Appendix M
Residential New Construction Baseline

M-1: Staff Testimony
M-2: “New Construction Baseline Assessment in Maine,”
Ridgeline Energy Analytics

Appendix M-1
Staff Testimony

Appendix M-1
Staff Testimony

By Laura Martel
8-27-2021

Introduction

1. What is the purpose of this testimony?

This testimony describes the Efficiency Maine Trust's (the Trust's or EMT's) interpretation of the Maine New Construction Baseline Assessment (attached hereto as Appendix M-2) for Triennial Plan V.

2. Who is introducing this testimony?

The testimony is provided by Laura Martel, Research and Evaluation Manager at the Trust.

3. Ms. Martel, please state your name, title, and business addresses.

My name is Laura Martel, and I am employed by EMT as the Research and Evaluation Manager. My business address is 168 Capitol Street, Suite 1, Augusta, ME 04330.

4. Please summarize your educational and professional experience.

I have a Bachelor of Science degree in Ocean Engineering from Florida Atlantic University and a Master of Engineering in Acoustics from Pennsylvania State University. I have over 21 years of technical leadership, project management, and research and evaluation experience. I was hired by EMT in 2014 to design and implement impact and process evaluations for energy efficiency programs. Prior to joining EMT, I was with Lockheed Martin in Manassas, Virginia, where I served in various engineering, management, and technical leadership roles of increasing responsibility.

Background

5. Why did the Trust commission the New Construction Baseline Assessment as part of the research for Triennial Plan V?

An earlier baseline study of residential new construction in Maine was conducted in 2008 by the Energy & Resource Solutions (ERS).[1] That study found that many homes in Maine were not being built to code and had significant opportunities for improvements that would achieve energy savings. In the intervening 12 years, Maine has implemented updated energy codes. The Trust sought to understand the level of code compliance and savings opportunity in recently constructed homes. The Trust commissioned Ridgeline Energy Analytics to complete this study for that purpose.

[1] Energy & Resource Solutions, Maine Residential New Construction Technical Baseline Study, May 2008.

6. How was the research conducted?

This study examined 127 homes across Maine, 29 of which were manufactured (mobile) homes. Home raters visited each home and recorded a detailed assessment of all home components that contribute to the energy use of the home, including the thermal envelope, heating equipment, lighting, and appliances. The on-site assessments were performed using Home Energy Rating System (HERS) inspections developed by RESNET[2], Inc. The study team modeled as-built energy use and potential energy savings through increased compliance with codes using REM/Rate[3] and Ekotrope Rater[4] software.

7. What were the key findings of the study?

The study team found that homes built between 2017 and 2020 are more energy efficient than the homes assessed for the 2008 ERS study, showing improvement in code compliance and construction techniques. Many of the new homes had one or more components that did not meet code. Though full code compliance for all components would reduce energy use, Ridgeline determined that the incremental savings would be minor for 25% of single and multifamily homes (less than 1 MMBtu/year) and moderate for the next 50% of single and multifamily homes (between 1 and 8 MMBtu/year/home). While 35% of all homes could achieve savings above 10 MMBtu/year/home, nearly all are manufactured homes that are not subject to local building codes. On the other hand, the potential energy and greenhouse gas emissions savings from electrification of space heating are significant (average savings of 23 MMBtu/year/home across all homes). This upgrade is applicable to 63% of homes not already heated with heat pumps and a portion of the 18% of homes that have fossil fuel-fired heating equipment in addition to heat pumps. Excluding homes already exclusively heated with heat pumps or heat pumps with small supplemental electric resistance (19%), the average savings per home achievable by electrification of space heating increases to 28 MMBtu/year/home equivalent to almost half of the average per home energy use as-built.

8. Given the findings of the study, will the Trust offer energy efficiency measures related to code compliance during Triennial Plan V?

No. Code compliance is legally required for new homes built in every municipality in Maine, and the savings potential from improving code compliance (i.e., improving building practices to bring previously non-compliant practices up to code) is moderate. Moreover, most components in most newly constructed homes are code compliant. The Trust finds that there is not a cost-effective opportunity for it to offer thermal envelope measures to target new construction that would otherwise fail to comply with code.

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[2] Residential Energy Services Network
[3] http://www.remrate.com
[4] https://www.ekotrope.com/ekotrope-rater

9. What other opportunities will the Trust pursue related to new construction during Triennial Plan V given the findings of the study?

The findings of the study indicate that code compliance improves over time as builders become more familiar with the requirements and techniques required to meet them. The Trust sees an opportunity to accelerate that process, with the recent adoption of IECC 2015 statewide, by offering training to builders and code enforcement officers.

The Trust will continue to offer incentives for the most efficient heating equipment for which new homes are eligible. The Trust will focus on whole home space heating solutions for new construction and continue to offer incentives on the most efficient domestic water heating solutions.

Appendix M-2

"New Construction Baseline Assessment in Maine,"

Ridgeline Energy Analytics

Maine New Construction Baseline Assessment

Prepared for the Efficiency Maine Trust
Ridgeline Energy Analytics
Advanced Building Analysis
August 1, 2021

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GLOSSARY

Acronym or Abbreviation	Definition
ACH50	Air Changes per Hour at 50 pascals of pressure. Measured as the number of times the amount of air equal to the interior volume of a home is exchanged every hour with the outdoors when the house is pressurized to 50 pascals using a blower door.
AHU	Air handling unit. In homes it is usually referred to as a furnace and it has a heat source, a heat exchanger, a fan and motor, and can contain a refrigerant coil for cooling. In the case of a heat pump, heating. Usually contains controls that serve to deliver heating, cooling and/or ventilating air to a space.
API	Application Programming Interface. It is a set of functions and procedures allowing the creation of applications that access the features or data of an operating system or application. For this project, API refers to a set of programming tools offered by Ekotrope, which allow access to specific pieces of data. We used these APIs extensively to gather data from the 127 Ekotrope reports built under this project.
BTU	British Thermal Unit, which is the quantity of heat required to raise the temperature of 1 pound (0.454 kg) of water 1°F. A common explanation of a BTU is that it is the heat from one wooden match.
BTUH	British Thermal Units per Hour. A firing rate or heat delivery rate of 1 BTU per hour.
Blower Door	Raters use a Blower Door or equivalent to conduct infiltration testing. A blower door contains a powerful fan that mounts into the frame of an exterior door. When used in negative pressure mode, the fan pulls air out of the house, lowering the air pressure inside. The higher outside air pressure then flows in through all unsealed cracks and openings. These tests determine the air infiltration rate of a building. Blower doors consist of a frame and flexible panel that fit in a doorway, a variable-speed fan, a pressure gauge to measure the pressure differences inside and outside the home, and an airflow manometer and hoses for measuring airflow.

Acronym or Abbreviation	Definition
Box and Whisker Plot	The Box and Whisker Plot is a statistical graphic designed to highlight important characteristics of a data set and its distribution. It provides basic statistical details like median and percentile groupings and illuminates outliers that exist beyond the central cluster of the data.
COP	Coefficient of Performance. This is a unitless ratio of heat added or removed by a heat pump or airconditioner to the energy used to move that heat. For example if 9,000 BTU (2.6 kWh) of heat is removed from a home during the cooling season, and this takes 3,000 BTU (0.88kWh) of electrical energy, the COP of the air conditioner is 3.0.
Duct Blaster®	Raters use a Duct Blaster® or equivalent to conduct duct leakage testing. It consists of a fan, duct work, and a flow and pressure measurement device.
DX	Direct expansion. DX refers to refrigerant systems that use refrigerant to directly cool air streams in air handling units. They are in contrast with chilled water systems where cooling is provided by chilled water or water glycol mixtures in cooling coils. Most residential cooling is through DX.
Ekotrope Rater	A brand of software commonly used by Home Energy Rating (HERS) raters that is published by Ekotrope[1]. Ekotrope was founded in 2011 by members of the MIT community and is headquartered in Boston.
ERW	Energy Recovery Wheel. A rotating wheel pervious to air flow that recovers heat from exhausted air.
GPM	Gallons Per Minute. A flow rate that often refers to heating hot water and domestic hot water.
Heat Pump (HP)	Heat pumps are refrigerant based systems that use the refrigeration cycle to move heat from the colder outdoors to the warmer interior of a house for heating and move heat from inside the house to outdoors for cooling, essentially what a refrigerator does. Heat pump is used to refer to either a ductless or mini-ducted system. The term ducted heat pump is used to refer to new air handler based, ducted heat pumps.

[1]https://www.ekotrope.com/ekotrope-rater

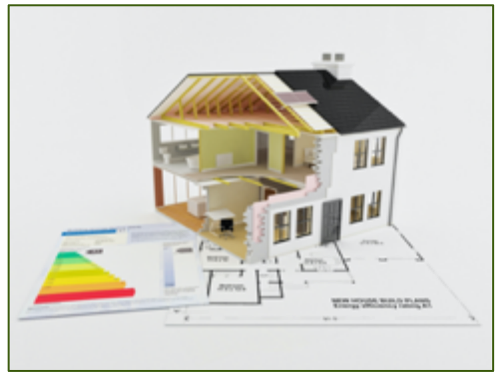
Acronym or Abbreviation	Definition
Heat Pump Water Heater (HPWH)	A heat pump water heater consists of a heat pump and a tank. It transfers heat from the surrounding environment into the hot water tank. They are also called hybrid water heaters because they include a conventional electrical resistance heater than can be used for periods of high demand.
HERS Index	Home Energy Rating System Index. A scoring system established by RESNET based on the IECC 2006. A score of 100 reflects a home built to the IECC 2006 and a score of 0 is equivalent to a net zero home. More recently HERS scores have been accepted as a component of code compliance where a score of 54 is equivalent to the IECC 2015.
HSPF	The Heating Seasonal Performance Factor measures heating efficiency over the heating season. It has units of BTU/watt hour or BTUH/watt and is 3.412 times the seasonal coefficient of performance (COP).
HUD Code	The Department of Housing and Urban Development (HUD) Code is the building standard manufactured home manufacturers must meet. It includes guidelines such as frame requirements, thermal protection, plumbing, and electrical. It was put in place in 1976 by (HUD), which manages the code and oversees enforcement.
IECC 2009, 2015	International Energy Construction Code dated 2009. Other years have similar nomenclature. The IECC is a model energy code, written in mandatory, enforceable language, so that state and local jurisdictions can easily adopt the model as their energy code. The International Code Council (ICC) develops codes and standards including the IECC.
kW	A kilowatt (kW) is 1,000 Watts of power, and is a rate of energy use. This measurement is usually used to show the peak power that a facility or a piece of equipment draws.
kWh	A kilowatt-hour (kWh) is a measurement of electricity consumption equivalent to one kilowatt of demand for one hour.

Acronym or Abbreviation	Definition
Manufactured Home	Mobile home and manufactured home are often used interchangeably. Mobile home refers to a prefabricated home built prior to 1976 when HUD Code was put into place. Manufactured homes built after 1976 are constructed according to a code administered by the U.S. Department of Housing and Urban Development (HUD Code). The HUD Code, unlike conventional building codes, requires manufactured homes to be constructed on a permanent chassis. All manufactured homes are built to the Manufactured Home Construction and Safety Standards, 24 CFR Part 3280. Manufactured homes are transported in one or more sections on a permanent chassis and display a red certification label on the exterior of each transportable section.
MMBTU	1 million BTUs. This nomenclature derives from the Roman numeral M for 1,000, so: a thousand, thousand BTUs.
Mobile Home	Mobile home and manufactured home are often used interchangeably. Mobile home refers to a prefabricated home built prior to 1976 when HUD Code was put into place. Manufactured homes are homes built after 1976 in compliance with the HUD Code. (see Manufactured Home.)
Modular Home	Modular homes are built to local and state building codes, unlike manufactured homes that are built to HUD code. Modular homes are placed on a foundation.
R-value	Thermal resistance per unit area. It tells how well a material insulates. Its units are square foot-hour- °F/BTU. It is the reciprocal of U-value. The higher the R-value, the better the material insulates. It is often used to refer to added insulation but can also be used to refer to the resistance to heat flow of a construction component.
REM/*Rate*™	A brand of software commonly used by HERS raters. REM/*Rate*™ is a trademark of NORESCO, LLC an indirect subsidiary of Carrier Global Corporation. Several of the raters in this study used REM/*Rate*™.[2]

[2] http://www.remrate.com

Acronym or Abbreviation	Definition
RESNET®	Residential Energy Services NETwork. It is a not-for-profit, membership corporation, governed by a board of 20 (who are elected by membership). It is a recognized national standards-making body for building energy efficiency rating and certification systems in the United States.
RWT	Return Water Temperature refers to the temperature of heating hot water as it returns to the boiler and enters the heat exchanger.
SEER	Seasonal Energy Efficiency Ratio. It measures cooling efficiency over the cooling season. It has units of BTU/watt hour or BTUH/watt and is 3.412 times the seasonal coefficient of performance (COP).
SWT	Supply Water Temperature. This refers to the temperature of heating hot water supplied to the heating system.
U-value	It is a measure of heat flow or thermal transmittance. Its units are BTU/(h·°F·ft^2). It is the reciprocal of R-value. It is usually used to refer to the heat flow through a construction component.
UA	UA is the product of the area of a construction detail (e.g., above grade walls) and a specified U-value. One pathway to code compliance is where the sum of the UA for all construction components is less than the value based on code U-values. This compliance pathway allows for some tradeoffs in insulation among construction components.
XML	extensible Markup Language. This data language was used to transfer data in and out of the Ekotrope and REM/*Rate*™ rating software.

1 EXECUTIVE SUMMARY



This study examined 127 homes across Maine, of which 29 were manufactured homes. Its purpose was to assess how homes were constructed between 2017 and 2020, how construction impacted energy use, and how building practices compare with the IECC 2009[3], the applicable building code during this time. The study analyzed energy savings if homes were all built to the IECC 2009, and in anticipation of the adoption of the IECC 2015, how much energy would be saved constructing to that new, more restrictive code. The Trust had last studied residential new construction in 2008[4] and completed a separate study of existing homes in 2015. We compared single family results to these previous studies of single family homes.

Figure 1 shows the insulation and infiltration details for single family homes compared with IECC prescriptive requirements. Single family homes were generally well insulated, but fell short of IECC 2009 for ceiling/roof and foundation walls. Figure 2 shows the insulation and infiltration details for multifamily homes. Their attributes were similar to single family homes but fell short for floors and above grade walls in addition to ceiling and foundation wall insulation. Both single family and multifamily homes had infiltration rates lower (i.e., better) than the code requirement of 7 ACH50.

This study modeled average energy use using Ekotrope Rater modeling software. Figure 3 shows energy use of homes by housing type and end use. Heating was the dominant energy use, followed by lighting and appliances. Single family homes used about as much energy as manufactured homes because while they were much larger, they were also more efficient. Multifamily homes used the least amount of energy because they were both small and efficient. For comparison, a stacked column for the 2008 study is shown where the average home used nearly twice the energy of this study's single family home.

[3] IECC (2009), the International Energy Conservation Code

[4] Maine Residential New Construction Technical Baseline Study, May 15, 2008.

Figure 1. Summary of Insulation, Windows, Infiltration for Single Family Homes

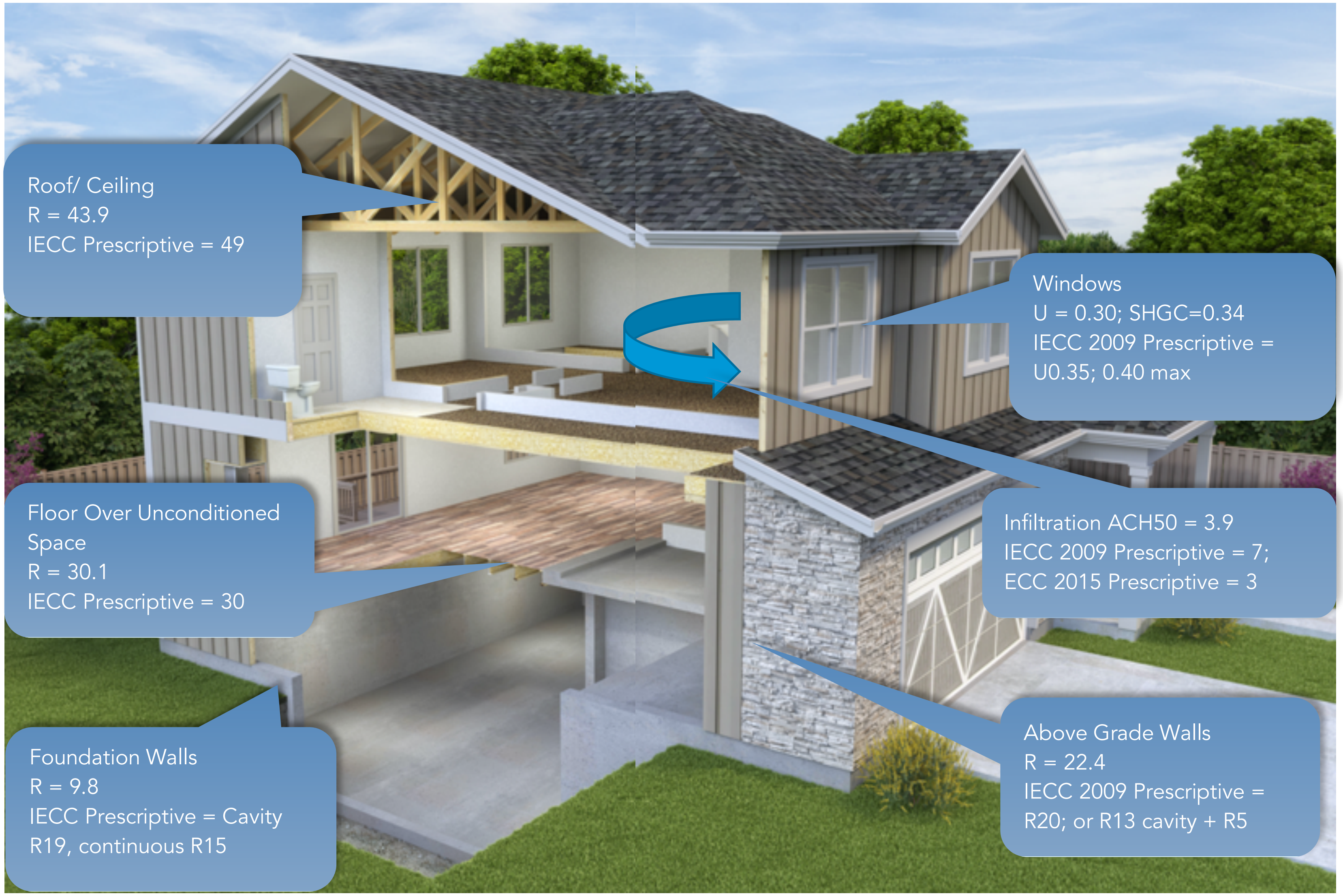


Figure 2. Summary of Insulation, Windows, Infiltration for Multifamily Homes

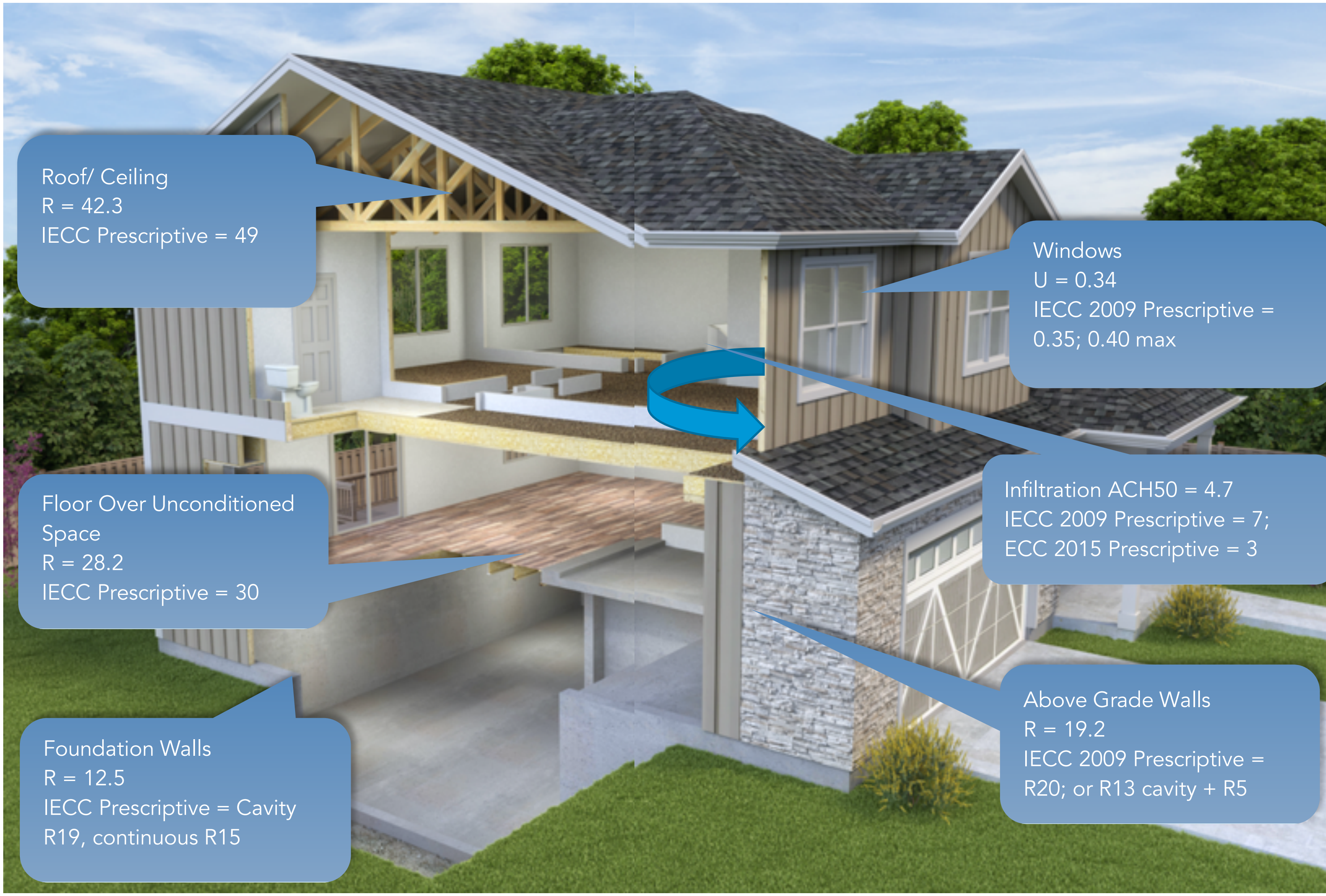


Figure 3. Annual Energy Use by End Use and Home Type

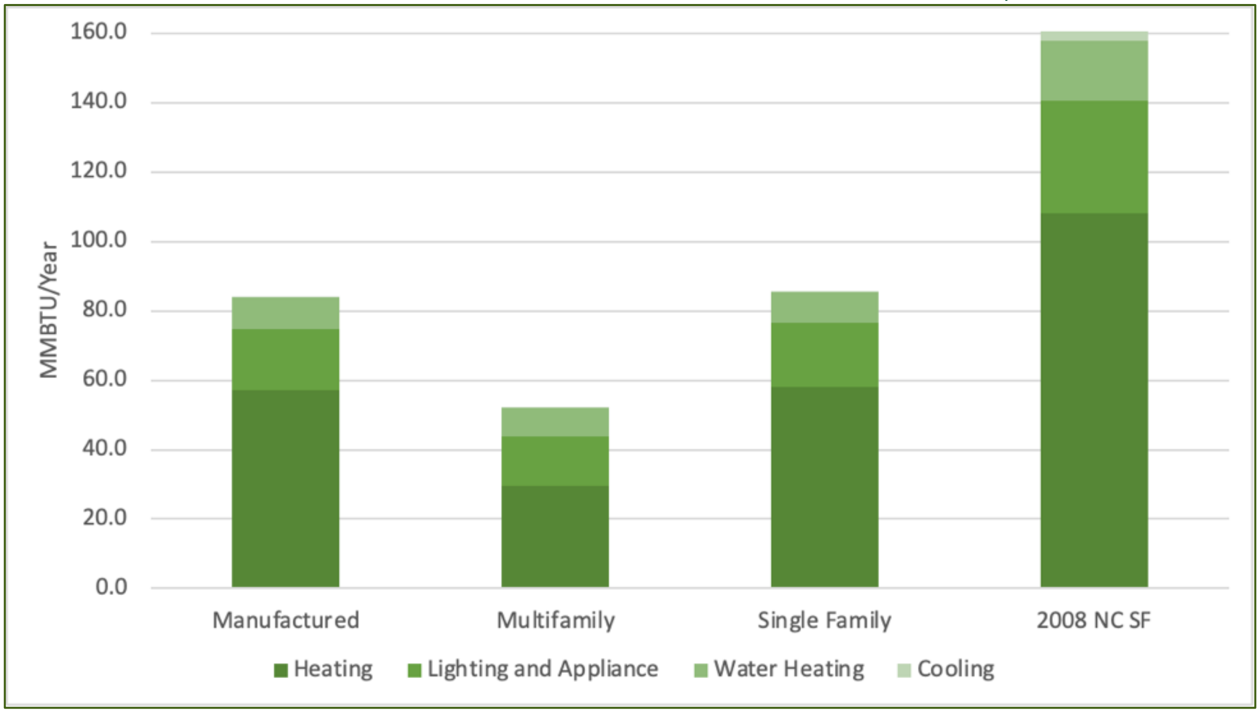


Figure 4 shows annual energy use of homes by home type and size of town. This study examined homes in towns with fewer than 4,000 persons where building codes were not required to be enforced by the municipality, and larger towns where code was enforced at the municipal level. The median predicted energy use for single family homes in smaller towns was about 25% higher than those in larger towns. A similar pattern was present for multifamily homes, but there were only seven multifamily homes in small towns, so this difference is not statistically significant. All single family homes, except for two outliers, had energy use lower than the 78,000 BTU/SF used by the average home in the 2008 study.

Figure 5 shows the heating systems used by the homes in this study. Approximately 20% of homes used electricity as their sole heating fuel, and these systems were heat pumps (HP) with some electric resistance (ER) backup. About 61% of homes used only fuel (oil, propane, or natural gas) for heating. Another 16% used a combination of heat pumps and fossil fuel for heating.

Figure 4. Predicted Energy Use of Homes by Town Population

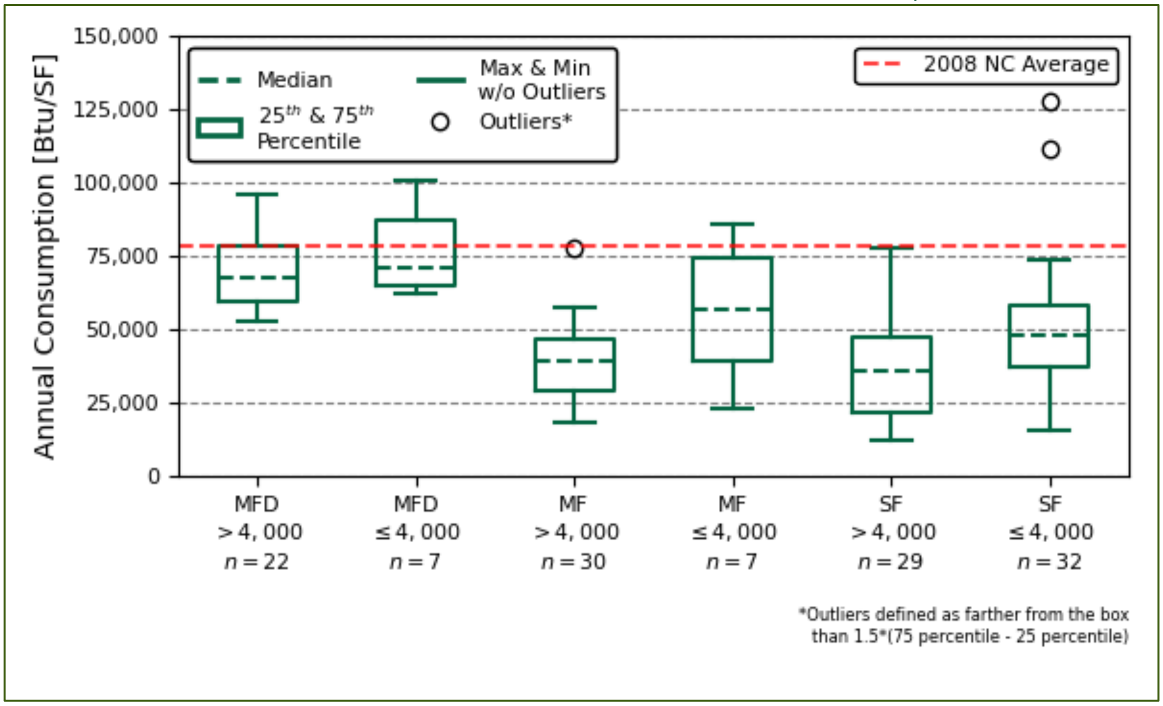
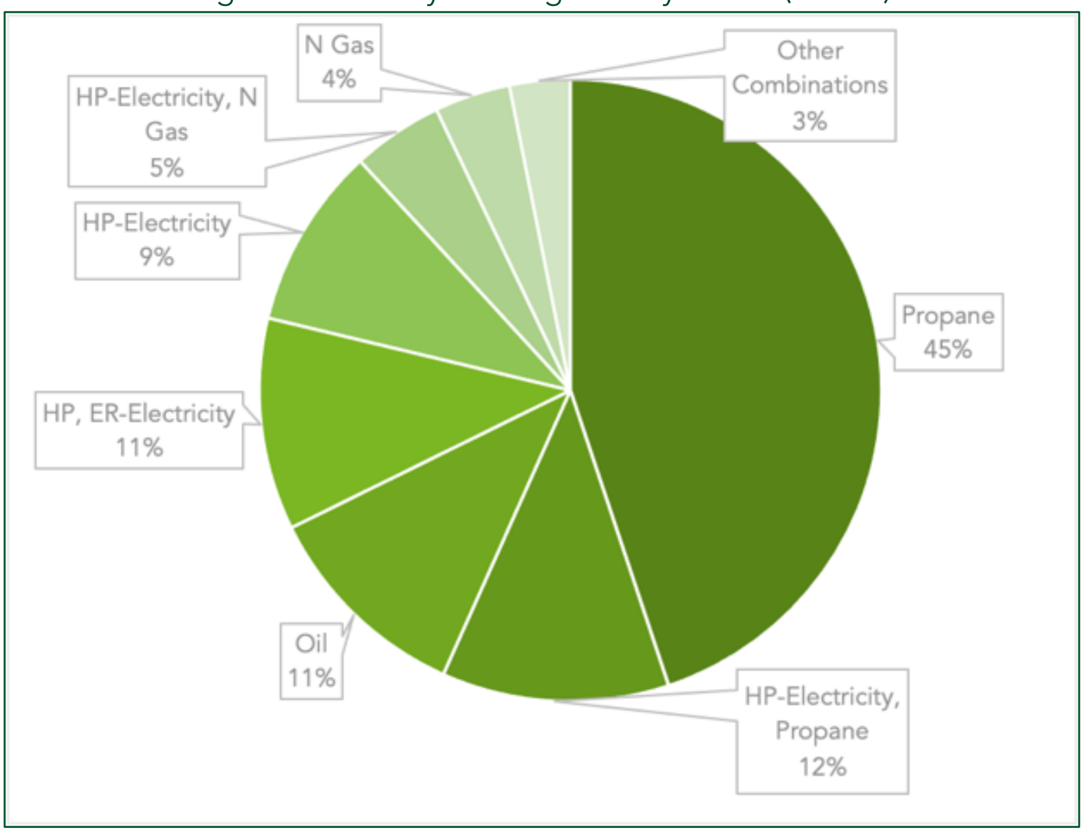
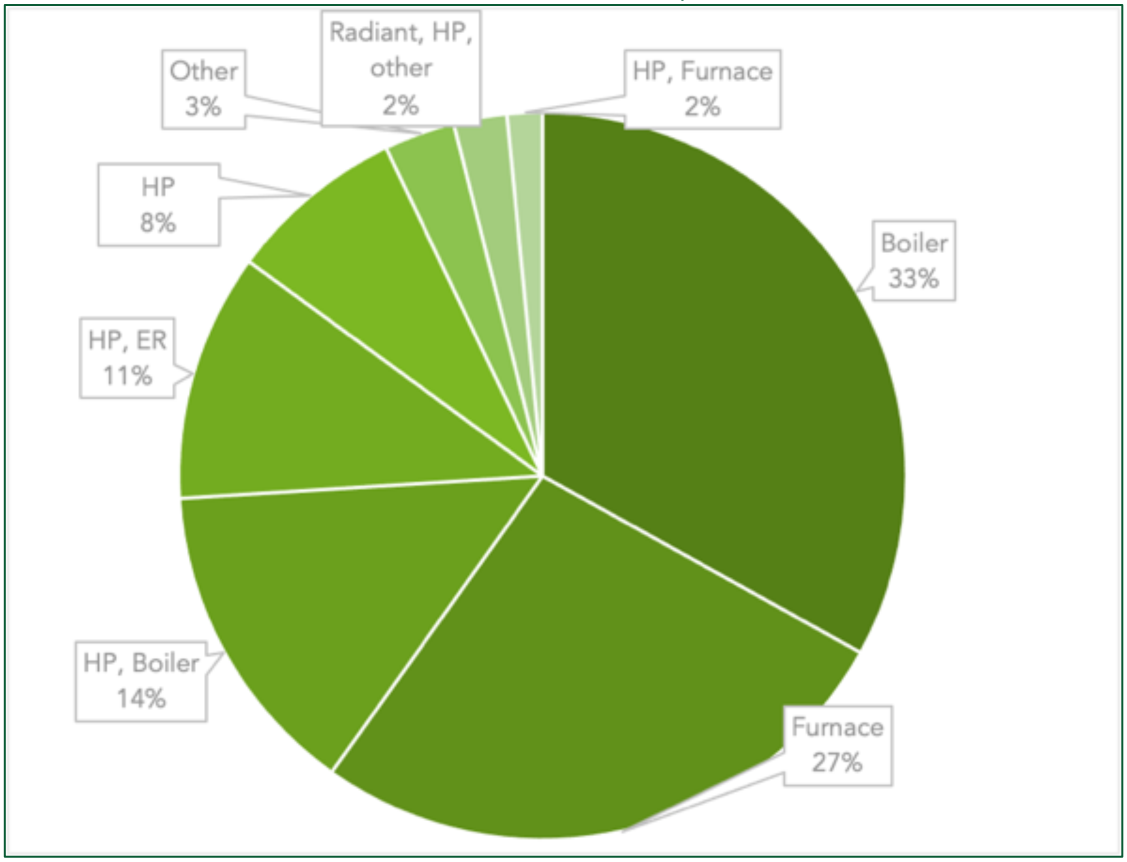


Figure 5. Primary Heating Fuel by Count (n=127)



As Figure 6 shows, while fossil fuel boilers and furnaces were still the most common heating source at a total of 60%, 37% of homes used heat pumps alone or in combination with another heating source. Homes that used only heat pumps or heat pumps with supplemental electrical resistance (ER) heat accounted for 19% of homes. This was a large change from previous Maine housing studies where heat pumps were rare and where present, provided supplemental heating.

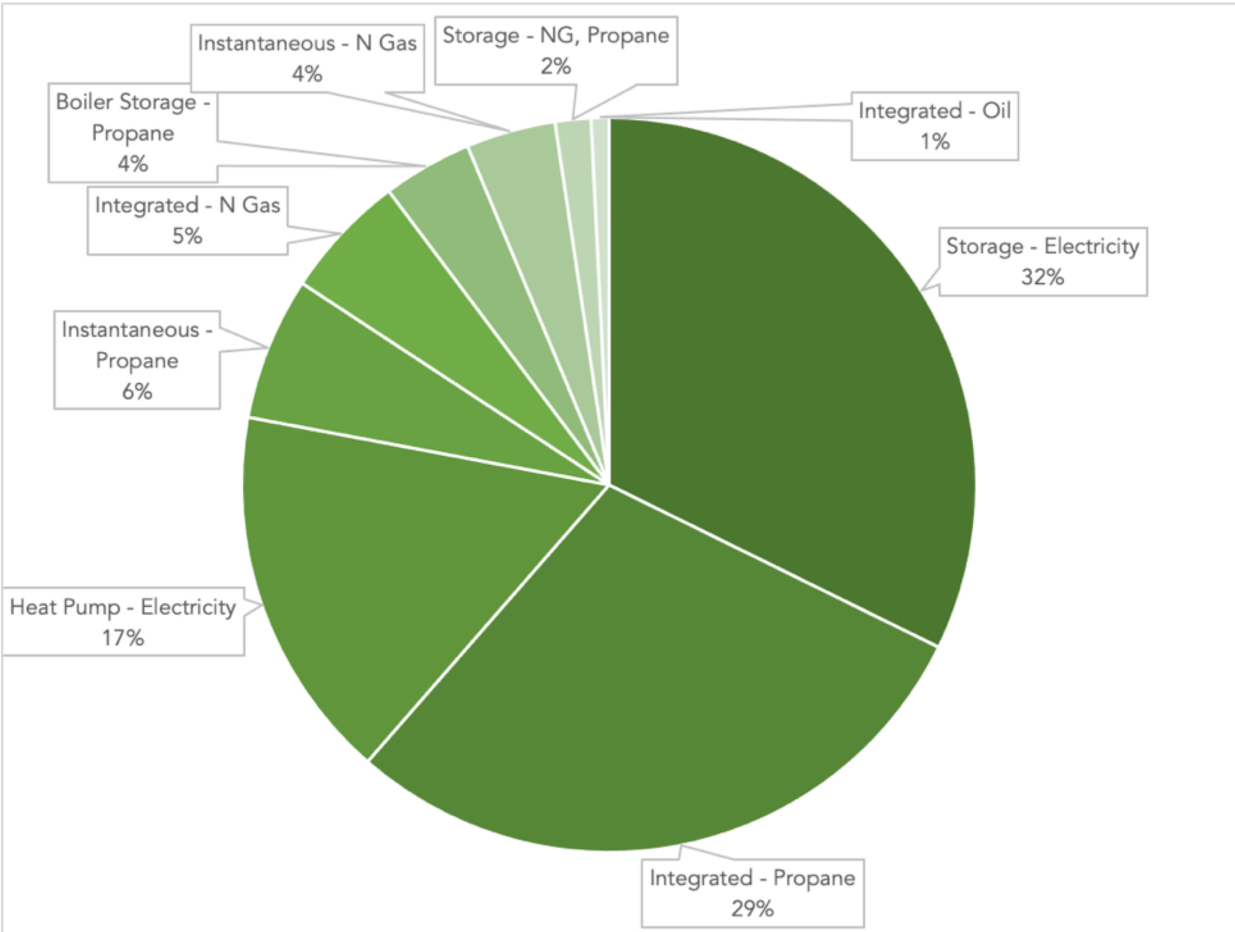
Figure 6. Primary Heating System Type by Home (n=127)



In the 2008 study, oil was the dominant fuel at 75%, while this study found for non-manufactured homes it was 11%. Propane and natural gas were a combined 19% in 2008, and found to be 66% in this study, albeit with a third of those homes in combination with heat pumps. Heat pumps were virtually non-existent for heating and but were the sole heat source for 22% in this study counting combinations with electric baseboard. Heat pumps were present in a total of 37% of homes, although some of those in boiler heated homes may, in practice, be used primarily for cooling.

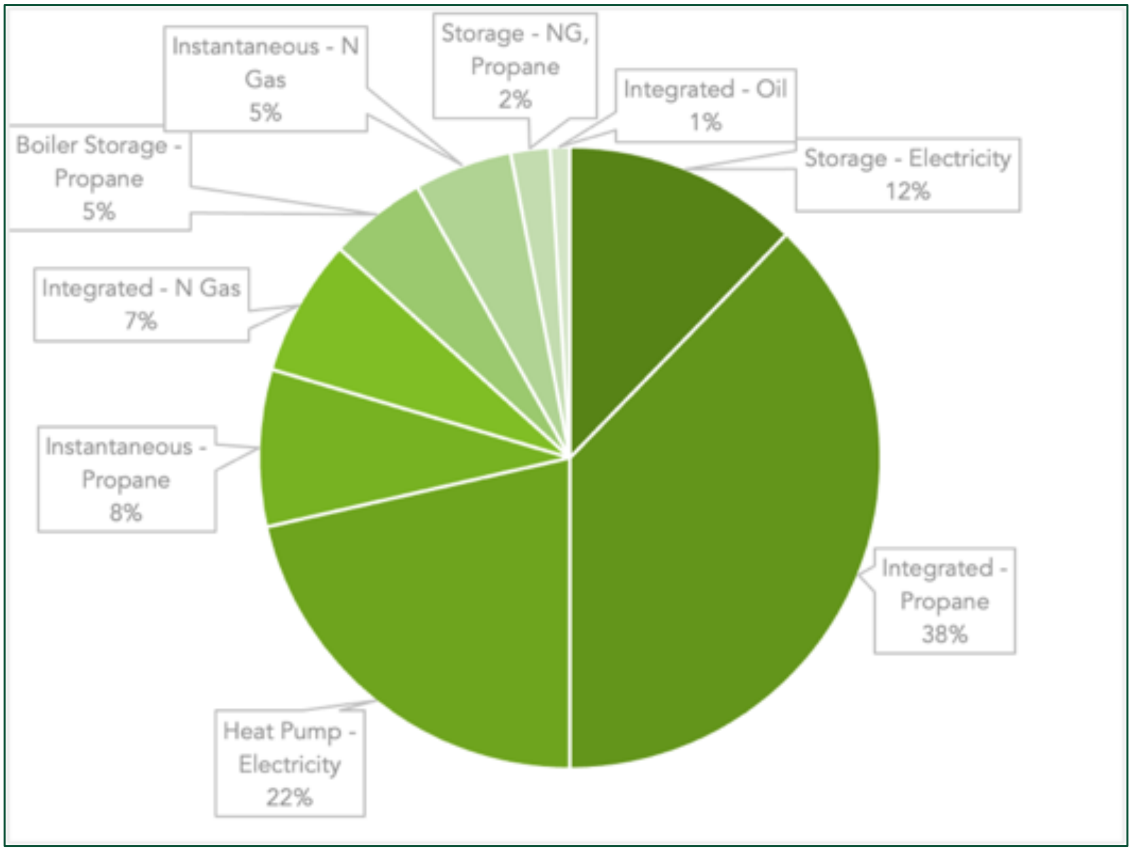
Of the 127 water heaters in this study, electric storage (*Storage - Electricity*) water heaters were the most common (32% of systems) (Figure 7). This was driven, in part, by their prevalence in the study's manufactured homes. Natural gas and propane-heated storage water heaters were not common (2%). Tankless systems integrated with boilers of all types accounted for 35% of systems (*Integrated-Propane; Natural Gas; Oil*). Heat pump water heaters served 17% of homes. Stand-alone instantaneous systems accounted for 10% (*Instantaneous-Natural gas; -Propane*) and systems where a boiler served a storage tank (Boiler Storage-Propane) accounted for 4%.

Figure 7. DHW Systems by Count



Looking at the 98 non-manufactured homes, the technologies shift with storage electric heaters drop to 12% and all other technologies increase proportionally (Figure 8).

Figure 8. DHW Systems by Count: Non-Manufactured Homes



We examined code passing rates for each home including UA values for each construction component, combined UA, infiltration, performance, and the mandatory check list (Table 1). Few homes passed the UA for above ground walls, largely due to insulation installation grading, and therefore few passed the overall UA. Homes performed well for infiltration and for performance.

