Massachusetts Mini Baseline Study of Homes Built at the End of the 2006 IECC Cycle

Final Report

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Executive Summary

This report presents the results of a Mini Baseline study of residential new construction building practices in Massachusetts at the end of the 2006 IECC (International Energy Conservation Code) cycle. On-site inspections of 50 non-ENERGY STAR® homes completed from late 2009 through early 2011 were conducted in April through June 2011. As part of this process, HERS (Home Energy Rating System) ratings were completed for each home. These 50 homes are the same homes evaluated in the Massachusetts Energy Code Pilot project that field tested 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. In that report, compliance rates using the checklist are compared to compliance rates under three other compliance pathways: the Overall Building UA[1] compliance path and the performance based Home Energy Rating (HERS Index) and Annual Energy Cost compliance paths. A full report on that project was issued in July 2011. See Section 3 **Code Compliance** for more detail.

This Mini Baseline Report focuses on the following:

- Consistency of study findings with current User Defined Reference Home[2] (UDRH) assumptions
- Comparison to individual prescriptive energy code requirements at the end of the 2006 IEC code cycle
- Identifying differences between custom and spec built homes

Findings are summarized in three tables. Table ES 1 compares Mini Baseline Study findings to UDRH inputs from the 2005 Baseline Study findings, 2010 UDRH inputs, and 2011 hybrid UDRH inputs. Table ES 2 compares the HERS indices of custom and spec homes. Table ES 3 provides a comparison of building practices, equipment efficiencies, and other characteristics in custom versus spec built homes. Detailed information supporting the findings presented in these tables is provided in the body of the report. Appendices A and B address how insulation installations were graded and provide examples of good and bad building practices observed during the site visits.

[1] UA = U-factor times area. UA stands for the "sum of the U-factor times the assembly area". 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. To determine the UA for the overall building the UA-values for the thermal boundary components are summed together.

[2] To calculate a HERS Index, REM/Rate compares the home being rated to a "reference home." The reference home used when calculating HERS ratings is a home of the same size, layout, and orientation as the home being rated built to 2004 IECC requirements. REM/Rate allows users to define a different reference home—a User Defined Reference Home (UDRH). The UDRH for the MA Program is based on the insulation characteristics and mechanical equipment efficiencies observed in non-participating homes inspected in a baseline study.

UDRH Inputs

Table ES 1 on the following page compares Mini Baseline Study findings to UDRH inputs from the 2005 Baseline Study findings, 2010 UDRH inputs, and current 2011 hybrid UDRH inputs. The 50 inspected homes reflect the mix of single-family custom and spec homes in the Massachusetts Program. Table cells highlighted in green identify current UDRH inputs that findings from the Mini Baseline Study suggest may underestimate the energy efficiency of current building practices or equipment. An example is heating system efficiency inputs—the average efficiencies of gas furnaces and boilers in the 50 inspected homes are higher than the current UDRH inputs. In other cases, study findings suggest UDRH inputs may overestimate the energy efficiency of current building practices. Examples are wall, floor and ceiling insulation levels.

Most of the 2005 UDRH inputs are based on the results of the 2005 Baseline Study weighted to reflect the mix of custom and spec housing units in the Program at that time. The 2005 Baseline Study did not include using REM/Rate™ to calculate HERS ratings and provide wall assembly U-values. Therefore, the final inputs incorporated assumptions on insulation installation grades and framing to estimate U-values. The 2006 federal minimum efficiency standard for air conditioning (SEER 13) was also incorporated in the final 2005 UDRH inputs. The 2010 UDRH inputs are the same as the 2005 UDRH inputs. The 2011 Hybrid UDRH inputs incorporate interim changes to address adoption of the 2009 IECC until 2011 Baseline Study results are available. The interim changes address wall, ceiling, floor, slab, foundation wall, window, duct insulation and duct leakage inputs.

Table ES 1: Comparison with 2005, 2010 & 2011 UDRH Inputs

Building Characteristic	2005 Baseline	2010 UDRH	2011 Hybrid UDRH	Code Pilot Homes*		
				All Homes	Custom Homes	Spec Homes
Building Information						
Wall Cavity	R=14.4	R=14.4	R=20	R=18.1 n=49	R=19.3 n=12	R=17.8 n=37
Flat Ceiling	U=0.058	U=0.058	U=0.041	U= 0.051 n=49	U=0.049 n=11	U=0.052 n=38
Slab		R=0.10	R=10	Auditors Unable to Verify Slab Insulation		
Floor	U=0.063	U=0.063	U=0.038	U=0.062 n=46	U=0.087 n=12	U=0.05 n=34
Foundation Wall	R=11.1	R=11.1 (cavity)	R=10.4 (continuous)	R=15.6 n=18	R=14.3 n=3	R=15.8 n=15
Window	U=0.37	U=0.37	U=0.35	Auditors Able to Verify U-value at Only Two Homes U-0.31 Assume 0.34 Based on Secondary Information		
	SHGC=0.35	SHGC=0.346	SHGC=0.346	Auditors Unable to Verify SHGC		
Infiltration	6.72 ACH50	6.72 ACH50	6.72 ACH50	5.8 ACH50 n=50	6.2 ACH50 n=12	5.7 ACH50 n=38
System Information						
Gas Furnace Efficiency (AFUE)**	89.2%	89.2%	89.2%	91.3% (all) n=47 93.6% n=35 (non-attic)	92.7% (all) n=7 94.8% n=5 (non-attic)	91.1% (all) n=40 93.4% n=30 (non-attic)
Gas Boiler Efficiency (AFUE)**	81.7%	81.7%	81.7%	91.1% n=5	95.0% n=3	85.3% n=2
Oil Furnace Efficiency (AFUE)	83.9%	83.9%	83.9%	81.0% n=3	80.0% n=1	81.5% n=2
Oil Boiler Efficiency (AFUE)	84.4%	84.4%	84.4%	85.7% n=6	No Homes with Oil Boilers	85.7% n=6
Gas Domestic Stand Alone Storage Tank Hot Water**	0.58 EF	0.58 EF	0.58 EF	0.62 EF n=22	0.69 EF n=3	0.62 EF n=19
Cooling Efficiency (SEER)	13	13	13	13.1 n=37	13.2 n=8	13.1 n=29
Duct Leakage (CFM25/100 Sq. Ft.)	21.7	21.7	12.0	17.2 n=40	21.4 n=9	16.0 n=31
Duct Insulation (supply)	R=4.11 (attic R=4.66)	R=4.11 (attic R=4.66)	R=5.0 (attic R=6.5)	6.4 (attic R=6.3)	6.2 (attic R=5.6)	6.4 (attic R=6.4)
Duct Insulation (return)	R=2.43 (attic R=4.37)	R=2.43 (attic R=4.37)	R=5.0 (attic R=5.0)	5.4 (attic R=5.6)	4.5 (attic R=3.6)	5.7 (attic R=6.1)

* Wall cavity insulation "n" excludes log home, flat ceiling "n" excludes attic that was not accessible.
**Gas includes both natural gas and propane equipment.

Comparison with IECC Prescriptive Insulation Requirements

Inspected homes are most likely to have at least R-19 conditioned/ambient wall insulation (2006 IECC prescriptive requirement) and least likely to have R-38 flat ceiling insulation (2006 IECC prescriptive requirement). Key findings are listed below:

- Most (84%) of the inspected homes met or exceeded the 2006 IECC prescriptive requirement of R-19 conditioned/ambient wall insulation.
- Almost three-fourths (73%) of the 18 inspected homes subject to basement wall insulation requirements met or exceeded the 2006 and 2009 IECC prescriptive requirement of R-10 continuous insulated sheathing on the interior or exterior of the home or R-13 cavity insulation on the interior of the basement wall.
- None of the 12 inspected homes with cathedral ceilings had R-38 cathedral ceiling insulation, but eight of the 12 homes (67%) had less than 500 square feet of cathedral ceiling area and, therefore, met the 2006 and 2009 IECC prescriptive requirement under the allowance for up to 500 square feet of cathedral ceiling to have R-30 insulation.
- Only 28% of the 46 inspected homes subject to floor insulation requirements met the 2006 and 2009 IECC prescriptive requirement of R-30 or insulation sufficient to fill the framing cavity, R-19 minimum.
- All 50 inspected homes had flat ceiling areas. Only 22% of inspected homes had insulation levels that met the 2006 and 2009 IECC prescriptive requirement of R-38 insulation.

Auditors were unable to verify window and skylight U-values in completed homes because virtually no homeowners kept the NFRC labels documenting window efficiency. Likewise, auditors were unable to verify slab insulation in completed homes. The only home subject to the mass wall insulation requirement is a log home that failed to meet the requirement of R-13. None of the 50 inspected homes have crawl spaces.

Custom and Spec Home HERS Indices

Table ES 2 shows the minimum, maximum, average and median HERS indices for all inspected homes, custom homes and spec built homes. As an overall indicator of a home's energy efficiency, the HERS ratings conducted on the 50 inspected homes suggest there is little difference between the energy efficiency of custom homes (average HERS 85.1) and spec homes (average HERS 82.7); the difference in the HERS Indices of custom and spec homes is not statistically significant at the 90% confidence level.

Table ES 2: Comparison of Custom and Spec Home HERS Indices

HERS Index	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum	64	64	68
Maximum	112	112	101
Average	83.3	85.1	82.7
Median	81.0	80.5	81.5

Comparison of Inspected Custom and Spec Homes

Table ES 3 on the following page compares the insulation R-values, glazing percentages, heating and cooling system efficiencies, water heater efficiencies, duct insulation and leakage, air infiltration, presence of energy-efficient lighting, and penetration of ENERGY STAR-qualified appliances in custom and spec homes. Also included are the percentages of custom and spec homes meeting 2006 IECC prescriptive requirements. In most cases the difference between custom and spec homes is minimal. Table cells highlighted in green identify which group of inspected homes, custom or spec, is more energy efficient. Custom homes tend to have higher R-value conditioned/ambient wall and flat ceiling insulation, while spec homes tend to have higher R-value floor and foundation wall insulation. Custom homes have slightly more efficient heating systems and spec homes have slightly more efficient water heating systems. Spec homes have lower duct leakage and air infiltration. Custom homes have more energy-efficient light bulbs and a slightly higher percentage of ENERGY STAR refrigerators and dishwashers.

Table ES 3: Comparison of Custom and Spec Homes

Building Component or Measure**	All Homes (n=50)*	Custom Homes (n=12)*	Spec Homes (n=38)*
Average Square Feet of Conditioned Floor Area	2,611	2,856	2,534
Conditioned/Ambient Wall Insulation Levels			
Average Conditioned/Ambient Exterior Wall R-value	17.9	19.3	17.5
Percent of Homes Meeting 2006 IECC Prescriptive Wall Insulation Requirement	86%	100%	81%
Conditioned/Basement Floor Insulation Levels			
Average R-value of Floor Insulation over Unconditioned Basements	21	18.8	21.8
Percent of Homes Meeting 2006 IECC Prescriptive Floor Insulation Requirement	28%	33%	26%
Flat Ceiling Insulation Levels			
Average Flat Ceiling Insulation R-value	32.0	34.5	31.2
Percent of Homes Meeting 2006 IECC Prescriptive Flat Ceiling Insulation Req.	22%	33%	18%
Cathedral Ceiling Insulation Levels			
Average Cathedral Ceiling Insulation R-value	28.8	None	28.8
Percent of Homes Meeting 2006 IECC Prescriptive Cathedral Ceiling Insulation Req.	67%	NA	67%
All Ceiling Insulation Levels			
Percent of Homes Meeting all 2006 IECC Prescriptive Ceiling Insulation Req.	20%	33%	16%
Foundation Wall Insulation Levels			
Average Foundation Wall Insulation R-value	15.6	14.3	15.8
Percent of Homes Meeting 2006 IECC Prescriptive Foundation Wall Insulation Req.	72%	67%	73%
Windows			
Average Percent Glazing (% of Wall Area)	16%	18%	15%
Average Percent of Total Glazing on South Walls (S, SE, SW)	38%	36%	38%
Heating Systems			
Percent ENERGY STAR heating systems	82%	83%	82%
Average Output Capacity (Btuh) per Square Foot Conditioned Floor Area	43	41	43
Central Air Conditioning			
Average Central Air Conditioning SEER	13.1	13.2	13.1
Average Square Feet per Ton of Central Air Conditioning	669	678	666
Natural Gas and Propane Stand Alone Storage Water Heaters			
Average Energy Factor	0.62	0.59	0.62
Ducts			
Average R-value Duct Insulation--All Ducts in Unconditioned Space	6	5.5	6.1
Average Duct Leakage CFM25 per 100 Sq. Ft. Conditioned Space	17.2	21.4	16.0
Air Infiltration			
Average Air Changes per Hour at 50 Pascals (ACH50)	5.8	6.2	5.7
Average CFM50 Leakage	1,960	2,242	1,871
Lighting			
Percent of Energy Efficient Bulbs	21%	21%	22%
Average Number of Screw-In CFL Bulbs	10.6	11.9	10.2
Average Number of All Energy Efficient Bulbs	14.2	20.2	12.2
Appliances			
Percent Primary Refrigerators ENERGY STAR	73%	75%	73%
Percent Dishwashers ENERGY STAR	89%	91%	88%

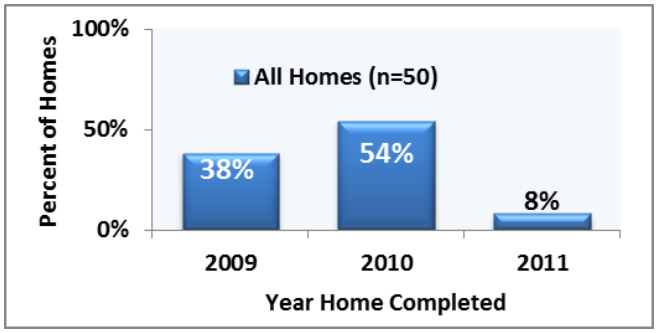
*The numbers of homes are the total number of homes in the studies. Not all homes have all features; therefore, the numbers of homes with a specific feature vary.

**Table cells highlighted in green identify which group of inspected homes, custom or spec, is more energy efficient.

1 Introduction

NMR and KEMA auditors conducted on-site audits at 50 recently-completed non-ENERGY STAR-qualified homes across Massachusetts built at the end of the 2006 IECC cycle. Figure 1-1 shows 38% of inspected homes were completed in 2009, 54% in 2010, and 8% in 2011.

Figure 1-1: Year Homes Completed



Homes were inspected between April and June of 2011 with three primary tasks in mind:

- Conducting a full HERS rating using REM/Rate software
- Filling out the 2006 IECC checklist developed by PNNL
- Providing Program Sponsors with a Mini Baseline Study of 50 non-ENERGY STAR-qualified homes completed at the end of the 2006 IECC code cycle

An on-site data collection form that contained the inputs required to conduct a full HERS rating and fill out the 2006 IECC checklist was developed. The data collection form was broken up into six primary sections that are detailed in Table 1-1. The code checklist section of the form identifies inputs that were needed to populate the checklist, but were not needed for REM/Rate. All other sections of the data collection form indicate areas of overlap between the checklist and REM/Rate, or they are indicative of data that are specifically required for HERS ratings.

Table 1-1: Data Collection Form Inputs

General Information	Insulation/Shell Measures	Mechanical Equipment	Test Results	Lighting & Appliances	Code Checklist
• 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	• HVAC piping insulation • Recessed fixtures • Damper openings • Certificate • Heat pump thermostat • Circulating hot water • Air sealing

One of the challenges of inspecting completed homes is that several building envelope components are not accessible or visible. In general, if estimates were necessary, auditors used all of the information available to make the most informed estimates possible. 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.

When wall insulation was not visible, which was the case for almost all conditioned/ambient exterior walls and interior basement walls in conditioned basements, the R-value and type of insulation were estimated based on the stud depth of the wall, the type(s) of insulation visible in other areas of the home, input from the homeowner and, when available, building plans or specifications. 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. Note that unobservable insulation was treated the same as observable insulation; both were included in the analyses and are reported on throughout the report with equal weight.

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 A for the 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 walkout basement and assigned a Grade II installation, then the above grade walls for that home were also assigned a Grade II installation.

Figure 1-2 shows a Grade I and a Grade III attic insulation installation.

Figure 1-2: Example of Grade I and Grade III Attic 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 cellulose or fiberglass insulation 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 2009 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.

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 2009.

Table 2-1: Sampling Plan

County	Permit Data under Stretch Code	Permit Data not under Stretch Code	Total On-Site Inspections	On-Site Inspections in Non-Stretch Code Communities	On-Site Inspections in Stretch Code Communities
Barnstable	16	323	3	3	0
Berkshire	44	85	1	1	0
Bristol	19	445	4	4	0
Dukes	0	107	1	1	0
Essex	56	355	4	3	1
Franklin	22	37	1	1	0
Hampden	93	220	3	2	1
Hampshire	41	142	2	2	0
Middlesex	455	683	11	7	4
Nantucket	0	46	0	0	0
Norfolk	37	414	4	4	0
Plymouth	96	464	5	4	1
Suffolk	61	4	1	0	1
Worcester	178	816	10	8	2
Total	**1,118**	**4,141**	**50**	**40**	**10**

The study considered the use of the Department of Energy's (DOE's) Building Energy Codes Program (BECP) State Sample Generator, a tool that generates the number of randomly sampled new homes to take from each county in the state based on an average of three previous years of construction data. However, in Massachusetts, there were additional factors important in the generation of the sample that are not considered by the State Sample Generator, namely, the number of homes in communities that have since adopted the 2009 IECC stretch code and the split between spec and custom built homes. These factors were included in the sampling plan for

the subsequent Massachusetts baseline study of 100 homes built under the 2009 IECC building code. It was decided to use the same sampling plan for the DOER Code Pilot study and Mini Baseline Study of homes built under 2006 IECC and simply cut the sample in half since the goal was to complete 50 rather than 100 on-site inspections.

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 Massachusetts New Homes with ENERGY STAR 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 drawn, following the sampling plan shown in Table 2-1, 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, new service requests may also involve additions to existing homes and other major renovations which must be screened out in scheduling the on-site inspections.

2.2.1 Data Cleaning

The sample for the on-site inspections was drawn from new residential permanent service requests received by the utilities from October 1, 2009 through June 30, 2010; these dates were used to target homes built at the end of the 2006 IECC code cycle in Massachusetts; building permits drawn starting on July 1, 2010 had to come under the 2009 IECC building code. The new service requests were cleaned to remove addresses where:

- The home had participated in the Massachusetts New Homes with ENERGY STAR 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 eliminating the above addresses, there were 1,924 possible addresses to be considered for the on-site inspections. The majority of these could be assumed not to involve new construction and would ordinarily be screened out when customers were called to set up appointments for the inspections. However, since building permits drawn between January 1 and June 30, 2010 could be under either 2006 IECC or 2009 IECC, it was necessary to check each possible new home address through the local building department to ensure that the home was built under 2006 IECC; the checks with the building departments also meant that new service requests that did not involve new home construction could be screened out at this stage.

