PNNL-30006, Rev. 1

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Oregon Residential Energy Code Field Study

August 2020

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

A research project in the state of Oregon identified opportunities to reduce homeowner utility bills in residential single-family new construction by increasing compliance with the state energy code. The study was initiated in November 2019; data collection began in November 2019 and continued through February 2020. During this period, the project team visited 162 homes at various stages of construction, resulting in a data set based on observations made directly in the field. Analysis of the data has led to a better understanding of the energy features present in homes and identified over $600,000 in potential annual savings to Oregon homeowners that could result from increased compliance with the 2017 Oregon Residential Specialty Code (2017 ORSC)[1]. Public and private entities within the state can use this information to justify and catalyze future investments in energy code training and related energy efficiency programs.

Methodology

The project team was led by TRC Companies and the Northwest Energy Efficiency Alliance. The team applied a methodology prescribed by the U.S. Department of Energy (DOE), which was based on collecting information for the energy code-required building components with the largest direct impact on energy consumption. These *key items* are a focal point of the study and drive the analysis and savings estimates. The project team implemented a customized sampling plan representative of new construction within the state; the sampling plan was developed by Pacific Northwest National Laboratory (PNNL) and vetted through stakeholder meetings.

Following data collection, PNNL conducted three stages of analysis on the resulting data set (Figure ES.1). The first stage identified compliance trends within the state based on the distributions observed in the field for each key item. The second stage modeled energy consumption of the homes observed in the field relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement, and are intended to inform future energy code education, training, and outreach activities.

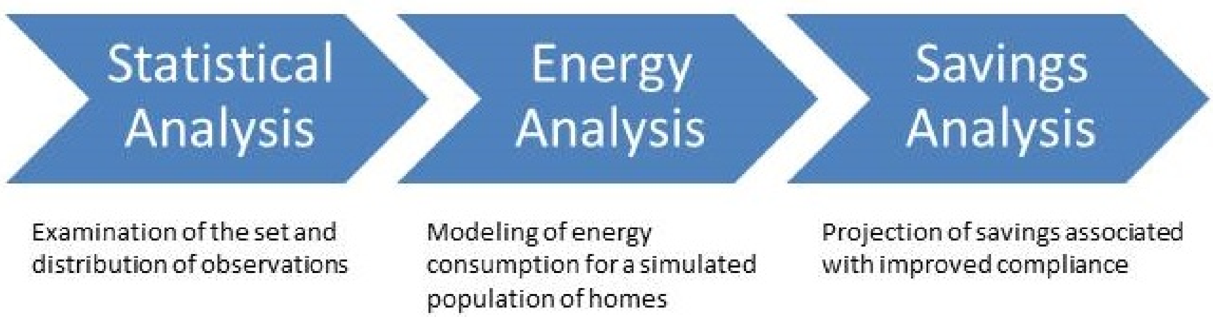

Figure ES.1. Stages of Analysis Applied in the Study

[1] On October 1, 2017, Oregon adopted the 2017 Oregon Residential Specialty Code, which is based on the 2015 International Residential Code with amendments.

Results

Table ES.1 shows the key items with the greatest savings potential that could be achieved through increased code compliance in Oregon. The estimates represent the savings associated with each measure and are extrapolated based on projected new construction. These items should be considered a focal point for compliance enhancement programs within the state, including energy code education and training initiatives.

Table ES.1. Estimated Annual Statewide Savings Potential in Oregon

Measure	**Total Energy Savings** (MMBtu)	**Total Energy Cost Savings** ($)	**Total State Emissions Reduction** (MT CO2e)
Exterior Wall Insulation	23,278	335,199	6,617
Ceiling Insulation	6,170	92,112	1,995
Envelope Air Tightness	5,220	62,574	552
Duct Leakage	3,379	55,466	1,464
Window U-Factor	2,673	29,864	122
Foundation Insulation	2,989	22,779	-649
High-Efficacy Lighting	289	13,202	751
TOTAL	**43,998 MMBtu**	**$611,195**	**10,852 MT CO2e**

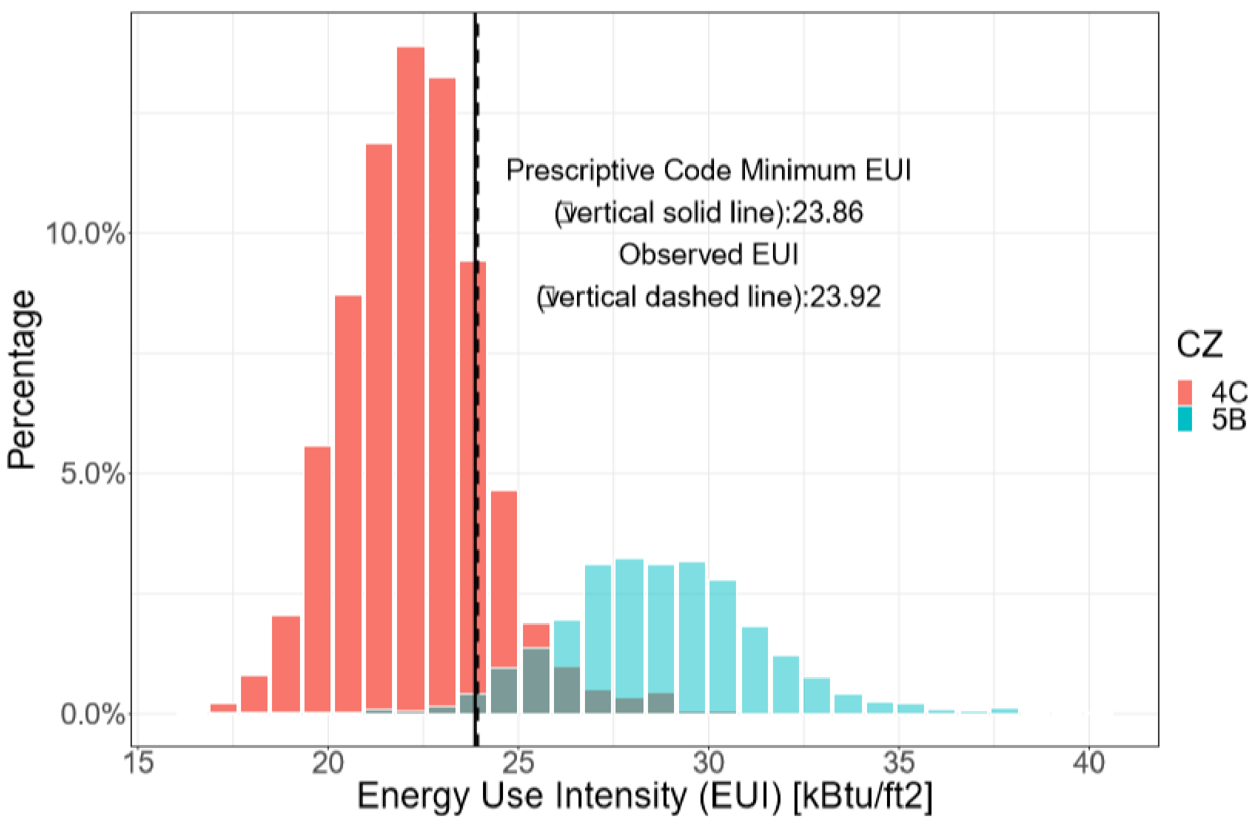

Figure ES.2. Modeled Distribution of Regulated EUI (kBtu/ft^2/year) in Oregon

In terms of overall energy consumption, the analysis shows that homes within the state use very *slightly more* energy than would be expected relative to homes built to the current minimum state code requirements (Figure ES.2). Analysis of the collected field data indicates average regulated energy use intensity (EUI) of 23.92 kBtu/ft^2-yr statewide compared to 23.86 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements. This suggests that, on average, the typical home in the state is about 0.3% worse than code.

Note that in an EUI analysis, items found to be better than code offset savings from items found to be worse than code. In contrast, the measure level savings analysis focuses solely on below-code observations. These below-code items represent a savings opportunity regardless of the above-code items. In this study, a significant portion of homes were found to not meet code in several key areas impacting energy use, durability, and comfort. Thus, there is an energy savings opportunity of $611,000 annually from energy code compliance enhancement activities in Oregon.

Acknowledgments

The following members comprised the Oregon project team:

- Greg Lasher, Project Manager, TRC
- Beth Baxter, Eric Mapson, Casey Phillips, Anna Hilbruner, Jacob Green, Field Auditors, TRC
- Jonathan Jones, David Freelove, Field Auditors

The Oregon project team wishes to acknowledge the Northwest Energy Efficiency Alliance (NEEA) for providing the funding for this project. The team would also like to thank Steve Phoutrides, Senior Project Manager of Market Research and Evaluation at NEEA, for managing the project and Bing Liu, Senior Manager of the Codes, Standards and New Construction Program at NEEA, for providing an insightful review of the report.

Additionally, the team extends its gratitude to Scott Leonard of the Energy Trust of Oregon for his continued support throughout the project:

Northwest Energy Efficiency Alliance

The Northwest Energy Efficiency Alliance (NEEA) is a non-profit organization working to effect market transformation through the acceleration and adoption of energy-efficient products, services and practices. NEEA is an alliance of more than 140 Northwest utilities and energy efficiency organizations working on behalf of more than 13 million energy consumers. For more information, visit neea.org.

Acronyms and Abbreviations

AC	air conditioning
ACCA	Air Conditioning Contractors of America
ACH	air changes per hour
AFUE	annual fuel utilization efficiency
AIA	American Institute of Architects
Btu	British thermal unit
cfm	cubic feet per minute
CO2e	carbon dioxide equivalent
CZ	climate zone
DOE	U.S. Department of Energy
EDC	electric distribution company
EERE	Office of Energy Efficiency and Renewable Energy
EPS	Energy Performance Scoring
EUI	energy use intensity
FOA	funding opportunity announcement
HERS	home energy rating system
HSPF	heating season performance factor
ICC	International Code Council
IECC	International Energy Conservation Code
kBtu	thousand British thermal units
MMBtu	million British thermal units
NA	not applicable
NEEA	Northwest Energy Efficiency Alliance
OBCD	Oregon Building Codes Division
ODOE	Oregon Department of Energy
OR	Oregon
ORSC	Oregon Residential Specialty Code
PNNL	Pacific Northwest National Laboratory
RESNET	Residential Energy Services Network
RFI	request for information
SHGC	solar heat gain coefficient

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1.0 Introduction

A research project in the state of Oregon investigated the energy code-related aspects of unoccupied, newly constructed, single-family homes across the state. The study followed a methodology prescribed by the U.S. Department of Energy (DOE), which allowed the project team to build an empirical data set based on observations made directly in the field. The data was then analyzed by Pacific Northwest National Laboratory (PNNL) to identify compliance trends, determine the impact of such trends on statewide energy consumption, and calculate savings that could be achieved through increased code compliance. Study findings can help to justify additional support for energy code education, training, and outreach activities, as well as catalyze future investments in compliance enhancement programs.

The Oregon field study was initiated in November 2019; data collection began in November 2019 and continued through February 2020. During this period, the project team visited 162 homes across the state at various stages of construction. At the time of the study, the state energy code was the 2017 Oregon Residential Specialty Code (ORSC) which is based on the 2015 International Building Code with Oregon amendments, effective October 1, 2017.[1] The study methodology, data analysis, and findings are presented throughout this report.

1.1 Background

Energy codes for residential buildings have advanced significantly in recent years; today's model codes are approximately 30% more efficient than codes adopted by the majority of U.S. states. [2,3] As such, there is a growing need to ensure code-intended energy savings are achieved and that consumers reap the benefits of improved codes— outcomes that will happen only through high levels of compliance.

The purpose of the Oregon field study is to gather field data on energy code measures as installed and observed in actual homes and identify trends and issues that can inform energy code training and other compliance enhancement programs. This study was modeled after DOE's field study, "Strategies to Increase Residential Energy Code Compliance Rates and Measure Results".[4] More information on DOE's interest in compliance is available on the DOE Building Energy Codes Program website.[5]

1.2 Project Team

TRC Companies led the Oregon project team and collected the field data; the Northwest Energy Efficiency Alliance (NEEA) funded TRC and provided technical guidance throughout the project. DOE and PNNL defined the methodology, conducted data analysis, and provided technical assistance to the project team. Funding for the data collection by the project team was provided by NEEA. More information on the organizations comprising the project team is included in the Acknowledgements section of this report.

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[1] Available at https://codes.iccsafe.org/content/document/1018?site_type=public.
[2] *National Energy and Cost Savings for New Single- and Multifamily Homes: A Comparison of the 2006, 2009, and 2012 Editions of the IECC*, available at http://www.energycodes.gov/development
[3] Available at http://www.energycodes.gov/adoption/states
[4] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study
[5] Available at https://www.energycodes.gov/compliance

1.3 Stakeholder Interests

Throughout the duration of the Oregon field study, the project team actively engaged with stakeholders representing the following groups:

- Building officials
- Homebuilders
- Energy efficiency advocates
- Residential appraisal experts
- Utilities (Energy Trust of Oregon)

Members of these and other groups are critical to the success of the project, as their buy-in to the results is necessary for future activities. Such stakeholders hold important information (e.g., building officials have the lists of homes under construction and are therefore key to the sampling process), control access to homes needed for site visits, are targets for training, or, as is often the case with government agencies, have oversight responsibilities for code adoption and implementation.

Utilities are also crucial stakeholders and often have direction from state regulatory bodies (e.g., the public utility commission) to achieve energy savings. Many utilities have expressed an increasing interest in energy code investments and are looking at energy code compliance as a means to provide assistance and generate additional savings. The field study can provide a strong, empirically-based case for such utility investment.

2.0 Methodology

2.1 Overview

The Oregon field study was based on a methodology developed by DOE to identify savings opportunities associated with increased energy code compliance. This methodology involves gathering field data on energy code measures as they are installed and observed in actual homes. The subsequent analysis identifies trends and issues with code compliance and can be used to inform energy code training and other compliance enhancement programs.

Highlights of the methodology:

- Focuses on **individual code requirements** within **new single-family homes**
- Based on a **single site visit** to reduce burden and minimize bias
- Prioritizes **key items** with the greatest impact on energy consumption
- Designed to produce **statistically significant results**
- **Data confidentiality** built into the study—no occupied homes were visited, and no personal data shared
- Results based on an **energy metric** and reported at the **state level**

PNNL identified the code-requirements (and associated energy efficiency measures) with the greatest direct impact on residential energy consumption. [1] These *key items* drive sampling, data analysis, and eventual savings projections:

1. Envelope tightness (ACH at 50 Pascals)
2. Window U-factor
3. Window SHGC
4. Wall insulation (assembly U-factor)
5. Ceiling insulation (R-value)
6. Lighting (% high-efficacy)
7. Foundation insulation (R-value)[2]
8. Duct tightness (expressed in cfm per 100 ft^2 of conditioned floor area at 25 Pascals)

PNNL evaluated the variability associated with each key item and concluded that a minimum of 63 observations would be needed for each one to produce statistically significant results at the state level. Both the key items themselves and the required number of observations were prescribed in the DOE methodology.

The following sections describe how the methodology was implemented as part of the Oregon study, including sampling, data collection, and data analysis. More information on the full DOE protocol and

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[1] Based on the *mandatory* and *prescriptive* requirements of the International Energy Conservation Code (IECC).
[2] Floor insulation, basement wall insulation, crawlspace wall insulation, and slab insulation were combined into a single category of foundation insulation.

PNNL analysis is published separately from this report (DOE/PNNL 2018) and is available on the DOE Building Energy Codes Program website.[3]

2.2 State Study

The prescribed methodology was customized for Oregon to reflect circumstances unique to the state, such as state-level code requirements and regional construction practices. Customization also ensured that the results of the study would have credibility with stakeholders.

2.2.1 Sampling

PNNL developed a statewide sampling plan statistically representative of recent construction activity within the state. The samples were apportioned to jurisdictions across the state in proportion to their average level of construction compared to the overall construction activity statewide. This approach is a proportional random sample, which PNNL based on the average of the three most recent years of Census Bureau permit data.[4] The plan specified the number of key item observations required in each selected jurisdiction (totaling 63 of each key item across the entire project coverage area). The sampling plan was vetted with stakeholders.