Table 1. IEC 2009 Code Passing Rates

Components	Ceilings	Windows, Doors	Above Ground Walls	Foundation Walls	Floor	Framed Floor	Combined UA	ACH 50 Test	Performance	Mandatory Checklist
Percent Pass Rate	55%	86%	14%	76%	71%	40%	22%	89%	67%	54%

This study used the Ekotrope models underlying the 127 home reports to model 17 scenarios of improved insulation, infiltration, and HVAC to understand how much energy could be saved by uniformly building to the existing IECC 2009 code and by adopting higher efficiency HVAC equipment and elements of the IECC 2015 code. Table 2 shows individual changes, for example shifting all walls to R-20 produced modest reductions in energy use, on the order of 2%, because only a portion of homes needed improvement to that single component. Scenario 7 (shown with dark borders) combines multiple elements of the IECC 2009 code. It saved 9% of fossil fuel use and 3% of electricity use. Scenario 10 examined the impact of converting fossil fuel heating to heat pumps. It saved 31% of energy shifting energy use to electricity, increasing it by 77% but cutting fuel use by 84%. The most far reaching scenario (17), combined the heat pumps of scenario 10 with envelope elements of the IECC 2015 code. It cut fossil fuel use by 84%, shifting a portion of it to electricity use, increasing electricity use by 51%. It resulted in a net decrease of 40% in overall energy use.

Homes built today are substantially more efficient than those built in 2008 and are also substantially more efficient than the stock of existing homes. There remain both challenges and opportunities in complying with the IECC 2009 and in meeting the future IECC 2015. Manufactured homes remain another source of savings that may be addressed by future HUD codes or other avenues. The growing availability of various types of cold weather heat pumps may present an opportunity for energy savings and reducing the carbon footprint of future new construction.

Table 2. Modeled Savings from Non-Manufactured Homes Meeting Elements of IECC 2009, IECC 2015, and Mechanical Improvements

% Savings Versus Base Case (As-Built)			
Scenarios	HERS Index	Electric Consumption [kWh]	Fossil Fuel [Million BTU]
As-built	0%	0%	0%
Grade I Insulation	4%	1%	5%
IECC 2009 Elements			
S1. R49 (U=0.026) Ceilings	1%	1%	2%
S2. R20 (U=0.060) Walls	2%	1%	2%
S3. R30 (U=0.033) Floors	1%	0%	2%
S4. R15 Foundations	1%	1%	1%
S5. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations	5%	2%	7%
S6. 7 ACH50	1%	1%	1%
S7. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50	6%	3%	9%
S8. U 0.35 Windows	1%	1%	1%
HVAC and Combined Scenarios			
S9. 95 AFUE Gas Equipment	1%	0%	1%
S10. Electric Heat Pump (12.5 HSPF 20 SEER)	2%	-77%	84%
S11. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50 & U 0.35 Windows & Electric Heat Pump (12.5 HSPF 20 SEER)	9%	-65%	84%
IECC 2015 Elements			
S12. 3 ACH50	3%	3%	8%
S13. R20+5 (U=0.045) Walls	6%	2%	8%
S14. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls	9%	3%	13%
S15. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls & 3 ACH50	12%	6%	21%
S16. U 0.32 Windows	1%	1%	1%
S17. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & Electric Heat Pump (12.5 HSPF 20 SEER) & R20+5 (U=0.045) Walls & 3 ACH50 & U 0.32 Windows	15%	-51%	84%

Positive numbers denote savings, (i.e., reductions from As-built). Negative numbers denote increases from the As-built case and arise from switching from fossil fuel to heat pumps for heating, thereby increasing electricity use.

2 INTRODUCTION

In May 2020, Efficiency Maine Trust contracted with Ridgeline Energy Analytics to perform a New Construction Baseline Assessment [of energy efficiency in homes]. Advanced Building Analysis joined the project to lead a team of HERS rating firms: BuildingWorks, Sopher Energy Analysis and Design, and William B. Winkel, Builder.

This study examined 127 homes across Maine, of which 29 were manufactured homes. Its purpose was to assess how homes were constructed between 2017 and 2020, how construction impacted energy use, and how building practices compare with the IECC 2009[5], the applicable building code during this time. The study analyzed energy savings if homes were all built to the IECC 2009, and in anticipation of the adoption of the IECC 2015, how much energy would be saved constructing to that new, more restrictive code. The Trust had last studied residential new construction in 2008[6] and completed a separate study of existing homes in 2015. We compared single family results to these previous studies of single family homes.

The study also examined homes in towns with fewer than 4,000 persons where building codes are not required to be enforced by the municipality[7], and larger towns where codes are enforced at the municipal level. The statistical goal of the study was to visit a sample size large enough to deliver an 80% confidence of 10% relative precision at the house type and at the code enforcement level. To examine homes that represented current techniques and ones that were built to meet the current IECC 2009-based Maine Universal Building Energy Code (MUBEC), we focused on homes built from 2017 to present.

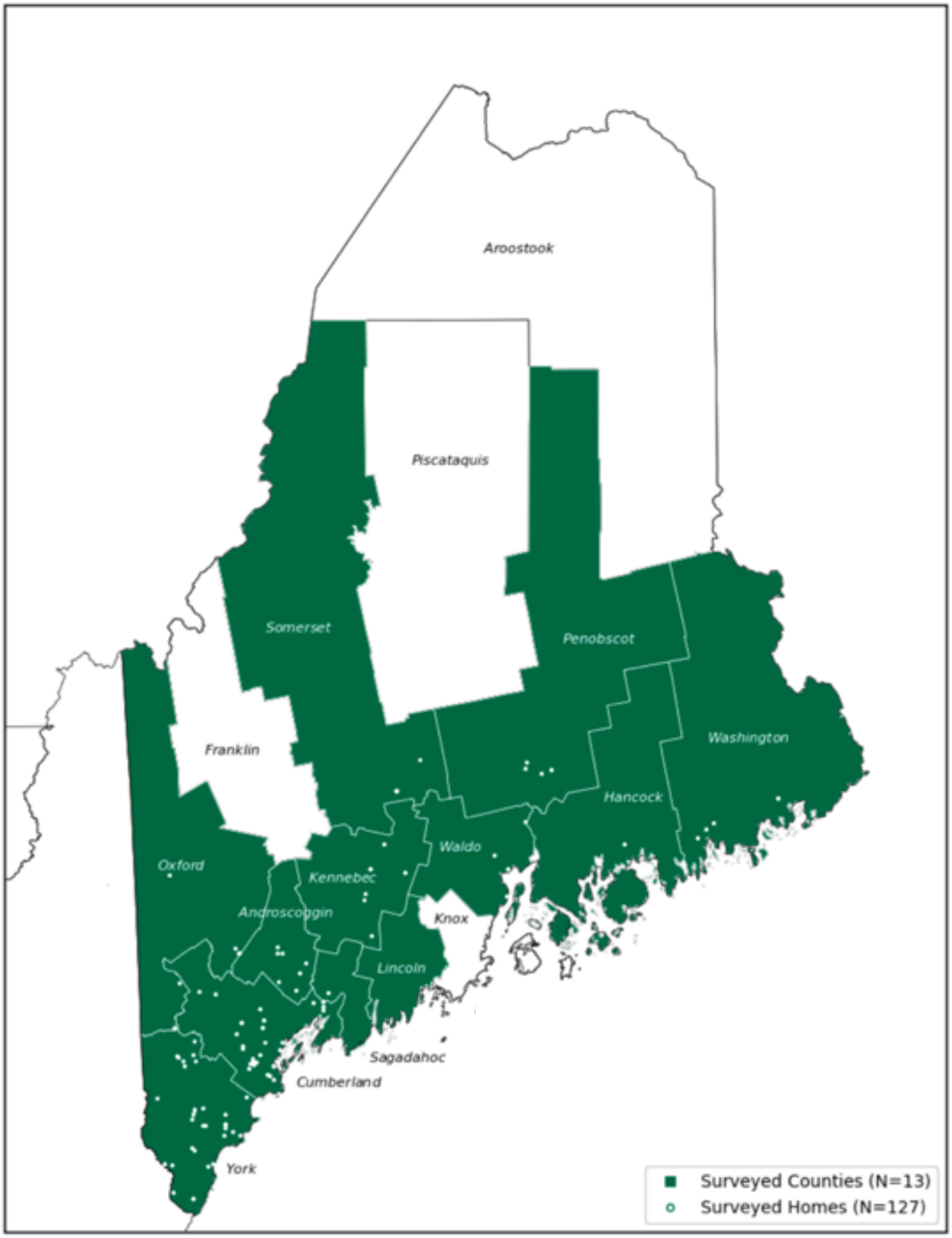
The study gathered details of home construction, and modeled potential energy savings through increased compliance with codes. The study was based on Home Energy Rating System (HERS) inspections developed by RESNET[8], Inc. because inspection and modeling techniques are well established, used throughout the US, ANSI[9] certified, and carried out by trained and certified practitioners. The raters who visited homes included a practicing home builder, an architect, and a building sciences

[5] IECC (2009), the International Energy Conservation Code
[6] Maine Residential New Construction Technical Baseline Study, May 15, 2008.
[7] 10 MRSA §9724, section 1-A "Municipalities up to 4,000 residents.
[8] Residential Energy Services Network
[9] American National Standards Institute

engineer, all of whom received extensive training. Raters used REM/Rate and Ekotrope Rater software to complete the home evaluations. Both software versions can export and import data using XML data transfer techniques. Using the software, Ridgeline simulated homes in both as-built and revised scenarios.

Planning for the study began in July 2020 and recruiting started in late-August and continued through December. Site visits started in late-September and were largely completed by December with a few sites completed in January 2021. In all, 29 manufactured homes, 57 single family homes, and 41 multifamily units were inspected, rated, and analyzed. Figure 9 shows the sites visited in 12 Maine counties. Recruiting effort covered all 16 of Maine's counties.

Figure 9. Homes Studied in Maine



3 METHODS

3.1 OVERVIEW

This section describes methods used for recruiting, home inspections, sample design, and analysis.

3.2 RECRUITING

We began recruiting in late-July 2020. Because of the COVID pandemic, we were concerned with rater and homeowner safety and with homeowner resistance to participation. We initially reached out to builders and manufactured and modular home dealers. We hoped to rate unoccupied homes, reasoning that it reduced COVID-related risk and allowed testing them, as built, with few modifications. While we found several dozen recruits in September and October, generally builders were either uninterested or too busy to participate. We shifted strategy in November to directly recruit homeowners by mail and increased the incentive from $200 to $250. We received a fairly enthusiastic response. More than 10% of recipients responded and we filled most of the study sample by the end of December. Homeowners were curious about how their homes performed with many wanting to discuss this during initial calls. While homeowners were generally enthusiastic to participate, we had several COVID-related cancellations in December and early January.

3.3 SAMPLE DESIGN

The sample targets set for the study were to provide relative precision of ±10% or better at 80% confidence for the following strata:

a. Type of home
b. Code enforcement regime (towns <4,000 persons; towns >4,000 persons)[10]

The type of home was used as a sampling frame based on the hypothesis that different types of homes have different performance. Ridgeline and the Trust discussed and agreed that the two categories of strata would meet 80/10 independently. Results would meet 80/10 for each of three home types, and results would meet 80/10 for two code enforcement categories: with and without code enforcement.

For sample planning we assumed a coefficient of variation of 0.5 and used a desired relative precision of 0.1 at an 80% confidence (2-tailed), Equation 1 returned a sample size of just over 41 which we rounded up to 42.

[10] Pursuant to 25 M.R.S. §2373, in municipalities with a population over 4,000, enforcement of the provisions of the MUBEC shall be the responsibility of the municipality.

Equation 1: Sample Size Calculation Formula for Single and Multifamily Homes

$$n = \left(\frac{1.282 * c.v.}{r.p.}\right)^2 = \left(\frac{1.282 * 0.5}{0.1}\right)^2 = 42$$

For two code enforcement strata, this yielded a total sample of 42 x 2 = 84 homes. Similarly, for single family and multifamily, the two strata yield a sample size of 84. For manufactured homes, we assumed that design and manufacturing controls would produce smaller standard deviations than conventionally built homes. Because we planned to examine a portion of manufactured homes at their distributor's site, post installation site variation would also be reduced. Based on these two factors, we assumed a CV of 0.4. The sample size for manufactured homes therefore was reduced as shown in Equation 2 and yielded a sample size of just over 26 which we rounded up to 27.

Equation 2: Sample Size Calculation Formula for Manufactured Homes

$$n = \left(\frac{1.282 * 0.4}{0.1}\right)^2 \cong 27$$

To provide the desired precision for three strata under each category required a sample of 42 + 42 + 27 = 111. These originally planned sample counts are shown in Table 3.

As we examined data for Maine's stock of newly constructed homes, we realized most multifamily homes were constructed in towns with populations greater than 4,000 persons and therefore recruiting multifamily sites in towns with populations less than 4,000 persons would be difficult. To help us recruit enough homes in the home-type and town-size categories, we developed the following revised sample size in cooperation with the Trust (Table 4). In this new sample, we increased the target of single family homes in towns with less than 4,000 persons and the count of multifamily units in towns with greater than 4,000 persons to help meet the goal of 80% confidence of 10% precision for home categories and town size.

We exceeded the target count of non-manufactured homes and by slightly oversampling multifamily homes in larger towns and single family homes in all towns, we achieved the goal of 80% confidence of 10% precision (Table 5). Of the 27 manufactured homes, 12 were measured on dealer lots. We originally designed the study to measure on dealer lots reasoning that the dealer lot homes were representative. At the onset of the study, we also assumed that direct recruitment of homeowners would be difficult given the COVID pandemic and therefore focused on recruiting builders and manufactured home dealers. As the study progressed, we shifted to homeowner recruitment including owners of manufactured homes.

Table 3. Sample Counts Initially Planned

Town Populations	SF (% RP)	MF (% RP)	Total SF, MF (% RP)	Manufactured
>4,000			42 (10%)	
< 4,000			42 (10%)	
T	42 (10%)	42 (10%)	84	27

SF – Single family; MF – Multifamily.

RP – relative precision at 80% confidence, CV = 0.5

Table 4. Revised Sample Counts

Town Populations	SF (% RP)	MF (% RP)	Total SF, MF (% RP)	Manufactured
>4,000	24	28	52 (9%)	
< 4,000	28	14	42 (10%)	
T	52 (9%)	42 (10%)	94	27

SF – Single family; MF – Multifamily.

RP – relative precision at 80% confidence, CV = 0.5

Table 5. Achieved Sample Counts

Town Populations	SF (% RP)	MF (% RP)	Total SF, MF (% RP)	Manufactured
>4,000	28	32	60 (8%)	
< 4,000	29	9	38 (10%)	
T	57 (9%)	41 (10%)	98	29

SF – Single family; MF – Multifamily.

RP – relative precision at 80% confidence, CV = 0.5

The sampling discussion is all based on a coefficient of variation (CV) of 0.5. While a reasonable assumption for initial design, in the report we noted actual CVs of data. In most cases the CVs of data of interest are below 0.5, and resulted in better than planned confidence and precision. For example, the CV for HERS scores for single family homes was about 15%, so the precision at 80% confidence was well below (better than) 10%.

3.4 EQUIPMENT USED BY HERS RATERS

Raters used the following equipment in performing site visits and rating of homes (Table 6).

Table 6. Equipment Used by HERS Raters

Measurement or Task	Equipment
House pressurization	Blower Door[11] or equivalent to conduct infiltration testing
Duct pressurization	Duct Blaster® [12] or equivalent to conduct duct leakage testing
Ventilation testing equipment	Exhaust fan flow hood or a powered flow hood were used to conduct ventilation testing
Infrared inspections to examine various heat signatures, for example to detect the presence of insulation in finished wall cavities	Thermal camera
Basic tasks	Ladders and step stools, set of screw drivers, tape or laser measure, flashlight
Air and water temperature measurements	Thermo-pens[13]
CO_2 measurements	Telaire[14] CO_2 meters
Safety	Facemask, gloves, safety glasses or goggles

3.5 FIELD DATA COLLECTION

3.5.1 General Data Collection

Raters collected the information outlined in Table 7. These data served as a basis for summary statistics and for HERS modeling and rating. An example of observing blown-in ceiling insulation is shown in Figure 10.

[11] https://energyconservatory.com/products/?categories=11, accessed January 21, 2021
[12] https://energyconservatory.com/products/product/ductblasterdg1000/?categories=11, accessed January 21, 2021
[13] https://www.thermoworks.com
[14] https://www.amphenol-sensors.com/en/air-quality-sensors

Table 7. General Data Collected

1. Basic characteristics:
    a. Conditioned space square footage
    b. Number of bedrooms
    c. Type of basement: conditioned/unconditioned/partially conditioned (if applicable)
    d. Existence of builder certificate on or in the electrical distribution panel detailing home energy features: R-values, U-values, SHGC, heating/cooling/water heating efficiencies
    e. HERS rating
        i. We determined a projected value and, where requested, developed a confirmed HERS Rating.
2. Building shell
    a. Type of foundation: basement, slab-on-grade, crawl space, skirt
    b. Insulation R-value and installation grade: ceiling/attic, walls, floor/basement
    c. Fenestrations square footage, U-values, SHGC, number of panes, frame
    d. Access doors and hatches weather stripping and R-value
3. Air leakage (using pressurization fan)
4. HVAC details
    a. Heating system(s) type, fuel, capacity and efficiency: primary and supplemental, including portable space heaters
    b. Heating distribution system(s): ducted, direct, hydronic, radiant
        i. Boiler pump details (if applicable)
        ii. Air handling fan details (if applicable)
    c. Mechanical system piping R-value (if applicable)
    d. Duct R-value (if applicable)
    e. Duct leakage (if applicable – using duct pressurization fan)
    f. Cooling system(s) type, efficiency, nameplates, A coils
    g. Setpoints and actual measured space temperature
5. Ventilation system(s) and fan(s) type, schedule, efficiency, existence of dampers.
    a. Air to air heat exchanger details (if applicable).
6. Domestic hot water system(s) type, fuel, set point and efficiency.
    a. Nameplates
    b. Actual temperature at nearest faucet
7. For hard-wired fixtures: lamp style, technology
8. Major appliances
    a. Refrigerator nameplate
    b. Clothes washer nameplate
    c. Clothes dryer fuel type and nameplate

Figure 10. Measuring Stick Aiding in Observation of Blown in Insulation

3.5.2 House Pressurization (Blower Door)

Raters used a Blower Door or equivalent to conduct infiltration testing and followed ANSI/RESNET/ICC 380-2019, Section 4. In the test, a pressurization fan was installed in an exterior doorway and all windows and all other exterior doors were closed (Figure 11). The procedure had detailed instructions for what to do with dampers, attic, and basement doors and other access points. The home was pressurized and air flow measurements were collected. Figure 11 shows a rater setting up a blower door.

3.5.3 Duct Pressurization Fan

Raters used a Duct Blaster® or equivalent to conduct duct leakage testing and followed ANSI/RESNET/ICC 380-2019, Section 5. In this test, the house was pressurized to the same pressure of the duct pressurization fan and the test was conducted to determine duct leakage outside of the building envelope. Figure 12 shows a Duct Blaster® set up on a ceiling register.

Figure 11. Rater in Action Using Blower Door

Figure 12. Duct Blaster® Attached to Ceiling Register

3.5.4 Other Ventilation Measurement

For other equipment, including bathroom fans and dedicated energy recovery ventilation, raters used either an exhaust fan flow hood or a powered flow hood[15] to conduct ventilation testing as described in ANSI/RESNET/ICC 380-2019, Section 6.

3.5.5 CO_2 Measurement

Using a Telaire CO_2 meter, raters took outdoor readings at selected sites and then took one or more readings in each home. The outdoor readings served to check the meters and the relative accuracy. (Figure 13)

Figure 13. Interior CO_2 Reading

3.5.6 Space Temperature Measurement

Raters collected one or more readings in each home, generally nearest the thermostat using an instant read digital thermometer.

3.5.7 Hot Water Temperature Measurement

Raters collected the hot water temperatures at kitchen sinks using an instant read digital thermometer.

3.6 ANALYSIS

3.6.1 Extraction of Ekotrope data, APIs and XML

[15] https://www.trutechtools.com/FlowFinder2?web=1&wdLOR=c8E748BB8-F15D-D643-8D66-6D8124620F2B

The raters recorded their site visits in either REM/*Rate*™ or Ekotrope software. REM/*Rate*™ models were converted to Ekotrope using the provided XML data pipeline. The data in Ekotrope was extracted and summarized using a combination of their batch download and API tools. Data was manipulated and built into graphs and tables using a combination of Excel and Python.

3.6.2 R-Values

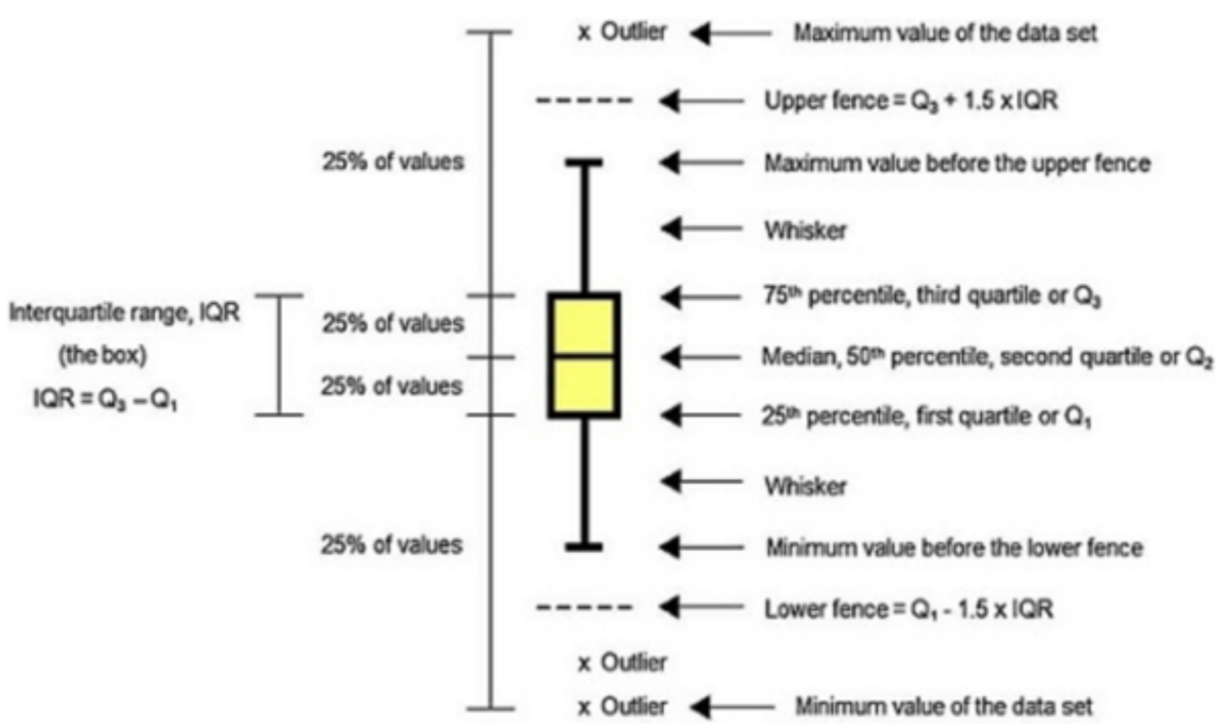
We show average R-values using two methods and each has its own purpose. The first is an area-weighted average that gives the reader a sense of what R-values are being installed. For example, if two-thirds of the wall area was insulated with R-19 batts and the other third with R-11 batts, the area weighted average R-value would be 16.4. The second method is more representative of heat loss in that it gives more weight to components with low insulation and high heat loss. First the area weighted U-value is calculated using the reciprocal of the added R-value. Then the reciprocal of that U-value yields a heat loss weighted average R-value. In this example the 16.4 above becomes 15.3. We display both values, and in most cases, they are similar.

3.6.3 Box and Whisker Figures

The box and whisker plots are used extensively in this report. These plots are a statistical graphic designed to highlight important characteristics of a data set and its distribution. They provide basic statistical details like median and percentile groupings, and illuminate outliers that exist beyond the central cluster of the data. The bottom and the top of the box show the 25th and the 75th percentile[16] values respectively and the mid-line of the box is the median value. The whiskers extend to the last data point within 1.5 times the height of the box, also termed the interquartile range or IQR. Outliers beyond the whiskers are shown as circles. Figure 14 illustrates the parts of the box and whisker plot.

[16] A percentile is a number where a certain percentage of scores fall below that number. For example, a data value at the 25th percentile means that 25 percent of the data are below that value and 75 percent are above that number. Conversely a value at the 75th percentile means that 75 percent of the data are below that value and 25 percent are above.

Figure 14. Elements of the Box and Whisker Plot[17]



3.6.4 Scenario modeling

We modeled various scenarios including:

- Converting insulation grades from III to I, essentially upgrading insulation that had been given the lowest grade III as required for any insulation that the rater could not see.
- Upgrading the insulation in individual construction elements (e.g., above grade walls) to IECC 2009 prescriptive U-value requirements.
- Upgrading the insulation in individual construction elements (e.g., above grade walls) to IECC 2015 prescriptive U-value requirements.
- Upgrading all insulation in each home to IECC 2009 and IECC 2015 prescriptive U-value requirements (2 scenarios)
- Upgrading infiltration to meet IECC 2009 and IECC 2015 requirements (2 scenarios)
- Upgrading fossil fuel heating systems to an AFUE of 95%.

[17] Source: Graphical representation of chemical periodicity of main elements through boxplot, João Elias Vidueira Ferreira, Maria Tayane Silva Pinheiro, Wagner Roberto Santos dos Santos, Rodrigo da Silva Maia. Universidad Nacional Autónoma de México, Facultad de Química, Vol 27, No 3 (2016)

- Converting all heating systems to heat pumps with an HSPF of 12.5 and a SEER of 20—the 75th percentile values of heat pumps actually installed in studied homes.

For each scenario, elements of homes that meet or exceed code requirements were left as is and only elements that were worse than code are upgraded.

To model these scenarios, we contracted with Ekotrope directly because the software is not yet fully equipped to run these complex scenarios. The software is currently capable of setting a set of parameters to a single target for a scenario, but this would have caused elements better than code to be downgraded to a code target. For simple scenarios in this report, we used the XML tool previously mentioned and the Ekotrope scenario building feature.

4 HOME CHARACTERISTICS

Although homes studied were essentially self-selected, we were able to recruit a wide range of homes. Homes studied varied in a variety of ways. Homes varied from those not yet occupied, offered by the builder, to homes that had been lived in for up to 3 years. Homes were located from the south in Kittery to Downeast Maine in Machias (Figure 9). Homes came from towns with less than 4,000 persons and from the largest towns and cities in Maine. Figure 15 shows that single family homes accounted for 45% of homes, split between town sizes, while multifamily homes accounted for 27% of homes, and were primarily from larger towns. Figure 16 shows homes by type and year constructed. Years 2018 – 2020 are approximately evenly represented with fewer homes constructed in 2017. Single family homes averaged about 2,123 SF (SF) of conditioned space and multifamily units and manufactured homes were smaller. The average home studied had 2.6 bedrooms (Table 8).

Figure 15. Homes Studied by House Type and Town Population

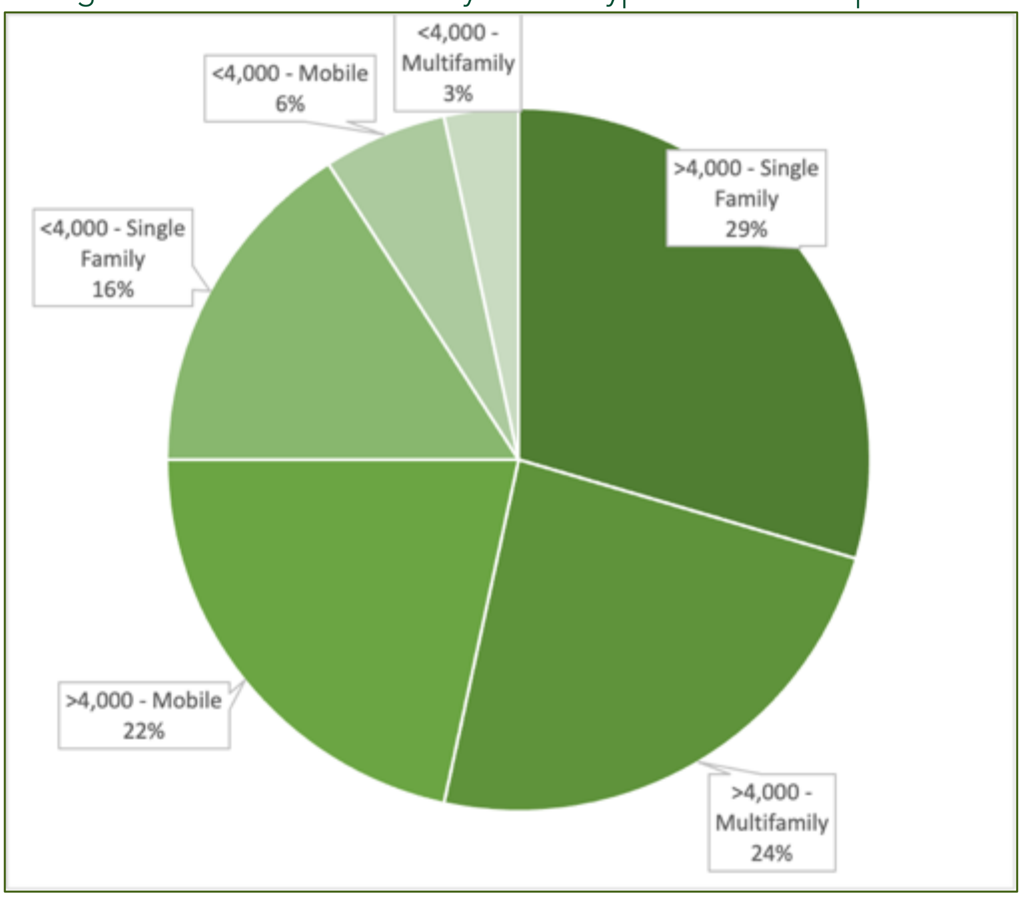


Figure 16. Homes Studied in Maine by House Type and Year Constructed

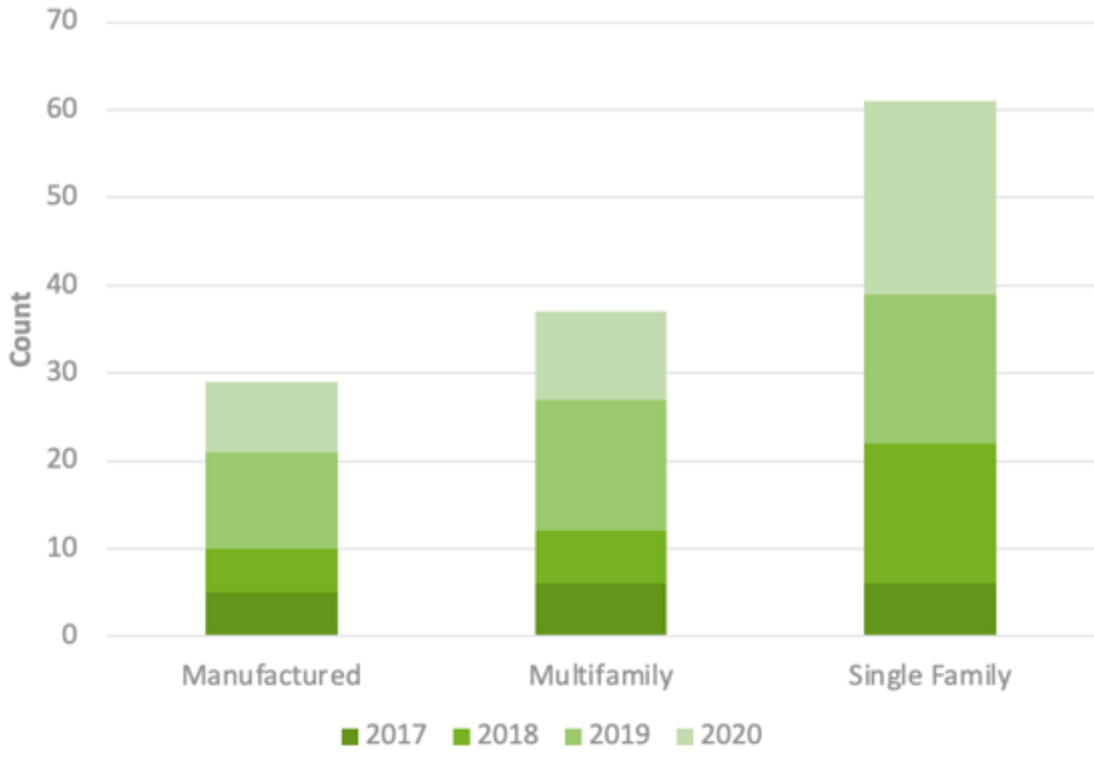


Table 8. Average Home Attributes by Home Type

	Conditioned Area	Bedrooms	Floors
Manufactured	1,200	2.4	1.0
Multifamily	1,299	2.3	1.7
Single Family	2,123	2.9	1.8
All Homes	1,584	2.6	1.6
2008 Study, single family	2,057	3.1	
2015 Existing Homes	2,245		

Figure 17 shows the range of home size by type. Single family homes varied widely with the median size nearly identical to that of the 2008 New Construction Study. Manufactured and multifamily units were smaller, as expected, but there were some multifamily units over 2,500 SF. Table 9 shows the type of underfloor space by unit type. All manufactured homes were over a crawl space, with the other units split among types, with an unconditioned space the most prevalent.

Figure 17. Size of Homes Studied

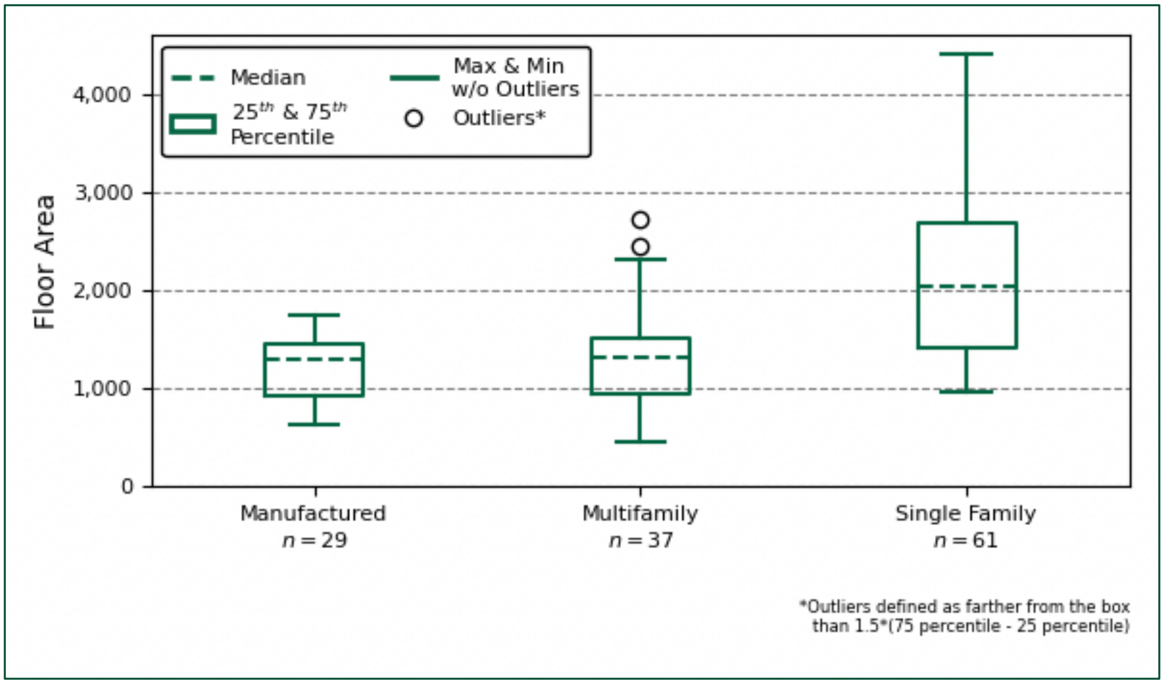
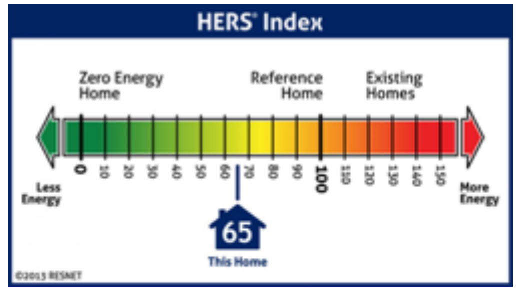


Table 9. Basement Type by Type of Home

	Manufactured	Multifamily	Single family	Total	%
Apartment above conditioned space		4		4	3%
Conditioned basement		2	12	14	11%
Enclosed crawl space	1		2	3	2%
More than one type		3	14	17	13%
Open crawl space/raised floor	28			28	22%
Slab		11	12	23	18%
Unconditioned basement		17	21	38	30%
Total	**29**	**37**	**61**	**127**	100%*

*Column does not add to 100% due to rounding

5 ENERGY USE AND HERS SCORES



5.1 OVERVIEW

The basis of this study was a HERS-based analysis using Ekotrope Rater and RemRate software to organize observations and develop calculated metrics. While the HERS analysis generated dozens of useful metrics, the HERS score was a simple high level means of comparing homes within the study and examining trends from previous studies. HERS is an index for calculating how energy efficient a home is. The Residential Energy Services Network (RESNET) originally launched this index in 2006 and it has become an industry standard for evaluating a house's overall energy performance. On the index, lower is better—it means that the home will generally use less energy. A score of 100 reflects a home built to IECC 2006 and a score of 0 is equivalent to a net zero home. More recently, HERS scores have been accepted as a component of code compliance where a score of 54 is consider compliant with IECC 2015.

5.2 HERS INDEX SCORES

Figure 18 shows box and whisker plots of HERS scores for manufactured, multifamily, and single family homes. For comparison, the HERS score equivalent to the performance pathway of IECC 2015 (54) is shown, as are the equivalent scores to IECC 2006 (100) and the rough approximation to IECC 2009 of 83 for Climate Zone 6.[18] The average multifamily score was 55, just above (worse than) the IECC 2015 performance score. The average single family score was 60, with a median of 57. Manufactured homes averaged about 88. These scores were tightly grouped as one might expect for a manufactured product. Figure 19 shows individual HERS scores. The highest score was 162 which came from a house with high infiltration rates.

[18] https://www.resnet.us/wp-content/uploads/HERS-Index-Scores-and-Versions-of-the-IECC.pdf

Figure 18. Ranges of HERS Scores by Residential Type

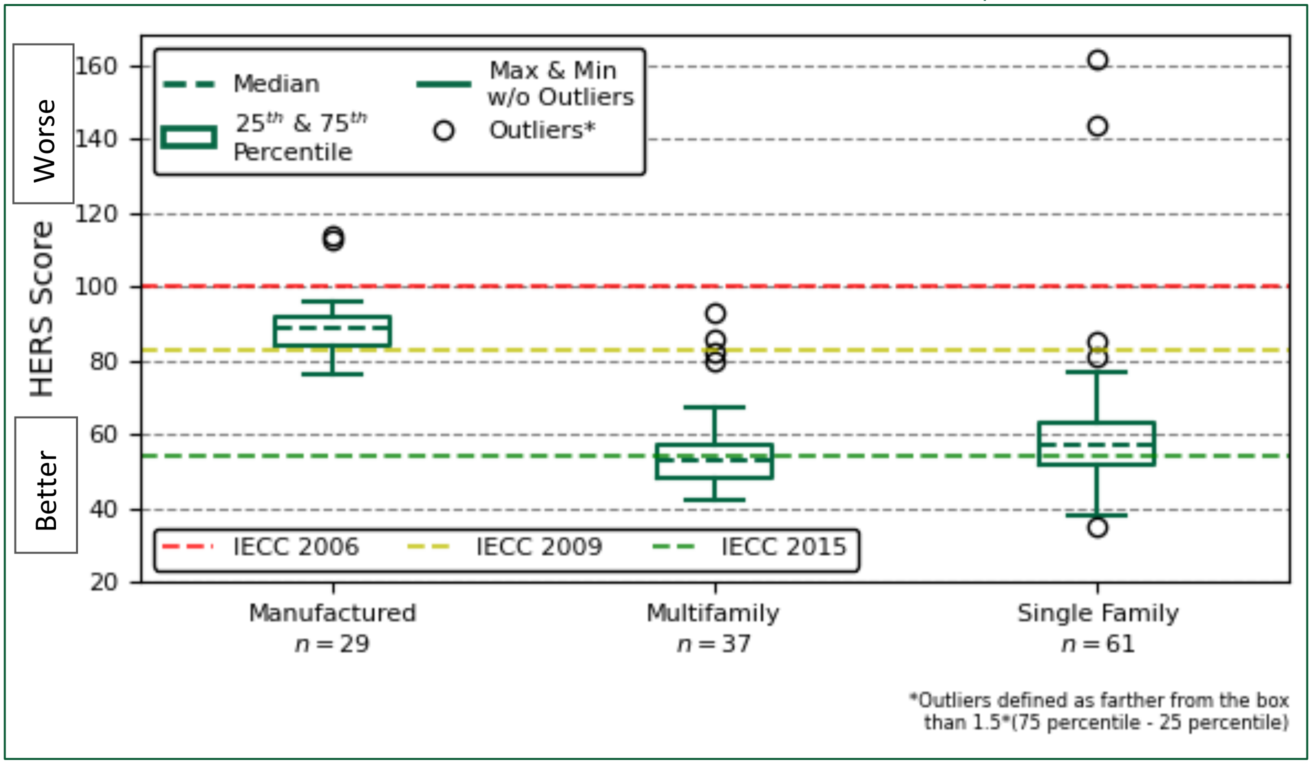


Figure 19. Individual HERS Scores by Residential Type

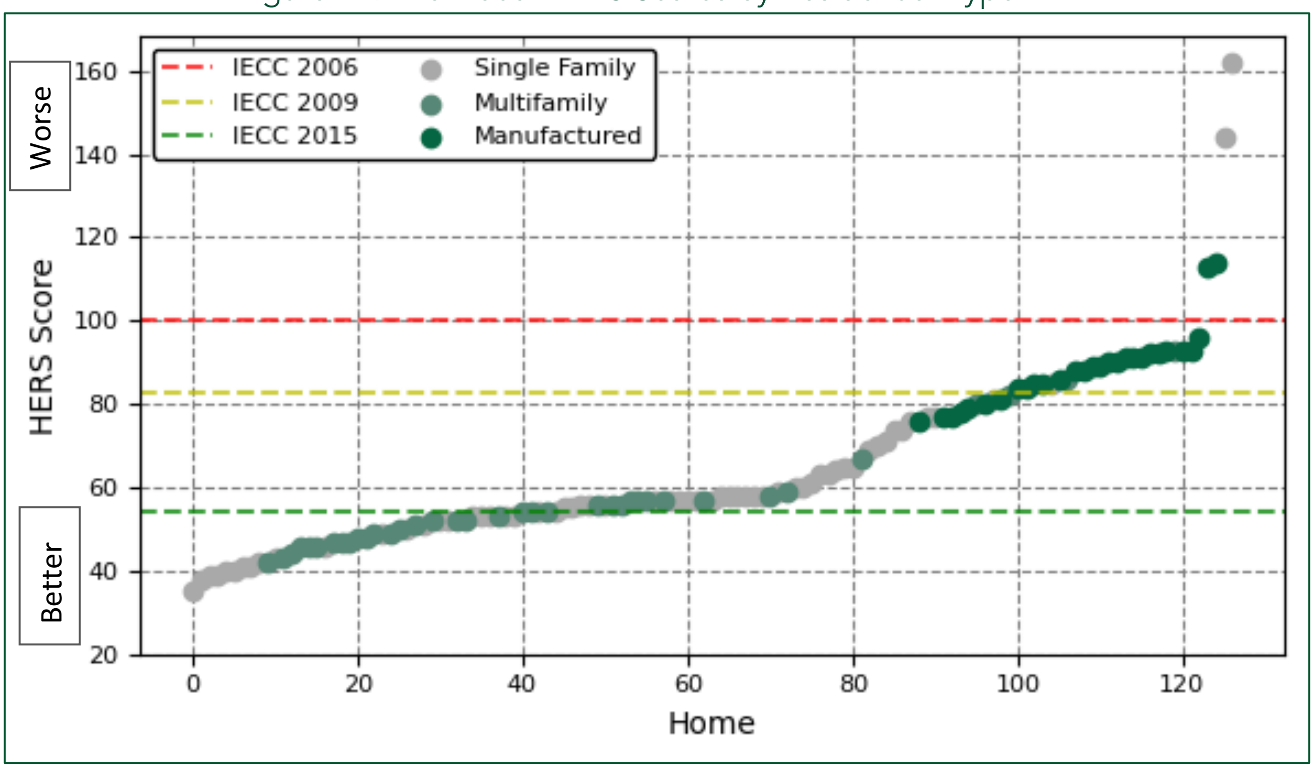
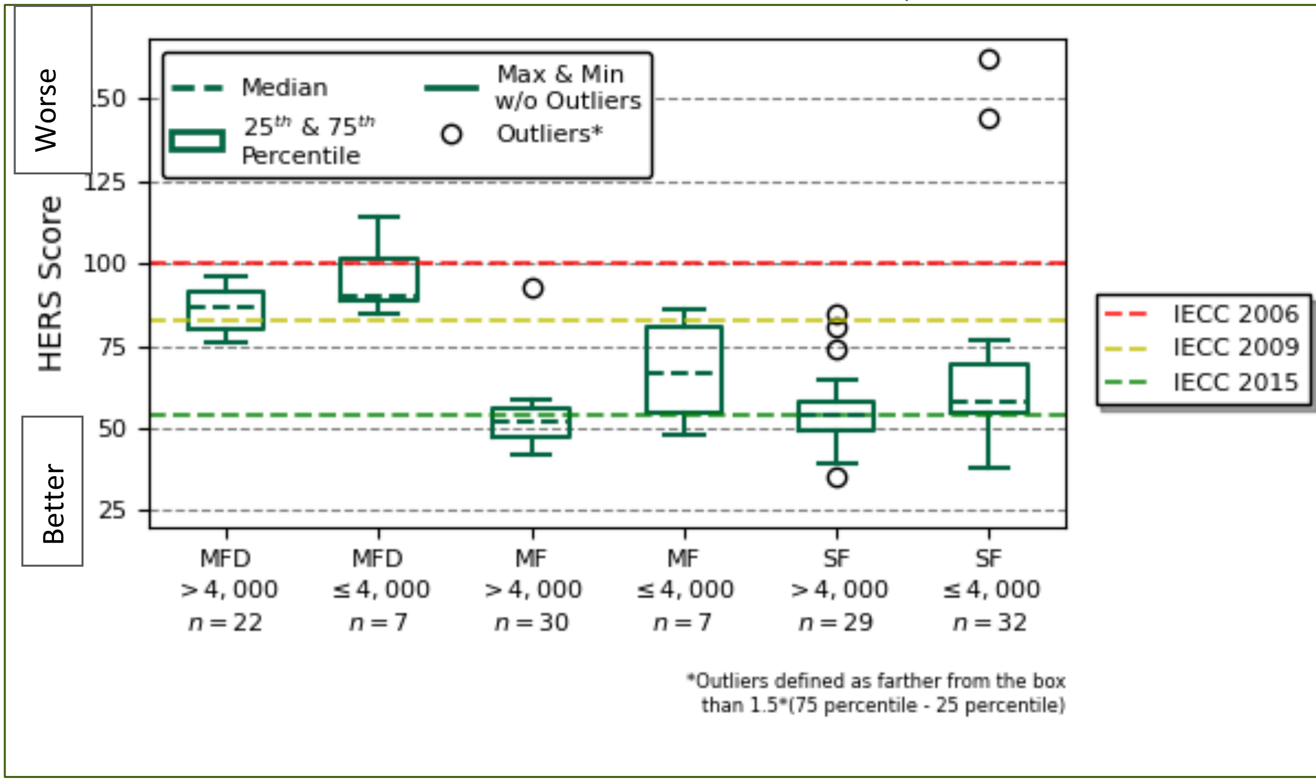


Figure 20 shows HERS scores by home type and by town size (<> 4,000 persons). The HERS scores for multifamily units in regions without code enforcement were higher (worse). The data ranges overlap, with the 75th percentile (poorer) of the HERS scores in large towns matching the 25th percentile (best) scores in smaller towns. Similarly, for single family homes, homes in large towns had lower (better) scores than small towns. However, the median scores were close, and the small-town scores were skewed higher by two outliers. Essentially the better homes had similar scores in large and small towns, but the small towns had more homes with poor scores.