2.2.2 Building Department Data Collection

The possible new homes identified by the new service requests covered 169 cities and towns across Massachusetts; local building departments were contacted to verify the homes were built under 2006 IECC. Table 2-2 presents the method used to gather the required information from the local building departments. Only about one in five municipalities had all the information needed available on-line, the easiest and most cost-effective option. Close to two-thirds required at least one phone call to look up the necessary data. Even more expensive and time-consuming were the in-person visits required by 20 municipalities. Four municipalities required payments from $15 to $39 for providing the needed data either over the phone or in person. Finally, the study was unable to gather data from 12 municipalities despite multiple attempts. These municipalities, however, accounted for only 75 building permits or 1.4% of the statewide total, so they are not likely to bias the sample.

Table 2-2: How Required Information Was Obtained from Local Building Departments

Method	Number of Municipalities	Percent of Municipalities
Telephone call	104	61%
Data available on-line	33	20%
In-person visit	20	12%
Data not provided	12	7%
Total	**169**	**100%**

After all available building department data had been checked, there were 592 names and addresses representing occupied homes in one to four unit buildings that were built under 2006 IECC and did not participate in the Massachusetts New Homes with ENERGY STAR Program. Each homeowner was mailed a letter, with the DOER and Program Sponsors' logos, explaining the purpose of the study, what the on-site inspections would be like, and the incentive of $150 offered for participation.

2.2.3 Recruitment

As noted above, the data cleaning and ascertaining the applicable code with the local building departments resulted in a starting sample of 592 names and addresses from which to recruit the 50 on-site inspections. However, the requirements for one inspection per community and the spec/custom mix meant that some of this sample could not be used. Of the 592 names, 161 were never called because the quota of inspections in a particular county was reached. Additionally, once an inspection was completed, every other contact in that community was considered not eligible; this accounted for an additional 194 names, leaving a valid sample of 237 names. Table 2-3 summarizes the disposition of the sample.

Table 2-3: Sample Disposition

Sample Description	Number	Percent
Starting Sample	592	
Never Called	161	
Sample Used	431	
Sample considered not eligible	194	
Valid Sample	237	
Completed on-site inspections	50	21%
Refusals	36	15%
Not reached	151	64%

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. Only a small number, 24, had wrong or disconnected numbers and only 2 had language barriers. Of the homeowners who were reached, there were more acceptances (50) than refusals (36). This is a very encouraging acceptance rate for a study where the homeowner has to be present and provide access to all parts of the home for two to four hours. The recruiter reported that many respondents were particularly interested in the verbal feedback about their new homes' energy efficiency that they would be getting as part of this study; she believes the high acceptance rate is most attributable to this factor. It is also possible that home owners want to confirm their belief that their homes have above average energy efficiency.

2.3 Completed On-Site Inspections

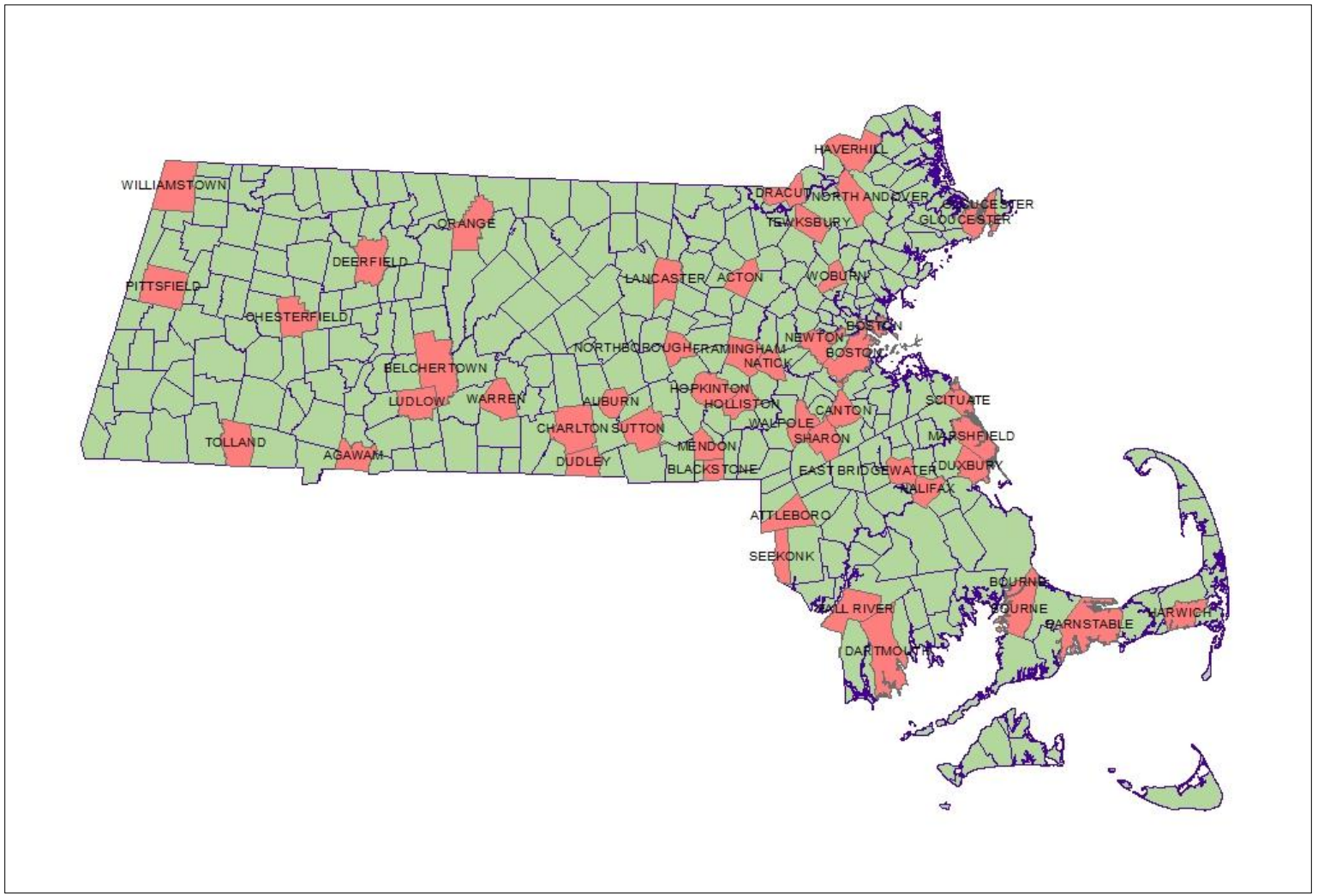
As Table 2-4 shows, the completed on-site inspections followed the sampling plan shown in Table 2-1 and the desired spec/custom mix fairly closely. The study has a mix of 76% spec built and 26% custom built homes. Two-thirds (66%) of the on-site inspections took place in non-stretch code communities and 34% took place in stretch code communities.

Table 2-4: Completed On-Site Inspections

County	Total On-Site Inspections	Non-Stretch Code	Stretch Code	Spec Built	Custom Built
Barnstable	3	3	0	2	1
Berkshire	2	0	2	0	2
Bristol	5	5	0	5	0
Dukes	0	0	0	0	0
Essex	3	2	1	1	2
Franklin	2	1	1	1	1
Hampden	3	3	0	3	0
Hampshire	2	0	2	1	1
Middlesex	9	3	6	9	0
Nantucket	0	0	0	0	0
Norfolk	4	4	0	4	0
Plymouth	6	5	1	3	3
Suffolk	1	0	1	1	0
Worcester	10	7	3	8	2
Total	**50**	**33**	**17**	**38**	**12**

Moreover, the inspections took place in 47 cities and towns across Massachusetts; there was only one inspection done in 44 communities and two inspections done in each of three communities. The 47 communities covered are shown in Figure 2-1.

Figure 2-1: On-Site Inspections



3 Code Compliance

IECC 2006 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. The results presented here, while not indicative of actual code compliance, provide useful information on the 2006 IECC from both prescriptive and performance perspectives. These results can serve as a tool for assessing specific prescriptive measure compliance and provide an estimate of how homes would likely perform under the different compliance paths.

3.1 Compliance Paths

3.1.1 Prescriptive Compliance Path

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

1) The item either meets or exceeds a minimum value provided for it (e.g. wall insulation R value)
2) The item either is, or is not, compliant with specific prescriptive requirements (e.g. wall insulation installation) on a yes/no basis

Prescriptive compliance is assessed in two ways: 1) the number and percentage of homes meeting specific prescriptive requirements and 2) compliance with applicable items on the 2006 IECC checklist developed by PNNL. The checklist was developed to help the Department of Energy (DOE) determine whether or not a consistent approach could be developed to gauge statewide compliance across the country. One of the objectives of this study was to provide feedback on the checklist.[3] It should be noted here that, the checklist was in a draft form during this project and may be updated in the future. The 2006 IECC checklist may be assessed assuming a home followed a performance approach, a UA trade-off approach, or a prescriptive approach; for the purposes of this analysis the checklist was assessed assuming homes followed a prescriptive compliance path. Using the 2006 IECC checklist to assess compliance under the

[3] The evaluation team provided feedback on the checklist in a separate report. That report can be found here: **http://neep.org/uploads/NEEPResources/id771/Massachusetts_FinalReport_NMR_2011.pdf**

prescriptive path, a home is deemed to be in compliance if it meets prescriptive requirements for all of the applicable and observable items on the checklist.[4]

2006 IECC Checklist: The checklist works on a point system—the system is structured such that each checklist item is worth a given number of points. If an item is deemed to be compliant then the house receives the total possible points for that item; conversely, if that item is deemed to be non-compliant then the house does not receive any points. The checklist accounts for the fact that not all items are applicable to all homes by allowing raters to specify an item as "N/A" or "Not Observable." When "N/A" or "Not Observable" is input, the possible points and the points received for that measure both default to zero, essentially removing that item from the compliance analysis.

The checklist is structured such that it provides a compliance percentage for any given home. The equation used to calculate the compliance percentage is presented below:

$$Compliance = \frac{Points\ Received}{Points\ Possible}$$

While this approach accounts for variance among homes by adjusting the total possible points, it also allows for a compliance assessment based on an extremely low number of total possible points. For example, during the site visits there were many checklist items that were listed as not observable due to the post occupancy nature of the study. In one case, a home was only eligible for 26 possible points (about nine checklist items). To put this in perspective, the checklist has a total of 130 possible points, though not all points apply to every home[5]; inspected homes, on average, were eligible for 36.6 possible points. Given the point structure of the checklist this home could have been considered compliant based on eight or nine checklist items, regardless of the significance of those measures.

Note, a home would only be considered compliant with Massachusetts energy code if the compliance percentage equaled 100%. That said, the checklist was developed to assess statewide compliance. PNNL suggests measuring statewide compliance by averaging the compliance percentages across a sample of homes[6]; this is why the checklist provides compliance percentages for individual homes even though a home is not actually partially compliant—it either is or is not compliant with the Massachusetts energy code.

3.1.2 Home Energy Rating Compliance Path (Performance)

In the amendments to the seventh edition of the Massachusetts building code, the Board of Building Regulations and Standards (BBRS) included the Home Energy Rating compliance path, a performance path that allowed builders to comply with the energy code if the home had a HERS rating conducted by a certified HERS rater and achieved a HERS index of 100 or fewer

[4] The checklist allows for code officials or raters to specify "not observable" for any item. In these cases the home does not need to meet the prescriptive requirement to be considered compliant.
[5] For example, the slab insulation checklist item may not apply to a home with an unconditioned basement.
[6] Pacific Northwest National Laboratory. "Measuring State Energy Code Compliance," 5.21-5.23.

points.[7][8] HERS ratings are performed using REM/Rate software, where REM/Rate compares the "design" or "as-built" home to the "reference" home. The current reference home is based on the 2004 IECC. To calculate a HERS index, REM/Rate models the reference home to be almost identical to the as-built home (e.g. size, shape, orientation), with the only major differences being that the reference home is built to meet the 2004 IECC prescriptive requirements. A home built precisely to 2004 IECC prescriptive code requirements should score a HERS index of 100.[9]

3.1.3 Annual Energy Cost Compliance Path (Performance)

The Annual Energy Cost compliance path is a performance path very similar to the Home Energy Rating path for compliance, though there are some important differences. Similar to the Home Energy Rating path, the Annual Energy Cost compliance path is based on REM/Rate models but compares the as built home to the 2006 IECC reference home, whereas the Home Energy Rating Path compares the as built home to the 2004 IECC reference home. The Annual Energy Cost compliance path differs from the Home Energy Rating path in that it 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 when assessing compliance. Examples of other measures not addressed are lighting, appliances, and photovoltaics.

3.1.4 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 2006 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)[10] there are several key differences. 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] The amendments went into effect on October 17th, 2008.
[8] **http://www.mass.gov/eopss/docs/dps/inf/780-cmr-6100-energy-efficiency.pdf**
[9] **http://www.resnet.us/home-energy-ratings**
[10] **http://www.energycodes.gov/REScheck/download.stm**

3.2 Compliance Results

Table 3-1 displays the estimated compliance results for the 50 inspected homes assuming they all were permitted under any one compliance path. For example, if all of the inspected homes were permitted under the Home Energy Rating path the compliance rate would be 92%. Specifically, Table 3-1 shows the minimum, maximum, average, and median compliance results under the checklist and REM/Rate compliance paths for the 50 non-ENERGY STAR homes inspected. The left side of the table displays code compliance results using the 2006 IECC checklist assuming the homes were permitted under the prescriptive compliance path. Using this approach, the average compliance rate is 45.2%; no homes were 100% compliant. That is, on average, the inspected homes scored 45.2% of the possible checklist points, but none of the homes would have complied using the prescriptive checklist approach. The Annual Energy Cost and the Overall Building UA trade-off compliance paths 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 our sample falls short of or exceeds the code. On average, the sample of 50 non-ENERGY STAR homes was -0.3% below code using the Annual Energy Cost compliance path, and -31.2% below code using the Overall Building UA trade-off approach. In other words, on average, annual energy costs were 0.3% higher than the 2006 IECC reference home and overall UA values were 31.2% higher than the 2006 IECC reference home. Fifty-percent of homes would be compliant under the Annual Energy Cost compliance path and no homes would be compliant under the Overall Building UA trade-off path. Finally, 92% of the homes achieved a HERS index of 100 or lower and, thus, would be compliant under the Home Energy Rating compliance path.

Table 3-1: Checklist and REM/Rate Compliance Results for 50 Inspected Homes

Statistic	Checklist			REM/Rate Compliance		
	Points Possible	Points Received	Compliance Percentage	HERS Index	Energy Cost Compliance % Above or Below Code	UA Compliance % Above or Below Code
Minimum	26	7	16.7%	64	-52.2%	-154.2%
Maximum	54	28	66.7%	112	27.9%	-8.1%
Average	**36.6**	**16.6**	**45.2%**	**83.3**	**-0.3%**	**-31.2%**
Median	35.5	16	45.2%	81	0.1%	-26.7%
Percent of Homes Compliant			**0%**	**92%**	**50%**	**0%**

Table 3-2 shows the percentage of inspected homes subject to IECC prescriptive insulation and fenestration requirements that complied with those requirements. The rows highlighted in blue are the requirements that changed from 2006 IECC to 2009 IECC. Auditors were unable to verify window and skylight U-values in completed homes because virtually no homeowners kept the National Fenestration Rating Council (NFRC) labels documenting window efficiency. Likewise, auditors were unable to verify slab insulation in completed homes. The only home subject to mass wall requirements is a log home. None of the 50 inspected homes have crawl spaces. As shown, 84% of homes subject to wood frame wall R-value requirements complied with 2006 IECC requirements, but only 6% complied with 2009 IECC requirements. Only 28% of homes subject to floor R-value requirements complied with the 2006 and 2009 IECC requirement. Almost three-fourths (73%) of homes subject to basement wall R-value requirements complied with 2006 and 2009 IECC requirements.

Table 3-2: Compliance with IECC Prescriptive Insulation and Fenestration Requirements

2006 IECC Prescriptive Component	2006 IECC Prescriptive Requirement[a]	Number of 50 Inspected Homes Subject to Requirement	Percent of Homes Meeting 2006 IECC Requirement	2009 IECC Prescriptive Requirement	Percent of Homes Meeting 2009 IECC Requirement
Fenestration U-Factor [b]	0.35	50	Unable to Verify	Same as IECC 2006	Unable to Verify
Skylight U-Factor [b]	0.60	6	Unable to Verify	Same as IECC 2006	Unable to Verify
Ceiling R- value	38	50	22% (flat) 20% (all)	Same as IECC 2006	22% (flat) 20% (all)
Wood Frame Wall R- value	19	49	84%	20 or 13+5[f]	6%
Mass Wall R- value [i]	13	1	0%	13/17[g]	0%
Floor R- value	30[e]	46	28%	Same as IECC 2006	28%
Basement Wall R- value [c]	10/13	18	73%	Same as IECC 2006	73%
Slab R- value & Depth [d]	10, 2 ft.	18	Unable to Verify	Same as IECC 2006	Unable to Verify
Crawl Space Wall R- value [c]	10, 2 ft.	No homes with crawl spaces	NA	Same as IECC 2006	NA

a. *R*-values are minimums, *U*-factors and SHGC are maximums. R-19 permitted to be compressed into a 2x6 cavity.
b. The fenestration *U*-factor column excludes skylights. The SHGC column applies to all glazed fenestration.
c. R-10 continuous insulated sheathing on the interior or exterior or R-13 cavity insulation on the interior of the basement wall.
d. R-5 shall be added to the required slab edge *R*-values for heated slabs.
e. Or insulation sufficient to fill the framing cavity, R-19 minimum.
f. R-13 cavity plus R-5 insulated sheathing
g. The second *R*-value applies when more than half the insulation is on the interior of the mass wall.

3.2.1 Variability in Compliance Based on Approach

There are a number of reasons for the variability in compliance rates across the four compliance paths. For the 50 non-ENERGY STAR homes inspected, the checklist approach assessed compliance under the prescriptive path. These homes were assessed on an item by item basis, which typically leads to lower compliance rates as builders struggle to meet the requirements of specific items. There were a number of assumptions that added to the low compliance rates. These assumptions and the associated checklist items are listed below:

- **Construction drawings and documentation available:** If plans were not available on site this item was marked as non-compliant.[11]
- **HVAC load calculations:** This item was marked as non-compliant for all 50 non-ENERGY STAR homes as load calculations were never verifiable on site. Note, this checklist item asks inspectors to verify that HVAC load calculations were completed; it does not ask inspectors to verify that the equipment installed meets the design standards.
- **Air sealing checklist items:** These items were consistently marked as being unobservable given the post occupancy nature of the study. Most of the homes visited by NMR and KEMA would have been compliant with the air sealing measures had the 2006 IECC allowed compliance to be assessed via a blower door test and the ACH50 results. Auditors conducted blower door tests at all homes, but the 2006 IECC checklist does not allow air leakage results as a substitute for the visual verification of air sealing measures—this was an addition to the 2009 IECC.
- **Ceiling insulation R-value:** If flat attic ceiling insulation had an R-value of less than R-38 it was considered non-compliant. The 2006 IECC allows for R-30 insulation in flat attic ceilings if the insulation is not compressed at the eaves. To meet this requirement almost certainly requires a raised heel truss which was rarely seen, if at all, during the site visits.
- **Heating and cooling equipment type and capacity as per plans:** This item was marked as being non-compliant for all 50 non-ENERGY STAR homes as load calculations were never verifiable on site.

