement space; weighted percentage is 99%. Insulation in conditioned/garage and conditioned/ambient floors are less likely to be verifiable; weighted percentages are 21% for conditioned/garage and 31% for conditioned/ambient floors. Auditors report only one home, a detached home, with no insulation in floor areas between conditioned and unconditioned space.

Fiberglass batt insulation and 2 x 10 16 inch-on-center framing dominate. Floors in almost all inspected homes are insulated with only fiberglass batts; weighted percentages are 98% for conditioned/basement floors, 99% for conditioned/garage floors, and 94% for conditioned/ambient floors. Weighted percentages for 2 x 10 16 inch-on-center framing are 63% for conditioned/basement floors, 69% for conditioned/garage floors, and 78% for conditioned/ambient floors.

[31] Only two detached homes had conditioned/crawl space floors--one had R-25 and one had R-40 insulation.

Auditors assigned a Grade I rating (the best) to floor insulation installations in only two homes. The Grade I ratings are for conditioned/garage and conditioned/ambient floors insulated with spray foam in one home and a conditioned/ambient floor insulated with open cell spray foam in another home; both of these homes have conditioned/basement floors with Grade III (the least efficient rating) fiberglass batt installations. Weighted Grade II insulation installation percentages are 34% for conditioned/basement, 54% for conditioned/garage, and 17% for conditioned/ambient floors. Weighted Grade III insulation installation percentages are 66% for conditioned/basement, 45% for conditioned/garage, and 79% for conditioned/ambient floors.

Table 9-13: Characteristics of Conditioned/Basement Floors

Conditioned/ Basement Floors	All Homes (n=85)	Detached Homes (n=80)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Average R-value	26.7	26.8	25.6	26.2
Framing				
2 x 8 16" On Center	5 (6%)	5 (6%)*	0 (0%)*	3%
2 x 10 12" On Center	2 (2%)	2 (3%)	0 (0%)	1%
2 x 10 16" On Center	56 (66%)	53 (66%)	3 (60%)	63%
2 x 12 16" On Center	13 (15%)	12 (15%)	1 (20%)	17%
2 X 10 12" & 16 " On Center	2 (2%)	1 (1%)	1 (20%)	10%
2 x 12 12" & 16" On Center	2 (2%)	2 (3%)	0 (0%)	1%
Other	5 (6%)	5 (6%)	0 (0%)	3%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	83 (98%)	78 (98%)	5 (100%)	99%
Grade I Installation	0 (0%)	0 (0%)	0 (0%)	0%
Grade II Installation	24 (29%)	22 (28%)	2 (40%)	34%
Grade III Installation	60 (71%)	57 (72%)	3 (60%)	66%
All Fiberglass Batts	82 (96%)	77 (96%)*	5 (100%)*	98%
Fiberglass Batts (no insulation in some areas)	2 (2%)	2 (3%)	0 (0%)	1%
No Insulation	1 (1%)	1 (1%)	0 (0%)	1%

* Significantly different at the 90% confidence level.

Table 9-14: Characteristics of Conditioned/Garage Floors

Conditioned/ Garage Floors	All Homes (n=51)	Detached Homes (n=47)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Average R-value	27.2	27.2	27.3	27.2
Framing				
2 x 8 16" On Center	5 (10%)	5 (11%)*	0 (0%)*	5%
2 x 10 12" On Center	2 (4%)	2 (4%)	0 (0%)	2%
2 x 10 16" On Center	33 (65%)	30 (64%)	3 (75%)	69%
2 x 12 16" On Center	7 (14%)	6 (13%)	1 (25%)	19%
Other	4 (8%)	4 (9%)	0 (0%)	4%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	19 (37%)	19 (40%)*	0 (0%)*	21%
Grade I Installation	1 (2%)	1 (2%)	0 (0%)	1%
Grade II Installation	19 (37%)	16 (34%)	3 (75%)	54%
Grade III Installation	31 (61%)	30 (64%)	1 (25%)	45%
Fiberglass Batts	50 (98%)	46 (98%)	4 (100%)	99%
Icynene	1 (2%)	1 (2%)	0 (0%)	1%

* Significantly different at the 90% confidence level.

Table 9-15: Characteristics of Conditioned/Ambient Floors

Conditioned/ Ambient Floors	All Homes (n=28)	Detached Homes (n=25)	Attached Homes (n=3)	Weighted (Detached/ Attached)
Average R-value	26.8	27.3	22.7	25.0
Framing				
2 x 8 16" On Center	1 (4%)	1 (4%)	0 (0%)	2%
2 x 10 12" On Center	3 (11%)	3 (12%)	0 (0%)	6%
2 x 10 16" On Center	17 (61%)	14 (56%)	3 (100%)	78%
2 x 12 16" On Center	5 (18%)	5 (20%)	0 (0%)	10%
Other	2 (7%)	2 (8%)	0 (0%)	4%
Insulation Verified, Installation Grade and Percent Fiberglass Batt				
Insulation Verified	8 (29%)	7 (28%)	1 (33%)	31%
Grade I Installation	2 (7%)	2 (8%)	0 (0%)	4%
Grade II Installation	8 (30%)	8 (33%)	0(0%)	17%
Grade III Installation	17 (63%)	14 (58%)	3 (100%)	79%
Fiberglass Batts	25 (89%)	22 (88%)	3 (100%)	94%
Spray Foam	2 (7%)	2 (8%)	0 (0%)	4%
No Insulation	1 (4%)	1 (4%)	0 (0%)	2%

Table 9-16 summarizes weighted floor insulation R-value statistics and comparisons with prescriptive insulation requirements. As shown, weighted average R-values are similar for conditioned/basement, conditioned garage, and conditioned/ambient floors; R-values range from R-25 for conditioned/ambient floors to R-27 for conditioned garage floors. The percentages of homes meeting prescriptive insulation requirements are more variable across floor categories.

The prescriptive floor insulation requirement under both 2006 and 2009 IECC is R-30 or a minimum of R-19 if the insulation fills the framing cavity. Weighted percentages of homes meeting prescriptive floor insulation requirements are 65% for conditioned/basement, 72% for conditioned/garage, and 55% for conditioned/ambient floors.

Table 9-16: Weighted Floor Insulation Statistics

Floor Insulation R-value Statistics	Conditioned/ Basement Weighted* (Detached/ Attached)	Conditioned/ Garage Weighted* (Detached/ Attached)	Conditioned/ Ambient Weighted* (Detached/ Attached)
Minimum R-value	0	19	0
Maximum R-value	38	38	40
Weighted Average R-value	**26**	**27**	**25**
Median R-value	30	30	30
Comparison to 2006 & 2009 IECC: R-30 or Filled Cavity (Min R-19)			
Less Than R-30 or Cavity Filled < R-19	35%	27%	45%
R-30 or Cavity Filled R-19	64%	70%	51%
More Than R-30 or Cavity Filled > R-19	1%	2%	4%

*Only the average is weighted.

Table 9-17 through Table 9-19 provide statistics for all inspected homes, detached homes, attached homes and weighted data reflecting the mix of single-family detached and attached housing in the Program. Figure 9-12 graphs the individual recorded conditioned/basement insulation R-values for the 85 inspected homes with floors over unconditioned basement space.

Table 9-17: Condition/Basement Floor Statistics

Insulation R-value Statistics Floors over Unconditioned Basements	All Homes (n=85)	Detached Homes (n=80)	Attached Homes (n=5)	Weighted* (Detached/ Attached)
Minimum R-value	0.0	0.0	19.0	0.0
Maximum R-value	38.0	38.0	30.0	38.0
Average R-value	**26.7**	**26.8**	**25.6**	**26.2**
Median R-value	30.0	30.0	30.0	30.0
Comparison to 2006 & 2009 IECC: R-30 or Filled Cavity (Min R-19)				
Less Than R-30 or Cavity Filled < R-19	26 (31%)	24 (30%)	2 (40%)	35%
R-30 or Cavity Filled R-19	57 (67%)	54 (68%)	3 (60%)	64%
More Than R-30 or Cavity Filled > R-19	2 (2%)	2 (3%)	0 (0%)	1%

*Only the average is weighted.

Figure 9-12: Recorded Insulation R-values for Floors over Unconditioned Basements

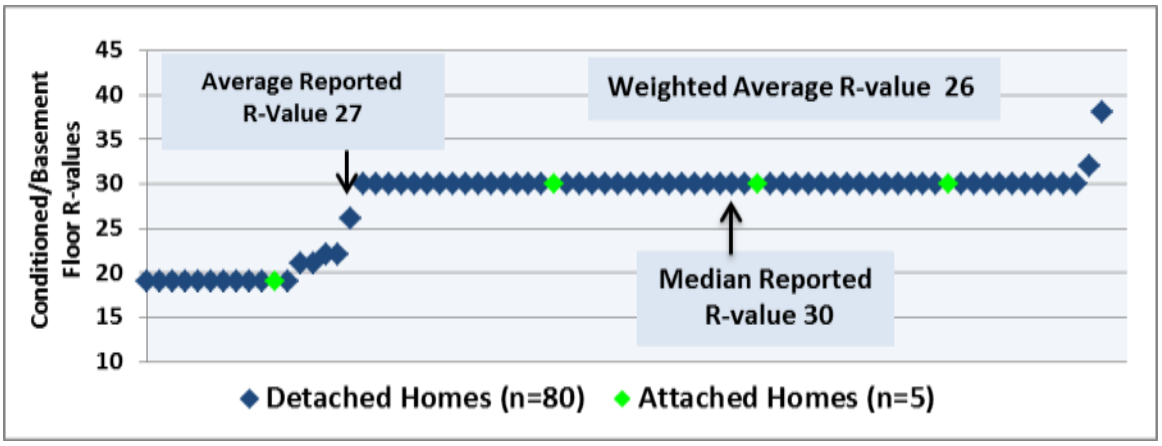


Table 9-18: Conditioned/Garage Floor Statistics

Insulation R-value Statistics Conditioned/Garage Floors	All Homes (n=51)	Detached Homes (n=47)	Attached Homes (n=5)	Weighted* (Detached/ Attached)
Minimum R-value	19	19	19	19
Maximum R-value	38	38	30	38
Average R-value	**27**	**27**	**27**	**27**
Median R-value	30	30	30	30
Comparison to 2006 & 2009 IECC: R-30 or Filled Cavity (min R-19)				
Less Than R-30 or Cavity Filled < R-19	15 (29%)	14 (30%)	1 (25%)	27%
R-30 or Cavity Filled R-19	34 (67%)	31 (66%)	3 (75%)	70%
More Than R-30 or Cavity Filled > R-19	2 (4%)	2 (4%)	0 (0%)	2%

*Only the average is weighted.

Table 9-19: Conditioned/Ambient Floor Statistics

Insulation R-value Statistics Conditioned/Ambient Floors	All Homes (n=28)	Detached Homes (n=25)	Attached Homes (n=3)	Weighted* (Detached/ Attached)
Minimum R-value	0	0	19	0
Maximum R-value	40	40	30	40
Average R-value	**27**	**27**	**23**	**25**
Median R-value	30	30	19	30
Comparison to 2006 & 2009 IECC: R-30 or Filled Cavity (min R-19)				
Less Than R-30 or Cavity Filled < R-19	8 (29%)	6 (24%)	2 (67%)	45%
R-30 or Cavity Filled R-19	18 (64%)	17 (68%)	1 (33%)	51%
More Than R-30 or Cavity Filled > R-19	2 (7%)	2 (8%)	0 (0%)	4%

*Only the average is weighted.

9.4 Windows

Auditors recorded the type(s) of windows in each home, but found it difficult to verify the U-value and solar heat gain coefficient (SHGC) for most windows.[32] Documented U-value and SHGC information was available for 18 homes where the original NFRC (National Fenestration Rating Council) sticker was visible. Auditors had access to the U-value and/or SHGC, or to information with which they could estimate the U-value and/or SHGC (such as the window manufacturer and series listed in a home's plans) for an additional 13 homes. Bearing in mind that the data were available for less than one-third of the sample and therefore are not representative of all 100 homes, the U-values auditors gathered range from 0.29 to 0.35, with an average of 0.31. Similarly, the SHGCs auditors were able either to observe or reasonably estimate range from 0.19 to 0.39, with an average of 0.28. The majority (24) of the 31 homes for which U-value and/or SHGC data were available are argon filled windows. All of these 31 homes meet the 2009 IECC prescriptive code requirement of maximum U-0.35.[33]

When homeowners could not provide information on the type of glazing in their windows, auditors used a lighter test, a flashlight test, or a Low-E coating detector to determine if the windows had a Low-E coating.[34] Although auditors were not able to test for argon fill, in some cases they were able to estimate if a window had argon fill based on one or more of the following: the window manufacturer and series, verbal confirmation from the homeowner or builder, or inspection of the window frame for the presence of plugs in the window frame visible between the panes of glass, which is typical of argon filled windows.

[32] The U-value is the direct inverse of the R-value; a higher U-value means a window is less efficient, allowing more heat to enter into or escape from the window. The Pacific Northwest National Lab explains, "In number values, R-value is the direct inverse of U-value (R-value=1/U-value). If a material has a U-value of .5, it has an R-value of 2. If it has a U-value of .25, it has an R-value of 4." Likewise, a lower SHGC is also desirable from an efficiency standpoint; the lower the SHGC, the more solar energy it blocks, leading to lower cooling costs.

[33] There is no 2009 IECC SHGC requirement for the climate zone in which in Massachusetts is located.

[34] It is standard industry practice to use a lighter to determine whether or not a Low-E coating is present on windows; a lighter held up to the glass yields a different color flame if there is a Low-E glaze. If windows are not absolutely clean the Low-E coating detector can give different readings in different areas of a window.

REM/Rate and IECC default values for U-value and SHGC are shown in Table 9-20. REM/Rate defaults are more detailed—addressing more window categories—than IECC defaults.[35] However, both appear to be conservative. For example, auditors were able to verify the U-value of double pane Low-E argon windows, with vinyl frames, in 18 homes. Of those 18 homes, 16 had verified U-values of 0.31 or lower, which is more energy efficient than the REM/Rate default of U-0.33.

Table 9-20: REM/Rate and IECC Default Values for Missing Window Data

Operable Window Type	REM/Rate Defaults		2009 IECC Defaults	
	U-Value	SHGC	U-Value	SHGC
Double Pane Wood Frame	0.49	0.58	0.55	0.70
Double Pane Vinyl Frame	0.46	0.57		
Double Pane Fiberglass Frame	n/a	n/a		
Double Pane Low -E Vinyl Frame	0.36	0.45		
Double Pane Low-E Wood Frame	0.39	0.46		
Double Pane Low-E Argon Vinyl Frame	0.33	0.45		
Double Pane Low-E Argon Wood Frame	0.36	0.45		

In an effort to develop more realistic default window U-values, NMR evaluation team members talked to staff personnel at two large lumber yards that sell windows to builders of new homes and with five major window companies exhibiting at Build Boston: Andersen, Harvey, JELD-WEN, Marvin and Pella. Everyone said basically the same thing, that the standard today is an ENERGY STAR-qualified Low-E with argon window.

Representatives for Andersen, Pella, and Marvin windows say that, in most cases, Low-E windows without argon are special order. When asked what they estimated their share of the New England market for new construction windows was, the Andersen representative estimated 13% (7% nationally), the Marvin representative estimated 8%, and the Pella representative estimated 6%. All window representatives pointed out that there are many, many small manufacturers of windows selling to builders, and that some of these companies produce high quality windows and others produce low-end windows for builders unwilling to pay for ENERGY STAR-qualified windows.

One of the lumber yard representatives commented:

> *"Anecdotally, I see builders typically opting for the least expensive way to build which would mean Vinyl windows from Harvey Industries or Anderson 200 series.*[36] *As far as custom houses designed by Architects, I would say 99% are specified as an ENERGY STAR-rated window. There is really a huge difference between those custom homes and the spec houses being built out there."*

[35] Default values are from REM/Rate version 12.95. The REM/Rate default window values are based on the 2005 ASHRAE handbook.

[36] The Andersen representative said that the standard option for 200series windows is now Low-E with argon.

Given that representatives of the major window manufacturers say their standard windows are ENERGY STAR-rated Low-E with argon, and current Version 5.0 ENERGY STAR window criteria for Massachusetts are U-0.32 or lower, depending on the SHGC (See Table 9-21), we propose an overall default window U-value of 0.34. A U-0.34 window does not meet current ENERGY STAR criteria for Massachusetts, and the U-value is higher than the standard U-value reported by the representatives of major window manufacturers; it may even be conservative. Without more information on what the large number of small window manufacturers are promoting and selling, it seems premature to assume a lower default U-value.

Table 9-21: Version 5.0 Northern Climate ENERGY STAR Window Criteria

Northern Climate ENERGY STAR Window Criteria as of January 4, 2010[37]			
U-Factor	≤ 0.30	= 0.31	= 0.32
SHGC	Any	≥ 0.35	≥ 0.40

9.4.1 Window Types

Table 9-22 shows the percentages of homes with various windows types. As shown, the predominant weighted average window type is double pane Low-E vinyl framed (66%) followed by double pane Low-E argon vinyl framed (26%). As described earlier, the auditors tested for Low-E glazing, but not for argon fill. Therefore, the weighted average percentage of argon filled windows may in fact be higher than 33%. Attached homes are significantly more likely than detached homes to have double pane Low-E vinyl windows, and significantly less likely than detached homes to have wood framed windows.

Table 9-22: Inspected Homes by Type of Window

Predominant Window Type	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	All Homes Weighted (Detached/ Attached)
Double Pane Low-E Vinyl	49%	46%*	86%*	66%
Double Pane Low-E Argon Vinyl	35%	37%	14%	26%
Double Pane Low-E Argon Wood	12%	13%*	0%*	7%
Double Pane Low-E Wood	4%	4%*	0%*	2%

*Attached homes are significantly different from detached homes at the 90% confidence level.

[37] http://www.energystar.gov/ia/partners/prod_development/archives/downloads/windows_doors/WindowsDoorsSkylightsProgRequirements7Apr09.pdf

9.4.2 Glazing Percentage

Table 9-23 and Figure 9-13 provide statistics on glazing percentages. Glazing percentages are window area as a percentage of conditioned/ambient wall area per home. As shown, glazing percentages range from 8% to 33%; the weighted average is 15%.

Table 9-23: Window Glazing Percentage Statistics

Percent Glazing Percent of Conditioned/Ambient Wall Area	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)*
Minimum	8%	8%	10%	8%
Maximum	33%	33%	18%	33%
Average	**16%**	**16%**	**15%**	**15%**
Median	15%	15%	15%	15%

*Only the average is weighted.

Figure 9-13: Glazing Percentage by Home

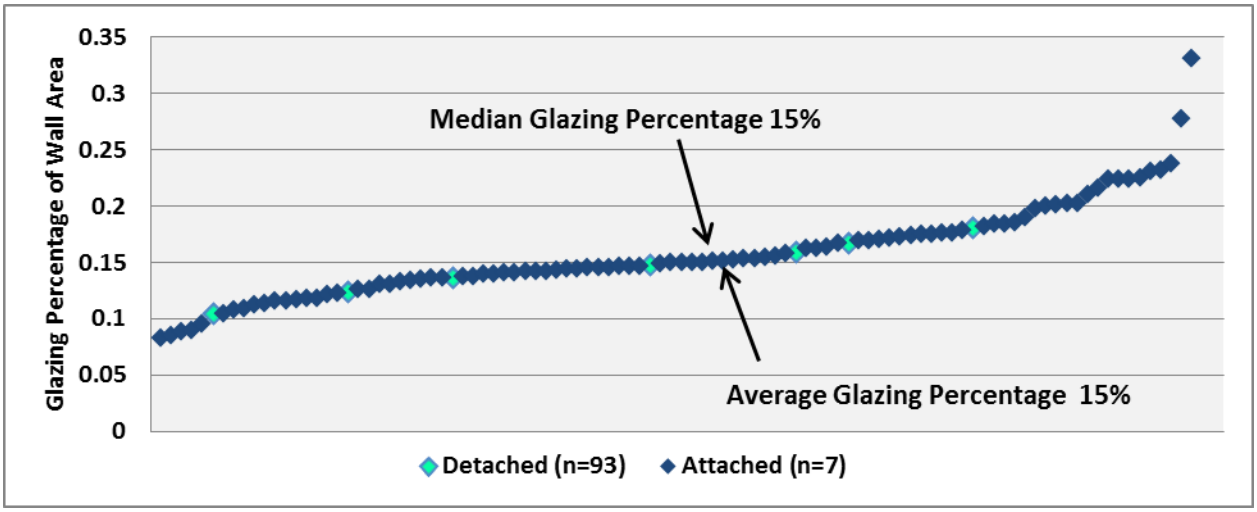


Table 9-24 shows the percent of south-oriented glazing per home. The percent of glazing oriented to the south ranges from zero to 73%; the weighted average is 42%.

Table 9-24: Percent of South Oriented Glazing

Percent of Exterior Wall South Glazing (S, SE, SW)	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)*
Minimum	0%	0%	29%	0%
Maximum	73%	73%	70%	73%
Average	**39%**	**39%**	**46%**	**42%**
Median	42%	42%	40%	42%

*Only the average is weighted.

9.4.3 Skylights

Only seven out of one hundred inspected homes have skylights. The data for skylights are questionable as auditors were often unable to reach the skylights to test for a Low-E glaze, let alone determine whether or not the skylights were argon filled. Auditors were able to confirm that two of the seven homes with skylights have skylights that are argon filled with a Low-E glaze.

9.5 Doors

Auditors recorded information on 378 doors in the 100 sampled homes. Note that auditors only recorded information on doors that are part of the thermal boundary; they did not record information on interior doors. Table 9-25 displays the weighted distribution of the types of doors. The weighted data show that fiberglass is the most common type of door.

Table 9-25: Type of Door

Door Type	All Doors Weighted (Detached/Attached) n=378
Fiberglass	51%
Wood	27%
Steel	22%

Table 9-26 shows the weighted percentage of doors with various characteristics. Most doors are insulated (84%), few have storm doors (13%), and almost one-half of the doors (47%) contain glazing. The weighted average glazing area in doors with glazing is 6.5 square feet. Nearly all of the doors with glazing (99%) have double pane Low-E, double pane clear or double pane Low-E glazing with argon.

Table 9-26: Door Characteristics

Door Characteristics	All Doors Weighted (Detached/Attached) n=378
Insulated	84%
Storm Door	13%
Glazing in Door	47%
Doors with Glazing Weighted (Detached/ Attached) (n=142)	
Avg. Sq. Ft. of Glazing/Door	6.5
Double Pane Low-E	64%
Double Pane (clear)	28%
Double Pane Low-E Argon	7%
Single Pane	1%

9.6 Slab Insulation

Auditors were instructed to collect slab data for homes with conditioned basements; 20 of the 100 audited homes have conditioned basements.[38] Table 9-27 displays the slab location for these 20 homes. Most homes with conditioned basements have slabs that are located both on-grade and below grade; the weighted percentage is 68%. This indicates that the majority of conditioned basements are walkouts.

Table 9-27: Slab Floor Location

Slab Floor Location	All Homes With Conditioned Basements Weighted (Detached/Attached) n=20
Mix (on/below grade)	68%
Below Grade	29%
On Grade	3%

For 11 of the 20 homes with conditioned basements, auditors were able to estimate whether or not the slab was insulated by consulting the home plans, the homeowner, or the builder. Nine of these 11 homes likely have uninsulated slabs. One homeowner with a below grade slab told auditors that the slab is insulated with R-10 extruded polystyrene. In another home, auditors were able to verbally confirm with the builder that the slab floor, which is a mix of both on and below grade, has R-5 extruded polystyrene insulation.

[38] For the purposes of this analysis conditioned basements include 18 finished basements that are directly conditioned and two unfinished basements where the foundation walls are fully insulated and clearly form the thermal/pressure boundary for the home.

9.7 Foundation Wall Insulation

By code, foundation walls in homes with conditioned basement space, where the conditioned space is bounded by a foundation wall, should be insulated. Code does not require foundation walls in homes with unconditioned basements or walls in conditioned basements where the conditioned space is not bounded by a foundation wall to be insulated. Twenty of the 100 homes have conditioned basement space bounded by foundation walls. Because the walls are typically finished (i.e. sheet rocked) in conditioned basements, the foundation wall insulation is not usually visible. Auditors were able to visually confirm the foundation wall insulation in 12 of the 20 homes, and recorded the insulation type, R-value, and whether the insulation was cavity or continuous. For the eight homes in which the foundation wall insulation was not visible, auditors estimated the foundation insulation characteristics based on stud depth and insulation types observed in other areas of the home. Please note this section only represents insulation that is in contact with the masonry foundation walls.[39] Table 9-28 displays the types of foundation wall insulation auditors recorded for these 20 homes. The majority of homes have fiberglass batt foundation wall insulation; the weighted percentage is 89%. One home with finished basement space has fiberglass batt insulation on a little over one-half of the foundation walls, but the rest of the foundation walls are uninsulated. Auditors assigned a Grade II rating to insulation installation in most homes; the weighted percentage is 76%.

Table 9-28: Type of Foundation Wall Insulation

Foundation Wall Insulation Type	All Homes with Conditioned Basements (n=20)	Detached Homes (n=19)	Attached Homes (n=1)	Weighted (Detached/ Attached)
% Insulation Visible	12 (60%)	12 (63%)	0 (0%)	32%
Insulation Type				
Fiberglass Batts	16 (80%)	15 (79%)	1 (100%)	89%
Rigid Foam	2 (10%)	2 (11%)	0 (0%)	5%
Structural Insulated Panels	1 (5%)	1 (5%)	0 (0%)	3%
Closed Cell Spray Foam	1 (5%)	1 (5%)	0 (0%)	3%
Installation Grade				
Grade I Installation	4 (20%)	4 (21%)	0 (0%)	11%
Grade II Installation	11 (55%)	10 (53%)	1 (100%)	76%
Grade III Installation	5 (25%)	5 (26%)	0 (0%)	13%

As shown in Table 9-29, the weighted average insulation level for homes with conditioned basement space bounded by foundation walls is R-16.6. Again, please note that this section is only reporting on insulation that is in contact with the foundation walls, not insulation that is in

[39] This section does not include insulation on top of masonry foundation walls. Walkout basements often have insulated wood-framed stud walls located on top of masonry foundation walls. These wood-framed walls are discussed in section 9.1Wall Insulation.

wood-framed stud walls on top of masonry foundation walls. The 2006 and 2009 IECC prescriptive code requirement for foundation wall insulation is the same: minimum R-10 for continuous insulation and R-13 for cavity insulation. Twelve out of 20 inspected homes with conditioned basements meet or exceed the prescriptive insulation requirement; the weighted percentage is 79%.

Table 9-29: Foundation Wall Statistics

Foundation Wall Insulation Level	All Homes with Conditioned Basements (n=20)	Detached Homes (n=19)	Attached Homes (n=1)	Weighted (Detached/ Attached)*
Minimum R-value	1.6	1.6	21.0	1.6
Maximum R-value	24.5	24.5	21.0	24.5
Average R-value	**12.7**	**12.3**	**21.0**	**16.6**
Median R-value	13.0	13.0	21.0	13.0
Comparison to 2009 IECC (R-10/13)				
Less Than R-10/13	8 (40%)	8 (42%)	0 (0%)	21%
R-10/13	6 (30%)	6 (32%)	0 (0%)	16%
More Than R-10/13	6 (30%)	5 (26%)	1 (100%)	63%

* Only the average is weighted.