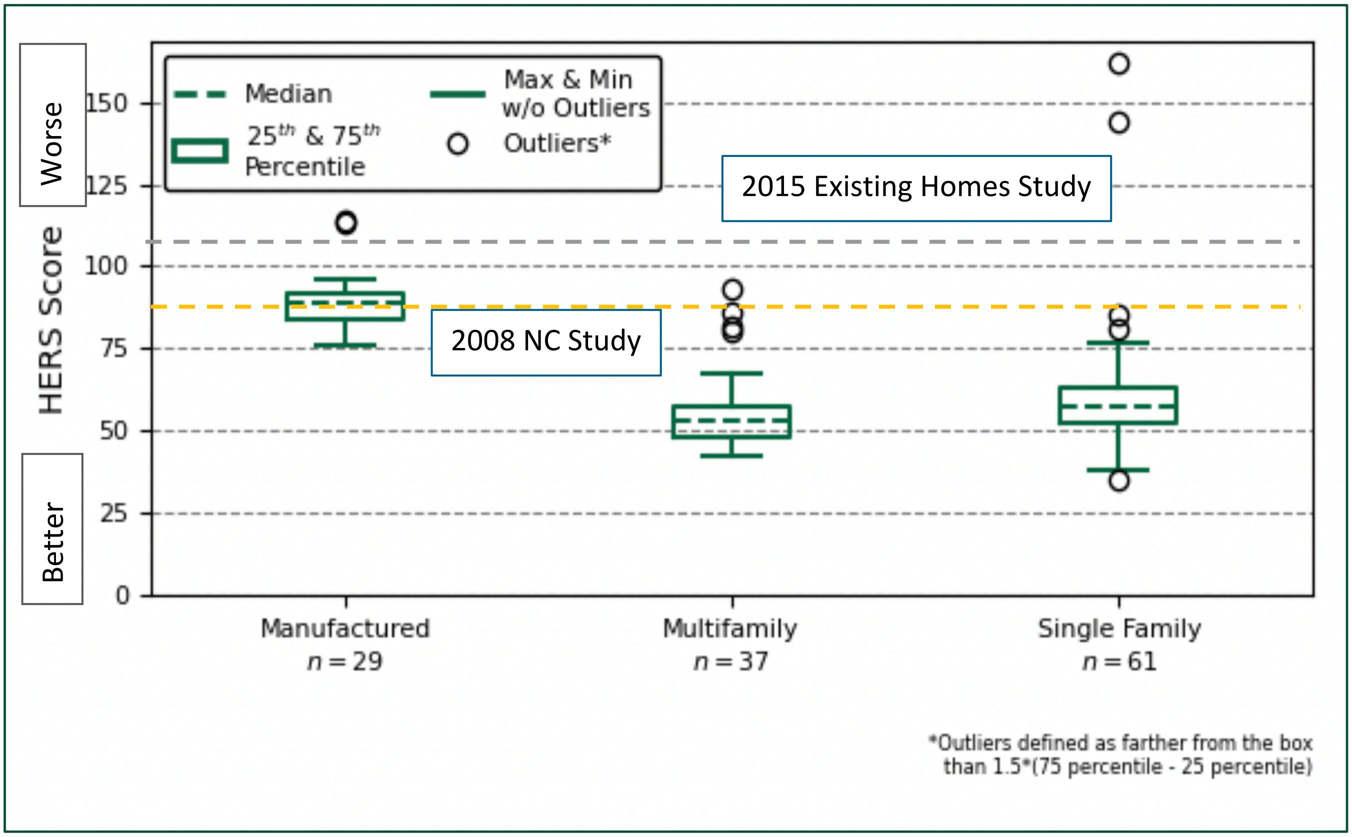
Figure 20. HERS Scores of Homes by Town Population



5.3 HERS SCORES COMPARED WITH PREVIOUS STUDIES

Figure 21 shows the same box and whisker plots shown in Figure 18 along with average HERS scores for the 2008 and 2015 Maine studies. Both of the studies were most directly comparable with non-manufactured homes. The average HERS score in the single family 2008 study was 86, well above (worse than) this study's single family home's average of 60. This drop of more than 25 points indicates that, today, single family homes in Maine are built to be substantially more energy efficient than even a decade ago. Scores in this study were also well below (better than) the housing stock study done in 2015.

Figure 21. HERS Scores by Home Type Versus Previous Studies



5.4 PREDICTED ENERGY USE

We used Ekotrope Rater to model energy use for each home. The average home was predicted to use 50 MMBTU of fuel and 24.5 MMBTU of electricity per year. This equates to about 550 gallons of propane and 7,180 kWh. In Figure 22, fuel and electricity use are shown in a stacked column where the top of the stack is the total annual energy use in MMBTU. It is interesting that the homes using the least energy tend to be all or mostly electric.

Figure 22. Predicted Annual Energy Use of Homes

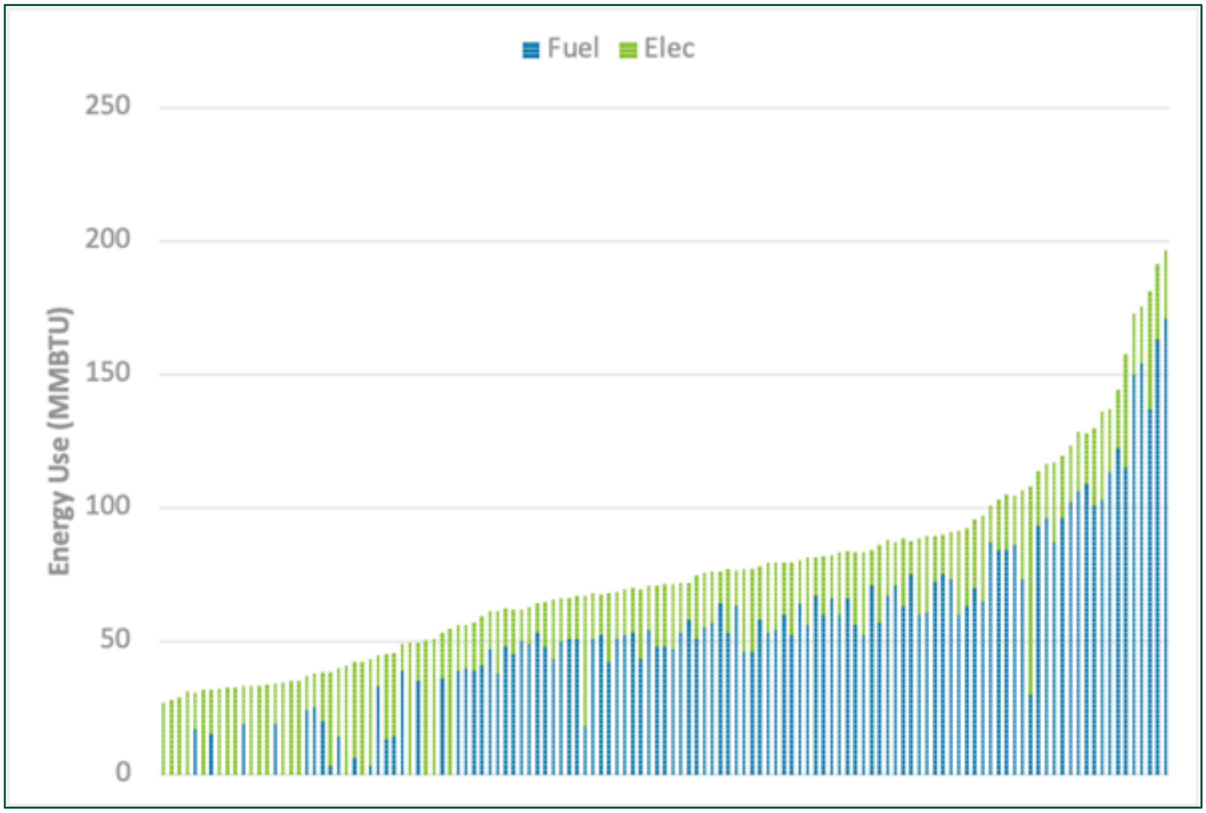


Figure 23 shows the predicted energy use for 127 homes with the type of home shown by colored dot. Manufactured homes are in the middle of the chart. They tend to be smaller using less energy, but they were also less efficient so therefore occupy the middle of the chart.

Figure 24 accounts for this, where energy use was normalized to square foot. Most manufactured homes were in the upper right signifying high energy use per square foot. They were joined by several outlier single family homes.

Figure 25 shows the energy use of homes by housing type and divided by end uses. Heating was the dominant energy use, followed by lighting and appliances. Single family homes used about as much energy as manufactured homes because while they were much larger, they were also more efficient. Multifamily homes used the least energy because they were both small and efficient. For comparison a stacked column for the 2008 study is shown. The average home used nearly twice the energy as this study's single family home.

Figure 23. Individual Energy Use (fuel plus electricity)

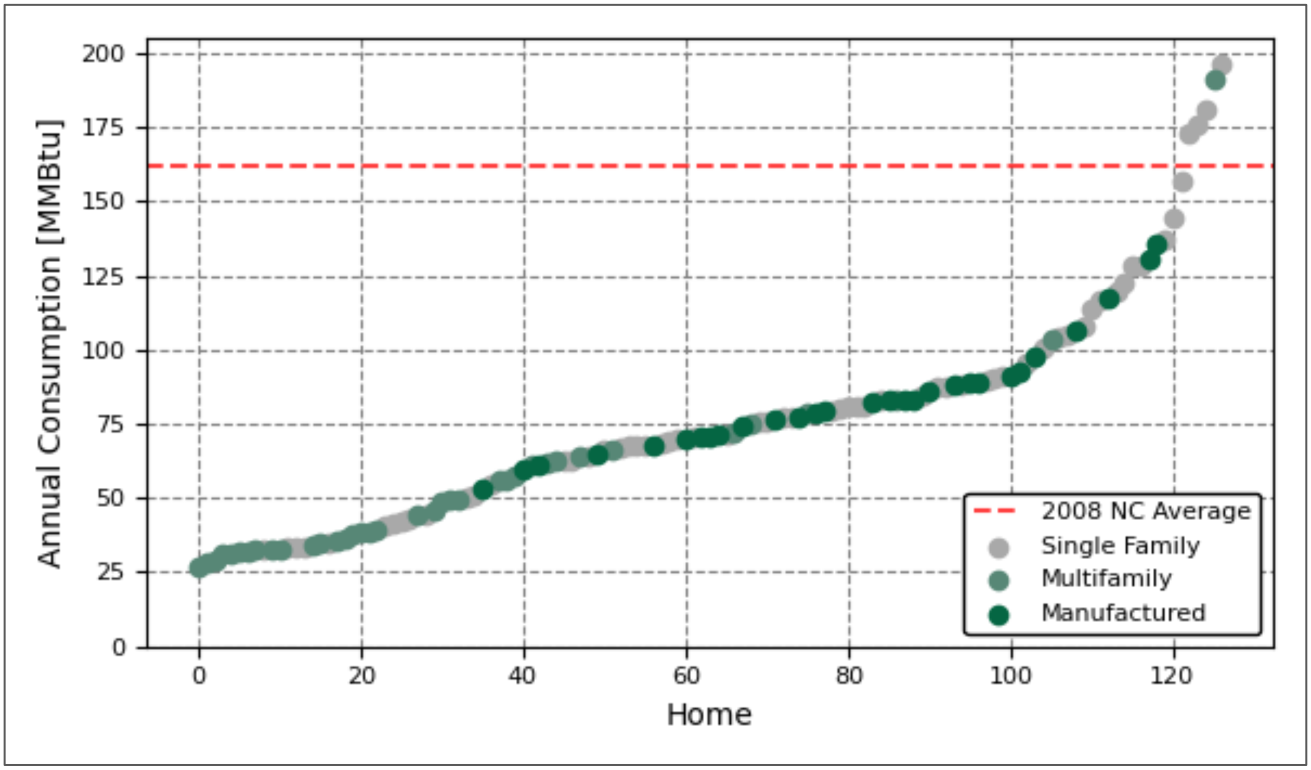


Figure 24. Individual Energy Use Normalized per Area

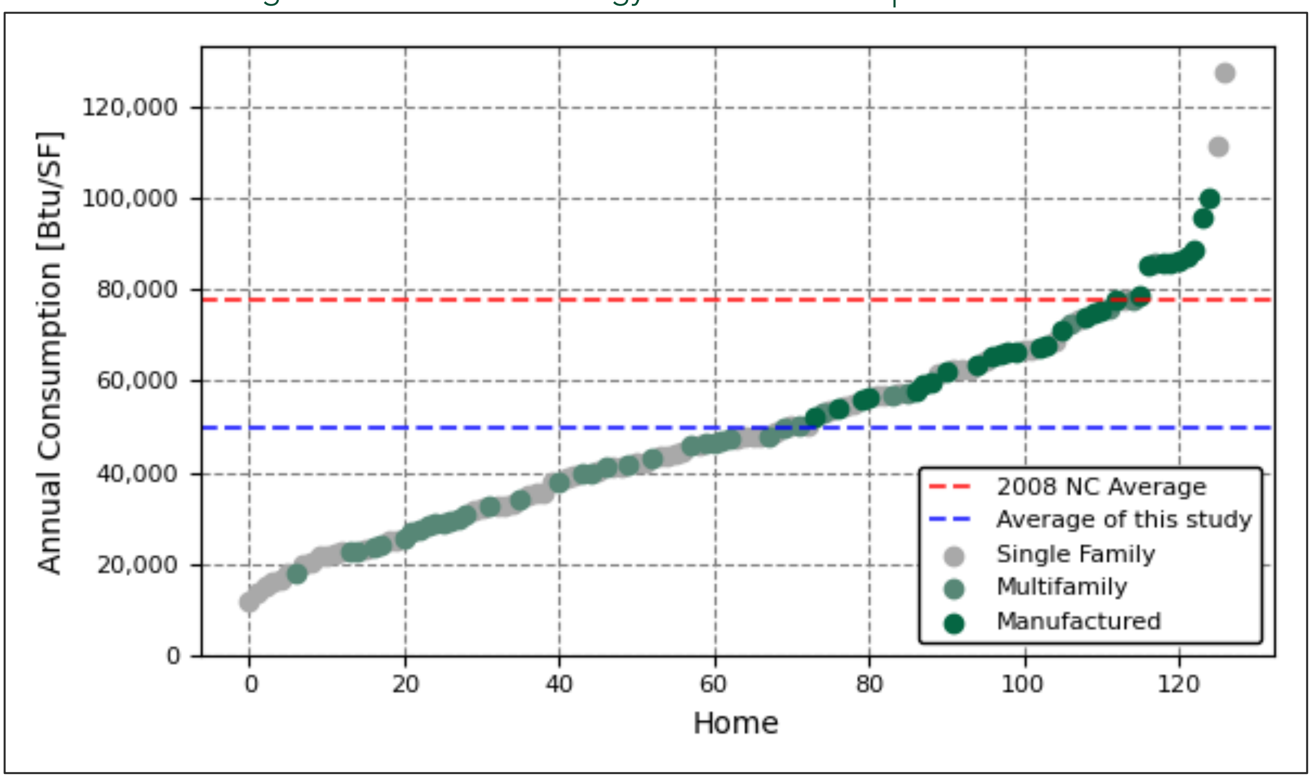


Figure 25. Annual Energy Use by End Use and Home Type

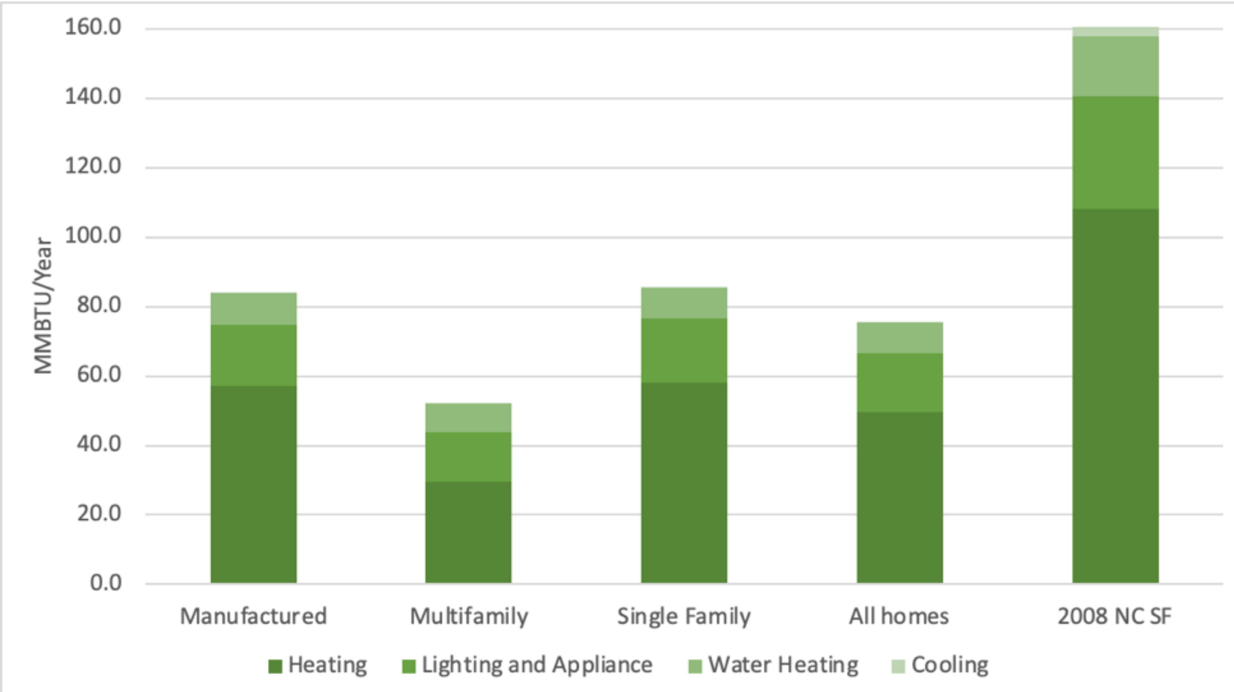
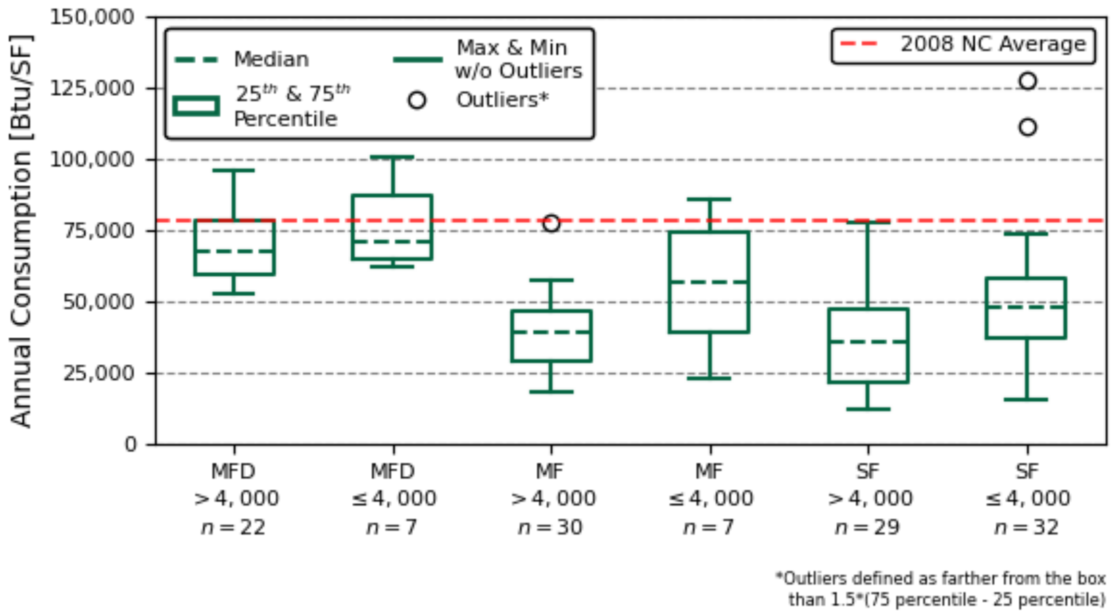


Figure 26 shows modeled energy use by home type and by town size (<> 4,000 persons). The range of energy use for multifamily units in small and large towns overlapped, but the range and median values were shifted higher. For single family homes the median values differed by about 25% but the data ranges were similar. In general, while the data ranges overlapped, it appears that small towns, without required code enforcement, had broader ranges of performance with some high performing homes but more low performing homes. The ranges for manufactured homes differed, which is surprising given that code did not apply to them. The medians were similar, but the range was skewed higher (worse). The small difference in medians is not statistically significant given that only 7 were in small towns.

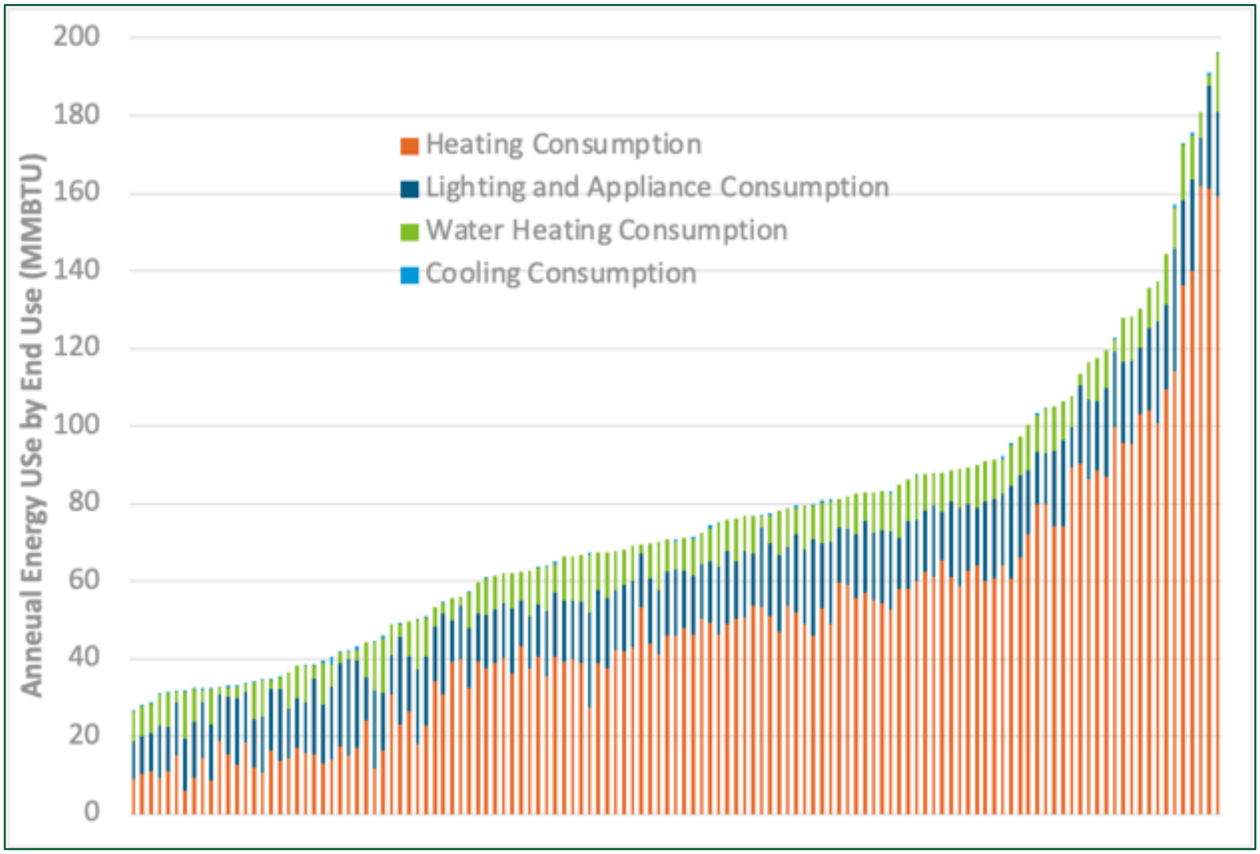
Figure 26. Predicted Energy Use of Homes by Town Population



5.5 PREDICTED ENERGY USE BY END USE

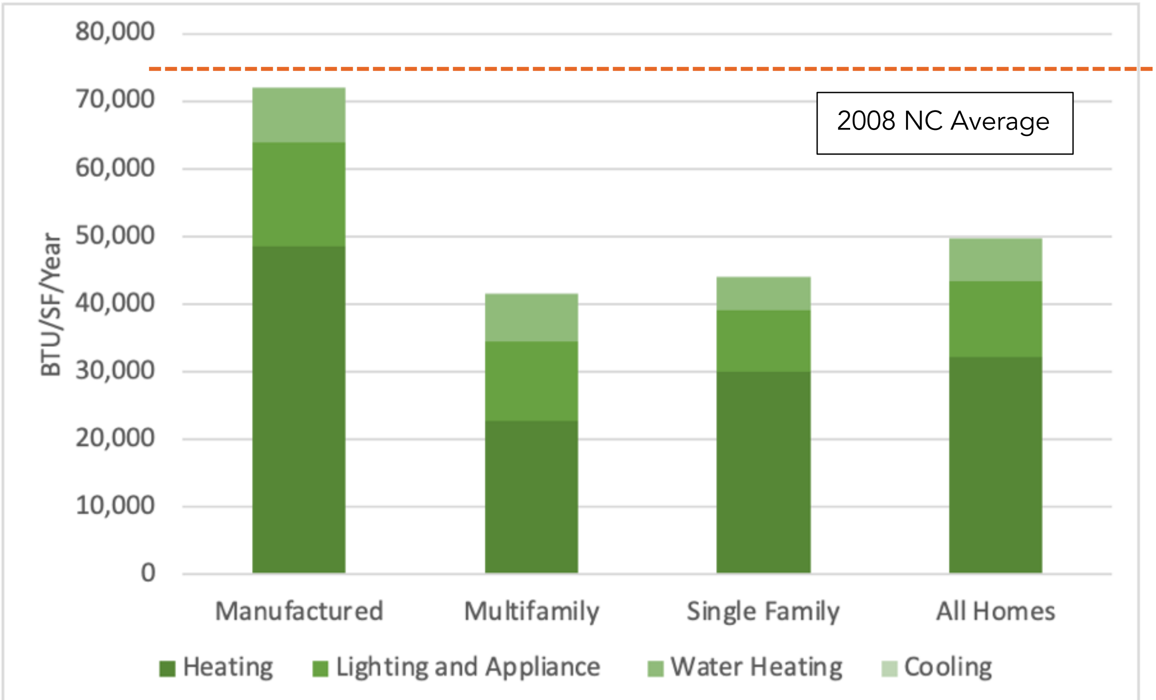
We used the Ekotrope Rater software to model energy use by four end use categories. Figure 27 shows energy use for heating, cooling, lighting and appliances, water heating and cooling. Predicted cooling use was either very low or the home had no cooling equipment. For most homes heating was the dominant energy use followed by lighting and appliances and water heating. For the approximately 25% of homes that used the least energy (approximately <50 MMBYU/year), heating made up a lower proportion and the three non-cooling energy uses were about equal.

Figure 27. Predicted Energy Use by End Use



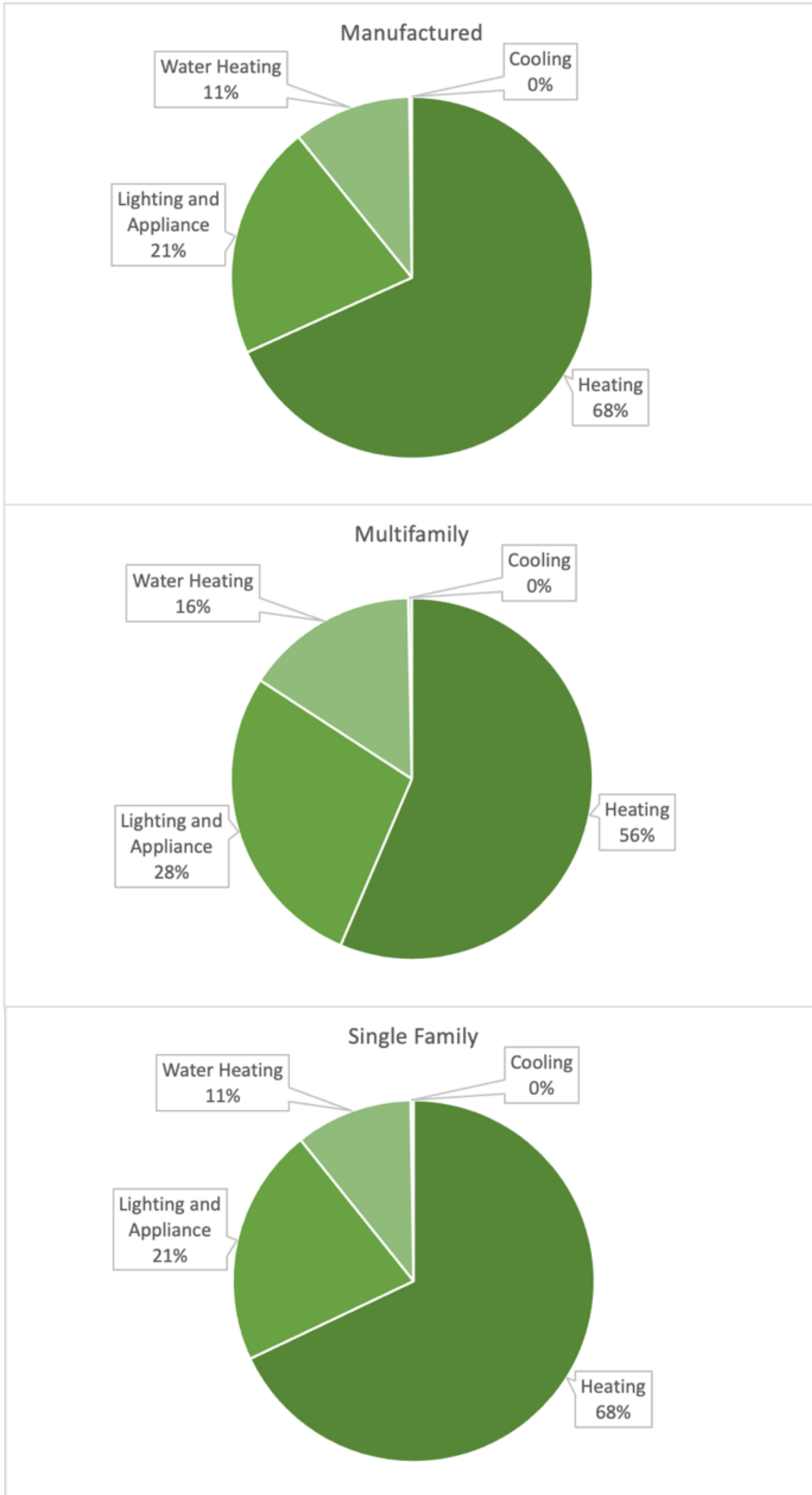
We examined the energy use per square foot broken down by housing type. Figure 28 shows that heating was by far the largest user of energy per square foot and that manufactured homes used about 50% more energy per square foot than multifamily or single family homes.

Figure 28. Normalized Energy End Use per Square Foot by Home Type



We examined end use of energy another way in Figure 29. We graphed the percent of energy use by housing type. The end use of energy was similar among home types with heating being the dominant energy use, and cooling being minor. Both lighting and appliances, and water heating were moderate energy uses.

Figure 29. Normalized Energy End Use per Square Foot by Home Type



5.6 PREDICTED SEASONAL HEATING CONSUMPTION

We used Ekotrope Rater to model annual heating use in MMBTU. Figure 30 shows the average predicted heat use by home type along with the average modeled heat use from the 2008 and 2015 reports. Table 10 shows average values by home type.

Figure 30. Annual Heating Energy Use by Home Type

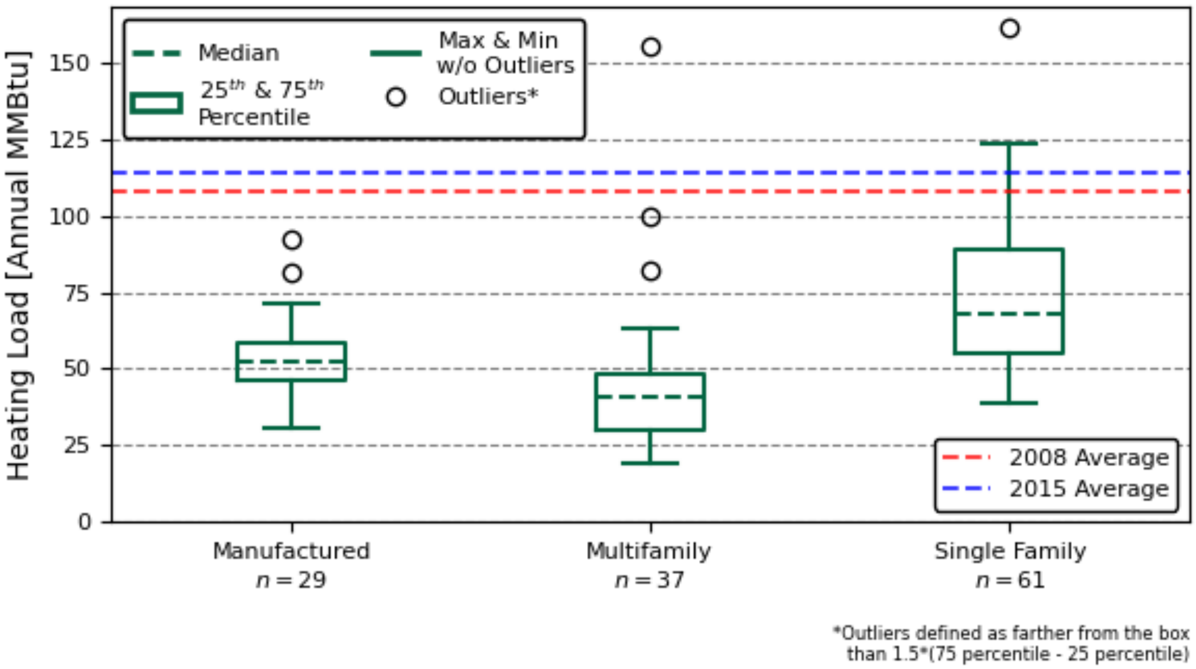
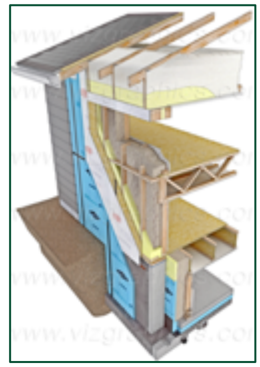


Table 10. Average Heating Load by Building Type

Building Type	Heating Load [Annual MMBtu]
Manufactured	54
Multifamily	45
Single Family	74

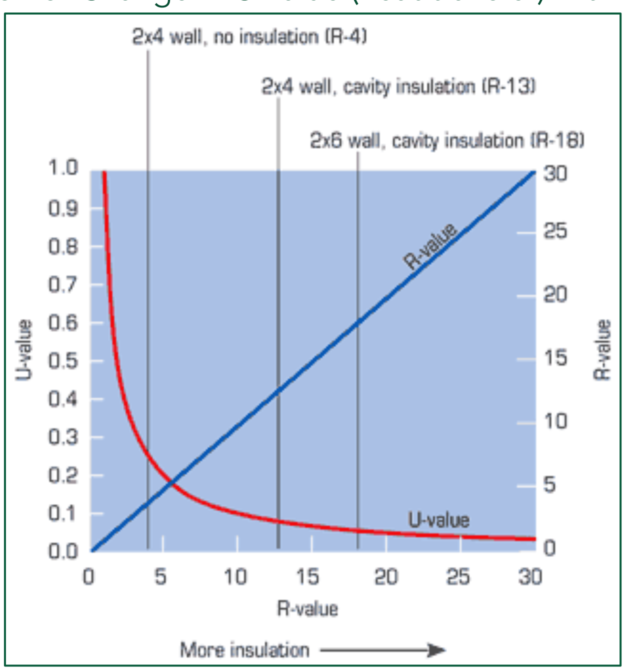
6 BUILDING ENVELOPE



This section describes components of the building envelope including walls, floors, ceilings, windows, and doors, and their associated insulation components. It also discusses leakage as measured by a blower door test. Raters used a combination of plan reviews, discussion with builders, thermal camera inspections, and observations to determine insulation levels.

Insulation levels are specified in two ways (1) R-values where R refers to the resistance to heat flow and a higher value means more insulation and less heat flow; and (2) U-values which indicate the rate of heat flow in BTUs of heat flow per hour, per square foot, per degree of temperature difference (F) across the component of interest. The R and U-values are reciprocals of each other meaning that 1/R = U, and 1/U = R. Figure 31 shows how u and R-values vary with each other. As the R-value grows the corresponding heat transfer coefficient (U-value), drops quickly, then flattens out. Increasing R-value from 20 to 30 will cut the heat loss by a third, but it is cutting a small rate of heat loss to an even smaller value.

Figure 31. Illustration of Change in U-value (heat transfer) with Change in R-value[19]



A builder can meet code by three prescriptive insulation pathways (options): 1) meeting prescriptive requirements that specify, for example, that insulation added to

[19] https://mycampusenergy.files.wordpress.com/2012/07/bs_02_fig2.gif

above grade walls must have a minimum R-value, shown in the first two rows of Table 11; 2) by meeting U-values of construction components where the U-value specifies the maximum rate of heat movement allowed through a construction element like a roof, shown in the second two rows of Table 11; or 3) by meeting a total area weighted U-value for all construction components, thereby allowing some trade off among components. Even if a home does not meet any of these three options, the home can still pass code via a performance pathway by using less energy than a maximum value. In this way some tradeoff between insulation and HVAC equipment efficiency is allowed.

In Table 11 the R-values and the U-values refer to slightly different things, although in practice they are equivalent. The R-value refers to the R-value of added insulation. The U-value is the effective heat transfer, and it includes other elements, like framing, drywall, and air gaps. It is calculated by various tools including REScheck[20] and by Ekotrope's online tool[21]. If one considers a 2 x 6 wall with wood siding, plywood sheathing, dry wall, and added R-22 insulation (e.g., 5.5" of dense pack fiberglass) the wall meets code by meeting the prescriptive added insulation requirement. Examining this wall using the Ekotrope tool, and assuming dry wall, sheathing and clapboard shingles, the U-value is 0.0546 and also meets code through the U-value requirement. The R-value approach is more straight forward in that a builder can see as they build what R-value they are adding, and an inspector can do the same. Checking the U-value requires calculations.

Table 11. Prescriptive IECC R and U-value Requirements for Construction Components in Maine

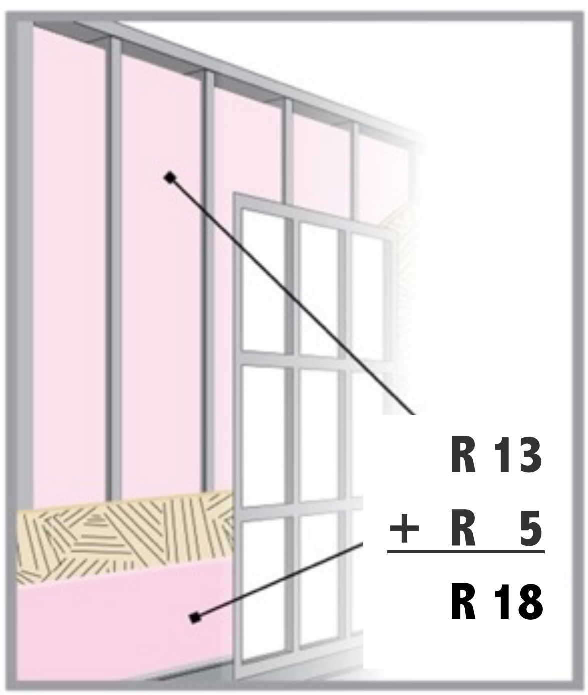
	Climate Zone	Fenestration u	Fenestration SHGC	Ceiling	Wood Frame Wall	Floor	Basement Wall	Crawl Space Wall
R-Table	6-Maine	0.35	NR	49	20 or 13+5	30	15/19	10/13
	7-Far North	0.35	NR	49	21	38	15/19	10/13
u-Table	6-Maine	0.35	NR	0.026	0.057	0.033	0.05	0.065
	7-Far North	0.35	NR	0.026	0.057	0.028	0.05	0.065

Note: The above grade wall requirement can be met with R20 cavity insulation or with R13 cavity insulation (such as with a 2 x 4 wall), combined with 5 inches of continuous insulation. Similarly, for a basement wall R-15 continuous and R-19 cavity both meet code.