2.2.2 Data Collection

Following confirmation of the sample plan, the project team utilized Construction Monitor to identify homes currently in the permitting process. Where Construction Monitor lacked data in some jurisdictions, TRC directly contacted local permitting offices. These local permitting offices responded by providing lists of homes at various stages of construction within their jurisdiction. These lists were then sorted using a random number generator and utilized by the project team to contact builders to gain site access. As prescribed by the methodology, each home was visited only once to avoid any bias associated with multiple site visits. Only installed items directly observed by the field team during site visits were recorded. If access was denied for a particular home on the list, field personnel moved onto the next home on the list.

2.2.2.1 Data Collection Form

The field teams relied on a data collection form customized to the *mandatory* and *prescriptive* requirements of the state energy code. The field teams used the DOE 2018 IECC form with Oregon amendments.[5] The final data collection form is available in spreadsheet format on the DOE website.[6] The form included all energy code requirements (i.e., not just the eight key items), as well as additional items required under the prescribed methodology. For example, the field teams were required to conduct a

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[3] Available at https://www.energycodes.gov/compliance/energy-code-field-studies.
[4] Available at http://censtats.census.gov/ (select the "Building Permits" data).
[5] Information about the Oregon energy code is available at https://codes.iccsafe.org/content/document/1018?site_type=public. The OR amendments for the form included two new data collection fields to specify the envelope enhancement measure and the conservation measure specified in Table 1101.1(2) of the OR code.
[6] Available at https://www.energycodes.gov/compliance/energy-code-field-studies and based on the forms typically used by the RES*check* compliance software.

blower door test and duct leakage test using RESNET[7] protocols on every home where such tests could be conducted.

The information beyond the key items was used during various phases of the analysis, or to supplement the overall study findings. For example, insulation installation quality impacts the energy-efficiency of insulation was used to modify that key item during the energy modeling and savings calculation. Equipment, including fuel type and efficiency rating, and basic home characteristics (e.g., foundation type) helped validate the prototype models applied during energy simulation. Other questions, such as whether the home participated in an above-code program, can assist in understanding whether other influencing factors are at play beyond the code requirements.

The data collected were the energy values observed, rather than the compliance status. For insulation, for example, the R-value was collected; for windows, the U-factor. The alternative, such as was used in DOE's older work, simply stated whether an item did or did not comply. The current approach provides an improved understanding of how compliance equates to energy consumption and gives more flexibility during analysis since the field data can be compared to any energy code.

2.2.2.2 Data Management and Availability

Once the data collection effort was complete, the project team conducted a thorough quality assurance review. This included an independent check of raw data compared to the information provided to PNNL for analysis, and helped to ensure completeness, accuracy, and consistency across the inputs. Prior to submitting the data to PNNL, the team also removed all personally identifiable information, such as project site locations and contact information. The final dataset is available in spreadsheet format on the DOE website.[8]

2.3 Data Analysis

PNNL conducted all data analysis in the study through three basic stages:

1. **Statistical Analysis:** Examination of the data set and distribution of observations for individual measures
2. **Energy Analysis:** Modeling of energy consumption for a simulated population of homes
3. **Savings Analysis:** Projection of savings associated with improved compliance

The first stage identified compliance trends within the state based on what was observed in the field for each key item. The second stage modeled energy consumption (of the homes observed in the field) relative to what would be expected if sampled homes just met minimum code requirements. The third stage then calculated the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance. Together, these findings provide valuable insight on challenges facing energy code implementation and enforcement, and are intended to inform future energy code education, training, and outreach activities.

The analysis of the ORSC has two unique features that differ from the typical codes analyzed using DOE's methodology. In addition to base prescriptive requirements (Table N1101.1(1) of the ORSC), there are requirements to select one additional measure from each of two categories: Envelope

[7] See http://www.resnet.us/standards/RESNET_Mortgage_Industry_National_HERS_Standards.pdf.
[8] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study.

Enhancement and Conservation (HVAC). Both requirements are expressed as a series of options in Table N1101.1(2) of the ORSC.

Table 2.1. Prescriptive Envelope Requirements

TABLE N1101.1(1)
PRESCRIPTIVE ENVELOPE REQUIREMENTS[a]

BUILDING COMPONENT	STANDARD BASE CASE		LOG HOMES ONLY	
	Required Performance	Equiv. Value[b]	Required Performance	Equiv. Value[b]
Wall insulation—above grade	U-0.059[c]	R-21 Intermediate[c]	Note d	Note d
Wall insulation—below grade[e]	C-0.063	R-15/R-21	C-0.063	R-15/R-21
Flat ceilings[f]	U-0.021	R-49	U-0.020	R-49 A[h]
Vaulted ceilings[g]	U-0.033	R-30 Rafter or R-30A[g,h] Scissor Truss	U-0.027	R-38A[h]
Underfloors	U-0.033	R-30	U-0.033	R-30
Slab edge perimeter	F-0.520	R-15	F-0.520	R-15
Heated slab interior[i]	n/a	R-10	n/a	R-10
Windows[j]	U-0.30	U-0.30	U-0.30	U-0.30
Window area limitation[j, k]	n/a	n/a	n/a	n/a
Skylights[l]	U-0.50	U-0.50	U-0.50	U-0.50
Exterior doors[m]	U-0.20	U-0.20	U-0.54	U-0.54
Exterior doors with > 2.5 ft^2 glazing[n]	U-0.40	U-0.40	U-0.40	U-0.40
Forced air duct insulation	n/a	R-8	n/a	R-8

Table 2.2. Additional Measures

TABLE N1101.1(2)
ADDITIONAL MEASURES

Envelope Enhancement Measures (Select One)	1	**High efficiency walls** Exterior walls—U-0.045/R-21 cavity insulation + R-5 continuous
	2	**Upgraded features** Exterior walls—U-0.057/R-23 intermediate or R-21 advanced, Framed floors—U-0.026/R-38, and Windows—U-0.28 (average UA)
	3	**Upgraded features** Exterior walls—U-0.055/R-23 intermediate or R-21 advanced, Flat ceiling[e]—U-0.017/R-60, and Framed floors—U-0.026/R-38
	4	**Super Insulated Windows and Attic OR Framed Floors** Windows—U-0.22 (Triple Pane Low-e), and Flat ceiling[e]—U-0.017/R-60 or Framed floors—U-0.026/R-38
	5	**Air sealing home and ducts** Mandatory air sealing of all wall coverings at top plate and air sealing checklist[f], and Mechanical whole-building ventilation system with rates meeting M1503 or ASHRAE 62.2, and All ducts and air handlers contained within building envelope[d] or All ducts sealed with mastic[b]
	6	**High efficiency thermal envelope UA[g]** Proposed UA is 8% lower than the code UA
Conservation Measure (Select One)	A	**High efficiency HVAC system[a]** Gas-fired furnace or boiler AFUE 94%, or Air source heat pump HSPF 9.5/15.0 SEER cooling, or Ground source heat pump COP 3.5 or Energy Star rated
	B	**Ducted HVAC systems within conditioned space** All ducts and air handlers contained within building envelope[d] *Cannot be combined with Measure 5*
	C	**Ductless heat pump** Ductless heat pump HSPF 10.0 in primary zone of dwelling
	D	**High efficiency water heater[c]** Natural gas/propane water heater with UEF 0.85 OR Electric heat pump water heater Tier 1 Northern Climate Specification Product

The selection of the appropriate options to implement for the analysis was made in consultation with NEEA. The Envelope Enhancement Measures impact the base prescriptive requirements for the building envelope, and Option 2 was selected[9], which requires increased insulation levels for exterior walls and floors and decreased window U-factor(See the discussion in Section 2.3.1 on how the base prescriptive requirements and the envelope enhancement measures option interact.)

The Conservation Measure Option A (High-efficiency HVAC system) was selected for the analysis.[10] This option does not impact any of the key items used in the analysis but does impact the HVAC equipment efficiency used for the prototype building models and therefore have impact on the modeled heating and cooling energy consumptions. The prototypes were modified for this analysis to reflect the higher efficiencies required for gas furnaces and air source heat pumps required in Conservation Measure A. The potential impact of these unique features of the ORSC is also discussed in each appropriate section.

Another unique feature of the Oregon analysis is that there is no prescriptive requirement for air tightness (expressed in terms of ACH50) or duct leakage (expressed in cfm/100 ft^2 of duct) in the ORSC. At NEEA's request, PNNL implemented an air tightness "prescriptive requirement" of 5 ACH50[11] and a duct leakage value of 6 cfm/100 ft of duct[12]. These values are used as if they were prescriptive code requirements.

The following sections provide an overview of the analysis methods applied to the field study data, with the resulting state-level findings presented in Section 3.0, State Results.

2.3.1 Statistical Analysis

Standard statistical analysis was performed with distributions of each key item plotted by climate zone. This approach enables a better understanding of the range of data and provides insight on what energy-efficiency measures are most commonly installed in the field. It also allows for a comparison of installed values to the applicable code requirement, and for identification of any problem areas where potential for improvement exists. The graph below represents a sample key item distribution and is further explained in the following paragraph.

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[9] Table 3.20 in Section 3.1.2.6 also shows that Option 2 and Option 5 were tied for the most commonly observed Envelope Enhancement Measure options in the data collected for this field study. Option 2 was selected over Option 5 as Option 2 impacted three key items (wall insulation, floor insulation, and window U-factor), while Option 5 only impacted two key items (air tightness and duct leakage) and the requirements in Option 5 were not as quantifiable as Option 2.

[10] Table 3.20 in Section 3.1.2.6 shows that Option A was the most often observed Conservation Measure option by far in the data collected for this field study.

[11] NEEA selected 5 ACH50 based on a field study for homes complying with 2017 ORSC in which the blower door testing data shows that the code compliant homes have 5 ACH50. NEEA stated that this is consistent with a broader field study from the Residential Building Stock Assessment as well and that Oregon Building Code Division and Oregon Department of Energy agree on the use of 5 ACH50 as well.

[12] NEEA selected 6 cfm/100ft^2 as the duct leakage value based on the study 'Residential HVAC and Distribution Research Implementation by LBNL, 2002, which shows typical leakage of untested residential ductwork is 12% for typical duct installation. Sealing ductwork with mastic (using Measure 5 from Table N1101.1(2)) assumes that overall leakage would drop in half to roughly 6 cfm/100ft^2.

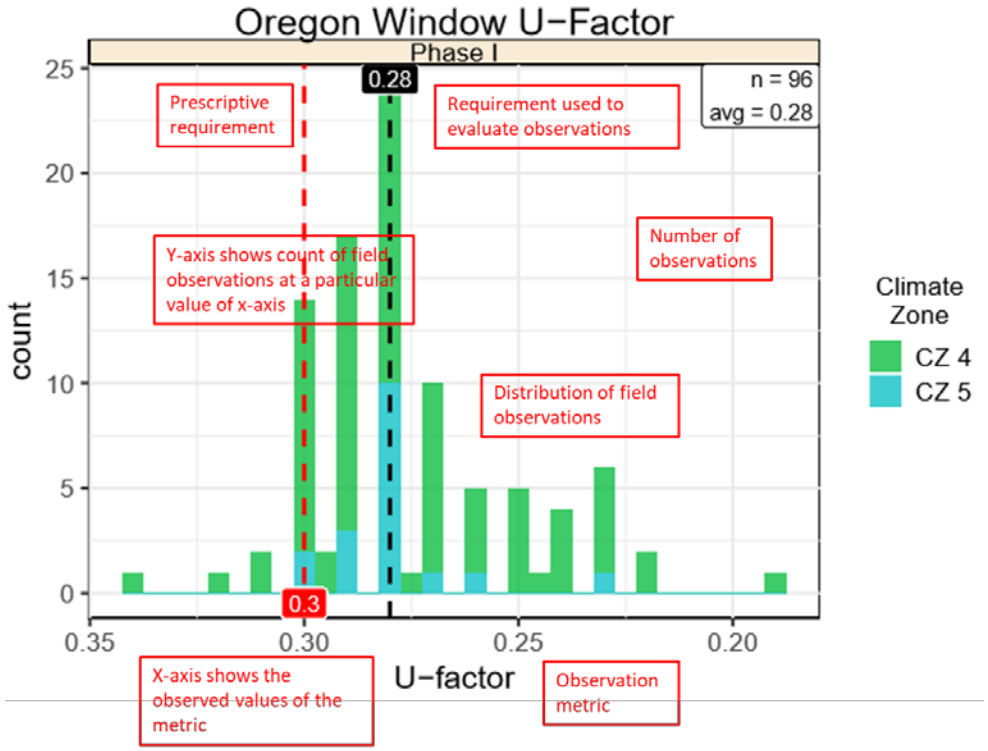

Figure 2.1. Sample Graph

Each graph is set up in a similar fashion, identifying the *state*, *climate zone*, and specific item being analyzed. The total *sample size* (n) is displayed in the top left or right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., window U-factor is measured in Btu/ft^2-hr-F), and a *count* of the number of observations is measured along the vertical axis. A vertical line is imposed on the graph representing the applicable code requirement (e.g., the requirement in climate zones 4 and 5 is 0.28)—values to the right-hand side of this line are *better than code*. Values to the left-hand side represent areas for improvement. Note that key items affected by envelope enhancement measure option 2 have graphs similar to Figure 2.1 with both a red dashed line and a black dashed line. In these cases, the black dashed line represents the requirement the observations were evaluated against. Typically, this would be the prescriptive code requirement, but in this case the black line is the envelope enhancement measure option 2 requirement, and the red dashed line represents the prescriptive requirement.

For walls and foundations, two graphs are included – one for R-value observations and another for U-factor observations. The R-value graphs show whether or not homes are being constructed with the required amount of insulation for the climate zone. The U-factor graphs indicate whether or not the combination of installed R-value and insulation installation quality meets the U-factor requirements in the climate zone. The combination of these two graphs can be used to determine if there is an issue with the amount of insulation, insulation installation quality, or both.

2.3.2 Energy Analysis

The next phase of the analysis leveraged the statistical analysis results to model average statewide energy consumption. A consequence of the field study methodology allowing only one site visit per home to minimize bias is that a full set of data cannot be gathered on any single home, as not all energy-efficiency measures are in place or visible at any given point during the home construction process. This lack of complete data for individual homes creates an analytical challenge because energy modeling and simulation protocols require a complete set of inputs to generate reliable results. To address this challenge, a series of "pseudo homes" were created, composed of over 1,500 models encompassing most of the possible combinations of key item values found in the observed field data. In aggregate, the models provide a statistical representation of the state's population of newly constructed homes. This approach is known in statistics as a Monte Carlo analysis[13].

Energy simulation was then conducted using the EnergyPlus™ software.[14] Each of the 1,500 models was run multiple times to represent each combination of heating systems and foundation types commonly found in the state. This resulted in upwards of 30,000 simulation runs for climate zone 6. An EUI was calculated for each simulation run and these results were then weighted by the frequency with which the heating system/foundation type combinations were observed in the field data. Average EUI was calculated based on regulated end uses (heating, cooling, lighting, and domestic hot water) for two sets of homes—one *as-built* set based on the data collected in the field, and a second *code-minimum* set (i.e., exactly meeting minimum code requirements). Comparing these values shows whether the population of newly constructed homes in the state is using more or less energy than would be expected based on minimum code requirements. Further specifics of the energy analysis are available in the methodology report (DOE/PNNL 2018).

2.3.3 Savings Analysis

To begin the third phase, each of the key items was examined individually to determine which had observed values that did not meet the associated code requirement. For these items, additional models were created to assess the savings potential, comparing what was observed in the field to a scenario of full compliance (i.e., where all worse-than-code observations for a particular item exactly met the corresponding code requirement).[15] This was done by individually upgrading each worse-than-code observation to the corresponding *prescriptive* code requirement, resulting in a second set of models (*full compliance*) that could be compared to the first (*as-built*). All other components were maintained at the corresponding prescriptive code value, allowing for the savings potential associated with a key item to be evaluated in isolation.

All variations of observed heating systems and foundation types were included, and annual electric, gas, and total EUIs were extracted for each building. To calculate savings, the differences in energy use calculated for each case were weighted by the corresponding frequency of each observation to arrive at an average energy savings potential for each climate zone. Potential energy savings for each climate zone were further weighted using construction starts in that zone to obtain the average statewide energy savings potential. State-specific construction volumes and fuel prices were used to calculate the maximum energy savings potential for the state in terms of *energy* (MMBtu), *energy cost* ($), and avoided *carbon emissions* (MT CO_2e).