9.8 Rim/Band Joist

Auditors recorded insulation information on all rim and band joists that were part of the thermal boundary and were not encompassed in other shell measures (i.e. frame floor). Insulating and air sealing rim/band joists is a mandatory requirement under the 2009 IECC. In general, rim joist insulation was visually verified while band joist insulation was not. In keeping with standard HERS rating practice, auditors assumed band joists were insulated similarly to conditioned/ambient walls so long as the walls above and below the joist were insulated when the home was built.[40] Rim joist insulation is often encompassed in the frame floor insulation. In many cases frame floor insulation extends all the way to the rim joist, in turn insulating the rim. In these cases rim joist insulation was not recorded as the rim joist is actually insulated by the frame floor insulation. The most pertinent example of this is in unconditioned basements where the frame floor insulation is separating the living space from the basement. In most of these cases the floor insulation is insulating the rim joist, removing the need to record rim joist insulation information.

[40] In a few instances the rim joist R-value was not the same as the exterior wall R-value. In these cases the band joist R-value was assumed to be the same as the rim joist, not the exterior walls.

Table 9-30 through Table 9-35 display a summary of the rim and band joist insulation recorded during the on-site visits.[41] The majority of rim and band joist insulation is located between conditioned spaces and ambient (outside) conditions. These joists have an average R-value of R-18.3 and 95% are spaced 16 inches apart. Weighted results indicate 21% Grade I insulation installations.

Table 9-30: Conditioned/Ambient Joists

Conditioned/Ambient	All Homes (n=86)	Detached Homes (n=79)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Average R-value	19.0	19.1	17.6	18.3
Framing				
Joist 16" On Center	79 (92%)	**72 (91%)***	**7 (100%)***	95%
Other spacing	7 (8%)	7 (9%)	0 (0%)	5%
Insulation Installation Grade[1][2]				
Grade I Installation	12 (14%)	10 (13%)	2 (29%)	21%
Grade II Installation	37 (44%)	34 (44%)	3 (43%)	43%
Grade III Installation	36 (42%)	34 (44%)	2 (29%)	36%
Type of Insulation				
% Fiberglass Batt	71 (83%)	67 (85%)	4 (57%)	71%
No Insulation	1 (1%)	1 (1%)	0 (0%)	1%

*Attached homes are significantly different from detached homes at the 90% confidence level.
[1]Two homes had multiple insulation grades for rime and band joists. In these homes the grade for the joist with the largest area is reported.
[2] Installation grade is only applied to sites where insulation was present.

Table 9-31: Conditioned/Garage Joists

Conditioned/Garage	All Homes (n=22)	Detached Homes (n=21)	Attached Homes (n=1)	Weighted (Detached/ Attached)
Average R-value	19.0	19.3	14.0	16.7
Framing				
Joist 16" On Center	20 (91%)	19 (90%)	1 (100%)	95%
Other spacing	2 (9%)	2 (10%)	0 (0%)	5%
Insulation Installation Grade				
Grade I Installation	8 (36%)	7 (33%)	1 (100%)	66%
Grade II Installation	7 (32%)	7 (33%)	0 (0%)	17%
Grade III Installation	7 (32%)	7 (33%)	0 (0%)	17%
Type of Insulation				
% Fiberglass Batt	14 (64%)	14 (67%)	0 (0%)	34%

[41] One detached home has a rim joist located between conditioned space and an unconditioned basement. This rim joist has R-14 spray foam insulation, the joists are spaced 16 inches apart, and the insulation installation was a grade I install.

Table 9-32: Conditioned/Attic Joists

Conditioned/Attic	All Homes (n=18)	Detached Homes (n=16)	Attached Homes (n=2)	Weighted (Detached/ Attached)
Average R-value	18.9	19.6	14.0	16.8
Framing				
Joist 16" On Center	17 (94%)	15 (94%)	2 (100%)	96.8%
Other spacing	1 (6%)	1 (6%)	0 (0%)	3.2%
Insulation Installation Grade				
Grade I Installation	2 (11%)	2 (13%)	0 (0%)	6%
Grade II Installation	7 (39%)	5 (31%)	2 (100%)	65%
Grade III Installation	9 (50%)	9 (56%)	0 (0%)	29%
Type of Insulation				
% Fiberglass Batt	16 (89%)	14 (88%)	2 (100%)	93.7%

Table 9-33: Unconditioned Basement/Ambient Joists

Unconditioned Basement/Ambient	All Homes (n=13)	Detached Homes (n=13)	Attached Homes (n=0)	Weighted (Detached/ Attached)
Average R-value	16.2	16.2		16.2
Framing				
Joist 16" On Center	10 (77%)	10 (77%)		77%
Other spacing	3 (23%)	3 (23%)		23%
Insulation Installation Grade[1]				
Grade I Installation	6 (67%)	6 (67%)		67%
Grade III Installation	3 (33%)	3 (33%)		33%
Type of Insulation				
% Fiberglass Batt	3 (23%)	3 (23%)		23%
No Insulation	4 (31%)	4 (31%)		31%

[1] Installation grade is only applied to sites where insulation was present.

Table 9-34: Conditioned/Adiabatic Joists

Conditioned/Adiabatic	All Homes (n=5)	Detached Homes (n=0)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Average R-value	18.6		18.6	18.6
Framing				
Joist 16" On Center	5 (100%)		5 (100%)	100%
Insulation Installation Grade				
Grade I Installation	2 (40%)		2 (40%)	40%
Grade II Installation	3 (60%)		3 (60%)	60%
Type of Insulation				
% Fiberglass Batt	3 (60%)		3 (60%)	60%

Table 9-35: Unconditioned Basement/Garage Joists

Unconditioned Basement/Garage	All Homes (n=7)	Detached Homes (n=7)	Attached Homes (n=0)	Weighted (Detached/ Attached)
Average R-value	17.3	17.3		17.3
Framing				
Joist 16" On Center	5 (71%)	5 (71%)		71%
Other spacing	2 (29%)	2 (29%)		29%
Insulation Installation Grade[1]				
Grade I Installation	3 (60%)	3 (60%)		60%
Grade III Installation	2 (40%)	2 (40%)		40%
Type of Insulation				
% Fiberglass Batt	2 (29%)	2 (29%)		29%
No Insulation	2 (29%)	2 (29%)		29%

[1] Installation grade is only applied to sites where insulation was present.

9.9 Sunspaces

According to REM/Rate a sunspace is, "a space which is not conditioned by the building's heating or cooling system and which can be isolated from the conditioned space by closing doors, windows, vents, etc. It should normally be open to the living space only when it is warm enough to deliver heat to the living space (rather than removing it)." Auditors applied this definition during the site visits and found space in one home that meets the criteria. All boundaries of this sunspace are insulated; both the common wall and exterior walls are insulated with R-19 Fiberglass Batts, the ceiling is insulated with R-38 Fiberglass Batts, and the slab is estimated to have R-8 rigid foam perimeter insulation.

10 Mechanicals

10.1 Heating Systems

Most inspected homes have natural gas heating systems, most have furnaces, and most heating systems are installed in unconditioned space. Table 10-1, Table 10-2, and Table 10-3 show the primary heating fuels, types of heating systems and locations of heating systems. Data are shown for all inspected homes, detached homes, attached homes and weighted results reflecting the mix of single-family detached and attached housing in the 2011 Program. Table 10-1 shows that most detached homes and all attached homes have natural gas heating systems; the weighted natural gas percentage is 79%.

Table 10-1: Primary Heating Fuel

Primary Heating Fuel	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Electric	3 (3%)	3 (3%)*	0 (0%)*	2%
Natural Gas	62 (62%)	55 (59%)*	7 (100%)*	79%
Oil	13 (13%)	13 (14%)*	0 (0%)*	7%
Pellet	1 (1%)	1 (1%)	0 (0%)	1%
Propane	21 (21%)	21 (23%)*	0 (0%)*	11%

* Significantly different at the 90% confidence level.

Table 10-2 shows most detached and all attached homes have furnace heating systems: the weighted furnace percentage is 87%.

Table 10-2: Heating System Type

Heating System Type**	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Furnace	76 (76%)	69 (74%)*	7 (100%)*	87%
Boiler	21 (21%)	21 (23%)*	0 (0%)*	11%
GSHP	3 (3%)	3 (3%)*	0 (0%)*	2%

* Significantly different at the 90% confidence level.

Table 10-3 shows the most common location of heating systems in both detached and attached homes is an unconditioned basement; the weighted unconditioned basement percentage is 48%. The next most common locations are conditioned basements (weighted average 25%) and attics (weighted average 19%). All of the heating systems installed in attics are gas furnaces (natural gas and propane) and they tend to be less efficient than the gas furnaces installed in basements. Some builders are not comfortable installing high-efficiency furnaces in unheated attics because of potential condensate freezing problems, especially if the units are installed horizontally.

Table 10-3: Heating System Location

Heating System Location	All Heating Systems (n=127)	Detached Homes (n=118)	Attached Homes (n=9)	Weighted (Detached/ Attached)
Uncond. Basement	65 (51%)	61 (52%)	4 (44%)	48%
Cond. Basement	35 (28%)	33 (28%)	2 (22%)	25%
Attic	21 (17%)	19 (16%)	2 (22%)	19%
Cond. Primary Area	4 (3%)	3 (3%)	1 (11%)	7%
Unconditioned Garage or Shed	2 (2%)	2 (2%)	0 (0%)	1%

There are several ways to group heating systems to compare efficiencies. Table 10-4 shows detailed annual fuel utilization efficiency (AFUE) statistics for all gas furnaces (natural gas and propane), gas furnaces not located in attics, gas furnaces located in attics, oil furnaces, gas (natural gas and propane) boilers, and oil boilers. Table 10-5 shows average AFUE, by type of heating system, for heating systems in all homes, detached homes, attached homes, and weighted average AFUEs reflecting the mix of single-family detached and attached housing in the 2011 Program. The weighted average AFUEs exceed ENERGY STAR minimum AFUEs for all but attic gas furnaces, oil furnaces, and gas boilers.

Table 10-4: Furnace and Boiler Efficiency Statistics

Heating System Efficiency Statistics**	Gas Furnaces (n=93)	Non-Attic Gas Furnaces (n=72)	Attic Gas Furnaces (n=21)	Oil Furnaces (n=7)	Gas Boilers (n=14)	Oil Boilers (n=6)
Minimum AFUE	80.0	82.0	80.0	80.3	80.0	83.6
Maximum AFUE	97.0	97.0	95.5	85.4	96.1	88.3
Average AFUE	**92.0**	**93.8***	**85.6***	**82.7**	**89.8**	**85.9**
Median AFUE	95.0	95.0	80.0	83.0	91.3	85.9

* Significantly different at the 90% confidence level.
**Gas heating systems include both natural gas and propane systems.

Table 10-5: Average AFUE by Type of Heating System and Housing

Average AFUE by System Type*	Heating Systems in All Homes	Heating Systems in Detached Homes	Heating Systems in Attached Homes	Weighted (Detached/ Attached)
Gas Furnaces	92.1 (93 furnaces)	92.1 (84 furnaces)	91.0 (9 furnaces)	**91.6**
Non-Attic Gas Furnaces	93.8 (72 furnaces)	93.8 (65 furnaces)	94.2 (7 furnaces)	**94.0**
Attic Gas Furnaces	85.6 (21 furnaces)	86.1 (19 furnaces)	80.0 (2 furnaces)	**83.1**
Oil Furnaces	82.7 (7 furnaces)	82.7 (7 furnaces)	n/a (no furnaces)	**82.7**
Gas Boilers	89.8 (14 boilers)	89.8 (14 boilers)	n/a (no boilers)	**89.8**
Oil Boilers	85.9 (6 boilers)	85.9 (6 boilers)	n/a (no boilers)	**85.9**
Pellet Boiler	92.0 (1 boiler)	92.0 (1 boiler)	n/a (no boilers)	**92.0**

*Gas heating systems include both natural gas and propane systems.

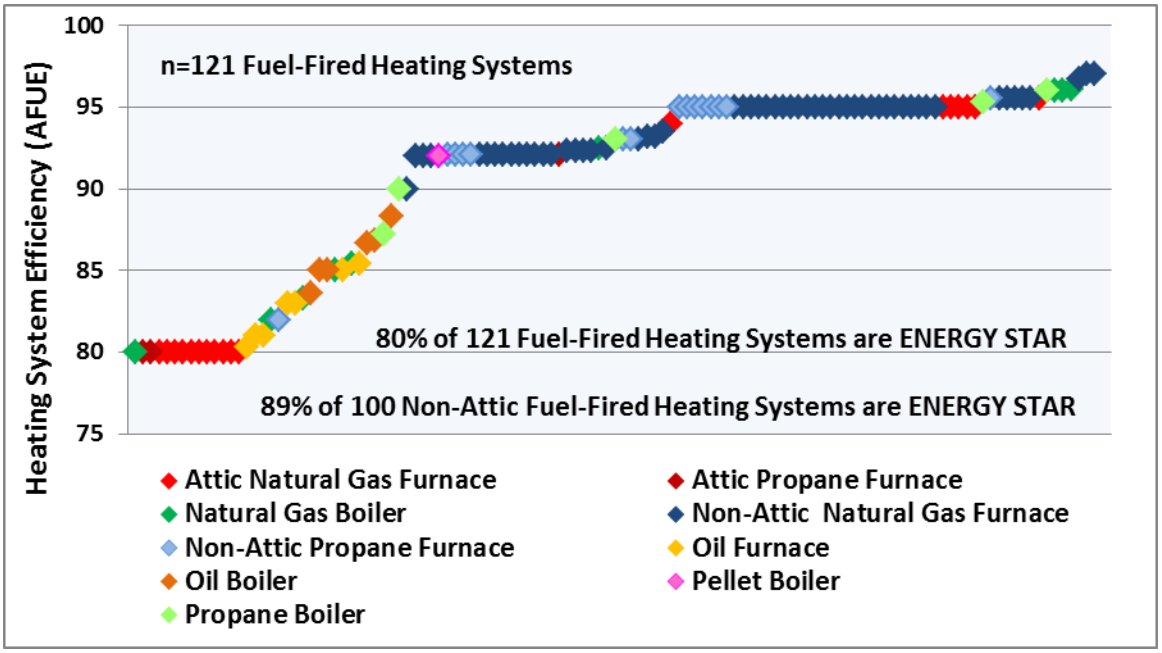
UDRH inputs group heating systems by fuel and type of distribution system. Table 10-6 shows current UDRH heating system efficiency inputs and the average efficiencies for the different types of heating systems in all inspected homes, detached homes, attached homes, and weighted average efficiencies reflecting the mix of single-family detached and attached housing units in the 2011 Program. As shown, all weighted efficiencies are higher than current UDRH inputs. The biggest increases in efficiency between current UDRH and 2011 baseline weighted efficiencies are for propane hydronic distribution systems (81.7 to 87.2 AFUE), natural gas hydronic distribution systems (81.7 to 86.8 AFUE), propane air distribution systems (89.2 to 92.0 AFUE), and natural gas air distribution systems (89.2 to 91.6 AFUE). The weighted efficiencies for oil air and hydronic distribution systems are only slightly higher than current UDRH inputs. Because all inspected attached homes have natural gas furnaces, the weighted efficiencies for all other types of heating systems are the same as the average efficiencies for detached homes. In the broader marketplace, not all attached homes will have access to natural gas and not all attached housing will have furnaces. However, data on homes completed through the 2011 Program show a high percentage of completed single-family attached homes (74%) have furnace heating systems.

Table 10-6: Heating System Efficiencies by Fuel and Distribution System

Heating System Categories in UDRH	JMC 2011 UDRH Heating System Efficiency	126 Heating Systems in 100 Homes		117 Heating Systems in Detached Homes		9 Heating Systems in Attached Homes		Weighted Average Efficiency (Detached/ Attached)
		Number of Heating Systems	Average AFUE or HSPF	Number of Heating Systems	Average AFUE or HSPF	Number of Heating Systems	Average AFUE or HSPF	
Natural Gas Air Distribution	89.2 AFUE	78	92.0	69	92.2	9	91.0	91.6
Natural Gas Hydronic Distribution	81.7 AFUE	6	86.8	6	86.8	0	n/a	86.8
Propane Air Distribution	89.2 AFUE	22	92.0	22	92.0	0	n/a	92.0
Propane Hydronic Distribution	81.7 AFUE	1	87.2	1	87.2	0	n/a	87.2
Oil Air Distribution	83.9 AFUE	10	84.1	10	84.1	0	n/a	84.1
Oil Hydronic Distribution	84.4 AFUE	3	84.5	3	84.5	0	n/a	84.5
Ground Source Heat Pump (UDRH converted to ASHP)	7.7 HSPF	6	14.4 HSPF	6	14.4 HSPF	0	n/a	14.4 HSPF

Figure 10-1 graphs the heating system AFUEs for the 121 natural gas, propane, oil, and pellet heating systems observed in inspected homes; not included on the graph are six ENERGY STAR-qualified ground source heat pumps observed in three detached homes. As shown, in general, the least efficient heating systems are gas furnaces installed in attics and the most efficient heating systems are a mix of high-efficiency gas furnaces and boilers.

Figure 10-1: Heating System Efficiencies by Type of System



10.1.1 ECM Motor

An electronically commutated motor (ECM) is a brushless DC motor that offers efficiency gains relative to the industry standard permanent split capacitor (PSC) motors. ECMs offer two major advantages over PSC motors. First, studies have shown that ECMs use significantly less electricity than PSC motors while producing comparable air flow. Second, ECMs are variable speed motors with the flexibility to adjust air flow depending on the demand being called for by the furnace or central air conditioning system. As one author put it,

> *"Multistage ECM furnaces offer a technological fix for the furnace-sizing problem; they operate mainly as smaller furnaces, but they offer that extra capacity to kick the temperature back up after a setback."*[42]

Of the 100 furnaces inspected during the on-site visits, auditors found that 18 had ECMs while the remaining 82 had PSC motors.

[42] Scott Pigg, "The Electric Side of Gas Furnaces" *Home Energy Magazine*, November 1, 2003.

10.1.2 Heating System Capacity

Table 10-7 provides statistics on heating system Btuh per square foot. Output capacity Btuh per square foot ranges from 10 to 122 and the weighted average is 43 Btuh per square foot.

Table 10-7: Heating System Btuh per Square Foot Statistics

Heating System Output Capacity (Btuh) per Square Foot Conditioned Floor Area	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)*
Minimum	10	10	29	10
Maximum	122	122	65	122
Average	**42**	**42**	**45**	**43**
Median	41	41	44	41

*Only the average is weighted.

10.1.3 Supplemental Heat Sources

Roughly three out of four inspected homes (72%) have at least one fireplace or stove. Five of the seven attached homes (71%) each have one natural gas fireplace. Table 10-8 shows the number of fireplaces and stoves in homes. Table 10-9 shows the percentages of natural gas, propane, wood, and pellet fireplaces and wood stoves in all homes, detached homes, attached homes, and the weighted average percentage reflecting the mix of single-family detached and attached housing in the 2011 Program. Weighted percentages are 81% natural gas, 10% propane, 8% wood, and 1% pellet.

Table 10-8: Fireplaces and Stoves

FIREPLACES & STOVES	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
None	28 (28%)	26 (28%)	2 (29%)	28%
One	62 (62%)	57 (61%)	5 (71%)	66%
Two	9 (9%)	**9 (10%)***	**0 (0%)***	5%
Three	1 (1%)	1 (1%)	0 (0%)	1%

* Significantly different at the 90% confidence level.

Table 10-9: Fireplace and Stove Fuel

FIREPLACE & STOVE FUEL	All Homes (n=72)	Detached Homes (n=67)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Natural Gas	47 (65%)	**42 (63%)***	**5 (100%)***	81%
Propane	13 (18%)	**13 (19%)***	**0 (0%)***	10%
Wood	11 (15%)	**11 (16%)***	**0 (0%)***	8%
Pellets	1 (1%)	1 (1%)	0 (0%)	1%

* Significantly different at the 90% confidence level.

10.1.4 Who Specified Heating System and Perceived Efficiency

Ninety-six homeowners completed the on-site survey, but not all owners responded to all questions. Therefore, the numbers of responses on which the presented results are based vary. The on-site homeowner survey asked owners who specified the heating system in their home. The choices were:

- I specified (Note that owners who are also the builder are treated as a separate category in this section.)
- Builder chose
- Selected from options offered by the builder
- Do not remember or do not know

If owners responded that they specified the heating system, they were asked, "Do you remember what you specified?" If they remembered, they were asked to check all options that applied; the options were:

- Heating fuel (electric, natural gas, propane, oil, etc.)
- Type of heating system (furnace, boiler, heat pump, ground source heat pump, etc.)
- Energy-efficient heating system
- ENERGY STAR-labeled heating system

Owners were also asked to rate the energy efficiency of their heating system. The choices were:

- Not Energy Efficient
- Average Efficiency
- Very Energy Efficient
- ENERGY STAR Labeled
- Do Not Know

Who Specified Heating System

Figure 10-2 shows builders chose the heating system in more than half of the homes (56%). Twenty-four owners plus all seven owner/builders who completed the survey say they specified the heating system for their home and eleven owners say they selected from options offered by their builder.

Figure 10-2: Who Specified Heating System

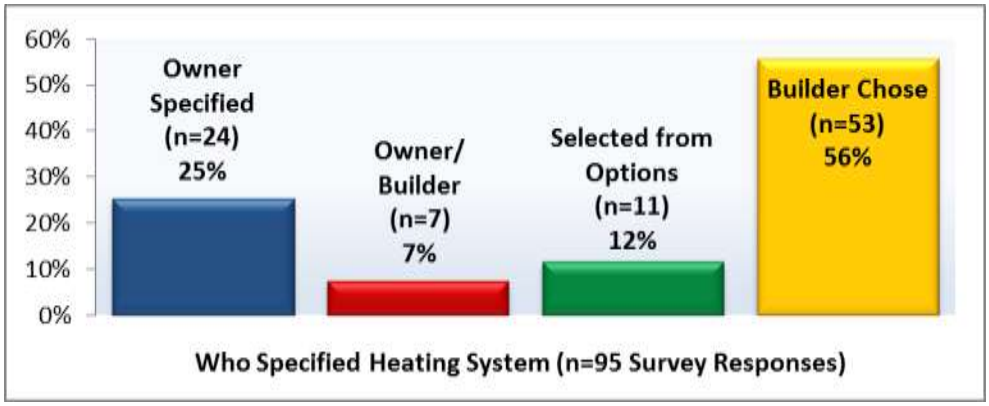


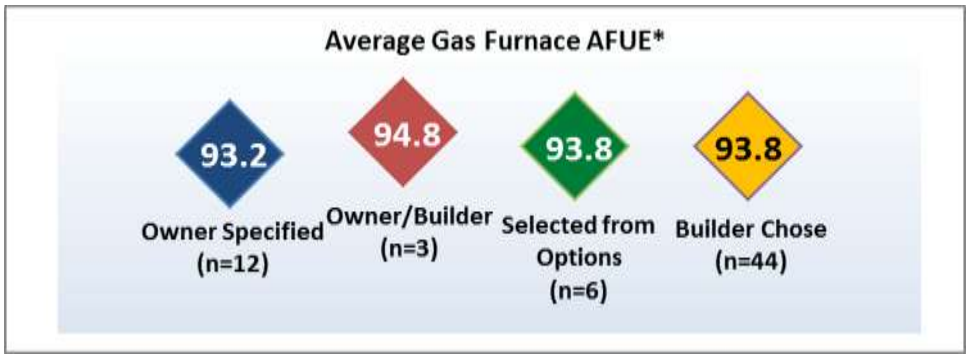
Table 10-10 shows what aspects of heating systems owners say they specified. (Note that some owners simply said they specified the heating system and did not identify what aspects of their heating system they specified.) As shown, owners who said they specified their heating system were most likely to say they specified the heating fuel (83%) and/or type of heating system (46%). In addition, almost half (46%) specified either an energy-efficient (17%) or an ENERGY STAR-labeled (29%) heating system.

Table 10-10: Heating System Aspects Owners Specified

Heating Systems: What Owners Specified (Multiple Responses)	Owners who Specified Heating System (n=24)	
	# of Owners	% of Owners
Heating fuel	20	83%
Type of Heating System	11	46%
Energy-Efficient Heating System	4	17%
ENERGY STAR-Labeled Heating System	7	29%

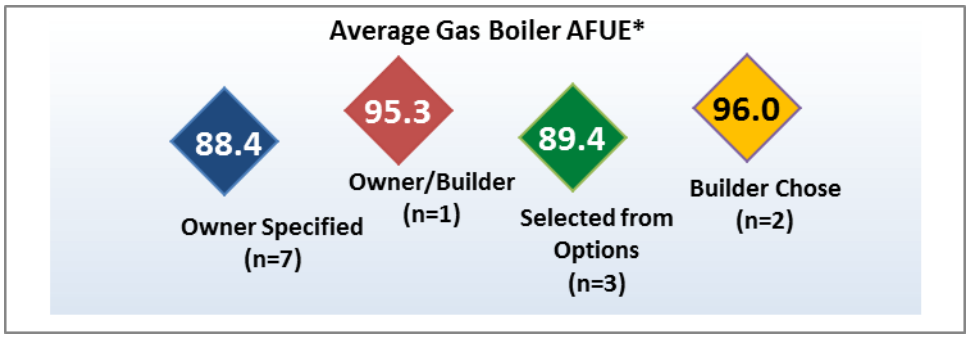
Figure 10-4Figure 10-3 through Figure 10-6 show the average AFUEs for gas (natural gas and propane) furnaces, gas boilers, oil boilers and oil furnaces by who specified the heating system.[43] In general, most inspected homes have high efficiency heating systems regardless of the type of heating system or who specified the heating system—the primary heating systems in the homes of 86 of the 96 owners who completed the survey are ENERGY STAR qualified. The average efficiencies of gas and oil furnaces are highest in homes where the owner was the builder. The lowest average efficiencies for gas furnaces and gas and oil boilers are in homes where the owners (not including owner/builders) say they specified at least some aspects of the heating system. The average efficiency of oil boilers is virtually the same whether the builder/owner specified the heating system, the owner selected from options offered by the builder or the builder specified the heating system—average AFUEs are 86.7 or 86.8.

Figure 10-3: Average Gas Furnace AFUE by Who Specified



*Includes both natural gas and propane water heaters.

Figure 10-4: Average Gas Boiler AFUE by Who Specified



*Includes both natural gas and propane water heaters.

[43] Not included in these figures are two owner/builders and one other owner who say they specified the heating systems for their homes and have ENERGY STAR-qualified ground source heat pumps plus one home that has a 92 AFUE pellet boiler that the homeowner says he selected from options offered by the builder.