Similar to the checklist approach, in terms of compliance, homes performed poorly under the Overall Building UA trade-off approach. On average, the 50 non-ENERGY STAR homes inspected were estimated to be 31.2% below code. None of these 50 homes would have been compliant with the 2006 IECC under either the checklist or Overall Building UA trade-off approach.

When assessed under the performance paths (i.e. the Home Energy Rating path and the Annual Energy Cost compliance path), compliance rates increased significantly. Using the Annual Energy Cost compliance path, these 50 homes were found to be 0.3% below code on average,

[11] If plans were available on site they had to sufficiently demonstrate energy code compliance; some did not.

and 50% of them would have complied under this approach. The Home Energy Rating path was even more impressive as 92% of the inspected homes would have complied under this approach.

There are a number of reasons for the jumps in compliance using the performance paths versus the prescriptive paths (i.e. the checklist and Overall Building 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. Key inputs such as high efficiency HVAC equipment, low air leakage, and low duct leakage are considered in a performance approach. These items are identified on the checklist, but they are given much more weight in the REM/Rate compliance models.[12]

Within the performance paths, the Home Energy Rating path is a much easier route to compliance than the Annual Energy Cost compliance path. This is evident by the overall compliance estimates of the 50 homes inspected (92% under the Home Energy Rating path and 50% under the Annual Energy Cost path). The Annual Energy Cost compliance path only considers costs related to heating, cooling, and domestic hot water. The HERS index is based on those areas in addition to lights, appliances, on-site power generation, and other measures. In other words, the HERS index allows for more tradeoffs in achieving compliance than the Annual Energy Cost compliance path. Additionally, the reference home for the Home Energy Rating Path is based on the 2004 IECC whereas the reference home for the Annual Energy Cost compliance path is based on the 2006 IECC.

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 a 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, we know there are significant differences between the REM/Rate Overall UA approach and the commonly accepted and used REScheck software and know that compliance under the REM/Rate UA approach will always be lower than when using REScheck.

[12] The 2006 IECC gives credit to high efficiency HVAC systems complying under the performance path. It should be noted that this does not apply to the 2009 IECC—in the 2009 code, homes are given no additional credit for high efficiency HVAC equipment.

4 General Characteristics of Inspected Homes

The most popular style of the homes inspected is colonial (45% of inspected homes) followed by contemporary (16%), ranch (12%), and cape (8%). Most of the homes (92%) are detached single-family homes; two homes are duplexes and two are townhouses. All homes are primary residences. The smallest home inspected is 798 square feet and the largest is 7,190 square feet (Figure 4-1). The average conditioned floor area[13] is 2,611 square feet, which is slightly lower than the average of 2,672 square feet of heated space in 2005 Baseline Study homes, and the median is 2,447 square feet. The majority of homes (64%) are two stories; 22% are one to one and one half stories and 14% are two and one half to three stories. Figure 4-2 shows examples of the different size homes inspected.

Figure 4-1: Conditioned Floor Area

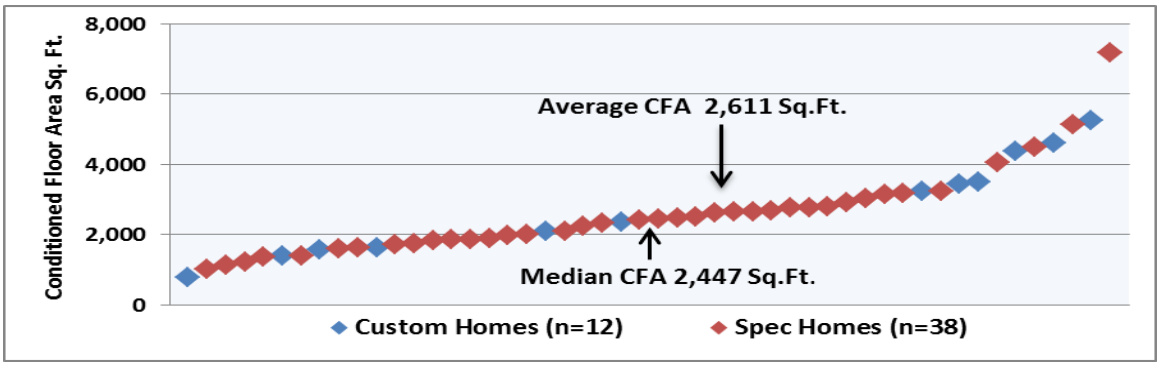


Figure 4-2: Examples of Inspected Homes

[13] 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**

5 Building Envelope

The on-site inspections included collecting information on wall, ceiling, floor, foundation wall, slab, and rim/band joist insulation and windows and doors on the thermal boundary of homes.

5.1 Wall Insulation

Auditors recorded insulation information for all walls on the thermal boundary of homes. This includes conditioned/ambient, conditioned/garage, conditioned/basement, conditioned/attic and unconditioned basement/ambient walls as well as 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 installed.

Fiberglass batt insulation is clearly dominant—only two homes did not have only fiberglass batt insulation. As shown in Table 5-1, average insulation levels range from R-12.8 in adiabatic walls to R-20.9 in conditioned/attic walls. All walls have 16 inch on center stud spacing and the majority of all but conditioned/basement and conditioned/attic walls are 2x6 construction. Insulation was least likely to be observable in conditioned/ambient walls (28%) and adiabatic walls (25%). Auditors assigned a Grade I rating (the best rating) to insulation installation in only one home—the conditioned/ambient walls in a home with R-13 fiberglass batts combined with two inches of closed cell foam insulation. Auditors assigned Grade III (the worse rating) insulation installation to half or more of conditioned/basement, conditioned/attic, and unconditioned basement/ambient walls.

Table 5-1: Characteristics of Each Wall Type

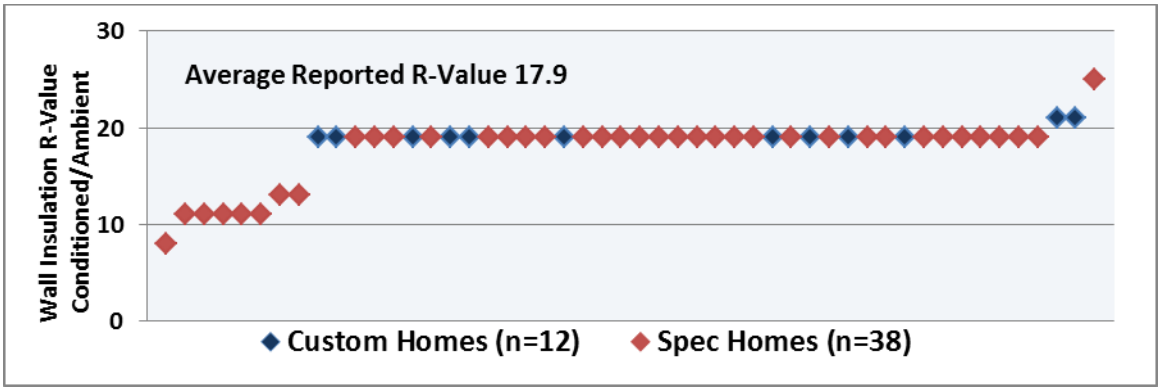
Wall Location →	Cond/ Ambient (n=50)	Cond/ Garage (n=23)	Cond/ Basement (n=23)*	Cond/ Attic (n=10)	Uncond Basement/ Ambient (n=10)	Adiabatic (n=4)	Uncond Basement /Garage (n=3)
Average R-value	17.9	16.9	14.4	20.9	19.0	12.8	19.0
Framing							
2x4 16" On Center	14%	39%	61%	59%	0%	25%	33%
2x6 16" On Center	82%	57%	39%	41%	100%	75%	67%
2x8 16" On Center	2%	4%	0%	0%	0%	0%	0%
% 6 Inch Logs	2%	0%	0%	0%	0%	0%	0%
Insulation Visibility, Installation Grade and Percent Fiberglass Batt							
Insulation Visible	28%	35%	52%	60%	60%	25%	100%
Grade I Installation	2%	0%	0%	0%	0%	0%	0%
Grade II Installation	70%	74%	50%	50%	40%	67%	67%
Grade III Installation	28%	26%	50%	50%	60%	33%	33%
Fiberglass Batt	96%**	100%	96%	100%	100%	75%	100%

* In one home the wall was not insulated. Installation grade percentages are based on homes with insulated walls.
** Two homes did not have fiberglass batt insulation: one was a log cabin (6" logs) and one had R-13 fiberglass batt plus two inches of closed cell foam insulation.

5.1.1 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-17.9. Figure 5-1 graphs the individual recorded R-values in conditioned/ambient walls for all 50 inspected homes.

Figure 5-1: 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 50 inspected homes (82%) conditioned/ambient wall framing is 2x6 studs 16 inch on center. Table 5-2 shows the average R-value is slightly higher in custom homes (R-19.3) than in spec homes (R-17.5). Comparing insulation levels observed in inspected homes to the 2006 and 2009 IECC prescriptive requirements for conditioned/ambient wall insulation, 84% of homes (all custom homes and 79% of spec homes) have R-19 or higher insulation (the 2006 IECC prescriptive requirement); only 6% of homes (17% of custom homes and 3% of spec homes) have at least R-20 insulation (the 2009 IECC prescriptive requirement).

Table 5-2: Conditioned/Ambient Wall Statistics

Conditioned/Ambient Exterior Wall R-values	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum R-value	8.0	19.0	8.0
Maximum R-value	25.0	21.0	25.0
Average R-value	17.9	19.3	17.5
Median R-value	19.0	19.0	19.0
Comparison to 2006 IECC Prescriptive Requirement of R-19 or R-13 + 5*			
Less than R-19 or R-13+5	16%	0%	21%
R-19 or R-13+5	78%	83%	76%
More than R-19 or R-13+5	6%	17%	3%
Comparison to 2009 IECC Prescriptive Requirement of R-20 or R-13+5*			
Less than R-20 or R-13+5	94%	83%	97%
R-20 or R-13+5	0%	0%	0%
More than R-20 or R-13+5	6%	17%	3%

*R-13 cavity plus R-5 insulated sheathing

5.2 Ceiling Insulation

Auditors reported data for attic insulation installations where the insulation covered the joists, attic insulation where the insulation did not cover the joists, and cathedral ceilings. Only 12 of the inspected homes have cathedral ceilings. The most energy-efficient practice for flat ceilings is to cover joists with insulation; only 19 of the 50 inspected homes (38%) had at least some flat ceiling area where the insulation covered the joists.

Table 5-3 shows the characteristics of the ceilings inspected. As shown, auditors were able to visibly inspect most ceiling insulation installations: 82% of uncovered flat joist, 89% of covered flat joist and 67% of cathedral ceilings. As shown, average R-values range from R-28.8 for cathedral ceilings to R-33.9 for flat ceilings with joists covered with insulation. The most common framing is 2x10 16 inch on center, followed by 2x8 16 inch on center. Together, 2x10 and 2x8 16 inch on center framing account for over 70% of flat ceilings and 92% of cathedral ceilings.

Table 5-3: Ceiling Characteristics

Ceiling Type →	Flat Joists Not Covered (n=34)	Flat Joists Covered (n=19)	Cathedral (n=12)
Average Reported R-value	30.7	33.9	28.8
Framing			
2x4 16" On Center	3%	0%	0%
2x4 24" On Center	9%	5%	0%
2x6 16" On Center	0%	5%	0%
2x6 24" On Center	3%	5%	8%
2x8 16" On Center	24%	16%	25%
2x10 16" On Center	47%	63%	67%
2x12 16" On Center	6%	0%	0%
2x12 24" On Center	3%	0%	0%
Truss	6%	0%	0%
Unknown	0%	5%	0%
Insulation Visibility and Installation Grade			
Insulation Visible	82%	89%	67%
Grade 1 Installation	9%	16%	0%
Grade 2 Installation	53%	74%	42%
Grade 3 Installation	38%	11%	58%
Type of Insulation			
Fiberglass Batt Insulation	91%	63%	100%
Cellulose	9%	16%	0%
Blown-in Fiberglass	0%	16%	0%
FG batts plus 2 inches foam	0%	5%	0%

Once again fiberglass batt insulation dominates. All cathedral ceilings, 91% of uncovered flat joist ceilings, and 63% of covered flat joist ceilings are insulated with fiberglass batts. Three homes have uncovered joists in one area and covered joists in another area. In all three of these homes, the uncovered joists are insulated with fiberglass batts; in one of these homes the covered joists are insulated with fiberglass batts, in one they are insulated with cellulose, and in one they are insulated using a combination of fiberglass batts and two inches of polyiso, foil-faced foam. In five homes, the joists are covered in all flat ceiling areas; three are insulated with blown-in fiberglass and two with cellulose.

Grade I insulation installation was reported for six homes; two homes with uncovered joists and flat ceilings insulated with cellulose, one home with uncovered joists and flat ceilings insulated with fiberglass batts, two homes with covered joists insulated with cellulose, and one home with covered joists insulated with blown-in fiberglass.

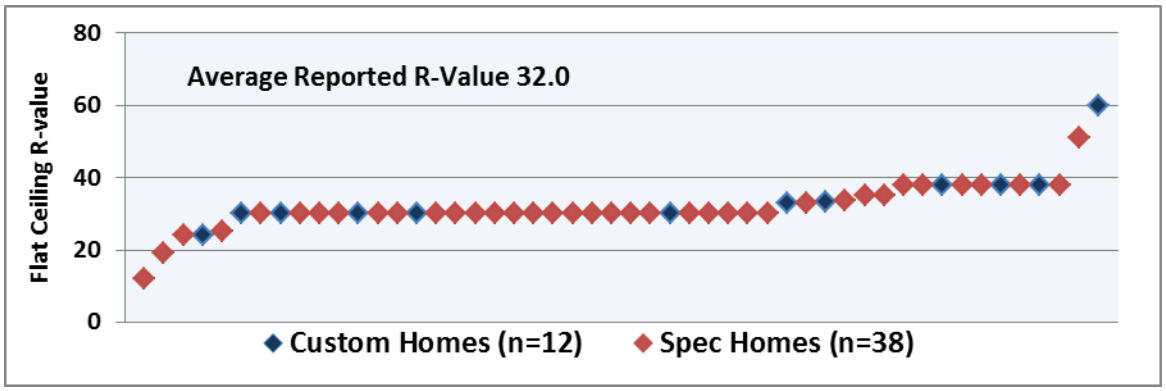
Table 5-4 shows that flat ceiling insulation levels range from R-24 to R-60 in custom homes and from R-12 to R-51 in spec homes. All cathedral ceilings are in spec homes with insulation levels ranging from R-21 to R-30. The prescriptive ceiling insulation requirement under both 2006 and 2009 IECC is R-38. One-third (33%) of flat ceilings in custom homes and 18% in spec homes have R-38 or higher insulation. No cathedral ceilings are insulated to R-38; the highest insulation level recorded is R-30. However, the code allows R-30 insulation for 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 compliance, 67% of homes with cathedral ceilings have no more than 500 square feet insulated to R-30. Twelve homes have both flat and cathedral ceiling areas. Not shown in Table 5-4, 20% of homes have all flat ceiling areas insulated to at least R-38 and no more than 500 square feet of cathedral ceiling area insulated to R30.; 33% of custom homes and 16% of spec homes.

Table 5-4: Ceiling Insulation Statistics and Compliance

Ceiling Insulation R-value Statistics	Flat Ceilings All Homes (n=50)	Flat Ceilings Custom Homes (n=12)	Flat Ceilings Spec Homes (n=38)	Cathedral Ceilings Spec Homes (n=12)
Minimum R-value	12.0	24.0	12.0	21.0
Maximum R-value	60.0	60.0	51.0	30.0
Average R-value	32.0	34.5	31.2	28.8
Median R-value	30.0	31.5	30.0	30.0
Comparison to 2006 & 2009 IECC Prescriptive Requirement of R-38 in Flat Ceilings and R-30 in not more than 500 Square Feet of Cathedral Ceiling Area				
Less than R-38 and/or more than 500 sq. ft. R-30 Cathedral Ceiling	78%	67%	82%	33%
R-38 Flat & not more than 500 sq. ft. R-30 Cathedral	18%	25%	16%	67%
More than R-38	4%	8%	3%	0%

Figure 5-2 graphs the individual recorded flat ceiling insulation R-values for all 50 inspected homes.

Figure 5-2: Recorded Flat Ceiling Insulation R-values



5.3 Floor Insulation

Auditors recorded data on floor insulation between conditioned spaces and unconditioned basements, garages and the outside. Table 5-5 shows that most inspected homes (46 out of 50 homes) have conditioned space over unconditioned basement space.

Table 5-5: Floor Characteristics

Floor Location →	Conditioned/ Basement (n=46)	Conditioned/ Garage (n=18)	Conditioned/ Outside (n=8)
Average Reported R-value	21.0	24.0	21.8
Framing			
2x8 16" On Center	11%	6%	0%
2x10 16" On Center	61%	50%	63%
2x12 16" On Center	15%	33%	25%
2x12 19" On Center	2%	6%	0%
2x12 24" On Center	2%	6%	13%
Truss	9%	0%	0%
Insulation Visibility and Installation Grade			
Insulation Visible	93%	22%	13%
Grade 1 Installation	2%	0%	0%
Grade 2 Installation	39%	33%	25%
Grade 3 Installation	52%	67%	75%
Type of Insulation			
Fiberglass Batt Insulation	93%	100%	100%
No Insulation	7%	0%	0%

Auditors were able to visually verify floor insulation or the lack of insulation for 93% of floors over unconditioned basement space, 22% of floors over garages, and 13% of floors over outside air. While floors over unconditioned basements should be insulated, they are not insulated in

three homes; in all other homes the floors are insulated with fiberglass batts. Only 18 homes have conditioned space over an unheated garage and 8 homes have conditioned space over outside air; in all cases these floors are insulated with fiberglass batts. The average level of floor insulation is R-21.0 over unconditioned basements, R-24.0 over garages, and R-21.8 over outside air. Only one home received a Grade I for insulation installation; this is a spec home with R-19 fiberglass batt insulation in the floor over a full unconditioned basement.

Table 5-6 shows that floor insulation levels range from no insulation to R-30 in floors over conditioned basements and from R-19.0 to R-30.0 in floors over garages and outside air. 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. Only 28% of homes with floors over unconditioned basements, 44% of homes with floors over garages, and 25% of homes with floors over outside air have floors insulated to R-30.