Note that this approach results in the maximum theoretical savings potential for each measure as it does not take "interaction effects" into account, such as the increased amount of heating needed in the winter

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[13] https://en.wikipedia.org/wiki/Monte_Carlo_method. This particular application of the Monte Carlo methods involves the creation of the "pseudo home" models from random draws from the probability distributions for the key items.
[14] *See* https://energyplus.net/
[15] Better-than-code items were not included in this analysis because the intent was to identify the maximum savings potential for each measure. The preceding energy analysis included both better-than-code and worse-than-code results, allowing them to offset each other.

when energy efficient lights are installed. A building's energy consumption is a dynamic and interactive process that includes all the building components present within a given home. In a typical real building, the savings potential might be higher or lower; however, additional investigation indicated that the relative impact of such interactions is very small and could safely be ignored without changing the basic conclusions of the analysis.

Another aspect of savings potential that is not included is the presence of better-than-code items. While it is indeed possible that one better-than-code component may offset the energy lost due to another worse-than-code component, the collected data does not allow for the assessment of paired observations for a given home. Additionally, the analysis identifies the maximum theoretical savings potential for each measure; therefore, credit for better-than-code measures is not accounted for in the savings analysis.

2.4 Limitations

The following sections address limitations of the project, some of which are inherent to the methodology itself, and other issues as identified in the field.

2.4.1 Applicability of Results

An inherent limitation of the study design is that the results can be considered statistically significant only at the state level. Other results of interest, such as analysis based on climate zone level, or reporting of non-key items, were identified. While some of these items are visible in the publicly available data set, they should not be considered statistically representative.

2.4.2 Determination of Compliance

The field study protocol is based on a single site visit, which makes it impossible to know whether a particular home complies with the energy code as not enough information can be gathered in a single visit to know whether all code requirements have been met. For example, homes observed during the earlier stages of construction often lack key features (e.g., walls with insulation), and in the later stages, many of these items may be covered and therefore unobservable. To gather all the data required in the sampling plan, field teams therefore needed to visit homes in various stages of construction. The analytical implications of this are described above in Section 2.3.2. This approach gives a robust representation of measure compliance across the state.

2.4.3 Sampling Substitutions

The Oregon field study did not require any substitutions to the sampling plan. The sampling plan is available in Appendix A.

2.4.4 Site Access

Site access was purely voluntary, and data was collected only in homes where access was granted, which can be characterized as a self-selection bias. While every effort was made to limit this bias (i.e., sampling randomization, outreach to builders, reducing the burden of site visits, etc.), it is inherent due to the voluntary nature of the study. The impacts of this bias on the overall results are not known.

2.4.5 Analysis Methods

All energy analysis was conducted using prototype models; no individually visited homes were modeled, as the self-imposed, one-visit-per-home limitation meant that not all necessary modeling inputs could be collected from a single home. Thus, the impact of certain field-observable factors such as size, height, orientation, window area, floor-to-ceiling height, equipment sizing, and equipment efficiency were not included in the analysis. In addition, duct leakage was modeled separately from the other key items due to limitations in the EnergyPlus™ software used for analysis. It should also be noted that the resulting energy consumption and savings projections are based on modeled data, and not on utility bills or actual home energy usage.

2.4.6 Presence of Tradeoffs

The field team was able to gather only a minimal amount of data regarding which code compliance paths were being pursued for homes included in the study; all analyses therefore assumed that the prescriptive path was used. The project team agreed that this was a reasonable approach. The overall data set was reviewed in an attempt to determine if common tradeoffs were present, but the ability to do this was severely limited by the single site-visit principle which did not yield complete data sets for a given home. To the extent it could be determined, it did not appear that there was a systematic presence of tradeoffs.

2.4.7 Presence of Options in the Oregon Code

The 2017 ORSC requires the choice of an envelope enhancement option and a conservation option (HVAC) as part of the prescriptive requirements of the code. The specific options used in this analysis are discussed in Section 2.3. However, it should be noted that the selection of a specific option represents a limitation when those options are applied to homes that may have been designed to use other options. While the most commonly observed envelope enhancement option was chosen for analysis, that option represented only a fraction of the observations and including that option as part of the prescriptive requirement for all homes is likely to make homes that did not use this option appear to be less compliant.

3.0 State Results

3.1 Field Observations

The eight key items form the basis of the study and are therefore the focus of this section. However, discussion of other findings is covered in this section as well, including a description of how certain observations, such as insulation installation quality, are used to modify key items. (See Section 2.3.1 for a sample graph and explanation of how they should be interpreted.) Oregon has two climate zones, zones 4C and 5B (CZ4 and CZ5), and both zones are represented in the sampling, data collection, resulting analysis, and statewide savings calculations.

3.1.1 Key Items

The field study and underlying methodology are driven by *key items* that have a significant direct impact on residential energy efficiency. The graphs presented in this section represent the key item results for the state based on the measures observed in the field. Note that these key items are also the basis of the results presented in the subsequent *energy* and *savings* phases of analysis.

The following key items were found to be applicable within the state:

1. Envelope tightness (ACH at 50 Pascals)
2. Window SHGC
3. Window U-factor
4. Exterior wall insulation (assembly U-factor)
5. Ceiling insulation (R-value)
6. Lighting (% high-efficacy)
7. Foundations – basement walls, crawlspace walls, slabs, and floors (assembly U-factor)
8. Duct tightness (expressed in cfm per 100 ft^2 of conditioned floor area at 25 Pascals)

Note that envelope tightness, window SHGC, and duct tightness are not regulated in the 2017 ORSC but are included in this analysis for completeness.

3.1.1.1 Envelope Tightness

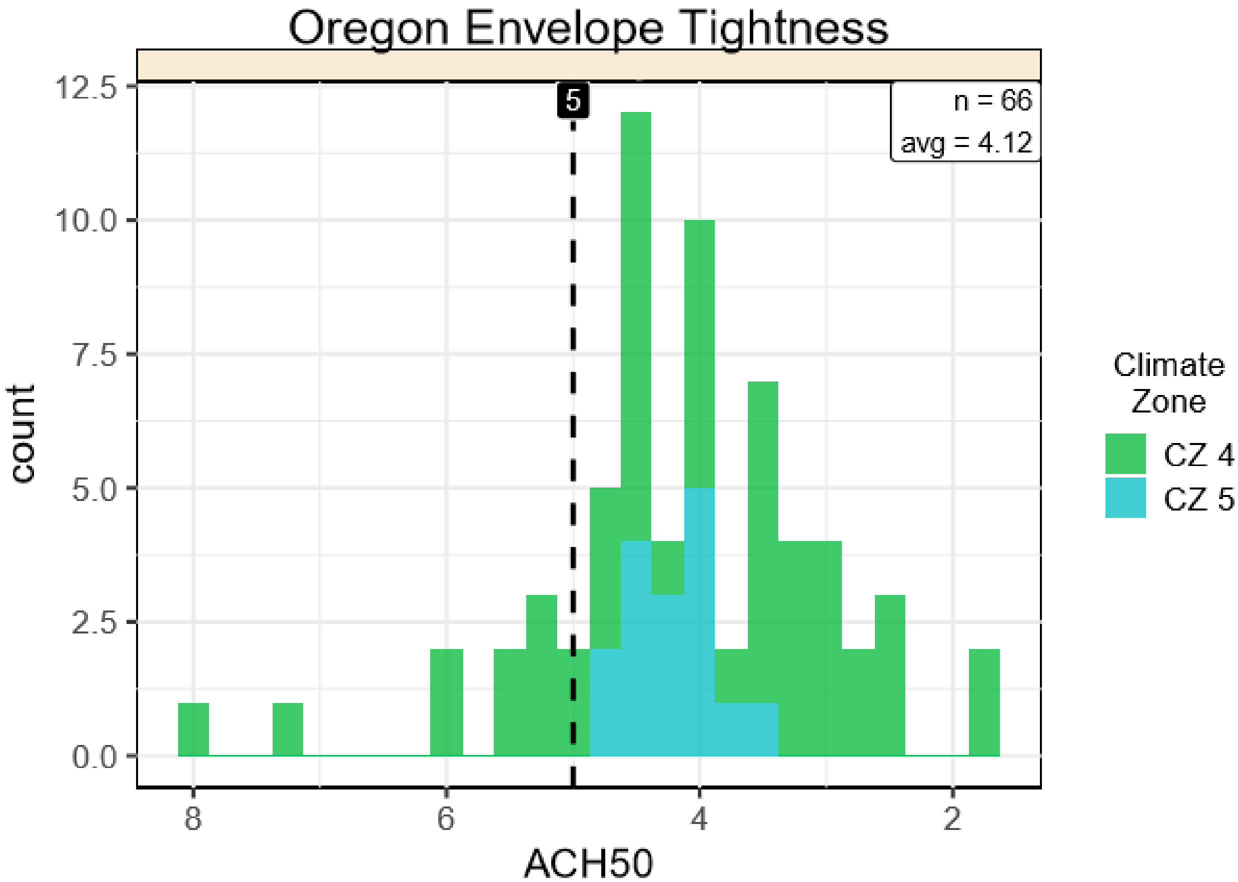

Figure 3.1. Envelope Tightness for Oregon

Table 3.1. Oregon Envelope Tightness

Climate Zone	CZ4	CZ5	Statewide
Number	50	16	66
Range	1.7 to 8.1	3.6 to 4.9	1.7 to 8.1
Average	4.1	4.2	4.1
Requirement	5	5	5
Compliance Rate	41 of 50 (82%)	16 of 16 (100%)	57 of 66 (86%)

Blower door testing for envelope tightness is not required in the 2017 ORSC. Instead the 2017 ORSC requires air tightness testing label of windows and doors and requires sealing around exterior joints. The quantitative value of 5 ACH50 shown in the table and figure above is based on previous NEEA field studies as discussed in Section 2.3.

- **Interpretations:**
  - Most (86%) of the observations met or exceeded the assumed prescriptive code requirement, with CZ5 meeting the requirement 100% of the time.

3.1.1.2 Window SHGC

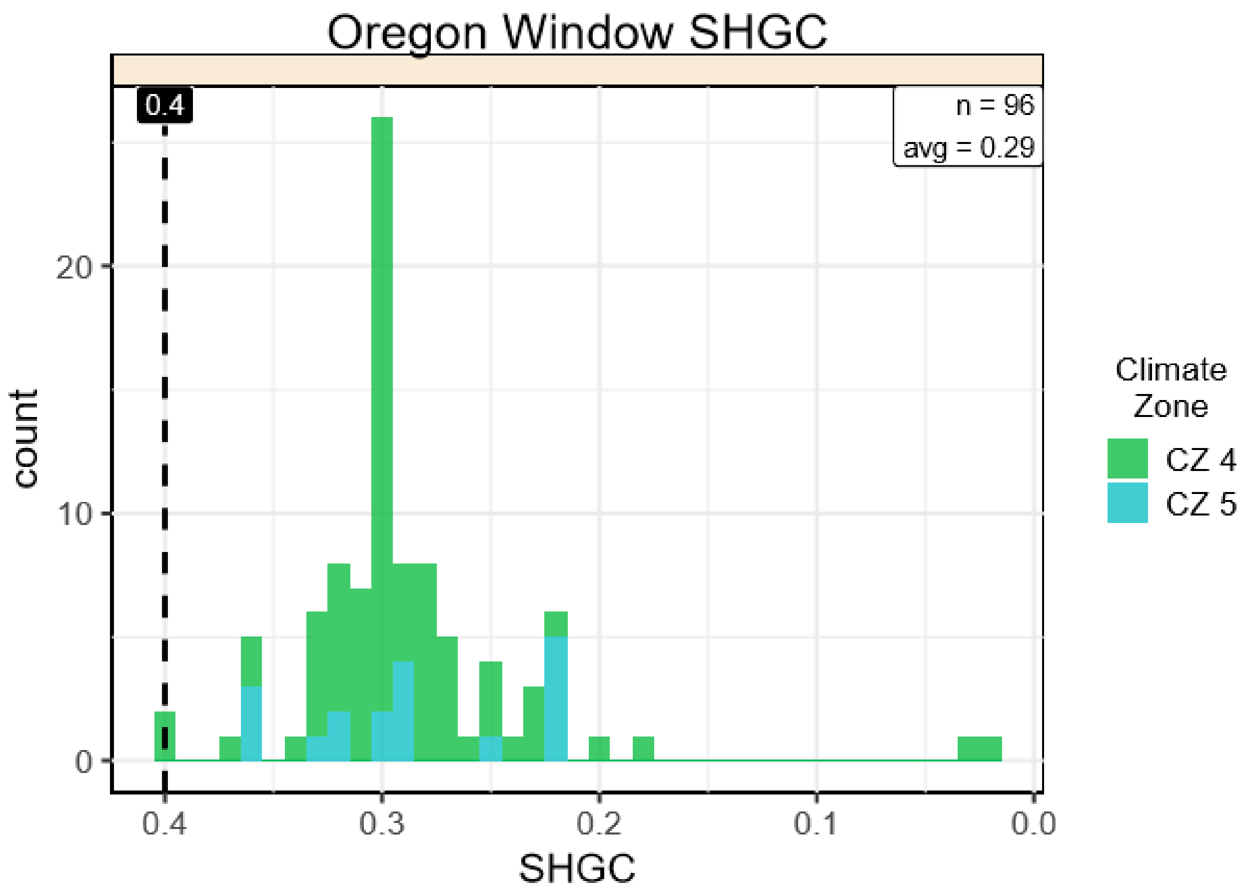

Figure 3.2. Window SHGCs for Oregon

Table 3.2. Oregon Window SHGCs

Climate Zone	CZ4	CZ5	Statewide
Number	78	18	96
Range	0.18 to 0.40	0.22 to 0.36	0.18 to 0.40
Average	0.29	0.29	0.27
Requirement	0.44	0.4	0.4
Compliance Rate	NA	NA	NA

- **Interpretations:**
  - Although there is no SHGC requirement in the 2017 ORSC, all observed SHGC values met the 2015 IECC prescriptive requirement of 0.4.

3.1.1.3 Window U-Factor

In Figure 3.3, the black dashed line represents the requirement the observations were evaluated against. Typically, this would be the prescriptive code requirement, but in this case the black line is the envelope enhancement measure option 2 requirement, and the red dashed line represents the prescriptive requirement.

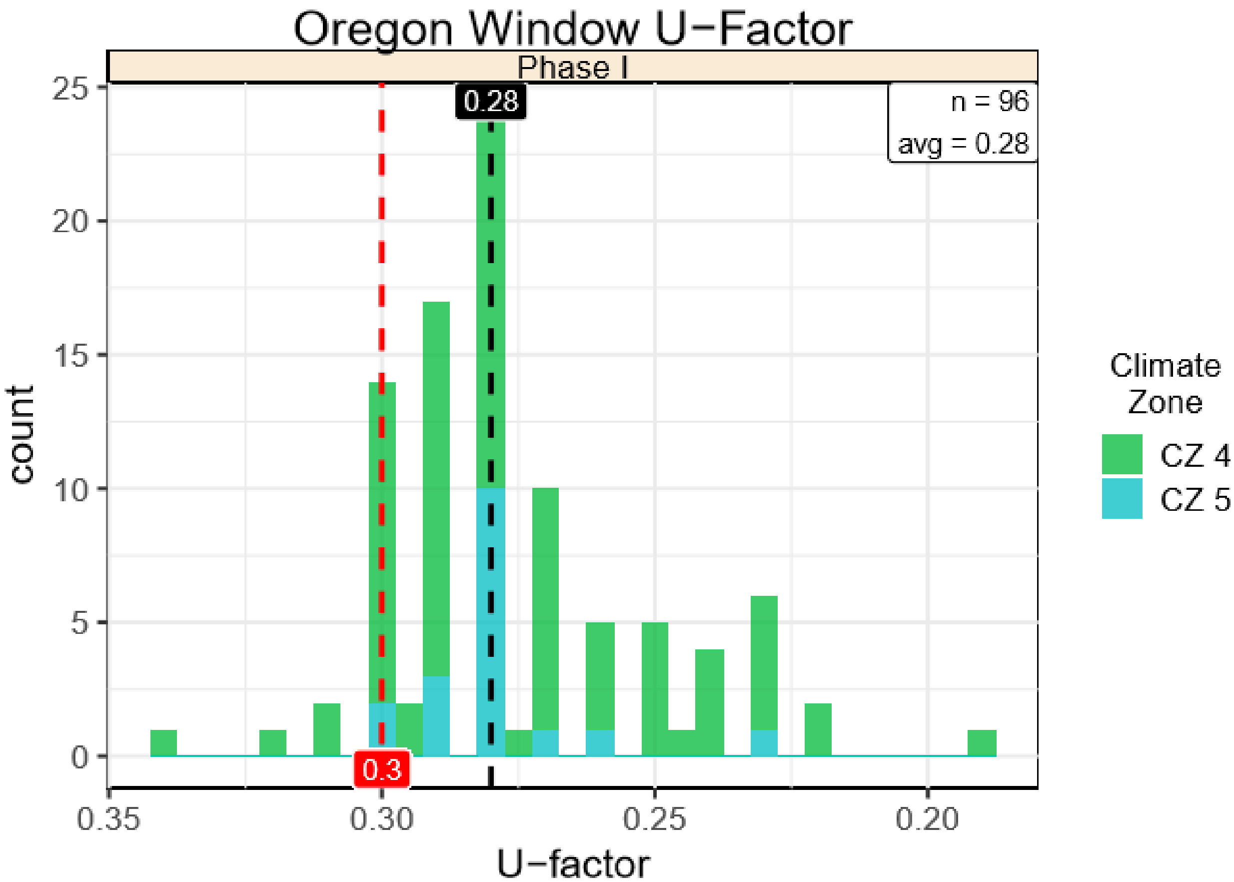

Figure 3.3. Window U-Factors for Oregon

Table 3.3. Oregon Window U-Factors

Climate Zone	CZ4	CZ5	Statewide
Number	78	18	96
Range	0.19 to 0.34	0.23 to 0.30	0.19 to 0.34
Average	0.27	0.28	0.28
Base Requirement	0.30	0.30	0.30
Option Requirement	0.28	0.28	0.28
Base Compliance Rate	74 of 78 (95%)	18 of 18 (100%)	92 of 96 (96%)
Option Compliance Rate	46 of 78 (59%)	13 of 18 (72%)	59 of 96 (61%)

The prescriptive window U-factor listed in the table and figure above represents the window U-factor required under envelope enhancement measure option 2. The actual prescriptive requirement in the 2017 ORSC is 0.30, but with the selection of envelope enhancement measure option 2 this value is lowered to 0.28.