Figure 10-5: Average Oil Boiler AFUE by Who Specified

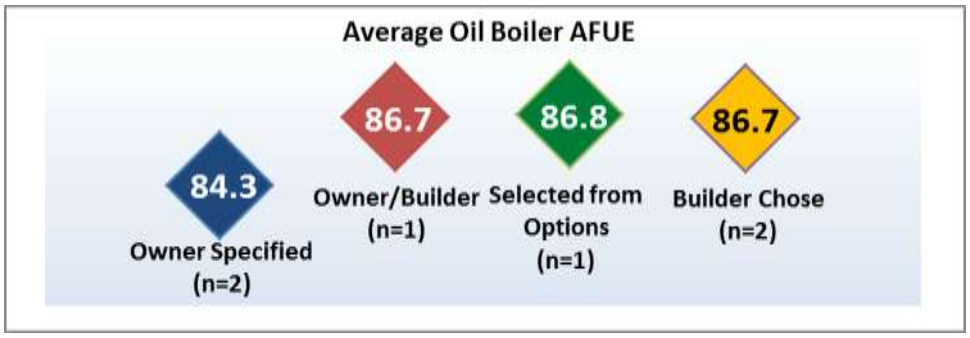
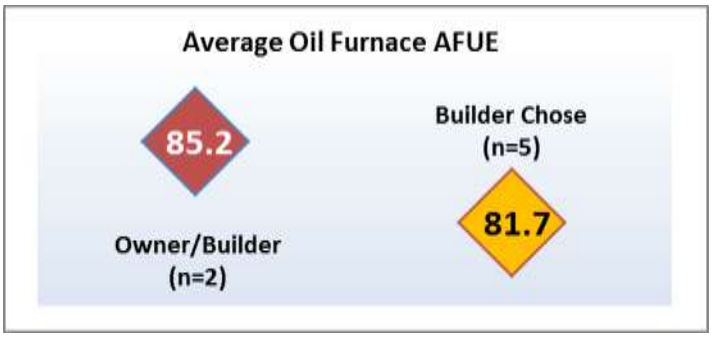


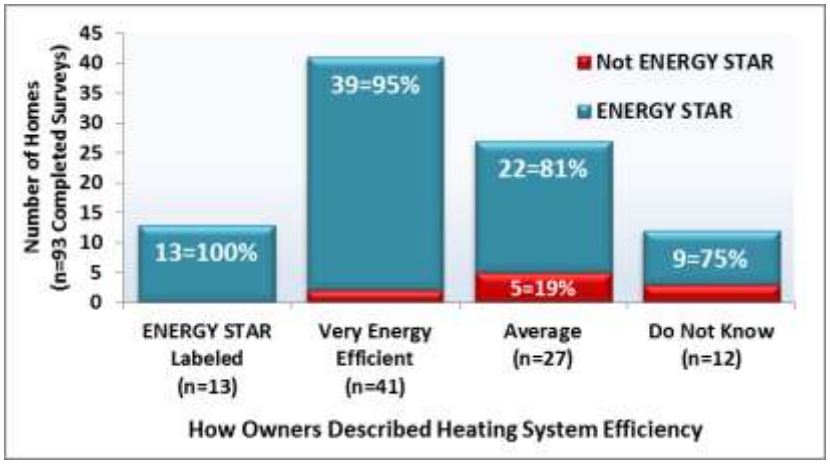
Figure 10-6: Average Oil Furnace AFUE by Who Specified



Perceived versus Actual Efficiency of Heating Systems

Figure 10-7 shows perceived versus actual ENERGY STAR heating systems. All survey respondents who think they have ENERGY STAR heating systems do. However, many homeowners who did not identify their heating systems as ENERGY STAR labeled also have ENERGY STAR heating systems. As shown, almost all (95%) homeowners who say their heating systems are very energy efficient, not ENERGY STAR, have ENERGY STAR heating systems, as do 81% of the homeowners who say the efficiency of their heating system is average, and 75% of the homeowners who say they do not know how efficient their heating system is. Clearly, most homeowners do not know if their heating system is ENERGY STAR qualified.

Figure 10-7: Perceived versus Actual ENERGY STAR Heating Systems



10.2 Cooling Systems

When visiting homes, auditors gathered information on central air conditioning units. Most inspected homes (89%) have central air conditioning—up from 63% in the 2005 Baseline Study. In two homes the central air conditioning units were not installed at the time of the audit. Of the 87 homes with central air conditioning installed, over half (57% or 50 homes) have SEER 13 systems, which is the federal minimum efficiency level for residential central air conditioners manufactured after January 23, 2006. Only 12 homes (11 detached and 1 attached) have ENERGY STAR cooling systems; 9 homes (8 detached and 1 attached) have ENERGY STAR central air conditioners and 3 detached homes have ENERGY STAR ground source heat pumps.

Table 10-11 provides information on the number of central air conditioning units per home. Data are shown for all inspected homes, detached homes, attached homes and weighted results reflecting the mix of single-family detached and attached housing in the 2011 Program. Homes with central air conditioning have from one to four units. Weighted percentage are: 6% no central air conditioning, 62% one unit, 29% two units, 2% three units, and 1% four units.

Table 10-11: Number of Central Air Conditioning Units per Home

Number of Central Air Conditioning Units per Home	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
One Unit	55 (55%)	50 (54%)	5 (71%)	62%
Two Units	30 (30%)	28 (30%)	2 (29%)	29%
Three Units	3 (3%)	**3 (3%)***	**0 (0%)***	2%
Four Units	1 (1%)	1 (1%)	0 (0%)	1%
No Central Air Conditioning	11 (11%)	**11 (12%)***	**0 (0%)***	6%

*Significantly different at the 90% confidence level.

Table 10-12 shows the location of central air conditioning units. As shown, most units are installed in unconditioned basements; weighted average is 58%.

Table 10-12: Location of Central Air Conditioning Units

Central Air Conditioning Unit Locations	All CAC Units (n=119)	CAC Units in Detached Homes (n=100)	CAC Units in Attached Homes (n=9)	Weighted (Detached/ Attached)
Unconditioned Basement	75 (60%)	70 (60%)	5 (56%)	58%
Attic	30 (24%)	28 (24%)	2 (22%)	23%
Conditioned Basement	15 (12%)	14 (12%)	1 (11%)	12%
Conditioned Primary Area	4 (3%)	3 (3%)	1 (11%)	7%
Garage	1 (1%)	1 (1%)	0 (0%)	0%

Total tons of air conditioning installed per home range from 2.0 to 9.3 tons. Table 10-13 shows the weighted average for all homes is 3.6 tons.

Table 10-13: Central Air Conditioning Tons per Home

Central Air Conditioning Tons per Home (Homes with CAC Data)	All Homes (n=87)**	Detached Homes (n=80)	Attached Homes (n=7)	Weighted*** (Detached/ Attached)
Minimum	2.0	2.4	2.0	2.0
Maximum	9.3	9.3	4.0	9.3
Average	4.0	**4.0***	**3.2***	**3.6**
Median	3.8	3.8	3.0	3.8

*Significantly different at the 90% confidence level. **Not yet installed in two homes.
***Only the average is weighted.

Table 10-14 shows square feet of conditioned floor area per ton of central air conditioning. As shown, values range from 354 to 1,712 square feet per ton of central air conditioning. The weighted average is 613 square feet per ton.

Table 10-14: Square Feet of Conditioned Space per Ton of Central Air Conditioning

Square Feet per Ton CAC	All Homes (n=87)	Detached Homes (n=80)	Attached Homes (n=7)	Weighted* (Detached/ Attached)
Minimum	354	354	410	354
Maximum	1,712	1,712	976	1,712
Average	**638**	**642**	**582**	**613**
Median	581	590	504	581

*Only the average is weighted

Auditors recorded model numbers for all central air conditioning units observed in inspected homes. All SEER and Energy Efficiency Ratio (EER) information available from equipment labels and nameplates was verified by looking up the model numbers in the Air Conditioning, Heating, and Refrigeration (AHRI) Directory of Certified Product Performance. Most (61%) of the 119 central air conditioning units with SEER information are SEER 13 units. Table 10-15 shows the SEERs of central air conditioning units range from 13.0 to 19.0. The weighted average SEER is 13.7; this is higher than the current UDRH input of SEER 13.0.

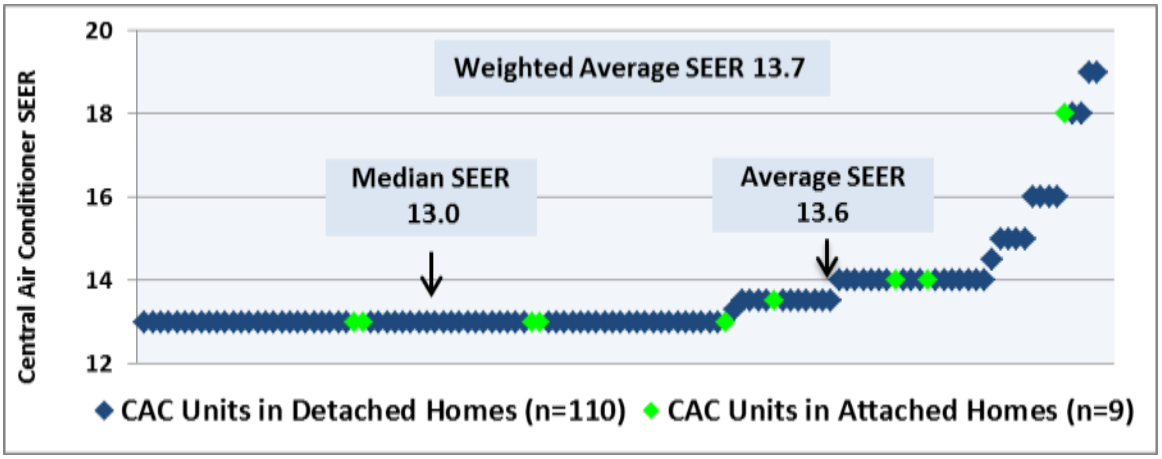
Table 10-15: Central Air Conditioning SEER

Central Air Conditioning SEER (CAC Units with SEER Data)	All CAC Units (n=119)	CAC Units in Detached Homes (n=100)	CAC Units in Attached Homes (n=9)	Weighted* (Detached/ Attached)
Minimum	13.0	13.0	13.0	13.0
Maximum	19.0	19.0	18.0	19.0
Average	**13.6**	**13.6**	**13.8**	**13.7**
Median	13.0	13.0	13.0	13.0

*Only the average is weighted.

Figure 10-8 graphs the recorded SEER of individual central air conditioning units.

Figure 10-8: Recorded Central Air Conditioning SEER



10.2.1 Who Specified Cooling System and Perceived Efficiency

Ninety-six homeowners completed the on-site survey, but not all owners responded to all questions. Therefore, the numbers of responses on which presented results are based vary. The on-site homeowner survey asked owners who specified the cooling system in their home. The choices were:

- I specified (Note that owners who are also the builder are treated as a separate category in this section.)
- Builder chose
- Selected from options offered by the builder
- Do not remember or do not know

If owners responded that they specified the cooling system, they were asked, "Do you remember what you specified?" If they remembered, they were asked to check all options that applied; the options were:

- Whether or not to install central air conditioning
- Type of system (standard central A/C system, air source heat pump, ductless mini-split system, combined heating and cooling system
- Energy-efficient system
- ENERGY STAR-labeled system

Owners were also asked to rate the energy efficiency of their cooling system. The choices were:

- Not Energy Efficient
- Average Efficiency
- Very Energy Efficient

- ENERGY STAR Labeled
- Do Not Know

Who Specified Cooling System

Figure 10-9 shows builders chose the cooling system in approximately two-thirds of homes (66%). Sixteen owners plus all seven owner/builders say they specified the cooling system for their homes and five owners say they selected from options offered by their builder.

Figure 10-9: Who Specified Cooling System

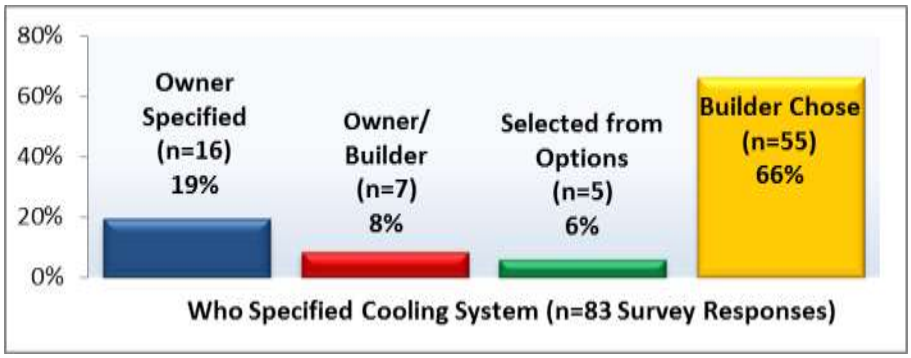


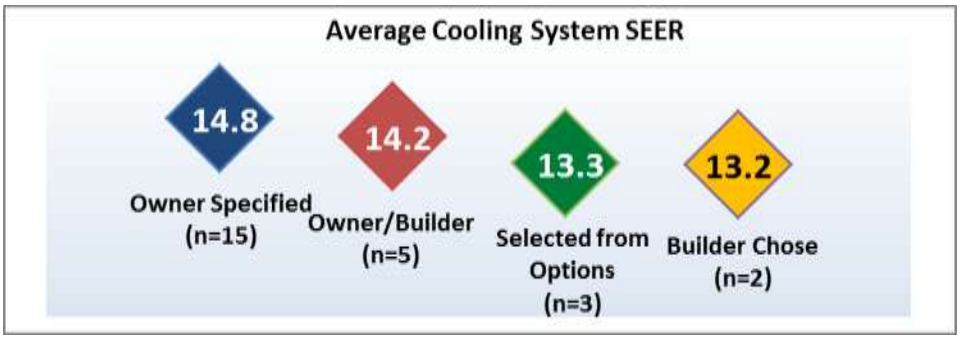
Table 10-16 shows what aspects of cooling systems owners say they specified. (Note that some owners simply said they specified the cooling system and did not identify what aspects of their cooling system they specified.) As shown, owners who said they specified their cooling system were most likely to say they specified whether or not to install central air conditioning (56%), specified an ENERGY STAR-labeled cooling system (50%), and/or specified the type of cooling system (44%). Nineteen percent of owners who said they specified the cooling system for their home specified an energy-efficient system, but not an ENERGY STAR-labeled system.

Table 10-16: Cooling System Aspects Owners Specified

Cooling Systems: What Owners Specified (Multiple Responses)	Owners who Specified Heating System (n=16)	
	# of Owners	% of Owners
Whether or not to Install Central Air Conditioning	9	56%
Type Of System	7	44%
Energy-Efficient System	3	19%
ENERGY STAR-Labeled System	8	50%

Figure 10-10 shows the average SEER of cooling systems by who specified the cooling system. As shown, the average efficiency of cooling systems is highest in homes where the owners say they specified the cooling system and in homes where the owner was also the builder. The average efficiencies of cooling systems in homes where owners selected from options offered by the builder or where the builder specified the system are similar, SEER 13.3 and 13.2 respectively. Figure 10-10 does not include three homes that have ENERGY STAR ground source heat pumps; two owner/builder homes and the home of an owner who specified an energy-efficient cooling system.

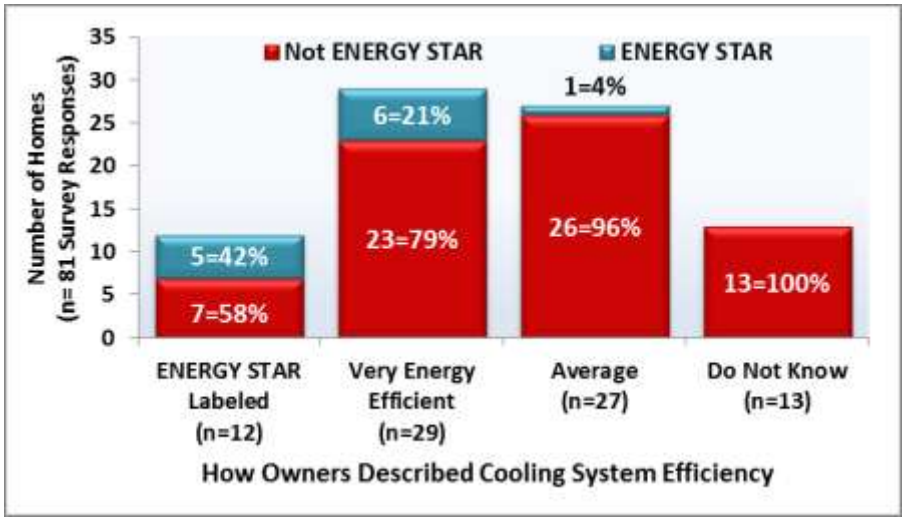
Figure 10-10: Central Air Conditioning SEER by Who Specified



Perceived versus Actual Efficiency of Cooling Systems

Figure 10-11 shows perceived versus actual ENERGY STAR cooling systems. As shown, only 5 of the 12 owners who think they have ENERGY STAR cooling systems do. A few owners who did not identify their heating systems as ENERGY STAR labeled do have ENERGY STAR heating systems. As shown, 6 of the 29 owners who say their cooling systems are very energy efficient, but not ENERGY STAR, actually have ENERGY STAR cooling systems, as does one of the 27 owners who say the efficiency of their cooling system is average.

Figure 10-11: Perceived versus Actual ENERGY STAR Cooling Systems



10.3 HVAC Performance Testing

In-field measurements were performed to calculate the actual cooling capacities and efficiencies of a sample of residential central air conditioning (CAC) systems throughout the state.[44] This section of the report provides an overview of the results from this data collection effort. More detail on in-field measurements, equipment, protocols, and analytical procedures can be found in Appendix F HVAC Performance Testing.

The measurements required to properly assess the operating performance of the CACs included air side temperatures and flow rates along with electric power draws of the condensing units and blower motors with controls. Although duct leakage, which affects the system performance as a whole, was measured for the REM/Rate analyses, that was not a part of the CAC performance analysis.

A total of 37 CAC units were measured to calculate their operating performance. One of those was excluded because of missing critical data and another was excluded because it was a ground source heat pump, and the relationship between its EER and SEER is radically different. If it were included, its rated EER of 22.6 would have skewed the averages of the remainder of the units. The air flow through the unit was excessively low, at only 229 CFM per rated ton, and the field measured cooling capacity was about 37% below its rated 3.2 tons.

The overall results of this study are summarized in Table 10-17, which shows the average values of the 35 sites that yielded meaningful results:

Table 10-17: Rated vs. Measured Operating Performance of CACs

CAC Testing Results (n=35)	Rated	Operating	Difference	Relative Error
Capacity Btuh	36,223*	28,300*	-21.9%	8.7%
SEER	13.5	13.1	-3.0%	6.7%

*Significantly different at the 90% confidence level

The average rated capacity and efficiency was 36,223 Btuh (3.02 tons) and 13.5 SEER respectively. The average field operating capacity was significantly lower, at 28,300 Btuh (2.36 tons). Low evaporator air flow appeared to be the primary reason for the reduced cooling capacity. In fact, of the units that measured at more than 25% reduction in capacity, the average evaporator air flow was only 317 CFM per rated ton.

The overall average evaporator airflow was 359 CFM per rated ton. The overall average operating efficiency was slightly less than rated, at 13.1 SEER.

One two-ton unit was performing exceptionally poorly, delivering only about 10% of its rated capacity at only 16% of its rated efficiency. The reason for this is unknown, but it is probably due to low refrigerant charge, which will tend to reduce both the cooling capacity and efficiency.

[44] Central heat pumps were included in the sample, but only the cooling performance of such systems was considered. Some homes used window air conditioning units, which were not included in the CAC analysis.

The evaporator air flow for this unit was a healthy 375 CFM per rated ton, but the temperature drops across the evaporator coil were extremely low at 4.5 degrees F dry bulb and 1.1 degrees F wet bulb. Healthy temperature drops are around 19 and 11 degrees, respectively.

Reduced airflow is quite common in residential CAC systems throughout the country, where averages range from 300 to about 370 CFM per ton. Studies have found that undersized ductwork with long runs or too many turns is common, and dirty evaporator coils and/or filters also contribute to low airflow problems.

Equipment efficiency is primarily reduced by poor heat transfer through dirty evaporator and/or condenser coils, improper refrigerant (especially low) charge and low air flow. It may also be affected by undersized or excessively long refrigerant lines.

The differences between the rated and operating performance are multifaceted, involving numerous possible installation and/or operational deficiencies, and the field deficiencies leading to loss of capacity and efficiency behave somewhat interactively. Rated conditions are ideal, assuming the equipment will be installed and operated as intended. Field conditions are hardly ever ideal, however, and the differences usually result in reduced performance.

10.4 Heating and Cooling Equipment Sizing–Manual J

One of the requirements of the 2011 Massachusetts Residential New Construction study was to contrast the central cooling and heating equipment capacities installed with the sizing requirements of the Eighth Edition of Manual J (MJ8). Similar to MJ8, REM/Rate provides both heating and cooling loads by component. The application of REM/Rate to size the cooling and heating systems was considered to be acceptable because REM/Rate design loads (cooling and heating loads under design conditions) agreed closely with MJ8 design loads for three randomly selected homes.

The REM/Rate input files were run to calculate the design cooling and/or heating loads for the 100 inspected homes, and the results are indicative of the MJ8 equipment sizing requirements. Eighty-seven of the inspected homes have central cooling systems installed. The REM/Rate results are probably more reliable and consistent with the objective of comparing actual installed equipment capacities to design equipment capacities because REM/Rate is a much more rigorous tool than MJ8, taking into account more detailed and specific site information to base the estimates on. At the same time the results are, on average, indicative of the MJ8 results as well.

10.4.1 Cooling System Sizing

Proper cooling equipment sizing is important for several reasons, the most important of which follow:

- Excessive oversizing causes the unit to operate for shorter periods of time, thus reducing the effective moisture removal capability. This may lead to discomfort, lower thermostat set points, or even allow mold or mildew to accumulate in humid climate conditions.

- Excessive oversizing may cause the system to cycle more often due to shorter run times. This may reduce the operating efficiency and decrease the working lifetime of the equipment.
- Excessively oversized equipment may emit more noise than necessary.
- Oversized systems lead to unnecessary costs.
- Oversized systems require larger equipment and ductwork, thereby increasing installation costs and causing installation problems when faced with limited spaces. Alternatively, this could lead to undersized ductwork, thereby increasing the external static pressure and possibly resulting in insufficient evaporator air flow.
- Equipment undersizing may lead to unhappy owners if these systems fail to maintain reasonable comfort conditions during peak cooling periods. Installation of ceiling fans and/or some type of load reduction measures may often mitigate this problem, while also reducing the energy bills.

Table 10-18 shows the results for the 87 homes with central cooling. Following the conditioned floor area, the next two columns in Table 10-18 show the installed (actual) cooling capacities in BTUs per hour (Btuh) and tons. Next, the REM/Rate design loads are shown in both Btuh and tons, followed by proper cooling equipment size in tons.[45] The cooling system size ratio is the ratio of the actual cooling tons to the proper equipment size tons. As shown, the average size ratio is 1.67, indicating that the average installed cooling system rated capacity is 1.67 times the properly sized system capacity. The maximum ratio of all 87 sites is 3.00, and the minimum is 0.83. There is only one site with a ratio less than 1.00 and two sites at exactly 1.00, while the other 84 sites all have oversized cooling systems based on MJ8 sizing allowances. Therefore, 84 out of 87 sites, or 96.6%, have oversized cooling systems, with size ratios ranging from 1.07 to 3.00.

Table 10-18: Comparison of Actual Cooling Capacities and REM/Rate Design Loads

All Homes with Central Air Conditioning (n=87)	Cond. Floor Area Sq. Ft.	Actual Cooling Capacity Btuh	Actual Cooling Capacity Tons	REM/ Rate Cooling Load Btuh	REM/ Rate Cooling Load Tons	Proper Equipment Size Cooling Tons	Cooling System Size Ratio
Minimum	1,179	24,000	2.0	13,800	1.15	1.50	0.83
Maximum	5,080	112,000	9.3	84,000	7.00	7.00	3.00
Average	**2,471**	**47,769**	**4.0**	**26,491**	**2.21**	**2.45**	**1.67**
Median	2,236	46,000	3.8	25,100	2.09	2.50	1.53

[45] The "Proper Equipment Size Cooling Tons" is the REM/Rate load in tons rounded up to the nearest half ton. This was done for each site, so the average of those (2.45) is not a rounded number and is slightly greater than the average REM/Rate load in tons.

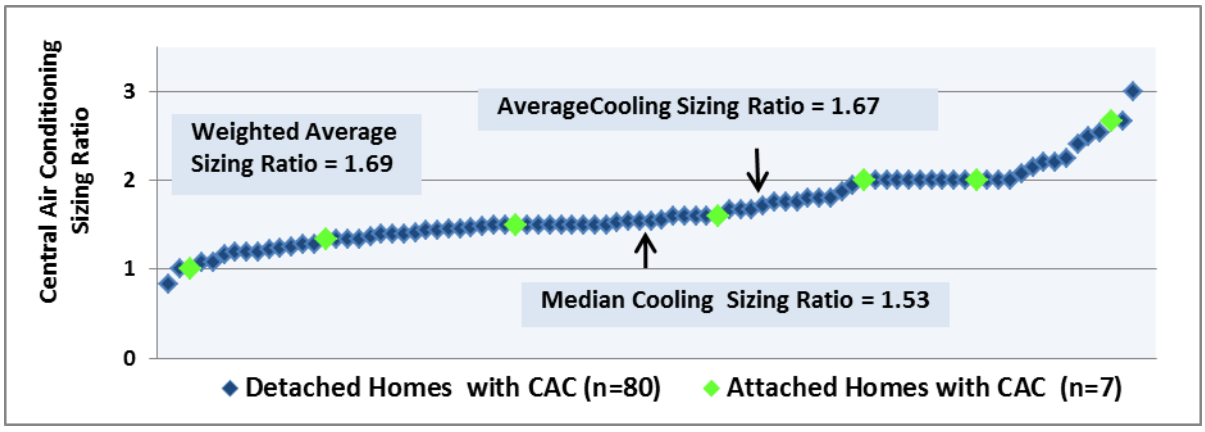
Table 10-19 shows cooling system size ratio statistics for all centrally air conditioned (CAC) homes, detached homes and attached homes, while Figure 10-12 graphs the cooling system size ratios by home. As shown, the average cooling system size ratio is higher for attached homes, but this difference is not statistically significant at the 90% confidence level. The weighted average cooling system size ratio is 1.69.

Table 10-19: Cooling System Size Ratios

Cooling System Size Ratio	All Homes with CAC (n=87)	Detached Homes with CAC (n=80)	Attached Homes with CAC (n=7)	Weighted (Detached/ Attached)*
Minimum	0.83	0.83	1.00	0.83
Maximum	3.00	3.00	2.67	3.00
Average	**1.67**	**1.66**	**1.73**	**1.69**
Median	**1.53**	1.53	1.60	**1.53**

*Only the average is weighted.

Figure 10-12: Cooling System Size Ratios by Home



10.4.2 Heating System Sizing

Oversizing of heating equipment, regardless of type, may lead to excessive installation costs, excessive noise and short cycling, the latter of which may reduce the annual efficiency and operating lifetime of the equipment. On the other hand, most homeowners like the warm, fuzzy feel of massive quantities of warm air emanating from their supply air registers or other heat distribution systems when they want to warm the house up in a hurry.

Table 10-20 shows the results for the 100 homes with heating systems. Following the conditioned floor area, the next column in Table 10-20 shows the installed (actual) heating capacities in BTUs per hour (Btuh). Next, the REM/Rate design loads are shown in Btuh, followed by the heating system size ratio. The heating system size ratio was calculated by taking the ratio of the installed heating capacity to the adjusted (rounded up to the nearest 10,000 Btuh) REM/Rate design load. The average heating equipment size ratio is 1.92. Ten of the 100 sites (10%) have undersized heating system equipment, with a minimum size ratio of 0.39. Perhaps

these results are an indication that fireplaces and stoves are being utilized in many of these homes. The remaining 90 homes (90%) have oversized heating systems, with size ratios ranging from 1.04 to 5.83.