Table 5-6: Floor Insulation Statistics

Floor Insulation R-value Statistics	Conditioned/ Basement (n=46)	Conditioned/ Garage (n=18)	Conditioned/ Outside (n=8)
Minimum R-value	0.0	19.0	19.0
Maximum R-value	30.0	30.0	30.0
Average R-value	21.0	24.0	21.8
Median R-value	19.0	20.0	19.0
Comparison to 2006 & 2009 IECC Prescriptive Requirement of R-30 or Filled Cavity (min R-19)			
Less than R-30	72%	56%	75%
R-30	28%	44%	25%
More than R-30	0%	0%	0%

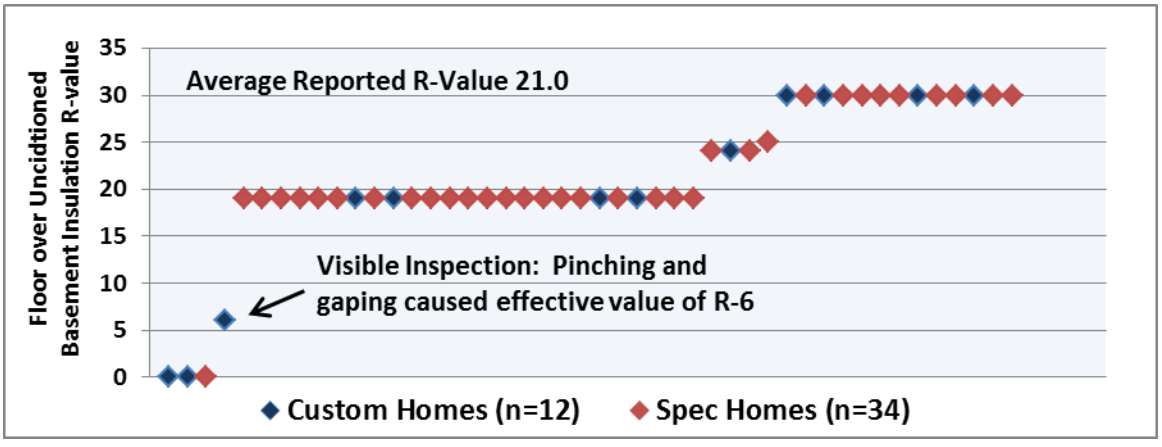
Table 5-7 shows that custom homes were more likely than spec homes to have R-30 insulation in floors over unconditioned basement space; 28% of all homes with floors over unconditioned basement space, 33% of custom homes and 26% of spec homes.

Table 5-7: Floors over Unconditioned Basements

Insulation R-value Statistics Floors over Unconditioned Basements	All Homes (n=46)	Custom Homes (n=12)	Spec Homes (n=34)
Minimum R-value	0.0	0.0	0.0
Maximum R-value	30.0	30.0	30.0
Average R-value	21.0	18.8	21.8
Median R-value	19.0	19.0	19.0
Comparison to 2006 & 2009 IECC Prescriptive Requirement of R-30 or Filled Cavity (min R-19)			
Less than R-30	72%	67%	74%
R-30	28%	33%	26%
More than R-30	0%	0%	0%

Figure 5-3 graphs the individual recorded R-values for floor insulation over unconditioned basements.

Figure 5-3: Recorded Floor over Unconditioned Basement Insulation R-values



5.4 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.[14] Documented U-value and SHGC information was available for only two homes. 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 manufacturers' web sites indicate the windows in both homes are Low-E with argon.

When homeowners could not provide information on the type of glazing in their windows, auditors used either a lighter test or a Low-E coating detector to determine if the windows were Low-E.[15] If the homeowner did not know if their windows had argon fill, auditors did not test for it and did not try to guess whether or not the windows had argon fill. Therefore, it is likely that some of the homes reported as having Low-E windows have Low-E with argon windows.

REM/Rate and IECC default values for U-value and SHGC are shown in Table 5-8. REM/Rate defaults are more detailed—addressing more window categories—than IECC defaults.[16] However, both appear to be conservative. For example, the verified U-value of the double pane, Low-E with argon, vinyl framed windows in the two inspected homes where the U-value could be documented is 0.31, which is more energy efficient than the REM/Rate default of U-0.33.

Table 5-8: REM/Rate and IECC Default Values for Missing Window Data

Operable Window Type	REM/Rate Defaults		2006 & 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		

[14] 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.

[15] 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.

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

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 Massachusetts or New England market for new construction windows was, the Andersen representative estimated 13% of the Massachusetts market (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.[17] However, this is changing, especially in Stretch Code towns. So, we have seen the jaws drop on builders when they see the cost increase. We have also seen builders order non-ENERGY STAR-rated windows in Stretch Code towns and then be forced to purchase new windows or somehow get around the code; there is a fair amount of confusion still out there. 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."

Additionally, we know that window U-values in 2010 ENERGY STAR-qualified housing units ranged from 0.17 to 0.47 and averaged 0.34.[18] 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 5-9), we propose an overall default window U-value of 0.34. A U-0.34 window is representative of what builders in the Massachusetts Program installed last year, 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.

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

[18] Dorothy Conant, Consultant. *The Massachusetts New Homes with ENERGY STAR® Program 2010 Progress Report: Final Report*, submitted to the Joint Management Committee, September 2011. (p 34)

Table 5-9: Version 5.0 Northern Climate ENERGY STAR Window Criteria

Northern Climate ENERGY STAR Window Criteria as of January 4, 2010[19]			
U-Factor	≤ 0.30	= 0.31	= 0.32
SHGC	Any	≥ 0.35	≥ 0.40

5.4.1 Window Types

Table 5-10 shows the percentages of homes with various windows types. As shown, the most predominant window type is double pane Low-E vinyl framed (60%) followed by double pane clear glass vinyl framed (20%). Only four homes (8%) have verified double pane Low-E with argon windows and only one home has windows with fiberglass frames. As described earlier, the auditors tested for Low-E glass, but not for argon fill. The percentage of homes with argon-filled windows is likely higher than 8%.

Table 5-10: Inspected Homes by Type of Window

Predominant Window Type	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Double Pane Low-E Vinyl Frame	60%	58%	61%
Double Pane Vinyl Frame	20%	17%	21%
Double Pane Low-E Wood Frame	10%	8%	11%
Double Pane Low-E Argon Vinyl Frame	8%	8%	8%
Double Pane Low-E Fiberglass Frame	2%	8%	0%

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

5.4.2 Glazing Percentage

Table 5-11 and Figure 5-4 provide statistics on glazing percentage. Glazing percentages are window areas as a percentage of conditioned/ambient wall area. As shown, glazing percentages range from 8% to 31%; the average is 16% and the median is 14%. Average and median percent glazing are higher in custom homes than in spec homes; average percent glazing for custom homes is 18% and 15% for spec homes; median percent glazing is 19% for custom homes and 14% for spec homes.

Table 5-11: Window Glazing Percentage Statistics

Percent Glazing Percent of Conditioned/Ambient Wall Area	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum	8%	8%	8%
Maximum	31%	31%	25%
Average	16%	18%	15%
Median	14%	19%	14%

Figure 5-4 shows glazing percentage by home.

Figure 5-4: Glazing Percentage by Home

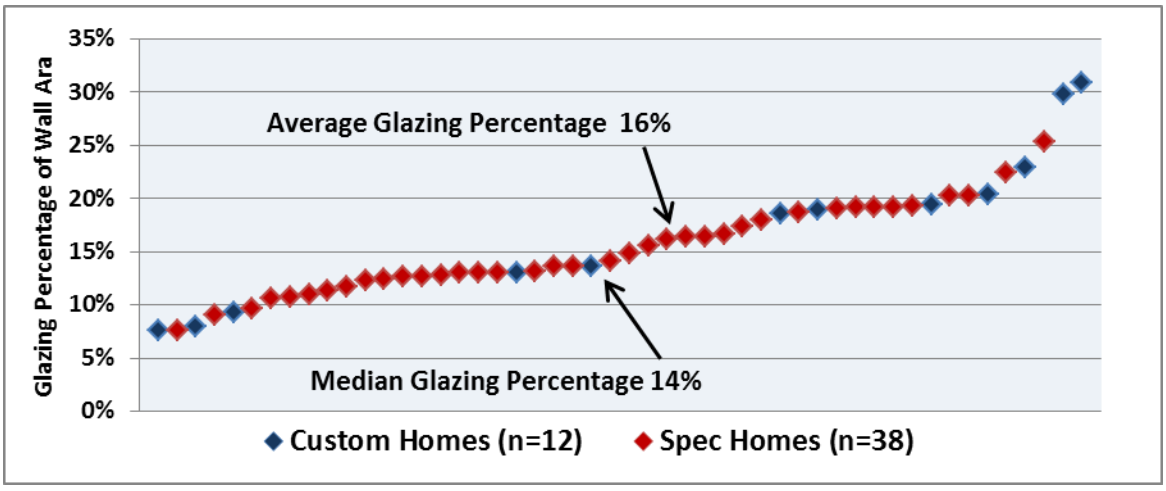


Table 5-12 shows the percent of south-oriented glazing. The percent of glazing oriented to the south ranges from zero to 67%; the average over all 50 homes is 38% and the median is 44%. The average percent of south oriented glazing is similar for custom (36%) and spec (38%) homes, but the median is much lower for custom homes (33%) than spec homes (45%).

Table 5-12: Percent of South Oriented Glazing

Percent of Exterior Wall South Glazing (S, SE, SW)	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum	0%	7%	0%
Maximum	67%	65%	67%
Average	38%	36%	38%
Median	44%	33%	45%

5.4.3 Skylights

Only six of the fifty homes had 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 estimate that three of the six skylights are double pane Low-E argon filled, two are double pane Low-E, and one is a standard double pane with no Low-E glaze or insulating gas.

5.5 Doors

Auditors recorded information on 167 doors in the 50 sampled homes. They were able to record the door material and whether or not the door was insulated for 165 of the 167 doors. Note that auditors only recorded information on doors that were part of the thermal boundary; they did not record information on interior doors. Table 5-13 displays the distribution of the types of doors observed. The majority of the doors (73%) are insulated steel or fiberglass. A little more than one quarter of the doors (26%) are wood.

Table 5-13: Type of Door

Door Type	Doors (n=165)*
Steel Insulated	37%
Fiberglass Insulated	36%
Wood Uninsulated	19%
Wood Insulated	7%

* Values may not total 100% due to rounding.

Table 5-14 shows the percentage of doors with various characteristics. Most doors are insulated (81%), few have storm doors (4%), and just over one third of the doors (35%) contain glass. The average glass area in doors with glass is 10 square feet. Most of the doors with glass (80%) have either double pane clear (61%) or double pane Low-E (19%) glass. A few doors have single pane (7%) or double pane Low-E argon (4%) glass. One door has decorative/foggy glass (2%).

Table 5-14: Door Characteristics

Door Characteristics	Percent of Doors (n=165)
Insulated	81%
Storm Door	4%
Glass in Door	35%
Doors with Glass (n=57)	
Avg. Sq. Ft. of Glass/Door	10*
Double Pane (clear)	61%
Double Pane Low-E	19%
Single Pane	7%
Double Pane Low-E Argon	4%
Decorative Glass/Foggy	2%
Unknown	7%

* Data on the Sq. Ft. of Glass were available for 56 of the 57 doors with glass.

5.6 Slab Insulation

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. Auditors were instructed to collect slab data for homes with conditioned basements; 18 of the 50 audited homes have conditioned basements. Table 5-15 displays the slab location for these 18 homes with conditioned basements. The majority of the homes have either below grade slabs (50%) or slabs that are a mix of on and below grade (39%); 11% have on grade slabs.

Table 5-15: Slab Floor Location

Slab Floor Location	Percent of Homes with Conditioned Basements (n=18)
Below Grade	50%
Mix (on/below grade)	39%
On Grade	11%

5.7 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. Of the 18 homes with conditioned basement space, 15 are spec homes and three are custom homes. The walls are typically finished (i.e. sheet rocked) in conditioned basements; therefore, the foundation wall insulation is not usually visible. Auditors were able to visually confirm the foundation wall insulation in eight homes, and estimated the foundation insulation characteristics in the other homes based on insulation they had visually confirmed in another area of the home. Table 5-16 displays the types of foundation wall insulation auditors recorded for these 18 homes. Please note this section only represents insulation that is in contact with the masonry foundation walls.[20] Nearly all (17) of the homes have interior, fiberglass batt insulation in the foundation walls. Exterior, rigid foam insulation was observed by auditors at one home.

Table 5-16: Type of Foundation Wall Insulation

Foundation Wall Insulation Type	All Homes (n=18)	Custom Homes (n=3)	Spec Homes (n=15)
% Insulation Visible	44%	33%	47%
Interior Fiberglass Batts	94%	100%	93%
Exterior Rigid Foam	6%	0%	7%

[20] 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 5.1Wall Insulation

The average insulation level for all 18 homes with conditioned basement space bounded by foundation walls is R-15.6. Again, please note that this section is only reporting on insulation that is in contact with the foundation walls, not insulation that is in wood-framed stud walls on top of masonry foundation walls. As shown in Table 5-17, the average insulation level is R-15.8 for spec homes and R-14.3 for custom homes. 2006 and 2009 IECC prescriptive code requirements for foundation wall insulation are the same: minimum R-10 for continuous insulation and R-13 for cavity insulation. Almost three-fourths (72%) of the homes met or exceeded the 2006 IECC and 2009 prescriptive compliance path requirement; 28% failed the prescriptive compliance path requirement—one custom home and four spec homes.

Table 5-17: Foundation Wall Statistics

Foundation Wall Insulation Level	All Homes (n=18)	Custom Homes (n=3)	Spec Homes (n=15)
Minimum R-value	7	11.0	7
Maximum R-value	19.0	19.0	19.0
Average R-value	15.6	14.3	15.8
Median R-value	19.0	13.0	19.0
Installation Grade			
Grade 1 Installation	0%	0%	0%
Grade 2 Installation	67%	0%	73%
Grade 3 Installation	33%	100%	27%
Comparison to 2009 IECC Prescriptive Requirement of R-10/13			
Less than R-10/13	28%	33%	27%
R-10/13	17%	33%	13%
More than R-10/13	56%	33%	60%

* Values may not total 100% due to rounding.

5.8 Rim and Band Joist Insulation

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). 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.[21] 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.

[21] Given the nature of new construction this was always the case. Band joists were always assumed to be the same insulation and grade as the above grade conditioned/ambient walls.

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.

Table 5-18 displays a summary of the rim and band joist insulation characteristics recorded during the on-site visits. The average R-value ranges from R-7.6 to R-17.5, depending on the location of the joists. 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-17.5, the majority is spaced 16 inches apart (91%), and there is a slightly higher rate of Grade II installation (49%) than Grade III installation (42%).

Table 5-18: Summary of Rim/Band Joist Insulation

Rim/Band Joist Location →	Cond/ Ambient (n=46)*	Cond/ Garage (n=8)	Cond/ Attic (n=1)	Uncond Basement/ Ambient (n=5)*	Adiabatic (n=4)	Uncond Basement /Garage (n=1)
Average R-value	17.5	15.5	13	7.6	17.5	0
Joist 16" On Center	91%	75%	100%	100%	100%	100%
Joist 19" On Center	2%	13%	0%	0%	0%	0%
Joist 24" On Center	7%**	13%	0%	0%	0%	0%
Installation Grade						
Grade I Installation	9%	0%	0%	50%	25%	0%
Grade II Installation	49%	38%	100%	0%	25%	0%
Grade III Installation	42%	63%	0%	50%	50%	0%
Type of Insulation						
% Fiberglass Batt	96%***	100%	100%	0%****	100%	0%

* In four homes there was at least one location where the rim/band joist was uninsulated. Installation grade percentages are based on insulated rim/band joists.
** Two homes had a truss floor system. The truss bays were spaced 24" on center.
*** Two homes were not classified as having fiberglass batt insulation: one was a log cabin (6" logs) and the other had a flash and batt system in the rim/band joist that consisted of 2" of closed cell spray foam in addition to an R-13 fiberglass batt.
**** Three out of the five homes with Unconditioned Basement/Ambient joists did not have any insulation; one had blown-in fiberglass installed, and the other had the aforementioned flash and batt system.

As previously mentioned, conditioned/ambient rim and band joist insulation is the most prevalent, and as such is the most important in terms of overall building efficiency. Among all homes, conditioned/ambient rim and band joists have R-values ranging from R-0 (uninsulated) to R-25. Custom homes have a slightly higher average R-value (18.5) than spec homes (17.3) (Table 5-19).

Table 5-19: Conditioned/Ambient Rim/Band Joist Insulation—Spec vs. Custom

Conditioned/Ambient Rim/Band Joist R-values	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum R-value	0	12	0
Maximum R-value	25	21	25
Average R-value	17.5	18.5	17.3
Median R-value	19	19	19

5.9 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 two homes that met the criteria. For both of these sunspaces the only insulated boundary is the common wall between the house and the sunspace. One is insulated with R-13 fiberglass batts and the other R-19 fiberglass batts. All other boundaries of the sunspaces are uninsulated (i.e. exterior walls, frame floor, and ceiling). One home has double pane Low-E windows in the sunspace while the other has flexible clear vinyl windows.[22]

[22] These windows are comparable to those found in a convertible car.

6 Mechanicals

6.1 Heating Systems

Most inspected homes have natural gas heating systems, most have furnaces, and most heating systems are installed in unconditioned space. Figure 6-1, Figure 6-2, and Figure 6-3 show, respectively, the primary heating fuels, types of heating systems and where the heating systems are located. Figure 6-1 shows that most homes have natural gas heating systems; 58% of both custom and spec homes. Custom homes are less likely than spec homes to have propane or oil heating systems and more likely to have an electric ground source heat pump.

Figure 6-1: Primary Heating Fuel

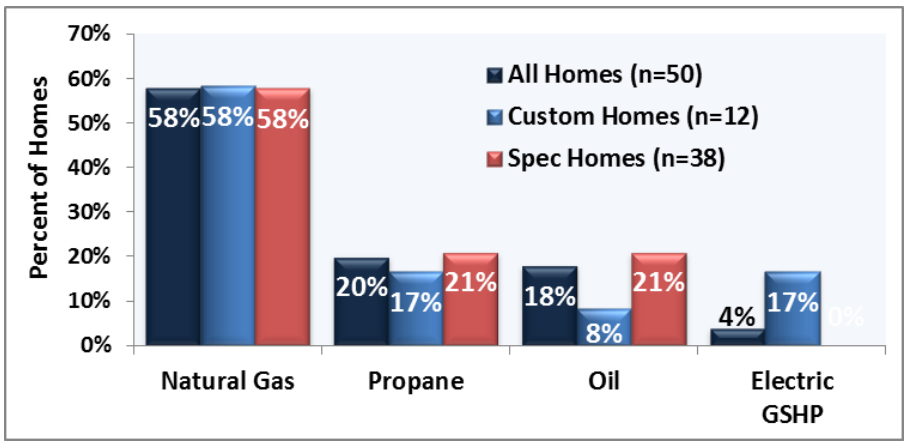


Figure 6-2 shows the majority of homes (74%) have furnace heating systems. Custom homes are less likely than spec homes to have a furnace and more likely to have a boiler or ground source heat pump (GSHP). Only two homes, both custom homes, have GSHP systems. One GSHP is an ENERGY STAR 4.3 Coefficient of Performance (COP) and 22.2 Energy Efficiency Ratio (EER) open loop air-to-water system. Efficiency information for the other GSHP was unavailable because it was being replaced due to problems.