- **Interpretations:**
  - There is a low rate of compliance for window U-factor compared to similar studies. This is likely tied into the selection of envelope enhancement measure option 2 as the baseline, and some of the homes visited may not have used that option. When observations are compared to the prescriptive value of 0.30, the compliance rate is much higher (92 of 96, 96%), which is in line with what has been seen in other states.

3.1.1.4 Wall Insulation

Wall insulation data is presented in terms of both frame cavity insulation and overall assembly performance in order to capture the conditions seen in the field. The cavity insulation data is based on the observed value (R-value), as printed on the manufacturer label and installed in the home. While cavity insulation is important, it is not fully representative of wall assembly performance, since this data point alone does not account for other factors that can have a significant effect on the wall system such as combinations of cavity and continuous insulation and insulation installation quality (IIQ). Therefore, wall insulation is also presented from a second perspective—overall assembly performance (U-factor). In Figure 3.4, the black dashed line represents the requirement the observations were evaluated against. Typically, this would be the prescriptive code requirement, but in this case the black line is the envelope enhancement measure option 2 requirement, and the red dashed line represents the prescriptive requirement.

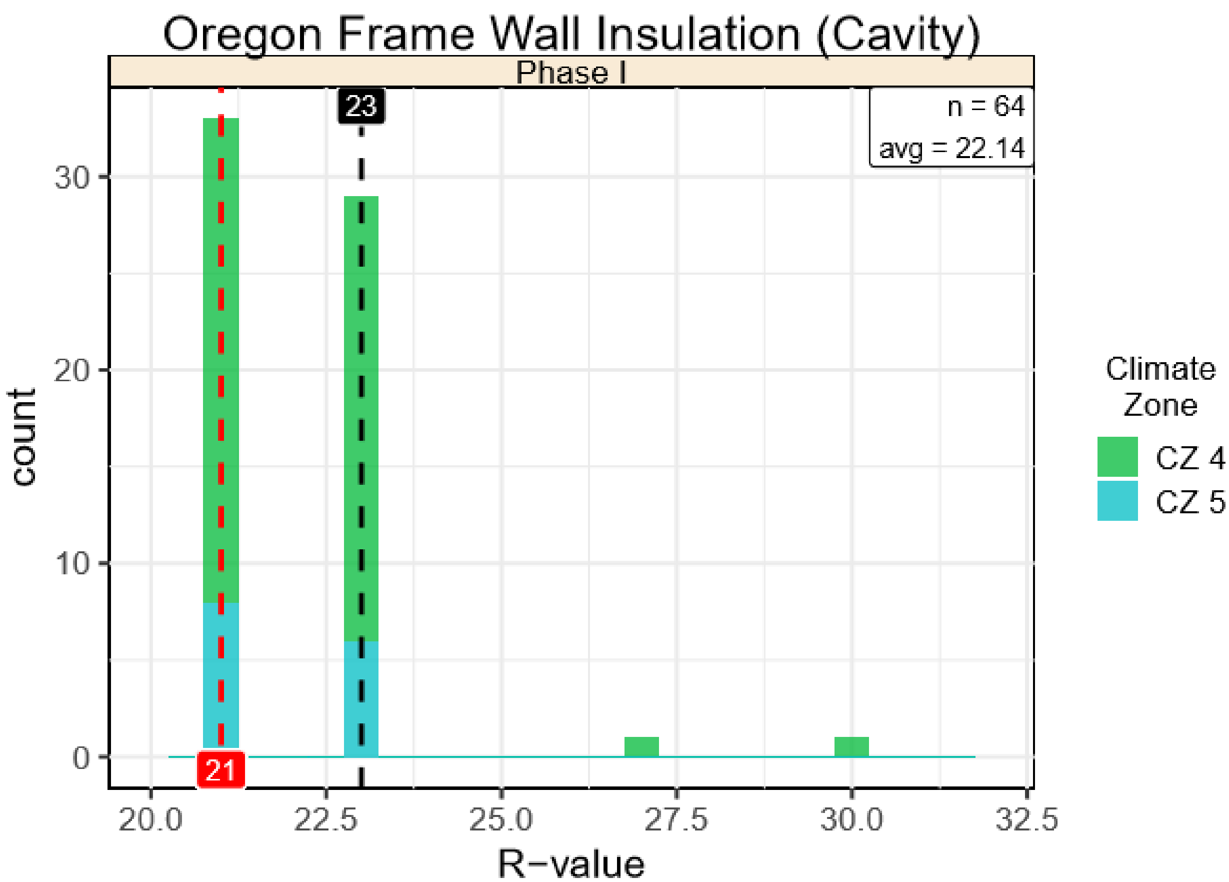

Figure 3.4. Wall R-Values for Oregon

Table 3.4. Oregon Wall R-Value

Climate Zone	CZ4	CZ5	Statewide
Number	50	14	64
Range	R-21 to R-30	R-21 to R-23	R-21 to R-30
Average	R-22.2	R-21.9	R-22.1
Base Requirement	R-21	R-21	R-21
Option Requirement	R-23	R-23	R-23
Base Compliance Rate	50 of 50 (100%)	14 of 14 (100%)	64 of 64 (100%)
Option Compliance Rate	25 of 50 (50%)	6 of 14 (43%)	31 of 64 (48%)

While IIQ is not an explicit energy code requirement, at the start of DOE's residential single-family projects[1], it was noted as a particular concern among project teams and stakeholders, as it plays an important role in the energy performance of envelope assemblies. IIQ was therefore collected by the field team whenever possible and applied as a *modifier* in the analyses for applicable key items (i.e., wall insulation, ceiling insulation, and foundation insulation). The team followed the RESNET[2] assessment protocol for cavity insulation which has three grades; Grade I being the best quality installation and Grade III being the worst.

Table 3.5 shows the number and percentage of IIQ observations by grade for above grade wall insulation.

Table 3.5. Above Grade Wall IIQ for Oregon

Above Grade Wall	Grade I	Grade II	Grade III	Total Observations
Observations	30	29	5	**64**
Percentages	47%	45%	8%	**100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Table 3.6. In the graph, observations are binned for clearer presentation based on the most commonly observed combinations.

[1] Projects were awarded under a funding opportunity announcement (FOA). See https://www.energycodes.gov/compliance/energy-code-field-studies for details.

[2] See the January 2013 version at https://www.resnet.us/wp-content/uploads/RESNET-Mortgage-Industry-National-HERS-Standards_3-8-17.pdf; the current version at the time the study began.

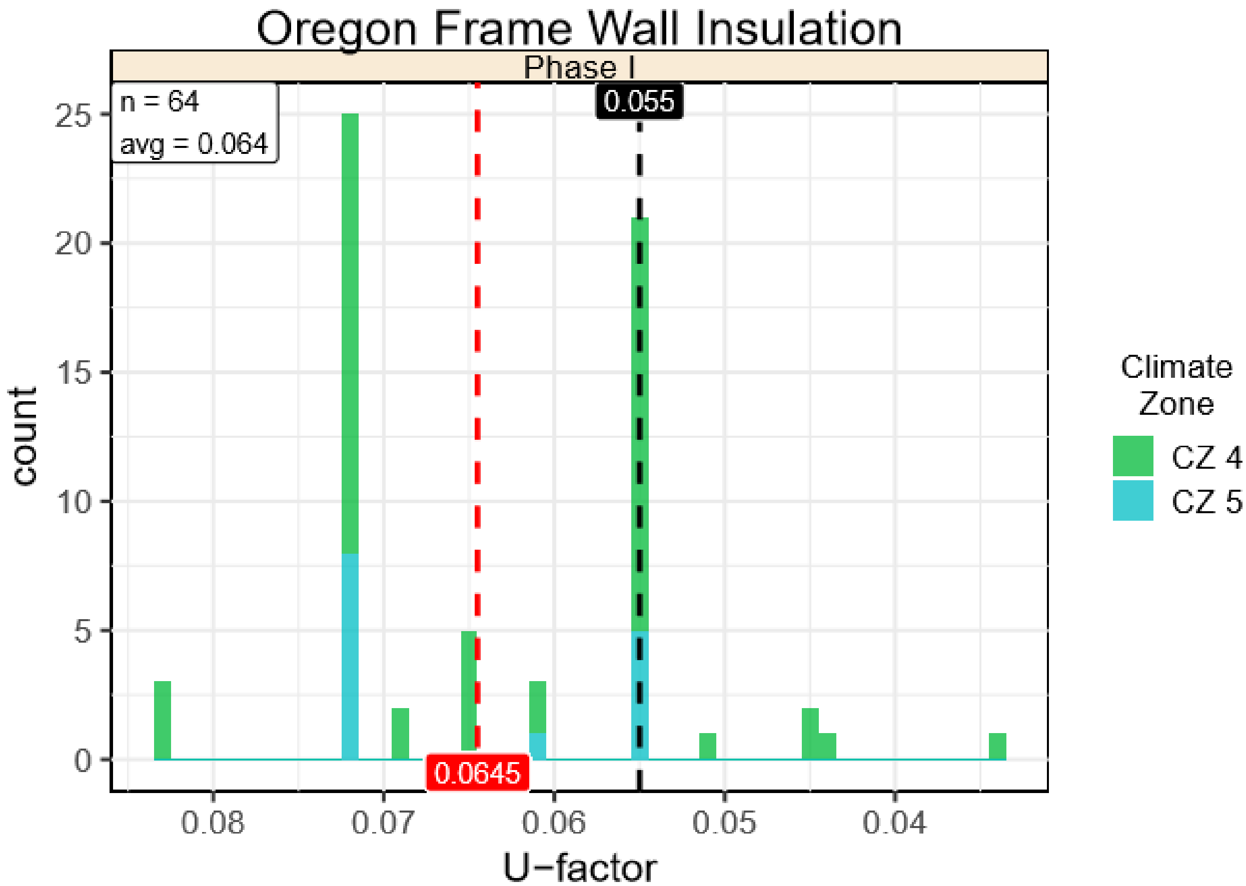

Figure 3.5. Wall U-Factors for Oregon

Table 3.6. Oregon Wall U-Factors

Climate Zone	CZ4	CZ5	Statewide
Number	50	14	64
Range	0.034 to 0.081	0.055 to 0.071	0.034 to 0.081
Average	0.063	0.065	0.063
Base Assembly U-factor (expected)	0.0645	0.0645	0.0645
Option Assembly U-Factor (expected)	0.055	0.055	0.055
Base Compliance Rate	23 of 50 (46%)	6 of 14 (43%)	29 of 64 (45%)
Option Compliance Rate	21 of 50 (42%)	5 of 14 (36%)	26 of 64 (41%)

The frame wall R-value and U-factor shown as the prescriptive requirement in the tables and figures in this section represent the values required under envelope enhancement measure option 2. The actual prescriptive requirement in the 2017 ORSC for walls is R-21, but with the selection of envelope enhancement option 2 this value is raised to R-23.

- **Interpretations:**
  - Looking at the R-values, less than one-half of the observations met or exceeded the requirement for envelope enhancement measure option 2. When evaluated against R-21 instead of R-23, all observations would meet or exceed the code requirement.
  - Looking at the U-factors, only 41% of the observations met or exceeded the requirement for envelope enhancement measure option 2. In 53% of observations, IIQ was rated as Grade II or Grade III, indicating that IIQ is an issue that should be addressed. Even when compared to the 2017 ORSC requirement of 0.0645, U-factor compliance only improves slightly, indicating that IIQ is really the biggest issue.

3.1.1.5 Ceilings

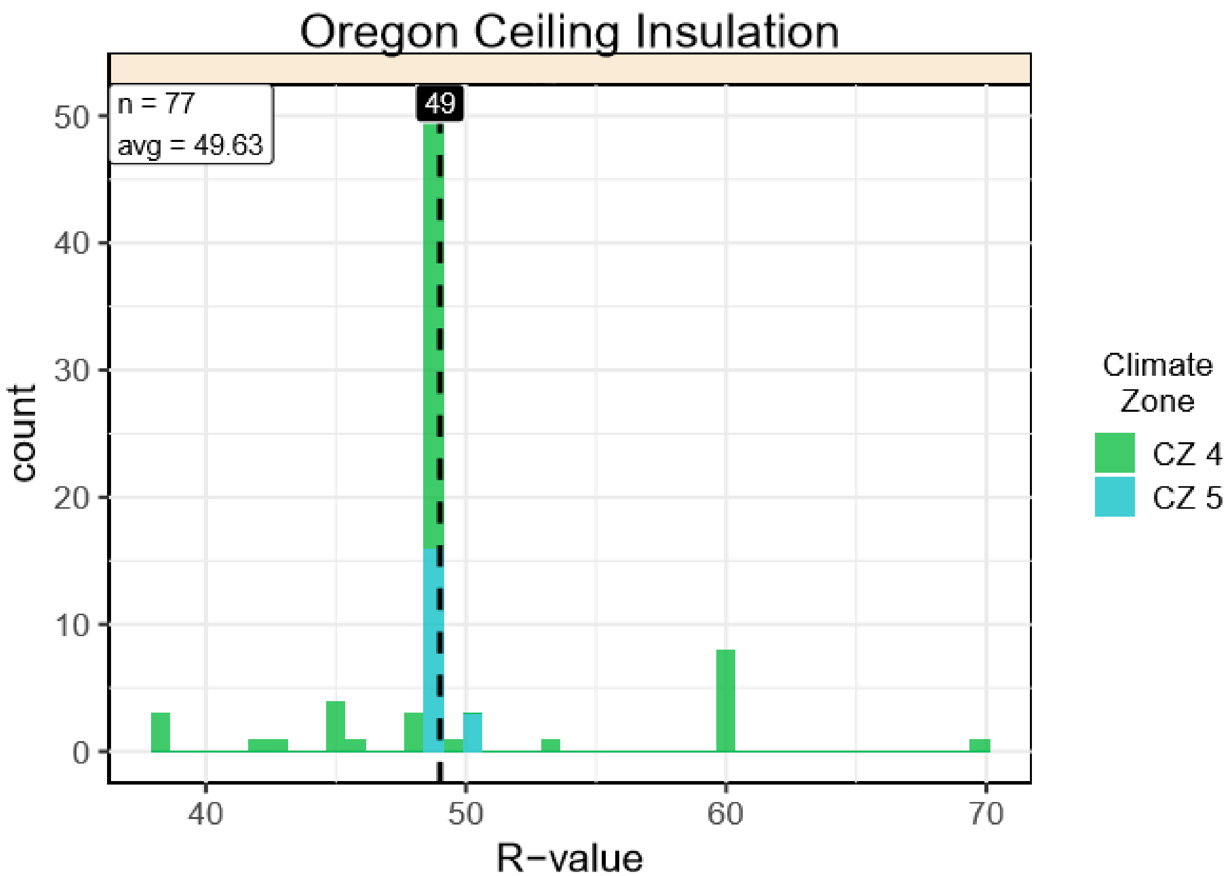

Figure 3.6. Ceiling R-Value

Table 3.7. Ceiling R-Value

Climate Zone	CZ4	CZ5	Statewide
Number	58	19	77
Range	R-38 to R-70	R-49 to R-50	R-38 to R-70
Average	R-49.8	R-49.2	R-49.6
Requirement	R-49	R-49	R-49

Compliance Rate	45 of 58 (78%)	19 of 19 (100%)	64 of 77 (83%)

Table 3.8 shows the number and percentage of IIQ observations by grade for roof cavity insulation.