Table 10-20: Comparison of Actual Heating Capacities and REM/Rate Design Loads

All Homes with Heating System (n=100)	Conditioned Floor Area Sq. Ft.	Actual Heating Capacity BTU/hr.	REM/Rate Heating Load BTU/hr.	Heating System Size Ratio
Minimum	959	16,500	14,900	0.39
Maximum	5,080	219,000	148,600	5.83
Average	**2,376**	**92,554**	**49,350**	**1.92**
Median	2,174	89,000	45,700	1.66

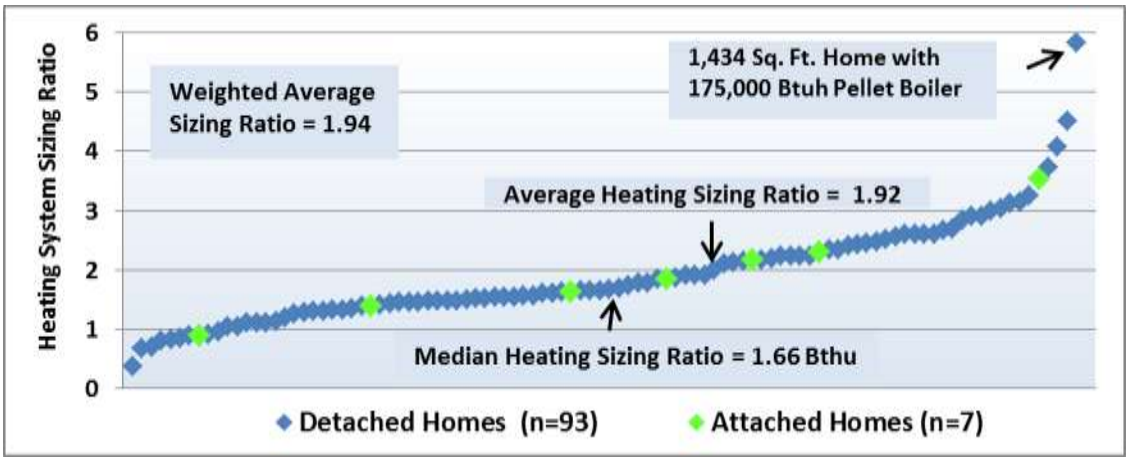
Table 10-21 shows heating system size ratio statistics for all homes, detached homes and attached homes, while Figure 10-13 graphs the heating system size ratios by home. As shown, the average heating system size ratio is higher for attached homes, but this difference is not statistically significant at the 90% confidence level. The weighted average cooling system size ratio is 1.94.

Table 10-21: Heating System Size Ratios

Heating System Size Ratio	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)*
Minimum	0.39	0.39	0.89	0.39
Maximum	5.83	5.83	3.53	5.83
Average	**1.92**	**1.91**	**1.97**	**1.94**
Median	1.66	1.66	1.85	1.66

*Only the average is weighted.

Figure 10-13: Heating System Size Ratios by Home



10.5 Water Heating

Auditors recorded information on 102 water heaters in the 100 inspected homes. Most homes, (71 homes) have conventional storage tank water heaters; one of these 71 homes has two natural gas conventional storage tank water heaters and another has a natural gas conventional storage tank water heater and a natural gas instantaneous water heater.

Table 10-22 shows the numbers and percentages of the different types of water heaters observed. Data are shown for all inspected homes, detached homes, attached homes and weighted results reflecting the mix of single-family detached and attached housing in the 2011 Program. As shown, weighted percentages are 60% natural gas and propane conventional storage tank, 17% electric conventional storage tank, 13% natural gas and propane instantaneous, and 9% storage tanks integrated with boiler heating systems.

Table 10-22: Types of Water Heaters

WATER HEATER TYPES	All Water Heaters (n=102)	Water Heaters in Detached Homes (n=95)	Water Heaters in Attached Homes (n=7)	Weighted (Detached/ Attached)
Conventional Storage (Natural Gas & Propane)	52 (51%)	47 (49%)	5 (71%)	60%
Conventional Storage (Electric)	20 (20%)	19 (20%)	1 (14%)	17%
Integrated with Tank	17 (17%)	17 (18%)*	0 (0%)*	9%
Instantaneous (Natural Gas & Propane)	13 (13%)	12 (13%)	1 (14%)	13%

*Significantly different at the 90% confidence level.

Table 10-23 shows most inspected homes have natural gas water heating systems. Weighted percentages are 71% natural gas, 17% electric, 9% propane, and 3% oil.

Table 10-23: Water Heater Fuel

WATER HEATER FUEL	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Natural Gas	58 (58%)	52 (56%)*	6 (86%)*	71%
Electric	20 (20%)	19 (20%)*	1 (14%)*	17%
Propane	16 (16%)	16 (17%)*	0 (0%)*	9%
Oil	6 (6%)	6 (6%)	0 (0%)	3%

*Significantly different at the 90% confidence level.

Most inspected homes (88 out of 100 homes) have water heating systems with storage tanks. One home has two storage tank water heaters with a total storage capacity of 100 gallons—one 40 and one 60 gallon tank. Weighted percentages are 42% 32 to 40 gallons, 43% 41 to 50 gallons, and 15% 52 to 100 gallons. (Table 10-24)

Table 10-24: Water Heater Tank Gallons per Home

WATER HEATER TANK GALLONS per Home	Homes with Storage Tanks (n=88)	Detached Homes (n=82)	Attached Homes (n=6)	Weighted (Detached/ Attached)
32 to 40 Gallons	31 (35%)	28 (34%)	3 (50%)	42%
41 to 50 Gallons	33 (38%)	30 (37%)	3 (50%)	43%
52 to 100 Gallons	24 (27%)	24 (29%)*	0 (0%)*	15%

*Significantly different at the 90% confidence level.

Water heater Energy Factors vary widely depending on the type of water heating system. Table 10-25, on the next page, shows that electric storage tank water heating systems in inspected homes have the highest average Energy Factors; conventional gas storage tank systems the lowest. The average Energy Factors of all instantaneous and all integrated tank systems observed in inspected homes are the same, at 0.83.[46] (No Energy factor was available for one Bosch commercial instantaneous water heater that has a thermal efficiency of 94%.) Energy Factors of natural gas and propane conventional storage tank systems, the most common type of system found in inspected homes, include estimated Energy Factors for six large conventional storage tank water heating systems that are not FVIR (Flammable Vapor Ignition Resistant) [47] construction and do not have reported Energy Factors: Energy Factors for these six water heaters were estimated using the RESNET Energy Factor Calculator for Commercial DHW Tanks.[48]

Weighted average Energy Factors are 0.64 for conventional gas (natural gas and propane) storage tank water heaters, 0.90 for conventional electric storage tank water heaters, 0.83 for indirect water heating systems (storage tanks integrated with boiler heating systems), and 0.88 for instantaneous gas (natural gas and propane) water heaters.

[46] Energy Factors for integrated tank systems are calculated as 92% of the boiler heating system AFUE.
[47] Flammable Vapor Ignition Resistance is a technology developed for gas-fired water heaters that resists ignition of flammable vapors that may occur outside and in close proximity to a water heater as a result of the mishandling of flammable products. Source: http://www.bradfordwhite.com/fvirtech.asp
[48] http://www.resnet.us/uploads/documents/standards/Commercial_Hot_Water_EF_Calculator_12-10.xls

Table 10-25: Water Heater Energy Factor Statistics

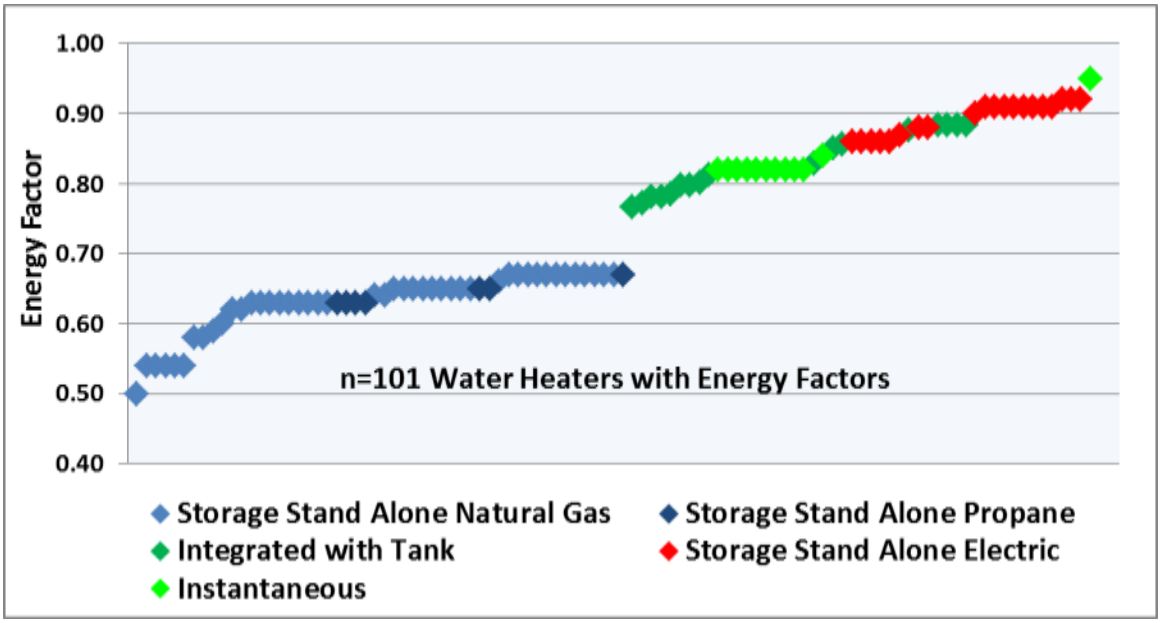
Conventional Storage Tank (Natural Gas & Propane)	All Water Heaters (n=52)	Water Heaters in Detached Homes (n=47)	Water Heaters in Attached Homes (n=5)	Weighted** (Detached/ Attached)
Minimum R-value	0.50	0.50	0.63	0.50
Maximum R-value	0.67	0.67	0.67	0.67
Average R-value	**0.63**	**0.63***	**0.65***	**0.64**
Median R-value	0.64	0.63	0.65	0.64
Conventional Storage Tank (Electric)	**All Water Heaters (n=20)**	**Water Heaters in Detached Homes (n=19)**	**Water Heaters in Attached Homes (n=1)**	**Weighted** (Detached/ Attached)**
Minimum R-value	0.86	0.86	0.90	0.86
Maximum R-value	0.92	0.92	0.90	0.92
Average R-value	**0.89**	**0.89**	**0.90**	**0.90**
Median R-value	0.91	0.91	0.90	0.91
Indirect: Integrated with Tank (Fossil-Fuel Fired)	**All Water Heaters (n=17)**	**Water Heaters in Detached Homes (n=17)**	**Water Heaters in Attached Homes (n=0)**	**Weighted** (Detached/ Attached)**
Minimum R-value	0.77	0.77	n/a	0.77
Maximum R-value	0.88	0.88	n/a	0.88
Average R-value	**0.83**	**0.83**	**n/a**	**0.83**
Median R-value	0.81	0.81	n/a	0.81
Instantaneous (Natural Gas & Propane)	**All Water Heaters (n=12)**	**Water Heaters in Detached Homes (n=11)**	**Water Heaters in Attached Homes (n=1)**	**Weighted** (Detached/ Attached)**
Minimum R-value	0.82	0.82	0.95	0.82
Maximum R-value	0.95	0.84	0.95	0.95
Average R-value	**0.83**	**0.82**	**0.95**	**0.88**
Median R-value	0.82	0.82	0.95	0.82

*Significantly different at the 90% confidence level.
**Only the average is weighted

Only one attached home has an instantaneous water heater—a very energy-efficient Navien America system with an Energy Factor of 0.95. This water heater's Energy factor should not be considered representative of the average instantaneous water heater in attached housing. There are 850 models on the current EPA product list for ENERGY STAR Qualified Whole-Home (natural gas and propane) Tankless Water Heaters and the average Energy Factor of these ENERGY STAR-qualified models is 0.85. The ENERGY STAR criteria are 0.67 Energy Factor for high efficiency gas conventional systems and 0.82 Energy Factor for gas instantaneous systems. The Navien America 0.95 Energy Factor system is clearly an outlier.

Figure 10-14 graphs the water heating system Energy Factors for the 101 water heaters for which Energy Factors are available.

Figure 10-14: Water Heater Energy Factors by Type of System



10.5.1 Who Specified Water Heating System and Perceived Efficiency

Ninety-six homeowners completed the on-site survey, but not all owners responded to all questions. Therefore, the numbers of responses on which presented results are based vary. The on-site homeowner survey asked owners who specified the cooling system in their home. The choices were:

- I specified (Note that owners who are also the builder are treated as a separate category in this section.)
- Builder chose
- Selected from options offered by the builder
- Do not remember or do not know

If owners responded that they specified the water heater, they were asked, "Do you remember what you specified?" If they remembered, they were asked to check all options that applied; the options were:

- Fuel used to heat water
- Type of system (stand-alone tank, integrated tank with boiler, tankless, tankless combined with boiler heating system, point of use, etc.)
- Energy-efficient system
- ENERGY STAR-labeled system

Owners were also asked to rate the energy efficiency of their water heater. The choices were:

- Not Energy Efficient
- Average Efficiency
- Very Energy Efficient
- ENERGY STAR Labeled
- Do Not Know

Who Specified Water Heater

Figure 10-15 shows builders chose the water heaters in 61% of homes. Nineteen owners plus six owner/builders who completed the survey say they specified the water heater for their home and eleven owners say they selected from options offered by their builder.

Figure 10-15: Who Specified Water Heater

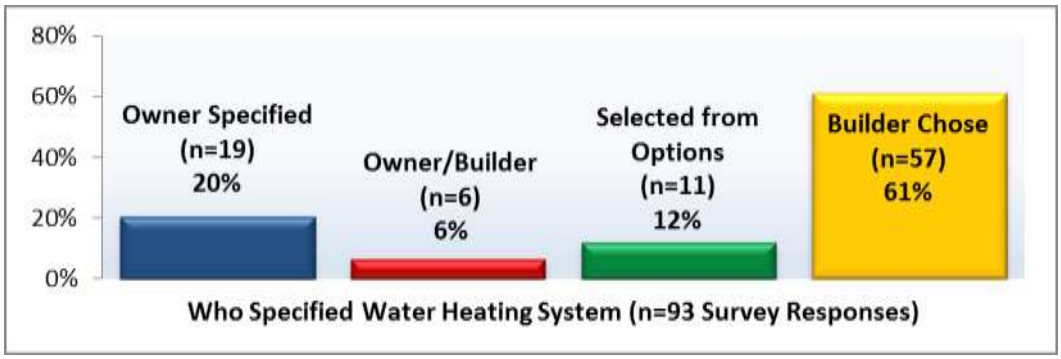


Table 10-26 shows what aspects of water heaters owners say they specified. (Note that some owners simply said they specified the water heater and did not identify what aspects of their water heater they specified.) As shown, owners who said they specified their water heaters were most likely to say they specified the water heater fuel (74%) and/or the type of water heater system (42%). Almost one-third (32%) of owners who say they specified their water heater specified an energy-efficient water heater, but not an ENERGY STAR-labeled water heater, and 21% say they specified an ENERGY STAR-labeled water heater.

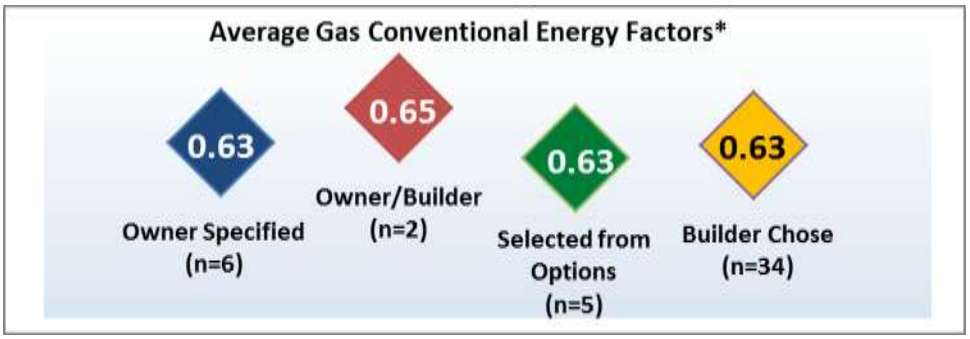
Table 10-26: Water Heater Aspects Owners Specified

Water Heating Systems: What Owners Specified (Multiple Responses)	Owners who Specified Water Heating System (n=19)	
	# of Owners	% of Owners
Water Heating Fuel	14	74%
Type of Water Heating System	8	42%
Energy-Efficient Water Heater	6	32%
ENERGY STAR-labeled Water Heater	4	21%

Figure 10-16 through Figure 10-19 show the average Energy Factors for conventional gas (natural gas and propane) storage tank water heaters, conventional electric storage tank water heaters, indirect water heating systems (storage tanks integrated with boiler heating systems), and gas (natural gas and propane) instantaneous water heaters by who specified the water heater.

The majority of owners who completed the on-site survey and responded to the question asking who specified the water heater in their home have conventional gas storage tank water heaters (47 of 93 respondents). Figure 10-16 shows that in the majority of these homes the builder chose the water heater. The average efficiency of conventional gas storage tank water heaters is highest in homes where the owner is also the builder (Energy Factor 0.65). The average Energy Factor is the same (Energy Factor 0.63) in homes where the owner says they specified the water heater, where the owner selected from options offered by the builder, and in homes where the builder chose the water heater.

Figure 10-16: Conventional Gas Storage Tank Water Heater Average Energy Factors by Who Specified



*Includes both natural gas and propane water heaters.

Figure 10-17 shows that in the majority of homes with conventional electric storage tank water heaters the builder specified the water heater. The average efficiency of conventional electric storage tank water heaters is highest in the home where the owner is also the builder (Energy Factor 0.92). The average Energy Factor is the same (Energy Factor 0.89) in homes where the owner specified the water heater and in homes where the builder chose the water heater. The average Energy Factor is lowest (Energy Factor 0.88) in the home where the owner selected the water heater from options offered by the builder.

Figure 10-17: Conventional Electric Storage Tank Water Heater Average Energy Factors by Who Specified

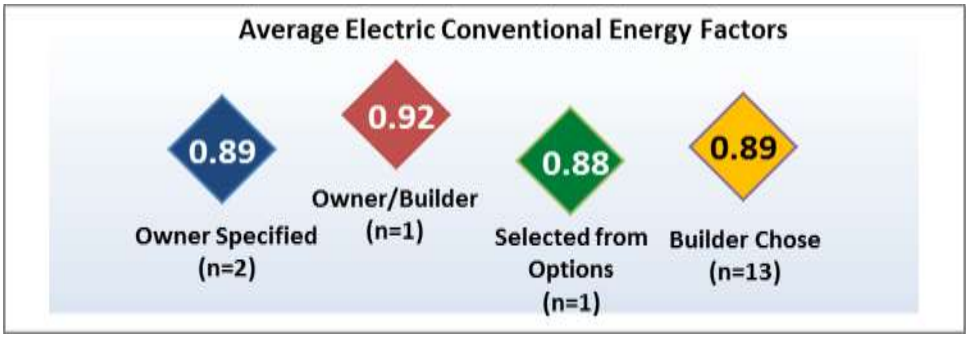


Figure 10-18 shows the average efficiency of indirect storage tank water heaters is highest in homes where the owner selected the water heater from options offered by the builder (Energy Factor 0.86), then homes where the owner is also the builder (Energy Factor 0.84) and homes where owners say they specified the water heater (Energy Factor 0.83). The lowest average efficiency is in homes where the builder chose to install an indirect water heating system (Energy Factor 0.81).

Figure 10-18: Indirect Storage Tank Water Heater Average Energy Factors by Who Specified

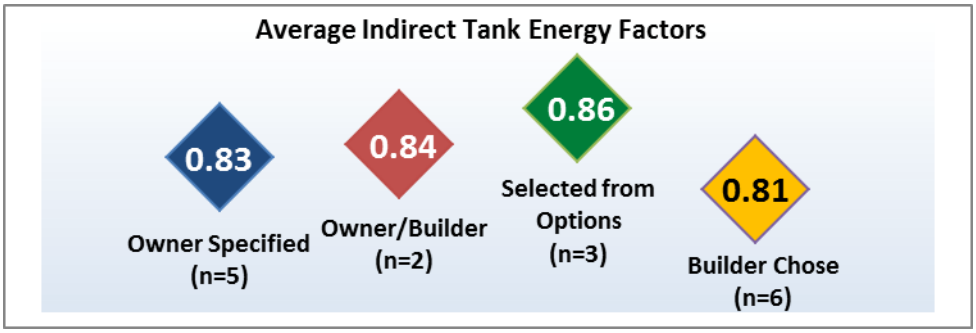
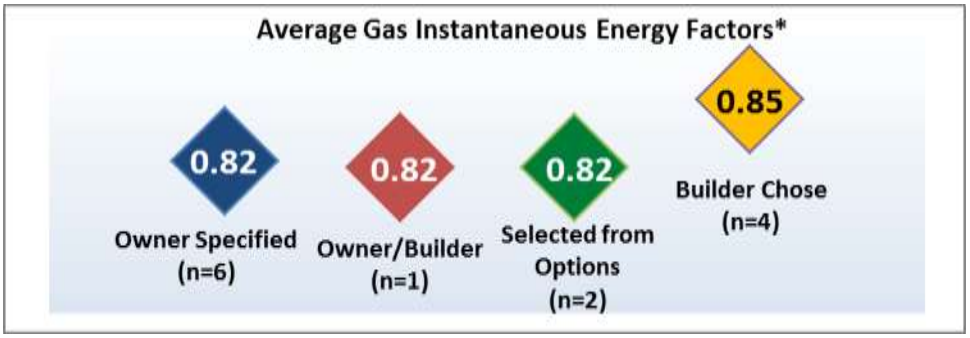


Figure 10-19 shows the average efficiency of instantaneous gas (natural gas and propane) water heaters is the same in homes where the owner says they specified the water heater, in homes where the owner is the builder, and in homes where the owner selected the water heater from options offered by the builder (Energy Factor 0.82). The higher average Energy Factor in homes where the builder chose the water heater (Energy Factor 0.85) is because one builder chose a very efficient water heater with an Energy Factor of 0.95—this is the only instantaneous water heater in inspected homes with an Energy Factor higher than 0.84.

Figure 10-19: Instantaneous Gas Water Heater Average Energy Factors by Who Specified



*Includes both natural gas and propane water heaters.

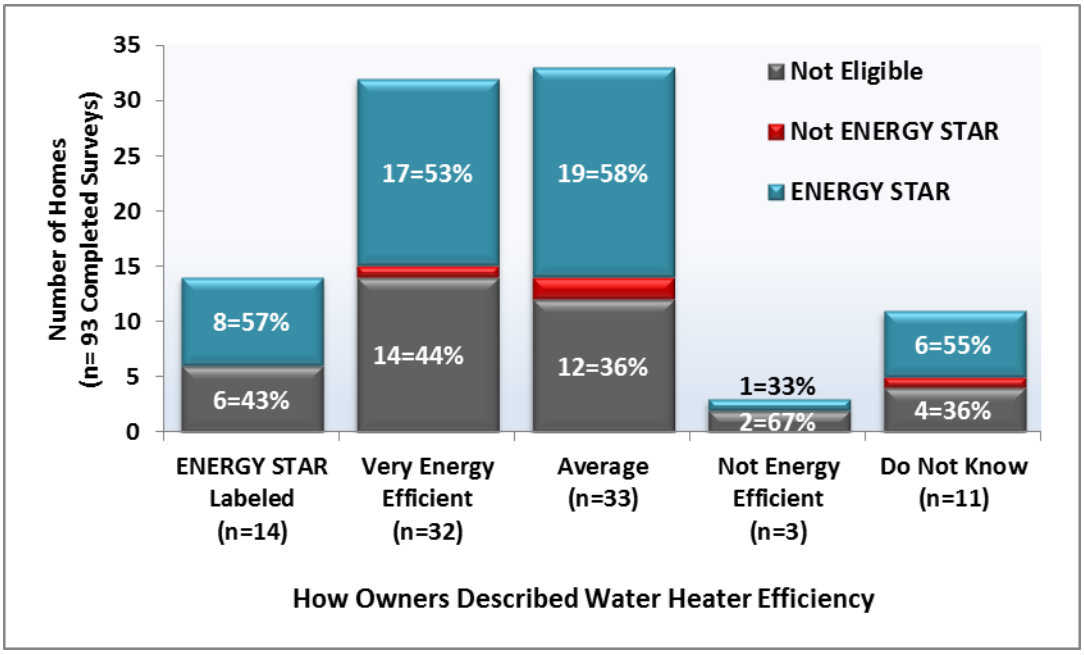
Perceived versus Actual Efficiency of Water Heaters

Only two types of residential water heaters encountered in the site visits are eligible for ENERGY STAR qualification—high-efficiency gas (natural gas and propane) storage and whole-home gas (natural gas and propane) tankless (instantaneous). To qualify for ENERGY STAR certification a gas instantaneous water heater must have an Energy Factor of 0.82 or higher. The criteria for ENERGY STAR-qualified gas storage water heaters changed as of September 1, 2010 from an Energy Factor of at least 0.62 to an Energy Factor of at least 0.67. Suppliers could sell any ENERGY STAR-labeled, in-stock water heaters with Energy Factors that met the old criteria as ENERGY STAR-compliant models until their stock was depleted. Because many of the inspected homes were completed prior to or within months of the change in criteria, it is likely that many of the gas storage water heaters with Energy Factors of at least 0.62, but below 0.67, were legitimately sold as ENERGY STAR compliant. Therefore, in this section, gas storage water heaters that meet the pre September 1, 2010 criteria for ENERGY STAR qualification are treated as being ENERGY STAR water heaters.

Figure 10-20 shows perceived versus actual ENERGY STAR water heaters. As shown, 8 of the 14 owners who think they have ENERGY STAR water heaters do, and 6 owners have types of water heaters that are not eligible for ENERGY STAR qualification. Over half of the owners who think their water heaters are very energy efficient, but not ENERGY STAR, or think their water heaters are average actually have ENERGY STAR water heaters. One of three owners who

thinks their water heater are not energy efficient and six of the eleven owners who say they do not know how energy efficient their water heater is also have ENERGY STAR water heaters.

Figure 10-20: Perceived versus Actual ENERGY STAR Water Heaters



10.6 Mechanical Ventilation

Auditors recorded information on mechanical ventilation during the on-site inspections. According to REM/Rate, mechanical ventilation is defined as "A fan designed to exchange the air in the house with outside air, sized to provide whole-house service per ASHRAE 62.2, and controlled automatically (i.e. not requiring human intervention to turn on and off)." Using this definition, only five of the audited homes have mechanical ventilation; one home has an Energy Recovery Ventilator (ERV), one home has a bathroom fan that continuously exhausts, and three homes have bathroom fans that are on timers.

ERVs deliver balanced mechanical ventilation to the whole house. That is, they exhaust stale air from the home and deliver fresh outside air simultaneously. The ERV found onsite exhausts at various rates ranging from 100 CFM to 200 CFM. The sensible recovery efficiency for this unit is 78% and the total recovery efficiency is 52%.