Figure 6-2: Heating System Type

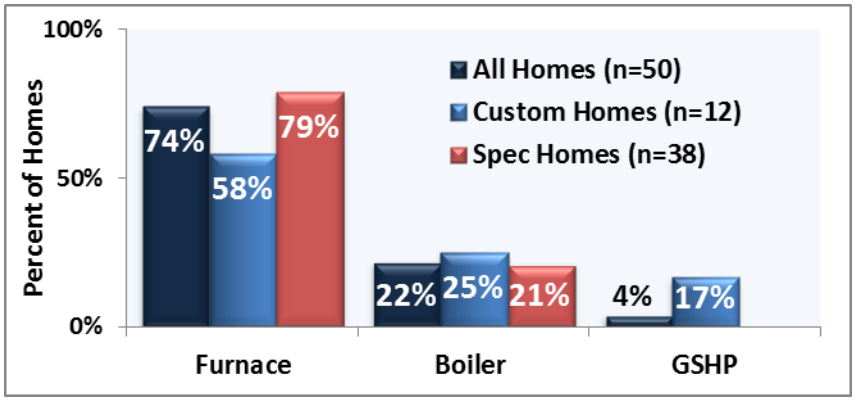
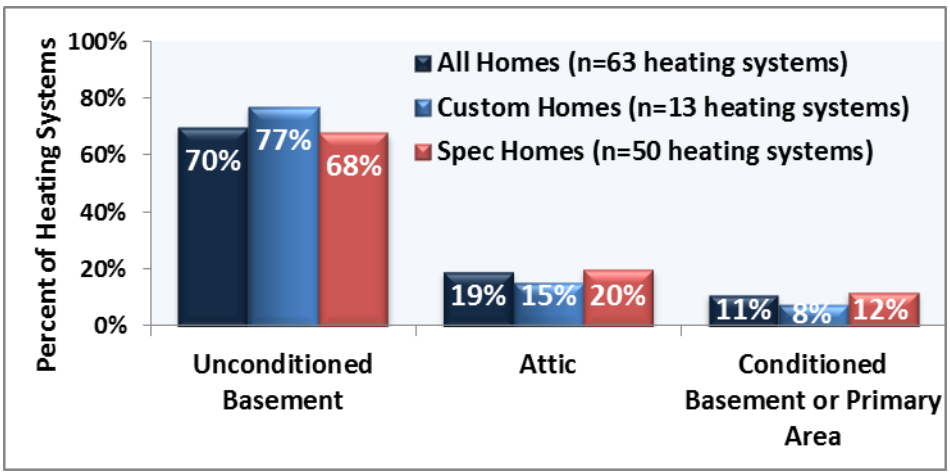


Figure 6-3 shows the majority of heating systems (70%) are located in unconditioned basements. Custom homes are somewhat more likely than spec homes to have heating systems located in unconditioned basements and less likely in the attic or conditioned space. All of the heating systems installed in attics are gas furnaces 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.

Figure 6-3: Heating System Location



There are several ways to group heating systems to compare efficiencies. Table 6-1 shows the annual fuel utilization efficiency (AFUE) statistics for all gas furnaces (natural gas and propane), gas furnaces not located in attics, gas boilers, oil furnaces and oil boilers. All gas furnaces not located in attics, all gas boilers and all oil boilers meet ENERGY STAR-qualification criteria. None of the oil furnaces are ENERGY STAR qualified (AFUE of 85% or higher).

Table 6-1: Furnace and Boiler Efficiencies

Heating System Efficiency Statistics	Gas Furnaces (n=47)	Non-Attic Gas Furnaces (n=35)	Gas Boilers (n=5)	Oil Furnaces (n=3)	Oil Boilers (n=6)
Minimum AFUE	80.0%	91.7%	85.0%	80.0%	85.0%
Maximum AFUE	95.5%	95.5%	96.0%	83.0%	86.9%
Average AFUE	91.3%	93.6%	91.1%	81.0%	85.7%
Median AFUE	92.3%	92.6%	93.1%	80.0%	85.2%

Table 6-2 compares the efficiencies of heating systems in custom and spec homes. As shown, the average efficiency of gas furnaces and boilers is higher for custom homes. No custom homes have oil boilers and the lowest efficiency oil furnace is in a custom home.

Table 6-2: Furnace and Boiler Efficiencies in Custom and Spec Homes

Average Heating System Efficiency (AFUE)	All Homes	Custom Homes	Spec Homes
Gas Furnaces (n=47; 7 custom, 40 spec)	91.3%	92.7%	91.1%
Non-Attic Gas Furnaces (n=35; 5 custom, 30 spec)	93.6%	94.6%	93.4%
Gas Boilers (n=5; 3 custom, 2 spec)	91.1%	95.0%	85.3%
Oil Furnaces (n=3; 1 custom, 2 spec)	81.0%	80.0%	81.5%
Oil Boilers (n= 6 spec homes))	85.7%	None	85.7%

UDRH inputs group heating systems by fuel and type of distribution system. Table 6-3 shows that all of the natural gas hydronic distribution, propane air distribution, and oil hydronic distribution heating systems in inspected homes are ENERGY STAR qualified.[23] Propane air distribution systems have the highest average and median AFUE. Oil heating systems have the lowest average and median AFUE.

Table 6-3: Heating System Efficiencies by Fuel and Distribution System

Heating System Efficiency Statistics	Natural Gas Air Distribution (n=36)	Natural Gas Hydronic Distribution (n=4)	Propane Air Distribution (n=12)	Oil Air Distribution (n=4)	Oil Hydronic Distribution (n=5)
Min AFUE	80%	85%	92%	80%	85%
Max AFUE	96%	96%	96%	87%	87%
Average AFUE	91%	90%	94%	82%	85%
Median AFUE	92%	89%	94%	82%	85%

Not included in Table 6-3 are two homes with ground source heat pumps. One of these homes has a 4.3 COP 22.2 EER ENERGY STAR ground source heat pump. The other home had a ground source heat pump installed but there were problems with the system and it was being replaced—there was no system at the home at the time of the audit, so auditors were unable to record efficiency or capacity information.

[23] ENERGY STAR criteria for furnaces and boilers are:

- Gas Furnaces—90% AFUE or greater
- Oil Furnaces—85% AFUE or greater
- Boilers—85% AFUE or greater

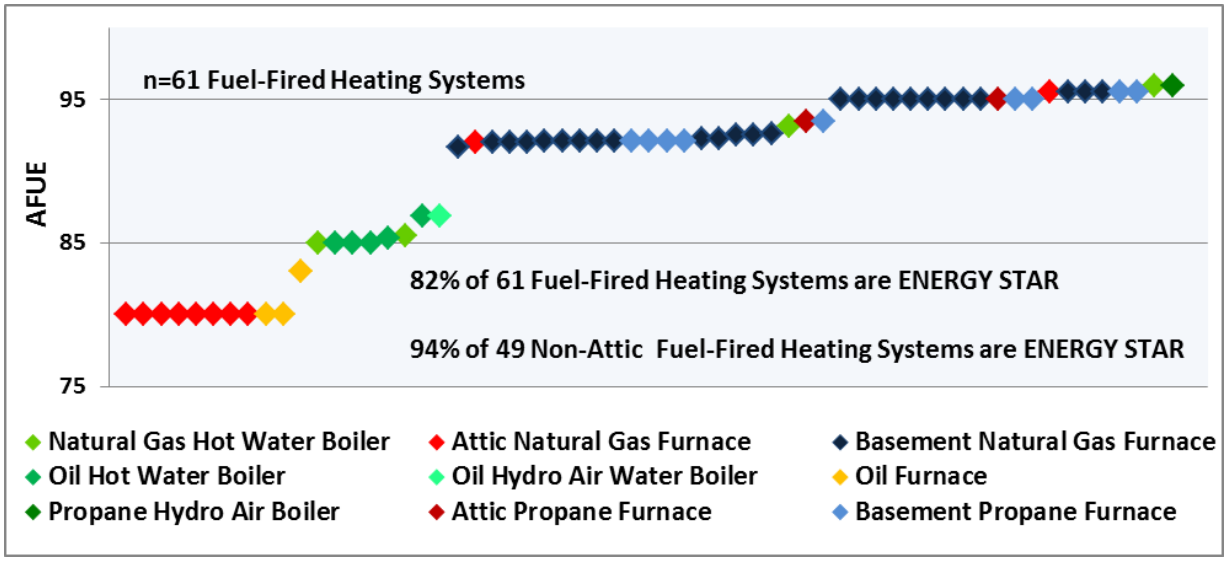
Table 6-4 shows the same information provided in Table 6-3 except that it includes current UDRH heating system AFUE inputs and separates out heating systems not located in attics. As discussed earlier, some builders are not comfortable installing high-efficiency condensing furnaces in attics. As shown, the average efficiencies for all types of heating systems in inspected homes, except oil air distribution systems, are higher than current UDRH inputs. The average AFUE of natural gas air distribution systems in inspected homes changes from 90.5% for all 36 natural gas air distribution systems to 93.6% for the 27 systems not located in attics.

Table 6-4: UDRH and Heating System Efficiencies by Location

Heating System Categories in UDRH	JMC 2011 UDRH Heating System AFUE	61 Fuel Fired Heating Systems in 48 Homes		50 Fuel Fired Heating Systems in 48 Homes not Including Second Systems in Attics	
		Number of Heating Systems	Average AFUE	Number of Heating Systems	Average AFUE
Natural Gas Air Distribution	89.2%	36	90.5%	27	93.6%
Natural Gas Hydronic Distribution	81.7%	4	89.9%	4	89.9%
Propane Air Distribution	89.2%	12	94.0%	10	93.9%
Propane Hydronic Distribution	81.7%	None in Inspected Homes			
Oil Air Distribution	83.9%	4	82.5%	4	82.5%
Oil Hydronic Distribution	84.4%	5	85.4%	5	85.4%

Figure 6-4 graphs the heating system efficiencies for the 61 gas and oil heating systems observed in inspected homes. The least efficient heating systems are natural gas furnaces installed in attics and oil furnaces. The most efficient heating systems include a variety of system types: basement natural gas furnaces, basement propane furnaces, a natural gas and a propane boiler.

Figure 6-4: Heating System Efficiencies by Type of System



6.1.1 Heating System Capacity

Figure 6-5 graphs heating system British thermal units per hour (Btuh) output per square foot of conditioned space for 49[24] inspected homes with heating system output capacity data and Table 6-5 provides statistics on heating system Btuh per square foot. As shown, output capacity per square foot of conditioned space varies wildly, suggesting many homes have oversized heating systems. Output capacity Btuh per square foot ranges from 20 to 102; 20 to 57 in custom homes and 21 to 102 in spec homes. The average and median Btuh per square foot are almost the same for custom homes and spec homes; both the average and median Btuh in custom homes is 41 while the average in spec homes is 43 and the median is 39. Overall, these results are lower than what was observed in the 2005 Baseline Study. In the 2005 study, output capacity Btuh per square foot of conditioned space ranged from 16 to 118 and the average was 54.

Figure 6-5: Heating System Btuh per Square Foot of Conditioned Space

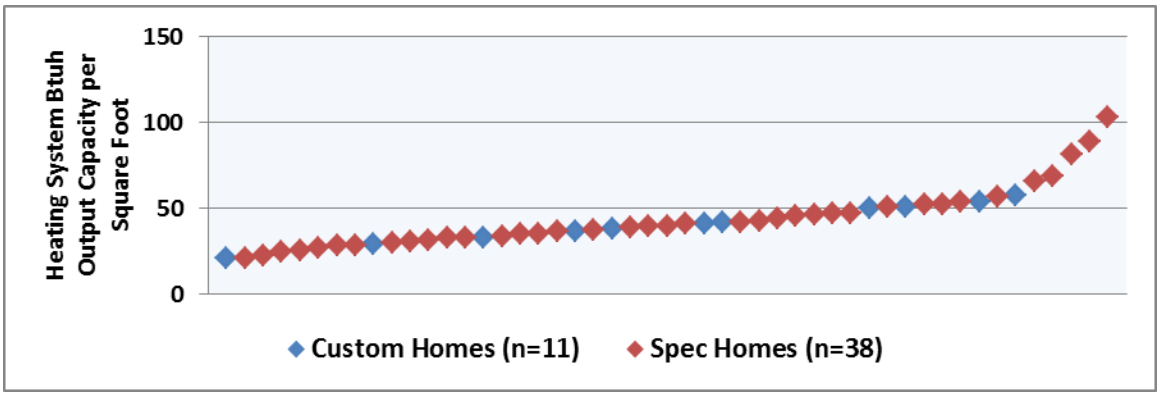


Table 6-5: Heating System Btuh per Square Foot Statistics

Heating System Output Capacity (Btuh) per Square Foot Conditioned Floor Area	All Homes (n=49)	Custom Homes (n=11)	Spec Homes (n=38)
Minimum	20	20	21
Maximum	102	57	102
Average	43	41	43
Median	39	41	39

[24] One home had a ground source heat pump that had problems and was being changed out. The system was not at the home when the inspection was done and no information on the efficiency or capacity was available.

6.1.2 Supplemental Heat Sources

Just over two-thirds (68%) of inspected homes have a fireplace or stove. Only two homes have electric portable space heaters. Custom homes are more likely to have a stove or fireplace; 11 of the 12 custom homes inspected have a fireplace or stove. Three of the inspected homes have more than one fireplace or stove; one custom home and one spec home each have two natural gas fireplaces or stoves and one custom home has three. Table 6-6 shows the percentages of natural gas, wood, propane, and pellet fireplaces and stoves. As shown, most are fueled by natural gas (56%), wood (24%), or propane (18%); only 3% are pellet stoves. Eight homes have wood burning fireplaces; five have gasketed doors and an outdoor air supply and three do not.

Table 6-6: Fireplace and Stove Fuel

Fireplace or Stove Fuel	All Homes (n=34)	Custom Homes (n=11)	Spec Homes (n=23)
Natural Gas	56%	45%	61%
Wood	24%	27%	22%
Propane	18%	18%	17%
Pellet	3%	9%	0%

6.2 Water Heating

Most inspected homes have conventional storage tank water heating systems. Figure 6-6 shows that roughly two-thirds (67%) of homes have conventional stand-alone water heating systems, 16% have indirect or integrated tank systems that use the home's boiler heating system to heat water, 12% have instantaneous water heating systems, and 4% have boiler heating systems with tankless coil water heating. Custom homes are less likely than spec homes to have a conventional storage tank water heater and more likely to have an instantaneous water heating system. The percentages of custom and spec homes with integrated tank water heating systems are almost the same; 17% of custom homes and 16% of spec homes. No custom homes and only 5% of spec homes have tankless coil systems.

Figure 6-6: Water Heating Systems

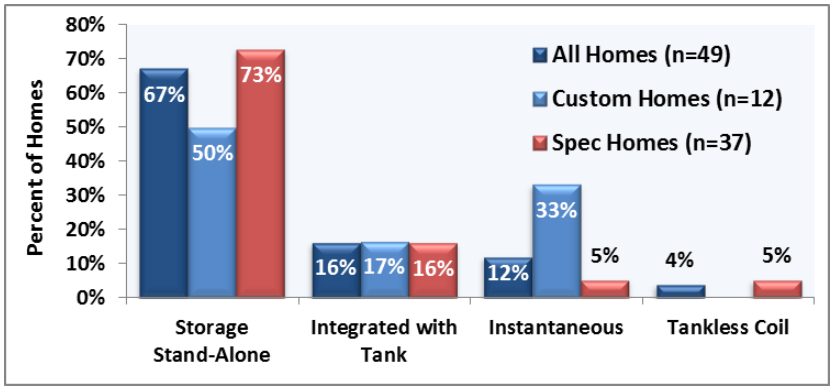
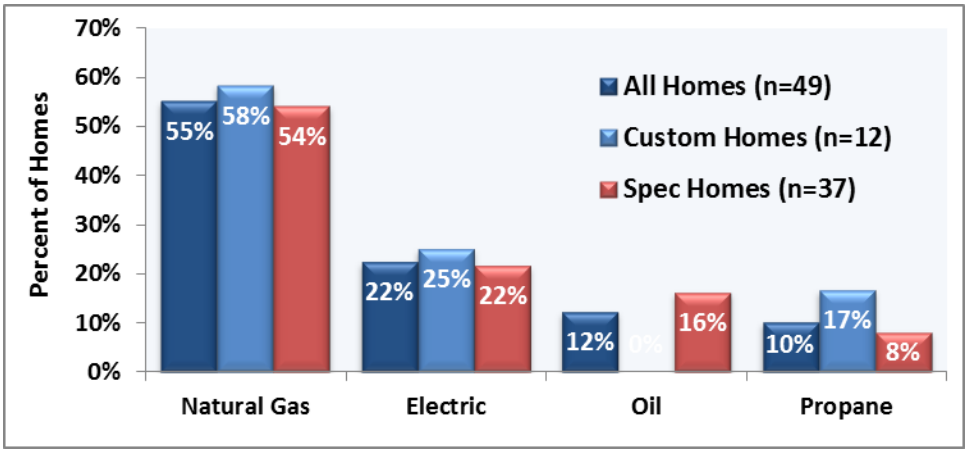


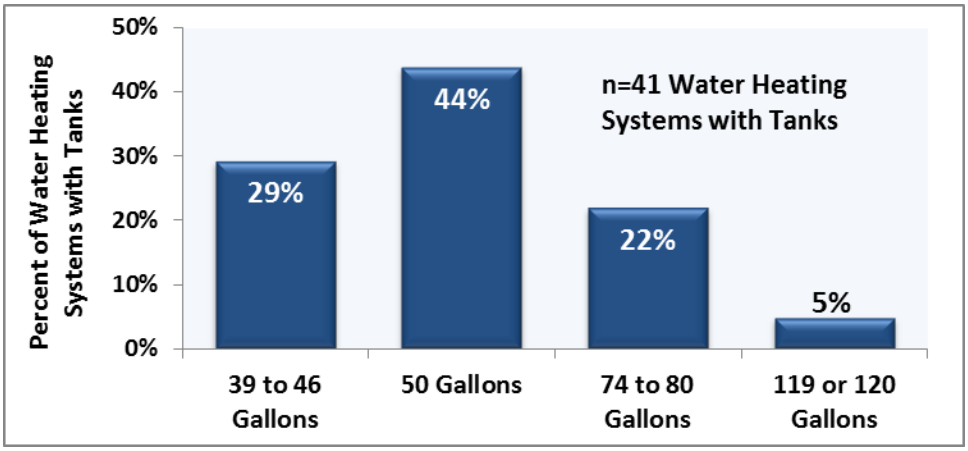
Figure 6-7 shows more than half of both custom and spec homes have natural gas water heating systems and approximately one-fourth have electric water heating systems. Custom homes are more likely than spec homes to have propane water heating systems; 17% of custom homes compared to 8% of spec homes. No custom homes, but 16% of spec homes, have oil water heating systems.

Figure 6-7: Water Heating Fuel



Most inspected homes (41 out of 50 homes) have water heating systems with storage tanks. Figure 6-8 shows that the most common tank size is 50 gallons. Over one-fourth of homes with water heater storage tanks (29%) have smaller than 50 gallon tanks and 27% have large 74 to 120 gallon tanks.