[20] https://www.energycodes.gov/software-and-web-tools
[21] https://www.ekotrope.com/r-value-calculator

In each construction component section, we show a graph of added R-value versus area. When raters record data for a home, they combine like construction details. For example, the prescriptive required insulation for above grade walls in IECC 2009 is R20 of added cavity insulation or R-13 of cavity insulation plus R-5 of continuous insulation (Figure 32). If all exterior above grade walls are the same 2 x 6 construction, the rater groups them as a single entry for that home. Other walls in that home that differ, for example a 2 x 4 wall facing an unheated attic, are entered as a separate wall construction. Therefore, the presence of a wall with less than the R20/13+5 noted above does not mean that the overall insulation package is worse than the prescriptive code or that the total of the walls in the home were worse than code. It simply shows that at least one wall in that home was below (worse than) the prescriptive code requirement. If a construction component of a home does not meet a prescriptive level of insulation, the home may still meet code by meeting a whole home insulation value (option 3 above) or may meet code through a performance pathway. Code compliance of individual homes is shown in the Code Analysis section later in this report.

Figure 32. Illustration of Alternate IECC 2009 Above Grade Wall Prescriptive Insulation R-Value[22]



[22] Modified from https://www.homedepot.com/c/ab/insulation-r-values/9ba683603be9fa5395fab9091a9131f

6.1 ROOFS AND CEILINGS

This section refers to insulation in roof and ceiling structures that bordered on unconditioned space or the outdoors. In many cases the insulation was above a ceiling separating the occupied space from an unconditioned attic. In other cases, it was an insulation layer in a roof structure like a vaulted ceiling. HERS Raters grouped like areas in a home and entered the area and insulation values of a section of ceiling or roof. In cases where a home's roof was uniform, they input a single section with an area totaling the home's roof area. In cases where the roof construction varied, e.g., in a home with a mix of vaulted ceiling and ceiling with attic, the rater entered two or more sections.

In general, roofs and ceilings were highly insulated with a mean area-weighted added insulation R-value of 41.7 across 269 wall sections and nearly 110,000 SF of roof/ ceiling (Table 12). These averages are below (worse than) the IECC prescriptive code value of 49.

Table 12. Summary Statistics for Total Roof/ Ceiling Insulation

Summary Statistic	R-value	SF	MF	Manufactured
Count	269	161	79	29
Reciprocal of area-weighted U	40.1	41.9	41.2	35.2
Area weighted R	41.7	43.9	42.3	35.3
Standard Deviation	13.5	15.3	12.2	2.0
Minimum	0.0	0.0	0.0	30.5
Maximum	70.3	70.3	62.9	36.1

To examine ceiling insulation more closely, we graphed R-value on area (Figure 33). Values ranged from R-30 to R-60 for most construction elements across a range of areas. There were some very small elements with low R-values such as uninsulated attic hatches. There was a set of data that appeared to form a line around 38. This corresponded to about 12 inches of batt insulation. One feature of this graph is that the data points are colored indicating whether the home associated with the components met or failed IECC 2009. We can see that many homes with roof components with R-40 to R-49 added insulation actually met code, and a few that met the R49 prescriptive level failed code for some other reason.

R-value data for the study's 29 manufactured homes are shown in Figure 34. Observed R-values were all well above the minimum HUD standard and clustered around R36.

Ekotrope modeled the area weighted U-value of each home's construction elements. As previously discussed, another prescriptive pathway for a builder is to meet the required U-value for each construction component. This allows a home with smaller sections of ceiling that do not meet the prescriptive R-value to still meet the overall U-value when all ceiling sections are considered collectively.

Figure 35 shows the variance between each home's actual UA value and the code requirement where a positive value means that it was better than IECC 2009 code. Here we can see that only about 60 homes met or exceeded code for the roof/ ceiling U-value.

Figure 33. Roof/Ceiling R-value versus Area

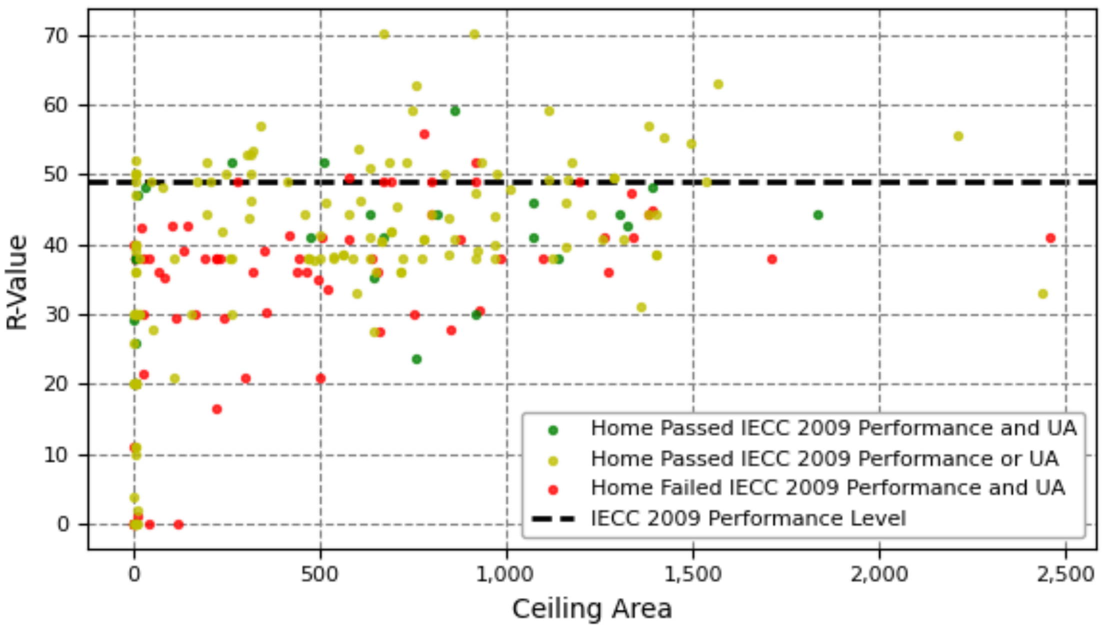


Figure 34. Manufactured Home - Roof/ Ceiling R-value versus Area

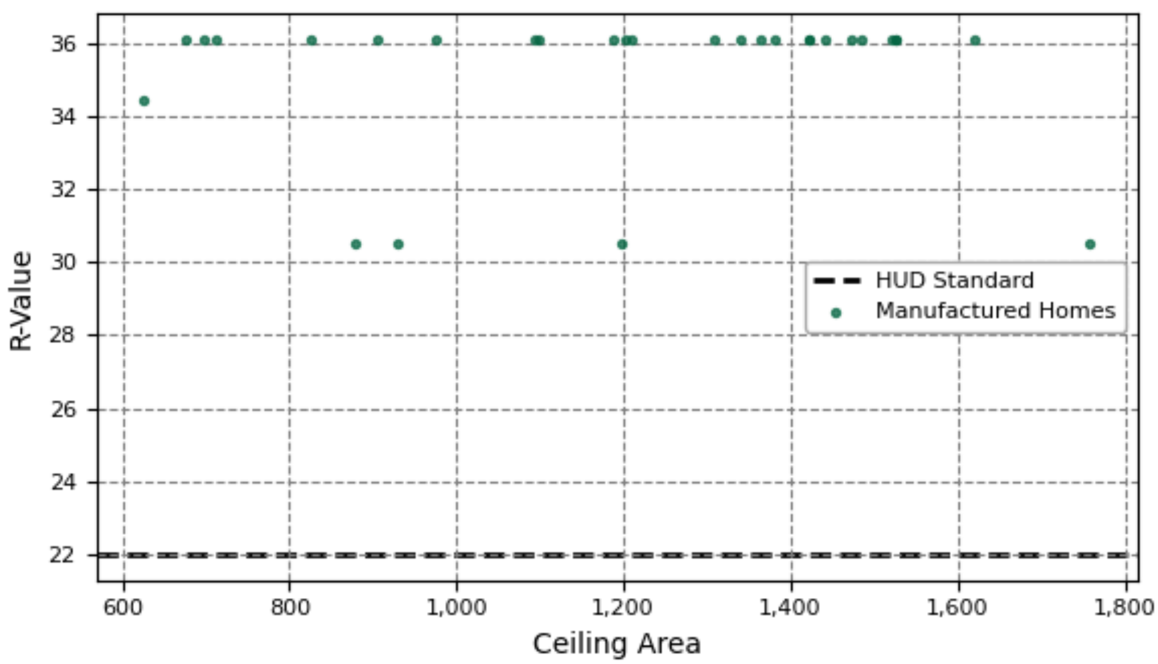
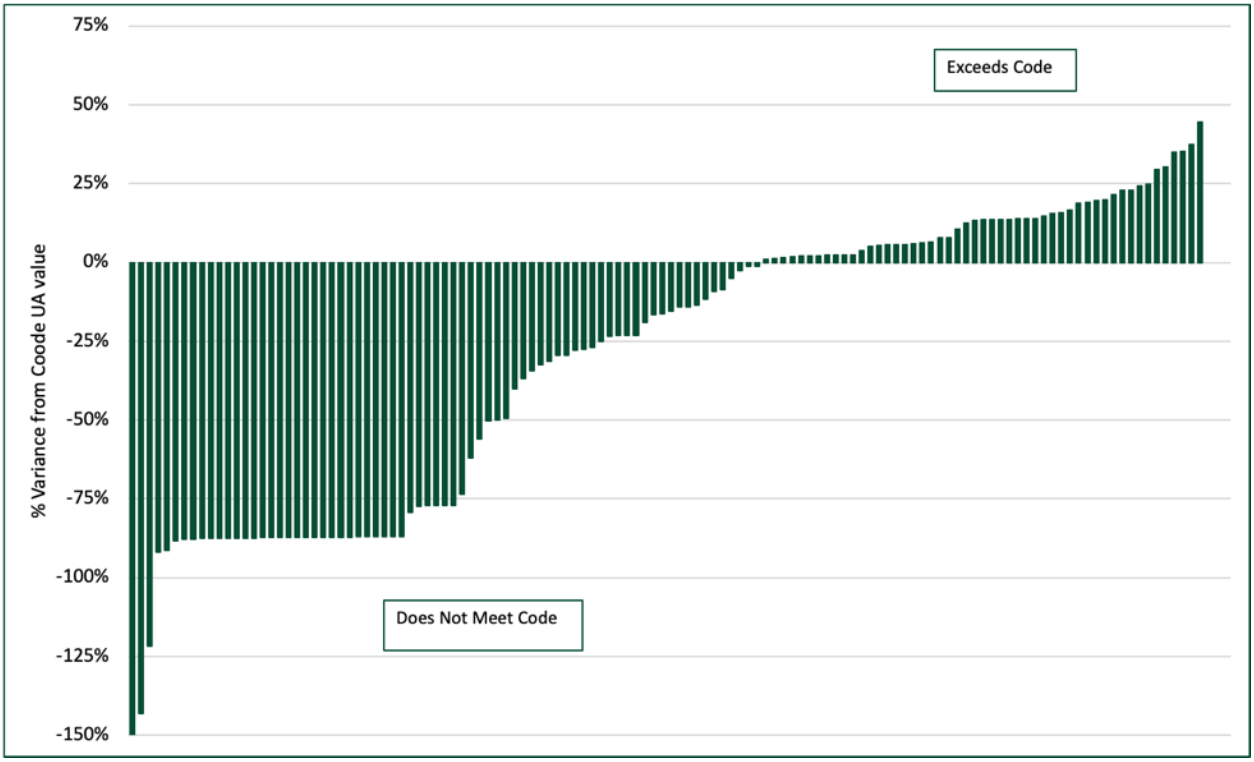


Figure 35. Roof/Ceiling UA Value vs. IECC 2009 UA



Negative numbers are worse than code. -100% means UA value is double code value. +25% means UA value is 25% better than code. An outlier of -329% is not shown. Banding of darker columns is an artifact of the charting software and carries no meaning.

6.2 ABOVE GRADE WALLS

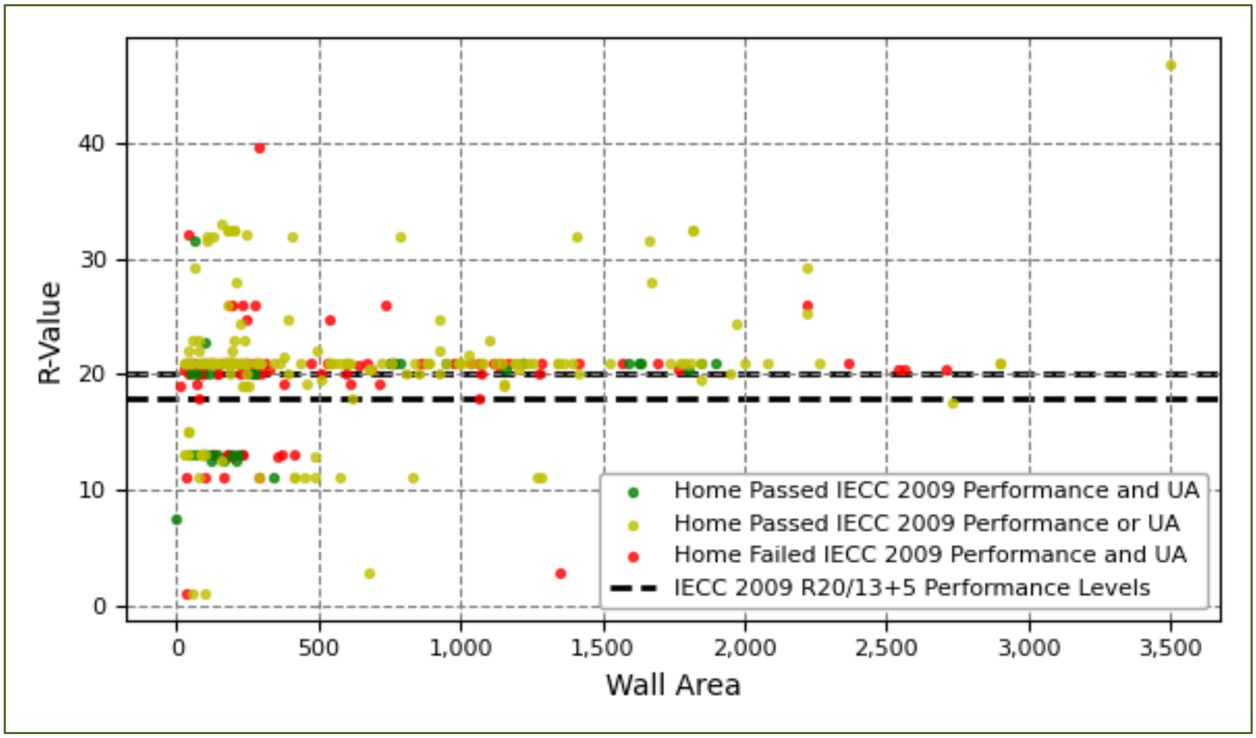
Walls were relatively highly insulated with a mean weighted insulation value of R-21.2 across 364 wall sections and nearly 228,000 SF of walls (Table 13). The average weighted R-value was above (better than) the IECC prescriptive code values of 13 plus 5, and 20.

Table 13. Summary Statistics for Above Grade Wall Insulation

Summary Statistic	R-value	SF	MF	Manufactured
Count	364	194	133	37
Reciprocal of area-weighted U	19.1	21.2	15.5	19.4
Area weighted R	21.2	22.4	19.2	19.5
Standard Deviation	5.1	5.3	5.2	1.4
Minimum	1.0	1.0	1.0	18.0
Maximum	46.9	46.9	39.6	21.0

To examine wall insulation more closely, we graphed R-value versus area (Figure 36). Values ranged from R-10 to R-25 for most construction elements across the range of areas. There were some small elements with low R-values, for example access hatches and several 500 – 1,500 square foot walls with little insulation. There were sets of data points that appeared to form lines around 11 and 14 that corresponded with standard and compressed batt insulation in 2x4 walls. Above grade walls must have R13 cavity insulation and an additional R5 of continuous insulation to meet the prescriptive pathway for IECC 2009. Alternately, R20 of cavity insulation is required which could be met with spray foam in 2x4 walls or a variety of insulation types in 2x6 walls. There were similar lines in the range of 19 to 21 that corresponded to cavity insulation in 2x6 walls. Data points were colored indicating whether the home associated with the components met or failed IECC 2009. Not all homes with one or more walls with insulation less than R18 failed code as can be seen in the chart.

Figure 36. Wall R-value versus Area of Wall



Manufactured homes were subject to the HUD code minimum of R-11.

Figure 37 shows that walls in all 29 homes were well above the minimum HUD standard although only a portion are above the R20 level that non-manufactured homes must meet.

Figure 38 shows the variance between each home's actual UA value and the code requirement where a positive value means that it was better than IECC 2009 code. Even though many of the added R-values shown in Figure 36 just met the added R-value requirement about 75% of the homes shown in Figure 38 missed the UA code requirement by 10% to 20%. The reason for this was, as explained in Section 6.8, the raters rated the quality of insulation installation. Where the walls were closed and they could not see the insulation, they were required to rate it as Grade III. This caused the U-value to be depressed by 20% causing the low UA scores.

Figure 37. Manufactured Homes – Above Grade Wall R-value versus Area

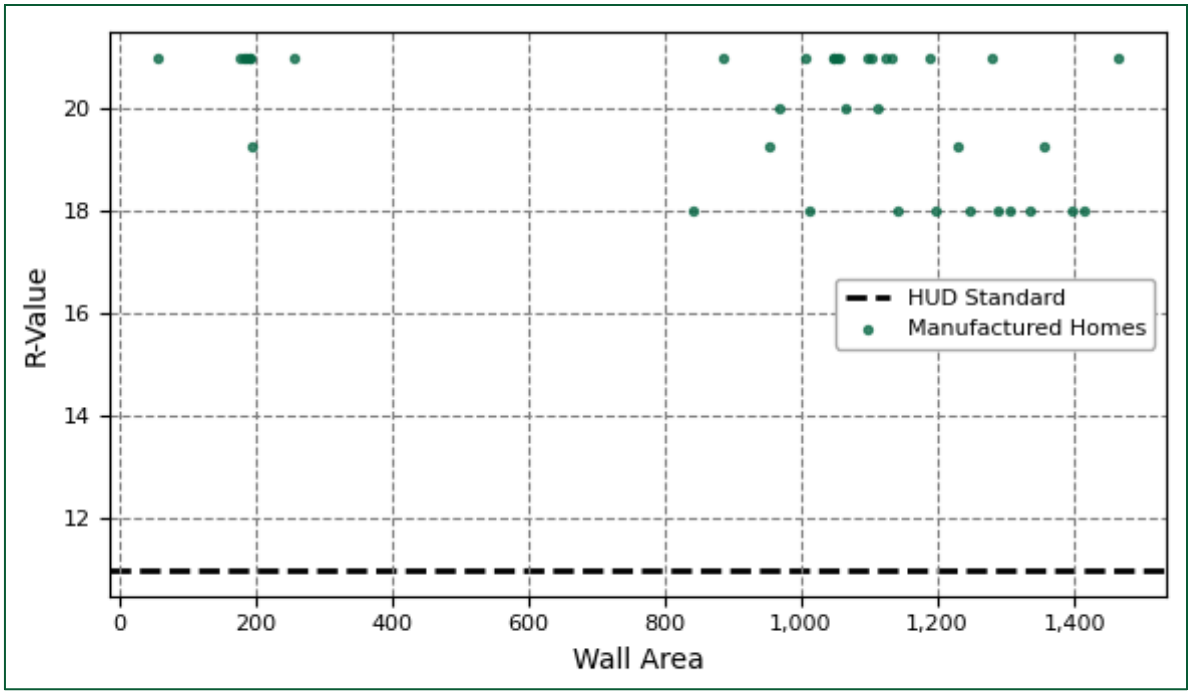
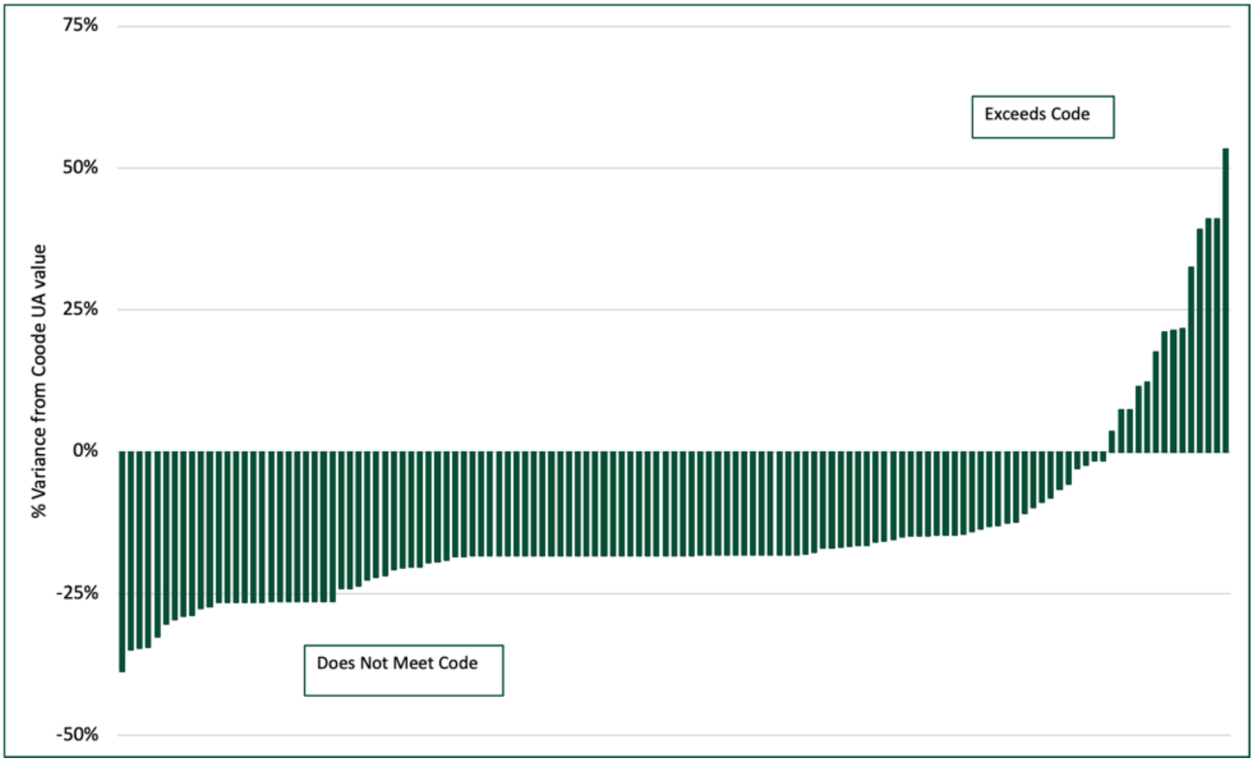


Figure 38. Above Grade Wall UA Value vs. IECC 2009 UA



Negative numbers are worse than code. -100% means UA value is double code value. +25% means UA value is 25% better than code.

6.3 FOUNDATION WALLS

The area-weighted R-value for foundation walls was 10.1, much less than above grade walls (Table 14). Many of the foundation wall sections observed were not insulated. This created a problem in calculating a heat loss weighted R-value because an added R-value of 0 creates an added U-value of infinity, making calculation impossible. To calculate the reciprocal of the weighted U-value, we ignored 0 values.

Table 14. Summary Statistics for Foundation Wall Insulation

Summary Statistic	R-value	SF	MF	Manufactured
Count	102	83	19	NA
Reciprocal of area- weighted U	6.0	5.2	18.3	NA
Area weighted R	10.1	9.8	11.5	NA
Standard Deviation	6.3	5.5	9.2	NA
Minimum	0.0	0.0	0.0	NA
Maximum	26.8	21.0	26.8	NA

To examine foundation wall insulation more closely, we graphed R-value on area (Figure 39). Values range from R-0 to R-15 for most construction elements across the range of areas. Many of the wall sections had no insulation. There were sets of data that appeared to form lines around R-10 and R-15 that corresponded with 2-inch and 3-inch foam board.

Figure 39. Foundation Wall R-value versus Area of Wall

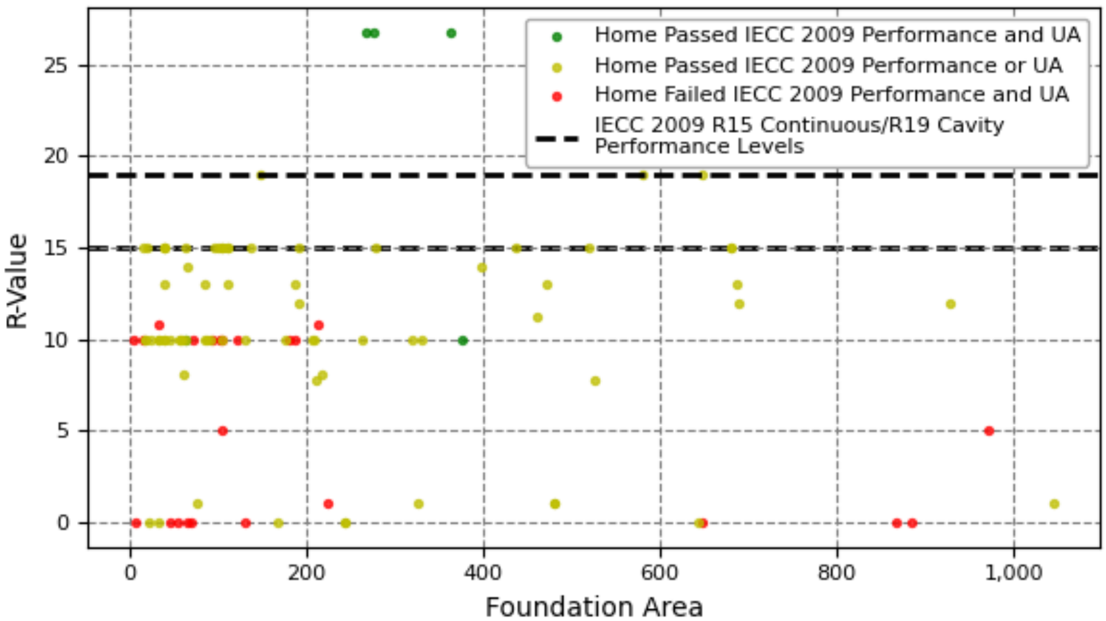
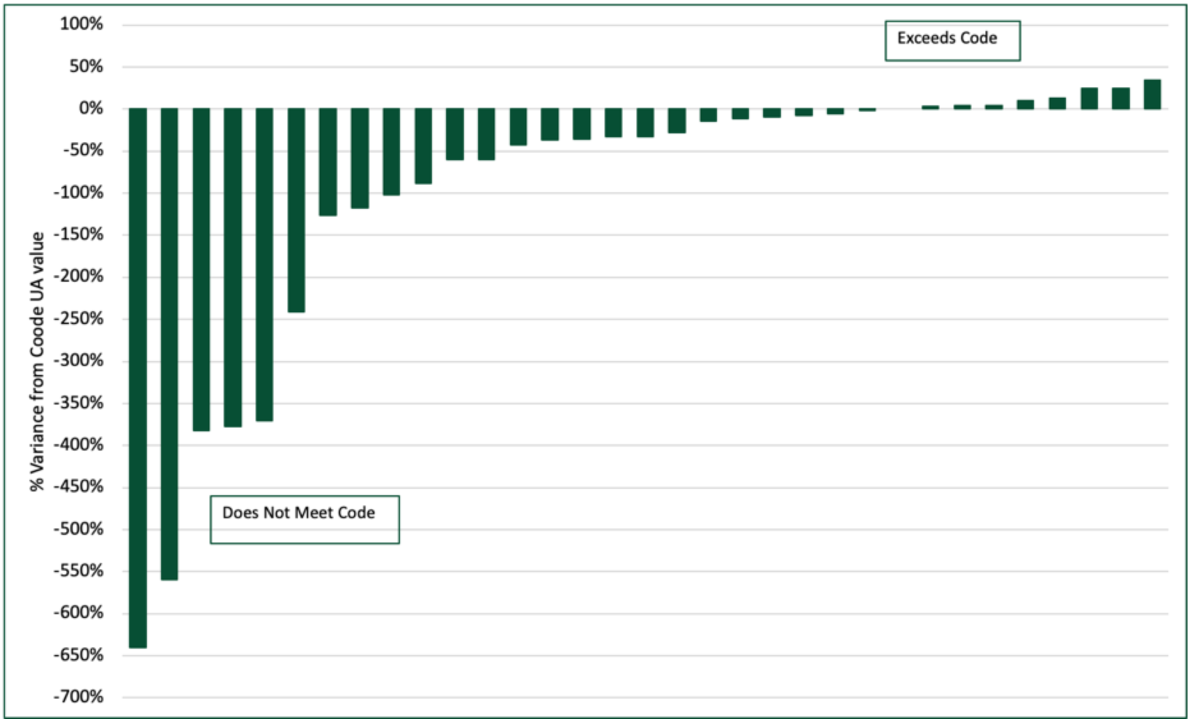


Figure 40 shows the variance between each home's actual UA value for foundation walls and the code requirement where a positive value means that it was better than IECC 2009 code. Most of the walls were worse than code as the previous figure showing R-values would indicate. This chart shows that heat transfer caused by the lacking insulation was up to 6.5 times that of a code compliant home.

Figure 40. Foundation Wall UA Value vs. IECC 2009 UA



Negative numbers are worse than code. -100% means UA value was double code value. +25% means UA value was 25% better than code.

6.4 FLOORS

Floors over unconditioned areas were usually insulated but several were left uninsulated. Based on the insulated floors, the weighted average R-value was 28.2

Table 15. Summary Statistics for Floor Insulation

Summary Statistic	R-value	SF	MF	Manufactured
Count	164	69	37	58
Reciprocal of area-weighted U	28.6	29.8	32.2	25.6
Area weighted R	28.2	30.1	28.2	26.0
Standard Deviation	9.9	11.3	8.1	8.9
Minimum	0.0	0.0	0.0	0.0
Maximum	76.0	76.0	46.9	49.2

To examine floor insulation more closely, we graphed R-value on area (Figure 42). Values ranged from R-20 to R-40 for most construction elements across the range of areas. There were sets of data that appeared to form a line around R-30 that corresponded to insulating with 9-inch batts. R-value data for the study's 29 manufactured homes are shown in Figure 42.

Figure 41. Non-Manufactured Homes – Floor R-value versus Area

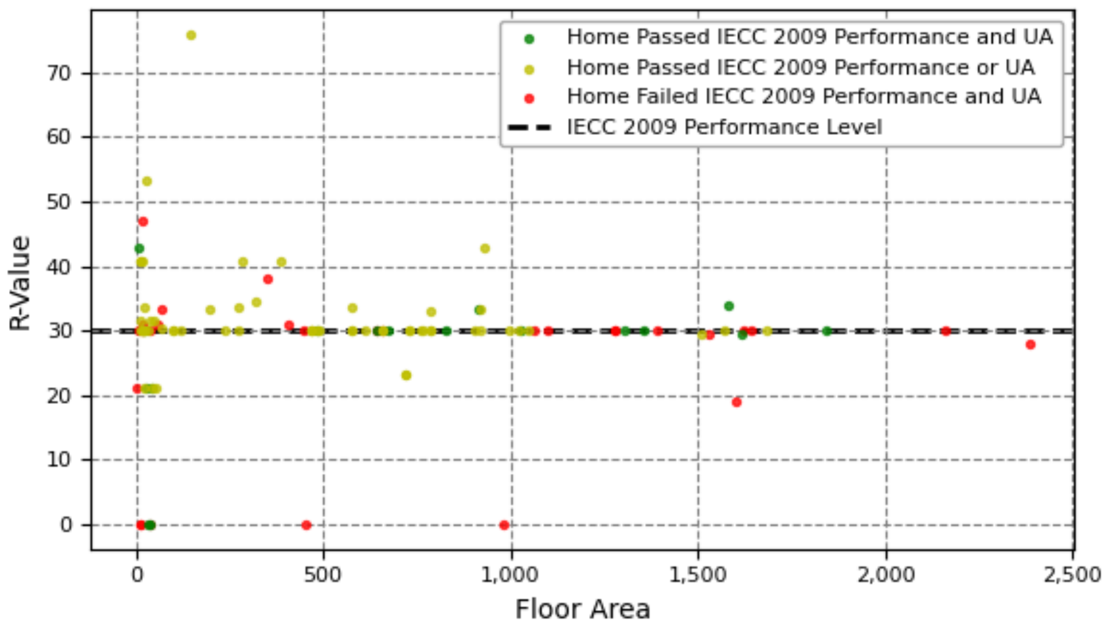


Figure 42. Manufactured Homes – Floor R-value versus Area

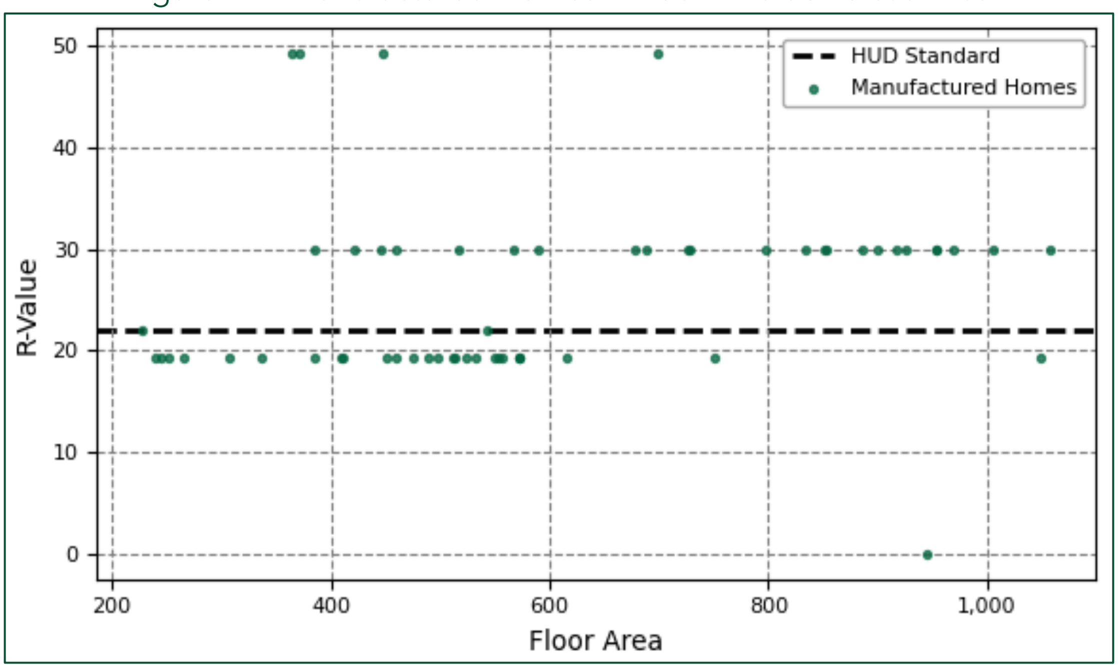
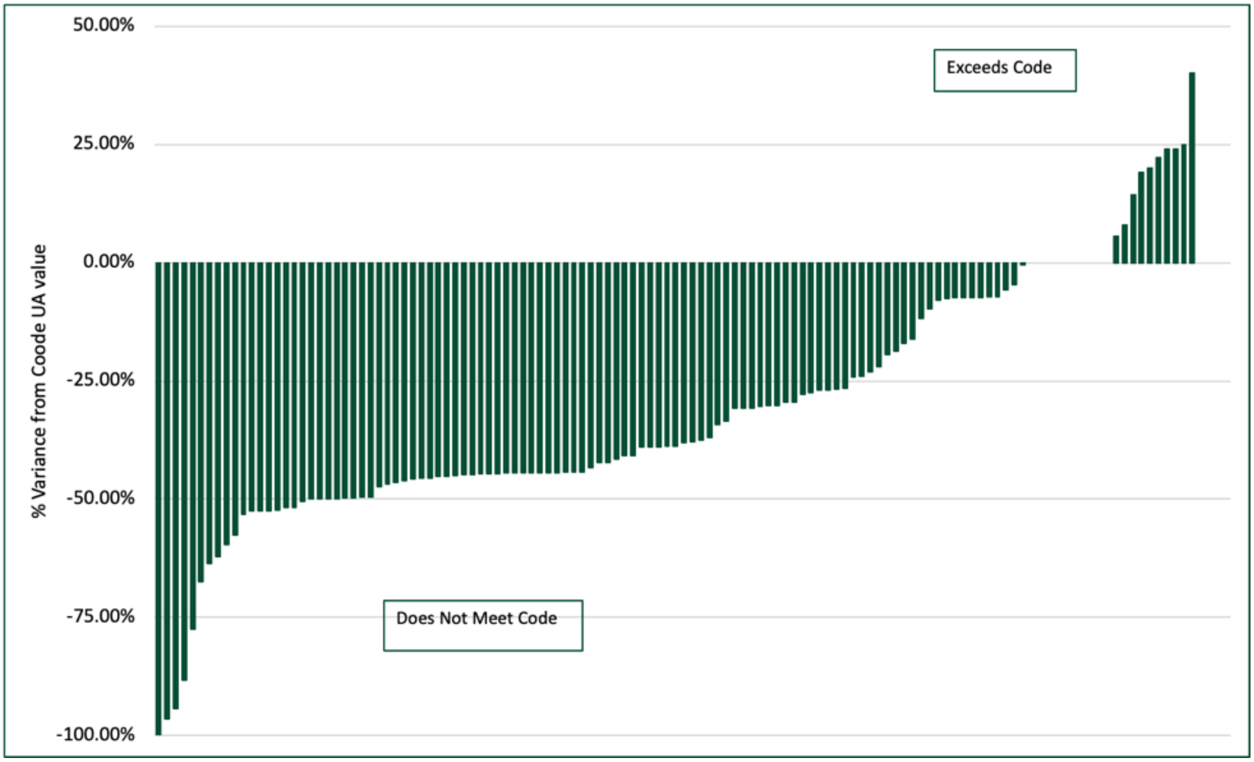


Figure 43. Floor UA Value vs. IECC 2009 UA



Negative numbers are worse than code. -100% means UA value is double code value. +25% means UA value is 25% better than code. An outlier of -770% is not shown. Banding of darker columns is an artifact of the charting software and carries no meaning.

6.5 WINDOWS

Windows have multiple uses and multiple impacts on a home's energy use. Windows can add aesthetic appeal, provide views, bring in sunlight, and provide fresh air. Windows can bring in desirable heat from the sun in the winter or can be a major source of cooling needs in the summer. Even high-quality double pane windows have low R-values compared with walls, averaging an R-value of 3 or lower, while walls that are not code compliant have R-values greater than11.

Windows have two energy related performance criteria: U-value and a solar heat gain coefficient (SHGC). A U-value is the reciprocal of the R-value and is the conductive heat flow in BTU/hour per square foot of window per 1 Fahrenheit degree difference. The lower the value, the better. A 20 square foot window with a U-value of 0.3 will conduct 120 BTU/hour on a 48F day. The SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower a window's solar heat gain coefficient, the less solar heat it transmits. What determines a desirable SHGC is dependent, in part, on the local climate and on the direction the window faces. In theory, on the south, southeast, and southwest sides of a building, in a heating dominated climate, a higher SHGC is better. In a cooling dominated climate, a lower SHGC is better. On northern sides of buildings, the U-value is important and the SHGC less so. In practice, windows tend not to be optimized for region and direction and the range of SHGCs available for a given U-value is limited. Table 16 lists summary statistics for windows. The average window had a U-value of 0.32 and a SHGC of 0.34, meaning that it met code for both IECC 2009 and IECC 2015.

Table 16. Window Summary Statistics

Summary Statistic	R-value	SF	MF	Manufactured
count	834	522	199	113
U- value				
mean	0.32	0.30	0.34	0.33
std	0.08	0.08	0.09	0.02
min	0.12	0.12	0.22	0.28
max	0.83	0.65	0.83	0.34
SHGC				
mean	0.34	0.35	0.37	0.28
std	0.12	0.12	0.12	0.01
min	0.07	0.07	0.20	0.25
max	0.80	0.66	0.80	0.31

Figure 44 shows the SHGC for 834 window assemblies. SHGCs are clustered in the 0.25 to 0.35 range, but there was a line of values around 0.46 and at about 0.58. IECC has no requirement for SHGC in Maine's climate zone and depending on the window's orientation, a higher value is better.

Figure 45 shows U-values for 834 window assemblies. Most U-values are in the 0.25 to 0.38 range with some in the 0.46 to 0.48 range. Some windows were not well labeled and the U-value of 0.46 to 0.48 were linked to default libraries in the rating software. It may be that these ratings were conservative and that actual ratings were somewhat better. The prescriptive requirement in IECC 2009 for Climate Zone 6 is 0.35, however there is a hard limit of 0.40 for the U-value of windows. This means that even if the overall insulation package meets the building level UA value discussed at the beginning of this section, the average area weighted U-value for a home's windows must be no higher than 0.40. Individual windows can, however, have higher values so long as the average is equal to or less than 0.40.