Including the five homes with mechanical ventilation, all 100 inspected homes have bathroom exhaust fans. The number of exhaust fans per home is generally equal to the number of bathrooms per home. In total, auditors counted 277 exhaust-only fans, ranging from one to four fans per home.

Auditors were unable to verify the exhaust rate for bathroom fans in any home. In general, bathroom fan exhaust rates range from 50 CFM to 150 CFM.

11 Ducts

11.1 Duct Insulation Requirements

The 2009 IECC prescriptive code requirement for duct insulation is a minimum of R-8 for supply ducts located in attics, and a minimum of R-6 for all other ducts located in unconditioned space.[49] Table 11-1 shows that the weighted average R-value of duct insulation calculated over all types of ducts in all unconditioned locations is R-5.7. With respect to the prescriptive insulation requirement, 23 of the 85 homes with ducts located in unconditioned space meet or exceed the 2009 IECC prescriptive insulation requirement; the weighted percentage is only 22%.

Table 11-1: Duct R-value Statistics

Duct Insulation Level All Ducts in Unconditioned Spaces	All Homes with Ducts Located in Unconditioned Space (n=85)	Detached Homes (n=78)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Minimum R-value	0.0	0.0	0.0	0.0
Maximum R-value	10.3	10.3	8.0	10.3
Average R-value	**5.9**	**6.0**	**5.4**	**5.7**
Median R-value	6.0	6.0	6.0	6.0
Comparison to 2009 IECC (supply-attic R-8, all other R-6)				
Supply-Attic < R-8 and/or All Other < R-6	60 (71%)	54 (69%)	6 (86%)	77%
Supply-Attic R-8, All Other R-6	10 (12%)	10 (13%)	0 (0%)	7%
Supply-Attic ≥ R-8 and/or All Other ≥ R-6	13 (15%)	12 (15%)	1 (14%)	15%
Don't Know*	2 (2%)	2 (3%)	0 (0%)	1%

*Auditors were not able to record the R-value of insulation on attic supply ducts in two homes; therefore, it is unclear whether these two homes meet the prescriptive code requirement of R-8 for supply ducts located in attics.

11.2 Homes with Ducts

The majority of the inspected homes (90 out of 100) have ductwork. Only five homes have all ducts installed in conditioned space; an additional 32 homes have some ducts installed in conditioned space. [50] Table 11-2 shows the various heating and cooling system combinations in the inspected homes. The majority of homes have a furnace with central air conditioning; the weighted percentage is 85%. All inspected attached homes have a furnace with central air conditioning. The next most common heating and cooling system combination is a hydro-air boiler with central air conditioning (11 homes), followed by a hot water boiler without central air conditioning (8 homes). Three homes each have a furnace without central air conditioning or a

[49] Homes demonstrating compliance via the performance path must meet a mandatory minimum insulation requirement of R-6 for all ducts located in unconditioned space.

[50] For the purposes of this analysis conditioned space includes conditioned floor area, basements where the foundation walls are fully insulated and attics where the rafters are fully insulated.

ground source heat pump. The least common heating and cooling system combination, observed in two homes, is a hot water or steam boiler with central air conditioning.

Table 11-2: Mechanical Equipment

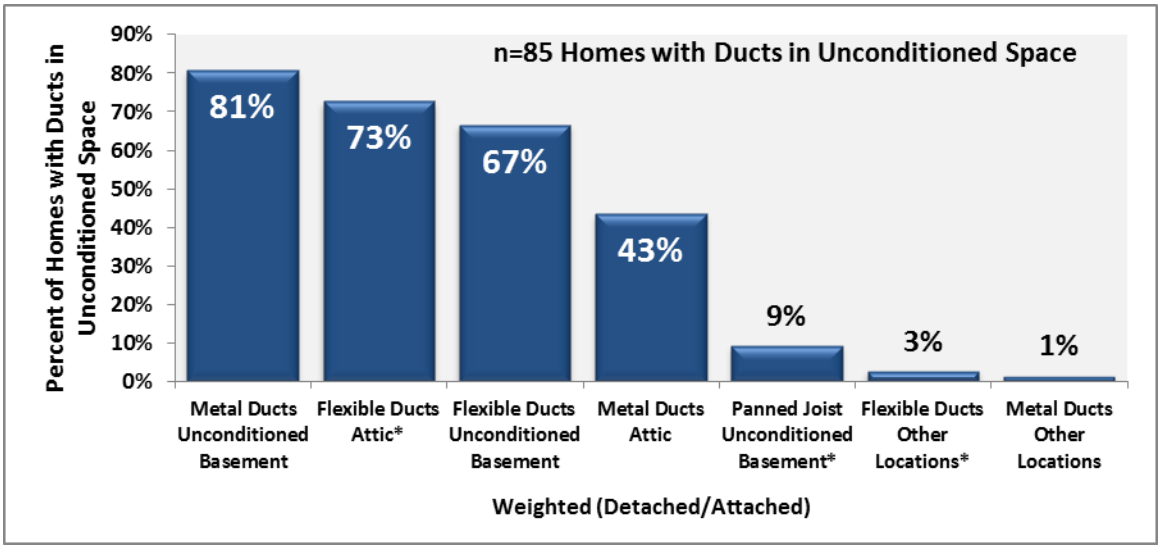
Heating/Cooling System Combination	All Homes (n=100)	Detached Homes (n=93)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Furnace with Central Air Conditioning	73 (73%)	66 (71%)*	7 (100%)*	85%
Boiler (hydro-air) with Central Air Conditioning	11 (11%)	11 (12%)*	0 (0%)*	6%
Boiler (hot water) without Central Air Conditioning	8 (8%)	8 (9%)*	0 (0%)*	4%
Furnace without Central Air Conditioning	3 (3%)	3 (3%)*	0 (0%)*	2%
Ground Source Heat Pump (Heating & Cooling)	3 (3%)	3 (3%)*	0 (0%)*	2%
Boiler (hot water or steam) with Central Air Conditioning	2 (2%)	2 (2%)	0 (0%)	1%

*Attached homes are significantly different from detached homes at the 90% confidence level.

11.3 Duct Types and Insulation

For all supply and return ducts located in unconditioned space, auditors recorded the duct type (metal, flexible or duct board), location, insulation type and insulation R-value. Figure 11-1 shows the weighted percentage of all homes with ducts in unconditioned space that have metal, flexible or duct board ducts in unconditioned basements, attics or other locations.[51] Homes typically have a mix of metal and flexible ducts. Attached homes are significantly more likely than detached homes to have flexible ducts in the attic, and significantly less likely to have panned joists in an unconditioned basement or flexible ducts in other locations.

Figure 11-1: Duct Type by Location

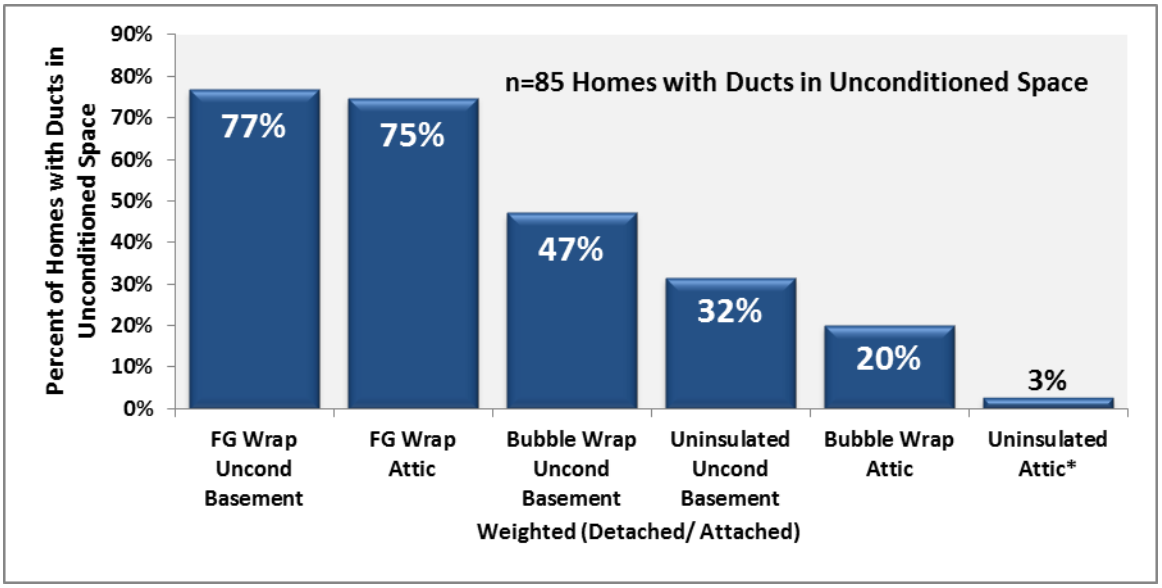


*Attached homes are significantly different from detached homes at the 90% confidence level.

[51] Other locations include crawl spaces and garages.

Figure 11-2 shows the type of duct insulation by location for all homes with ductwork in unconditioned space. Fiberglass wrap (including pre-wrapped flex ducts) is the most common type of duct insulation. As shown, the weighted percentage of homes with ducts in unconditioned basements insulated with fiberglass wrap is 77%. The weighted percentage of homes with attic ducts insulted with fiberglass wrap is 75%. Weighted results show that about one-third of homes have uninsulated ducts in unconditioned space: the weighted results are 32% of homes with uninsulated ducts in an unconditioned basement, and 3% with uninsulated ducts in the attic. Attached homes are significantly less likely to have uninsulated ducts in the attic than detached homes.

Figure 11-2: Duct Insulation Type by Location



*Attached homes are significantly different from detached homes at the 90% confidence level.

11.4 Supply and Return Duct Insulation R-values

Table 11-3 shows the average R-value of duct insulation for supply and return ducts in unconditioned space by location. As shown, the weighted average R-value for supply ducts in all unconditioned locations (5.9) is higher than for return ducts (5.4). Additionally, while the weighted average R-value for attic supply ducts (6.5) is greater than the weighted average R-values for supply and return ducts in all unconditioned locations, it is still less than the 2009 IECC prescriptive path minimum requirement of R-8 for supply ducts located in an attic.

Table 11-3: Average Supply and Return Duct Insulation R-value by Location

Duct Location	All Homes with Ducts Located in Unconditioned Space (n=85)			Detached Homes (n=78)			Attached Homes (n=7)			Weighted (Detached/ Attached)	
	n	Average Supply Duct R-value	Average Return Duct R-value	n	Average Supply Duct R-value	Average Return Duct R-value	n	Average Supply Duct R-value	Average Return Duct R-value	Average Supply Duct R-value	Average Return Duct R-value
Attic	60	6.5	6.2	54	6.5	6.2	6	6.5	6.3	6.5	6.2
Unconditioned Basement	76	5.9	5.1	71	6.0	5.2	5	4.9	4.3	5.5	4.8
Other*	7	6.6	6.6	7	6.6	6.6	0			6.6	6.6
Average R-value Over All Ducts in Unconditioned Locations											
All Ducts in Unconditioned Space	85	6.2	5.6	78	6.2	5.7	7	5.6	5.2	5.9	5.4

* Refers to unconditioned spaces other than unconditioned basements and attics (i.e. crawl spaces and garages).

11.5 Conditioned Volume Basements

During the on-site visits NMR auditors found that many homes with walk-out basements did not have a clear thermal and/or pressure boundary. It is common in new construction to have a walk-out basement where the frame floor (separating the basement ceiling from the floor above) is insulated and a significant portion of the basement walls are insulated as well. More often than not, the insulated walls in these basements are stud walls located on top of the foundation walls—the foundation walls themselves are not typically insulated. That said, the insulated wall area in these situations typically accounts for a substantial portion of the total basement wall area (foundation wall area plus the area of any studs located on top of the foundation walls).

These basement areas are typically unfinished and could be considered "indirectly conditioned;" the temperature in these spaces is often similar to the temperature in other areas of the home. Finally, these spaces often include features that are not found in typical unconditioned basements, such as high quality windows and doors and exercise equipment. Figure 11-3 shows two examples of these types of basements.

Figure 11-3: Examples of Basements Considered Conditioned Volume

In reality, these basements are more of a buffer zone than conditioned or unconditioned space. Due to this, NMR auditors consulted their RESNET accredited rating provider to determine the best way to handle these situations. After a fair amount of back and forth it was decided that a zonal pressure test would be conducted at each of these homes to determine how "connected" the basement was to the rest of the house.

Zonal pressure tests were conducted at every home with a walk-out basement to find out if the basement was more connected with the house than it was with the outside.[52] Basements determined to be more connected to the house than the outside were treated as conditioned volume and auditors ran the diagnostic tests accordingly.

[52] With the house depressurized to -50 Pascals (Pa), zonal pressure tests measuring the basement pressure with respect to (WRT) the house always had a reading of 25 Pa or less indicating the basement was more connected with the house than the outside.

Including these basements in the conditioned volume significantly affected the diagnostic results in these homes. The reason for this is that when a space is considered conditioned volume it must be included in the diagnostic tests per RESNET standards.[53] For duct leakage, this meant that the basement was pressurized during the leakage to outside tests and ultimately decreased the leakage to outside values for the distribution systems located in these basements. For air leakage, this meant the basement door was open during the blower door test and the volume of the basement was included in ACH50 (air changes per hour @ 50 Pa) calculations; increasing the volume in these calculations decreases the subsequent ACH50 value.

Duct blaster tests were performed on duct systems in 24 homes where the basements were considered conditioned volume, not conditioned floor area. Of these 24 systems, 13 have ducts associated with the basement system located in other spaces (e.g. exterior walls, garages, and attics), while the other 11 systems have all of their associated ducts located entirely within the basement. The duct leakage results from the 13 systems with ducts located in spaces other than the basement are excluded from the duct leakage results presented in this report and in the UDRH. Total leakage was substituted for leakage to the outside for the 11 systems where all of the associated ducts are located entirely within the basement. In these conditioned volume basements, total leakage is a reasonably proxy for leakage to the outside results that would have been achieved had the basement been considered fully unconditioned. These adjustments were made to make the baseline data reflective of the Program and how similar situations would have been handled and tested by Program raters.

Blower door tests were conducted on 26 homes with conditioned volume basements. These 26 homes were excluded from the air leakage results presented in this report and in the UDRH in order to make the baseline data as comparable to the Program as possible.

[53] http://www.resnet.us/standards/DRAFT_Chapter_8_July_22.pdf

11.6 Duct Leakage

As discussed earlier, 90 of the 100 inspected homes have duct systems and in five of these homes all ducts are installed in conditioned space. Auditors were able to conduct usable duct leakage tests at 69 of the 90 homes with ducts.[54] In some homes with multiple duct systems, there was not enough time to test all the systems. Other reasons ducts could not be tested include:

- Couldn't seal all the registers because they were an odd rounded shape and suspended over a 20 foot high vault—no way to reach them
- Could not test upstairs ducts due to baby sleeping
- Attic system was too hard to reach in the blown in insulation
- Ran out of time—owner had time constraints

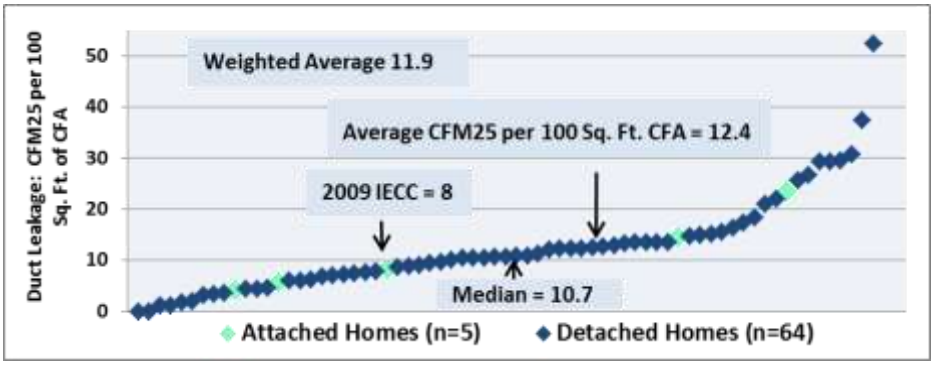
Table 11-4 shows duct leakage statistics for 69 tested homes with usable data. Data are shown for all inspected homes, detached homes, attached homes and weighted results reflecting the mix of single-family detached and attached housing in the 2011 Program. Duct leakage to the outside ranged from 0.0 to 52.3 CFM25 per 100 sq. ft. of conditioned floor area.[55] The weighted average is 11.9 CFM25 per 100 sq. ft. of conditioned floor area; this is virtually the same as the current UDRH input of 12. Figure 11-4 shows duct leakage by homes.

Table 11-4: Duct Leakage Statistics

Duct Leakage	All Homes (n=69)	Detached Homes (n=64)	Attached Homes (n=5)	Weighted* (Detached/ Attached)
Min	0.0	0.0	4.2	0.0
Max	52.3	52.3	23.4	52.3
Average	12.4	12.5	11.2	**11.9**
Median	10.7	10.8	8.3	10.7

*Only the average is weighted.

Figure 11-4: Duct Leakage by Home



[54] This excludes the 11 systems where the basement was considered conditioned volume and some of the ducts were not located in the basement.

[55] The home with very high leakage is one that had four duct systems and three were tested. Two of the tested systems were very leaky and served small areas. The reason the leakage rate is so high is that the three tested duct systems serve an area that could have been served by one duct system!

Mandatory 2009 IECC duct leakage requirements for ducts tested post construction are that homes meet one of the following:

- Leakage to outdoors less than or equal to 8 CFM25 per 100 square feet of conditioned floor area
- Total leakage less than or equal to 12 CFM25 per 100 square feet of conditioned floor area
- Duct tightness test is not required if the air handler and all ducts are located within conditioned space.

Table 11-5 shows duct leakage compliance statistics for 71 homes—69 homes where duct leakage testing was performed and 2 homes where the ducts were not tested, but all ducts were in conditioned space. As shown, 28 of the 71 homes complied with 2009 IECC mandatory duct leakage requirements: the weighted compliance rate is 49%.

Table 11-5: Compliance with 2009 IECC Mandatory Duct Leakage Requirements

Compliance with 2009 IECC Mandatory Duct Leakage Requirement	All Homes (n=71)*	Detached Homes (n=66)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Complies	28 (39%)	25 (38%)	3 (60%)	49%
Fails	43 (61%)	41 (62%)	2 (40%)	51%

*Includes two homes not tested—all ducts in conditioned space.

Putting duct leakage results into perspective, the average leakage to the outside of 11.9 CFM25 per 100 sq. ft. of conditioned floor area in homes where ducts were tested is:

- Sharply lower than 2005 Baseline Study average leakage to the outside of 21.7 CFM25 per 100 sq. ft. of conditioned floor area
- Almost 50% higher than the 2009 IECC mandatory requirement of 8 or less CFM25 per 100 sq. ft. of conditioned floor area for ducts tested post construction
- Almost three times the ENERGY STAR Version 3 performance path requirement that duct leakage to outdoors be 4 or less CFM25 per 100 sq. ft. of conditioned floor area
- More than three times the average duct leakage of 3.6 CFM25 per 100 sq. ft. of conditioned floor area in single-family homes completed through the 2011 Program

12 Air Infiltration

Auditors conducted blower door tests on 99 of the inspected homes.[56] As previously mentioned, results from 26 homes where the basement was considered conditioned volume have been excluded from the results presented below.

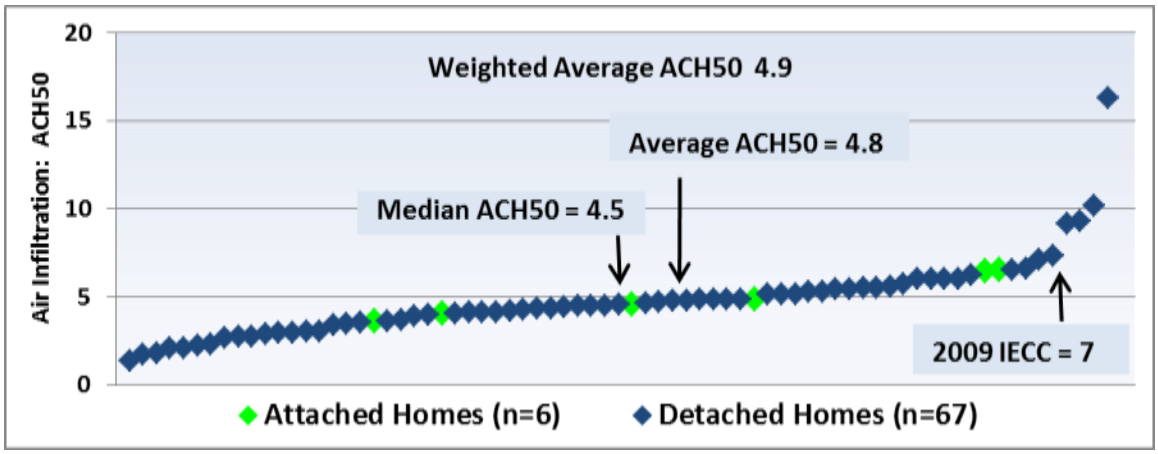
Blower door tests measure how airtight, or leaky, a home is and can determine the source of leaks. Homes that are too tight may need mechanical ventilation to bring air into the home. Very leaky homes will be expensive to heat and cool, and will likely feel drafty. Table 12-1 shows air changes per hour measured at 50 Pascals range from 1.36 to 16.30 in the 73 baseline homes with analyzed blower door testing results.[57] Data are shown for all inspected homes, detached homes, attached homes and weighted results reflecting the mix of single-family detached and attached housing in the 2011 Program. The weighted average ACH50 is 4.88; this is lower than the current UDRH input of 6.72 ACH50. Figure 12-1 graphs ACH50 by home.

Table 12-1: Air Infiltration Statistics

ACH50	All Homes (n=73)	Detached Homes (n=67)	Attached Homes (n=6)	Weighted* (Detached/ Attached)
Min	1.36	1.36	3.60	1.36
Max	16.30	16.30	6.54	16.30
Average	4.78	4.76	5.01	**4.88**
Median	4.54	4.51	4.72	4.54

*Only the average is weighted.

Figure 12-1: Air Changes per Hour by Home



[56] Auditors were unable to perform a blower door test at one home due to a missing door between the conditioned basement and the bulkhead.

[57] In the home with 16.3 ACH50 the auditor reports there was excessive leakage from the basement, knee walls, and an unfinished room.

The overall average of 4.78 ACH50 and the weighted average of 4.88 ACH50 are measurably lower than the 2005 Baseline Study average of 6.72 ACH50. 2009 IECC allows building tightness and insulation installation to be considered acceptable if tested air leakage is 7 ACH50 or lower; an impressive 95% or 69 of the 73 baseline homes have 7 or lower ACH50. The ENERGY STAR Version 3 performance path requires air infiltration to be 4 ACH50 or lower; 48% or 35 of the 73 baseline homes have 4 or lower ACH50. Average air infiltration in 2011 Program homes was 3.7 ACH50; 29% or 21 of the 73 baseline homes have 3.7 or lower ACH50.

Table 12-2 shows total CFM50 for the 73 baseline homes ranges from 285 to 4,434; the weighted average is 1,399 CFM50.

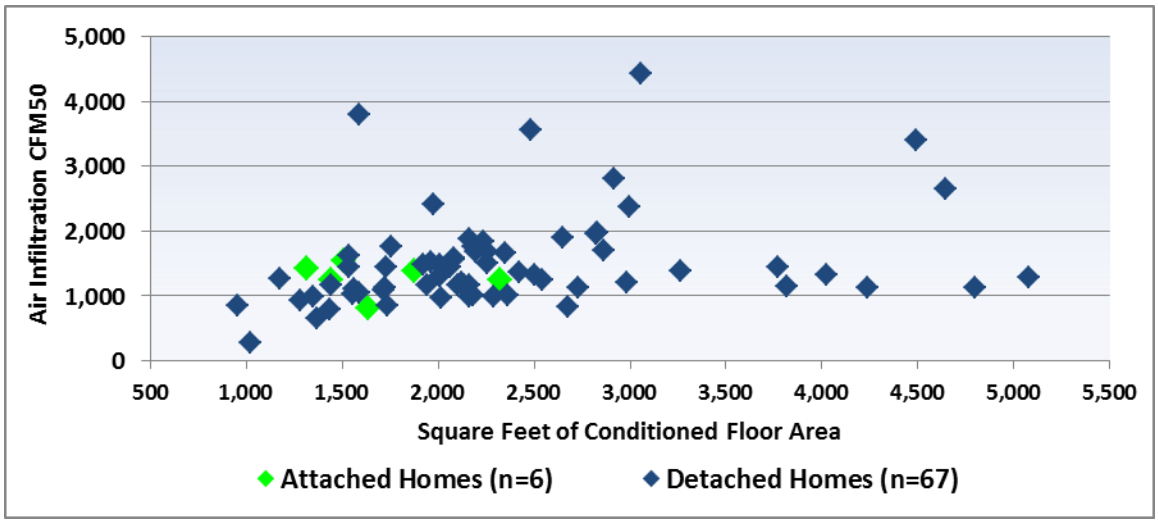
Table 12-2: Air Infiltration CFM50 Statistics

Air Infiltration CFM50	All Homes (n=73)	Detached Homes (n=67)	Attached Homes (n=6)	Weighted** (Detached/ Attached)
Min	285	285	820	285
Max	4,434	4,434	1,550	4,434
Average	**1,497**	**1,516***	**1,278***	**1,399**
Median	1,315	1,315	1,318	1,315

*Significantly different at the 90% confidence level.
**Only the average is weighted.

Figure 12-2 shows total CFM50 by home size. As shown, total leakage varies widely for homes of similar size.