Table 3.8. Roof IIQ for Oregon

Roof Cavity	Grade I	Grade II	Grade III	Total Observations
Observations	65	11	1	**77**
Percentages	84%	14%	2%	**100%**

Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Table 3.9.

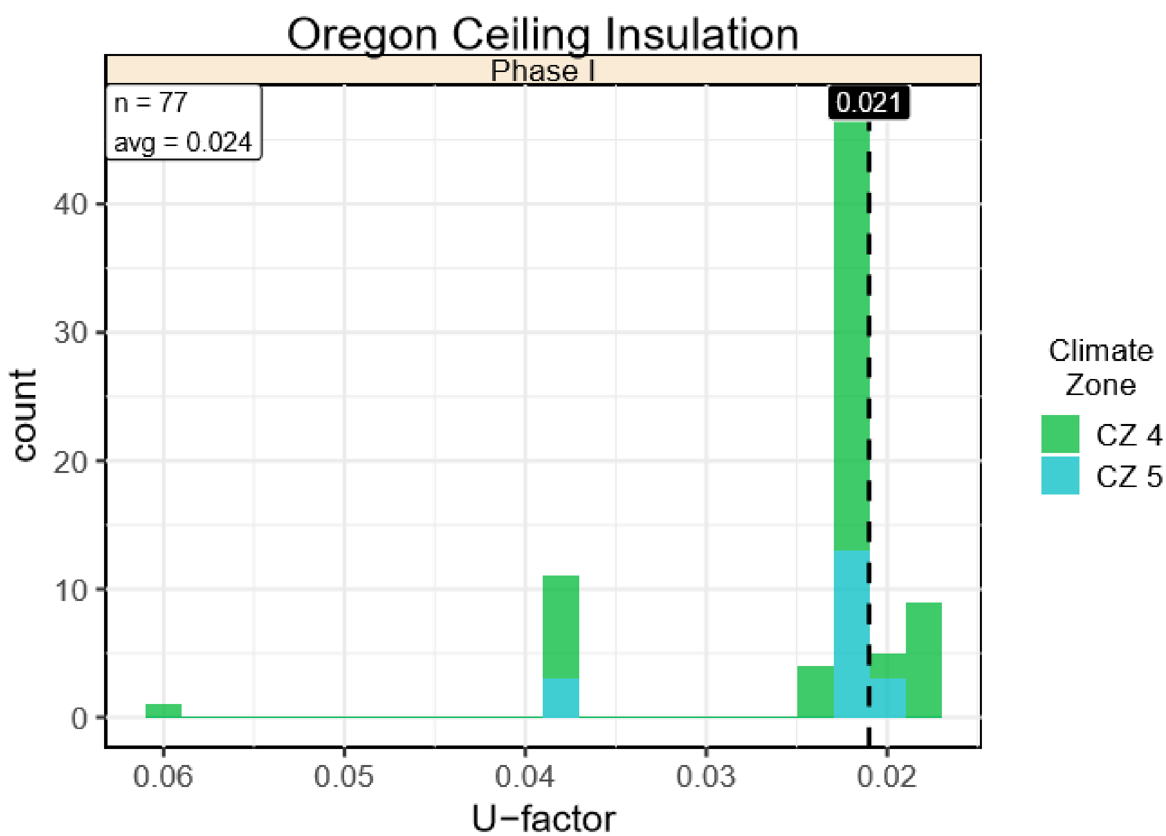

Figure 3.7. Ceiling U-Factor

Table 3.9. Ceiling U-Factors for Oregon

Climate Zone	CZ4	CZ5	Statewide
Number	58	19	77

Range	0.018 to 0.061	0.021 to 0.037	0.018 to 0.061
Average	0.0239	0.0235	0.0238
Assembly U-Factor (expected)	0.021	0.021	0.021
Rate	38 of 58 (66%)	16 of 19 (84%)	54 of 77 (70%)

- **Interpretations:**
  - Most (83%) ceiling R-value observations met or exceeded the code requirement.
  - A lower fraction (70%) of ceilings met the U-factor requirement indicating that IIQ is an issue. Most (84%) of the roof cavity IIQ observations were Grade I, but the 16% that were Grade II or Grade III influence the U-factor results.

3.1.1.6 High-Efficacy Lighting

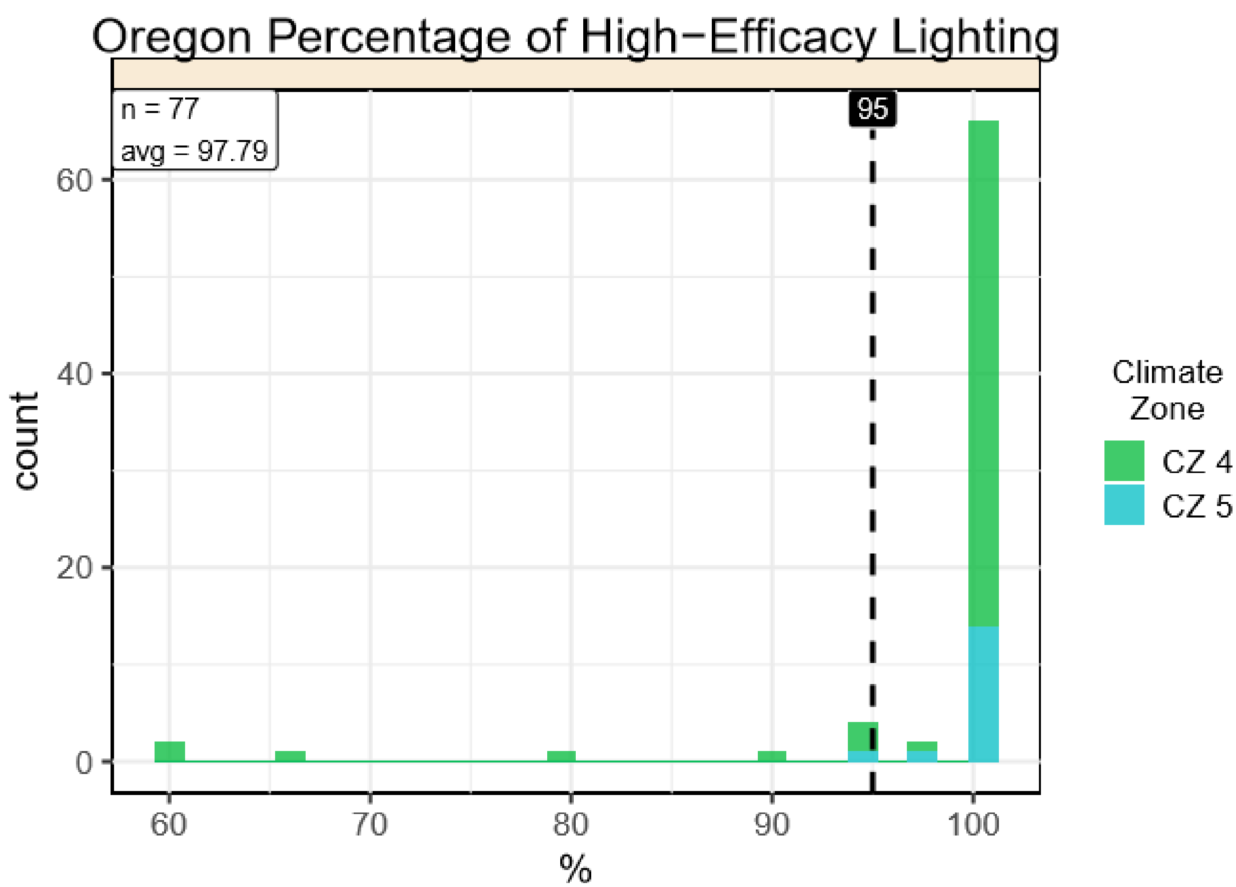

Figure 3.8. High-efficacy Lighting Percentages for Oregon

Table 3.10. Oregon High-efficacy Lighting Percentages

Climate Zone	CZ4	CZ5	Statewide
Number	61	16	77
Range	60 to 100	95 to 100	60 to 100
Average	97.3	99.5	97.8

Requirement	95	95	95
Compliance Rate	55 of 61 (90%)	16 of 16 (100%)	71 of 77 (92%)

- **Interpretations:**
  - Nearly all (92%) of the field observations met the code requirement.

3.1.1.7 Foundation Assemblies

There were three predominant foundation types observed in Oregon: heated basements, floors over unconditioned space, and slabs. Two graphs are shown for foundations, insulation (R-value), and binned assembly (U-factor). The R-value graphs show the insulation R-values observed. The binned U-factor graphs indicate the U-factor of the assembly, including cavity and continuous insulation layers and framing, and considering IIQ, as observed in the field. The U-factors are binned to reduce the number of bars in the chart as individual U-factor observations may be only slightly different. For slabs, only an R-value graph is shown.

While initially combined into a single key item (i.e., foundation assemblies), the variety of observed foundation types are disaggregated in this section, as described above. This approach helps to portray the combinations of cavity and continuous insulation employed across each foundation type, which is anticipated to be of value for energy code training programs. From a savings perspective, results are calculated for both the aggregated perspective and for individual foundation types (presented later in Section 3.3); however, only the aggregated observations should be considered statistically representative at the statewide level.

Basement Walls

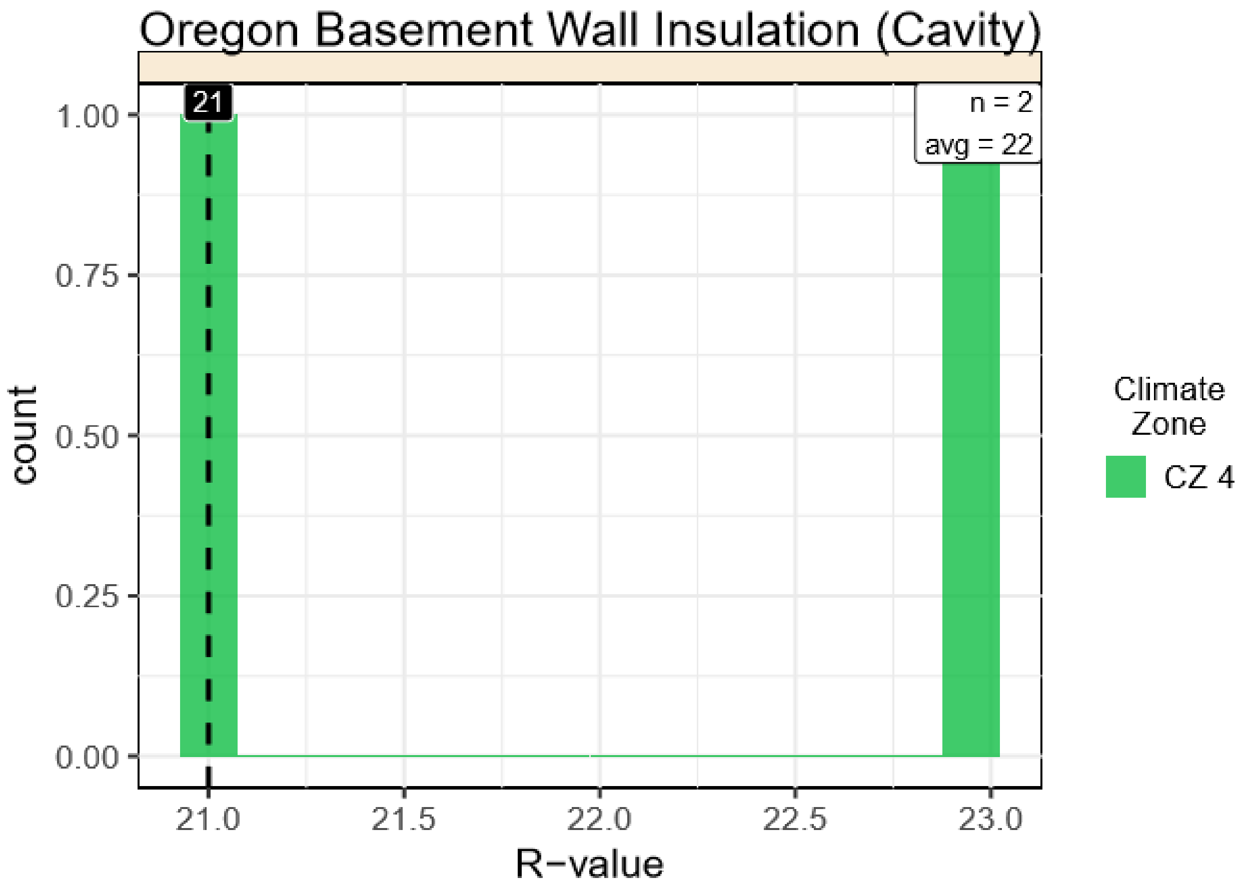

Figure 3.9. Basement Wall Cavity R-Values for Oregon

Table 3.11. Oregon Basement Wall Cavity R-Values

Climate Zone	CZ4	CZ5	Statewide
Number	2	0	2
Range	R-21 to R-23	NA	R-21 to R-23
Average	R-22	NA	R-22
Assembly U-Factor (expected)	R-21	R-21	R-21
Rate	2 of 2 (100%)	NA	2 of 2 (100%)

Table 3.12 shows the number and percentage of IIQ observations by grade for basement wall insulation. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Table 3.13.

Table 3.12. Basement Wall IIQs for Oregon

Assembly	Grade I	Grade II	Grade III	Total Observations
Basement Wall Observations	1	1	0	**2**

Basement Wall Percentages	50%	50%	0%	**100%**

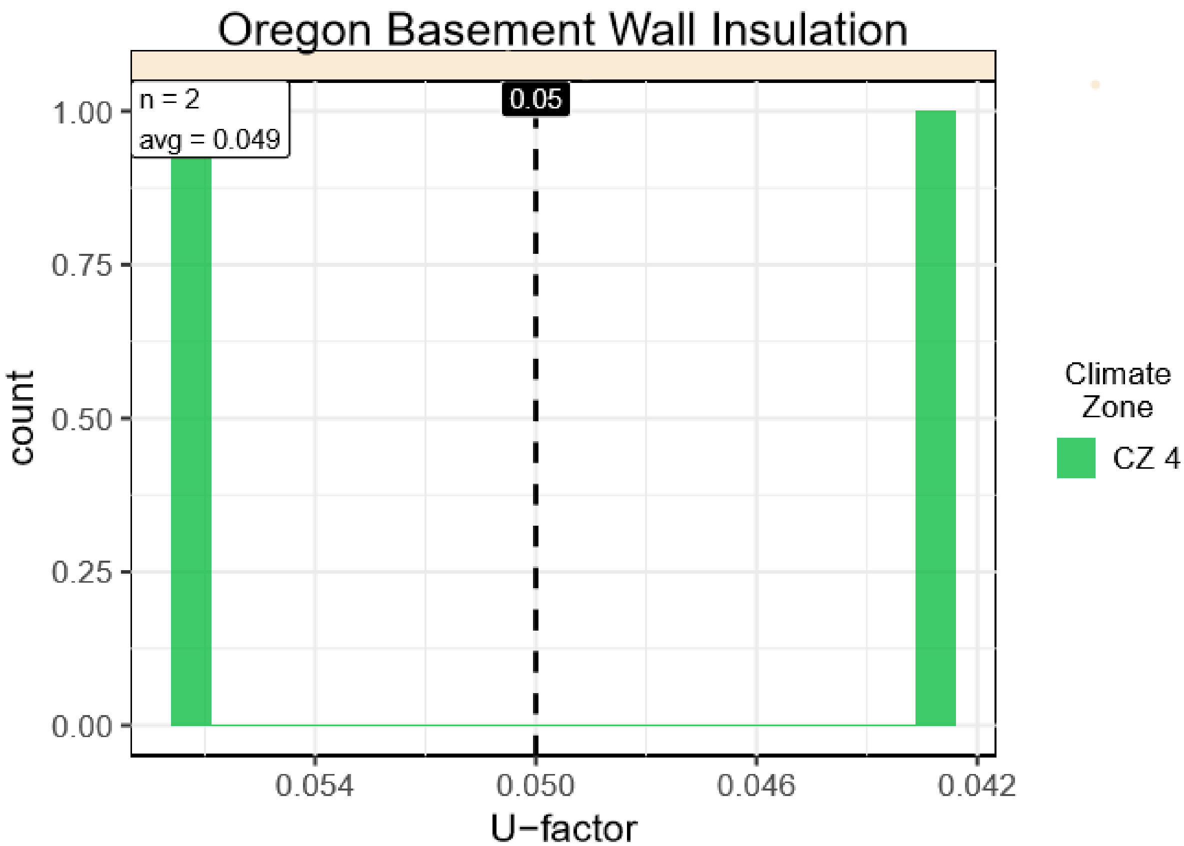

Figure 3.10. Basement Wall U-Factors for Oregon

Table 3.13. Oregon Basement Walls U-Factor

Climate Zone	CZ5	CZ5	Statewide
Number	2	0	2
Range	0.043 to 0.056	NA	0.043 to 0.056
Average	0.049	NA	0.049
Assembly U-Factor (expected)	0.05	0.05	0.05
Rate	1 of 2 (50%)	NA	1 of 2 (50%)

- **Interpretations:**
  - The sample size is too small to draw overall conclusions regarding basement wall insulation in the state, but the graphs show that both observations passed at the R-value level, but only one passed at the U-factor level. This is the result of lower IIQ for the R-value observation that just passed.