Figure 44. Window SHGC Value versus Area of Window

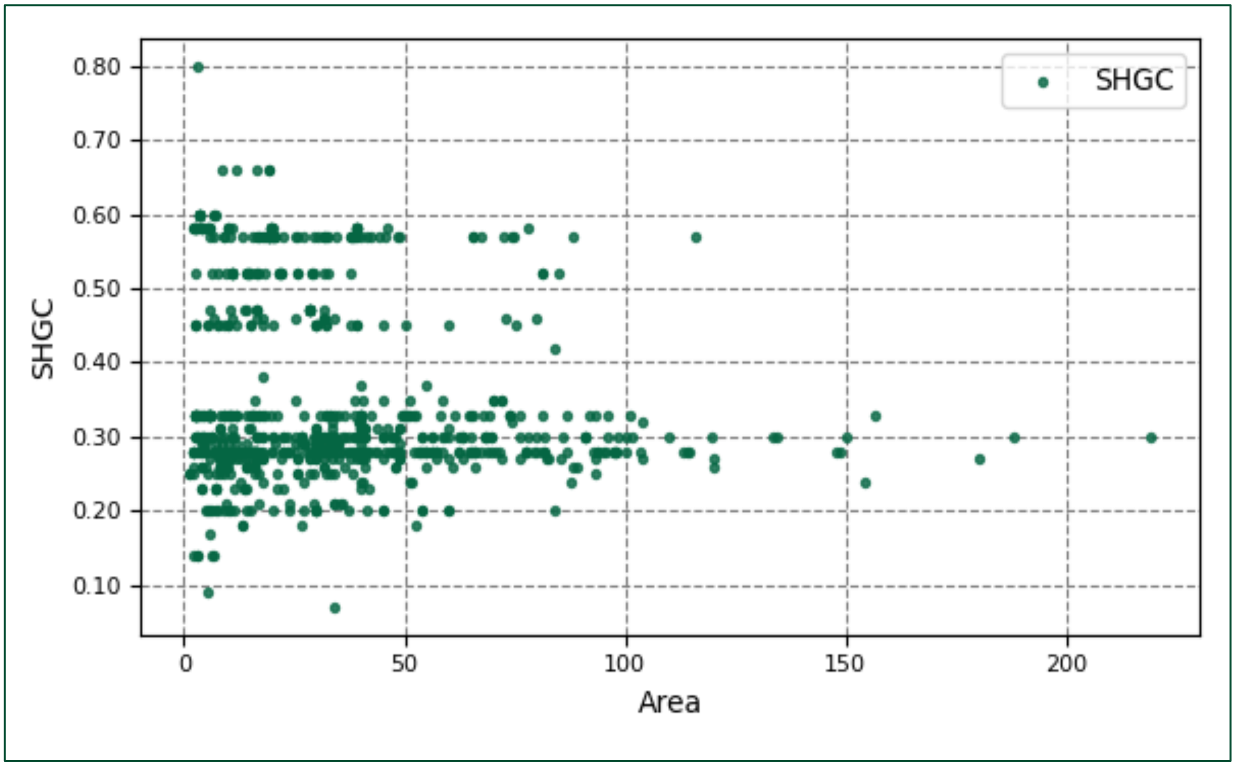
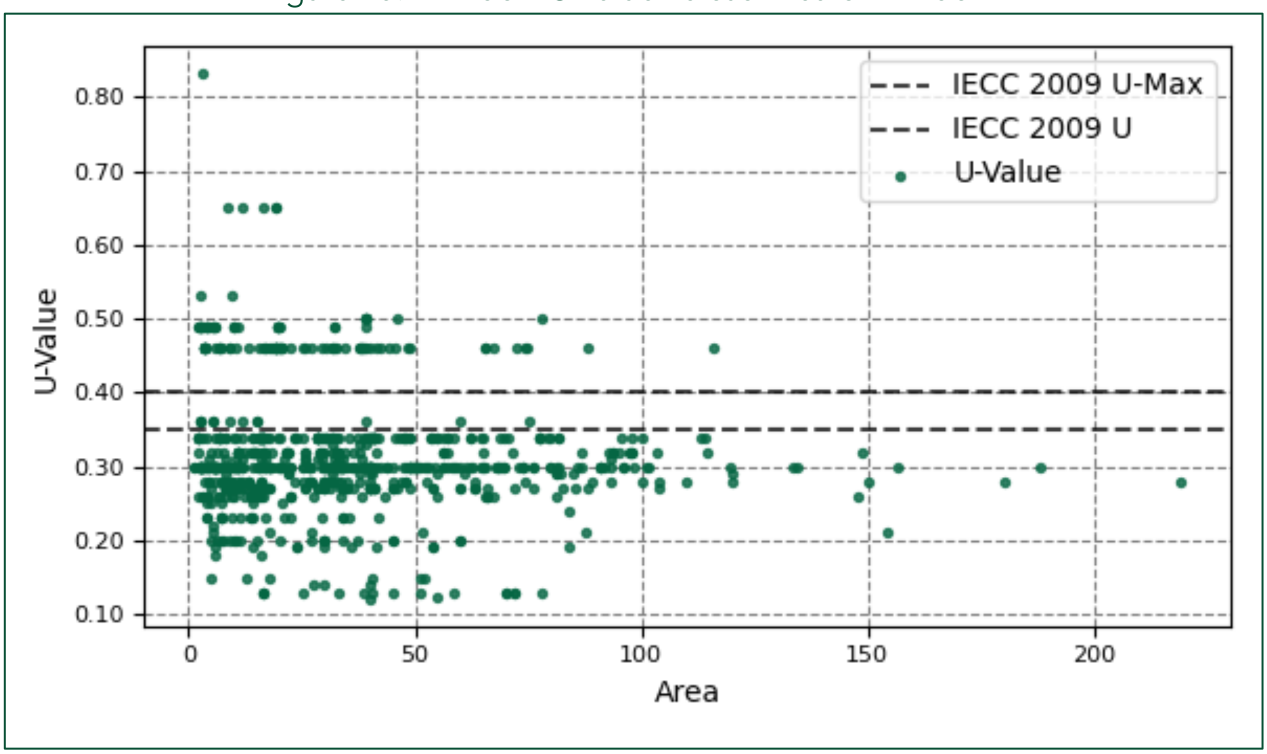


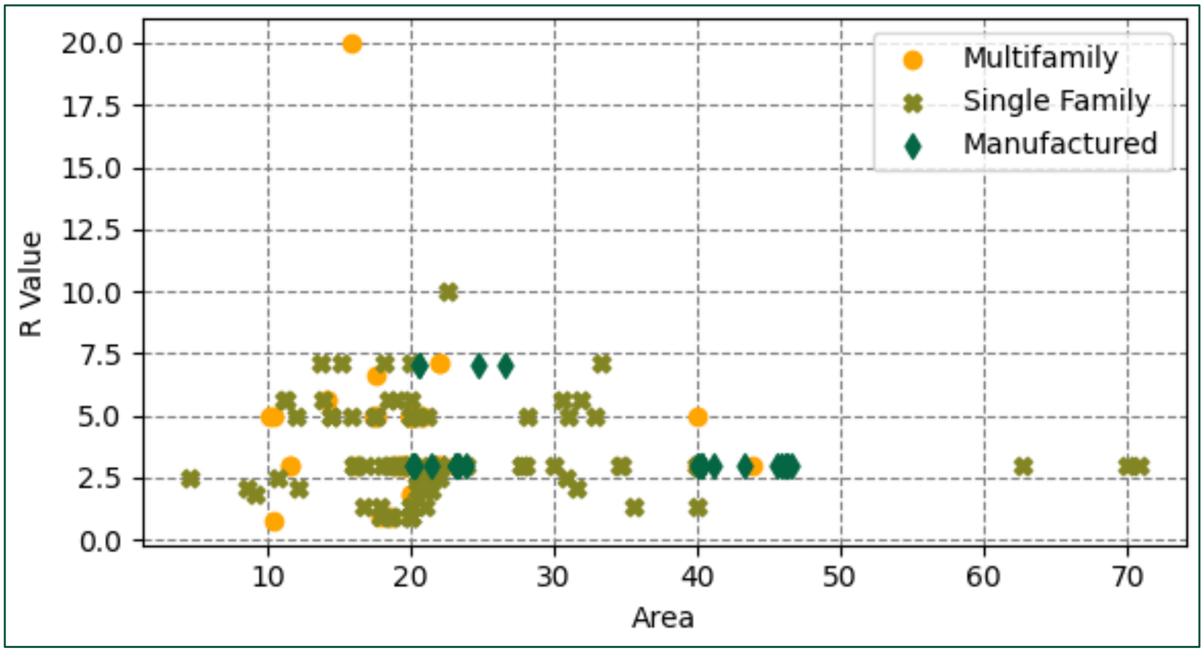
Figure 45. Window U-value versus Area of Window



6.6 DOORS

Doors accounted for a relatively small amount of the building envelope so even if they had low R-values, the impact was minor. The area weighted R-value was 3.5. The heat-loss averaged effective R-value was 2.75 for the 4,200 SF of 182 doors. As shown in Figure 46, R-values ranged from about 1 to 20 with a line of values at R-3 and R-5 corresponding to about ¾-inch and 1-inch of closed cell foam. The larger doors were garage doors with R-values of about 3.

Figure 46. Door R- Value versus Area of Door

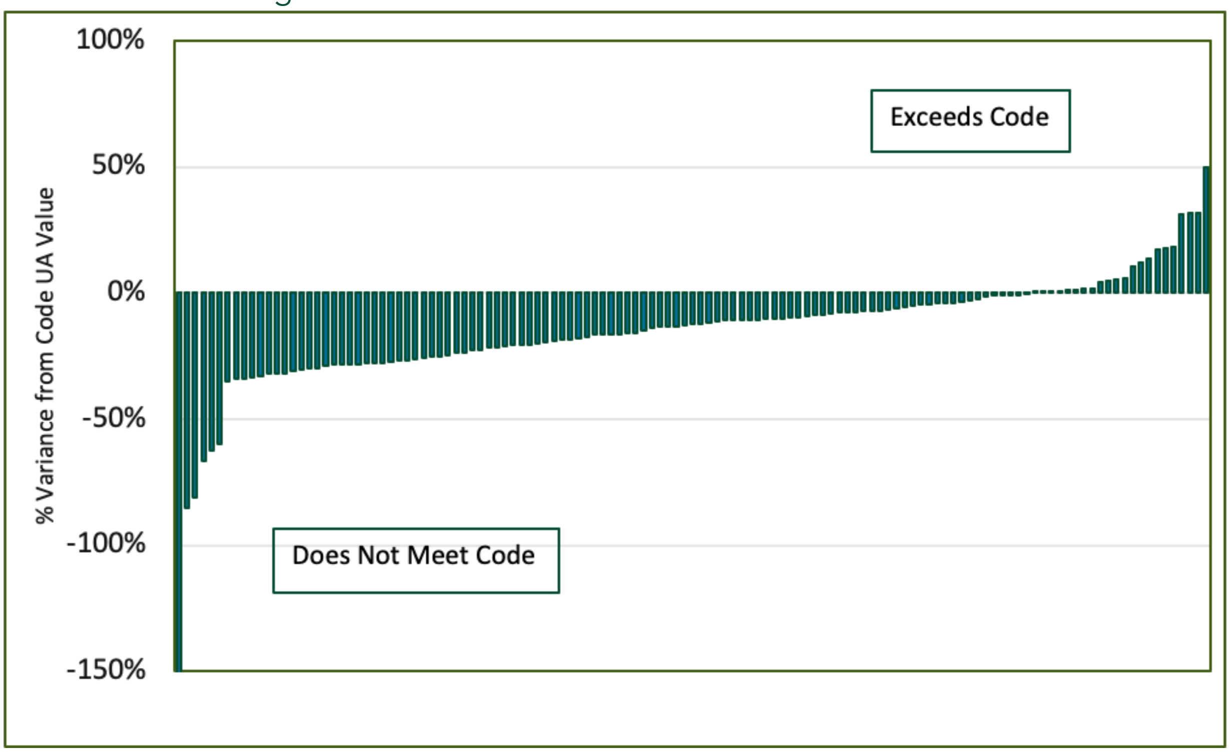


6.7 OVERALL INSULATION (UA) VALUE

As stated earlier, homes could comply with code with an overall insulation package meeting a maximum heat loss value. For each home, the value was calculated by multiplying the area of each construction detail by the permitted U-value in the code table. For example, consider a home with 1,000 SF of above grade wall. Code requires a U-value of 0.057. Therefore, the maximum allowed UA for that wall is 1,000 sf x 0.057 =57. The units of UA are BTUs/hour – F, meaning that the wall can lose a maximum of 57 BTUs per hour per degree of temperature difference between indoors and outdoors. On a 48F day this would mean (57 * (68F – 48F)) = 1,140 BTU/hour of heat loss. The UA rises with the area of a home's walls and ceiling, so a larger home is not disadvantaged.

In theory, a builder could choose to put slightly less insulation in a roof and more in walls and comply with code. We examined the UA values for each home and found that, on average, homes had UA values 12.8% higher (worse) than the IECC 2009 compliance value and non-manufactured homes, that are subject to the code, were 8.9% higher (worse) than the IECC 2009 compliance value. That means that conductive heat loss was 8.9% higher than code. Figure 47 shows that homes varied widely in comparison to the IECC 2009 UA prescriptive requirement with the worst home losing heat at a rate 1.75 times the code requirement, but approximately 20 homes were better than code with the best home losing heat at a rate 50% of code. Some of the homes that are approximately 5% or less from meeting code would meet code had their walls been observable and met Grade 1 installation requirements.

Figure 47. Total Home UA Value vs. IECC 2009 UA

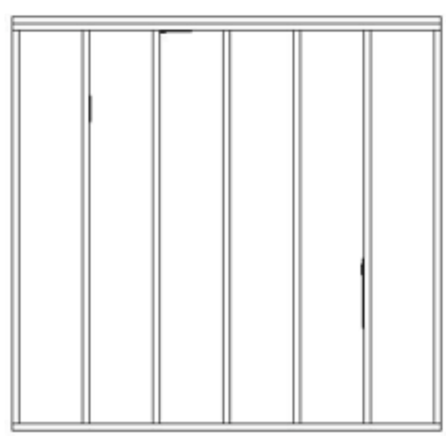


Negative numbers are worse than code. -100% means UA value is double code value. +25% means UA value is 25% better than code.

6.8 INSULATION GRADING

One aspect of conducting a HERS inspection is grading insulation. HERS Ratings allow for three grades of insulation where it is directly observable. If the home was under construction, the Rater would assign Grade I (best), Grade II, or Grade III, depending on the quality of installation (Table 17). See Figure 48 for an example of an inspection by a rater prior to drywall installation. When insulation could not be visually inspected by a HERS Rater, the Rater graded unobserved insulation as Grade III for a Registered Rating. We followed this procedure for all inspections. Figure 49 illustrates examined insulation in a closed wall. The derating of insulation as either Grade II or Grade III depressed the reported U-value and energy calculations, affecting a home's ability to pass code based on either UA or performance, as discussed in the text preceding Figure 38.

Table 17. RESNET Insulation Grading for a HERS Inspection

Grade	Meaning	Notes
Grade I – Minor Defects	R-value of the insulating material is modelled as the full nominal R-value of the insulation. For example, a typical R21 fiberglass batt in a 2x6 wall with standard framing 16" on center has an overall effective assembly R-value of R17.1. (U-value of 0.0584) [Note this includes all layers of the typical wall and the air films attached to the interior and exterior and it is less than the nominal R-value because the framing has a lower R-value than the insulation and it allows a significant amount of heat to bypass the insulation.]	This is the IECC 2009 Prescriptive R-value level that energy code nominally requires. For the Performance path of code, the model creates a reference home which uses a wall U-value of 0.057 which would correspond to grade 1 R20 batts (R20 batts are made in Canada) and 2x6 framing, 24 inches on center, and with some advanced framing techniques like open corners and insulated headers. The following illustrations represent the boundary conditions between Grade I and Grade II, that is, the installation shall be at least this good to be labeled as "Grade I":  Occasional very small gaps are acceptable for "Grade I".
Grade II– Moderate Defects	R-value is decreased in the model by the HERS Rating software which calculated the	An unadopted guideline published by RESNET suggested that thermographic inspection by qualified personnel under

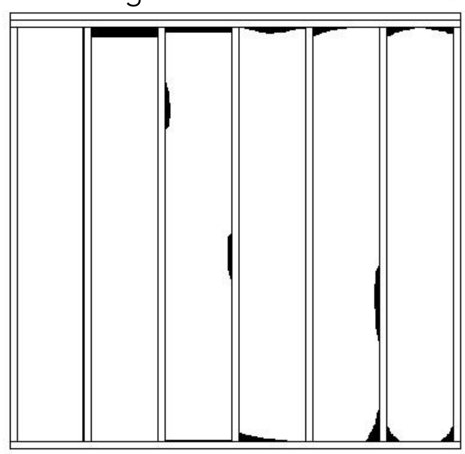
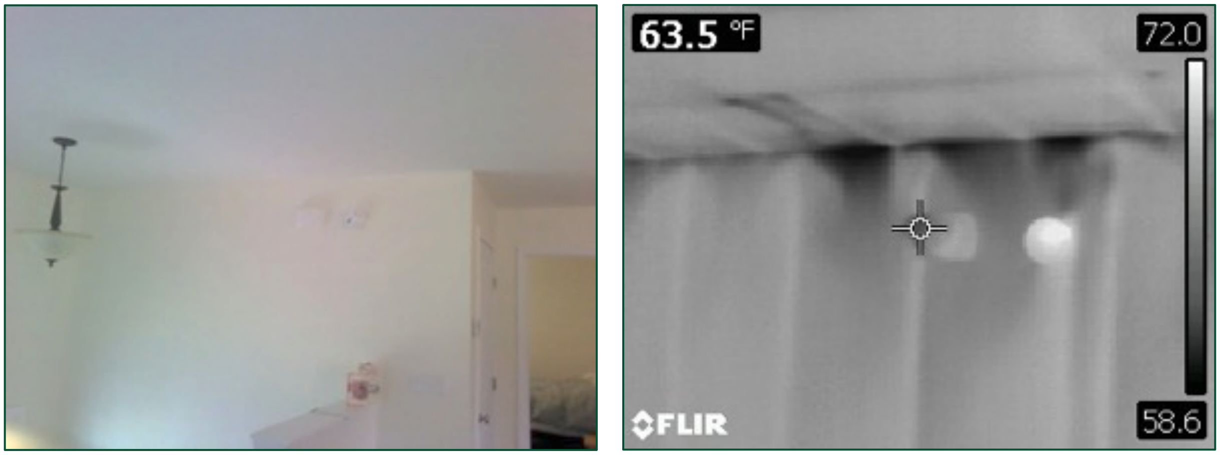
Grade	Meaning	Notes
	overall U-value of an assembly including 2% of the insulated cavity area as an empty cavity. For illustration, a typical R21 fiberglass batt in a 2x6 wall with standard framing 16" on center has an overall effective assembly R-value of R15.7 (U-value of 0.0636).	certain conditions could be permitted to be used to determine that an assembly achieves a Grade II. However, it suggested that It was not possible to reliably determine whether the insulation was grade I with this approach. Confirmed HERS Ratings are not permitted to use grading by thermographic inspection in any case because the guideline was never adopted as part of the HERS Standard. The following illustrations represent the boundary conditions between Grade II and Grade III, that is, the installation shall be at least this good to be labeled as "Grade II":  No more than 2% of surface area of insulation missing is acceptable for "Grade II"
Grade III – Substantial Defects	R-value is decreased in the model by the HERS Rating software which calculated the overall U-value of an assembly including 5% of the insulated cavity area as an empty cavity. For illustration, a typical R21 fiberglass batt in a 2x6 wall with standard framing 16" on center has an overall effective assembly R-value of R14 (U-value of 0.0715).	Grade III is the level used in a Confirmed HERS Rating if the insulation is determined to be present but was not visually inspected by the HERS Rater.

Figure 48. Rater's Photograph Showing Insulation Around Electrical Box and Framing

Figure 49. Visual (L) and Thermal Camera (R) Views of a Wall



Because of the requirement to rate unobserved walls as Grade III, the HERS approach yielded a conservative reading of the sample homes' insulation values which may have resulted in the following:

1. It may have caused the site's report to exaggerate the potential savings from increased insulation values if the existing unobserved values were expected to be Grade II or Grade I while the Rater used a Grade III. As shown in Table 17, the wall U-value for an example wall construction increased from 0.058 to 0.072 moving from Grade I to Grade III, an increase of over 20%.
2. Compared to a HERS model with Grade I wall insulation, Grade III wall insulation could depress HERS Ratings on the order of 2 HERS Index points.

Table 18 shows the grading of insulation by construction component. Ceiling and roofs had the highest proportion of Grade I insulation at 38.5%, because the insulation in them was the most observable. Walls and floors were more often closed and the proportion of Grade I and II insulation was much lower.

Table 18. Insulation Grading by Construction Component

Component	Grade I	Grade II	Grade III
Ceiling/ Roof	38.5%	6.0%	55.4%
Above Grade Walls	9.1%	5.3%	82.2%
Floors	16.2%	4.8%	78.1%

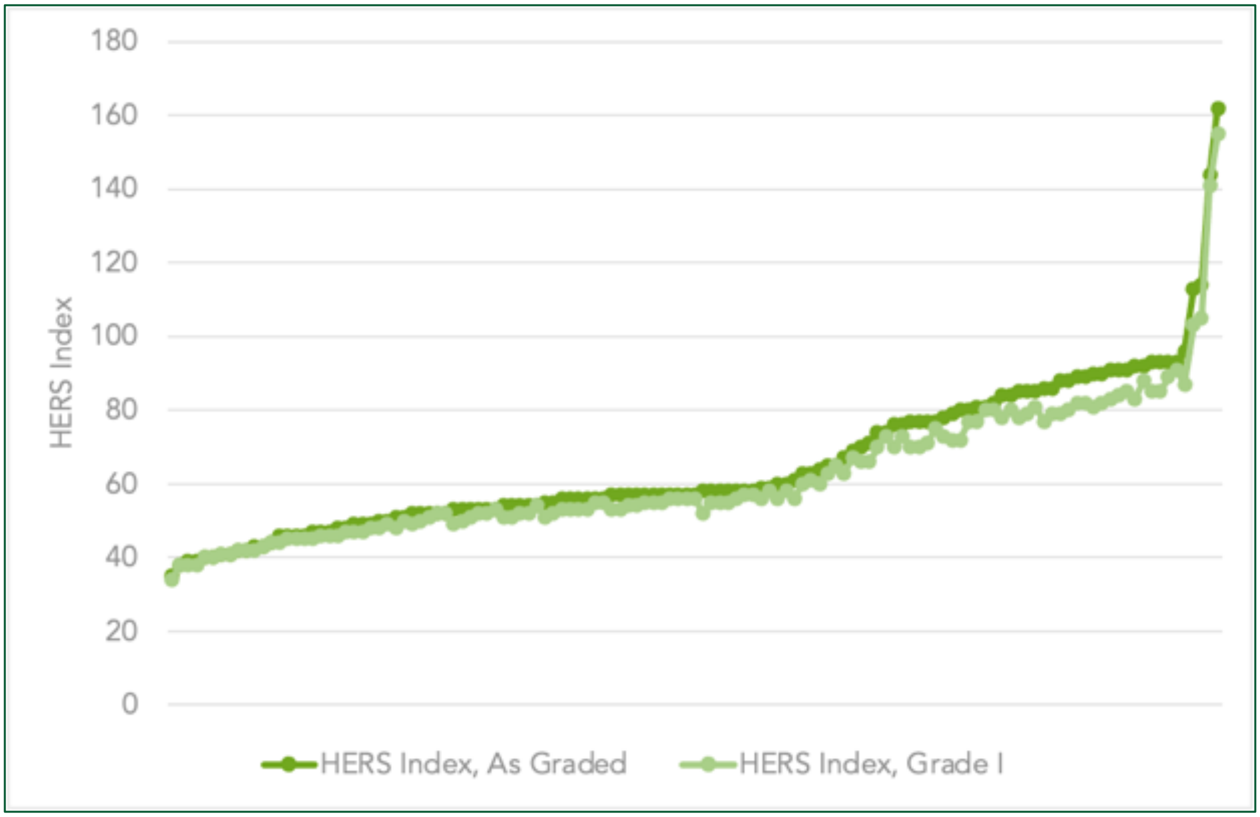
The percent of homes with open walls (about 11%) is known, but the precise percent of which wall sections were open was not tracked. Based on a review of raters' notes, homes with open walls had walls graded 64% Grade 1, 3% Grade 2, and 33% Grade 3. These percentages can be slightly misleading however, because the portion of walls open was almost certainly not an unbiased sample of all wall sections. It is likely that builders who allowed open wall inspections were either confident in their insulation installation practices or would have taken some steps to ensure a successful inspection. Grade 3 is not allowed by ENERGY STAR Homes or LEED or PHIUS, so there is a natural incentive for some builders to correct any deficiencies.

This means that the true state of insulation is likely better than 82% Grade 3 based on the HERS grading requirement, but is almost certainly not as good as the 33% Grade 3 that the observed open walls would imply. Because walls are only a portion of the homes UA value and because the change was moderate, the rate of homes passing the UA pathway would have been better, but not substantially so, if all walls could have been inspected without biasing the outcome.

6.9 INSULATION GRADING AND HERS

We reran the HERS scores converting all II and III insulation grades to Grade I. This revised analysis shows the results as if all components met Grade I installation criteria (Figure 50). The average HERS score decreased (improved) by about 3 points on average, or 5%. Figure 50 shows revised HERS scores. Score improvements were largest for homes with poorer scores at about 7% and only about 2% for homes with better scores.

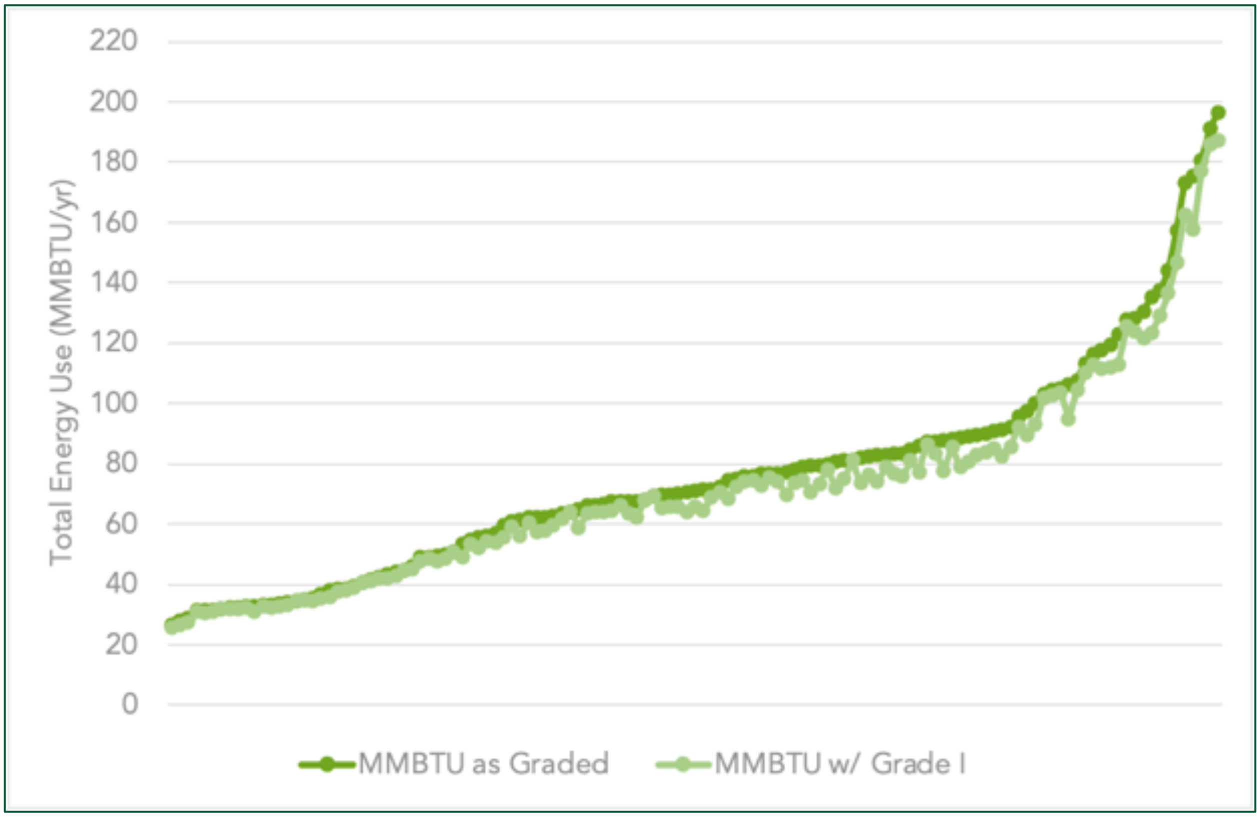
Figure 50. HERS Scores as Graded and Using Grade I for Insulation



6.10 INSULATION GRADING AND MODELED ENERGY USE

As described in the section above, we reran the energy modeling, converting all Grade II and III insulation grades to Grade I. Figure 51 shows energy reductions in MMBTU from revised energy modeling. Overall, the average energy use decreased (improved) by about 5% on average. Energy use improvements were largest for homes using moderate to high amounts of energy at about 6 - 7% and were about 2% for the homes with lowest energy use.

Figure 51. Predicted Energy Use as Graded and Using Grade I for Insulation



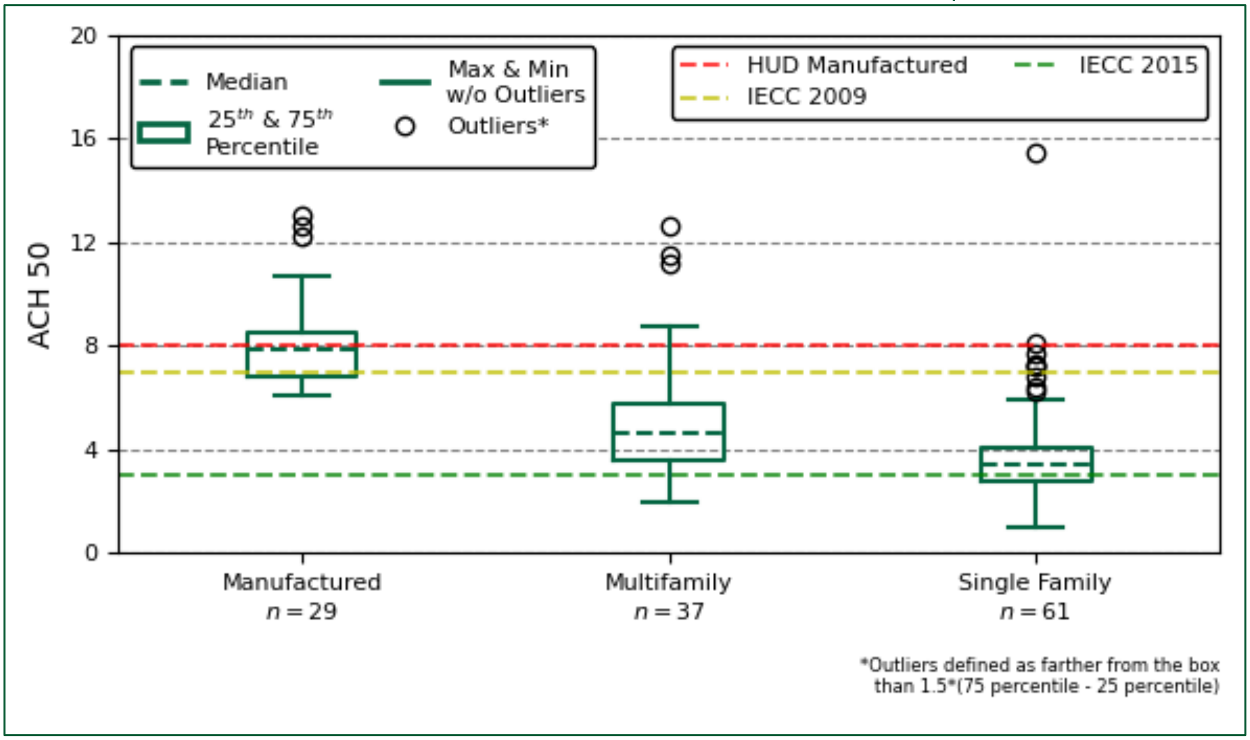
6.11 INFILTRATION

As outlined in the Methods section, raters tested infiltration using a blower door test. The test produces a leakage flow in cubic feet per minute (CFM) at a test pressure of 50 pascals.[23] This flow can be normalized by multiplying it by 60 and dividing by the home's volume to yield air changes per hour at 50 pascals (ACH50). Figure 52 shows the range of the ACH50 number for studied manufactured homes, multifamily homes, and single family homes. Manufactured homes had the highest leakage and the largest spread of leakage values. The median value of 8 corresponds to the HUD requirement, but means that was approximately half of these homes fail the HUD standard. The large data spread was interesting particularly for a manufactured product. The IECC 2009 requirement for infiltration was an ACH50 of 7 or less and IECC 2015 lowers that requirement to 3. Multifamily units had lower values, and single family the lowest, albeit with some fairly leaky outliers.

23 This is equivalent to about 0.007 psi, or about 0.05% of ambient atmospheric pressure.

The multifamily values were somewhat inflated because some of the leakage was into an adjacent unit. Normally the adjacent unit would be at the same pressure so there would be virtually no leakage between units. Where a whole multifamily building was tested, adjacent units can also be pressurized, reducing that inter-unit leakage. This is termed a guarded test. Because we only had permission for testing one unit at a time, we did not perform any guarded tests in this study. Studies have compared guarded to unguarded tests and suggest ratios for decreasing the unguarded test results. [24] We did not apply any models or corrections, but the multifamily leakage would likely correct to a value similar to the median single family value.

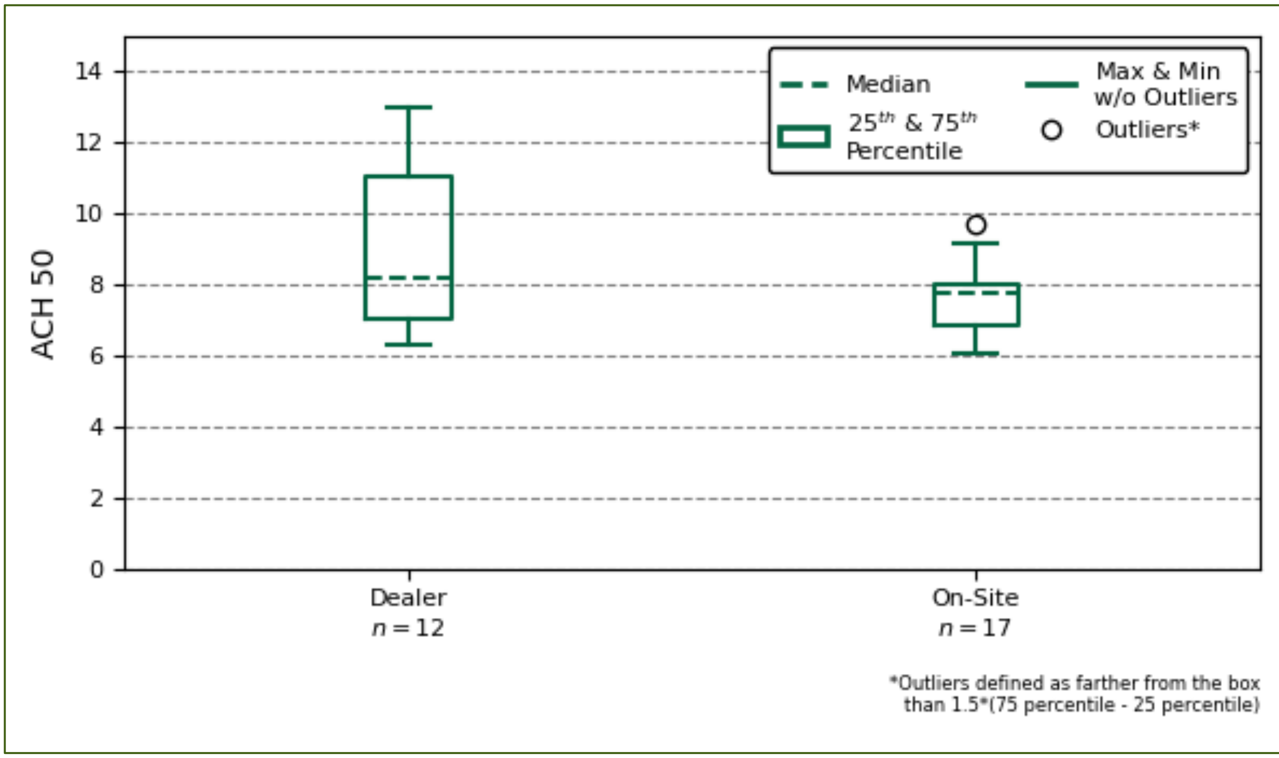
Figure 52. Infiltration ACH50 Value by Home Type



Of the 29 manufactured homes, 12 were tested at dealers and 17 were occupied, and were tested on skirts. We examined infiltration in these two sub populations and saw the differences illustrated in Figure 53. The medians of the two sub-populations were nearly identical but the upper values were not. The upper 75th percentile for homes was about 8 ACH, while the dealer homes had a 75th percentile value at about 11 ACH. It was likely that penetrations in lot homes are not fully sealed, while the installed homes were more fully sealed. In either case, half of homes on dealer lots and nearly half of installed homes do not meet the HUD code for infiltration.

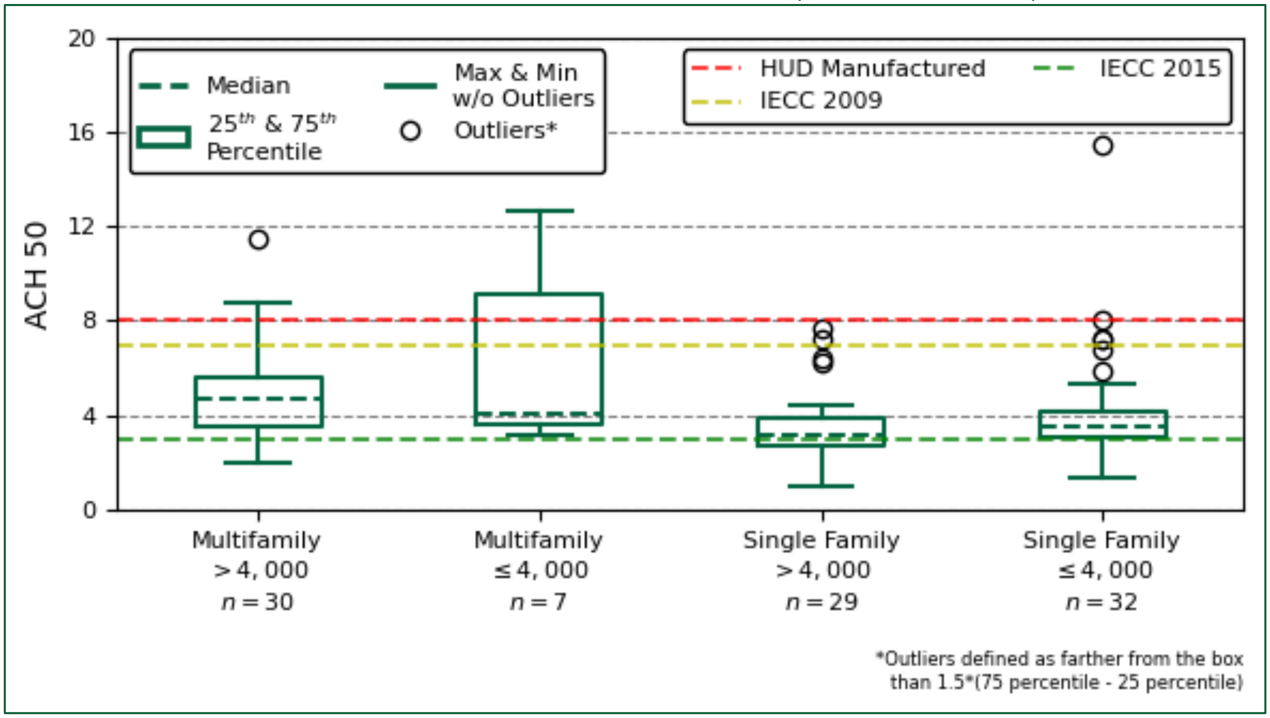
[24] https://www.nrel.gov/docs/fy15osti/62675.pdf

Figure 53. Infiltration ACH50 Value for Manufactured Homes by Testing Location



Looking at the infiltration data by town population yielded some interesting, but not statistically significant differences (Figure 54). Single family homes built in non-enforcement towns had a nearly identical spread of infiltration values to those built in larger towns, albeit with a slightly higher median value. The multifamily units built in smaller towns had a much larger infiltration range but had a slightly lower median value than that in larger towns. This is explained by the outliers shown in Figure 52.

Figure 54. Infiltration ACH50 Value by Home Type and Town Population

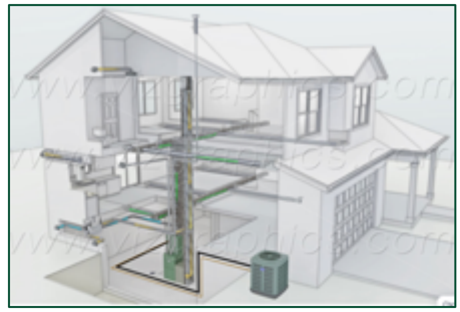


While the ACH50 values provided standardized value for comparisons and are the basis of code compliance, actual, "natural infiltration" was about 16 times lower, based on Ekotrope modeling. The natural ventilation rate was used to model energy usage. Table 19 shows the modeled natural ventilation for the 127 homes.

Table 19. Natural Infiltration (ACH50)

Summary Statistic	Natural ACH	Single Family	Multifamily	Manufactured
Count	127	61	37	29
Mean	0.32	0.25	0.32	0.45
Std	0.17	0.16	0.16	0.11
Min	0.07	0.07	0.11	0.33
25 pct	0.20	0.18	0.21	0.37
50 pct	0.29	0.22	0.30	0.42
75 pct	0.39	0.29	0.38	0.50
Max	1.16	1.16	0.98	0.70

7 MECHANICAL SYSTEMS



7.1 BACKGROUND

This section describes the characteristics of heating, cooling, and ventilating equipment installed in the study's homes. Hot water heating systems, dedicated ventilating systems, heating and cooling distribution systems, and thermostats are also included in this section. The choice of these systems can greatly affect, for decades to come, the cost to operate the home, the consumption of the home, and the carbon emissions resulting from use of the home.

7.2 HEATING EQUIPMENT

Broadly speaking, a builder or contractor wants to not only technically meet the heating loss of a normal cold day, but also meet the highest possible heating need, and meet a customer's expectations to generate satisfaction. The installing HVAC contractor also wants to eliminate the possibility of a call back. This last item can lead to oversizing heating systems as documented in previous HVAC studies. A heating system is sized to heat a home on the coldest expected day to a common indoor temperature setpoint. Sizing methods include heat load calculations using methods including Manual J, rules of thumb often tied to square footage, and contractor experience. Heating system sizing in relation to calculated heat load is shown later in this section by comparing modeled design heat load with each site's total heating equipment capacity.

The choice of a system is a combination of the heating fuel available, the builder's and HVAC contractor's opinion of an ideal system, the desire for combined domestic hot water heating, and the cost of a system. Minimum efficiencies are established by code, but these code minimums are well below (worse than) even generally purchased heating equipment. Beyond minimum code, efficiency can be looked at from several viewpoints, including site fuel conversion efficiency, source fuel efficiency, operating fuel cost, and carbon emissions.

In the 2008 study, oil was the dominant fuel at 75%, and for non-manufactured homes in this study, it was 11%. Propane and natural gas were a combined 19% in 2008, and were 66% in this study, albeit a third of those homes in combination with heat pumps. Heat pumps were virtually non-existent for heating and were the sole heat source for 22% of homes in this study counting combinations with electric baseboard. Heat pumps were present in a total of 37% of homes, although some of those in boiler heated homes may, in practice, be used primarily for cooling.

The range of nominal efficiencies shown for fossil-fueled systems in the 2008 Study were similar to today's for oil systems. There are three major differences in efficiency between 2008 and this study: 1) The average boiler efficiency in the 2008 study was 85.3%, it was 94.4% in this study. The average furnace efficiency actually went down, primarily because of the low efficiency units found in manufactured housing in this study (Table 20).