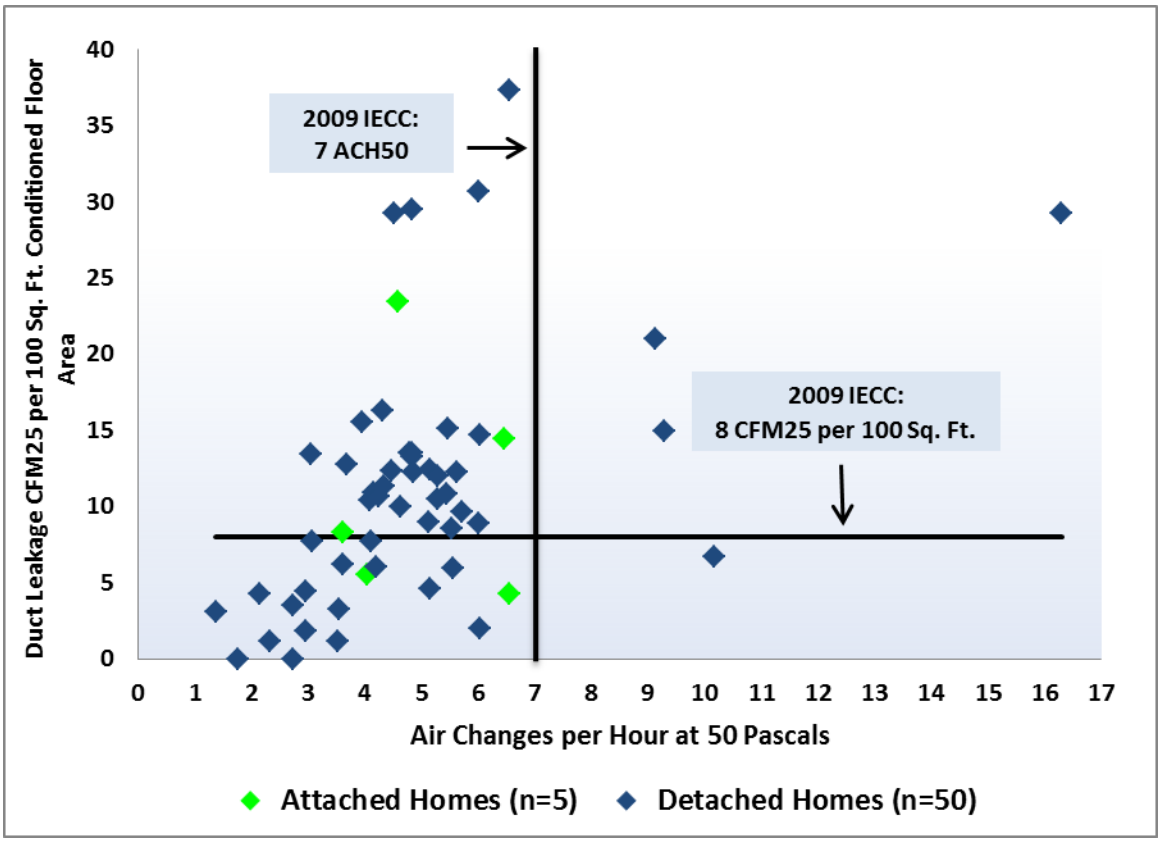
Figure 12-2: Total CFM50 Leakage by Home Size



12.1 Air Infiltration and Duct Leakage

Many tight homes have leaky ducts. Figure 12-3 shows air infiltration and duct leakage levels for the 55 homes with both air infiltration and duct leakage data. Twenty homes (lower left) meet 2009 IECC requirements for both duct leakage and air infiltration. Over one-half of the homes, 31 homes (upper left), meet the 2009 IECC air infiltration requirement but not the duct leakage requirement. One home (lower right) meets the 2009 IECC duct leakage requirement, but not the air infiltration requirement. Three homes (upper right) do not meet either the 2009 IECC duct leakage or air infiltration requirements.

Figure 12-3: Air Infiltration and Duct Leakage



13 Lighting

Auditors collected information on the total number of fixtures and ceiling fans and types of light bulbs (including fluorescent tubes) in each fixture in each of 99 homes visited; one home did not have its fixtures installed at the time of the audit. In addition to establishing a baseline, these data were used to determine that only 19% of the 99 homes visited would be in compliance with the 2009 IECC prescriptive requirement to have a minimum of 50 percent of the lamps in permanently installed lighting fixtures be high-efficacy lamps for homes complying under a prescriptive approach. The 2006 IECC has no lighting requirement.

13.1 Lighting Counts from the On-Site Inspections

Auditors counted the number of fixtures containing: screw-in CFL bulbs, pin-based CFL bulbs, LED bulbs, fluorescent tubes, and incandescent bulbs in each home. For the purposes of this analysis, the first four are considered energy efficient.[58] Close to two-thirds (65%) of the homes visited have very few fixtures with energy-efficient bulbs installed, accounting for 10% or less of all fixtures installed in the home. Only 19% of the homes visited have 50% or more of their fixtures fitted with bulbs classified as energy efficient and would be in compliance with the prescriptive lighting requirement for 2009 IECC for homes complying under a prescriptive approach. Eight percent of the homes visited have 75% or more of their fixtures fitted with bulbs classified as energy efficient and would be in compliance with 2012 IECC (Table 13-1).[59]

Table 13-1: Portion of Homes with Fixtures Containing Energy-Efficient Bulbs

Percent of Fixtures with Energy-Efficient Bulbs in the Home	All Homes (n=99)	Detached Homes (n=92)	Attached Homes (n=7)	Weighted (Detached/ Attached)
10% or less	60 (61%)	55 (60%)	5 (71%)	65%
11% to 30%	15 (15%)	15 (16%)	0 (0%)	8%
30% to 49%	12 (12%)	12 (13%)	0 (0%)	7%
Compliance with 2009 IECC (50% or more energy efficient)				
50% to 74%	8 (8%)	7 (8%)	1 (14%)	11%
75% to 100%	4 (4%)	3 (3%)	1 (14%)	8%

[58] It is important to note here that the auditors only counted fixtures; there may well be homes with plug-in lamps that contain CFL bulbs which are not reflected in the analyses presented in this chapter.

[59] The compliance analysis assumes that the proportion of energy-efficient fixtures would be equal to the proportion of energy efficient bulbs or lamps installed in the home.

A similar analysis was performed for the 73 homes where the homeowner answered the question of who specified the lighting fixtures in the home, based on whether the builder or home owner chose the fixtures installed. As Table 13-2 shows, builders and owners chose to install similar proportions of fixtures with energy-efficient bulbs; the differences is not statistically significant, at the 90% confidence level.

Table 13-2: Portion of Homes with Fixtures Containing Energy-Efficient Bulbs by Decision Maker

Percent of Fixtures with Energy-Efficient Bulbs in the Home	All Homes (n=73)	Builder Chose Fixtures (n=20)	Owner Chose Fixtures (n=53)
10% or less	45 (62%)	10 (50%)	35 (66%)
11% to 30%	12 (16%)	4 (20%)	8 (15%)
30% to 49%	9 (12%)	4 (20%)	5 (9%)
Compliance with 2009 IECC (50% or more energy efficient)			
50% to 74%	5 (7%)	2(10%)	3 (6%)
75% to 100%	2 (3%)	0 (0%)	2 (4%)

Looking at the total number of fixtures counted in visited homes, only an average of 23% of fixtures contain energy-efficient bulbs.[60] As expected, this is much higher than the 2005 baseline where only 4.6% of the bulbs installed qualified as high efficiency bulbs. In the current baseline, detached homes have slightly more fixtures with energy-efficient bulbs than attached homes, but they also have significantly more total fixtures than attached homes. That is due to the fact that detached homes are, not surprisingly, larger than attached homes with an average conditioned floor area of 2,410 square feet compared with 1,792 square feet for attached homes. Attached homes thus have a higher percentage of fixtures containing energy-efficient bulbs than detached homes.

Detached homes have significantly more fixtures containing LED bulbs and fluorescent tubes, but these numbers are fairly small. All homes have an average of 9.0 fixtures containing energy-efficient bulbs, but the median is only 3.0 fixtures containing energy-efficient bulbs because relatively few homes account for the bulk of fixtures with energy-efficient bulbs installed. (Table 13-3)

[60] An alternative methodology for calculating the percentage of fixtures with energy efficient bulbs is to first determine the percentage of fixtures with energy efficient bulbs in each home and then calculate the average of those percentages across all homes; this methodology is intended to avoid having very large or small homes bias results. However, using this methodology, the average percentage of fixtures with energy efficient bulbs across all homes is only slightly lower at 21% versus 23%. The average percentage of fixtures with energy efficient bulbs in detached homes is 18% and in attached homes is 24%.

Table 13-3: Types of Fixtures Installed—All Homes

Number of Fixtures by Type of Bulb Installed in All Homes	All Homes (n=99)	Detached Homes (n=92)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Average number of fixtures containing screw-in or pin-based CFL bulbs	7.8	7.8	8.4	8.1
Average number of fixtures containing LED bulbs	0.1	0.1*	0.0*	0.1
Average number of fluorescent tube fixtures	1.3	1.3*	0.3*	0.8
Average number of fixtures containing energy-efficient bulbs	9.2	9.2	8.7	9.0
Median number of fixtures containing energy-efficient bulbs	3.0	3.0	0.0	n/a
Average number of total fixtures	45.5	46.5*	32*	39.4
Percent of fixtures containing energy-efficient bulbs	20%	20%	27%	23%

*Attached homes are significantly different from detached homes at the 90% confidence level.

The analysis was rerun to exclude 27 homes that had only fixtures with incandescent bulbs installed. When looking at the 72 homes that had at least one fixture with energy-efficient bulbs installed, the average percentage of fixtures containing energy-efficient bulbs per home is higher at 42% (Table 13-4). Again, detached homes have significantly more total fixtures than attached homes most likely due to the former having more conditioned floor area. It is also important to note that only three of the seven attached homes audited have energy-efficient bulbs in fixtures versus 69 of the 92 detached homes. However, the three attached homes had three-fifths of their fixtures (60%) containing energy-efficient bulbs versus one-quarter (25%) of the detached homes.

Table 13-4: Types of Fixtures Installed—Homes with One or More Fixture Containing Energy-Efficient Bulbs

Number of Fixtures by Type of Bulb Installed in All Homes	All Homes (n=72)	Detached Homes (n=69)	Attached Homes (n=3)	Weighted (Detached/ Attached)
Average number of fixtures containing screw-in or pin-based CFL bulbs	10.8	10.4	19.7	15.0
Average number of fixtures containing LED bulbs	0.1	0.1	0.0	0.1
Average number of fluorescent tube fixtures	1.7	1.8	0.7	1.3
Average number of fixtures containing energy-efficient bulbs	12.6	12.3	20.4	16.3
Median number of fixtures containing energy-efficient bulbs	7.0	7.0	21.0	n/a
Average number of total fixtures	49.8	50.5*	34.0*	42.4
Percent of fixtures containing energy-efficient bulbs	26%	25%	60%	42%

*Attached homes are significantly different from detached homes at the 90% confidence level.

Table 13-5 summarizes saturation of fixtures containing energy-efficient bulbs by the major room types. Because not every home contains the same room types, saturations were calculated based only on those homes where the room type was present. Saturations by room type are calculated as averages of the percentages of fixtures with energy-efficient bulbs in the particular room. It is important to note, again, that the on-site inspections were designed to collect information on the total number of fixtures based on bulb type but did not collect bulb counts. When interpreting data presented in this table, the reader should bear in mind that one fixture may contain a single bulb or multiple bulbs and, as such, fixture counts do not represent bulb counts. For example, kitchen fixtures are often recessed cans with one bulb per fixture, while dining rooms or foyers are more likely to have a lighting fixture with multiple bulbs.

It is worth noting that fixtures found in utility rooms (33%) and basements (32%) are the most likely to contain energy-efficient bulbs—about one in three.[61] In contrast, fixtures found in family rooms or dens (11%), foyers (11%), bathrooms (11%) and outdoors (10%) are the least likely to contain energy-efficient bulbs. There is thus some evidence that the most energy-efficient bulbs are installed in relatively low use areas.

The weighted averages for dining rooms and garages show a very high saturation out of proportion with the other rooms studied, 58% and 59%, respectively, but that is due to a single attached home that had 100% energy-efficient fixtures in the dining room and another attached homes that had 100% energy-efficient fixtures in the garage. For this reason, it is inadvisable to draw conclusions about dining room and garage saturations from the weighted data.

[61] These areas were also more likely to have qualifying bulbs in the 2005 baseline; 19% for utility rooms and 12% for basements.

Table 13-5: Average Number and Percent of Fixtures Containing Energy-Efficient Bulbs by Room

Rooms	All Homes		Detached Homes		Attached Homes		Weighted Average Percent of Fixtures with Energy-Efficient Bulbs per Home in each Room
	Number of Homes	Average Percent of Fixtures with Energy-Efficient Bulbs per Home in each Room	Number of Homes	Average Percent of Fixtures with Energy-Efficient Bulbs per Home in each Room	Number of Homes	Average Percent of Fixtures with Energy-Efficient Bulbs per Home in each Room	
Kitchen	97	17%	90	16%	7	33%	24%
Bathroom	97	14%	90	15%	7	7%	11%
Outdoor	94	7%	87	7%	7	14%	10%
Bedroom	92	23%	85	23%	7	30%	26%
Hallway	87	22%	81	21%	6	33%	27%
Living Room	84	18%	78	17%	6	33%	25%
Dining Room	59	19%	58	17%	1	100%	58%
Family Room or Den	50	15%	47	16%	3	5%	11%
Foyer	48	21%	46	22%	2	0%	11%
Garages	41	21%	40	19%	1	100%	59%
Utility Room	36	33%	36	33%	0	n/a	33%*
Basement	31	32%	31	32%	0	n/a	32%*

*Since there were no attached homes with utility room or basement counts, the unweighted percentages for detached homes are reported.

13.2 Ceiling Fans

More than two-thirds (68%) of the homes visited have at least one ceiling fan. As Table 13-6 shows, homes that have ceiling fans are most likely to have one, two, three or four; a few homes have five or more ceiling fans.

Table 13-6: Homes with Ceiling Fans

Number of Ceiling Fans	All Homes (n=99)	Detached Homes (n=92)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Zero	23 (23%)	20 (22%)	3 (43%)	32%
One	14 (14%)	14 (15%)	0 (0%)	8%
Two	19 (19%)	17 (18%)	2 (29%)	23%
Three	15 (15%)	14 (15%)	1 (14%)	15%
Four	19 (19%)	18 (20%)	1 (14%)	17%
Five	6 (6%)	6 (7%)	0 (0%)	4%
Six	2 (2%)	2 (2%)	0 (0%)	1%
Seven or more	1 (1%)	1 (1%)	0 (0%)	1%

14 Appliances

Auditors collected detailed information on refrigerators, both primary and secondary, dishwashers, and clothes washers.[62] Limited information was also collected for clothes dryers and cooking ranges. There are no appliance requirements for 2006 IECC or 2009 IECC compliance.

14.1 Refrigerators

Auditors recorded refrigerator information on the ENERGY STAR status, condition, age, type, and size. More than five out of six (85%) primary refrigerators are ENERGY STAR (Table 14-1).

Table 14-1: ENERGY STAR Status for Primary Refrigerators

Status	All Homes (n=97)	Detached Homes (n=91)	Attached Homes (n=6)	Weighted (Detached/ Attached)
ENERGY STAR	83 (86%)	78 (86%)	5(83%)	85%
Not ENERGY STAR	14 (14%)	13 (14%)	1 (17%)	15%

Bottom freezer models are the most common accounting for more than three out of five (61%) primary refrigerators; most of the rest are side-by-side models. As might be expected, almost all of the primary refrigerators in the new homes inspected are considered to be in good condition (Table 14-2).

Table 14-2: Primary Refrigerator Type and Condition

Type	All Homes (n=98)	Detached Homes (n=92)	Attached Homes (n=6)	Weighted (Detached/ Attached)
Bottom freezer	56 (57%)	52 (56%)	4 (66%)	61%
Side-by-side	33 (34%)	32 (35%)	1 (17%)	26%
Top freezer	9 (9%)	8 (9%)	1 (17%)	13%
Condition				
Good	97 (99%)	91 (99%)	6 (100%)	99%
Fair	1 (1%)	1 (1%)	0 (0%)	1%

[62] Some information was collected on 98 primary refrigerators, 13 secondary refrigerators, 91 clothes washers, and 97 dishwashers; there were two homes that did not have a refrigerator installed, nine homes that did not have a clothes washer, and three homes that did not have a dishwasher at the time of the audits. Some parameters, such as age, type, size, condition, and ENERGY STAR status are missing values for a few of the homes visited; the number of homes included for each parameter is shown in the appropriate tables.

More than three-quarters (76%) of primary refrigerators are 23 cubic feet or larger; with nearly one-half (47%) being over 25 cubic feet (Table 14-3). Almost all primary refrigerators are new, but the ones in attached homes are significantly more likely to be two years or less (Table 14-4).

Table 14-3: Primary Refrigerator Size

Size	All Homes (n=77)	Detached Homes (n=73)	Attached Homes (n=4)	Weighted (Detached/ Attached)
16 to 19 cubic feet	5 (7%)	4 (5%)	1 (25%)	15%
20 to 22 cubic feet	14 (18%)	14 (19%)	0 (0%)	10%
23 to 25 cubic feet	24 (31%)	23 (32%)	1 (25%)	29%
Over 25 cubic feet	34 (44%)	32 (44%)	2 (50%)	47%

Table 14-4: Primary Refrigerator Age

Age	All Homes (n=97)	Detached Homes (n=91)	Attached Homes (n=6)	Weighted (Detached/ Attached)
2 years or less	93 (96%)	**87 (96%)***	**6 (100%)***	98%
3 to 5 years	1 (1%)	1 (1%)	0 (0%)	1%
6 to 10 years	3 (3%)	3 (3%)	0 (0%)	2%

*Attached homes are significantly different from detached homes at the 90% confidence level.

Thirteen of the one hundred homes visited have secondary refrigerators; all secondary refrigerators are in detached homes. A weighted average of attached and detached homes would yield a saturation rate of 7% for secondary refrigerators. Over three-quarters (77%) of these refrigerators are not ENERGY STAR. They tend to be older, smaller, and in poorer condition than primary refrigerators. Close to one-half (46%) of these refrigerators are top-freezer models (Table 14-5).

Table 14-5: Secondary Refrigerator Characteristics

ENERGY STAR Status (n=13)	
ENERGY STAR	3 (23%)
Not ENERGY STAR	10 (77%)
Condition (n=13)	
Good	11 (85%)
Fair	2 (15%)
Age (n=13)	
10 years or less	6(46%)
11 years or more	7 (54%)
Type (n=13)	
Top freezer	6(46%)
Side-by-side	3 (23%)
Bottom freezer	3 (23%)
Single door	1 (8%)
Size (n=8)	
15 cubic feet or less	2
16 to 19 cubic feet	3
20 to 25 cubic feet	3

14.2 Dishwashers

Auditors recorded dishwasher information on the ENERGY STAR status, condition, and age. More than five out of six (85%) dishwashers are ENERGY STAR (Table 14-6). As might be expected, all of the dishwashers in the new homes inspected are new and almost all are considered to be in good condition (Table 14-7).

Table 14-6: ENERGY STAR Status for Dishwashers

Status	All Homes (n=96)	Detached Homes (n=90)	Attached Homes (n=6)	Weighted (Detached/ Attached)
ENERGY STAR	83 (86%)	78 (87%)	5(83%)	85%
Not ENERGY STAR	13 (14%)	12 (13%)	1 (17%)	14%

Table 14-7: Dishwasher Condition

Condition	All Homes (n=97)	Detached Homes (n=90)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Good	96 (99%)	89 (99%)	7(100%)	99%
Fair	1 (1%)	1 (1%)	0 (0%)	1%

14.3 Clothes Washers

Auditors recorded clothes washer information on the ENERGY STAR status, type, age, and condition. Four-fifths (80%) of clothes washers in the homes audited are ENERGY STAR (Table 14-8). More than three out of five (61%) are front load models (Table 14-9). Most (83%) are new (Table 14-10). Almost all clothes washers are in good condition but those in attached homes are significantly more likely to be in good condition (Table 14-11).

Table 14-8: ENERGY STAR Status for Clothes Washers

Status	All Homes (n=88)	Detached Homes (n=83)	Attached Homes (n=5)	Weighted (Detached/ Attached)
ENERGY STAR	70 (80%)	66 (80%)	4 (80%)	80%
Not ENERGY STAR	18 (20%)	17 (20%)	1 (20%)	20%

Table 14-9: Clothes Washer Type

Type	All Homes (n=89)	Detached Homes (n=83)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Front load	54 (61%)	51 (61%)	3 (60%)	61%
Top load	35 (39%)	33 (39%)	2 (40%)	39%

Table 14-10: Clothes Washer Age

Age	All Homes (n=85)	Detached Homes (n=81)	Attached Homes (n=4)	Weighted (Detached/ Attached)
2 years or less	77 (91%)	74 (91%)	3 (75%)	83%
3 to 5 years	2 (2%)	2 (3%)	0 (0%)	2%
6 to 10 years	5 (6%)	4 (5%)	1 (25%)	15%
11 years or more	1 (1%)	1 (1%)	0 (0%)	1%

Table 14-11: Clothes Washer Condition

Condition	All Homes (n=90)	Detached Homes (n=85)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Good	85 (94%)	80 (94%)*	5 (100%)*	97%
Fair	4 (4%)	4 (5%)	0 (0%)	2%
Poor	1 (1%)	1 (1%)	0 (0%)	1%

*Attached homes are significantly different from detached homes at the 90% confidence level.

14.4 Other Appliances

The only information collected on clothes dryers is the fuel type. More than seven out of ten (71%) clothes dryers use electricity; most of the rest use natural gas (Table 14-12).

Table 14-12: Clothes Dryer Fuel

Fuel	All Homes (n=88)	Detached Homes (n=83)	Attached Homes (n=5)	Weighted (Detached/ Attached)
Electricity	56 (64%)	52 (63%)	4 (80%)	71%
Natural Gas	24 (27%)	23 (28%)	1 (20%)	24%
Propane	8 (9%)	8 (9%)	0 (0%)	5%

Information on type and fuel used was collected for cooking ranges. The vast majority of homes have combination cook top and oven ranges with attached homes significantly more likely to have them than detached homes (Table 14-13). Just over one-half (53%) use natural gas; most of the rest use propane (Table 14-14).

Table 14-13: Cooking Range Characteristics

Type	All Homes (n=97)	Detached Homes (n=90)	Attached Homes (n=7)	Weighted (Detached/ Attached)
Combination cook top and oven	88(91%)	81 (90%)*	7 (100%)*	95%
Separate cook top and stand-alone oven	9 (9%)	9 (10%)	0 (0%)	5%

*Attached homes are significantly different from detached homes at the 90% confidence level.

Table 14-14: Cooking Range Fuel

Fuel	All Homes (n=97)	Detached Homes (n=91)	Attached Homes (n=6)	Weighted (Detached/ Attached)
Natural Gas	54 (56%)	51 (56%)	3 (50%)	53%
Propane	25 (26%)	22 (24%)	3 (50%)	37%
Electricity	18 (18%)	18 (20%)	0 (0%)	10%

Appendix A 2009 IECC Prescriptive Requirements

Table A-1: 2009 IECC Insulation Fenestration Requirements by Component [a]

Climate Zone	Fenestration U-Factor [b]	Skylight [b] U-Factor	Glazed Fenestration SHGC [b,e]	Ceiling R-value	Wood Frame Wall R-value	Mass Wall R-value [i]	Floor R-Value	Basement [c] Wall R-Value	Slab [d] R-Value & Depth	Crawl Space [c] Wall R-value
1	1.2	0.75	0.30	30	13	3/4	13	0	0	0
2	0.65[j]	0.75	0.30	30	13	4/6	13	0	0	0
3	0.50[j]	0.65	0.30	30	13	5/8	19	5/13[f]	0	5/13
4 except Marine	0.35	0.60	NR	38	13	5/10	19	10/13	10, 2 ft	10/13
5 and Marine 4	**0.35**	**0.60**	**NR**	**38**	**20 or 13+5[h]**	**13/17**	**30[g]**	**10/13**	**10, 2 ft**	**10/13**
7	0.35	0.60	NR	49	20 or 13+5[h]	15/19	30[g]	15/19	10, 4 ft	10/13
7 and 8	0.35	0.60	NR	49	21	19/21	30[g]	15/19	10, 4 ft	10/13

a. R-values are minimums. U-factors and SHGC are maximums. R-19 batts compressed into a nominal 2x6 framing cavity such that the R-value is reduced by R-1 or more shall be marked with the compressed batt R-value in addition to the full thickness R-value.
b. The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration.
c. "15/19" means R-15 continuous insulated sheathing on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "10/13" means R-10 continuous insulated sheathing on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.
d. R-5 shall be added to the required slab edge R-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in zones 1 through 3 for heated slabs.
e. There are no SHGC requirements in the Marine zone.
f. Basement Wall Insulation is not required in warm-humid locations.
g. Or insulation sufficient to fill the framing cavity. R-19 is minimum.
h. "13+5" means R-13 cavity insulation plus R-5 insulated sheathing. If structural sheathing covers 25 percent or less of the exterior, insulating sheathing is not required where structural sheathing is used. If structural sheathing covers more than 25 percent of exterior, structural sheathing shall be supplemented with insulated sheathing of at least R-2.
i. The second R-value applies when more than half the insulation is on the interior of the wall.
j. For impact rated fenestration complying with SectionR301.2.1.2 of the International Residential Code or Section 1608.1.2 of the International Building code, the maximum U-factor shall be 0.75 in Zone 2 and 0.65 in Zone 3.

The information presented here is derived from the 2009 International Energy Conservation Code, Table 402.1.1.