Floors

In Figure 3.11, the black dashed line represents the requirement the observations were evaluated against. Typically, this would be the prescriptive code requirement, but in this case the black line is the envelope enhancement measure option 2 requirement, and the red dashed line represents the prescriptive requirement.

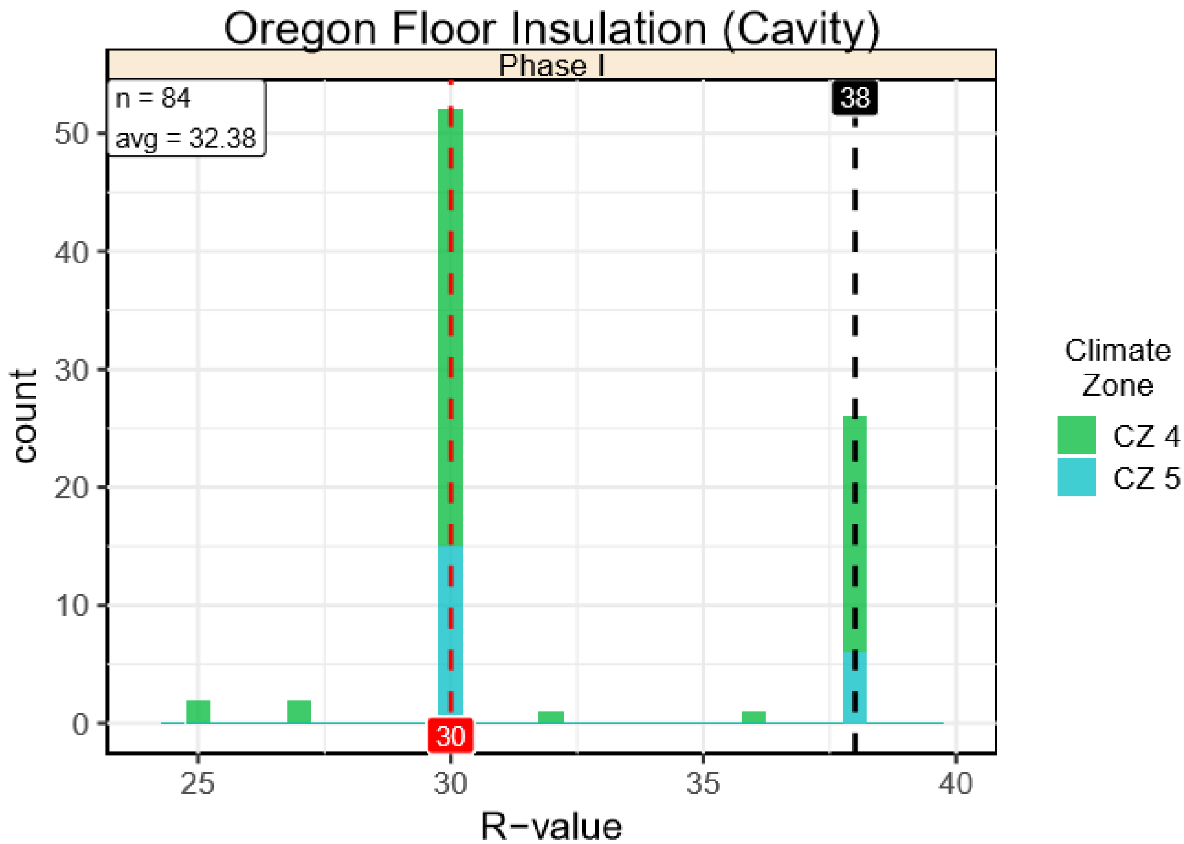

Figure 3.11. Floor R-Values for Oregon

Table 3.14. Oregon Floor R-Values

Climate Zone	CZ4	CZ5	Statewide
Number	63	21	84
Range	R-25 to R-38	R-30 to R-38	R-25 to R-38
Average	R-32	R-32	R-32
Base Assembly U-Factor (expected	R-30	R-30	R-30
Option Assembly U-Factor (expected)	R-38	R-38	R-38
Base Compliance Rate	59 of 63 (94%)	21 of 21 (100%)	80 of 84 (95%)
Option Compliance Rate	20 of 63 (32%)	6 of 21 (29%)	26 of 84 (31%)

The floor R-value and U-factor shown as the prescriptive requirement in the tables and figures in this section represent the values required under envelope enhancement measure option 2. The actual prescriptive requirement in the 2017 ORSC for floors is R-30, but with the selection of envelope enhancement measure option 2 this value is raised to R-38.

Table 3.15 shows the number and percentage of IIQ observations by grade for floor insulation. Given the importance of IIQ, in addition to reviewing the observations for cavity insulation, U-factors were calculated and reviewed including the effects of IIQ as shown in Table 3.16.

Table 3.15. Floor IIQs for Oregon

Assembly	Grade I	Grade II	Grade III	Total Observations
Floor Observations	33	49	2	**84**
Floor Percentages	40%	58%	2%	**100%**

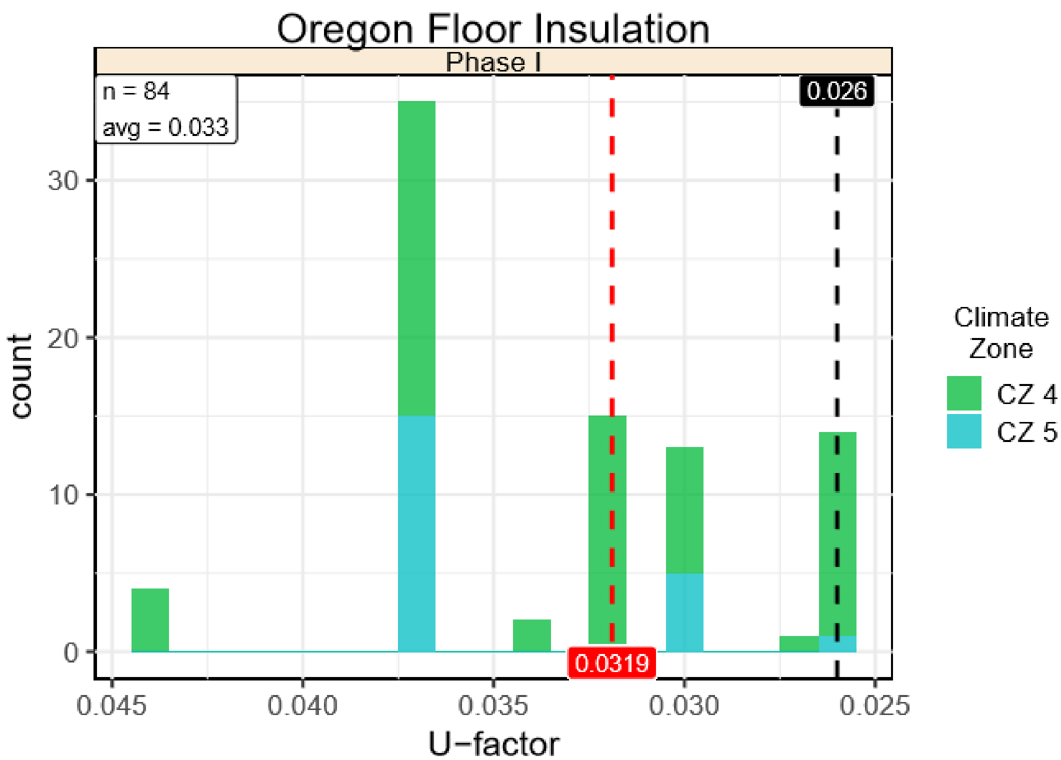

Figure 3.12. Floor U-Factors for Oregon

Table 3.16. Oregon Floor U-Factors

Climate Zone	CZ5	CZ5	Statewide
Number	63	21	84
Range	0.026 to 0.044	0.026 to 0.037	0.026 to 0.044
Average	0.033	0.035	0.033
Base Assembly U-Factor (expected)	0.0319	0.0319	0.0319

Option Assembly U-Factor (expected)	0.026	0.026	0.026
Base Compliance Rate	37 of 63 (59%)	6 of 21 (29%)	43 of 84 (51%)
Option Compliance Rate	13 of 63 (21%)	1 of 21 (5%)	14 of 84 (17%)

- **Interpretations:**
  - Based on Figure 3.11 and Figure 3.12 and Table 3.16, overall compliance for floors is only 31% at the R-value level and 17% at the U-factor level. The decrease from R-value to U-factor compliance levels can be attributed to low IIQ, with 60% of the observations of IIQ being Grade II or Grade III. However, the low R-value compliance rates are related to the assumption of envelope enhancement measure option 2, which requires R-38 instead of R-30 in floors. When compared to the prescriptive requirement of R-30, R-value compliance increases to 95% and U-factor compliance increases to 51%. The decrease from R-value to U-factor compliance indicates that IIQ for floors is an issue.

Slabs

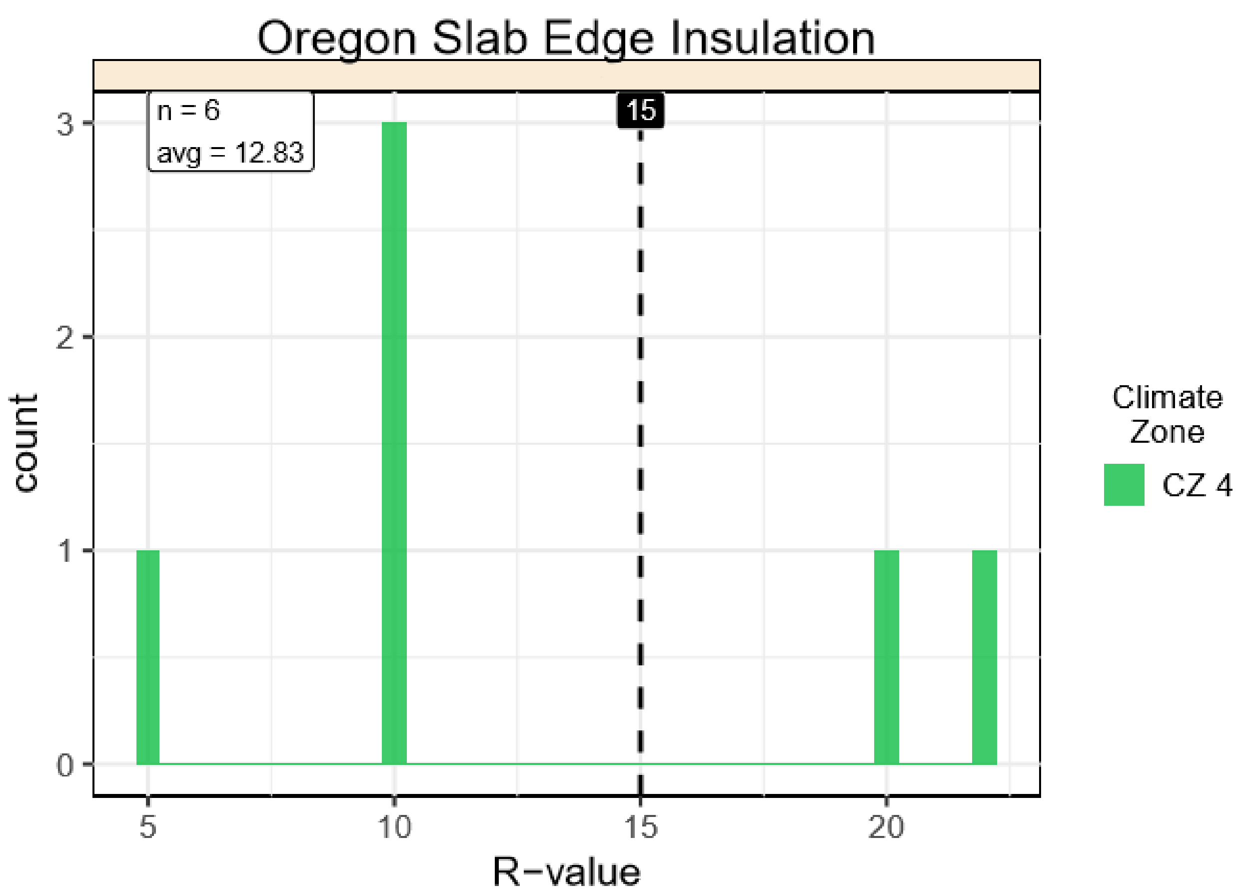

Figure 3.13. Slabs for Oregon

Table 3.17. Oregon Slabs

Climate Zone	CZ4	CZ5	Statewide
Number	6	0	6
Range	R-5 to R-22	NA	R-5 to R-22
Average	13	NA	13
Requirement	15	15	15
Rate	2 of 6 (33%)	NA	2 of 6 (33%)

- **Interpretations:**
  - One-third of the slab edge insulation observations met the code requirement.

3.1.1.8 Duct Tightness

For ducts, this report presents both unadjusted (raw) duct leakage and adjusted duct leakage. Unadjusted duct leakage is simply the values of duct leakage observed in the field. Adjusted duct leakage looks at the location of the ducts and adjusts the leakage values for any ducts which are entirely in conditioned space by setting the leakage of those ducts to zero (0). The adjustment reflects the fact that duct leakage tests are not required if the ducts are entirely in conditioned space. Duct leakage testing is not required in the 2017 ORSC in the energy efficiency chapter. Instead, ducts are required to be sealed in the Duct Systems chapter. No testing is mandated. The quantitative value of 6 cfm per 100 ft^2 cfa at 25 Pascals shown in the table and figure above is based on previous NEEA field studies as discussed in Section 2.3.