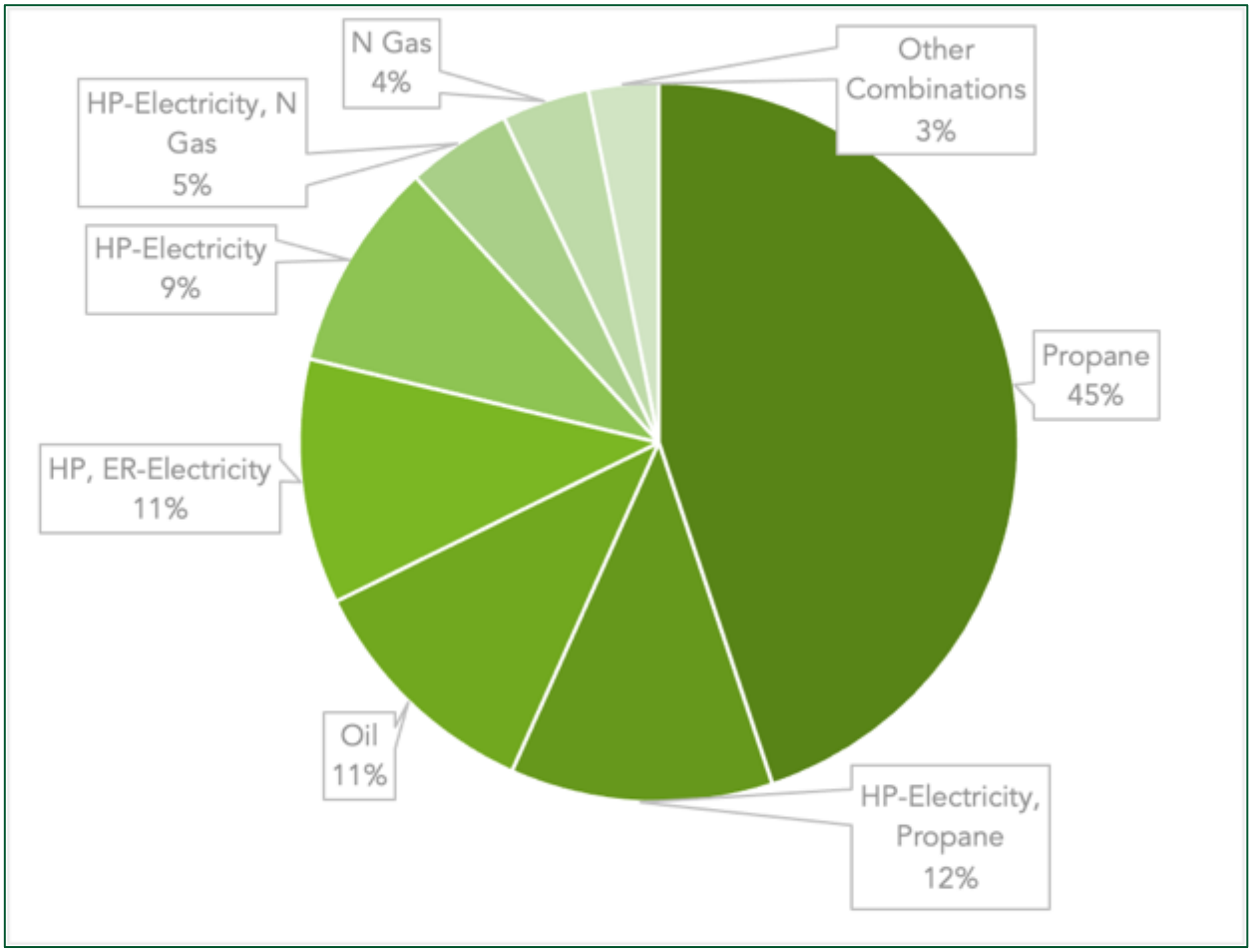
Table 20. Heating System Efficiencies for 2008, 2015, and 2021 Studies

	2008 Study	2015 Study	Count	Average Heating Capacity [thousand BTUH]	Average Heating Efficiency
Heat Pump	NA		54	23.0	337.9%
Boiler	85.3%		60	108.9	94.4%
Natural Gas		83%	10	101.6	95.0%
Oil		83%	3	160.7	87.0%
Propane		86%	47	107.2	94.7%
Furnace	87.7%		38	62.6	85.7%
Natural Gas			1	78.0	96.2%
Oil		81%	12	71.3	83.3%
Propane			25	57.9	86.4%
Radiant Floor Electric			4	1.2	94.0%
Resistance Heater			25	10.1	100.0%
Wood Stove		72%	2	53.8	55.0%
Total	86.3%	81%	183	57.3	

7.2.1 Heating Fuel

Figure 55 shows the systems used in the study homes. Approximately 20% of homes used electricity as their sole heating fuel, and these were heat pumps (HP) with some electric resistance (ER) backup. About 61% of homes used only fuel (oil, propane, or natural gas) for heating. Another 16% used a combination of heat pumps and fossil fuel for heating.

Figure 55. Primary Heating Fuel by Count (n=127)



7.2.2 System Type

Figure 56 shows, while fossil fuel boilers and furnaces were still the most common heating source at 60%, 37% of homes used heat pumps alone or in combination with another heating source. Homes using only HP or HP with supplement ER heat account for 19% of homes. This was a large change from previous Maine housing studies where heat pumps were rare and where present, provided supplemental heating.

Figure 56. Primary Heating System Type by Home (n=127)

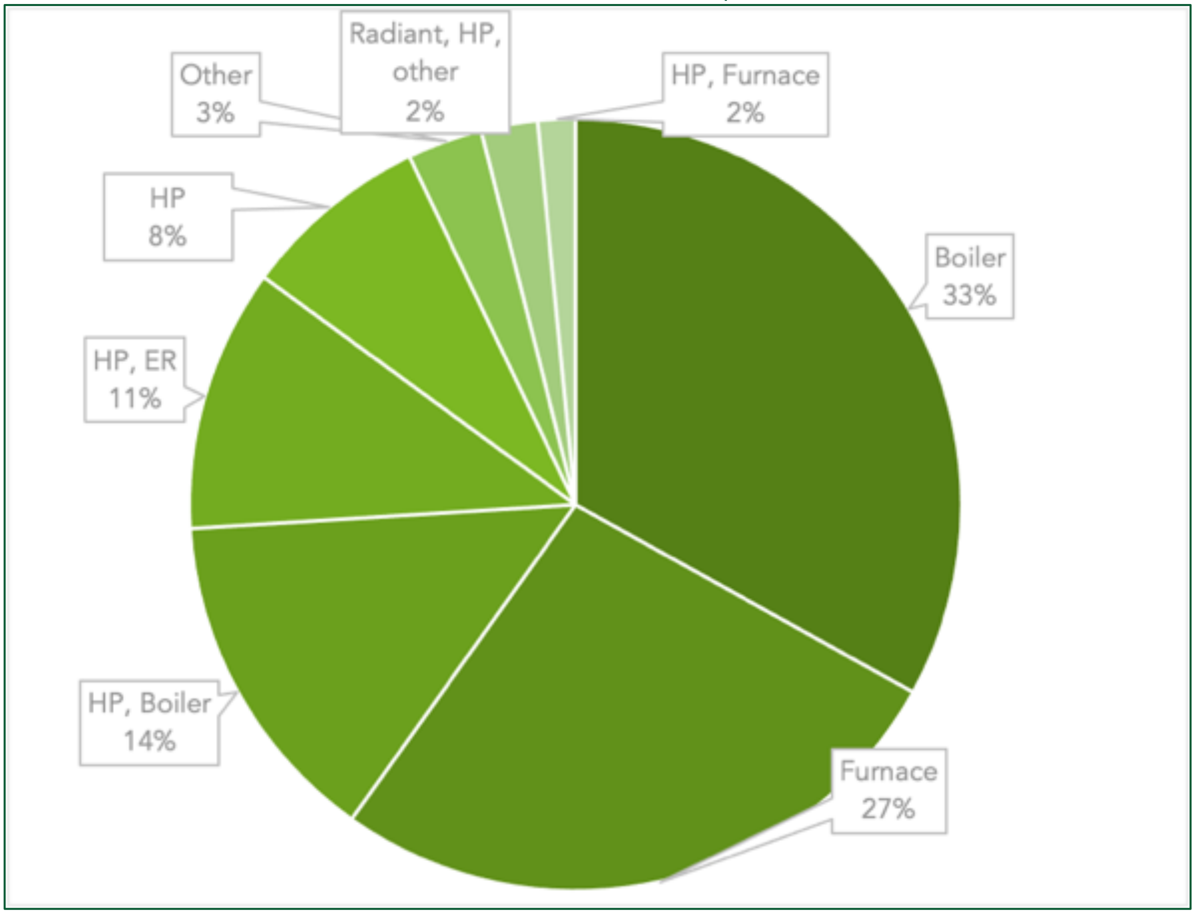


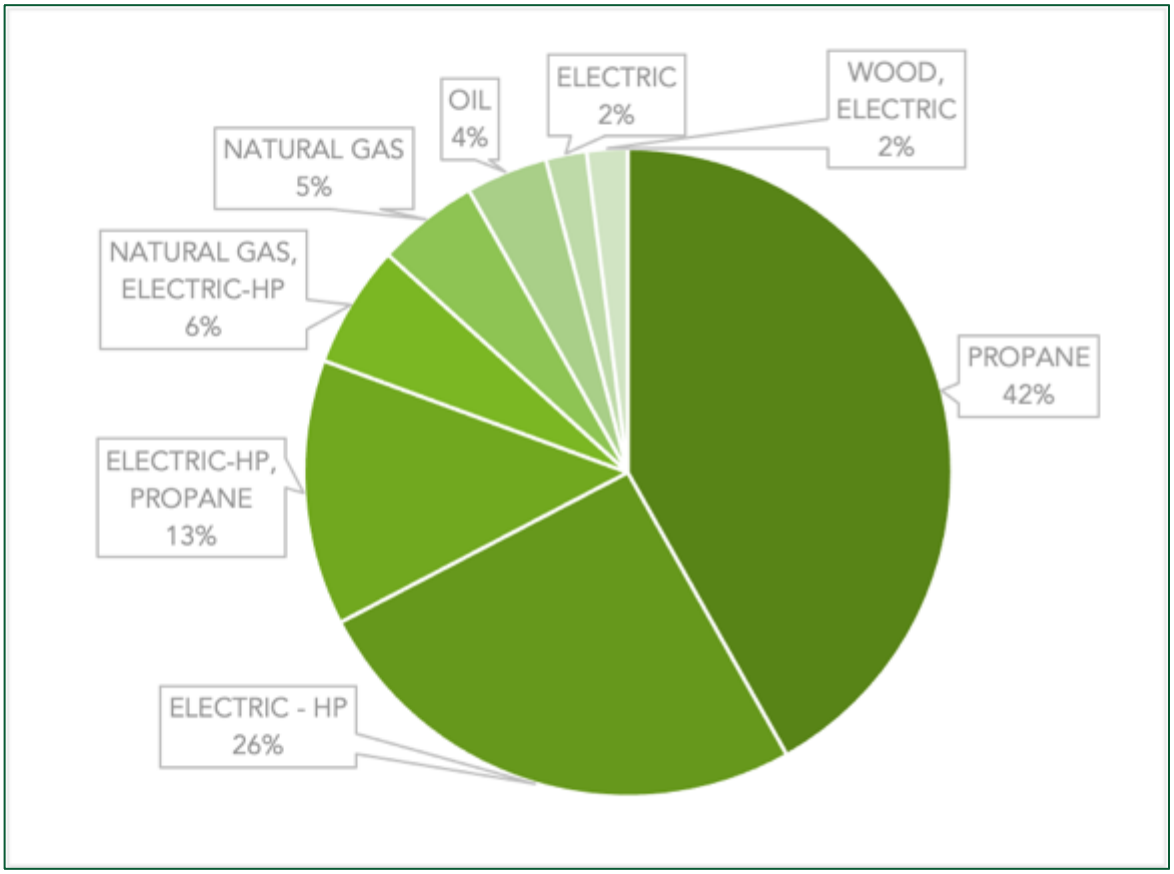
Table 21 shows heating system type by home type. Manufactured homes used furnaces, two had furnaces in combination with a heat pump.

Table 21. Heating Systems in Studied Homes by Count and Capacity

Combinations of Heating Systems	Manufactured	Multifamily	Single Family	Total	Percent
Heat Pump		2	8	10	8%
Heat Pump, Boiler		8	10	18	14%
Heat Pump, Resistance Heater		10	4	14	11%
Boiler		13	29	42	33%
Furnace	27	2	5	34	27%
Furnace, Heat Pump	2			2	2%
Propane Stove			1	1	1%
Radiant Floor Electric, Heat Pump		1		1	1%
Radiant Floor Electric, Heat Pump, Propane Stove, Resistance Heater			1	1	1%
Radiant Floor Electric, Heat Pump, Resistance Heater		1		1	1%
Resistance Heater			1	1	1%
Wood Stove, Resistance Heater			2	2	2%
Total	29	37	61	127	100%

Manufactured homes were primarily heated with fossil fuel furnaces. We therefore examined the heating fuel for single family and multifamily homes to look at heat pump penetration. As shown in Figure 57, about 45% of non-manufactured homes have heat pumps.

Figure 57. Heating Fuel by Home Count (non-manufactured)



7.2.3 Backup and Secondary Heat

Of the homes that rely solely on heat pumps, about half had electric resistance heaters for zones like bathrooms. Of the homes with heat pumps, about one third also have a fossil fuel heating source.

7.2.4 Design Heating Load

We used Ekotrope Rater to calculate the design heating load that was the total heat load at an outdoor temperature called the design temperature. While most contractors use another set of tools called Manual J and Manual S[25] for sizing heating and cooling

[25] For residential applications, the Air Conditioner Contractors of America's (ACCA's) Manual J, Eighth Edition (MJ8TM) is recognized by the American National Standards Institute (ANSI) and is specifically required by some residential building codes.

systems, the Ekotrope values were used for assessing how contractors size systems in relation to predicted loads. The average design heat load was 22,000 BTU/hr. One customary way of normalizing heat load is to divide it by the conditioned area in square feet and adjust the units to yield BTUH/SF. Figure 58 shows the normalized design heat load by type of home. The mean value was 14.6 BTUH/SF and 14.1 BTUH/SF weighted by area, but varied with multifamily at 12.5 and manufactured homes at 17.2 BTUH/SF.

Figure 58. Normalized Design Heat Load

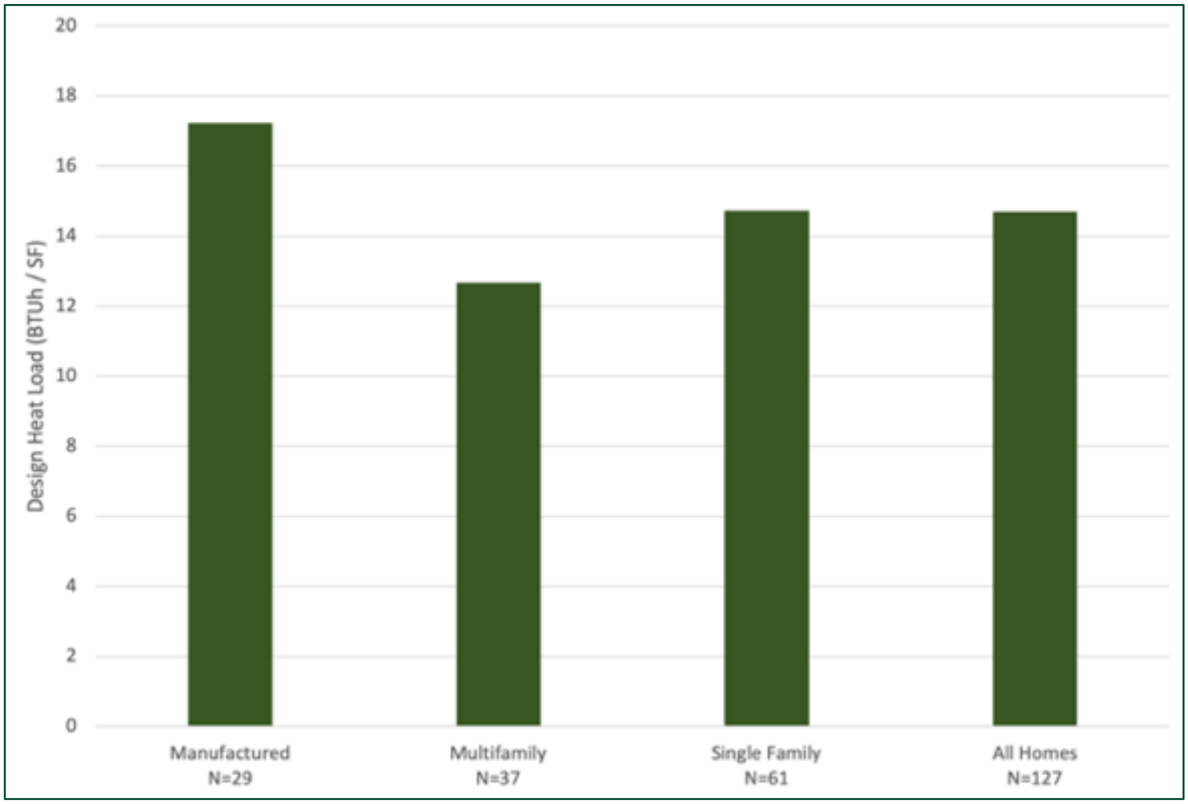
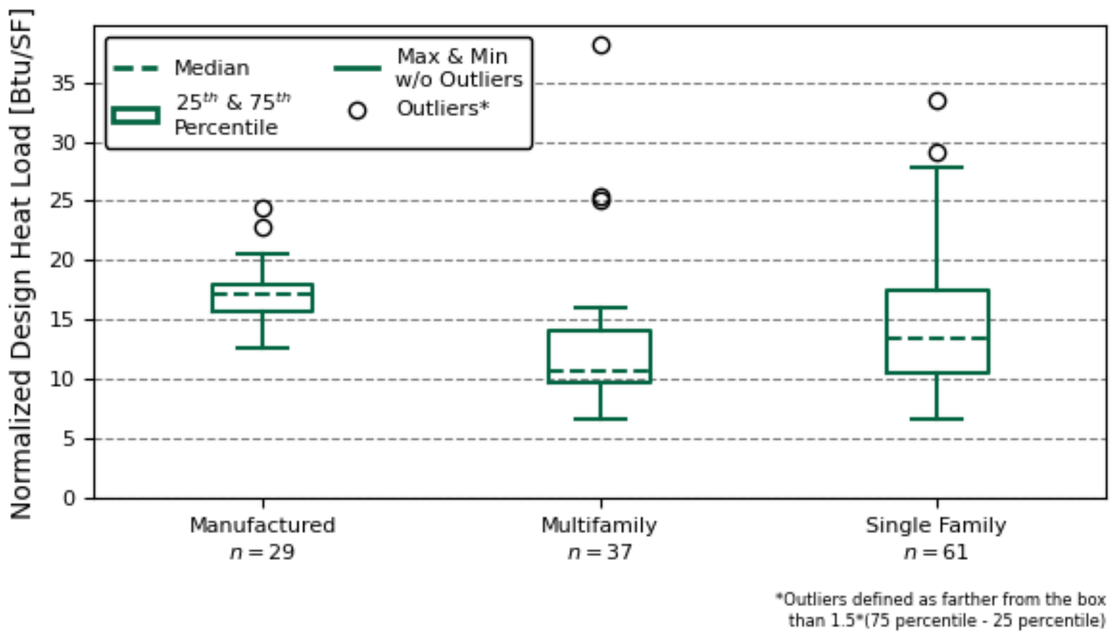


Figure 59 shows the same data as a box and whisker plot showing the range of the data.

Figure 59. Box and Whisker Plot of Normalized Design Heat Load



This variation across home types was understandable in that multifamily units shared at least one surface with another unit of similar indoor temperature so had lower loads and manufactured units had higher infiltration rates than other types of homes so would have had a higher median load.

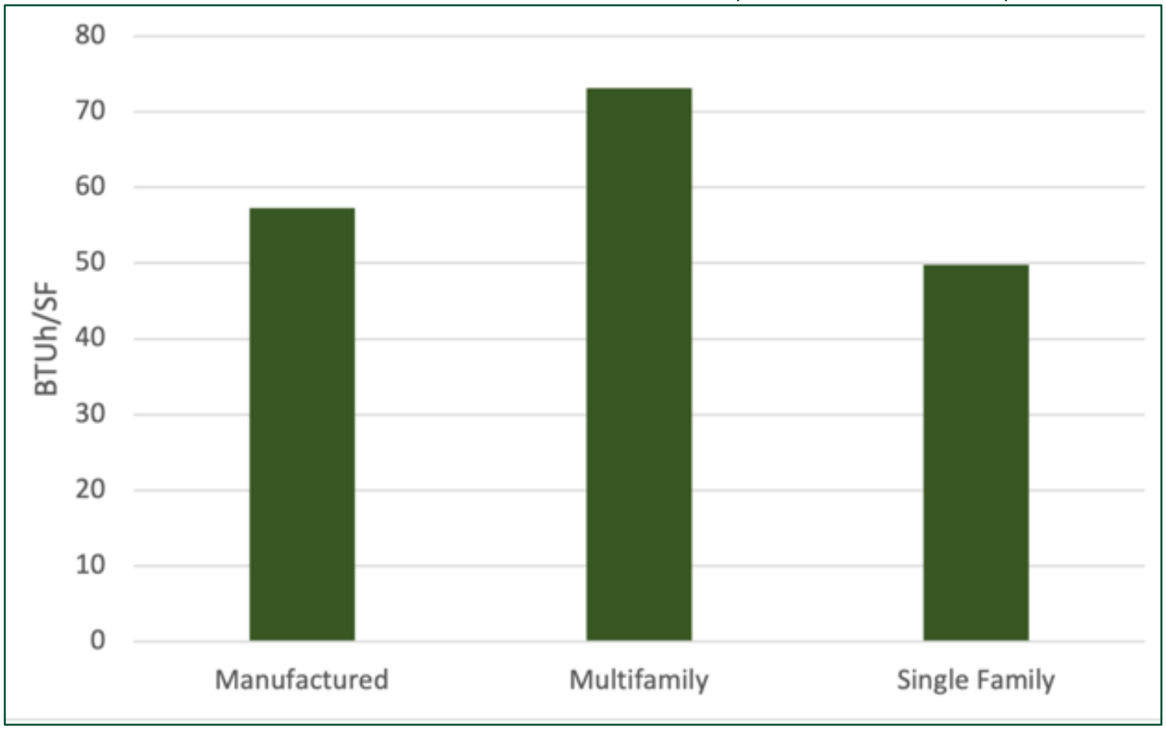
These heat loads are quite low compared with older conventionally constructed homes that may have little or no wall and foundation insulation, have single pane windows, possibly with storm windows, and comparatively high levels of infiltration. As a point of comparison, the average design heat load from the 2008 study was 47,000 BTUH. While the normalized average was not given, the average home in the study was 2,057 SF so approximately[26] the normalized design heat load would be 22.8 BTU/SF or about 50% higher than the median value of this study (Figure 59). Similarly, the median design heat load from the 2015 study was 46,500 BTUH and the median home size was 1,998 SF. The resulting approximate estimate of normalized load is 23.3 BTU/SF, about 50% higher than this study's normalized design heat load.

[26] The average heat load divided by the average home size does not yield the same value as the average of normalized heat load because different sized homes will have lesser or great weight on that average value. It is nevertheless useful for an approximation when the exact value is not available.

7.2.5 Installed Heating Capacity

As shown in Figure 60, the normalized heating capacity ranged by home type with manufactured homes over 55 BTUH/SF, multifamily homes over 70 BTUH/SF and single family at 50 BTUH/SF. These capacities were much higher than the modeled heating as shown in the following section.

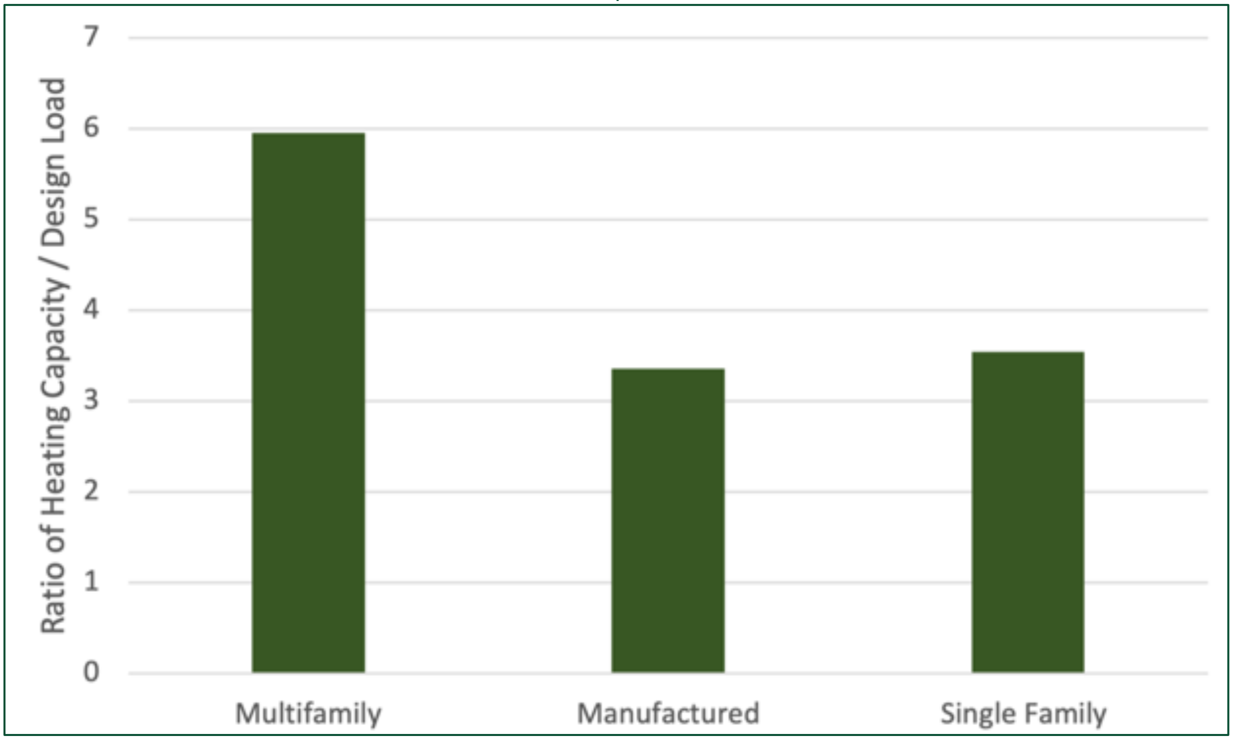
Figure 60. Normalized Heating System Capacity by Home Type



7.2.6 Heating Capacity versus Modeled Heat Load

The average installed heating capacity in the study was nearly 60 BTUH/SF, and this average was skewed somewhat (high) by manufactured homes. The average modeled design heat load was 14.1 BTUH/SF. Therefore, the average ratio of installed to design heating capacity was about 3.76:1. Weighting the ratio by area yielded a slightly higher ratio of 3.85:1. Looking at this ratio by housing type, multifamily had the highest ratio, and single family and manufactured were similar (Figure 61). This may have been due to the small loads in multifamily because of shared walls.

Figure 61. Normalized Ratio of Heating System Capacity to Heat Load by Housing Type



Examining the ratio by heating system type we saw that design practices varied greatly by system type. Propane boilers had a sizing ratio to design load of over 6:1 while heat pumps were about 1.5:1. Interestingly, electric baseboard came in at less than 1:1. The exact reason for this large differential is not known but integrated hot water could be part of the reason.

While Ekotrope is not the customary system sizing tool for contractors, this ratio indicates over sizing and may indicate that sizing methods were lagging behind the lower heating needs of better built houses. That is, homes with low leakage and uniform high levels of insulation do not need the capacity installed. Part of the reason for the large differential in boilers could be integrated hot water, but this does not explain the oversizing of furnace systems.

Figure 62 shows the sizing ratio as box and whisker plots that capture the spread of the data. While the mean of boiler sizing ratios was about 6, 25% of boilers are over 7. Furnaces were sized a bit smaller, but 25% of furnaces were sized at greater than 3.8 times the modeled load. Because furnaces do not also heat water these units were clearly over-sized. Heat pumps were sized the closest to actual load, in the 1.5 to 2 range, and heat pumps combined with electrical resistance (ER) heating were higher.

Figure 62. Ratio of Heating System Capacity/ Heat Load

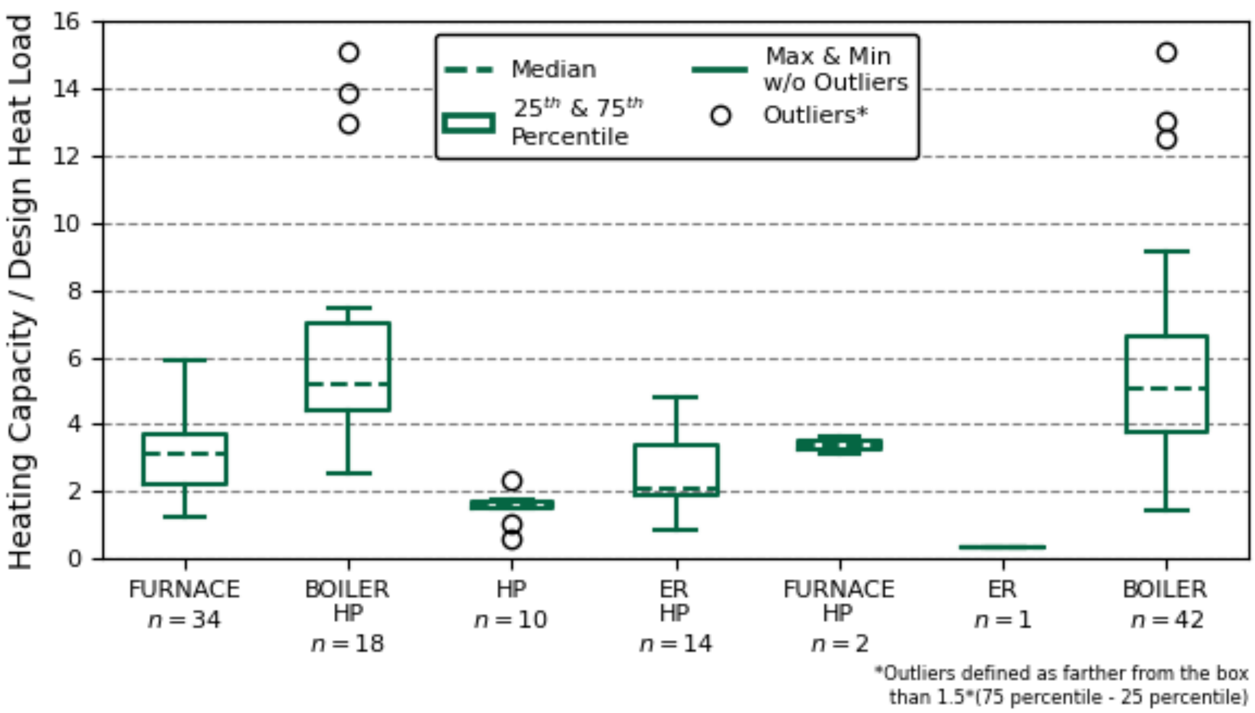
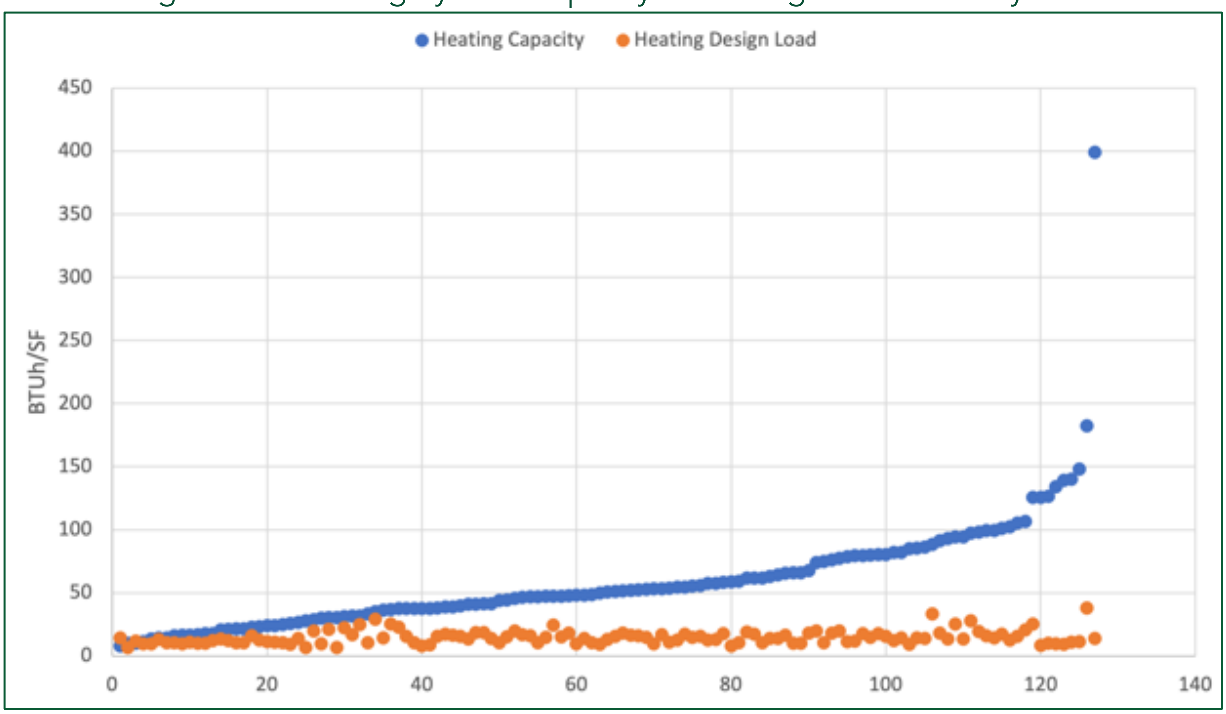


Figure 63. Heating System Capacity and Design Heat Load by Home



7.2.7 Efficiency

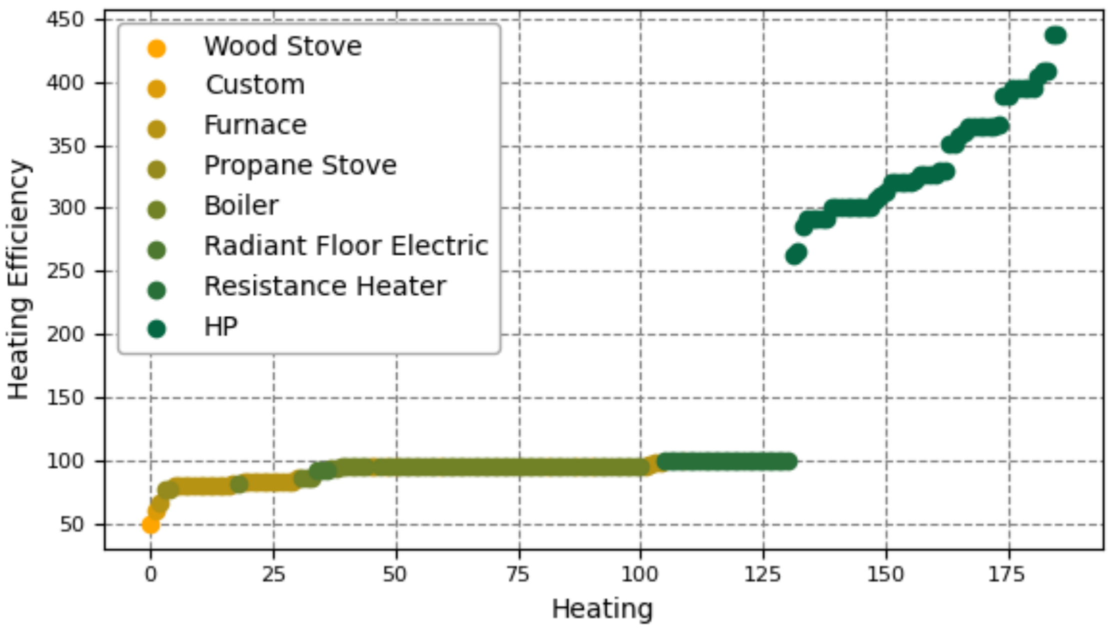
The site efficiencies of the homes' heating systems are shown in Table 22 with fossil fuel systems shown as AFUE, other systems as efficiency, and heat pumps as an efficiency equivalent, termed a coefficient of performance (COP), based on their rated heating system performance factor (HSPF).[27] The efficiencies were derived from Raters' review of nameplates and AHRI data. The Federal minimum is shown, and the installed systems were well above these minimums. The maximum achievable efficiency is 100% for systems that create heat through combustion. Heat pumps do not convert heat but rather move heat from outside the building into the building. Because they are simply moving heat from one place to another, they are not bound by the 100% efficiency limit. Leading systems have seasonal heating efficiencies as high as 14 (HSPF), equivalent to a COP of 410%. Of the systems shown, wood was the least efficient at 55% and oil was low at 83% to 87%. Natural gas and propane systems varied with units found in the study but are capable of 95%. Heat pumps averaged 338%. As with AFUE, the HSPF (or COP equivalent) of heat pumps represented the annual average efficiency under the AHRI testing conditions. Figure 64 shows the site efficiency of heating systems found in homes.

Table 22. Heating System Nominal Efficiencies

System (Fed Min. Efficiency)	Count	Average Heating Capacity [thousand BTUH]	Average Heating Efficiency
Heat Pumps (8.2: 240%)	54	23.0	337.9%
Boiler	60	108.9	94.4%
Natural Gas (82%)	10	101.6	95.0%
Oil (84%)	3	160.7	87.0%
Propane (82%)	47	107.2	94.7%
Furnace (78%)	38	62.6	85.7%
Natural Gas	1	78.0	96.2%
Oil	12	71.3	83.3%
Propane	25	57.9	86.4%
Radiant Floor Electric	4	1.2	94.0%
Resistance Heater	25	10.1	100.0%
Wood Stove	2	53.8	55.0%
Total	183	57.3	163.8%

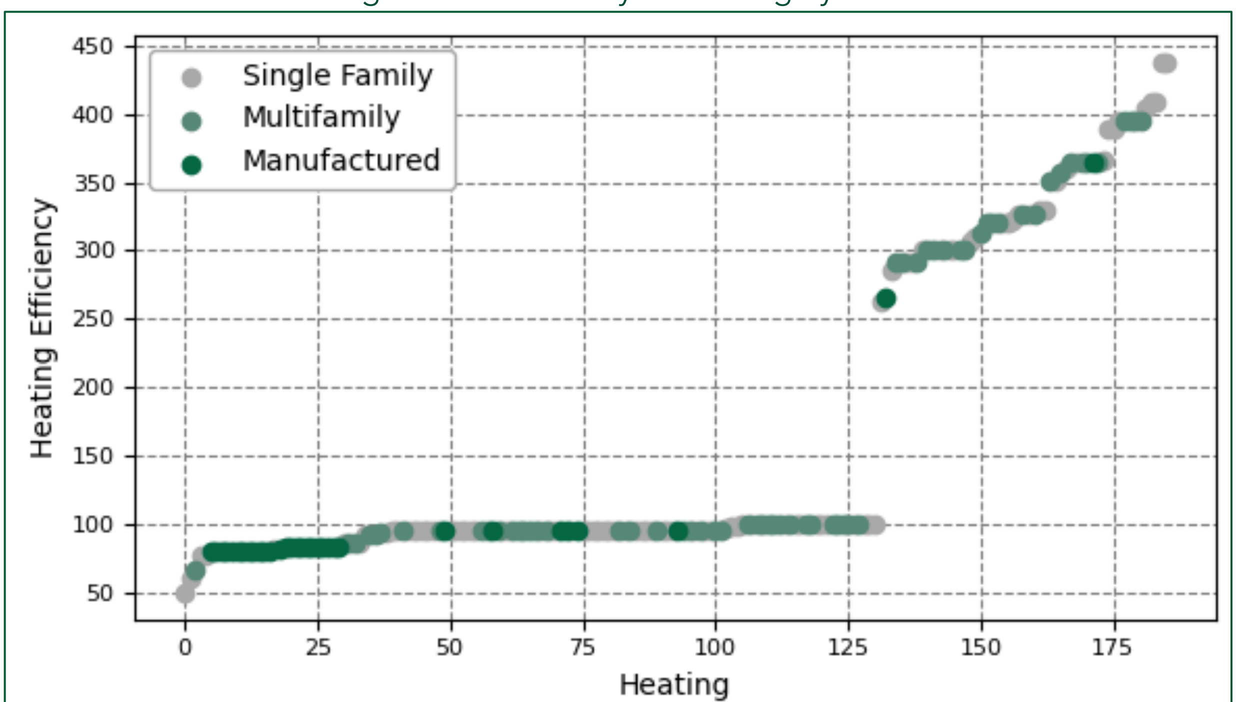
[27] A heat pump's HSPF is based on AHRI testing. The numbers are referenced here as reported and have not been modeled or otherwise adjusted to a specific climate.

Figure 64. Efficiency of Heating Systems



In Figure 65, the efficiency of the heating systems in each of the 127 homes is shown by home type. Manufactured homes had the least efficient systems, and they were clustered in the low 80s.

Figure 65. Efficiency of Heating Systems



7.3 COOLING EQUIPMENT

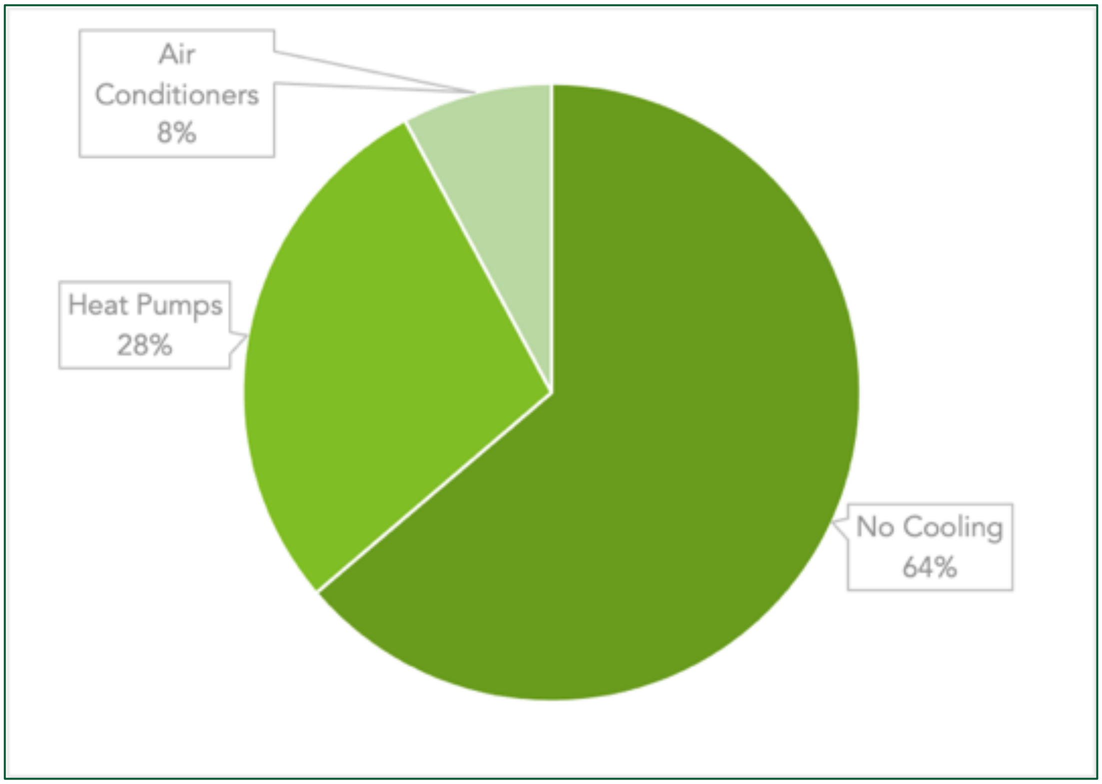
Similar to heating equipment, a builder or contractor wants to install cooling equipment that not only meets the heat gains of a normal hot day, but also meets the highest possible cooling need, and meets a customer's expectations to generate satisfaction. The installing HVAC contractor also wants to eliminate the possibility of a call back. This last item can lead to oversizing cooling systems. Cooling equipment is sized to cool a home on the warmest expected day to a common indoor temperature setpoint. Sizing methods include heat gain calculations using Manual J, equipment selection using Manual S, rules of thumb often tied to square footage, and contractor experience. Cooling system sizing in relation to calculated heat gain is shown later in this section by comparing a design heat gain calculated by Ekotrope with each site's total cooling equipment capacity. Because heat pumps are sized for a heating load, oversizing in relation to a cooling load was expected in Maine's cooler climate.

Of the houses studied, 46 or 36% had a cooling system installed (Figure 66) some with more than one unit. It was possible that some homes had room air conditioners that were not observed. Most cooled homes had heat pumps. The 11 central air conditioners installed varied in size from 2 tons to about 3.5 tons and had an average SEER of 14.1. These units were installed in combination with fossil fuel heating systems. Heat pumps averaged 24,500 BTUH in cooling capacity and 20.9 SEER (Table 23). While high compared with the central units, the average of 20.9 was actually low considering the range of SEERs available. Units with SEERs as high as 30 are now common. Some homes had more than one heat pump; the 51 units were installed in 46 homes.