Appendix B Comparison to 2009 IECC Prescriptive Insulation Requirements by Site

Table B-1: Comparison to Prescriptive Requirements by Site

Site	Attached/ Detached Home	Wood Framed Wall Insulation R-20	Foundation Wall R-10/R-13 (cont./cavity)	Duct Insulation in Unconditioned Space R-8 Attic Supply Ducts R-6 all other Ducts	Ceiling Insulation R-38	Floor Insulation over Unconditioned Space	Applicable Prescriptive Requirements Met
1	Attached	Exceed	Exceed	Exceed	Meet	n/a	4 out of 4
2	Detached	Exceed	n/a	Exceed	Meet	Meet	4 out of 4
3	Detached	Exceed	n/a	Meet	Meet	Meet	4 out of 4
4	Detached	Exceed	n/a	Meet	Meet	Meet	4 out of 4
5	Detached	Exceed	n/a	n/a	Meet	Meet	3 out of 3
6	Detached	Exceed	Exceed	n/a	Exceed	n/a	3 out of 3
7	Detached	Exceed	Exceed	n/a	Exceed	n/a	3 out of 3
8	Detached	Fail	Exceed	Exceed	Meet	Exceed	4 out of 5
9	Detached	Exceed	Exceed	Fail	Meet	Meet	4 out of 5
10	Detached	Fail	Exceed	Fail	Meet	Meet	3 out of 5
11	Detached	Fail	Exceed	Fail	Meet	Meet	3 out of 5
12	Detached	Fail	Exceed	Fail	Exceed	Meet	3 out of 5
13	Detached	Fail	Exceed	Meet	Fail	Meet	3 out of 5
14	Detached	Fail	Exceed	Meet	Fail	Meet	3 out of 5
15	Detached	Fail	Exceed	Meet	Fail	Meet	3 out of 5
16	Detached	Exceed	Exceed	Exceed	Fail	n/a	3 out of 4
17	Detached	Exceed	n/a	Exceed	Fail	Meet	3 out of 4
18	Detached	Fail	n/a	Exceed	Exceed	Meet	3 out of 4
19	Detached	Fail	n/a	Exceed	Meet	Meet	3 out of 4
20	Detached	Exceed	n/a	Exceed	Fail	Meet	3 out of 4
21	Detached	Fail	n/a	Exceed	Meet	Meet	3 out of 4
22	Detached	Exceed	n/a	Fail	Meet	Meet	3 out of 4
23	Detached	Exceed	n/a	Fail	Meet	Meet	3 out of 4
24	Detached	Exceed	n/a	Fail	Meet	Meet	3 out of 4
25	Detached	Exceed	n/a	Fail	Meet	Meet	3 out of 4
26	Detached	Exceed	Exceed	Fail	Exceed	n/a	3 out of 4
27	Detached	Fail	n/a	Meet	Meet	Meet	3 out of 4
28	Detached	Exceed	n/a	Meet	Exceed	Fail	3 out of 4
29	Detached	Fail	Exceed	Fail	Meet	Fail	2 out of 5
30	Detached	Fail	Exceed	Fail	Fail	Meet	2 out of 5

Site	Attached/ Detached Home	Wood Framed Wall Insulation R-20	Foundation Wall R-10/R-13 (cont./cavity)	Duct Insulation in Unconditioned Space R-8 Attic Supply Ducts R-6 all other Ducts	Ceiling Insulation R-38	Floor Insulation over Unconditioned Space	Applicable Prescriptive Requirements Met
31	Detached	Exceed	n/a	Don't Know	Fail	Meet	2 out of 4
32	Detached	Fail	n/a	Exceed	Meet	Fail	2 out of 4
33	Detached	Fail	n/a	Exceed	Meet	Fail	2 out of 4
34	Detached	Fail	n/a	Exceed	Exceed	Fail	2 out of 4
35	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
36	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
37	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
38	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
39	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
40	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
41	Detached	Exceed	n/a	Fail	Fail	Meet	2 out of 4
42	Attached	Fail	n/a	Fail	Meet	Meet	2 out of 4
43	Detached	Fail	n/a	Fail	Exceed	Meet	2 out of 4
44	Detached	Exceed	n/a	Fail	Fail	Meet	2 out of 4
45	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
46	Attached	Exceed	n/a	Fail	Fail	Meet	2 out of 4
47	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
48	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
49	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
50	Detached	Exceed	n/a	Fail	Fail	Meet	2 out of 4
51	Detached	Exceed	n/a	Fail	Fail	Meet	2 out of 4
52	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
53	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
54	Detached	Fail	n/a	Fail	Meet	Exceed	2 out of 4
55	Attached	Fail	n/a	Fail	Meet	Meet	2 out of 4
56	Detached	Fail	n/a	Fail	Exceed	Meet	2 out of 4
57	Detached	Exceed	n/a	Fail	Exceed	Fail	2 out of 4
58	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
59	Detached	Exceed	n/a	Fail	Meet	Fail	2 out of 4
60	Detached	Fail	n/a	Fail	Meet	Meet	2 out of 4
61	Detached	Exceed	n/a	Meet	Fail	Fail	2 out of 4
62	Detached	Exceed	n/a	Meet	Fail	Fail	2 out of 4
63	Detached	Fail	n/a	n/a	Meet	Meet	2 out of 3
64	Detached	Fail	n/a	n/a	Meet	Meet	2 out of 3
65	Detached	Fail	Exceed	n/a	Meet	n/a	2 out of 3
66	Detached	Fail	Exceed	n/a	Meet	n/a	2 out of 3

Site	Attached/ Detached Home	Wood Framed Wall Insulation R-20	Foundation Wall R-10/R-13 (cont./cavity)	Duct Insulation in Unconditioned Space R-8 Attic Supply Ducts R-6 all other Ducts	Ceiling Insulation R-38	Floor Insulation over Unconditioned Space	Applicable Prescriptive Requirements Met
67	Detached	Fail	Exceed	n/a	Meet	n/a	2 out of 3
68	Detached	Fail	n/a	n/a	Meet	Meet	2 out of 3
69	Detached	Fail	Exceed	Don't Know	Fail	n/a	1 out of 4
70	Detached	Fail	n/a	Exceed	Fail	Fail	1 out of 4
71	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
72	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
73	Detached	Fail	n/a	Fail	Meet	Fail	1 out of 4
74	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
75	Detached	Fail	n/a	Fail	Meet	Fail	1 out of 4
76	Detached	Fail	Exceed	Fail	Fail	n/a	1 out of 4
77	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
78	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
79	Attached	Fail	n/a	Fail	Fail	Meet	1 out of 4
80	Attached	Fail	n/a	Fail	Exceed	Fail	1 out of 4
81	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
82	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
83	Detached	Fail	n/a	Fail	Meet	Fail	1 out of 4
84	Detached	Fail	n/a	Fail	Meet	Fail	1 out of 4
85	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
86	Detached	Fail	n/a	Fail	Fail	Meet	1 out of 4
87	Detached	Exceed	n/a	Fail	Fail	Fail	1 out of 4
88	Detached	Fail	n/a	Meet	Fail	Fail	1 out of 4
89	Detached	Exceed	n/a	n/a	Fail	Fail	1 out of 3
90	Detached	Fail	n/a	n/a	Fail	Meet	1 out of 3
91	Detached	Fail	n/a	n/a	Meet	Fail	1 out of 3
92	Detached	Fail	n/a	n/a	Meet	Fail	1 out of 3
93	Detached	Exceed	n/a	n/a	Fail	Fail	1 out of 3
94	Detached	Fail	n/a	n/a	Fail	Meet	1 out of 3
95	Detached	Fail	n/a	Fail	Fail	Fail	0 out of 4
96	Detached	Fail	n/a	Fail	Fail	Fail	0 out of 4
97	Detached	Fail	n/a	Fail	Fail	Fail	0 out of 4
98	Detached	Fail	n/a	Fail	Fail	Fail	0 out of 4
99	Detached	Fail	n/a	Fail	Fail	Fail	0 out of 4
100	Attached	Fail	n/a	Fail	Fail	Fail	0 out of 4

Appendix C Code Compliance Details

This appendix provides additional details on the annual energy cost and UA trade-off compliance paths.

Table C-1 breaks out attached and detached homes and compares the annual energy cost for the IECC 2009 reference to the cost across the inspected homes. Attached homes have total annual energy costs that are 17% greater than the reference home, while detached homes have costs that are 14% greater than the reference home. For each end use, attached homes have higher annual energy costs, relative to the reference home.

Table C-1: Average Annual Energy Cost by Home Type and End Use

End Use	All Homes (n = 100)		Detached (n = 93)		Attached (n = 7)		Weighted (Detached/Attached)	
	Reference	Design	Reference	Design	Reference	Design	Reference	Design
Heating	$1,630	$1,966	$1,685	$2,029	$896	$1,126	$1,297	$1,585
Cooling	$207	$194	$210	$196	$159	$162	$185	$179
Domestic Hot Water	$373	$369	$380	$376	$280	$275	$331	$326
Overall	**$2,210**	**$2,529**	**$2,275**	**$2,601**	**$1,334**	**$1,562**	**$1,812**	**$2,090**

Table C-2 breaks out the average UA values by component and home type. On average, observed overall UA values exceed reference UA values by 19%. Of the key shell measures with reliable data, above grade walls and foundation walls were the closest to compliance, with observed UA values exceeding reference UA values by 28% and 19% respectively.

Table C-2: Average UA Values by Component and Home Type

Component	All Homes (n = 100)		Detached (n = 93)		Attached (n = 7)		Weighted (Attached/Detached)	
	Reference	Design	Reference	Design	Reference	Design	Reference	Design
Ceiling	44.5	62.9	45.5	64.6	30.6	40.3	38.2	52.6
Above Grade Wall	126.4	156.2	128.7	158.3	96.2	128.7	112.7	143.7
Over Garage	13.2	19.4	13.6	20.0	8.3	12.0	11.0	16.1
Over Ambient	1.7	2.4	1.8	2.5	0.9	1.4	1.3	2.0
Over Unconditioned Basement	35.9	53.7	36.5	54.5	27.1	40.8	31.8	47.8
Over Unconditioned Crawlspace	25.7	40.6	25.7	40.6	n/a	n/a	25.7	38.2
Basement Wall	56.6	70.5	58.7	73.3	17.9	17.8	38.6	46.0
Overall*	**357.8**	**416.6**	**365.8**	**424.5**	**251.6**	**312.2**	**309.6**	**369.2**

*Overall does not equal sum components because this table does not present every component and not every home had every component.

Appendix D Insulation Grades

The Residential Energy Services Network (RESNET) provides guidelines and definitions for defining the quality of insulation installation. RESNET has specified three grades for designating the quality of insulation installation; the grades range from Grade I (the best) to Grade III (the worst). The RESNET definitions of Grade I, Grade II, and Grade III installation are provided below.[63]

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. .

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

Figure D-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 little to no gaps, has no compression, and the cavity is enclosed on all six sides.[64]

Figure D-1: Grade I Closed Cell Spray Foam—Exterior Walls

Figure D-2 shows a Grade II install of unfaced fiberglass batts in a conditioned basement.[65] 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 D-2: Grade II Fiberglass Batts—Basement Walls

[64] 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.
[65] The basement in this case was considered conditioned volume, not conditioned floor area.

Figure D-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 D-3: Grade III Fiberglass Batts—Attic Kneewalls

Figure D-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 with substantial gaps and compression.

Figure D-4: Grade II Fiberglass Batts—Frame Floor

Figure D-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 D-5: Grade III Fiberglass Batts—Frame Floor

Figure D-6 shows a Grade I installation of blown fiberglass in an attic. This received a Grade I designation as 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 D-6: Grade I Blown Fiberglass—Attic

Appendix E Building Practices—Examples from the Site Visits

During their visits to new homes, auditors photographed examples of good building practices that contributed to a home's energy efficiency and poor building practices where the builder missed opportunities to improve the home's energy efficiency. Below are examples of the practices that auditors saw in homes, with photos and brief descriptions.

Foundation and Basement Walls

Builders rarely insulated foundation walls. Basements were typically unfinished and the concrete foundation walls were left uninsulated, even in walkout basements where a large percentage of the basement walls were above grade, insulated stud walls. (Note that by code, basement walls in unconditioned basements are not required to be insulated.)[66]

Figure E-1 demonstrates where a builder attempted to bring the basement into the thermal envelope by insulating the foundation walls with rigid foam. However, there was no insulation on the above grade portion of the concrete wall, where the foam would have provided substantial benefit (the insulation was only visible just above grade level). The builder should have installed the rigid foam insulation on the entire foundation wall, including the above grade portion. Not continuing the insulation all the way up the foundation wall was a lost opportunity for energy savings, and for making the basement more comfortable, particularly since the homeowner planned to finish the basement. This insulation was also not well protected from the elements, and will likely degrade in the sun and may break off over time due to weathering.

Figure E-1: Foundation Wall Rigid Insulation

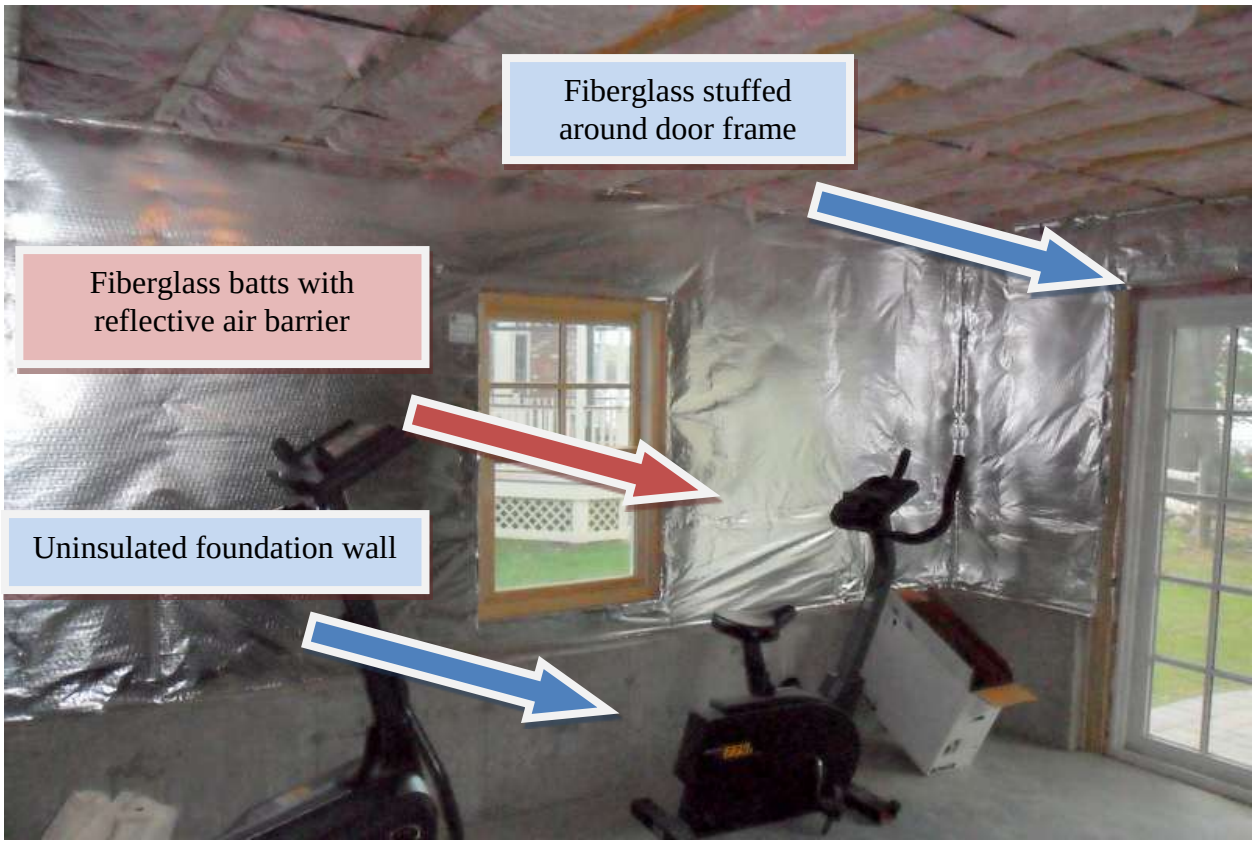
[66] It is common practice to insulate the stud walls on top of foundation walls in an unconditioned walkout basement. This gives homeowners the flexibility to easily finish such spaces in the future, adding to their conditioned floor area and useable living space.

Figure E-2 shows a walkout basement viewed from the inside. The above grade stud walls in this example were well insulated with fiberglass batts and covered with a silver, reflective air barrier. The use of a reflective barrier over insulation was extremely rare. Above grade basement stud wells often had a clear vinyl air barrier over the insulation, and frequently the insulation was not enclosed at all, degrading its insulating properties.

This arrangement of partially below grade concrete walls topped with insulated, above grade, framed walls was common in walkout basements, but, like in the example below, most builders did not insulate the concrete portion of the walls. The energy efficiency of such homes would always have been improved by bringing the basement fully into the thermal envelope because at least some of the mechanical equipment was always located in the basement, and homeowners often had plans to finish these walkout basements at some point in the future.

Also visible in this photo are small pieces of fiberglass insulation that were stuffed between the door frame and the rough opening of the door, allowing air infiltration. Windows and doors in basements and joints between concrete and stud framing would have often benefited from the use of spray foam as an air sealing measure. While this house at least had fiberglass stuck in these gaps, many homes had nothing to seal these gaps.

Figure E-2: Insulated Walkout Basement Walls, with Basement Door Leakage



Slab Floors

Slab floors in basements were rarely insulated, either underneath or at their perimeter, meaning that the basement floor would always be cold in the winter. This was a lost opportunity in new homes whose homeowners planned to finish their basements, as these homeowners would have uncomfortable, cold floors in the basement for the life of the home.

Figure E-3 demonstrates a builder who insufficiently insulated the floor of a slab on grade home. According to construction documents, the slab was uninsulated except for the perimeter of the slab of the small sunroom at the back of the house. Auditors could not confirm positively that there was no under slab insulation, but the construction documents indicated there was none, and slab edge insulation was only visible on the sunroom. The builder should certainly have insulated the entire slab of this home.

Figure E-3: Incomplete Slab Insulation

Frame Floors

Fiberglass batt insulation in frame floors over basements (basement ceilings) was often poorly installed (and missing in some cases), with some exceptions.

Figure E-4 shows an unconditioned basement with no frame floor insulation. Most new Massachusetts homes had frame floor insulation over unconditioned basements, but this basement lacked any such insulation, on the frame floor or the rim joists. The insulation visible in the photo on the above grade stud wall portion of the basement wall was only installed by the homeowner after construction. The frame floor bump-out area under a bay window in the living room was also problematic because there appeared to be a vent on its underside, allowing outside air to flow freely into the basement, where the HVAC system with unsealed ductwork was located.

Figure E-4: Missing Frame Floor Insulation & Improperly Sealed Basement

Figure E-5 shows a poor frame floor insulation installation. R-30 fiberglass batts were sloppily installed in a floor truss system over a vented crawl space. The insulation was heavily compressed and sagging away from the frame floor. A section of the frame floor, visible in the below photo, had no insulation at all.

Between the sagging, compression, gaps, and the air spaces on the sides of the batts created by the truss system, this insulation was providing very little benefit. The water heater in this home was also installed in this vented crawl space area, decreasing its energy efficiency.

Figure E-5: Poorly Installed Frame Floor Insulation

Figure E-6 shows frame floor insulation that was mostly well installed. However, there were significant gaps and compression in the insulation, largely to accommodate HVAC ductwork. HVAC and plumbing contractors not working in conjunction with insulation contractors often created such conflicts. Some bays were missing insulation entirely, and the insulation was heavily compressed around ductwork and to accommodate the cross bracing between floor joists.

Figure E-6: Frame Floor Insulation with Gaps and Compression

Rim/Band Joists & Sealing Penetrations to the Outside

Rim joists were commonly insulated by the same fiberglass batts that insulated the frame floors above basements, and builders did not consistently seal around HVAC, plumbing, electrical, or other penetrations to the outside of the house in the rim joist area.

Figure E-7, in contrast, shows a home with an abundance of well installed, open cell foam insulating the rim joist in an unconditioned basement. The foam was extremely thick, at least 7.5 inches, and well over a foot in others, and this foam was also used in the entire frame floor under the garage and on the flat ceiling. Such foam in the rim joists fully sealed gaps around utility penetrations to the outdoors, minimizing air leakage in the basement. Homes with this type of spray foam in the rim joists, rather than the more common fiberglass batts, tended to perform quite well in blower door tests, though such homes may have had additional air sealing measures that auditors were not able to see so easily.

Figure E-7: Rim Joist with Insulated with Spray Foam

Figure E-8 similarly shows another home where the builder used a large amount of open cell spray foam to seal the rim joists, above grade basement stud walls, some of the frame floor, and to completely surround the air handlers that were suspended from the basement ceiling. This photo shows the foam covering the above grade basement stud walls.

The builder used a huge amount of foam in the basement, particularly around the air handlers mounted on the basement ceiling that were almost completely surrounded by foam. Oddly, the builder only installed foam in the small, unfinished portion of the basement. There was no foam in the basement area that was to be finished, just fiberglass batts.

Figure E-8: Basement Stud Walls and Rim Joist Insulated with Spray Foam

Exterior Walls

Most homes had fiberglass batts as their exterior wall insulation, and as discussed previously, builders often did not consistently insulate basement walls, whether above or below grade.

Figure E-9, in contrast, shows a home with open cell spray foam in all of the exterior walls, except for the above grade basement walls, which contained fiberglass batts. The wall separating the conditioned space from the attic, visible in this photo, shows the insulation material. The insulation in this wall separating conditioned area from the attic was even thicker than the insulation in the main walls, because there was no defined 2x6 cavity to fill.

Figure E-9: Walls with Open Cell Spray Foam Insulation

Figure E-10, on the other hand, shows a mixed insulation installation separating a conditioned space (the side of a vaulted bedroom wall) from the attic. While some of the insulation was acceptably installed, much of it had compression and large gaps, it was compressed rather than cut to fit around wiring, and some was falling out of the cavities. Such sloppiness was common in areas that were not readily accessible by the homeowner (knee walls, attics, etc.).

Figure E-10: Poorly Installed Fiberglass Attic Wall Insulation

Ceiling and Attic Insulation

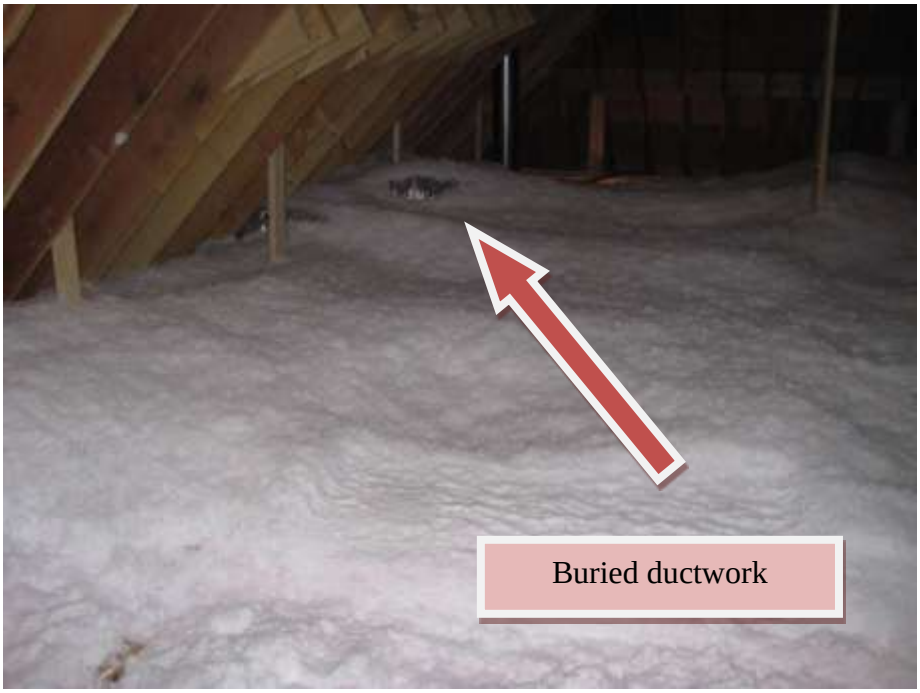
Builders who used blown-in insulation in attics (fiberglass or cellulose) tended to achieve superior insulation installations to those who used fiberglass batts. They minimized insulation gaps, easily prevented thermal bridging by covering attic joists with insulation, and in some cases used the insulation to bury attic ducts. All types of insulation were susceptible to compression, however, particularly if the HVAC contractors disturbed the attic insulation.

Figure E-11 shows a poor attic insulation installation, with sloppily installed R-38 fiberglass batts. The batts were not horribly compressed, but there were significant gaps between batts, and places where the batts were not in contact with the ceiling.

Figure E-11: Poorly Installed Fiberglass Batt Attic Insulation

Figure E-12 shows extremely well installed blown-in fiberglass insulation in an attic. The distribution was not perfectly even, but the builders went above and beyond – this insulation was a few feet thick in some places, and there are wind baffles. Ideally there would not have been ductwork in the vented, unconditioned attic, but the ductwork was mostly buried under the fiberglass insulation.

Figure E-12: Well Installed Blown-in Fiberglass Attic Insulation

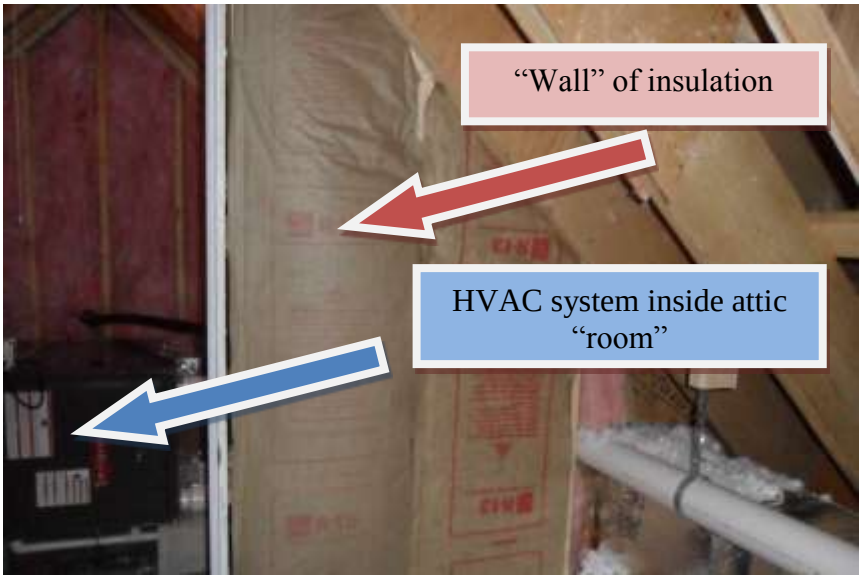


On the other hand, Figure E-13 shows a blown-in cellulose attic installation that was mostly well installed and had wind baffles, but it was not installed at full thickness between two vaulted ceiling areas. This area should have been insulated completely.

Figure E-13: Uneven Attic Cellulose Installation

Figure E-14 shows an unusual situation where the builder attempted to bring the attic HVAC system at least partially into conditioned space by building a makeshift "room" around the attic furnace. The builder created a 2x4 stud frame, and stapled fiberglass batts into the cavities between the studs, but did not sheetrock it on either side. One could push his hand through the fiberglass – it was not a true wall.

Figure E-14: "Walled-In" Attic HVAC System



Windows, Doors, and Basement Air Sealing

Homes with unfinished basements allowed auditors to see instances where builders had not properly air sealed around windows and doors.

Figure E-15 shows an unconditioned basement with no door to its bulkhead. The bulkhead hatch had large gaps around it, allowing air infiltration into the basement. Light is visible through a gap around the bulkhead hatch. Builders commonly failed to install a door in the foundation wall separating the basement from the bulkhead door. Installing a weather-stripped door in this foundation wall would have greatly reduced air leakage in the basement.

Figure E-15: Basement Missing Door to Bulkhead Hatch

Similarly, the previously referenced Figure E-2 showed an example of a common source of basement air leakage – window and door frames where gaps around the rough opening were filled only with bits of fiberglass batts, rather than spray foam.

Duct Quality and Location – Minimizing Ducts in Unconditioned Space

Homes that demonstrated the least duct leakage to the outside were typically those that minimized the amount of unconditioned space in the home, by bringing the attic and basement into the thermal envelope.

Figure E-16 shows an attic space with foam insulation sprayed between the roof rafters, bringing the attic heating system and ducts into the conditioned space. The builder was attempting to improve upon the common practice of installing a heating system in an uninsulated, vented attic. Ducts installed behind kneewalls in vented attic spaces were particularly problematic in terms of duct leakage.

Figure E-16: HVAC System in Conditioned Attic

In contrast, Figure E-17 shows uninsulated supply ductwork on the floor of a vented attic space. The attic floor had been insulated with R-38 fiberglass batts and covered in plywood. All duct leakage was completely lost to the outside, which was particularly problematic in this case because the ducts were completely unsealed. Some large gaps in the sheet metal were filled with caulk, but most were not. The ductwork in the unconditioned basement of this home was also completely unsealed and uninsulated, which was unusual in Massachusetts, where uninsulated supply ducts were rare.