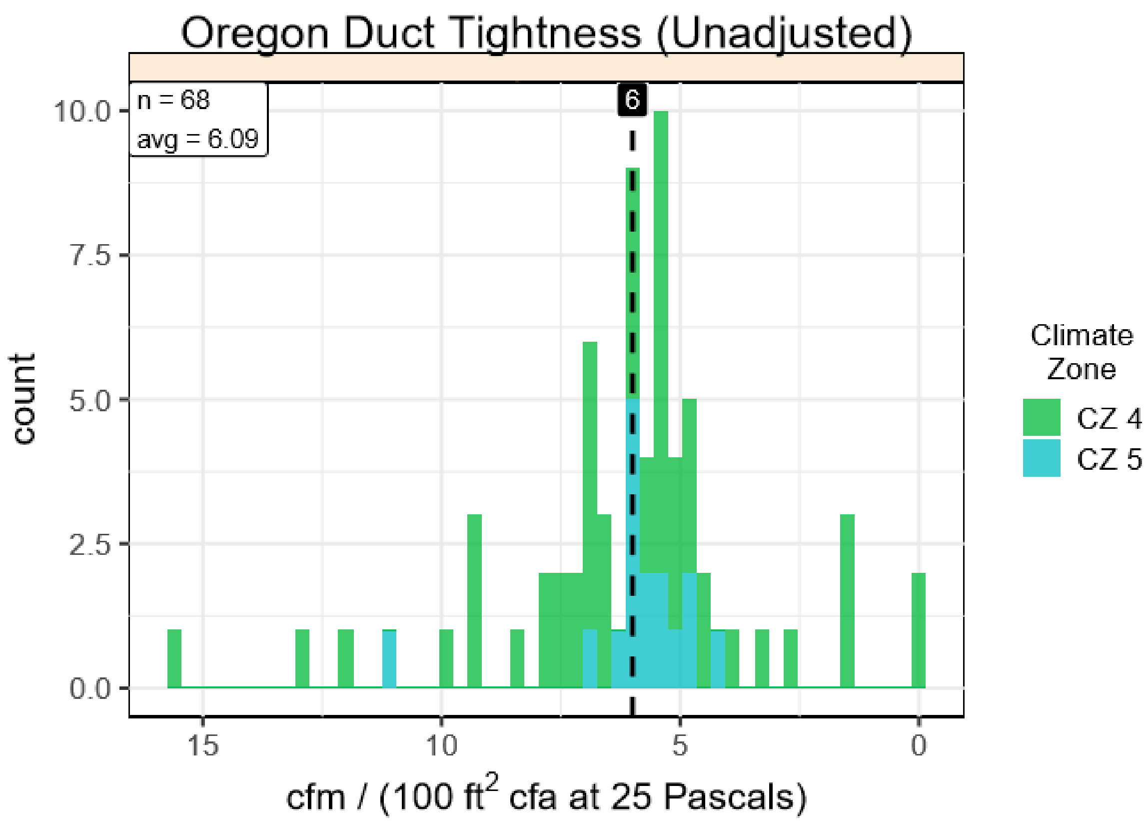

Figure 3.14. Duct Tightness Values for Oregon

Table 3.18. Oregon Duct Tightness Values (unadjusted)

Climate Zone	CZ4	CZ5	Statewide
Number	52	16	68
Range	0.05 to 15.6	4.3 to 11.0	8.8 to 45.0
Average	6.1	6.0	6.1
Requirement	6	6	6
Compliance Rate	27 of 52 (52%)	10 of 16 (63%	37 of 68 (54%)

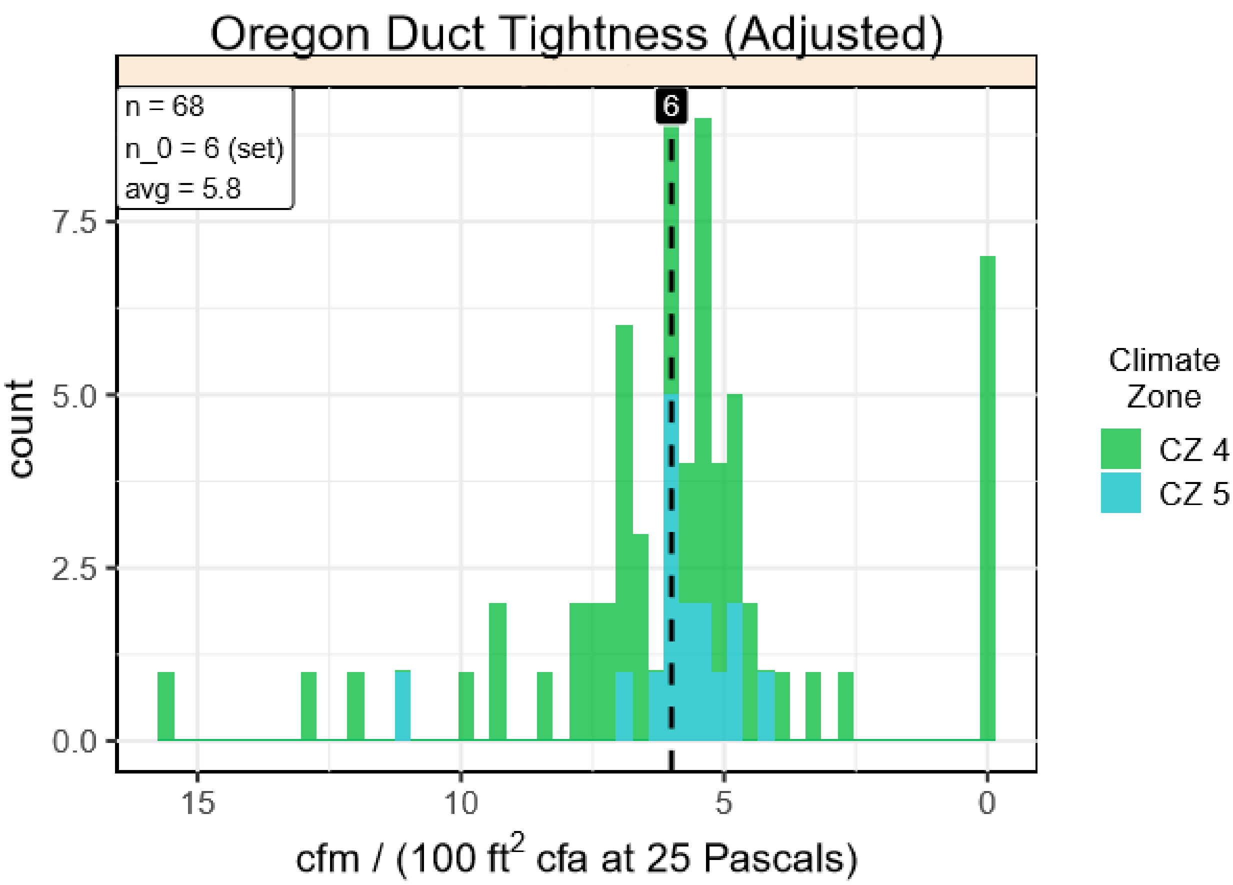

Figure 3.15. Adjusted Duct Tightness Values for Oregon

Table 3.19. Oregon Adjusted Duct Tightness

Climate Zone	CZ4	CZ5	Statewide
Number	52	16	68
Range	0.0 to 15.6	4.3 to 11.0	0.0 to 15.6
Average	5.7	6.0	5.8
Requirement	6	6	6
Compliance Rate	28 of 52 (54%)	10 of 16 (63%)	38 of 68 (56%)

- **Interpretations:**
  - The two duct systems that appear to have a “zero” unadjusted duct leakage are instead actually very low, non-zero values. One of those values is set to zero in the adjusted duct leakage plot and 5 additional duct leakage values are set to zero based on 100% of the ducts being in conditioned space.
  - Just over half (54%) of the raw observations do not meet the requirement for duct leakage.
  - Just over half (56%) of the adjusted observations meet the requirement for duct leakage, indicating that many homes do not have ducts installed entirely in conditioned space.
  - Reductions in duct leakage represent a significant area for improvement and should be given increased attention in future training and enforcement.

3.1.2 Additional Data Items

The project team collected data on all code requirements within the state as well as other areas to inform the energy simulation and analysis for the project (e.g., home size, installed equipment systems, etc.). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some insight surrounding the energy code and residential construction within the state.

The following sections summarize this data and outline some of the more significant findings, in many cases including the observation or compliance rate associated with the specified item. A larger selection of the additional data items collected as part of the state field study is contained in Appendix B.

3.1.2.1 Average Home

- Size: 2,012 ft^2 and 1.6 stories

3.1.2.2 Compliance

- All 161 of visited homes (100%) were permitted under the 2017 ORSC.
- 41 homes were noted as participating in an above-code program, with Energy Trust of Oregon’s Energy Performance Scoring (EPS), Earth Advantage, both EPS and Earth Advantage, and LEED representing 38 of those homes.

3.1.2.3 Envelope

- **Profile:**
  - Foundations: Mix of crawlspaces (87%), basements (1%), and slab on grade (12%) (n=160)
- **Successes (percentage of observations that complied):**
  - Insulation labeled (98%) (n=94)
  - IC-rated light fixtures sealed (100%) (n=48)
- **Areas for Improvement:**
  - Attic access openings complied (73%) (n=44)
  - Rim joists sealed (31%) (n=13)

- Knee walls sealed (31%) (n=13)
- Envelope areas behind bathroom tubs & showers sealed (72%) (n=31)
- Dropped ceilings sealed (29%) (n=7)

3.1.2.4 Duct & Piping Systems

- **Profile:**
  - Ducts were generally not located within conditioned space (percentage of duct system):
    - Supply: 21% (n=119)
    - Return: 15% (n=117)
  - 8% of duct systems located *supply* ducts entirely within conditioned space (119 homes with 10 duct systems entirely within conditioned space)
  - 8% of duct systems located *return* ducts entirely within conditioned space (117 homes with 9 duct systems entirely within conditioned space)
  - 8% of duct systems had the *entire* system within conditioned space (n=117)
  - Pipe Insulation (R-value): 3 (n=25)
- **Successes:**
  - Air handlers sealed (84%) (n=83)
  - Filter boxes sealed (91%) (n=69)
- **Areas for Improvement:**
  - Air ducts sealed (45%) (n=66)

3.1.2.5 HVAC Equipment

- **Profile:**
  - Heating: Mostly gas furnaces with an average efficiency of 95 AFUE
  - Cooling: Mostly central AC with an average efficiency of 14 SEER (all cooling)
  - Water Heating: Mix of gas (70%) and electric (30%) storage (75%) with an average capacity of 50 gallons and average efficiency rating of EF 1.35
- **Successes:**
  - User manuals for mechanical systems provided (79%) (n=56)

3.1.2.6 Additional Efficiency Options

The 2017 ORSC requires selection of two additional measures for prescriptive compliance - an envelope enhancement measure and a conservation measure. There are 6 envelope enhancement measures and 4 conservation measures as listed below. Questions were added to the 2018 IECC compliance forms to track selection of these measures and the Oregon field team collected this information for 34 homes. The Field Team identified that the Additional Efficiency Options compliance information was difficult to obtain on site. These were the acceptable methods for obtaining the Oregon Code Additional Measures (AM) choices:

- If the plan set was available for the home being observed and the stated AM choices were marked on the plan set.
- If the builder representative was aware of the AM choices and the Field Auditor thought the answer was credible. It was observed that many builders had no idea what the choices were, and some would answer with uninformed responses such as “Energy Star appliances”— that answer would have been marked as “Unobservable.” If a builder representative answered with the AM choices such as “5-D” then that was recorded as a legitimate data value.

Table 3.20 shows the responses to the question about combinations of envelope enhancement and options and conservation measures. While the response rate was small (responses are available for 34 of 162 homes visited), it shows several trends that influenced the selection of the options used in this analysis. First, by far the most common conservation option was a high-efficiency HVAC system. PNNL and NEEA attribute this to the desire on the part of builders for a “plug-and-play” option that allows use of existing building designs and construction methods and simply requires the procurement of a more efficient HVAC unit.

For Envelope Enhancement measures, two options (Measure 2 and Measure 5) were clearly the most common selections by builders, with Measure 6 close behind. Given that Measure 6 was the least common of the three top-ranking Measures and given that its use would have required additional assumptions on “how” the builder chose to reduce the UA of the home, this Measure was rejected. Comparing Measure 2 and Measure 5, Measure 2 was chosen because it impacted requirements that are explicit in the ORSC. Measure 5, which requires air sealing of the home and ducts, would impact items that are not explicitly required in the ORSC, but which are analyzed in this document based on field data collected by NEEA.[3]

A combination of Envelope Enhancement Measure 2 (Upgraded features for exterior walls, framed floors, and windows) and Conservation Measure A (high efficiency HVAC system) was used in the development of the prescriptive baseline for this analysis.[4] This impacted the EUI analysis; measure level savings analysis for walls, floors, and windows; and the key analysis for walls, floors, and windows.

Table 3.20. Observations for Combinations of Envelope Enhancement and Conservation Measures

Conservation Measure Options to the Right, Envelope Enhancement Measures Below	Option A - High Eff HVAC System	Option B - Ducted HVAC in Conditioned Space	Option C - Ductless Heat Pump	Option D - High Efficiency Water Heater	Total
Measure 1 - High Efficiency Walls	0	1	0	0	1
Measure 2 - Upgraded Features 1	9	1	1	0	11
Measure 3 - Upgraded Features 2	2	0	0	0	2
Measure 4 - Super Insulated Windows and Attic or Framed Floors	0	0	0	0	0

[3] See discussion in Section 2.3 for details of the assumptions used for envelope air tightness and duct leakage.
[4] This combination was chosen based on the results shown in Table 3.20 below and as discussed with NEEA.

Measure 5 - Air Sealing Home and Ducts	10	0	0	1	11
Measure 6 - High Efficiency Thermal Envelope UA	7	0	0	0	7
Measure - Blank	0	0	0	2	2
Total	**28**	**2**	**1**	**3**	**34**

Note that while Envelope Enhancement Measure 2 was tied for the most common envelope measure with Measure 5, the combination of Measure 5 and Option A was the single most common combination. Envelope Enhancement Options 2 and 5 were tied for the most total observations, but Option 2 impacted three key items (wall insulation, floor insulation, and window U-factor), while Option 5 impacted only two key items (air tightness, duct leakage). In addition, the impacts of Option 5 were not judged to be as "quantifiable" as those of option 2. Also note that two of the 34 homes did not have an Envelope Enhancement Measure listed. These two homes are listed as "Measure-Blank".

3.2 Energy Intensity

The statewide energy analysis results are shown in Figure 3.16, which compares the weighted average energy consumption of the observed data set to the weighted average consumption based on the state energy code. The observed data set (as gathered in the field) was compared against the same set of homes meeting prescriptive code requirements (including envelope enhancement measure option 2 for above grade walls, floors, and window U-factor). In terms of overall energy consumption, the average home in Oregon appears to use *more* energy than would be expected relative to a home built to the current minimum state code requirements.

Analysis of the collected field data indicates an average regulated EUI (dashed line in Figure 3.16) of approximately 23.92 kBtu/ft^2-yr compared to 23.86 kBtu/ft^2-yr for homes exactly meeting minimum *prescriptive* energy code requirements (black line in Figure 3.16). This suggests the EUI for a "typical" home in the state is about 0.3% worse than code.

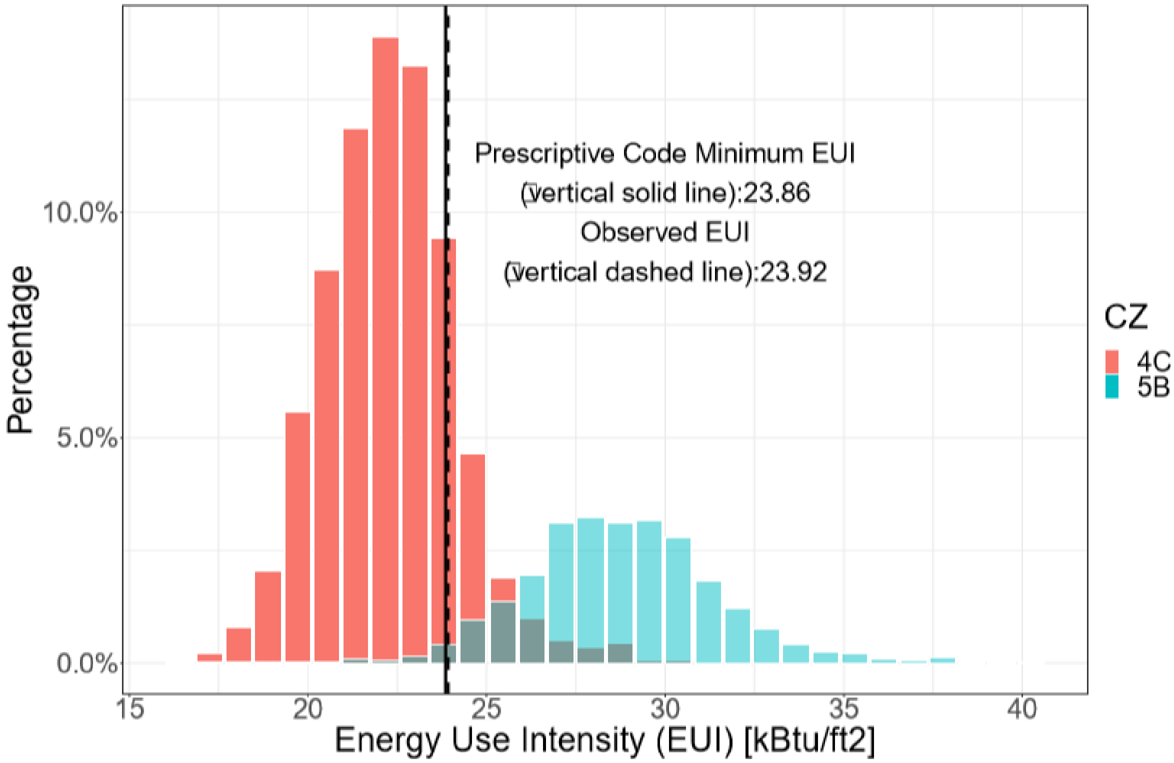

Figure 3.16. Statewide EUI Analysis for Oregon

3.3 Savings Potential

The key items with the greatest potential are defined here as those key items with any observations (or calculated U-factors which include consideration of IIQ in the case of opaque assemblies) not meeting the prescriptive code requirement. These key items are shown below, followed by the percentage that did not meet code. The key items were then analyzed to calculate the associated savings potential, including energy, cost, and carbon savings.