Figure 6-8: Water Heating Tank Size



Water heater Energy Factors vary widely depending on the type of water heating system. Table 6-7 shows that electric storage tank water heating systems have the highest Energy Factors and tankless coil systems the lowest. The average electric storage tank Energy Factor is 0.89 and the

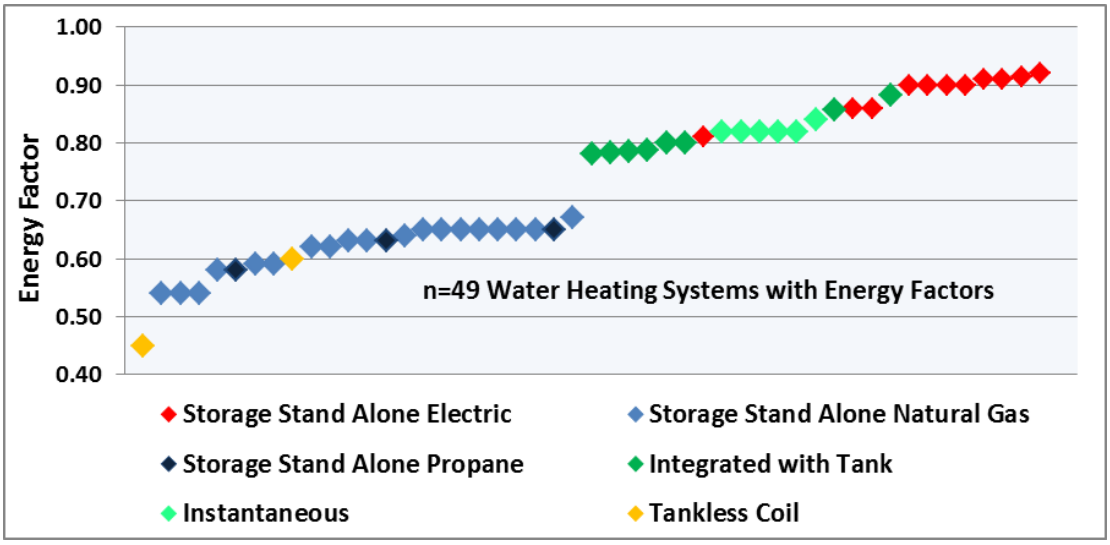
average tankless coil Energy Factor is 0.53.[25] The average Energy Factors of instantaneous and integrated tank systems are very close at 0.82 and 0.81, respectively. Energy Factors for integrated tank systems are calculated as 92% of the heating system AFUE. The average Energy Factor of natural gas and propane conventional storage tank systems, the most common type of system found in inspected homes, is 0.63 for systems with reported Energy factors. Energy Factors are not available for four large conventional storage tank water heating systems that are not FVIR (Flammable Vapor Ignition Resistant) construction[26]; including estimated Energy Factors for these four tanks using a RESNET calculation reduces the average Energy Factor to 0.62.

Table 6-7: Water Heating Energy Factor Statistics

Water Heating Energy Factor	Instantaneous Natural Gas & Propane (n=6 homes)	Integrated With Tank Natural Gas, Propane & Oil (n=8 homes)	Storage Stand Alone Electric (n=11 homes)	Storage Stand Alone Natural Gas & Propane (n=22 homes)	Tankless Coil Oil (n=2 homes)
Minimum	0.82	0.78	0.81	0.54	0.45
Maximum	0.84	0.88	0.92	0.67	0.60
Average	0.82	0.81	0.89	0.62	0.53
Median	0.82	0.79	0.90	0.63	0.53

Figure 6-9 shows water heating system Energy Factors by type of system.

Figure 6-9: Water Heater Energy Factors by Type of System



[25] Consistent with the NE-HERS manual, the Energy Factor for tankless coil water heating systems is estimated based on occupancy: 0.45 for three occupants, 0.50 for four occupants, .0.55 for five occupants, and 0.60 for six occupants.

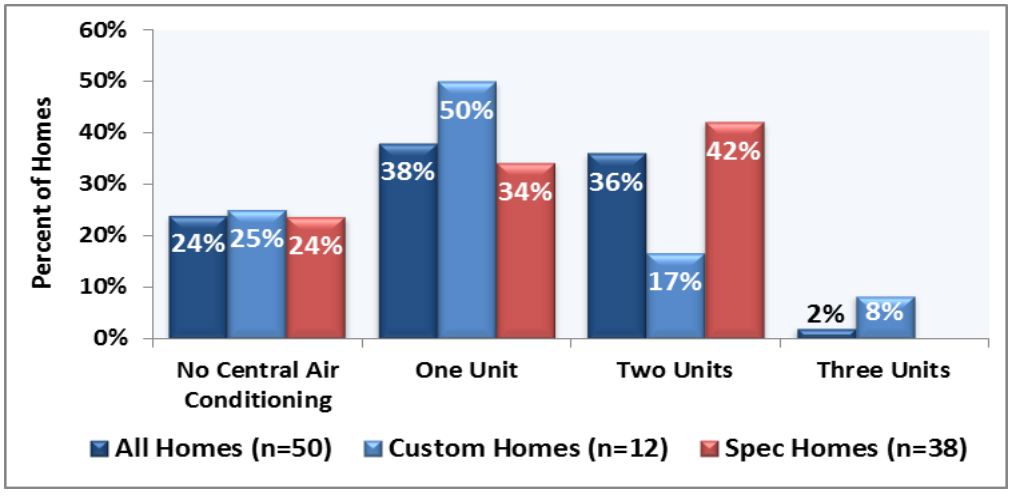
[26] Flammable Vapor Ignition Resistance is a technology developed for gas-fired water heaters that resists ignition of flammable vapors that may occur outside and in close proximity to a water heater as a result of the mishandling of flammable products. Source: http://www.bradfordwhite.com/fvirtech.asp

6.3 Cooling

When visiting homes, auditors gathered information on both central and window air conditioning units. Most of the inspected homes (76%) have central air conditioning—up from 63% in the 2005 Baseline Study—and another 6% of homes (three homes) have window air conditioning units. Auditors were unable to obtain efficiency information for the window units. Of the 38 homes with central air conditioning, 92% (35 homes) have 13 SEER systems. Two homes, one custom and one spec home, have 14.5 SEER split systems. The spec home, a 3,180 square foot home purchased as a finished home, has two 14.5 SEER/12 EER ENERGY STAR-qualified American Standard systems totaling 6.5 tons; the square feet per ton of air conditioning for this home is 489. The custom home, a 4,389 square foot home, has one 5 ton Bryant 14.5 SEER[27] split system; the square feet per ton of air conditioning for this home is 878. Another custom home, a 3,443 square foot home built by the owner, has one 5 ton Climate Master 22.2 EER/4.3 COP ENERGY STAR-qualified open loop water-to-air ground source heat pump; the square feet per ton of air conditioning for this home is 689.

Figure 6-10 shows the number of central air conditioning units per home. As shown, 24% of inspected homes do not have central air conditioning, 38% of homes have one central air conditioning unit, 36% have two units, and 2% (one custom home) has three units. In general, custom homes are much more likely than spec homes to have only one central air conditioning unit and much less likely to have two units.

Figure 6-10: Number of Central Air Conditioning Units per Home



[27] This system may be ENERGY STAR qualified. The auditor did not record the indoor unit model number and the SEER and EER vary depending on the indoor and outdoor unit combination; several, but not all, combinations meet ENERGY STAR-qualification criteria of 14.5 SEER/12 EER for split systems.

Total tons of air conditioning installed per home range from 2.5 to 9.5 tons. Table 6-8 shows the average for all homes is 4.5 tons; 4.9 tons for custom homes and 4.3 tons for spec homes.

Table 6-8: Central Air Conditioning Tons per Home

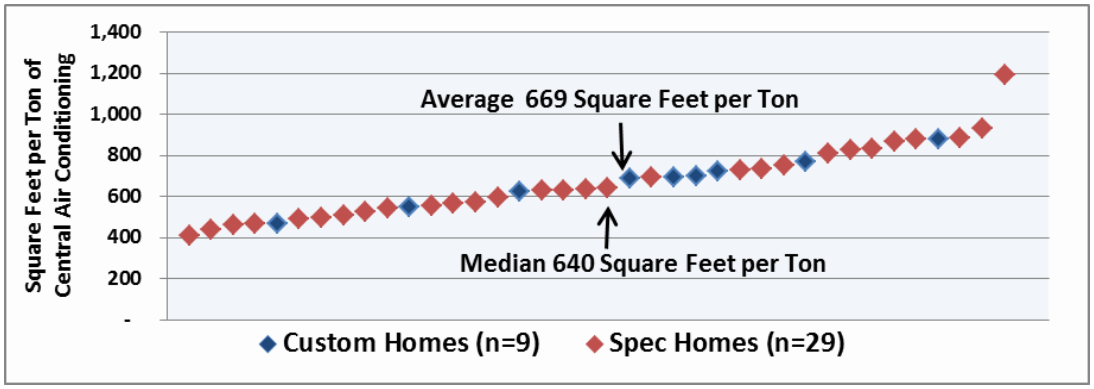
Central Air Conditioning Tons per Home	All Homes (n=38)	Custom Homes (n=9)	Spec Homes (n=29)
Minimum	2.5	2.5	2.5
Maximum	9.5	9.5	8.0
Average	4.5	4.9	4.3
Median	4.0	5.0	4.0

Table 6-9 shows square feet of conditioned floor area per ton of central air conditioning and Figure 6-11 graphs square feet of conditioned space per ton of cooling for the 38 homes with central air conditioning. As shown, values range from 414 to 1,190 square feet per ton of central air conditioning; this is smaller than the range found in the 2005 Baseline Study—300 to 1,459 square feet per ton. Average square feet per ton is similar for custom and spec homes inspected in this year's study; the average is 678 square feet per ton for custom homes and 666 for spec homes. The overall average square feet per ton is 669, which is higher than the overall average of 618 square feet found in the 2005 Baseline Study. In any case, the wide range of square feet per ton suggests that many cooling systems are not properly sized.

Table 6-9: Square Feet of Conditioned Space per Ton of Central Air Conditioning

Square Feet per Ton of Central Air Conditioning	ALL HOMES (n=38)	Custom Homes (n=9)	Spec Homes (n-29)
Minimum	414	470	414
Maximum	1,190	878	1,190
Average	669	678	666
Median	640	696	630

Figure 6-11: Square Feet of Conditioned Floor Area per Ton of Central Air Conditioning



6.4 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 two of the audited homes have mechanical ventilation; one home has a bathroom fan on a timer and the other has a bathroom fan that is continuously exhausting. Both of these are exhaust-only systems.

Including the two homes with mechanical ventilation, 49 out of the 50 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, among the 49 homes with bathroom fans, auditors counted 122 exhaust-only fans, ranging from one to five fans per home.

Auditors were only able to verify the exhaust rate for bathroom fans in one home. This home has four bathrooms fans, all exhausting at a rate of 50 CFM. In general, bathroom fan exhaust rates range from 50 CFM to 150 CFM.

7 Ducts

7.1 Mandatory Duct Insulation Requirements

Under 2006 IECC and the seventh edition of the Massachusetts building code, it is a mandatory requirement that ducts located in unconditioned space have a minimum of R-8 insulation. During the 50 site visits at non-ENERGY STAR homes, NMR and KEMA raters rarely identified R-8 insulation on ducts; only 10% of the 39 home with ducts in unconditioned space met 2006 IECC duct insulation requirements.

Under 2009 IECC, duct insulation requirements were relaxed. Under 2009 IECC, 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.

7.2 Homes with Ducts

The majority of the inspected homes (44 out of 50) have ductwork. Only five homes have all ducts installed in conditioned space; an additional ten homes have some ducts installed in conditioned space. Table 7-1 shows the various heating and cooling system combinations in the homes with ducts in unconditioned space. The majority (74%) of the 39 homes with ducts located in unconditioned space have a furnace and central air conditioning. Three homes each have either a furnace and no central air conditioning, or a hot water boiler and central air conditioning. Two homes each have a hydro-air boiler heating system and central air conditioning, or a ground source heat pump.

Table 7-1: Mechanical Equipment and Duct Systems

Heating/Cooling System Combination	Homes with Ducts Installed in Unconditioned Space (n=39)
Furnace with Central Air Conditioning	74%
Furnace without Central Air Conditioning	8%
Boiler (hot water) with Central Air Conditioning	8%
Boiler (hydro-air) with Central Air Conditioning	5%
Ground Source Heat Pump Heating & Cooling	5%

7.3 Duct Types and Insulation

For all supply and return ducts located in unconditioned space, auditors recorded the duct type (metal, flexible or panned joists), location, insulation type and insulation R-value. Figure 7-1 shows the percentage of all homes with ducts in unconditioned space that have metal, flexible or panned joist ducts in unconditioned basements, attics or other locations.[28] Homes typically have

[28] Other locations include crawl spaces and garages.

a mix of metal and flexible ducts. As shown, 74% of homes with ducts in unconditioned space have at least some metal ducts in an unconditioned basement and 44% have metal ducts in the attic; 38% have flexible ducts in the attic and 36% have flexible ducts in an unconditioned basement. All of the panned joists observed by auditors serve as return ducts, and are in compliance with the code requirement stipulating that panned joists are not permitted to be used as supply ducts.

Figure 7-1: Duct Type by Location

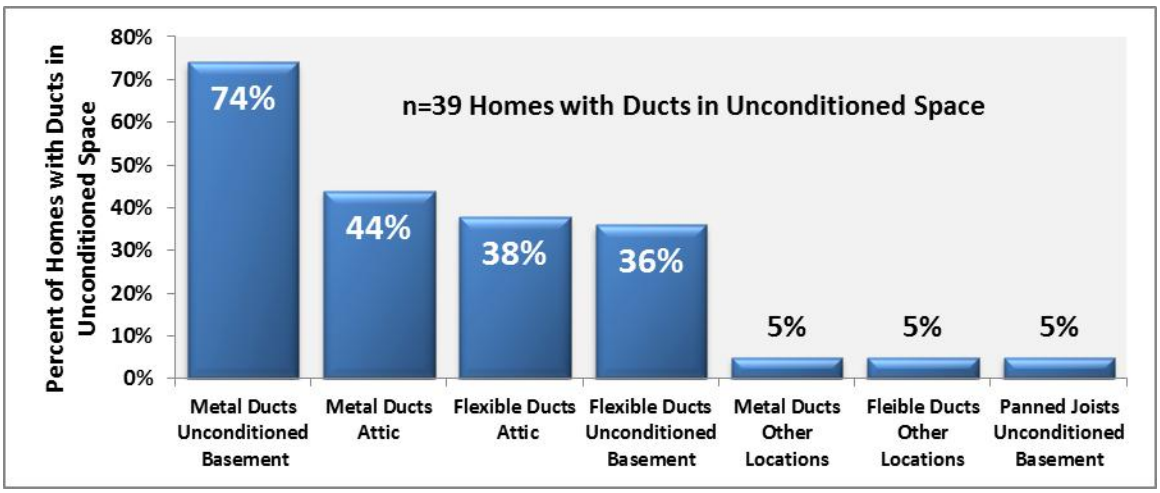
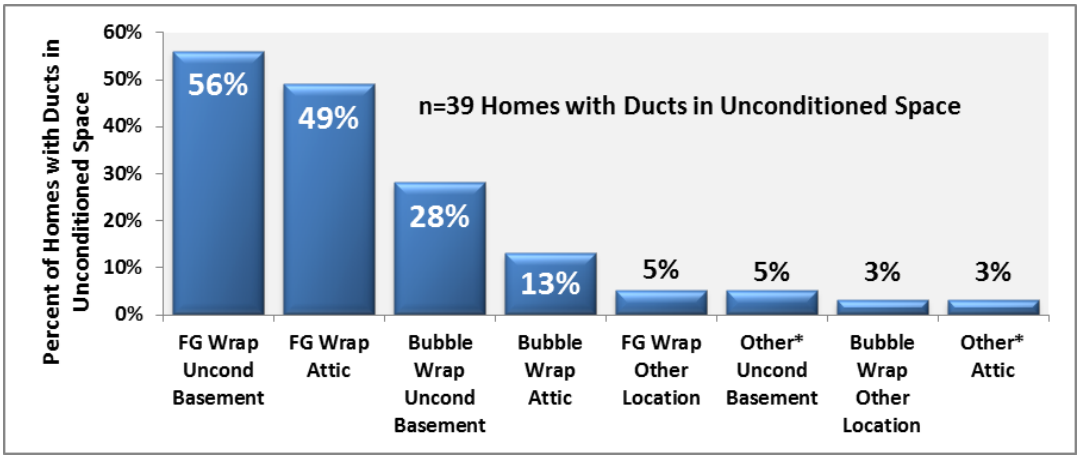


Figure 7-2 shows the type of duct insulation by location for all homes with ductwork in unconditioned space. Fiberglass wrap is the most commonly observed type of duct insulation. As shown, 56% of homes with ducts in unconditioned space have ducts in unconditioned basements insulated with fiberglass wrap and 49% have attic ducts insulted with fiberglass wrap; 28% have ducts in unconditioned basements insulated with bubble wrap and 13% have attic ducts insulated with bubble wrap. Uninsulated ducts in unconditioned space were observed in six homes: five homes have uninsulated ducts in unconditioned basements and one home has uninsulated ducts in the attic.

Figure 7-2: Duct Insulation Type by Location



* Other types of duct insulation include reflective foil and thermal blanket wrap.

7.4 Duct Insulation R-values

Table 7-2 shows the average R-value of duct insulation for supply and return ducts in unconditioned space by location. As shown, the average R-value for supply ducts is higher than for return ducts. This is due in part to return ducts being more likely to be uninsulated than supply ducts; in the six homes with uninsulated ducts in unconditioned space, all the uninsulated ducts are return ducts.

Table 7-2: Average Supply and Return Duct Insulation R-value by Location

Duct Location	All Homes (n=39)		Custom Homes (n=10)		Spec Homes (n=29)	
	Average Supply Duct R-value	Average Return Duct R-value	Average Supply Duct R-value	Average Return Duct R-value	Average Supply Duct R-value	Average Return Duct R-value
Unconditioned Basement (n=31)	6.4	5.3	6.6	4.9	6.4	5.5
Attic (n=23)	6.3	5.6	5.6	3.6	6.4	6.1
Other* (n=3)	6.4	5.0	5.0	5.0	6.8	--
Average R-value Over All Ducts in Unconditioned Locations						
All Ducts in Unconditioned Space	6.4	5.4	6.2	4.5	6.4	5.7

* Refers to unconditioned spaces other than unconditioned basements and attics.

The average R-value of duct insulation calculated over all types of ducts in all unconditioned locations is R-6.0. Table 7-3 shows the average R-value is slightly higher in spec homes (R-6.1) than in custom homes (R-5.5).