Figure E-17: Uninsulated, Unsealed Ductwork in Vented Attic

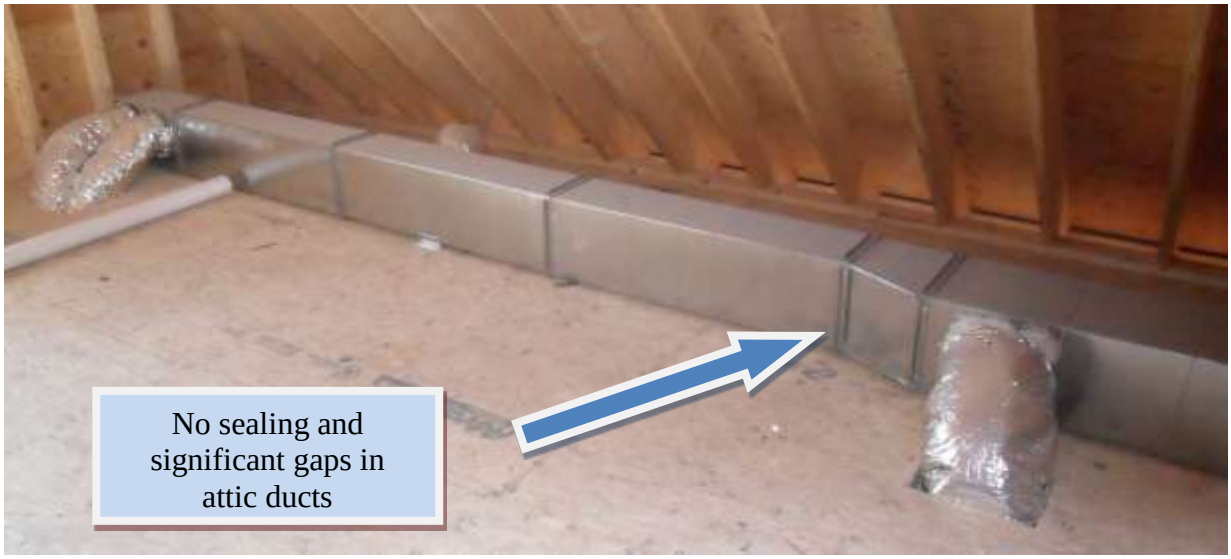


Figure E-18 shows where an HVAC contractor tried to install ductwork so as to bypass a steel I-beam running the length of the basement. These ducts were wrapped tightly around this support beam, compressing the insulation and constricting airflow in some cases. Flexible ducts were often twisted and crushed to fit in tight spaces.

Figure E-18: Kinked HVAC Ducts in Basement

Ventilation

Even extremely "tight" homes that auditors tested, those with very low air exchange rates, usually did not have automatic ventilation systems installed to provide fresh air. Builders installed standard bathroom fans, but rarely installed timed or automatic ventilation systems to bring fresh air into homes.

Mechanical Equipment

Figure E-19 shows an HVAC system where the installer had directly connected the supply and return ductwork just a few feet from the furnace. This opening in the supply plenum sends conditioned air right back to the return plenum of the hair handler, perhaps to control unwanted air pressure, noise, or uneven air delivery, likely caused by an oversized HVAC system.

Figure E-19: Connected Supply and Return Ducts

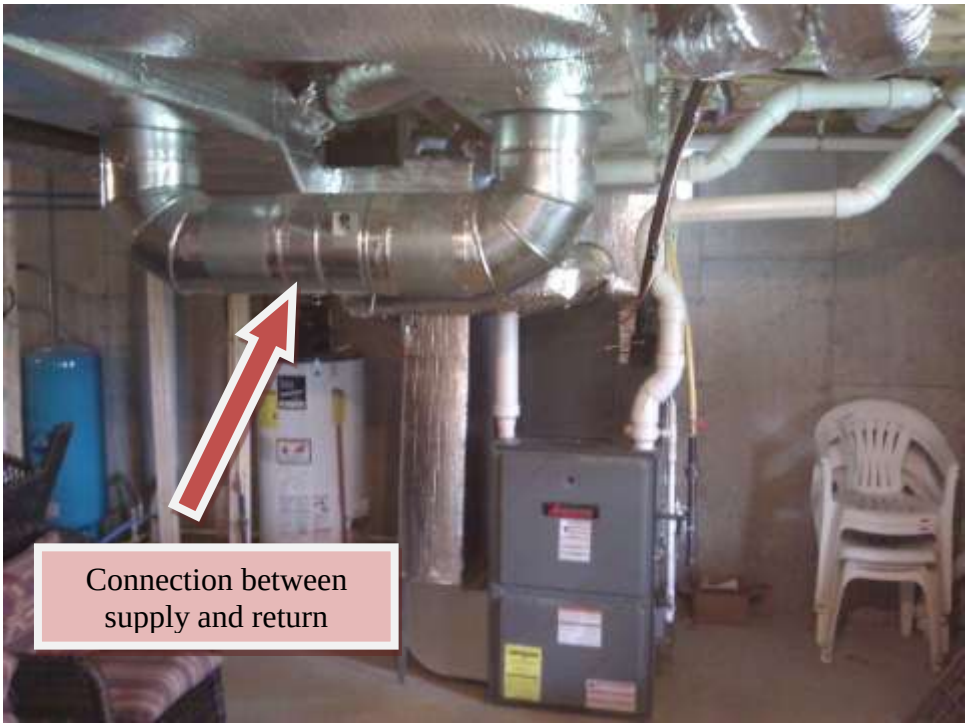


Figure E-20 shows the four CAC condensing units of a large home, over 4,000 square feet. The home was well insulated, with closed cell spray foam in the rim joists and multiple feet of blown-in insulation in some parts of the attic, because the homeowners were concerned about energy efficiency. However, despite these efforts, the fact remains that nearly ten tons of cooling power was being used to condition over 4,000 square feet for only two people.

Figure E-20: Large Home with Many HVAC Systems

Builders also often installed lower efficiency, non-condensing furnaces in attics, perhaps due to the risk of condensate freezing in unconditioned attics, especially if the furnaces need to be installed horizontally instead of vertically because of space limitations.[67] Bringing mechanical systems into the building envelope by insulating the attic and basement always greatly increased the performance of homes in the auditors' diagnostic tests, and would allow builders to install higher efficiency secondary furnaces in attics.

[67] It would not be surprising to find that this is also a helpful cost-cutting measure by some builders, because they can install cheaper, lower efficiency systems in attics, where homeowners may be less likely to notice the presence of a less efficient system.

Appendix F HVAC Performance Testing

In-field measurements were performed to calculate the actual cooling capacities and efficiencies of a sample of residential central air conditioning (CAC) systems throughout the state. This appendix describes the in-field measurements, equipment, protocols and analytical procedures used to determine the actual operating characteristics of the systems. Central heat pumps were included in the sample, but only the cooling performance of these was considered. Although some of the RNC sample homes used window air conditioners, these units were not included in the CAC analysis.

Field Measured Data: The measurements required to properly assess the operating performance of the CACs included air side temperature and flow rates along with electric power draws of the condensing units and blower motors with controls. Although duct leakage, which affects the system performance as a whole, was measured for the REM/Rate analyses, that was not a part of the CAC performance analysis.

Specific air side measurements include the following:

- Air flow rate in cubic feet per minute (CFM) through the evaporator coil,
- Supply air static pressure with filter in place,
- Supply air static pressure with True Flow array in place,
- Supply air dry bulb temperature in degrees F,
- Supply air wet bulb temperature in degrees F,
- Return air dry bulb temperature in degrees F,
- Return air wet bulb temperature in degrees F.

Specific power side measurements include:

- Power input to the condensing unit in Watts or kW,
- Power input to the blower motor and controls transformer in Watts.

Field Measurement Instrumentation: The instruments used in the field measurements had to yield enough precision to support the analysis without introducing unmanageable contradictions in the analysis at different stages. In keeping with this requirement, auditors used relatively high precision thermometers and power meters and utilized a "True Flow Array" designed specifically for the purpose of measuring air flow through a CAC system.

The instruments utilized during the in-field measurements included the following:

- "True Flow Array" designed by The Energy Conservatory to measure CAC air flow to within 7%,
- Digital thermometers with 0.1 degree F resolution,
- Hand held clamp-on true RMS power meters capable of +/- 1% accuracy at 40 Amps.

Field Measurement Protocols: Auditors were trained both in the classroom and in the field, at test sites and sample sites, to conduct the CAC performance measurements. Emphasis was placed on the proper care, placement and usage of the instruments and on the importance of precision.

Specific field protocols included the following:

- Record the cooling temperature setting at the thermostat,
- Allow the house to warm up by disabling the cooling system during the blower door and duct leakage tests before starting the CAC performance measurements,
- Drill holes if necessary in the supply and return ducts to allow insertion of thermometers in appropriate locations to accurately measure the supply and return air temperatures,
- Install the true flow array and set up its digital gauge to measure air flow in CFM,
- Locate the circuits in the breaker panel that feed the condensing unit and the blower motor and test the power meter Voltage reference contacts, Amp clamp and range setting,
- Set the control thermostat to its coldest setting and allow the AC system to reach steady state operation,
- Have one auditor take the air side measurements while the other simultaneously takes the power readings, recording the start and end times to the nearest minute for each series of measurements,
- Record the simultaneous outside air temperature,
- Check the measurements for consistency against charts of reasonable ranges based on the equipment rated capacity and efficiency,
- Identify and correct any problems and repeat the series of readings if inconsistencies are observed,
- Repeat the series of measurements as needed to obtain consistency between series,
- Observe and record the outdoor temperature again,
- Remove and pack all instruments, replace the filter, seal the holes in the ductwork and insulation using aluminum tape, and return the thermostat to its original setting.

Data analysis: Field data were cleaned and analyzed utilizing a spreadsheet which calculates the field rated cooling capacity and efficiency of each system and converts said data to the standard conditions applied by the American Heating and Refrigeration Institute (AHRI) to rate the equipment. These results were then compared to the rated capacities and efficiencies observed on the equipment nameplates or taken from manufacturers' performance data for the model numbers on the nameplates.

Although the analytical formulae and processes were too complex and lengthy to describe fully in this report, the following steps outline the general analytical steps that were applied to all or most of the individual data sets:

- Clean the data by checking for expected reasonable ranges and referring back to the original audits when discrepancies were observed,

- Adjust the air flow measurements to normal by applying the supply air static pressure measurements with true flow array in place and filter in place,
- Compare the dry bulb and wet bulb temperature measurements for consistency, correcting for obvious errors such as "slipped" decimal places, etc.,
- Compare temperature ranges against the adjusted air flow measurements to obtain a sanity check on the consistency of the data,
- Calculate the cooling capacity of the equipment at the field conditions from the air side measurements,
- Check the power measurements for consistency, converting any kW entries to Watts and correcting for obvious decimal place errors,
- Calculate the total power input in Watts by summing the condensing unit and blower motor/controls power,
- Calculate the ratio of the delivered cooling capacity in BTU per hour (Btuh) and Watts input to obtain EER in Btuh per Watt,
- Convert the actual field cooling capacity to rated capacity utilizing the field measured indoor and outdoor temperatures and the AHRI standard indoor and outdoor temperatures,
- Convert the actual field energy input ratio (EIR) to standard EIR utilizing the field measured indoor and outdoor temperatures and the AHRI standard indoor and outdoor temperatures,
- Convert standard EIR to EER and then to SEER to obtain the actual system efficiency at standard conditions.

Results: The overall results of this study are summarized in Table F-1, which shows the average values of the 35 sites that yielded meaningful results:

Table F-1: Rated vs. Measured Operating Performance of CACs

CAC Testing Results (n=35)	Rated	Operating	Difference	Relative Error
Capacity Btuh	36,223*	28,300*	-21.9%	8.7%
SEER	13.5	13.1	-3.0%	6.7%

*Significantly different at the 90% confidence level

The average rated capacity and efficiency was 36,223 Btuh (3.02 tons) and 13.5 SEER respectively. The average field operating capacity was significantly lower, at 28,300 Btuh (2.36 tons). Low evaporator air flow appeared to be the primary reason for the reduced cooling capacity. In fact, of the units that measured at more than 25% reduction in capacity, the average evaporator air flow was only 317 CFM per rated ton.

The overall average evaporator airflow was 359 CFM per rated ton. The overall average operating efficiency was slightly less than rated, at 13.1 SEER.

Procedures required to obtain precise measurements of field operating conditions for any individual site would require more precise instrumentation and more on-site time. Even if these precision requirements had been met, the fact that these homes were occupied and the operating and weather conditions were not controlled within a tight range of temperatures would have made it virtually impossible to obtain highly precise test measurements at every site.

Appendix G Data Collection Form

Baseline Study(s) Field Data Form-2011				Field Data Collection Form		
Site ID Number:		Name:		General Information		
Fill out all data available from recruitment before going to site. Collect more detail during on-site audit.						
Auditor 1		Date of Audit		Ambient Temp.		
						(Degrees F)
Auditor 2		Evaluation Region/County				
Street Address		City				
House Type		Attached/Detached		Stories		
Area conditioned space (calc.)				Bedrooms		
Volume conditioned space (calc.)						
Primary Heating Fuel		Total Heated Area				
		(from recruitment data)				
Basement type		Bsmt. Area		% Cond.		
		(approx. square feet)				
Completion Date		ENERGY STAR Home		Primary/Seasonal		
(month/year)						(Time-of-use if seasonal)
Location of Home		Builder Type				
		Own or Rent?				
				Winter	*Summer*	
Type of Thermostat:		Preferred Temperature:				
Use Night Temp. Setback?		No of Occupants, Nights:				
Use Daytime Temp. Setback?		No of Occupants, Workdays:				
How many Fireplaces?		Indoor Temperature:			Zones:	
How many Portable Space Heaters?		Fireplace/ Stove Fuel:			T'stats:	
How many Stoves?		Space Heater Fuel:				
Wood fireplace gasketed?						
Do Blower Door?		Do Duct Blaster?		Do AC Performance Test?		

Insulation/Shell

Foundation Wall

For foundations, include ALL insulation (even walls in unconditioned space). Note where insulation was verified.

Wall Type	Int/Ext Insul	Location	Length	Height	Above Grade	Insul Type	R-Value

Notes:

Slab Floor

Note where insulation was verified.

Grade/Below Grade	Location of Slab Insulation	Total Perimeter	Exposed Perimeter	Above Grade Exposed Perimeter	Depth Below Grade	Area, SqFt	I-Type	R-Value

Notes:

Frame Floor

Note where insulation was verified.

Floor Description	Location	Area, SqFt	I Type	Cavity?	R-Val/Grade

Notes:

Rim/ Band Joists

Note where insulation was verified.

Joist Description	Location	Area, Linear F	I Type	R-Value	Thickness	Grade	Rim/Band

Notes:

Exterior Walls

Note where insulation was verified.

Wall Description	Location	Area	I Type	Cavity?	R-Val/Grade

Notes:

Windows	*Windows/glass doors and skylights. Note whether or not tested for Low-e*							
Type of Glass	**SqFt**	**Frame**	**Location**	**U-value**	**SHGC**	**T Break**	**O'hang/Dist.To Top**	**Orient**
Notes:								

Ext. Doors							
Door Type	**Material**	**Insulated**	**Storm?**	**Type of Glass**	**Dr_SqFt**	**Gl SqFt**	**Orient.**
Notes:							

Ceiling Insulation	*Note where insulation was verified.*					
Ceiling Construction	**Flat/Cathedral**	**Area, SqFt**	**V Barrier**	**I Type**	**Cavity?**	**R-Val/Grade**
Notes:						

Sky Lights								
Type of Glass	**SqFt**	**Frame**	**Location**	**U-value**	**SHGC**	**T Break**	**Orient**	**Angle**
Notes:								

Mass Wall

Note where insulation was verified.

Wall Type	Int/Ext Insul	Location	R-value

Notes:

Sunspace

*If sunroom need to treat like normal room, take all measurements, area, R-value, etc.

Surface Type	Location	Area	I Type	Cavity?	R-Val/ Grade	Orient.	Glass Frame Type

Notes:

Mechanicals

Heating Equipment

Manufacturer	Model	Type	Age	Fuel	Location	Cap. Out	Efficiency

For Forced Air System, How is Fan Controlled?

R-value for hydronic piping insulation:

Notes:

Furnace Motors

*We need to record any information on ECM motors. To be safe please record make and model of all furnace n

Manufacturer	Model	Type

Notes:

Water Heating

Manufacturer	Model	Type	Age	Fuel	Location	Gallons	Energy Factor

R-value for water heater wrap:

Notes:

Cooling Equipment

Manufacturer	Model	Type	Age	Evap. Location	Tons	Efficiency

Notes:

Duct Insulation

Supply/Return	Location*	For Insulation Only: Type	Quality	R-Value	Duct Type	Duct Sealing	Duct Leakage

Notes:

* If ductwork is all within the conditioned space, no duct blaster test is required.

# of return grills

Test Results

Blower door and Duct blaster

Repeat tests as needed to ensure precision.

Blower Door Test 1 (at 50 Pa)

Blower door type	Type 3
Ambient Temperature	
Fan Pressure (Pa)	
House Pressure (Pa)	
Rings/Holes	
CFM Leakage	

Duct Blaster Test 1 (at 25 Pa)

	Total Leak Test	Out. Leak Test	System
D.B. Fan Pressure (Pa)			
Duct Pressure	25	25	
Rings			CFA Served
Blower door Fan (Pa)	0		
House Pressure (Pa)	0	25	
CFM Leakage			

Blower Door Test 2 (at 50 Pa)

Blower door type	Type 3
Ambient Temperature	
Fan Pressure (Pa)	
House Pressure (Pa)	
Rings/Holes	
CFM Leakage	

Duct Blaster Test 2 (at 25 Pa)

	Total Leak Test	Out. Leak Test	System
D.B. Fan Pressure (Pa)			
Duct Pressure	25	25	
Rings			CFA Served
Blower door Fan (Pa)	0		
House Pressure (Pa)	0	25	
CFM Leakage			

Blower Door Test 3 (at 50 Pa)

Blower door type	Type 3
Ambient Temperature	
Fan Pressure (Pa)	
House Pressure (Pa)	
Rings/Holes	
CFM Leakage	

Duct Blaster Test 3 (at 25 Pa)

	Total Leak Test	Out. Leak Test	System
D.B. Fan Pressure (Pa)			
Duct Pressure	25	25	
Rings			CFA Served
Blower door Fan (Pa)	0		
House Pressure (Pa)	0	25	
CFM Leakage			

Visual House Leakage:

Visual Supply Duct Leakage:

Visual Return Duct Leakage:

Lighting

Room	No. of CFL Fixtures	No. of Incan. Fixtures	No of Fluor. Tube Fixtures	No of LED Fixtures	# of Ceiling Fans by Room

Appliances

Appliance	Mfg.	Model No	Type	CuFt/Fuel	Age	Condition	E-Star?
Primary Refrigerator:							
Second Refrigerator:							
Stand-alone Freezer:							
Clothes Washer:							
Clothes Dryer:							
Dishwasher:							
Range or Combination							
Stand-alone Oven							

						Renewables			
PV Array? Y____ N____	SqFt:		Total kW:						
Windmill? Y____ N____	Count:		Total kW:						
						Miscellaneous/Code			

Inspect whole house ventilation equipment for compliance with Code. Document type of system and note any deficiencies below. Include any bathroom fans.						
Type of ventilation system:		**Fan Loc.**	**Rated CFM**	**Required**	**Control**	
Notes:						
		Total	0	0	NA	

ERV/HRV Manufacturer	**ERV/HRV Model No.**	**Efficiency**	Notes:

Appendix H On-site Homeowner Survey

2011 MA Baseline On-site Survey Questions

SITE ID:_____

OWNER NAME:_____

HOME ADDRESS: _____

1. Name of Builder or Development: _____

2. Verify how home was purchased; verify with response recorded when home was recruited.
   - ___ A. Purchased a lot from a builder, selected one of several house plans offered by the builder and selected from various available upgrade options.
   - ___ B. Purchased a home that was under construction and selected from various available upgrade options.
   - ___ C. Purchased land on my own and worked with an architect or designer to design the entire home.
   - ___ D. Had a house plan and a lot and hired a contractor/builder to build the home.
   - ___ E. Purchased a finished home.
   - ___ F. I/we am/are the owner(s) and builder(s).
   - ___ G. Other→ Please describe: _____

3. How comfortable would you say your home is?
   - ___ A. Very comfortable
   - ___ B. Somewhat comfortable
   - ___ C. Somewhat uncomfortable
   - ___ D. Very uncomfortable
   - ___ E. Don't know

   Comments:
   _____

4. Do you have any complaints about your home?
   - ___ A. Yes
   - ___ B. No

   If yes, would you describe your complaints? _____

5. Did your builder or real estate agent talk to you about energy efficiency or the benefits of energy-efficient windows, heating and cooling equipment, insulation, etc.?
   - ___ A. Yes
   - ___ B. No
   - ___ C. Do not remember

6. Did you ask your builder or the real estate agent marketing your home about energy efficiency?
   - ___ A. Asked about energy efficiency
   - ___ B. Did not ask about energy efficiency
   - ___ C. Do not remember

7. How important was *getting a home that is energy efficient* in your decision to buy or build this particular home? Using a scale from 0 to 10, where 0 is "one of the least important features" and 10 is "one of the most important features." Please circle your response:

One of the least important features										One of the most important features
0	1	2	3	4	5	6	7	8	9	10

8. How strongly do you agree or disagree with the following statement: "All new homes are equally energy-efficient"?
   - ___ A. Strongly agree
   - ___ B. Agree
   - ___ C. Neither agree or disagree
   - ___ D. Disagree
   - ___ E. Strongly disagree
   - ___ F. Do not know

9. How energy efficient do you think your home is compared to other new homes?
   - ___ A. Much more energy efficient
   - ___ B. Somewhat more energy efficient
   - ___ C. About as energy efficient as most other new homes
   - ___ D. Somewhat less energy efficient
   - ___ E. Much less energy efficient
   - ___ F. Do not know

Why do you say that? _____

10. Did you have a custom home built or purchase your home before it was completed and had the opportunity to choose various options for your home?
    ___ A. Yes
    ___ B. No (SKIP TO QUESTION 19)

For Questions 11 through 18 – Please indicate, as far as you know, who made the decision for each of the following energy efficiency-related components in your home?

11. **Windows**
    ___ A. I Specified aspects of the windows to install (Check all that apply:)
        ___ 1. I specified the style (double hung, casement, awning, slider, frame material or color, panes dividers, etc.)
        ___ 2. I specified the number of panes of glass (single-, double- or triple-pane)
        ___ 3. I specified the Energy efficiency (U-value)
        ___ 4. I specified that they be ENERGY STAR windows
    ___ B. The builder chose the windows
    ___ C. I Selected the windows from options offered by the builder
    ___ D. Do not remember or do not know

12. **Heating System**
    ___ A. I Specified aspects of the heating system (Check all that apply:)
        ___ 1. Heating fuel (electric, natural gas, propane, oil, etc.)
        ___ 2. Type of heating system (furnace, boiler, heat pump, ground source heat pump, etc.)
        ___ 3. Energy efficient heating system
        ___ 4. ENERGY STAR-labeled heating system
    ___ B. Builder chose the heating system
    ___ C. I Selected the heating system from options offered by the builder
    ___ D. Do not remember or do not know

13. **Central Air Conditioning**
    ___ A. No Central Air Conditioning
    ___ B. I Specified aspects of the central air conditioning (Check all that apply:)
        ___ 1. Whether or not to install central air conditioning
        ___ 2. Type of system (standard central A/C system, air source heat pump, ductless mini-split system, combined heating and cooling system)
        ___ 3. Energy efficient system
        ___ 4. ENERGY STAR-labeled system
    ___ C. Builder chose
    ___ D. I Selected from options offered by the builder
    ___ E. Do not remember or do not know

14. **Water Heating**
    - ___ A. I Specified aspects of the water heater (Check all that apply:)
        - ___ 1. Fuel used to heat water
        - ___ 2. Type of system (stand-alone tank, integrated tank with boiler, tankless, tankless combined with boiler heating system, point of use, etc.)
        - ___ 3. Energy efficient system
        - ___ 4. ENERGY STAR-labeled system
    - ___ B. Builder chose
    - ___ C. I Selected from options offered by the builder
    - ___ D. Do not remember or do not know

15. **Kitchen Appliances**
    - ___ A. I Specified aspects of appliances to install (Check all that apply:)
        - ___ 1. Gas or electric
        - ___ 2. Brand/manufacturer
        - ___ 3. Color/style
        - ___ 4. Energy efficient appliances
        - ___ 5. ENERGY STAR-labeled appliances
    - ___ B. Builder chose the appliances
    - ___ C. I Selected the appliances from options offered by the builder
    - ___ D. Do not remember or do not know

16. **Framing:** (2x4 or 2x6 wood framing; 16 or 24 inch-on-center wood framing: steel framing; SIPS (Structural Insulated Panels); ICF (Insulated Concrete Form) blocks; etc.)
    - ___ A. I Specified the wall framing
    - ___ B. Builder chose the wall framing
    - ___ C. I Selected the wall framing from options offered by the builder
    - ___ D. Do not remember or do not know

17. **Type and/or level of insulation**
    - ___ A. I Specified the type and/or level of insulation (Check all that apply:)
        - ___ 1. Type of insulation (fiberglass batts, blown-in cellulose, spray foam, rigid foam, etc.)
        - ___ 2. Level of insulation (R-value)
    - ___ B. Builder chose
    - ___ C. I Selected the insulation from options offered by the builder
    - ___ D. Do not remember or do not know

18. **Lighting Fixtures**
    - ___ A. I Specified aspects of the lighting fixtures (Check all that apply:)
        - ___ 1. I could choose any fixtures from any stores
        - ___ 2. I was given a budget allowance to use at a specific store or catalog
        - ___ 3. I wanted energy –efficient lighting fixtures
        - ___ 4. I wanted ENERGY STAR lighting fixtures
    - ___ B. Builder chose the lighting fixtures
    - ___ C. I Selected the lighting fixtures from options offered by the builder
    - ___ D. Do not remember or do not know

19. In the following table, please put an X in the column that best describes how energy efficient you believe each of the listed components in your home to be. Please put an X in the "ENERGY STAR® Labeled" column if you know it is an ENERGY STAR-labeled product.

Home Component	Very Energy Efficient	Average	Not Energy Efficient	Do Not Know	ENERGY STAR Labeled
Windows					
Heating System					
Central Air Conditioning					
Water Heater					
Refrigerator					
Dishwasher					
Clothes Washer					
Type of insulation					
Level of insulation					
Lighting fixtures					

20. Have you ever seen or heard of a newly constructed home being referred to as an ENERGY STAR home?
    - ___ A. Yes
    - ___ B. No (SKIP TO QUESTION 23)
    - ___ C. Do not know (SKIP TO QUESTION 23)

21. Did any builders or real estate agents you talked to while shopping for a home bring up the subject of ENERGY STAR homes?
    - ___ A. Yes
    - ___ B. No
    - ___ C. Do not remember

22. Did you ask any builders or real estate agents about ENERGY STAR Homes when you were making your plans for building or buying a home?
    - ___ A. Yes
    - ___ B. No
    - ___ C. Do not remember

23. Are you a first-time home buyer, or did you already own a home before you bought this one?
    - ___ A. First-time home buyer
    - ___ B. Already owned home
    - ___ C. Don't know or prefer not to answer

24. How long do you expect to stay in your new home?
    - ___ A. One year or less
    - ___ B. Two to three years
    - ___ C. Four to five years
    - ___ D. Six to ten years
    - ___ E. More than ten years
    - ___ F. Indefinitely/the rest of my life
    - ___ G. Don't know

25. What is the highest level of education that you have completed?
    - ___ A. Less than high school
    - ___ B. High school graduate
    - ___ C. Technical or trade school graduate
    - ___ D. Some college
    - ___ E. College graduate
    - ___ F. Some graduate school
    - ___ G. Graduate degree
    - ___ H. Prefer not to answer

26. What is your age?
    - ___ A. 18 to 24
    - ___ B. 25 to 34
    - ___ C. 35 to 44
    - ___ D. 45 to 54
    - ___ E. 55 to 64
    - ___ F. 65 or over
    - ___ G. Prefer not to answer

27. What category best describes your total household income in 2010, before taxes?
    - ___ A. Less than $35,000
    - ___ B. $35,000 to $49,999
    - ___ C. $50,000 to $74,999
    - ___ D. $75,000 to $99,999
    - ___ E. $100,000 to $149,999
    - ___ F. $150,000 or more
    - ___ G. Prefer not to answer

THANK YOU!