- Exterior Wall Insulation (59%)
- Ceiling Insulation (30%)
- Envelope Air Tightness (14%)
- Duct Leakage (44% of adjusted observations)
- Window U-factor (39%)
- Foundations
  - Floor Insulation (83%)
  - Basement Wall Insulation (50%), and
  - Slab Edge Insulation (67%)
- High-Efficacy Lighting (8%).

For analytical details, refer to Section 2.3.3 (Savings Analysis) or the DOE methodology document (DOE/PNNL 2018).

Estimated savings (total energy, total energy cost, and total state emissions reduction) resulting from the analysis are shown in Table 3.21 in the order of highest to lowest energy cost. There are significant savings opportunities, with the greatest total savings potential associated with exterior wall insulation, ceiling insulation, and envelope air tightness. In addition, Table 3.23 shows the total savings and emissions reductions that will accumulate over 5, 10, and 30 years of construction.

Table 3.21. Statewide Annual Measure-Level Savings for Oregon

Measure	**Climate Zone**	**Electricity Savings** (kWh/ home)	**Natural Gas Savings** (therms/ home)	**Total Savings** (kBtu/home)	**Number of Homes**	**Total Energy Savings** (MMBtu)	**Total Energy Cost Savings** ($)	**Total State Emissions Reduction** (MT CO2e)*
Exterior Wall Insulation	4C	98.75	15.51	1,888.19	8,243	15,564	223,850	4,404
	5B	146.24	22.58	2,756.79	2,798	7,713	111,349	2,213
	State Total	**110.79**	**17.30**	**2,108.29**	**11,041**	**23,278**	**335,199**	**6,617**
Ceiling Insulation	4C	29.89	3.96	497.75	8,243	4,103	61,277	1,329
	5B	44.16	5.88	738.89	2,798	2,067	30,835	666
	State Total	**33.50**	**4.45**	**558.85**	**11,041**	**6,170**	**92,112**	**1,995**
Envelope Air Tightness	4C	7.08	4.03	427.21	8,243	3,522	41,666	332
	5B	14.10	5.59	607.17	2,798	1,699	20,908	220
	State Total	**8.85**	**4.43**	**472.81**	**11,041**	**5,220**	**62,574**	**552**
Duct Leakage	4C	22.55	1.88	265.15	8,243	2,186	36,544	996
	5B	31.12	3.20	426.45	2,798	1,193	18,922	468
	State Total	**24.72**	**2.22**	**306.03**	**11,041**	**3,379**	**55,466**	**1,464**
Window U-Factor	4C	0.72	2.12	214.85	8,243	1,771	19,285	44
	5B	4.88	3.06	322.31	2,798	902	10,579	78
	State Total	**1.77**	**2.36**	**242.08**	**11,041**	**2,673**	**29,864**	**122**
Foundation Insulation**	4C	-15.24	5.56	504.18	Varies	2,042	14,216	-543
	5B	-6.84	7.28	704.18	Varies	946	8,563	-106
	State Total	**-13.11**	**6.00**	**554.86**	**Varies**	**2,989**	**22,779**	**-649**
High-Efficacy Lighting	4C	12.90	-0.17	26.95	8,243	222	9,955	563
	5B	12.67	-0.19	24.03	2,798	67	3,247	188
	State Total	**12.84**	**-0.18**	**26.21**	**11,041**	**289**	**13,202**	**751**
Total	**State Total**	**179.38**	**36.57**	**4269.13**	**Varies**	**43,998**	**611,195**	**10,852**

* Negative values mean that savings or reductions decrease if the measure is brought up to code.
**See Table 3.22 for annual measure-level savings results by foundation type.

Table 3.22. Statewide Annual Measure-Level Savings by Foundation Type for Oregon

Measure	**Climate Zone**	**Electricity Savings** (kWh/ home)	**Natural Gas Savings** (therms/ home)	**Total Savings** (kBtu/home)	**Number of Homes****	**Total Energy Savings** (MMBtu)	**Total Energy Cost Savings** ($)	**Total State Emissions Reduction** (MT CO2e)
Floors Over Unconditioned Space	4C	-14.07	3.04	256.42	7,526	1,930	12,995	-546
	5B	-8.53	3.78	349.06	2,555	892	7,941	-109
	State Total	**-12.67**	**3.23**	**279.90**	**10,081**	**2,822**	**20,936**	**-655**
Slab Insulation	4C	1.53	1.84	189.68	538	102	1,145	5
	5B	3.65	2.60	272.09	182	50	576	4
	State Total	**2.07**	**2.04**	**210.56**	**720**	**152**	**1,721**	**9**
Basement Wall Insulation*	4C	-2.69	0.67	58.08	179	10	76	-2
	5B	-1.95	0.90	83.03	61	5	45	-1
	State Total	**-2.51**	**0.73**	**64.40**	**240**	**15**	**122**	**-3**
Foundation Insulation Total	4C	-15.24	5.56	504.18	Varies	2,042	14,216	-543
	5B	-6.84	7.28	704.18	Varies	946	8,563	-106
	State Total	**-13.11**	**6.00**	**554.86**	**Varies**	**2,989**	**22,779**	**-649**

*For basement wall insulation and floors over unconditioned space, note that while total energy savings are positive, electricity savings are negative. This is the result of increased insulation leading to lower natural gas usage in the winter, but higher electricity usage in the summer. Note also that floor insulation total energy cost savings and emissions reductions are negative, even though total energy savings are positive. This is again related to lower gas usage in the winter, but higher electricity use in the summer.

** For foundation measures, the total number of homes is multiplied by the foundation share for each foundation type and is therefore smaller than the total number of homes shown for other measures.

Table 3.23. Five-years, Ten-years, and Thirty-years Cumulative Annual Statewide Savings for Oregon

	Total Energy Savings (MMBtu)			Total Energy Cost Savings ($)			Total State Emissions Reduction (MT CO2e)		
Measure	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**	**5yr**	**10yr**	**30yr**
Exterior Wall Insulation	349,168	1,280,282	10,824,205	$5,027,986	$18,435,947	$155,867,553	99,257	363,941	3,076,956
Ceiling Insulation	92,555	339,368	2,869,205	$1,381,680	$5,066,159	$42,832,074	29,927	109,732	927,737
Envelope Air Tightness	78,306	287,121	2,427,475	$938,604	$3,441,549	$29,096,732	8,281	30,362	256,698
Duct Leakage	50,683	185,838	1,571,179	$831,983	$3,050,605	$25,791,482	21,963	80,532	680,862
Window U-Factor	40,092	147,005	1,242,859	$447,960	$1,642,519	$13,886,753	1,828	6,703	56,672
Foundation Insulation*	44,830	164,378	1,389,743	$341,686	$1,252,847	$10,592,252	-9,733	-35,686	-301,709
High-Efficacy Lighting	4,340	15,915	134,550	$198,030	$726,109	$6,138,919	11,259	41,281	349,015
Total	**659,975**	**2,419,907**	**20,459,215**	**$9,167,928**	**$33,615,736**	**$284,205,766**	**162,782**	**596,866**	**5,046,230**

* For Foundation Insulation, note that total energy savings and energy cost savings are positive, while total state emission reduction is negative. This is a result of the loss of free cooling in the summer associated with uninsulated basement walls and floors.

4.0 Conclusions

The Oregon field study provides an enhanced understanding of statewide code implementation and suggests that potential savings are available through increased compliance. From a statewide perspective, the average home in Oregon uses about 0.3% more energy than a home exactly meeting the state energy code. Savings potential exists through increased compliance with targeted measures. Potential statewide annual energy savings are 44,000 MMBtu, which equates to $611,000 in cost savings, and emission reductions of over 10,800 MT CO2e. Over a 30-year period, these impacts grow to 20.5 million MMBtu, $284 million, and over five million metric tons CO2e in avoided emissions.

Several key measures directly contribute to these savings and should be targeted through future education, training and outreach activities. The savings associated with each are shown in Table 4.1.

Table 4.1. Annual Statewide Savings Potential in Oregon

	Annual Savings		
Key Measure	**Energy** (MMBtu)	**Cost** ($)	**Carbon** (MT CO2e)
Exterior Wall Insulation	23,278	335,199	6,617
Ceiling Insulation	6,170	92,112	1,995
Envelope Air Tightness	5,220	62,574	552
Duct Leakage	3,379	55,466	1,464
Window U-Factor	2,673	29,864	122
Foundation Insulation	2,989	22,779	-649
High-Efficacy Lighting	289	13,202	751
TOTAL	**43,998 MMBtu**	**$611,195**	**10,852 MT CO2e**

5.0 References

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Appendix A

State Sampling Plan

Appendix A

State Sampling Plan

Table A.1. State Sampling Plan

Place, County	Sample/Actual
Redmond, Deschutes	6
Bend, Deschutes	5
Deschutes County Unincorporated, Deschutes	1
Jefferson County Unincorporated, Jefferson	2
Clatsop County Unincorporated, Clatsop	1
Lincoln City, Lincoln	1
Medford, Jackson	3
Eagle Point, Jackson	1
Ashland, Jackson	1
Douglas County Unincorporated, Douglas	2
Grants Pass, Josephine	1
Hood River County Unincorporated, Hood River	1
Hermiston, Umatilla	1
Eugene, Lane	3
Springfield, Lane	3
Albany, Linn	2
Salem, Marion	3
Silverton, Marion	1
Newberg, Yamhill	1
Oregon City, Clackamas	2
Estacada, Clackamas	2
Clackamas County Unincorporated, Clackamas	2
Happy Valley, Clackamas	1
Portland, Multnomah	6
Washington County Unincorporated, Washington	7
Tigard, Washington	1
Hillsboro, Washington	1
Beaverton, Washington	1
Sherwood, Washington	1
	63

A.1 Substitutions

No substitutions to the sample plan were required.

Appendix B

Additional Data

Appendix B

Additional Data Collected by the Field Team

The project team made observations on several energy efficiency measures beyond the key items alone. The majority of these additional items are based on code requirements within the state, while others were collected to inform the energy simulation and analysis for the project (e.g., installed equipment, whether the home participated in an above-code program, etc.). While these items were not the focal point of the study, and many are not considered statistically representative, they do provide some additional insight surrounding the energy code and residential construction within the state.

The following is a sampling of the additional data items collected as part of the Oregon field study. Each item is presented, along with a brief description and statistical summary based on the associated field observations. The full data set is available on DOE's website.[1]

B.1 General

The following represents the general characteristics of the homes observed in the study:

B.1.1 Average Home

- Size (n=152): 2012 ft^2
- Number of Stories (n=161): 1.6

Table B.1. Conditioned Floor Area (ft^2)

Conditioned Floor Area (ft^2)	< 1000	1000 to 1999	2000 to 2999	3000 to 3999	4000+
Percentage	4%	53%	36%	7%	1%

Table B.2. Number of Stories

No. of Stories	1	2	3	4+
Percentage	40%	54%	6%	0%

B.1.2 Wall Profile

- Framing Type (n=159):
  - *Almost all* were framed construction (99%)
- Framing Material (n=157):
  - Wood (100%)
  - Steel (0%)

[1] Available at https://www.energycodes.gov/compliance/residential-energy-code-field-study

B.1.3 Foundation Profile

- Foundation Type (n=160):
  - Heated Basement (1%)
  - Slab on Grade (12%)
  - Vented Crawlspace (87%)

B.2 Compliance

The following summarizes information related to compliance, including the energy code associated with individual homes, whether the home was participating in an above-code program, and which particular programs were reported. The percentages provided in the sections below represent percentages of total observations or the percentage of observations that complied.

B.2.1 Energy Code Used (n=161):

Table B.3. Energy Code Used

2017 ORSC	161
Percentage	100%

- Was the home participating in an above-code program (n=142)?
  - Yes (29%)
  - No (71%)

Table B.4. Above Code Program Used

Program	Count	Percentage
Energy Performance Scoring (EPS)	24	59%
Earth Advantage + EPS	7	17%
Earth Advantage	5	12%
Earth Advantage Net Zero	1	2%
LEED	1	2%
“No” or “?”	3	7%

B.2.2 Envelope

The following list of questions focus on average characteristics of the thermal envelope:

B.2.2.1 Insulation Labels

- Was insulation labeled (n=94)?

- Yes (98%)
- No (2%)

B.2.2.2 Ceilings

- Did the attic hatch/door exhibit the correct insulation value (n=38)?
  - Yes (53%)
  - No (47%)

B.2.2.3 Air Sealing[1]

- Thermal envelope sealed (n=40) (78%)
- Openings around windows and doors sealed (n=50) (98%)
- Utility penetrations sealed (n=67) (64%)
- Dropped ceilings sealed (n=7) (29%)
- Knee walls sealed (n=13) (31%)
- Garage walls and ceilings sealed (n=31) (100%)
- Envelope behind tubs and showers sealed (n=32) (72%)
- Common walls sealed (n=3) (100%)
- Attic access openings sealed (n=44) (7 %)
- Rim joists sealed (n=13) (31%)
- Other sources of infiltration sealed (n=30) (70%)
- IC-rated light fixtures sealed (n=48) (100%)

B.2.3 Duct & Piping Systems

The following represents an average profile of observed air ducting and water piping systems, followed by a list of additional questions related to such systems:

B.2.3.1 System Profile

- Duct Location in Conditioned Space (percentage):
  - *Supply* (n=119): 21% (10 homes with systems located entirely within conditioned space)
  - *Return* (n=117): 15% (9 homes with systems located entirely within conditioned space)
- Duct Insulation (R-value):
  - *Supply* (n=153): 8
  - *Return* (n=149): 8

[1] Note that results in this section are from checklist items that are addressed via visual inspection. When comparing these visual results with the actual tested results, it is clear that there can be significant differences in the two methods.

- Air ducts sealed (n=66) (45%)
- Air handlers sealed (n=83) (84%)
- Filter boxes sealed (n=69) (91%)

B.2.4 HVAC Equipment

B.2.4.1 Heating

- Fuel Source (n=124):
  - Gas (81%)
  - Electricity (19%)
- System Type (n=121):
  - Furnace (83%)
  - Heat Pump (14%)
  - Electric Strip Heat (2%)
- System Capacity (n=69):
  - Furnace: 58,200 Btu
  - Heat Pump: 30,000 Btu
- System Efficiency (n=97):
  - Furnace: 95 AFUE
  - Heat Pump: 10.3 HSPF

B.2.4.2 Cooling

- System Type (n=45):
  - Central AC (80%)
  - Heat Pump (20%)
- System Capacity (n=37):
  - 32,900 (Btu/hr)
- System Efficiency (n=30):
  - 14 SEER (observations ranged from 13 to 18 SEER)

B.2.4.3 Water Heating

- Fuel Source (n=108):
  - Gas (70%)
  - Electric Resistance (16%)
  - Electric Heat Pump (14%)

- System Type (n=101):
  - Storage (75%)
  - Tankless (25%)
- System Capacity (n=52):
  - 52 gallons (observations ranged from 40 to 100 gallons)

Table B.5. Water Heating System Storage Capacity Distribution

Capacity	< 50 gal	50-59 gal	60-69 gal	70-79 gal	80-89 gal	90+ gal
Percentage	10%	73%	15%	0%	0%	2%

- System Efficiency (n= xx):
  - EF 1.35 (range from EF 0.56 to EF 3.70)

B.2.4.4 Ventilation

- System Type (n=89):
  - Exhaust Only (51%)
  - Standalone ERV/HRV (7%)
  - AHU Integrated (42%)
- Exhaust Fan Type (n=35):
  - Dedicated Exhaust (8%)
  - Bathroom Fan (92%)

B.2.4.5 Other

- Mechanical manuals provided (n=56) (79%)

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