Table 7-3: Duct R-value Statistics

Duct Insulation Level All Ducts in Unconditioned Spaces	All Homes (n=39)	Custom Homes (n=10)	Spec Homes (n=29)
Minimum R-value	0.0	0.0	0.0
Maximum R-value	10.0	10.0	9.6
Average R-value	6.0	5.5	6.1
Median R-value	6.0	6.0	6.0
Comparison to 2006 IECC Requirement of R-8			
Less than R-8	90%	80%	93%
R-8	10%	20%	7%
More than R-8	0%	0%	0%
Comparison to 2009 IECC Requirement: (Supply-Attic R-8, All Other R-6)			
Less than Supply-Attic R-8, All Other R-6	69%	70%	69%
Supply-Attic R-8, All Other R-6	13%	10%	14%
More than Supply-Attic R-8, All Other R-6	18%	20%	17%

Comparing insulation levels observed in inspected homes to the 2006 and 2009 IECC requirements, 90% of homes with ducts in unconditioned space have less insulation than the 2006 IECC mandatory requirement of R-8 for all ducts (supply and return) located in unconditioned space.[29] Only 10% of homes—two spec homes and two custom homes—have R-8 insulation. 2006 IECC duct insulation requirements are more stringent than 2009 IECC requirements. Under 2009 IECC, 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. Not surprisingly, a higher percentage of homes (31% of all homes, 30% of custom homes, and 31% of spec homes) met or exceeded the 2009 IECC requirements than met 2006 IECC requirements. Nonetheless, the majority of homes (69%) did not have supply ducts in attics insulated to R-8 and all other ducts in unconditioned locations insulated to R-6, the 2009 IECC mandatory requirement.

[29] 2006 IECC makes an exception for ducts located in floor trusses, which only need to be insulated to R-6. However, auditors did not collect data specific to ducts in floor trusses and therefore assumed non-compliance if duct insulation was less than R-8.

7.5 Duct Leakage

As discussed earlier, 44 of the 50 homes inspected have duct systems and in five of these homes all ducts are installed in conditioned space. Auditors were able to conduct duct leakage tests at 40 of the 44 homes with ducts. Auditors were unable to test ducts in four homes for the following reasons:

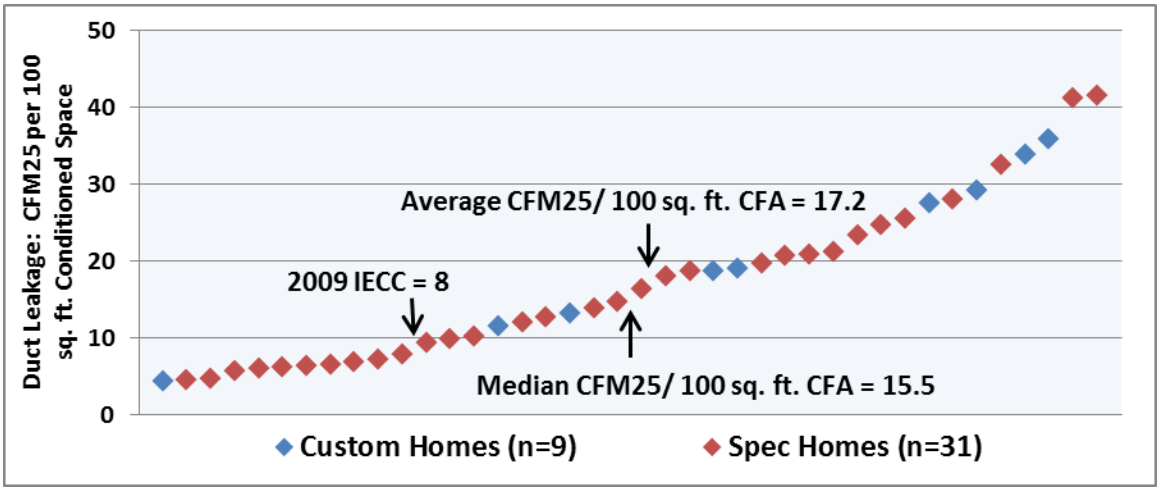
- A register was underneath an extremely heavy china cabinet that the owner did not want moved.
- Auditors could not seal off ductwork in 18 foot high cathedral ceilings.
- In two homes, testing could not be conducted because of problems with automatic dampers.

Table 7-4 shows duct leakage to the outside ranged from 4.3 to 41.5 CFM25 per 100 sq. ft. of conditioned floor area. The overall average is 17.2 CFM25 per 100 sq. ft. of conditioned floor area; the average for custom homes is 21.4 and the average for spec homes is l6.0. Median duct leakage, at 15.5 CFM25 per 100 sq. ft. of conditioned floor area, is the same for both custom and spec homes. Figure 7-3 shows duct leakage by homes. Just over one-fourth (28%) of homes with ducts met the 2009 IECC requirement of 8 or lower CFM25 per 100 sq. ft. of conditioned floor area.

Table 7-4: Duct Leakage Statistics

Duct Leakage CFM25 per 100 Sq. Ft. Conditioned Space	All Homes (n=40)	Custom Homes (n=9)	Spec Homes (n=31)
Minimum	4.3	4.3	4.4
Maximum	41.5	35.8	41.5
Average	17.2	21.4	16.0
Median	15.5	15.5	15.5

Figure 7-3: Duct Leakage by Home



Putting duct leakage results into perspective, 17 CFM25 per 100 sq. ft. of conditioned floor area is:

- Only slightly better than 2005 Baseline Study average leakage to the outside of 21.7 CFM25 per 100 sq. ft. of conditioned floor area
- More than double the 2009 IECC mandatory requirement of 8 or less CFM25 per 100 sq. ft. of conditioned floor area for ducts tested post construction
- More than four 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
- Five times the average duct leakage of 3.4 CFM25 per 100 sq. ft. of conditioned floor area in ENERGY STAR homes certified through the 2010 Massachusetts New Homes with ENERGY STAR Program[30]

[30]Dorothy Conant, Consultant. *The Massachusetts New Homes with ENERGY STAR® Program 2010 Progress Report: Final Report*, submitted to the Joint Management Committee, September 2011. (p 42)

8 Air Infiltration

Auditors conducted blower door tests on all 50 inspected homes. 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 8-1 shows air changes per hour measured at 50 Pascals range from 2.2 to 17.1. One very leaky home (ACH50 of 17) is a 1,598 square foot spec home purchased as a finished home. Average ACH50 is 5.8 and median ACH50 is 5.3. Average ACH50 for custom homes is 6.2, which is slightly higher than the average for spec homes of 5.7. The median for both custom and spec homes is 5.3 ACH50. Figure 8-1 graphs ACH50 by home.

The overall average of 5.8 ACH50 is measurably lower than the 2005 Baseline Study average of 6.7 ACH50. Under 2009 IECC, building tightness and insulation installation will be considered acceptable if tested air leakage is 7 ACH50 or lower; an impressive 84% or 42 of the 50 inspected homes have 7 or lower ACH50. The ENERGY STAR Version 3 performance path requires air infiltration to be 4 ACH50 or lower; 20% or 10 of the inspected homes have 4 or lower ACH50. Average air infiltration in ENERGY STAR homes certified through the 2010 Massachusetts New Homes with ENERGY STAR Program was 3.6 ACH50; 12% or 6 of the inspected homes have 3.6 or lower ACH50.

Table 8-1: Air Infiltration Statistics

ACH50	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum ACH50	2.2	2.4	2.2
Maximum ACH50	17.1	9.1	17.1
Average ACH50	5.8	6.2	5.7
Median ACH50	5.3	5.3	5.3

Figure 8-1: Air Changes per Hour by Home

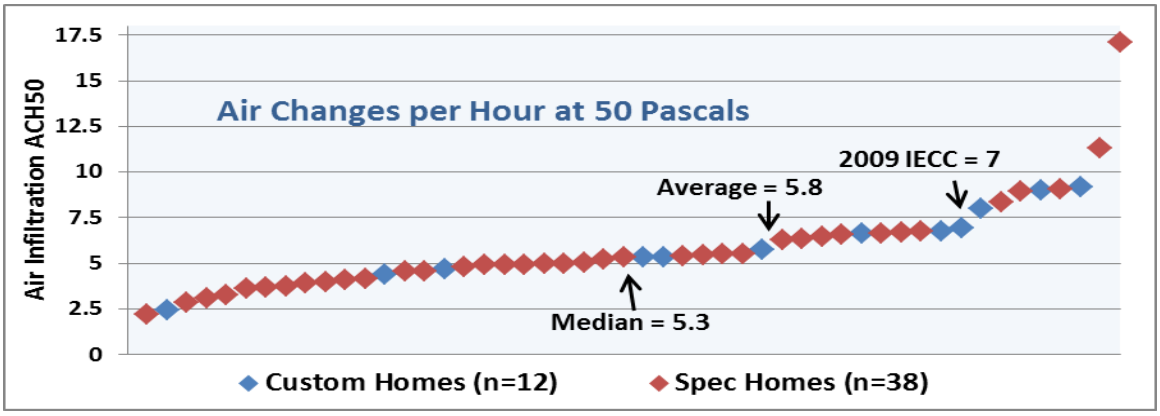
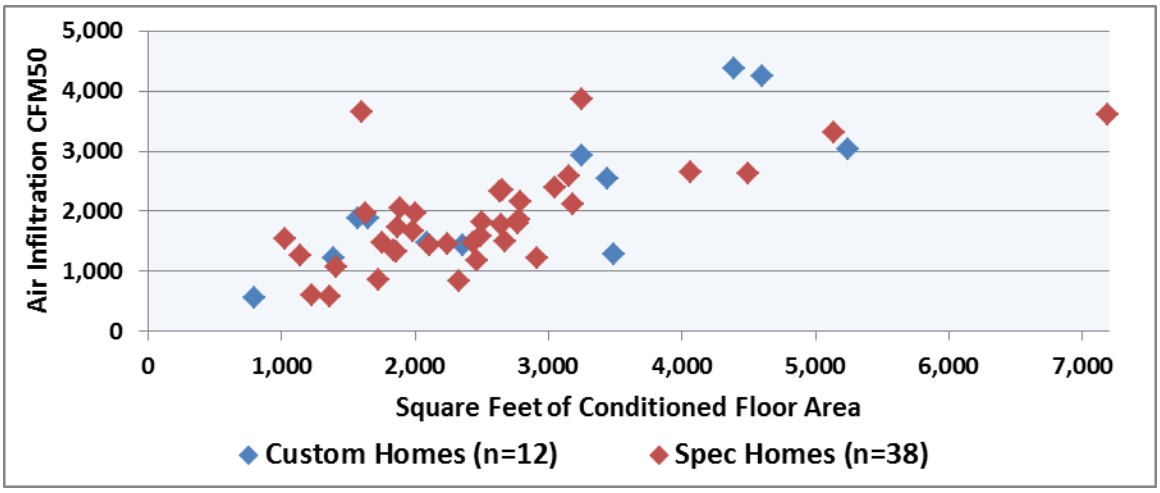


Table 8-2 shows average CFM50 for the 50 inspected homes ranges from 570 to 4,385; the average is 1,960 and the median is 1,793 CFM50. Average CFM50 for custom homes is 2,242 and the average for spec homes is lower, at 1,871 CFM50. Figure 8-2 shows total CFM50 by home size. As shown, total leakage varies widely for homes of similar size.

Table 8-2: Total CFM50 Leakage Statistics

Total CFM50	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Minimum CFM50	570	570	589
Maximum CFM50	4,385	4,385	3,870
Average CFM50	1,960	2,242	1,871
Median CFM50	1,793	1,880	1,763

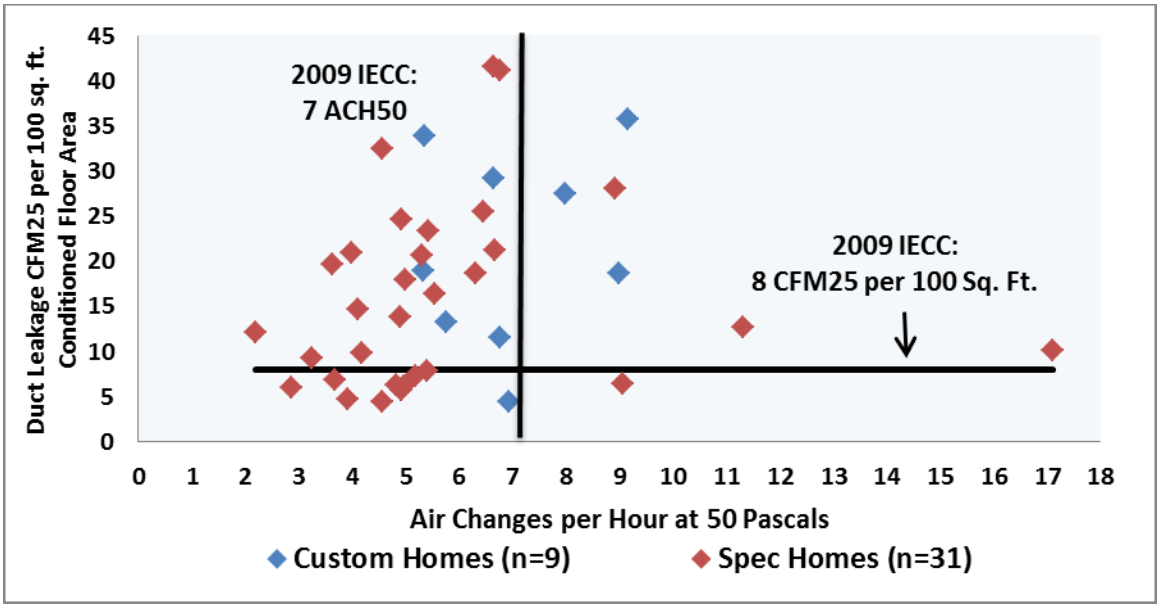
Figure 8-2: Total CFM50 Leakage by Home Size



8.1 Air Infiltration and Duct Leakage

Many tight homes have leaky ducts. Figure 8-3 shows air infiltration and duct leakage levels for the 40 inspected homes with both air infiltration and duct leakage data. Ten homes (lower left) meet 2009 IECC requirements for both duct leakage and air infiltration. Over one-half of the homes, 23 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. Six homes (upper right) do not meet the 2009 IECC duct leakage or air infiltration requirements

Figure 8-3: Air Infiltration and Duct Leakage



9 Lighting

The on-site inspections collected information on the total number and types of light bulbs (including fluorescent tubes) and ceiling fans found in each home. These data were used to determine how many homes would be in compliance with the 2009 IECC[31] prescriptive requirement to have a minimum of 50 percent of the lamps in permanently installed lighting fixtures be high-efficacy lamps for homes complying through the prescriptive path.

The lighting information gathered through the on-site inspections was also compared to the lighting data from the randomly drawn sample of 50 ENERGY STAR homes for which the HERS raters, as part of the Energy Code Pilot Report submitted in July of 2011, completed and commented on the 2006 IECC checklists.

9.1 Lighting Counts from the On-Site Inspections

The on-site inspections counted the number of 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.

Nearly one-half (46%) of the homes visited have very few energy-efficient bulbs installed, accounting for 10% or less of all the bulbs installed in the home. (One of the 50 homes did not have any lighting fixtures installed at the time of the visit.) Only 16% of the homes visited have 50% or more of their bulbs classified as energy efficient and meet the prescriptive lighting requirement for 2009 IECC.[32] One-quarter of custom homes have more than 50% energy efficient lights versus 13% of spec homes; however, due to the small numbers involved this difference is not statistically significant at the 90% confidence level. (Table 9-1)

Table 9-1: Portion of Homes with Energy Efficient Bulbs

Percent of Energy Efficient Bulbs in the Home	All Homes (n=49)	Custom Homes (n=12)	Spec Homes (n=37)
10% or less	46%	41%	49%
11% to 30%	18%	17%	19%
30% to 49%	18%	17%	19%
Comparison to 2009 IECC Prescriptive Requirement (50% or more energy efficient)			
50% to 79%	12%	25%	8%
80% to 100%	4%	0%	5%

[31] The 2006 IECC has no lighting requirement.
[32] It must be noted that all these homes were actually built under 2006 IECC and thus did not have to comply with this requirement.

The lighting data available for 48 homes from the randomly drawn sample of 50 ENERGY STAR homes indicate that at least 80% of available sockets had energy-efficient lighting; as shown in Table 9-1, that is the case for only 4% of the non-ENERGY STAR homes visited for this study.

Looking at the total number of bulbs counted in the non-ENERGY STAR homes[33], only 21% are energy efficient bulbs. Custom homes have more bulbs than spec homes, but the percentage of energy efficient bulbs is almost the same. The homes with bulb counts have an average of 14.2 energy efficient bulbs installed, but the median is only 2.5 bulbs because relatively few homes account for the bulk of energy efficient bulbs installed.[34] (Table 9-2)

Table 9-2: Types of Bulbs Installed—All Homes

Number of Bulbs by Type in All Homes	All Homes (n=48)	Custom Homes (n=12)	Spec Homes (n=36)
Average number of screw-in CFL bulbs	10.6	11.9	10.2
Average number of pin-based CFL bulbs	1.5	4.1	0.6
Average number of LED bulbs	0.3	1.0	0.1
Average number of fluorescent tubes	1.8	3.2	1.3
Average number of all energy efficient bulbs	14.2	20.2	12.2
Median number of energy efficient bulbs	2.5	8	2
Average number of all bulbs	66.7	97.8	56.4
Percent of energy efficient bulbs	21%	21%	22%

The analysis was rerun to exclude eight homes that had only incandescent bulbs installed. When looking at the 40 homes that had at least one energy efficient bulb installed, the percentage of energy efficient bulbs is only slightly higher at 27%. (Table 9-3)

[33] Bulbs were not counted in one home, but the auditor noted that all lights were incandescent. Thus, the potion of homes with energy efficient bulbs (Table 9-1) is based on 49 homes while the numbers of bulbs installed (Table 9-2) is based on 48 homes.

[34] An alternative methodology for calculating the percentage of energy efficient bulbs is to first determine the percentage of 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 energy efficient bulbs across all homes is only slightly higher at 23% versus 21%. The average percentage of energy efficient bulbs in custom homes is 23% and in spec homes is 22%.

Table 9-3: Types of Bulbs Installed—Homes with One or More Energy Efficient Bulbs

Number of Bulbs by Type in Homes with Any Energy Efficient Bulbs	All Homes (n=40)	Custom Homes (n=10)	Spec Homes (n=30)
Average number of screw-in CFL bulbs	12.8	14.3	12.2
Average number of pin-based CFL bulbs	1.8	4.9	0.7
Average number of LED bulbs	0.4	1.2	0.1
Average number of fluorescent tubes	2.1	3.8	1.6
Average number of all energy efficient bulbs	17.1	24.2	14.6
Median number of energy efficient bulbs	5.0	14.0	3.5
Average number of all bulbs	63.1	86.7	55.1
Percent of energy efficient bulbs	27%	28%	26%

9.2 Ceiling Fans

Twenty-two of the fifty homes visited (44%) have at least one ceiling fan. As Table 9-4 shows, homes that have ceiling fans are most likely to have one, two or three; a few homes have four or five ceiling fans.