Table 23. Central Air Conditioner Size and Capacity

System Type	Count	Average of Cooling Capacity [thousand BTUH]	Average of SEER	# Homes	SF Served
Ducted HP/ CAC	11	37.4	14.1	10	21,040
Heat Pump	40	24.5	20.9	36	57,895
All Units	51	27.3	19.4	46	78,935

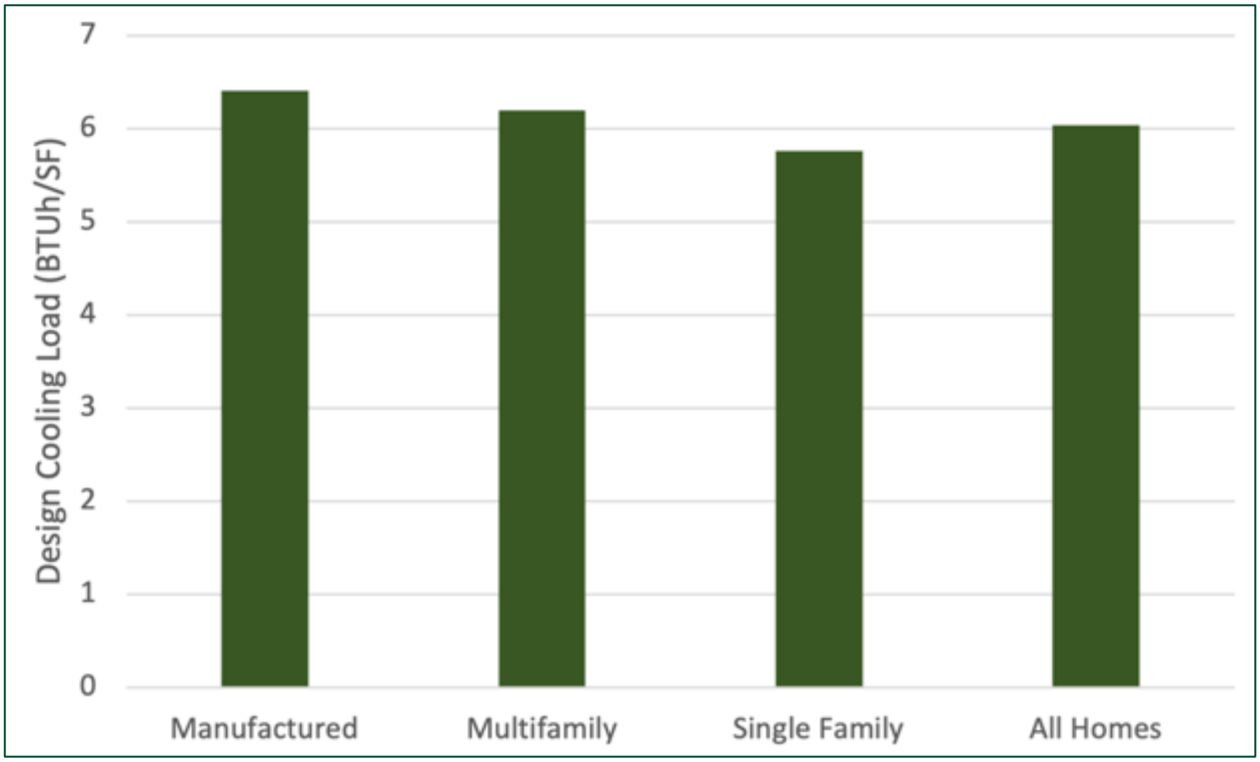
Figure 66. Cooling Systems by Count of Homes



7.3.1 Design Cooling Load

We used Ekotrope Rater to calculate the design cooling load which was the total heat gained at an outdoor temperature called the design temperature. While most contractors use another set of tools called Manual J and Manual S for sizing heating and cooling systems, the Ekotrope values were used to assess how contractors sized systems in relation to predicted loads. The average design cooling load was 9,500 BTU/hr. One customary way of normalizing cooling load is to divide it by the conditioned area in square feet and adjust the units to yield BTUH/SF. Figure 67 shows the normalized design cooling load by type of home. The area weighted mean value was 6.0 BTUH/SF. Unlike heating design load, it varied little with building type. This was likely because cooling load is driven by internal heat gains and from solar gain from windows and was not heavily impacted by small differences in insulation.

Figure 67. Normalized Cooling Load



Examined another way, contractors for years sized cooling equipment using a rule of thumb between 500 and 750 SF/ton[28] of air conditioning capacity. This is equivalent to 16 to 24 BTUH/SF, or 2.5 to 4 times the modeled loads of these houses.

These cooling loads were quite low compared with older conventionally constructed homes that might have had little or no wall and foundation insulation, had single pane windows, possibly with storm windows, and comparatively high levels of infiltration. As a point of comparison, the average design cooling load from the 2015 study was 17,800 BTUH. While the normalized average was not given, the median home in the study was 1,998 SF so approximately[29] the normalized design cooling load would be 8.76 BTU/SF or about 50% higher than the median value of this study (Figure 67).

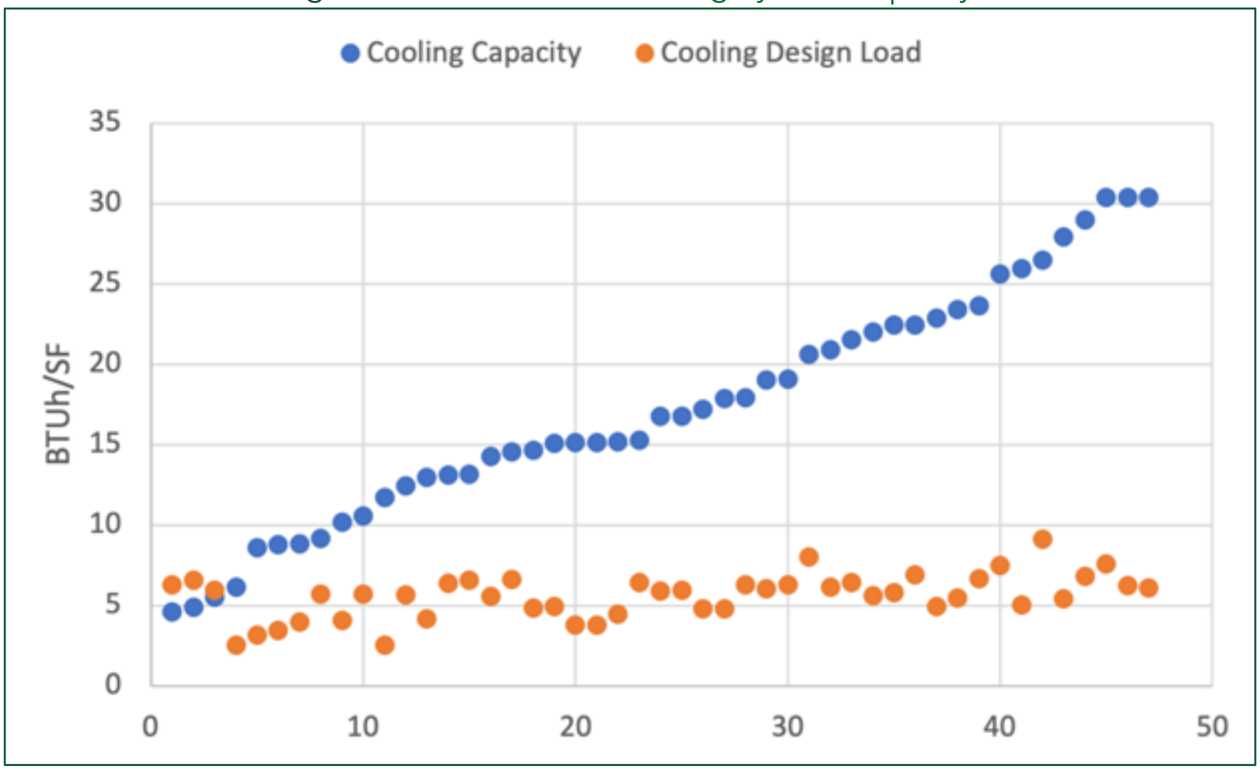
[28] A ton of cooling is the equivalent to the heat absorbed by melting 1 ton of ice in 24 hours, a measurement derived from early days when cooling was provided by ice and a measurement that is in frequent use today. It is equal to 12,000 BTUH, or 288,000 BTUs of cooling in a day.

[29] The median cooling load divided by the median home size does not yield the same value as the median of normalized cooling load because different sized homes will have lesser or greater weight on that average value. It is nevertheless useful as an approximation when the exact value is not available.

7.3.2 Installed Cooling Capacity

Figure 68 shows the normalized cooling capacity and the design cooling load for the 46 homes with heat pumps and air conditioners. For all but three homes, the installed capacity was much greater than the design load. Only two homes had lower capacity than design load, albeit slightly lower.

Figure 68. Normalized Cooling System Capacity



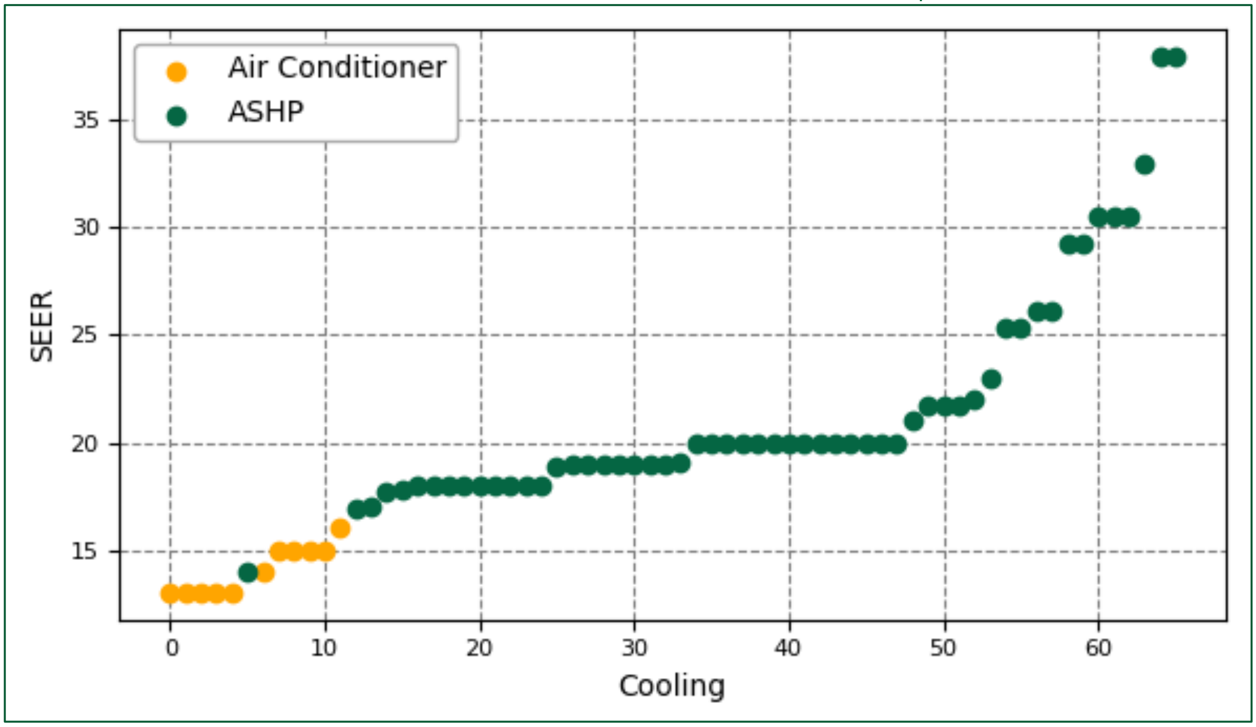
7.3.3 Cooling Efficiency

Cooling efficiency was determined by Raters collecting nameplate information and accessing AHRI data. SEER is the measure of the efficiency of the cooling system for a season (Figure 69). By that measure, heat pumps required about 70% of the energy of a central air conditioner to provide a given amount of cooling[30], implying an energy savings of 30%. Some additional savings occurred by heat pumps eliminating duct heat gains, on the order of 10%.[31] How air conditioners are actually used can cause heat pumps to produce far larger savings. Central ducted air conditioners are typically single-zone units. If a homeowner wants any part of the home cooled, they need to

[30] This is based on a central air conditioner with a SEER of 14.5 and a heat pump with a SEER of 21.
[31] http://www.calmac.org/publications/CPUC_HVAC_Baseline_Market_Study_Final_Report.pdf

cool every part of the home. In contrast, heat pumps are used to cool only the portion of the home desired by the homeowner. As pointed out in a 2015 study of heat pumps in MA[32], these zonal savings, combined with SEER advantages, can produce savings of well over 50%.

Figure 69. Cooling Efficiency by System Type



7.4 COOLING SYSTEMS COMPARISON

The 2008 New Construction study was completed before cold climate heat pump systems were popular in the U.S. In that study, 12% of homes had central air conditioning with an average SEER of 12.8 and an average capacity of 59,000 BTUH. This study had units with systems ranging from 14.1 to 20.8 average SEER, and with smaller capacities. Of the 2008 homes, 34% had one or more room air conditioners. The efficiency was not noted, but was likely 10 EER, typical for room air conditioners at that time. In total, 46% of homes were partially or fully cooled.

In this study, 36% of homes were cooled, a 10% decrease. One difference is that the cooling systems in this study were all permanent while only 12% of homes in 2008 had permanent cooling systems. The 2015 residential stock study found only 3 heat pumps in 41 homes and those had an average SEER of 21.5, slightly higher than that found in

[32] Cadmus, 2016. Ductless Heat Pump Evaluation, Cool Smart.

this study. The room air conditioners found had an EER of 10.1, slightly above (better than) the Federal minimum at the time of 9.7. The single central air conditioner found had a SEER of 10.

7.5 DUCTS

In this study, 29 manufactured homes and 10 non-manufactured homes had ducts. On average these ducts served 1,402 SF of conditioned space per home, with the relatively low area driven by the prevalence of manufactured homes.

7.5.1 DUCT LEAKAGE

Raters tested duct leakage to outside, based on the industry standard test condition of 25 Pascals duct pressure. The average duct leakage rate per home was 200 cubic feet per minute (CFM). Normalized by area, this was 14.7 CFM/100 SF. This was much leakier than the ENERGY STAR Homes standard of less than 6 CFM-25 per 100 SF. Table 24 shows the leakage rate by home type. The average single family home duct leakage was much lower at 10.1 CFM/100 SF of conditioned space but was still above (worse than) the ENERGY STAR home value. Figure 70 shows total duct leakage in CFM.

Figure 70. Duct Leakage by Home Type

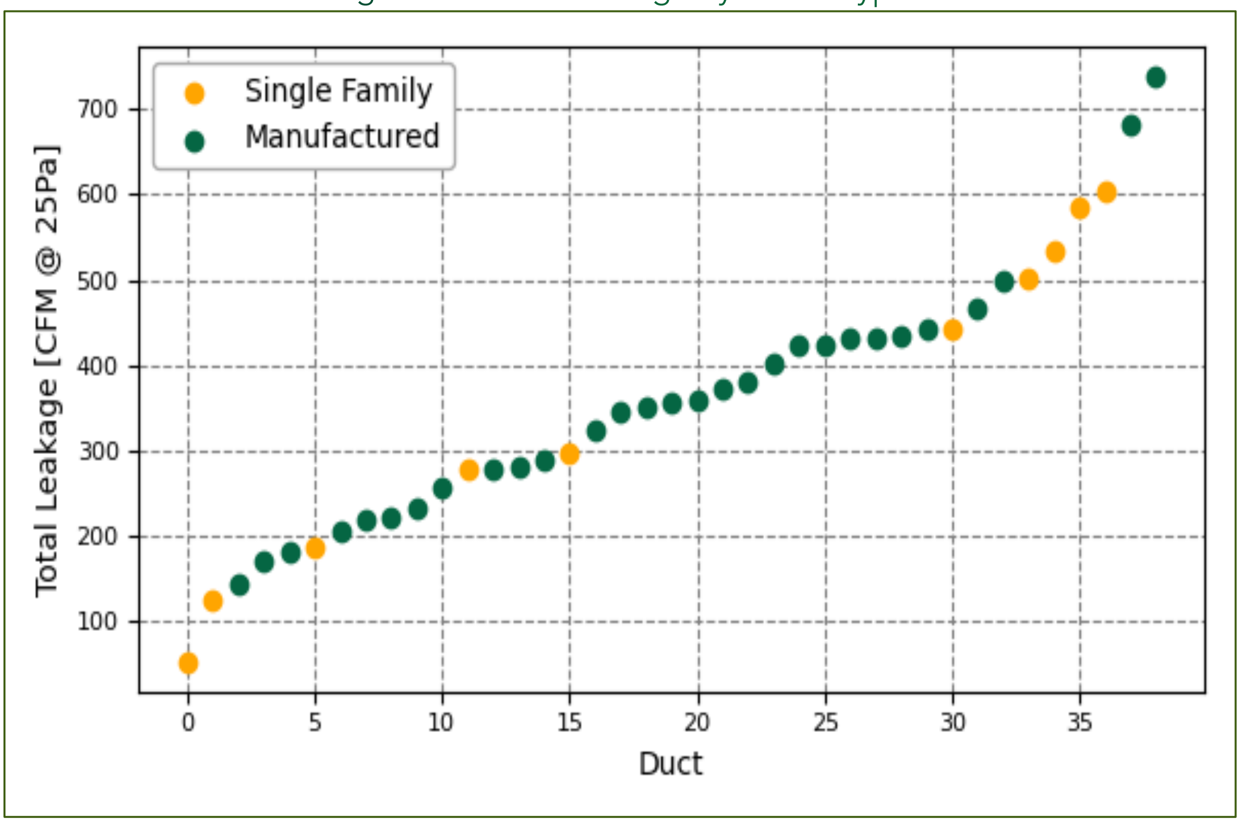


Table 24. Duct Leakage

	Count of Type	Average of Leakage to Outside/ 100 SF
Manufactured	29	16.3
Single Family	10	10.1
Total	39	14.7

7.5.2 Insulation of Ducts

Most of the ducts in this study were flex ducts and most of the ducts were in manufactured homes. Insulation varied from R-1 to R-10 with a mean of 5.5. Duct insulation values were reported at the house level and Table 25 reports simple averages. While areas served by ducts were reported, the length of ducts was not, so the averages of duct insulation are not weighted by length.

Table 25.Duct Insulation by Home Type

	Home Count	Min	Max	Average	Std Dev
Manufactured	29	3.0	10.4	5.7	1.4
Single Family	10	1.0	6.1	4.8	1.7
Total	39	1.0	10.4	5.5	1.5

7.6 HYDRONIC DISTRIBUTION

Most of the homes in the study were heated with boilers and the heat was distributed via pumped loops, and fin and tube radiators.

7.6.1 Pumping

There are two main variations in pumping design, one where there is a dedicated pump per zone (which sometimes includes a zone for DHW) and a second where there is a single distribution pump and an electrically operated zone valve for each zone.

During home inspections, raters found both distribution layouts. High efficiency boilers have a primary pump inside the unit, and either secondary pumps for each zone, a single secondary pump and zone valves, or only zone valves. See Figure 71 for an example of zone valves for each of two zones.

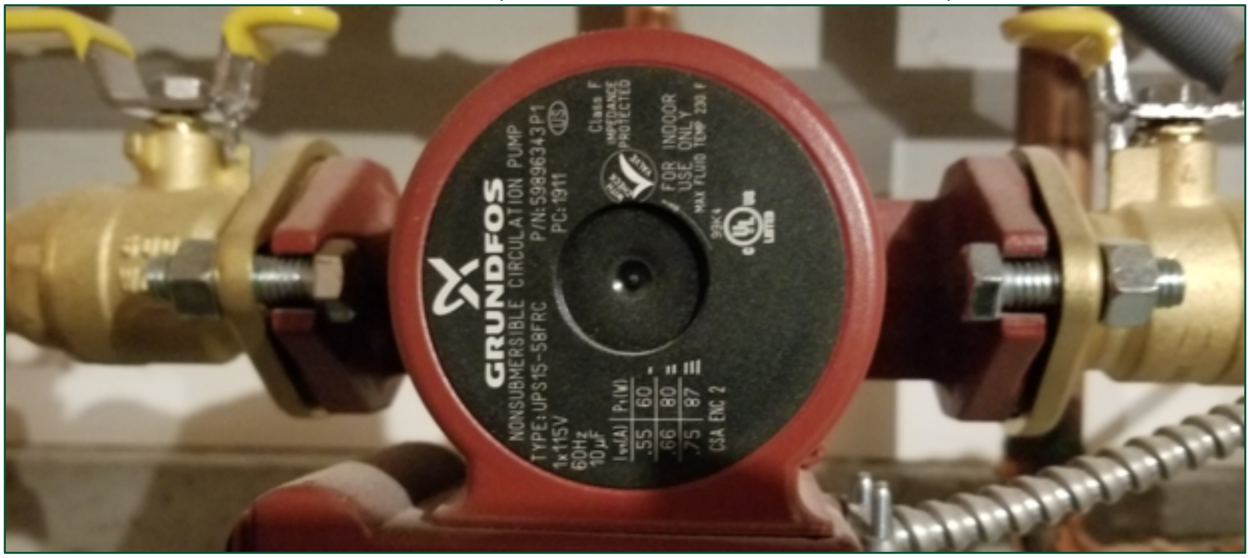
Single speed pumps were small units typically about 1/25 horsepower. We observed both single speed units and larger 3-speed units (see Figure 72). Most pumps did not have electrically commutated motors (ECMs).

7.6.2 Hydronic Design

Most of the boilers in this study were condensing models where return water cools the exhaust to below the dew point of water vapor. Water condensing out of the exhaust gives up heat of vaporization allowing efficiencies above 90%. The average natural gas boiler AFUE in this study was 95%, and the average propane boiler had an AFUE just under 95%, therefore the majority were condensing boilers. When one of these boilers does not condense, the heat of vaporization is lost in the combustion exhaust and the attained efficiency, will be in the range of 88%.

Figure 71. Two Heating Zones with Two Honeywell Zone Valves

Figure 72. 3-Speed Hydronic Circulation Pump



A key determiner of whether the boiler exhaust condenses is the temperature of the water returning to the boiler and this is determined by the supply water setpoint, the heat load of the home, and the length and design of the fin and tube radiators. A study in Massachusetts in 2015[33] showed that only a small portion of boilers reliably operated in a condensing mode and some operated in a manner so that they never condensed. If boilers and the attached hydronic system are designed correctly and the control sequence is set correctly, they should be able to condense for all but the coldest periods.

7.7 MECHANICAL VENTILATION

Only 20 homes had mechanical ventilation systems beyond standard bath fans and kitchen range hoods. The average ventilation rate was 63 CFM. Figure 73 shows a heat recovery ventilation system installed in one of the rated homes.

[33] Cadmus, High Efficiency Heating Equipment Impact Evaluation, Match 2015.

Figure 73. Heat Recovery Ventilation System Observed by a Rater

7.7.1 Measured CO_2

Raters measured CO_2 in most homes except for model homes tested in dealer lots. CO_2 is an analog for ventilation in inhabited homes. People and pets exhale CO_2 and this can build up if ventilation rates are insufficient. Outdoor ambient concentrations of CO_2 have been rising in the last several decades and are approximately 420 parts per million (PPM) in winter months. There is no current standard for a healthful level of CO_2 in a home. CO_2 levels are approximately indicative of ventilation rates of fresh air in relation to the number of occupants. CO_2 levels in the range of 1,000 to 2,000 PPM are not toxic but there have been recent studies linking higher CO_2 levels to drowsiness and inattention. For purposes of this study CO_2 was collected as a general indication of ventilation rates, but was not intended as a determiner of ventilation or building health. Because the meters are at best accurate to 50 PPM and the meters drift, ,the readers should be interpreted as approximate.

Raters took outdoor readings at selected sites and then took one or more readings in each home. The outdoor readings served to check the meters and their relative accuracy. The average outdoor CO_2 is about 420 PPM with some variation due to wind direction and green plant activity which would have been low during this study. We removed 12 readings that were either below 250 or above 500 as erroneous readings. The average of 408 PPM is just below what would be expected outdoors (Table 26), and is well within Telaire meters stated accuracy of ± 50 PPM.

Table 26. Outdoor CO_2 Readings

Summary Statistic	CO_2 (PPM)
Count	78
Mean	408
Min	331
Max	488
St Dev	43
CV	0.10

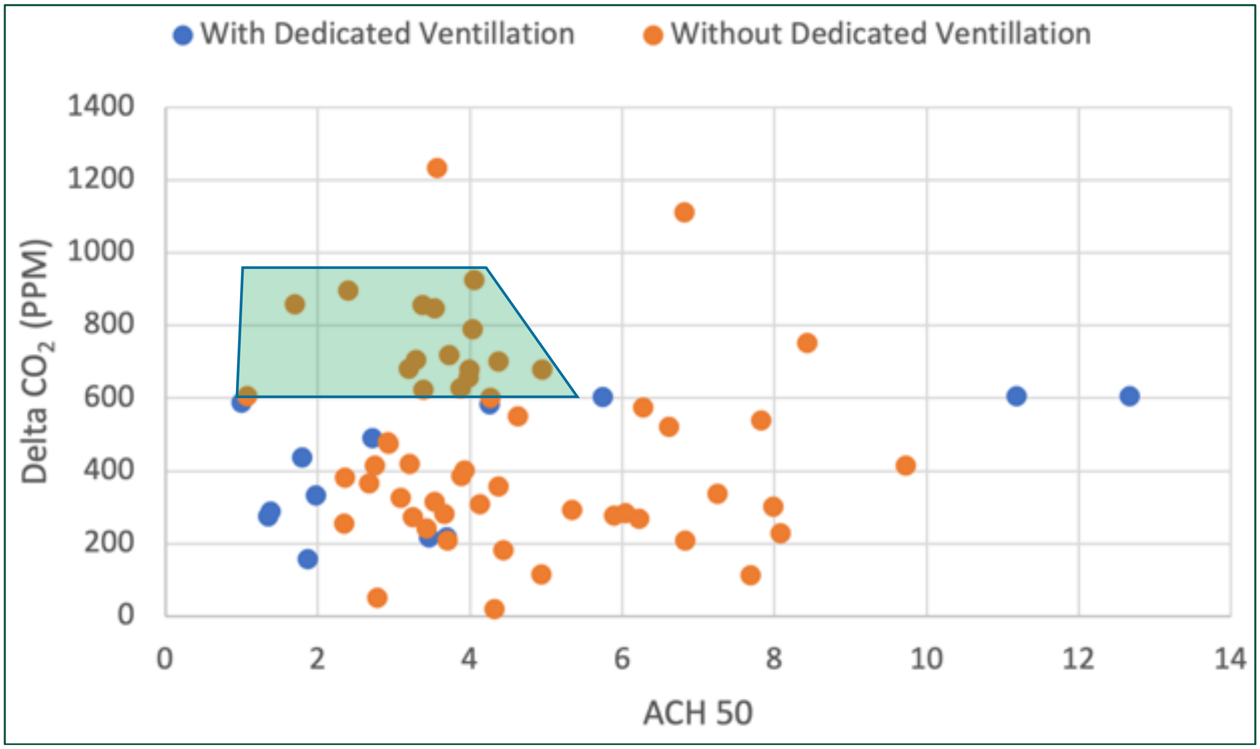
Indoor readings averaged 844 PPM, with a range from 461 PPM (close to ambient) to 1,643 PPM (Table 27) with most homes having two internal locations measured. Of the 110 homes metered, we dropped homes where the heating system was not operating indicating an unoccupied home, such as a builder shown home. Of the occupied homes metered, 30 had one or more readings in excess of 1,000 PPM.

Table 27. Indoor CO_2 Readings

CO_2 (PPM)	With Dedicated Ventilation	w/o Dedicated Ventilation	All Homes
Count	13	55	68
Mean	851	880	874
Min	607	461	461
Max	1,101	1,643	1,643
St Dev	174	257	243
CV	0.2	0.3	0.28

The CO_2 concentration is a factor of both the ventilation rate and the number of people in a house, where a high reading is indicative of a high occupancy rate relative to the ventilation rate. An empty home will have a CO_2 near 420 PPM no matter the ventilation rate. During periods of occupancy, a home with either high ventilation or infiltration (high ACH50) will maintain low CO_2 concentrations, while a tight home with no added ventilation will have higher CO_2 concentrations. In Figure 74 we graph the concentration of indoor CO_2 above the outdoor against the ACH50 infiltration reading. Homes with and without dedicated ventilation are shown as different colors. As expected, there was not a clear relationship between CO_2 and ACH50 because occupancy will be varied. We do see, however, that all of the readings above 600 PPM except for 2 outliers, were homes with fewer than 5 ACH50. The shaded region shows that most higher readings were in homes that have an ACH50<5 and no dedicated ventilation. Curiously two homes with high ACH50s and dedicated ventilation had relatively high readings (right most points on graph). These readings are not particularly high, however.

Figure 74. Indoor CO_2 Readings versus ACH50



7.8 THERMOSTATS

7.8.1 SET POINTS

Raters collected setpoints at one or more thermostats per home. The mean was 66°F but with a broad range of set points (Table 28). Some homes were unoccupied and showed by the builder and had low setpoints. Ignoring these values and considering occupied spaces only, the mean reading was 67°F and the standard deviation of readings was 4°F. Overall, the majority of setpoints were lower than 70°F.

Table 28. Thermostat Setpoints

Summary Statistic	Occupied Indoor Setpoint (°F)
Count	165
Mean	67.4
Min	56.3
Max	79
St Dev	4.12
CV	0.06

7.8.2 Measured Air Temperature

Raters collected the indoor temperature at two locations per home using an instant read digital thermometer.[34] The mean reading was 65°F and the standard deviation of readings was 7°F, nearly identical to the setpoints above (Table 29). A few homes had lower temperatures because they were unoccupied. Ignoring these values and considering occupied spaces only, the mean reading was 68°F and the standard deviation readings was 4°F, again similar to setpoints above.

Table 29. Indoor Temperature Readings

Summary Statistic	All Indoor Temperature (°F)	Occupied Indoor Temperature (°F)
Count	176	154
Mean	65.9	67.8
Min	43	57
Max	78	78
St Dev	6.49	4.02
CV	0.10	0.06

7.9 DOMESTIC HOT WATER (DHW) HEATING

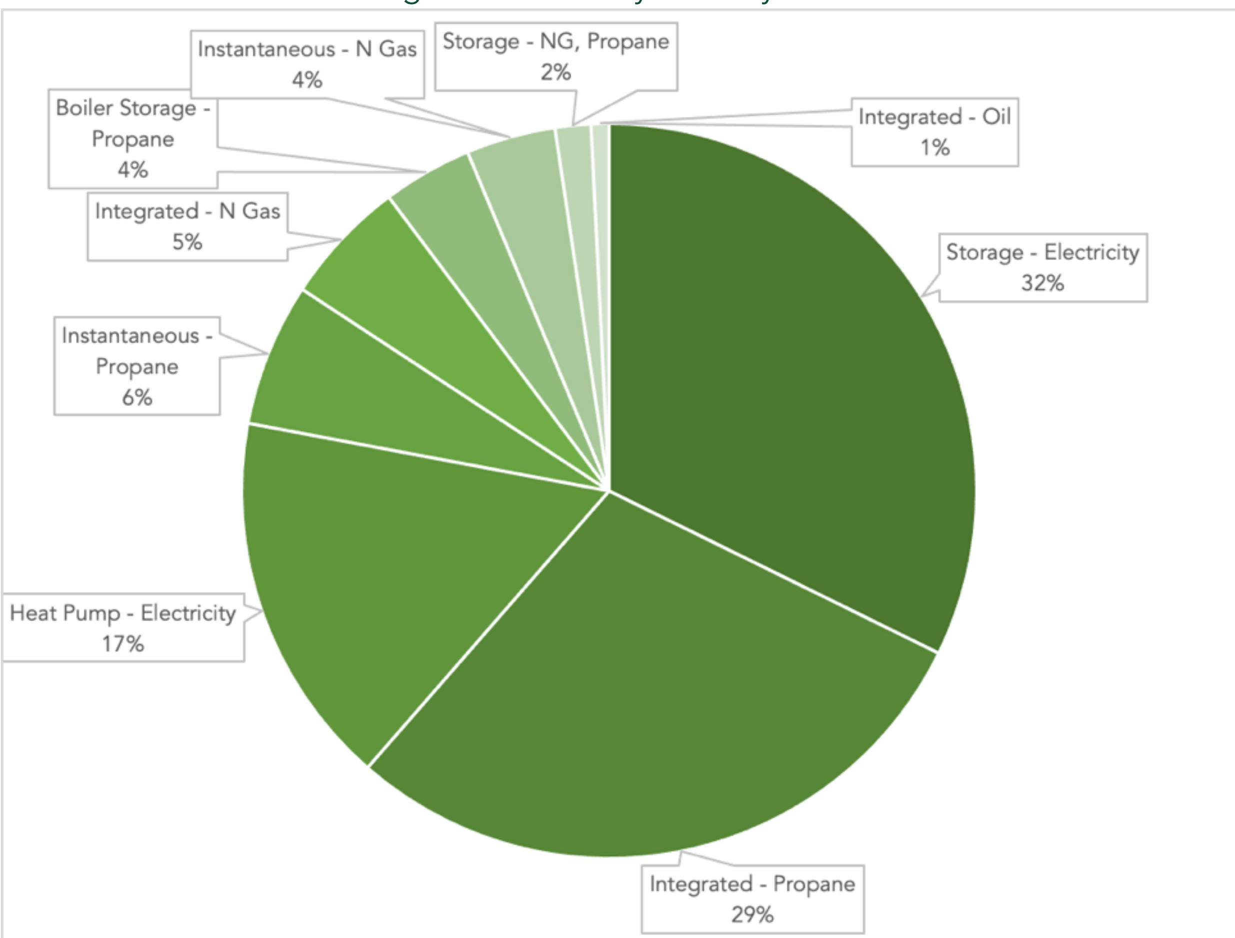
The choice of domestic water heating technology is not an independent one in that it is influenced by a builder's choice of space heating technology. For example, propane fired boilers are one of the most numerous space heating technologies and, in this study, they correlated with heating domestic water with that same boiler. Homes heated with ducted and ductless air distribution systems have independent water heating systems.

[34] https://www.thermoworks.com/Thermapen-Mk4?quantity=1&color=5

7.9.1 DHW System Type

Of the 127 water heaters in this study, electric storage (Storage - Electricity) water heaters were the most common (32% of systems) (Figure 75). This was driven, in part, by their prevalence in the study's manufactured homes. Natural gas-heated storage water heaters were not common (1%). Tankless systems integrated with boilers of all types accounted for 36% of systems (Integrate-Propane, Natural Gas; Oil). Heat pump water heaters served 17% of homes. Standalone instantaneous systems accounted for 10% (Instantaneous Natural gas; Propane) and systems where a boiler serves a storage tank (Boiler Storage-Propane) accounted for 4%.

Figure 75. DHW Systems by Count



Looking at the 98 non-manufactured homes the technologies shift, with storage electric heaters dropping to 12% and all other technologies growing proportionally.

7.9.2 Fuel

The primary DHW fuels were electricity (49%), including 17% that were heat pumps. and propane (40%) with natural gas limited by availability (10%) (Figure 77). Oil was a minor fuel (1%).

Figure 76. DHW Systems by Count: Non-Manufactured Homes

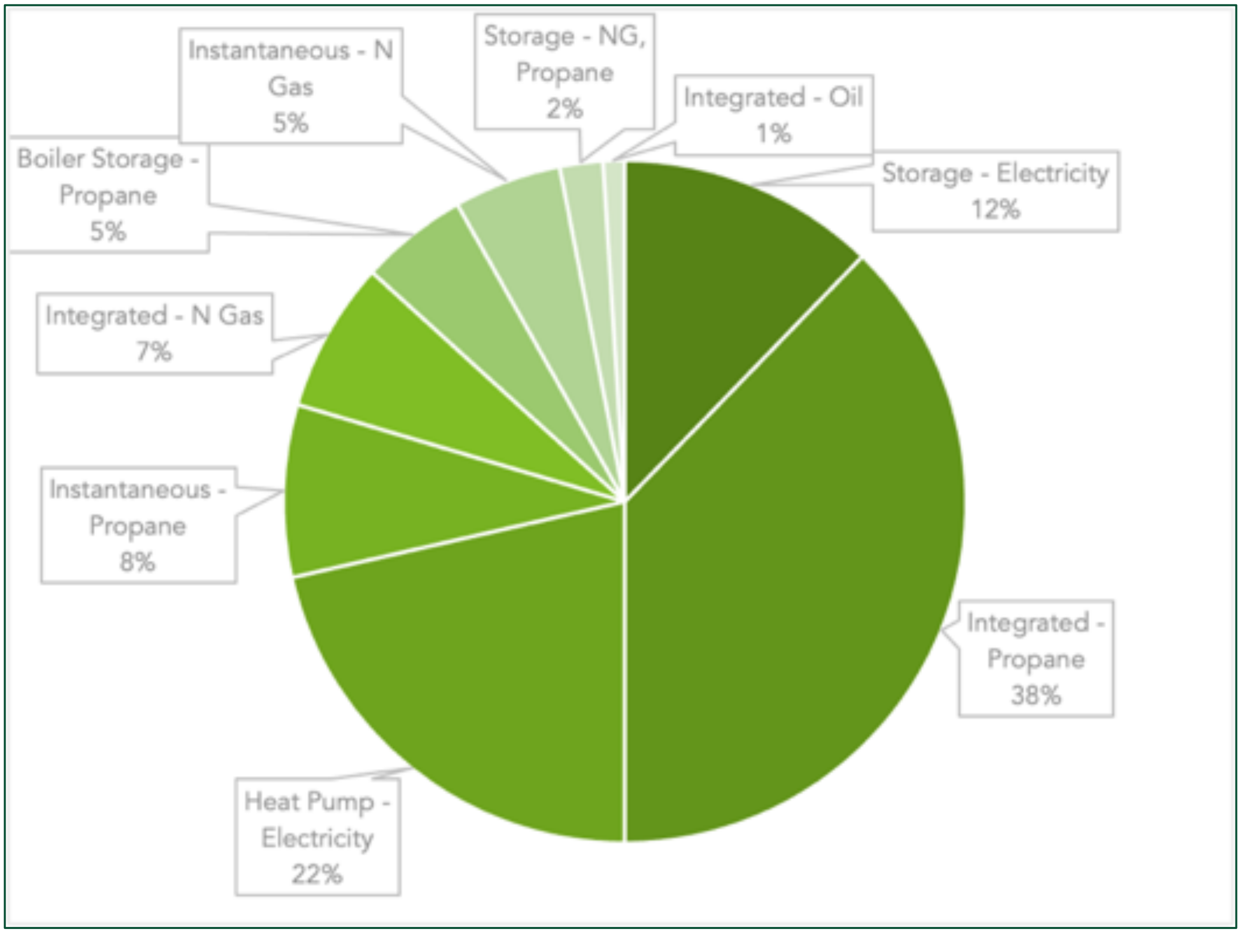
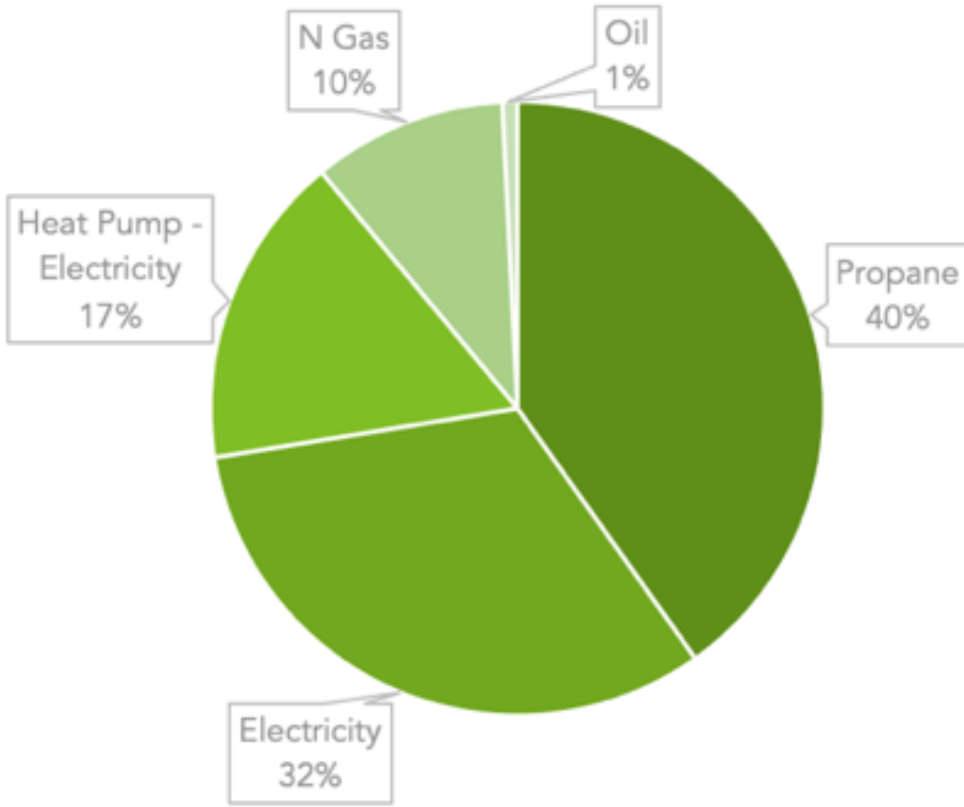
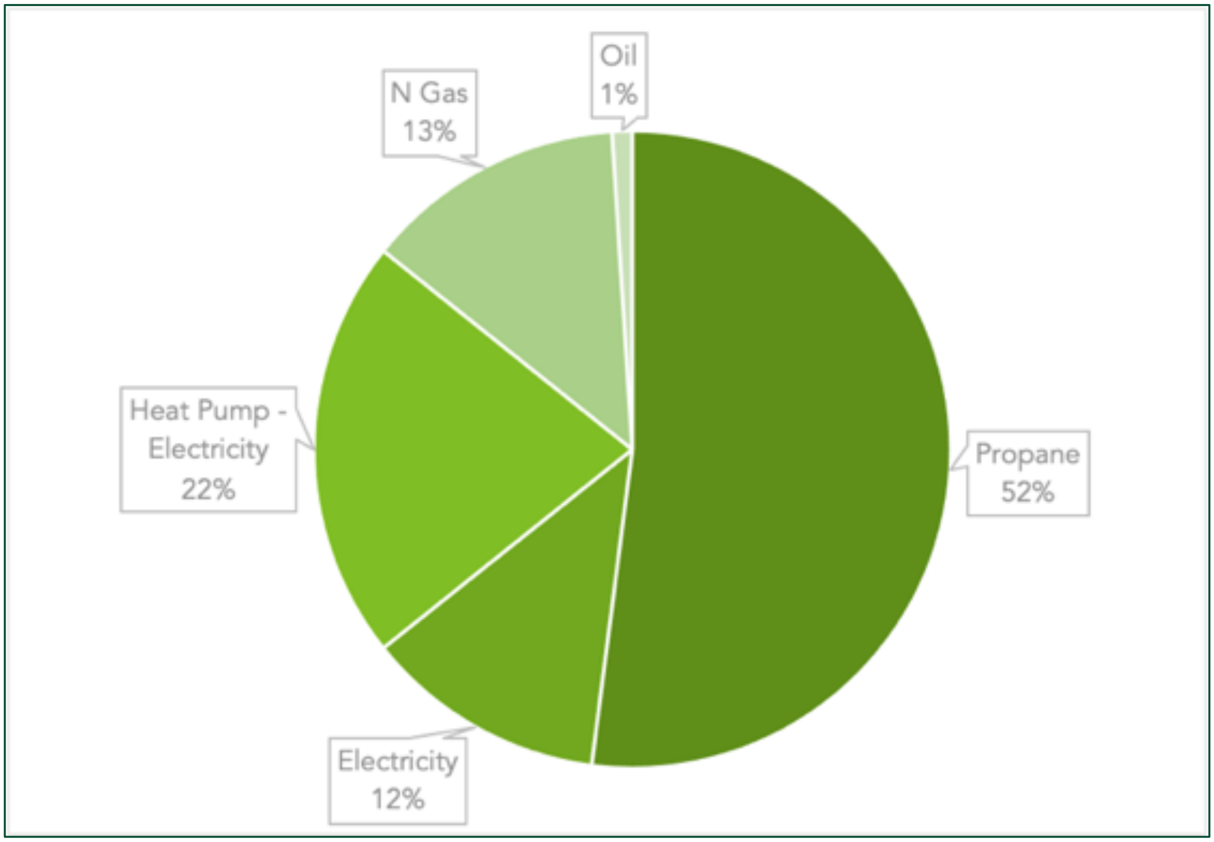


Figure 77. DHW Fuel by Count



Excluding manufactured homes, fuels shifted towards propane and electricity. The heat pump share was larger at 22% because no manufactured homes had heat pump water heaters.

Figure 78. DHW Fuel by Count: Non-Manufactured Homes



7.9.3 Hot Water Efficiency

The efficiency of water heating systems varied widely and was closely associated with technology. Table 30 shows the efficiencies of the types of DHW found in the study. Each row shows the average efficiency across a type of unit and the total was the average efficiency across all units. Heat pump water heaters had an energy factor of nearly 3.5 or 350%. Instantaneous gas heaters, integrated gas and propane heaters, and electric tank storage systems all had energy factors over 0.9 or 90%.

The remaining gas, oil, and propane systems varied from 67 to 88%. Instantaneous propane heaters averaged 86% while many systems in the study were at 81%. The highest efficiency propane heaters found in the study were 94% efficient. The average energy factor of all of the DHW heaters was 134%.

Table 30. Average Efficiency of DHW

System Type	Average Energy Factor	Count
Heat Pump - Electricity	346%	21
Instantaneous - N Gas	94%	5
Integrated - Propane	94%	37
Integrated - N Gas	93%	7
Storage - Electricity	93%	41
Boiler Storage - Propane	88%	5
Integrated - Oil	87%	1
Instantaneous - Propane	86%	8
Storage - Propane	75%	1
Storage - N Gas	67%	1
All Water Heaters	134%	127

7.9.4 Capacities

Of the 127 DHW heaters, 69 had storage tanks with an average storage size of 45.1 gallons (Table 31). Most of the tank water heaters in this study were 50 gallons in capacity.

Table 31. Storage Tank Size by Type of DHW Heater

	Count	Average	Min	Max
Boiler Storage - Propane	4	46.5	40	65
Heat Pump - Electricity	21	54.4	50	80
Integrated - N Gas	1	40.0	40	40
Storage - Electricity	41	40.7	20	50
Storage - N Gas	1	40.0	40	40
Storage - Propane	1	40.0	40	40
Total	69	45.1	20	80

7.10 DHW TECHNOLOGY

Table 32 compares the fuel types and technologies found in the 2008 New Construction Study, the 2015 residential stock assessment and in this 2021 study. From 2008 to present, DHW shifted from indirect storage and tankless coil to integrated combi boilers and heat pumps. Conventional storage systems were relatively flat.

Table 32. Trends in DHW Technology

System Type	2008 New Construction Study	2015 Residential Study	This Study*
n	76	44	98
Indirect storage	63%	32%	5%
Tankless coil	17%	28%	0%
Boiler with integrated on demand water heating	0%		46%
Conventional storage	13%	28%	14%
Heat pump	0%	5%	22%
Stand-alone instantaneous	5%	5%	13%
Solar	0%	3%	0%

*Non-manufactured homes.

The average DHW efficiency in the 2008 study was 76%. In this study including heat pumps (HPWH), the efficiency was 134%.

7.10.1 Measured Water Temperature

Raters collected the hot water temperature at kitchen sinks using an instant read digital thermometer.[35] The mean reading was 122F and the standard deviation of readings was 9F (Table 33). Because of losses in piping, it is likely that the actual set point is at least 5F higher.

Table 33. Kitchen Sink Hot Water Temperature

Summary Statistic	Temperature (F)
Count	102
Mean	122
Min	99
Max	155
St Dev	9
CV	0.07

[35] https://www.thermoworks.com/Thermapen-Mk4?quantity=1&color=5

7.10.2 Water Temperature Setting

Raters collected the hot water temperature setpoint where it was available. In general, it was shown on heat pump water heater screens but was otherwise not visible. This was the reason for taking actual temperatures. The few readings available averaged 120°F, similar to the mean of the readings above, albeit without pipe losses (Table 34). The average temperature reading at the kitchen sink at these 8 homes was 117°F. It is therefore likely that the non-heat pump heaters have a slightly higher setpoint than these eight heat pump water heaters.

Table 34. Hot Water Temperature Setpoints

Summary Statistic	Temperature (F)
Count	8
Mean	120
Min	120
Max	120
St Dev	0
CV	0.0

8 APPLIANCES AND LIGHTING

8.1 REFRIGERATORS

Table 35 shows the rated annual energy consumption of examined refrigerator models. Consumption varied by a factor of about 4 from minimum to maximum with a mean value of 623 kWh.

Table 35. Refrigerator Annual Energy Consumption

Summary Statistic	Annual Energy Use (kWh)
Count	127
Mean	651
Min	363
Max	2080
St Dev	215
CV	0.33

8.2 CLOTHES WASHERS

Like refrigerators, clothes washers have also come a long way since the 1990s when they were vertical axis top loaders that used upwards of 40 gallons per load and spun at relatively slow speeds. Today's models are primarily, although not exclusively, front loading horizontal-axis machines. Rather than soaking clothes in water, the new machines spin them through the water and use less than 15 gallons per load. Spin rates as high as 1,400 rpm subject the clothes to very high g-forces that can remove most of the water left from the wash, greatly decreasing clothes dryer energy. Table 36 shows the projected energy use in kWh, termed the LER in Ekotrope.

The energy and water efficiency of clothes washers is rated with IMEF[36] and IWF[37] by manufacturers and Energy Star. The Ekotrope rating was an annual energy use from the DOE appliance label allowing for a simple and readily collectable value. It was

[36] Integrated Modified Energy Factor, IMEF, is the energy performance metric for ENERGY STAR certified residential clothes washers as of March 7, 2015. The higher the value, the more efficient the clothes washer is.

[37] Integrated Water Factor, IWF, is the water performance metric for ENERGY STAR certified residential clothes washers as of March 7, 2015. It allows the comparison of clothes washer water consumption independent of clothes washer capacity. The lower the value, the more water efficient the clothes washer is.

based on 300 loads per year and includes modeled associated hot water use converted to electricity. There was initially a wide range of LERs because some raters used Ekotrope's default values that were relatively high (704), in some cases for pre-occupied homes with no laundry system. We removed the default values, retaining only actual tag values.

Table 36. Clothes Washer Annual Energy Consumption

Summary Statistic	LER Annual Energy Use (kWh)
Count	96
Mean	217
Min	60
Max	400
St Dev	130
CV	0.60

8.3 CLOTHES DRYERS

Clothes dryers are rated by manufacturers and Energy Star using the Combined Energy Factor (CEF), which is the clothes dryer clothes load in pounds divided by the energy consumption (higher is better). Ekotrope used this same factor. Table 37 shows the CEF for 127 clothes dryers collected during this study.

Table 37. Clothes Dryer Energy Factor

Summary Statistic	CEF
Count	127
Mean	3.56
Min	2.62
Max	6.37
St Dev	0.56
CV	0.16

8.4 LIGHTING

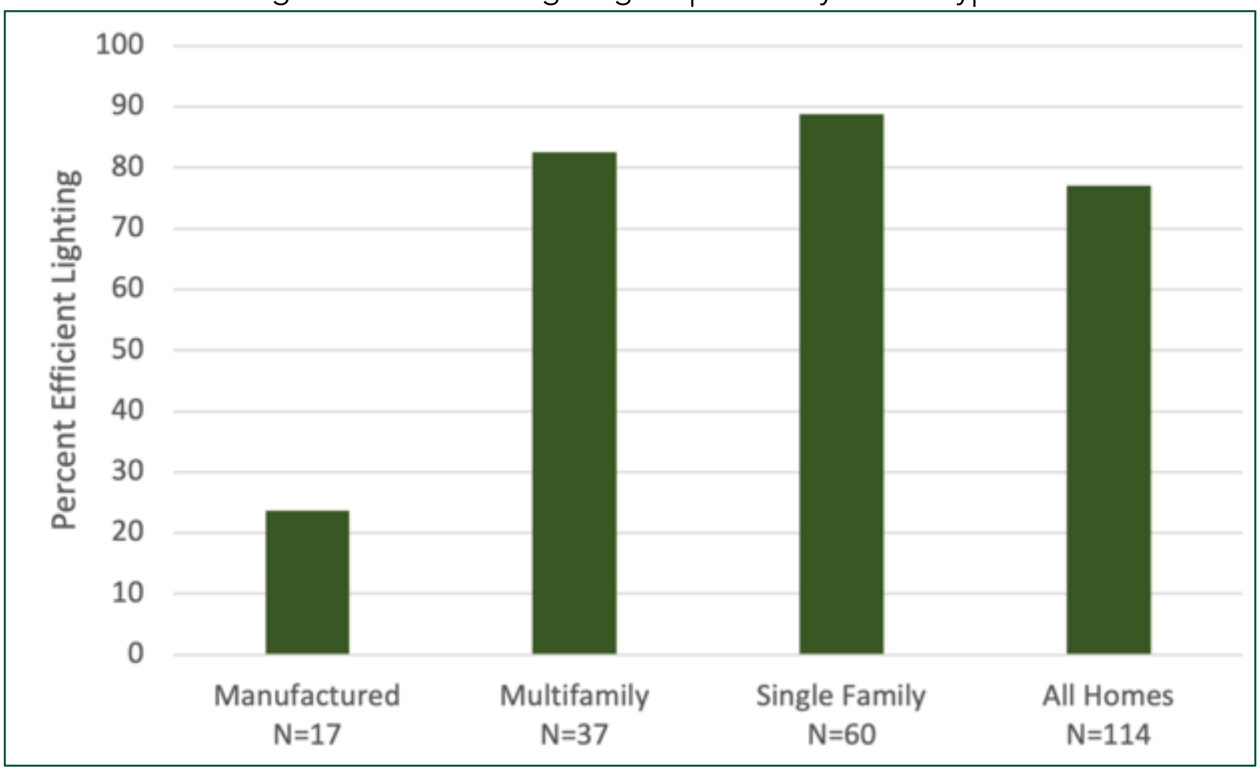
Raters examined the lighting technology used in hard wired lighting, consistent with RESNET procedures, based on the reasoning that these lights are contributed by builders in contrast to table lamps, for example, that are bought by the homeowner. LED and fluorescent lighting were characterized as efficient, and halogen and incandescent technologies were categorized as inefficient. We excluded 12 manufactured homes that were in dealer lots. Raters found an average of 77% of lighting was efficient (Table 38). Code requires that at least 50% of lights be efficient in non-manufactured homes.

Table 38. Portion of Hardwired Lighting that was CFLs or LEDs

Summary Statistic	% Efficient (interior)
Count	115
Mean	77.2
Min	0
Max	100
St Dev	33.186
CV	0.430

We looked at efficient lighting saturation by home type and saw that excluding manufactured homes that efficient lighting approached 90% in single and multifamily homes. Manufactured homes were 24%, below (worse than) the HUD requirement for 34% of lighting being efficient (Figure 79).

Figure 79. Efficient Lighting Proportion by Home Type



The 2008 study found by socket, 71% incandescent and 8% halogen, with 20% filled by efficient technologies. Considering single family homes, this was a major shift from 20% to 87%.

9 CODE ANALYSIS

9.1 CODE OVERVIEW

A municipality of up to 4,000 residents is not required to enforce, but may not adopt or enforce a building code other than the Maine Uniform Building Code, the Maine Uniform Energy Code or the Maine Uniform Building and Energy Code.[38]

The current version of the Maine Uniform Building and Energy Code (MUBEC) bases its energy requirements on the IECC 2009. These requirements apply to non-manufactured homes. Manufactured homes were subject to HUD standards discussed later. There were essentially three main pathway options to code compliance:

1. Prescriptive
2. U-value methods
3. Simulation model methods

The prescriptive requirements (Option 1) are met by demonstrating that each component contains the prescriptive amount of added insulation (e.g., R49 for ceilings and roofs). Infiltration cannot be observed and must be demonstrated using a blower door test. It was our understanding that not all code jurisdictions require third party blower door tests. While Option 2 above could, in theory, be shown with a simple calculation, it would normally be shown using ResCheck or similar software including Ekotrope Rater or RemRate. The builder can either meet the U requirements of all components or the calculated UA, where the as-built home needs to have a UA equal to or less than the calculated code value. Numerically, the UA value is equal to the BTUH conductive heat loss per degree of temperature difference between the home and outdoors. This heat loss is in addition to heat lost through infiltration. Option 3 uses performance pathways to establish energy code compliance and requires "modeling" the building to predict energy usage against an acceptable baseline. This modeling is performed by using commonly available software e.g., Ekotrope Rater, Energy Gauge, or REMRate that creates a "virtual" building, then uses historical weather information to predict how it would perform under those conditions. It, in theory, allows tradeoffs between insulation and mechanical system efficiency. Older codes set prescriptive limits on energy use and energy cost. Beginning with the IECC 2015, a HERS score of 54 meets the performance requirement.

[38] 10 MRSA §9724, section 1-A "Municipalities up to 4,000 residents.

In addition to the three Options described, builders must meet a mandatory check list that includes elements like insulating DHW piping, thermostats, infiltration, and duct insulation.

Options 2 and 3 above can involve a number of tradeoffs and the third option is a computer simulation pathway. Most builders choose Option 1 because it is straight forward and is tangible in that code compliance and remedies can be readily determined.

9.2 PRESCRIPTIVE CODE COMPONENTS

The prescriptive code components in the IECC 2009 are shown in Table 39. There are other requirements, but these were the major requirements that we used to assess the energy savings of studied non-manufactured homes meeting code. In previous graphs in the Building Envelope Section, these prescriptive requirements are diagrammed against measured or observed parameters.

Table 39. Prescriptive IECC 2009 R and U-values for Construction Components in Maine

	Fenestration u	Fenestration SHGC	Ceiling	Wood Frame Wall	Floor	Basement Wall	Crawl Space Wall	Inf. ACH50
R-Table	2.85	NR	49	20 or 13+5	30	15/19	10/13	7
u-Table	0.35	NR	0.026	0.057	0.033	0.05	0.065	

9.3 CODE COMPLIANCE OF STUDIED HOMES

We used Ekotrope software to assess the code compliance of each non-manufactured home. We found that about two-thirds of homes met the IECC 2009 based on Ekotrope modeling. Because the software tests all three pathways listed above, a house could fail to meet a prescriptive element and yet still meet code. More specifically a home could fail the UA prescriptive requirement meaning that its insulation does not meet code, yet could meet the performance pathway. Essentially this is a trade-off between insulation and HVAC efficiency in action. This does not mean that the builder intentionally made a trade-off involving insulation nor does it mean that the builder knew that they had passed code via a performance pathway. It only means that the Ekotrope Rater software indicated that the homes met code.

The HERS index of multifamily homes failing code was 68.6 while for single family homes it was 73 (Table 40). The performance HERS criterion for IECC 2015 is 54.

Table 40. IECC 2009 Test and Associated HERS Index

	Count	Average of HERS Index	%
Multifamily	**37**	**55.5**	**100%**
Fails 2009 Code	8	68.6	22%
Meets 2009 Code	29	51.8	78%
Single Family	**61**	**60.0**	**100%**
Fails 2009 Code	23	73	38%
Meets 2009 Code	38	52.1	62%
All Non-Manufactured Homes	**98**	**58.3**	

Table 41 compares the 98 non-manufactured homes with IECC 2009 code requirements and assesses whether they met U-value requirements for ceilings, above grade walls, foundation walls, slab floors (where not present they are rated as pass), and framed floors. The table then shows the status of the home compared with the overall UA prescriptive pathway, the infiltration requirement of <7 air changes per hour (ACH50), and lastly the energy use performance pathway. The homes were sorted in order from least modeled energy use at 26.8 MMBTU/yr. to most at 196.5 MMBTU/yr. A home can pass by meeting all of the construction component U-value requirements, or the combined UA, and the ACH50 requirement. Alternately it can pass the code by passing the performance test, even if it fails the other tests. For any of these pathways the home must also pass a list of minimum requirements to pass code, including that 50% of lighting is efficient and a mandatory checklist of on-site tasks is completed.

Table 41. Compliance of Non-manufactured Homes with IECC by Code Pathway

Total Energy Consumption (MMBTU/YR)	HERS	Ceilings	Windows, Doors	AG Walls	Foundation Walls	Slab Floor	Framed Floor	Combined UA	ACH 50 Test	Performance	Mandatory Checklist
26.8	57	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
28.0	54	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
28.8	56	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
31.2	59	Fail	Pass	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail
31.3	43	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
31.7	48	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
31.8	42	Pass	Fail	Fail	Pass	Fail	Pass	Fail	Pass	Pass	Pass
32.3	56	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Pass
32.5	39	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass
32.6	44	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass
32.7	67	Fail	Pass	Fail	Pass	Pass	Pass	Fail	Fail	Fail	Fail
33.0	46	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
33.2	39	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
33.5	50	Pass	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass
34.0	46	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
34.7	54	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Fail	Pass
34.9	40	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass
35.2	52	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
36.5	48	Fail	Pass	Fail	Pass	Pass	Pass	Fail	Pass	Pass	Pass
38.1	50	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
38.4	52	Pass	Pass	Fail	Pass	Pass	Fail	Pass	Fail	Pass	Fail
38.5	47	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
39.5	46	Pass	Fail	Fail	Pass	Pass	Pass	Fail	Pass	Pass	Fail
40.7	38	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass
41.7	43	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Fail
42.3	40	Fail	Pass	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail
43.2	35	Fail	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail

Total Energy Consumption (MMBTU/YR)	HERS	Ceilings	Windows, Doors	AG Walls	Foundation Walls	Slab Floor	Framed Floor	Combined UA	ACH 50 Test	Performance	Mandatory Checklist
44.1	49	Pass	Pass	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail
44.6	41	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Fail
45.8	58	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Pass	Pass
48.8	47	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Fail
49.2	46	Pass	Pass	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail
49.7	49	Pass	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
50.2	57	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
50.9	52	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass
54.7	63	Pass	Pass	Fail	Fail	Pass	Fail	Fail	Pass	Pass	Fail
55.7	86	Fail	Pass	Fail	Pass	Pass	Pass	Fail	Fail	Pass	Fail
56.0	80	Pass	Fail	Fail	Pass	Pass	Pass	Fail	Fail	Fail	Fail
57.2	52	Fail	Pass	Fail	Fail	Pass	Pass	Fail	Pass	Pass	Pass
60.9	57	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Pass
62.2	57	Pass	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Pass	Pass
62.2	53	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
62.4	61	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Fail	Fail	Fail
62.9	56	Pass	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Pass
63.7	57	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Pass
64.0	53	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Fail
66.3	57	Pass	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
66.3	51	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
66.8	53	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
67.5	54	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Pass
67.6	77	Pass	Fail	Fail	Pass	Fail	Pass	Fail	Fail	Pass	Fail
67.6	58	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Pass	Pass	Pass
68.1	41	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
69.3	42	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
69.6	64	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Fail
70.1	57	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
71.4	54	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass

Total Energy Consumption (MMBTU/YR)	HERS	Ceilings	Windows, Doors	AG Walls	Foundation Walls	Slab Floor	Framed Floor	Combined UA	ACH 50 Test	Performance	Mandatory Checklist
72.4	57	Pass	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Pass
75.1	54	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
76.0	65	Pass	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail
76.1	58	Pass	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail	Fail
76.9	53	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass
77.0	53	Pass	Fail	Fail	Fail	Fail	Fail	Fail	Pass	Pass	Pass
78.3	47	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
79.5	53	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Pass
79.8	49	Fail	Pass	Fail	Pass	Pass	Fail	Pass	Pass	Pass	Fail
80.8	58	Fail	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Fail
81.1	51	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
81.2	65	Pass	Pass	Fail	Fail	Pass	Fail	Fail	Pass	Fail	Fail
82.7	55	Fail	Pass	Fail	Fail	Pass	Pass	Fail	Pass	Pass	Pass
83.0	56	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
84.8	63	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Fail	Fail	Pass
87.5	58	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Fail	Pass
87.5	56	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Pass	Pass
88.0	76	Fail	Pass	Fail	Fail	Pass	Pass	Fail	Pass	Fail	Fail
89.4	57	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Pass	Pass
90.1	57	Pass	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Pass
91.1	58	Pass	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
95.7	57	Pass	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Pass	Pass
100.3	60	Pass	Fail	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Pass
103.3	82	Pass	Pass	Fail	Fail	Pass	Pass	Fail	Pass	Fail	Fail
104.5	81	Pass	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Fail
105.0	52	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
107.8	162	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail	Fail
113.4	69	Pass	Pass	Fail	Fail	Pass	Pass	Fail	Pass	Fail	Fail
116.6	56	Fail	Pass	Fail	Pass	Fail	Fail	Fail	Pass	Pass	Pass
119.5	55	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail

Total Energy Consumption (MMBTU/YR)	HERS	Ceilings	Windows, Doors	AG Walls	Foundation Walls	Slab Floor	Framed Floor	Combined UA	ACH 50 Test	Performance	Mandatory Checklist
122.8	71	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Fail	Pass
128.0	74	Pass	Fail	Fail	Fail	Fail	Pass	Fail	Pass	Fail	Pass
128.1	60	Pass	Pass	Fail	Fail	Fail	Fail	Fail	Pass	Pass	Pass
137.3	59	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Pass	Pass	Fail
144.3	74	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Pass	Pass	Pass
157.1	58	Fail	Pass	Fail	Fail	Fail	Fail	Fail	Pass	Pass	Fail
173.0	70	Fail	Pass	Fail	Fail	Fail	Fail	Fail	Pass	Fail	Fail
175.6	77	Fail	Pass	Pass	Pass	Pass	Fail	Fail	Pass	Fail	Pass
180.8	144	Fail	Fail	Fail	Fail	Pass	Pass	Fail	Fail	Fail	Fail
191.1	93	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Fail
196.5	85	Fail	Pass	Fail	Pass	Pass	Fail	Fail	Fail	Fail	Pass
73.0	58.3	Averages									
Percent Pass Rate		55%	86%	14%	76%	71%	40%	22%	89%	67%	54%

9.4 ENERGY SAVINGS FROM IECC 2009 AND OTHER HVAC COMPONENTS

To assess the impact of having each non-manufactured home follow the prescriptive requirements of IECC 2009, we first modeled each home as built and calculated the predicted energy use. We then, using the as built situation as a baseline, determined the impact of adopting each of the following scenarios[39]:

1. Set all non-code compliant ceiling components to have R-values of 49 (code minimum). (U=0.026)
2. Set all non-code compliant above grade wall components to have R-values of 20 (U=0.060)
3. Set all non-code compliant floor components to have R-values of R30 (U=0.033)
4. Set all non-code compliant foundation wall components to have R-values of 15
5. Combine Scenarios 1 - 4
6. Set infiltration rate (ACH50) to 7 for all non-code compliant homes.
7. Combine scenarios 5 & 6
8. Set maximum window U-value to 0.35

We then examined the impact of changing the following:

9. All furnaces and boilers shift to 95% AFUE furnace and boilers
10. All heating systems are shifted to heat pumps (12.5 HSPF, 20 SEER)

Lastly, we combined scenarios:

11. Combine scenarios 7, 8, and 10.

We then examined the impact of adopting components of the IECC 2015 code as follows:

12. Set maximum infiltration (ACH50) to 3
13. Set the minimum wall R-value to 25 (U=0.045)
14. Adapt Scenario 5 above to include Scenario 13.
15. Combine Scenarios 12 and 14.
16. Set maximum windows U-value to 0.32
17. Combine scenarios 15 and 16 with 10.

[39] The stated equivalent code u values were used to model the scenarios.

As shown in Table 43 and Table 44, each individual change, for example shifting all walls to R-20, produced modest improvements on the order of 2% because only some homes needed improvement to that single component. Combining scenarios as in Scenario 5 saved 8% because all homes received some improvement. The IECC 2015 wall requirement was a large improvement, saving 6% alone. The combined IECC 2015 scenario (15) saved over 20% of total energy use. The most far reaching scenario (17), saved 44% of energy and shifts energy use to electricity, increasing it by 48% but cutting fuel use by 88%.

In Figure 80, Figure 81, and Table 42, we show the energy use reduction from Scenario 7. The savings were low for homes with energy use lower than 50 MMBTU, which is logical because these homes likely have high levels of insulation and low infiltration.

The homes with the highest as-built energy use (>125 MMBtu/year) have reduced energy use under Scenario 7, but still use a relatively large amount of energy. The reason is that the energy use of these homes is driven by larger size, with the normalized energy use per square foot only slightly greater than homes using less than 125 MMBtu/year.

Figure 80. Energy Use As-Built and Under Scenario 7 – Code Compliant Insulation and Air Sealing

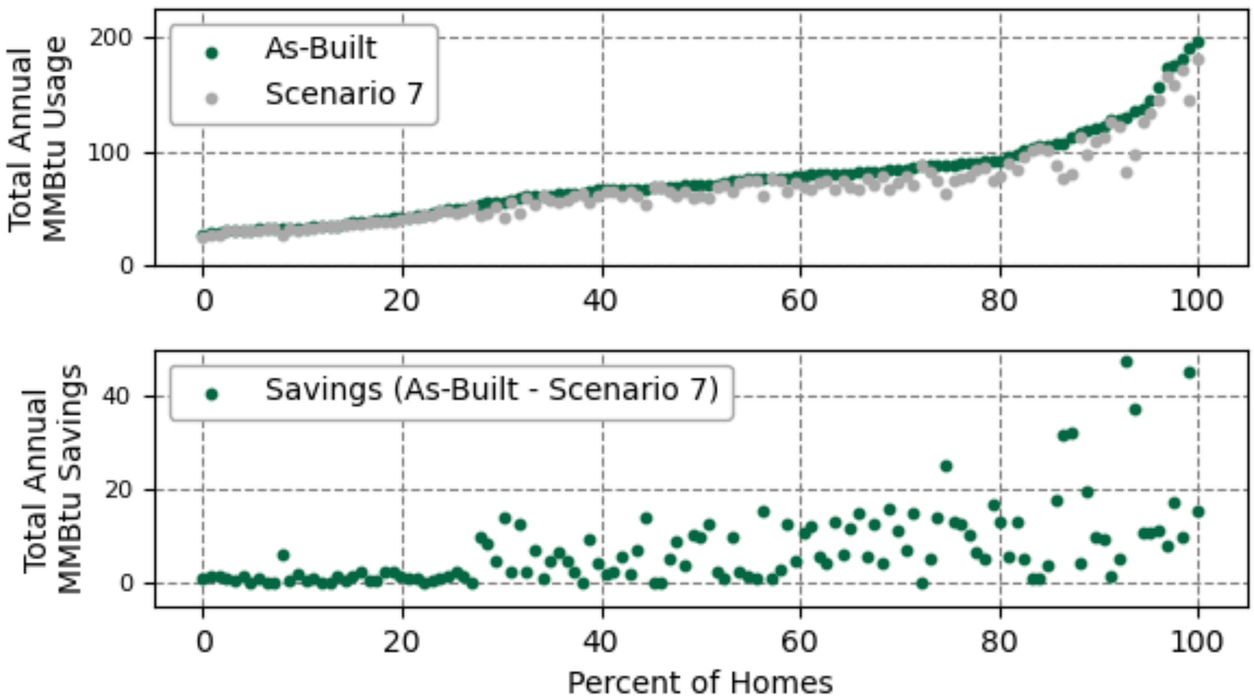


Figure 81. Energy Savings As-Built Minus Scenario 7 – Code Compliant Insulation and Air Sealing

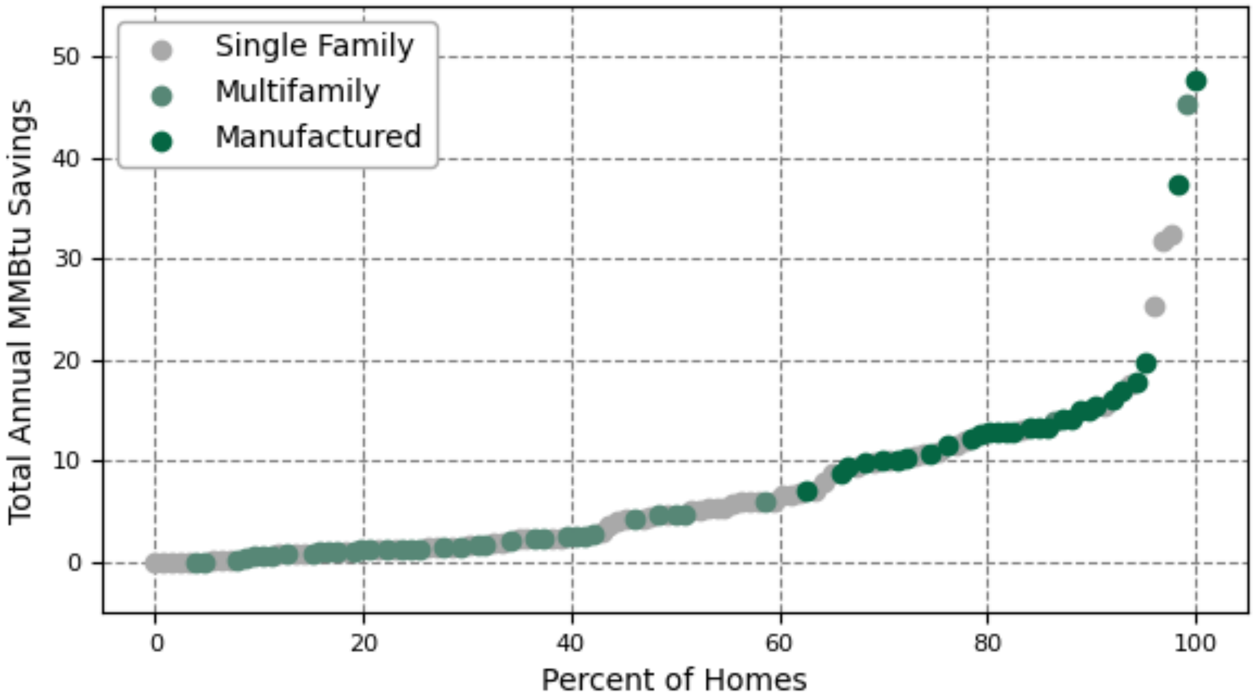


Table 42. Summary Statistics of Scenario 7 Annual MMBtu Savings Versus As-Built

Statistic	Single Family	Multifamily	Manufactured
Count	61	37	29
Average (MMBTU)	6	3	15
Standard Deviation (MMBTU)	7	8	8
Minimum (MMBTU)	0	0	7
25th Percentile (MMBTU)	1	1	11
50th Percentile (MMBTU)	5	1	13
75th Percentile (MMBTU)	8	3	15
Maximum (MMBTU)	32	45	48

Table 43. Analysis of Homes Meeting Elements of IECC 2009, IECC 2015, and Mechanical Improvements

Scenarios	Average of HERS Index	Average of Electric Consumption [kWh]	Average of Fossil Fuel [Million BTU]	Average Total Energy Use [Million BTU]
As-built	58	7034	49.0	73.0
Grade I Insulation	56	6951	46.4	70.1
IECC 2009 Elements				
S1. R49 (U=0.026) Ceilings	57	6995	48.0	71.9
S2. R20 (U=0.060) Walls	57	6994	47.8	71.7
S3. R30 (U=0.033) Floors	58	7009	48.2	72.1
S4. R15 Foundations	58	6988	48.2	72.0
S5. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations	55	6883	45.3	68.8
S6. 7 ACH50	58	6982	48.3	72.1
S7. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50	55	6831	44.6	67.9
S8. U 0.35 Windows	58	6998	48.5	72.4
HVAC and Combined Scenarios				
S9. 95 AFUE Gas Equipment	58	7034	48.6	72.6
S10. Electric Heat Pump (12.5 HSPF 20 SEER)	57	12,451	7.6	50.1
S11. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50 & U 0.35 Windows & Electric Heat Pump (12.5 HSPF 20 SEER)	53	11,609	7.6	47.2

Scenarios	Average of HERS Index	Average of Electric Consumption [kWh]	Average of Fossil Fuel [Million BTU]	Average Total Energy Use [Million BTU]
IECC 2015 Elements				
S12. 3 ACH50	56	6850	44.9	68.3
S13. R20+5 (U=0.045) Walls	55	6900	45.1	68.6
S14. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls	53	6789	42.7	65.9
S15. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls & 3 ACH50	51	6606	38.7	61.2
S16. U 0.32 Windows	57	6986	48.3	72.1
S17. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & Electric Heat Pump (12.5 HSPF 20 SEER) & R20+5 (U=0.045) Walls & 3 ACH50 & U 0.32 Windows	50	10,617	7.6	43.8

Table 44. Projected Savings of Homes Meeting Elements of IECC 2009, IECC 2015, and Mechanical Improvements

% Savings Versus Base Case (As-Built)					
Scenarios	HERS Index	Electric Consumption %	Fossil Fuel %	Energy Reduction %	Energy Reduction [Million BTU]
As-built	0%	0%	0%	0%	0.0
Grade I Insulation	4%	1%	5%	4%	2.9
IECC 2009 Elements					
S1. R49 (U=0.026) Ceilings	1%	1%	2%	2%	1.1
S2. R20 (U=0.060) Walls	2%	1%	2%	2%	1.3
S3. R30 (U=0.033) Floors	1%	0%	2%	1%	0.9
S4. R15 Foundations	1%	1%	2%	1%	1.0
S5. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations	5%	2%	8%	6%	4.2
S6. 7 ACH50	1%	1%	1%	1%	0.9
S7. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50	6%	3%	9%	7%	5.1
S8. U 0.35 Windows	1%	1%	1%	1%	0.6
HVAC and Combined Scenarios					
S9. 95 AFUE Gas Equipment	1%	0%	1%	1%	0.4
S10. Electric Heat Pump (12.5 HSPF 20 SEER)	2%	-77%	84%	31%	22.9
S11. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50 & U 0.35 Windows & Electric Heat Pump (12.5 HSPF 20 SEER)	9%	-65%	84%	35%	25.8

% Savings Versus Base Case (As-Built)					Total Energy Reduction [Million BTU]
Scenarios	HERS Index	Electric Consumption %	Fossil Fuel %	Energy Reduction %	
IECC 2015 Elements					
S12. 3 ACH50	3%	3%	8%	6%	4.7
S13. R20+5 (U=0.045) Walls	6%	2%	8%	6%	4.4
S14. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls	9%	3%	13%	10%	7.1
S15. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & R20+5 (U=0.045) Walls & 3 ACH50	12%	6%	21%	16%	11.8
S16. U 0.32 Windows	1%	1%	1%	1%	0.9
S17. R49 (U=0.026) Ceilings & R30 (U=0.033) Floors & R15 Foundations & Electric Heat Pump (12.5 HSPF 20 SEER) & R20+5 (U=0.045) Walls & 3 ACH50 & U 0.32 Windows	15%	-51%	84%	40%	29.2

Positive numbers denote savings, (i.e., reductions from As-built). Negative numbers denote increases from the As-built case and arise from switching from fossil fuel to heat pumps for heating, thereby increasing electricity use.

9.5 MANUFACTURED HOMES, HUD CODE AND A HYPOTHETICAL STRETCH CODE

Manufactured Homes are regulated by federal HUD Standards (Table 45). These minimum requirements allow for less insulation and higher leakage levels than the IECC 2009. The manufactured homes in this study greatly exceeded the minimum insulation values in all cases, but only half of the homes met or exceeded the infiltration threshold. The average manufactured home had a duct leakage to outside rate of 16 CFM/100 SF of conditioned space, well in excess of the HUD limit of 12 CFM/100 SF. HUD is considering changes to codes, but these are delayed at present until later in 2021.

Table 45. HUD Minimums for Manufactured Homes

Element	HUD Baseline	Count Passing	%
Wall Insulation	R-11	29	100
Floor Insulation	R-22	28	97
Ceiling Insulation	R-22	29	100
Windows	U = 1.08	29	100
ACH50	8	10	34
Duct leakage	12	7	24
High efficiency lighting	34%	4	24

Using scenarios similar to those discussed for non-manufactured homes, we examined the impact of manufactured homes meeting a hypothetical stretch code that had insulation and infiltration levels similar to those in IECC 2009. We also examined the impact of improving mechanical systems. In Table 46, we show the modeled HERS index and energy consumption of the study's 29 manufactured homes. The HERS score for manufactured homes remains high at 74 even after meeting a hypothetical stretch code, while non-manufactured homes have much lower HERS scores. There are two reasons for this: (1) Many non-manufactured homes were already better insulated and had lower infiltration than was specified in Scenario 7, resulting in modest improvements in HERS scores compared to as-built. The average HERS index dropped from 58 to 55. For manufactured homes, Scenario 7 dropped average HERs scores from 88 to 74, however the manufactured homes in this scenario would still be less insulated and have higher infiltration than many non-manufactured homes. (2) The manufactured homes in this study generally had low efficiency space heating and water heating systems, and inefficient lighting. In Table 47, these modeled consumptions are translated into percent savings versus the as-is case.

Table 46. Analysis of Manufactured Homes Meeting a Hypothetical Stretch Code

Scenarios	Average of HERS Index	Average of Electric Consumption [kWh]	Average of Fossil Fuel [Million BTU]
As-is	88.4	7735	57.4
Grade I Insulation	81.4	7689	50.4
S1. R49 (U=0.026) Ceilings	83.2	7700	52.5
S2. R20 (U=0.060) Walls	86.3	7724	55.6
S3. R30 (U=0.033) Floors	84.1	7705	52.3
S4. R15 Foundations	88.4	7735	57.4
S5. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations	76.8	7660	45.4
S6. 7 ACH50	86.1	7721	54.8
S7. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50	74.5	7646	42.8
S8. U 0.35 Windows	88.4	7735	57.4
HVAC and Combined Scenarios			
S9. 95 AFUE Gas Equipment	83.7	7735	53.8
S10. Electric Heat Pump (12.5 HSPF 20 SEER)	77.4	13809	1.3
S11. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50 & U 0.35 Windows & Electric Heat Pump (12.5 HSPF 20 SEER)	66.1	12130	1.3

Table 47. Savings by % of Manufactured Homes Meeting a Hypothetical Stretch Code

	% Savings Versus Base Case (As-Built)		
Scenarios	HERS Index	Electric Consumption [kWh]	Fossil Fuel [Million BTU]
As-is	0%	0%	0%
Grade I Insulation	8%	1%	12%
S1. R49 (U=0.026) Ceilings	6%	0%	9%
S2. R20 (U=0.060) Walls	2%	0%	3%
S3. R30 (U=0.033) Floors	5%	0%	9%
S4. R15 Foundations	0%	0%	0%
S5. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations	13%	1%	21%
S6. 7 ACH50	3%	0%	5%
S7. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50	16%	1%	25%
S8. U 0.35 Windows	0%	0%	0%
HVAC and Combined Scenarios			
S9. 95 AFUE Gas Equipment	5%	0%	6%
S10. Electric Heat Pump (12.5 HSPF 20 SEER)	13%	-79%	98%
S11. R49 (U=0.026) Ceilings & R20 (U=0.060) Walls & R30 (U=0.033) Floors & R15 Foundations & 7 ACH50 & U 0.35 Windows & Electric Heat Pump (12.5 HSPF 20 SEER)	25%	-57%	98%

Positive numbers denote savings, (i.e., reductions from As-is). Negative numbers denote increases from the As-is case and arise from switching from fossil fuel to heat pumps for heating, thereby increasing electricity use.

If manufactured homes had R49 in ceilings, R20 in walls, R30 in floors and had infiltration limited to 7ACH50, they would save 25 percent of fossil fuel on average. Adding in more efficient furnaces would increase savings to nearly 30%.

10 SUMMARY AND CONCLUSION

This study examined 127 homes across Maine of which 29 were manufactured homes. Its purpose was to assess how homes were being constructed, how the construction impacted energy use and how the home construction compared with the IECC 2009, the code in force at the time the homes were built. The study included analyses of improvements and energy savings if homes were all built to the IECC 2009 and, in anticipation of the adoption of the IECC 2015, how much energy would be saved constructing to that new, more restrictive code.

New construction in Maine was last studied in 2008, with that study focusing on single family homes. To compare this study's results to that study and to identify trends in construction practices, we compare single family results from this study to the 2008 study.

10.1 ENVELOPE CHARACTERISTICS

Single family homes were well insulated compared with homes included in the 2008 study, but fell short of IECC 2009 for ceiling/roof, and foundation walls (Table 48). Homes built between 2017 and 2020 were tighter and were better than the code requirement of no more than 7 ACH50. Compared with existing homes, new homes were better insulated overall, and in particular had much better insulation in floors over unconditioned space.

Table 48. Comparison of Envelope Attributes Between IECC 2009 and 2008, 2015, and 2021 Studies

	IECC Prescriptive	2008 NC Study (flat/ vaulted)	2015 Existing Homes Study (flat/ vaulted)	2021 NC Study SF
Ceiling/Roof R	49	30.8/31.3	28.6/20.5	43.9
Walls R	13+5; 18	17.5	13.1	22.4
Floors R	30	15.3	2.7	30.1
Foundation Walls R	15/19	3.4; 66% no insulation	5.4	9.8
Windows U	0.35	0.37	np	0.30
Infiltration ACH50	7	5.4	11.2	3.9

np – not provided

Unlike the previous studies, this study included a population of manufactured homes. In general, manufactured homes had less insulation and higher rates of infiltration than single and multifamily homes, but they were better than HUD code requirements by a wide margin, except for infiltration, where the median value equaled the HUD value (Table 49).

Table 49. Comparison of Average Envelope Attributes of Manufactured Homes with HUD Code

	HUD	2021 NC Study - Manufactured
Ceiling/Roof R	22	35.3
Walls R	11	19.5
Floors R	22	26
Windows U	1.08	0.33
Infiltration ACH50	8	8*
Percentage of High Efficiency Lighting	34	24

*median

10.2 HVAC AND DHW

There has been a shift in homes' HVAC systems since 2008 and today's new homes have HVAC systems that are different from the current housing stock. Trends include a shift away from furnaces in non-manufactured homes, a shift towards boilers, principally condensing models, a shift away from oil as a fuel source, and a shift towards heat pumps. There has been a shift in DHW systems driven, in part, by the increased use of boilers. DHW shifted from indirect storage and tankless coils to integrated combi boilers and heat pumps. Conventional storage systems were relatively flat at about 15%.

10.3 TOWN SIZE AND CODE ENFORCEMENT

The study also examined homes in towns with fewer than 4,000 persons where building code was not required to be enforced by the municipality, and larger towns where code was enforced at the municipal level. The median predicted energy use for single family homes in smaller towns was about 25% higher than those in larger towns. A similar pattern was observed for multifamily homes but there were only 7 multifamily homes in small towns. The median HERS index for these homes in smaller town was higher (worse). The median infiltration values were nearly the same for the town sizes for multifamily and also for single family homes. The only discernable difference in infiltration was that the 75th percentile infiltration was higher for multifamily homes in smaller towns. This may, in part, have been due to the small sample size of 7. Overall, there were well insulated, tight homes in small towns without code enforcement, but the range of performance was broader in those towns with more homes built in ways that result in higher predicted energy use and higher (worse) HERS scores.

10.4 OPPORTUNITIES FOR SAVINGS

This study used the Ekotrope models underlying the 127 home reports to model 17 scenarios of improved insulation, infiltration, and HVAC to understand how much energy could be saved by uniformly building to the existing IECC 2009 code and by adopting higher efficiency HVAC equipment and elements of the IECC 2015 code. Because most non-manufactured homes already met prescriptive code for infiltration and wall insulation, improvements from changes to single aspects of construction were small, on the order or 1-2%. Adding up the components of IECC 2009 yielded higher savings, on the order of 9% for fossil fuels and 3% for electricity. Shifting to IECC 2015 code components yielded higher savings at 21% of fossil fuel and 6% of electricity. Combining the IECC 2015 components with a complete shift to heat pumps for space heating reduced fossil fuel use by 84% with an increase in electricity use of 51%. These percentages correspond to an average reduction of 41 MMBTU/year of fossil fuel per home and an increase of 3,600 kWh (12.3 MMBTU) per home due to the shift to heat pump heating.

Manufactured homes were built better than HUD code for insulation but did not fully meet infiltration requirements. They lagged in performance behind IECC 2009 equivalent construction techniques. In a manner similar to that for single and multifamily homes, we modeled the energy use of manufactured homes using Ekotrope Rater. We found that for manufactured homes built to a stretch code outlined in Section 9, energy use would drop by 25% for fossil fuels and 1% for electricity. Converting these homes to heat pumps for space heating, fossil fuel use would drop by 98% or about 56 MMBTU/year. This would cause an increase in electricity use of about 6,000 kWh/year (20.5 MMBTU). If the stretch code construction were combined with heat pumps, the increase in electricity use would be limited to about 4,000 kWh/year (13.6 MMBTU).