Table 9-4: Homes with Ceiling Fans

Number of Ceiling Fans	All Homes (n=50)	Custom Homes (n=12)	Spec Homes (n=38)
Zero	56%	58%	55%
One	12%	17%	11%
Two	14%	8%	16%
Three	10%	17%	8%
Four	6%	0%	8%
Five	2%	0%	2%

10 Appliances

The on-site inspections collected detailed information on refrigerators, both primary and secondary, and dishwashers.[35] Limited information was also collected for clothes dryers, clothes washers, ranges, stand-alone ovens, and stand-alone freezers.

10.1 Refrigerators

Auditors recorded refrigerator information on the ENERGY STAR status, condition, age, type, and size. Slightly fewer than three out of four (73%) primary refrigerators are ENERGY STAR. As might be expected, almost all primary refrigerators in the new homes inspected are new and in good condition. Bottom freezer models are the most common accounting for more than four out of ten primary refrigerators (42%) closely followed by side-by-side models. The vast majority (85%) of primary refrigerators are at least 20 cubic feet with one-third being over 25 cubic feet. (Table 10-1)

Table 10-1: Primary Refrigerator Characteristics

ENERGY STAR Status (n=49)	
ENERGY STAR	73%
Not ENERGY STAR	27%
Condition (n=48)	
Good	94%
Fair	6%
Age (n=42)	
2 years or less	90%
3 to 5 years	5%
6 years or more	5%
Type (n=48)	
Bottom freezer	42%
Side-by-side	35%
Top freezer	21%
Single door	2%
Size (n=42)	
15 cubic feet or less	2%
16 to 19 cubic feet	12%
20 to 25 cubic feet	52%
Over 25 cubic feet	33%

[35] Some information was collected on 49 primary refrigerators and 48 dishwashers; one of the homes did not have any of its appliances installed at the time of the inspection and one home did not have a dishwasher. Some parameters, such as age, type, size, and condition, are missing values for a few of the homes visited; the number of homes included for each parameter is shown in the appropriate tables.

Eleven of the fifty homes visited have secondary refrigerators. Most of these refrigerators are not ENERGY STAR. They tend to be older and in poorer condition than primary refrigerators (size data was not collected). More than one-half of these refrigerators are single door models. (Table 10-2)

Table 10-2: Secondary Refrigerator Characteristics

ENERGY STAR Status (n=10)	
ENERGY STAR	2
Not ENERGY STAR	8
Condition (n=11)	
Good	8
Fair	2
Poor	1
Age (n=8)	
2 years or less	5
3 to 5 years	1
6 years or more	2
Type (n=9)	
Single door	5
Top freezer	3
Side-by-side	1

10.1 Dishwashers

Auditors recorded dishwasher information on the ENERGY STAR status, condition, and age. Nearly nine out of ten (89%) dishwashers are ENERGY STAR. As might be expected, almost all dishwashers in the new homes inspected are new and in good condition. (Table 10-3)

Table 10-3: Dishwasher Characteristics

ENERGY STAR Status (n=45)	
ENERGY STAR	89%
Not ENERGY STAR	11%
Condition (n=44)	
Good	98%
Fair	2%
Age (n=35)	
2 years or less	97%
3 years or more	3%

10.2 Other Appliances

Forty-two of the fifty homes visited have clothes dryers; the only information collected is the fuel type. Close to four out of five clothes dryers (79%) use electricity; the remaining 21% use natural gas. Forty-four of the fifty homes visited have clothes washers; no further relevant information was collected on clothes washers.

Fuel type information was collected on 42 ranges; close to two-thirds (62%) use natural gas. Additional fuel type information was collected on 12 stand-alone ovens; in one case, the auditors note that "the range and oven is a combo unit, however the oven part is electric and the range is gas." (Table 10-4)

Table 10-4: Range and Oven Characteristics

Range Fuel (n=42)	
Natural gas	62%
Electricity	24%
Propane	14%
Oven Fuel (n=12)	
Natural gas	5
Electricity	5
Propane	2

Five of the fifty homes visited have stand-alone freezers; no further relevant information was collected on stand-alone freezers.

Appendix A Insulation Grades

The Residential Energy Services Network (RESNET) provides guidelines and definitions for defining the quality of insulation installation. RESNET has specified three grades for designating the quality of insulation installation; the grades range from Grade I (the best) to Grade III (the worst). The RESNET definitions of Grade I, Grade II, and Grade III installation are provided below.[36]

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. .

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

Figure A-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.[37]

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

Figure A-2 shows a Grade II install of unfaced fiberglass batts in a conditioned basement.[38] 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 A-2: Grade II Fiberglass Batts—Basement Walls

[37] 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.
[38] The basement in this case was considered conditioned volume, not conditioned floor area.

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

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

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

Figure A-6 shows a Grade I installation of blown-in 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 A-6: Grade I Blown Fiberglass—Attic

Appendix B 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 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.)[39]

Figure B-1 demonstrates where a builder attempted to bring the walkout basement into the thermal envelope by insulating the foundation walls with two inches of rigid foam. However, there was no insulation on the above grade portion of the concrete wall, where the foam would have provided the most benefit. It was not entirely clear when talking to the homeowner, but it appeared that the builder had not fully insulated this wall, and the homeowner had mistakenly cut away any remaining above grade insulation for aesthetic reasons.

Figure B-1: Foundation Wall Rigid Insulation

Figure B-2 shows this same wall viewed from inside the basement. This arrangement of partially below grade concrete walls topped with insulated, above grade, framed walls was common in walkout basements, but most builders did not insulate the concrete portion of the walls. The

[39] 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.

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.

Figure B-2: Partially Insulated Walkout Basement Walls

Slab Floors

Slab floors 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 property.

Figure B-3 demonstrates one of the few homes where the slab was at least insulated at its perimeter with two inch thick rigid foam, but there was no rigid insulation protection, and the insulation had been badly damaged.

Figure B-3: Damaged Slab Edge Insulation

Frame Floors

Fiberglass batt insulation in frame floors over basements (basement ceilings) was often poorly installed, with some exceptions. Figure B-4 shows poorly installed frame floor insulation. This installation of R-30 fiberglass batts had significant gaps and compression, particularly in bays with ductwork. Auditors frequently saw such flaws in the audited homes.

Figure B-4: Poorly Installed Frame Floor Insulation

Figure B-5 shows frame floor insulation that was originally well installed and in substantial contact with the subfloor. However, the insulation appeared to have been damaged or removed to accommodate the installation of hot water and plumbing equipment. HVAC and plumbing contractors not working in conjunction with insulation contractors often created such conflicts. Note that in this photo, the hot water lines in the basement were uninsulated; this was a common oversight among builders, for both domestic hot water and hydronic heating pipes.

Figure B-5: Damaged Frame Floor Insulation and Uninsulated DHW Lines

At first glance, Figure B-6 looks like an example of well installed fiberglass insulation in a frame floor because the insulation looks uncompressed and fairly uniform from below. However, these eight inch thick R-30 batts sagged significantly away from the subfloor, decreasing their effectiveness. This was often a problem in houses with wood I-beam floor joists, where the insulation sagged away from the subfloor and rested on the lower joist flange.

Figure B-6: Frame Floor Insulation—Sagging but Without Gaps

Rim/Band Joists & Sealing Penetrations to the Outside

Figure B-7 shows a rim joist that has been poorly insulated with fiberglass batts. The fiberglass batts were not properly fit around the water lines that run outside, creating significant gaps in the insulation. The gaps around the utility penetrations are also not sealed with foam, allowing substantial air leakage into the basement.

Figure B-7: Rim Joist with Penetrations to Outside

Figure B-8, on the other hand, shows a home[40] with well installed closed cell foam insulating the rim joist in an unconditioned basement. The foam also fully seals gaps around utility penetrations to the outdoors, minimizing air leakage in the basement. Homes with this type of spray foam in the rim joists tended to perform quite well in blower door tests, though such homes may have had additional air sealing measures that auditors weren't able to see so easily.

Figure B-8: Rim Joist with Penetrations to Outside

Exterior Walls

Figure B-9 shows a home that used a well implemented "flash and batt" insulation system in the exterior walls, with two inches of closed cell foam in every 2x6 wall cavity, and the remainder of the cavity filled with three and a half inch thick R-13 fiberglass batts.

Figure B-9: Exterior Walls with Foam and Fiberglass Insulation

[40] Note that this particular house was not visited as a part of the Mini Baseline Study, but these photos are similar to what auditors found in the few homes in this study that had rim joists insulated with foam.

Figure B-10, in contrast, shows a particularly sloppy wall insulation installation, with R-13 fiberglass batts falling entirely out of their cavities. Such sloppiness was common in areas that were not readily accessible by the homeowner (knee walls, attics, etc.).

Figure B-10: Poorly Installed Fiberglass Wall Insulation

Ceiling Insulation

Figure B-11 shows an extremely poor attic insulation installation. The fiberglass batts had been strewn across the attic rafters—sometimes in cavities, and sometimes not. However, the homeowner had spray foamed the roof rafters to bring the entire attic inside the thermal envelope, making this insulation irrelevant. It is not clear whether this insulation was installed poorly from the outset, or if it was damaged by later work in the attic. This attic area was extremely difficult to access, with a very low ceiling, and could only be reached by crawling over HVAC equipment.

Figure B-11: Poorly Installed Fiberglass Batt Attic Insulation

In contrast, Figure B-12 demonstrates extremely well installed attic insulation, with even cellulose distribution, wind baffles, and ceiling rafters that are fully covered by insulation to reduce thermal bridging. There was also no ductwork in the attic, minimizing the loss of conditioned air.

Figure B-12: Well Installed Cellulose Attic Insulation

Windows, Doors, and Basement Air Sealing

Figure B-13 shows a basement door where small pieces of fiberglass insulation were stuffed between the door frame and the rough opening of the doorway, creating a poor air barrier. In this photo, one can also see fiberglass stuffed in the gap between the framing and the lower concrete foundation wall, allowing air leakage where the wood abuts the concrete. 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, allowing significant air leakage into basements.

Figure B-13: Walkout Basement – Fiberglass as Ineffective Air Sealing

Minimizing Unconditioned Space in Homes

Figure B-14 shows an attic space with closed cell foam sprayed between the roof rafters, bringing the attic heating system and ducts into a conditioned and insulated space, greatly reducing duct leakage to outside. This, however, was done by the homeowner after the home was completed. The builder intended this heating system to be installed in an unconditioned, vented attic, which is what auditors typically saw in homes with more than one heating system.

Figure B-14: HVAC System in Conditioned Attic

Builders also often installed lower efficiency, non-condensing furnaces in attics, perhaps due to the risk of condensate freezing in unconditioned attics.[41] 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.

[41] 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.

Figure B-15 shows a vented attic space separated from conditioned space by a short, sloppily insulated knee wall on the right. This house was located on a windy site, and strong winds blew directly into the soffit vents (sunlight from the vents is visible on the left), wind washing the exposed fiberglass batts on the right. Ductwork was also run through this space (visible in the background), and any duct leakage was completely lost to the outside.

Figure B-15: Knee Wall and Ducts Exposed to Wind Washing

Duct Insulation and Location

Figure B-16 shows a variety of ductwork practices—some good and some not. In this photo one can see a few positive practices, such as duct sealing with metal tape that performed adequately and well insulated metal trunk lines (R-6). However, this photo also shows an uninsulated panned floor joist serving as a return, and flexible supply ducts with insulation (R-6) crushed in numerous places and twisted over and around various obstructions, restricting the air flow through the flexible ducts.

Figure B-16: Basement Ductwork of Varying Quality

Figure B-17 shows the ductwork for a well-designed ground source heat pump system that also demonstrated a mix of practices. This system was well-sealed with mastic, which was not present on every system, but while the supply ducts in the basement were insulated with R-8 insulation, all returns ducts were uninsulated.

Figure B-17: Basement Ductwork without Return Insulation

Ventilation

Even extremely "tight" homes that auditors tested, those with very low air exchange rates, typically 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.

Appendix C Data Collection Form

MA DOER 2011 Code Pilot Study				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	
(ex: colonial)	Area conditioned space (calc.)					Bedrooms	
	Volume conditioned space (calc.)						
Primary Heating Fuel		Total Heated Area			Number of Fireplaces		
(from recruitment data)		(from recruitment data)				(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?				
Type of Thermostat:			Preferred Temperature:				
Use Night Temp. Setback?			No of Occupants, Nights:				
Use Daytime Temp. Setback?			No of Occupants, Workdays:				
Do Blower Door?		Do Duct Blaster?			Do AC Performance Test?		

Insulation/Shell

Exterior Walls

Wall Description	Location	Area	Orient.	I Type	Cavity?	R-Val/Grade

Notes: Looka A OK

Ceiling Insulation

Ceiling Construction	Flat/Cathedral	Area, SqFt	V Barrier	I Type	Cavity?	R-Val/Grade

Notes:

Frame Floor

Floor Description	Location	Area, SqFt	I Type	Cavity?	R-Val/Grade

Notes:

Rim/ Band Joists

Joist Descnripti	Location	Area, SqFt	I Type	R-Value	Thickness	Grade

Notes: Notes galore.

Windows

Windows/glass doors and skylights.

Type of Glass	SqFt	Frame	Location	U-value	SHGC	T Break	O'hang/Dist.To Top	Orient

Notes:

Sky Lights

Sky lights & Glass Doors

Type of Glass	SqFt	Frame	Location	U-value	SHGC	T Break	Orient	Angle

Notes:

Ext. Doors

Door Type	Material	Insulated	Storm?	Type of Glass	Dr SqFt	Gl SqFt	Orient.

Notes:

Slab Floor

Grade/Below Grade	Location of Slab Insulation	Depth /Width Below/Under Grade	Area, SqFt	Type	R-Value

Notes:

Foundation Wall

For foundations, include ALL insulation (even walls in unconditioned space)

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

Notes:

Mass Wall

Wall Type	Int/Ext Insul	Location	Rvalue

Notes:

Mechanicals

Heating Equipment

Manufacturer	Model	Type	Age	Fuel	Location	Cap. Out	Efficiency

For Forced Air System, How is Fan Controlled?		Indoor Temperature:		Zones:	
How many Fireplaces or Stoves?		Fireplace/ Stove Fuel:		T'stats:	
How many Portable Space Heaters?		Space Heater Fuel:			
R-value for hydronic piping insulation:					

Water Heating

Manufacturer	Model	Type	Age	Fuel	Location	Gallons	Efficiency

R-value for water heater wrap:		Low Flow Shower Heads:	
		Faucet Aerators:	

Notes:

Cooling Equipment

Manufacturer	Model	Type	Age	Evap. Location	Tons	Efficiency

Notes:

Duct Insulation

		For Insulation Only					
Supply/Return	Location*	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**

Sunspace

*If sunroom need to treat like normail room, take all measurements, area, r-value, etc.

Surface Type	Location	Area	I Type	Cavity?	R-Val/ Grade	Orient.	Glass Frame Type

Notes:

						Test Results
Blower door and Duct blaster		**Repeat tests as needed to ensure precision.**				
Blower Door Test 1 (at 50 Pa)			**Duct Blaster Test 1** (at 25 Pa)			
				Total Leak Test	Out. Leak Test	
Blower door type	Type 3		D.B. Fan Pressure (Pa)			
Ambient Temperature			Duct Pressure	25	25	
Fan Pressure (Pa)			Rings			
House Pressure (Pa)			Blower door Fan (Pa)	0		
Rings/Holes			House Pressure (Pa)	0	25	
CFM Leakage			CFM Leakage			
Blower Door Test 2 (at 50 Pa)			**Duct Blaster Test 2** (at 25 Pa)			
				Total Leak Test	Out. Leak Test	
Blower door type	Type 3		D.B. Fan Pressure (Pa)			
Ambient Temperature			Duct Pressure	25	25	
Fan Pressure (Pa)			Rings			
House Pressure (Pa)			Blower door Fan (Pa)	0		
Rings/Holes			House Pressure (Pa)	0	25	
CFM Leakage			CFM Leakage			
Blower Door Test 3 (at 50 Pa)			**Duct Blaster Test 3** (at 25 Pa)			
				Total Leak Test	Out. Leak Test	
Blower door type	Type 3		D.B. Fan Pressure (Pa)			
Ambient Temperature			Duct Pressure	25	25	
Fan Pressure (Pa)			Rings			
House Pressure (Pa)			Blower door Fan (Pa)	0		
Rings/Holes			House Pressure (Pa)	0	25	
CFM Leakage			CFM Leakage			
Visual House Leakage:			Visual Supply Duct Leakage:			
			Visual Return Duct Leakage:			
Document areas of high leakage that were observed during either test:						

Lighting

Room	No. of Screw in CFL Bulbs	No of Pin Based CFL Bulbs	No. of Incand. Bulbs	No of Fluor. Tubes	No of LED Bulbs	# of Ceiling Fans by Room
Total Incandescent Fixtures:						
Total Incandescent Lamps:						

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							

TV Sets & Peripherals	Size	Type	Service Type	Peripherals	Size	Type	Service Type	Peripherals
1,2								
3,4								
5,6								
7,8								

No. of Printers/Type: _____ List other Peripherals: _____

No. of Computers: _____ Is there an in-home office? _____ Ofc. Area _____

Computer Monitors: _____ Is there a Swimming Pool? _____ Heated? _____

Smart Power Strips: _____ Does pool have a pump timer? _____ Pump HP _____

Is there a Hot Tub or Spa? _____ Heated? _____

Computer No	Mon Size	Mon Type	Print Type	E Star?
1				
2				
3				
4				

Notes:

Renewbles

PV Array? Y____ N____	SqFt:		Total kW:		
Windmill? Y____ N____	Count:		Total kW:		

Miscellaneous/Code

Inspect any combustion equipment for compliance with Code. This includes space and hot water heating equipment, fireplaces, wood and pellet stoves. Does not include cooking equipment (including charcoal or gas grilles) or clothes dryers. Note any deficiencies below.

Equipment Type	Fuel	Venting	Comply?	% of Heat	Comments, esp. for Non-Compliance

Notes:

Inspect whole house ventilation equipment for compliance with Code. Document type of system and note any deficiencies below.					
Type of ventilation system:		**Fan Loc.**	**Rated CFM**	**Required**	**Control**
Notes:					
	Total	0	0	NA	

ERV Manufacturer	**ERV Model No.**	**Efficiency**	Notes:
Is Clothes Dryer properly vented?		Notes:	

HVAC/Hot Water Piping Insulation			
System	**Insulation Type**	**R-value**	**Notes:**

Micellaneous Code				
Recessed Fixtures meet infiltration criteria?				
Dampers on all outdoor intake and exhaust openings?				
Certificate posted?				
Wood burning fireplace--gasketed doors and outdoor air supply?				
Heat Pump thermostats installed on heat pumps?				
Circulating service hot water systems have automatic or accessible				
Pool heaters, covers, and automatic or accessible manual controls?				
Is there an RBES sticker posted?				
Air Sealing of opening and penetrations? (fenestration, window/door openings, utility penetrations)				
Air Sealing of envelope joints and seams? (dropped ceiling, kneewall, tub or shower, common wall, assemblies separating garage)				
Air Sealing of all other sources of penetration?				

Document noteworthy and valuable information regarding the quality and performance of the home as it pertains to building science and energy usage.
Notes: