April 9, 2014

REPORT #E14-276

Oregon Residential Energy Code Compliance

Prepared by:
Cadmus Group
720 SW Washington St. Suite 400
Portland, OR, 97205

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
FAX
503-688-5447
EMAIL
info@neea.org

Prepared by:
Allen Lee
Eli Caudill
Shannon Donohue
Mihir Desu

Cadmus

This page left blank.

Table of Contents

Table of Figures

Table of Tables

Executive Summary

Background

The Northwest Energy Efficiency Alliance (NEEA) contracted with Cadmus to conduct a study of residential energy code compliance in Oregon. This effort to measure compliance has its roots in the 2009 American Recovery and Reinvestment Act (ARRA); funding to states was contingent upon a commitment to adopt the latest model energy codes, as of 2009, and to develop a plan—including active training and enforcement provisions—to achieve ninety percent compliance with target codes by 2017. This commitment included measuring current compliance each year.

This report describes the study of Oregon compliance with the revised state energy residential code: Chapter 11 of the 2011 Oregon Residential Specialty Code (ORSC). Builders can choose from three approaches to demonstrate compliance: prescriptive, component performance, and alternative systems. The prescriptive approach sets minimum requirements for each building component. The component performance approach allows a builder to trade off efficiencies of different components, as long as the overall component thermal performance (UA) is at least fifteen percent better than a building fully complying with all prescriptive requirements listed in ORSC Table N1104.1(1). The alternative systems approach requires the modeled energy use of a proposed house to not exceed the modeled use of the same house built to just meet the prescriptive requirements (the reference house).

Objectives and Approach

Based on discussions with stakeholders and NEEA's research goals, Cadmus and NEEA defined the following project objectives:

- Analyze and report the current rate of statewide energy code compliance in Oregon new residential construction, based on the 2011 ORSC.
- Review and comment on the various approaches for assessing code compliance.
- Assess an approach to analyze code compliance, based on the most significant items in determining energy impacts.
- Determine which energy code aspects would lead to the largest reductions in energy consumption through enhanced code compliance. Perform blower door tests on forty-four houses and report results.
- Analyze and report the current rate of statewide energy code compliance in Oregon new residential construction, based on the 2008 ORSC.
- Test a method to increase the total number of observable items by increasing the sample size.

This study's compliance rate analysis assesses actual compliance of homes built to the current code. The **compliance rate analyses** conducted for this study must be distinguished from and the **compliance demonstration approach** used by builders to show compliance with the code for individual houses.

Data Collection

The study first developed a sample frame and a sample of newly constructed homes. The approach drew upon one developed by the Pacific Northwest National Laboratory (PNNL) to provide a common methodology for analyzing compliance of buildings constructed to code. The initial data came from the U.S. Census Bureau Building Permits Survey. The study used the following three-stage approach to select a sample of new homes for site visits:

- County selection
- Jurisdiction selection
- Building selection

Due to the challenges expected in trying to conduct site visits and multiple visits to each home, the study team expanded the sample to eighty-eight homes, rather than the forty-four generated by the PNNL methodology. The team had to deviate from the sample plan, under-sampling in some jurisdictions and over-sampling in some jurisdictions, ultimately visiting ninety homes. This increased the number of homes on which to perform blower door testing and to inspect for additional significant items. Field staff could observe insulation and some construction features only in homes under construction. This changed the sample to forty-four completed homes and forty-four homes under construction.

Cadmus and Britt Makela Group Inc. (BMG) staff conducted the site visits and obtained building department permit information. The study team compiled building characteristics in a checklist designed for tracking Oregon code compliance and based on a similar checklist developed by PNNL. Based on fifty-four criteria, the study organized the checklist into eleven building components. Additional data collected allowed building energy simulation runs.

Data Analysis

The study team analyzed the compliance rate related to meeting code requirements and energy impacts from code compliance. The team used two different approaches to assess the degree to which homes in Oregon complied with the new code:

1. The modified PNNL checklist method: This approach tested PNNL's method for compliance analysis studies. It analyzed how well studied homes complied with each process and code efficiency requirement.
2. Significant item methodology: This approach analyzed compliance based only on measures considered to have the most significant impacts on energy use. It offered a less complex alternative to the complete checklist method.

The PNNL checklist method produces a compliance rate using analyzed site visit data based on the approach builders used to comply with the code. Each item on the checklist received a weight used to calculate compliance points. The checklist incorporated all code requirements, including process and documentation requirements as well as energy-efficiency requirements. In some cases, the study team used available data from homes to fill data gaps for other homes. The study team calculated compliance as the ratio of points for measures complying with the code to points possible for all observable measures.

Many PNNL checklist items have little direct effect on a home's energy consumption. To address this, in collaboration with NEEA, Cadmus developed an alternate, less complex methodology that only addressed items with the most significant effect on compliance and energy use. The analysis included ten items, with compliance determined as the ratio of the number complying with the total number observable and all items weighted equally. The analysis used the following ten items:

1. Window glazing U-factor.
2. Duct sealing.
3. Heating equipment.
4. Water heating equipment.
5. Under-floor insulation R-value.
6. Wall insulation R-value.
7. Ceiling insulation R-value.
8. Slab insulation R-value.
9. Air sealing.
10. High-efficiency lighting.

In the third analysis, Cadmus provided an estimate of the energy effects of code compliance in terms of an energy compliance index. Cadmus used a building simulation model, SEEM94, to determine the relative energy use of each as-built home, compared to the energy use of a reference home built to the prescriptive code. The analysis drew upon the approach specified by the 2011 ORSC.

In the analysis of energy use, the SEEM94 model needed to be augmented. The code specified lighting requirements, but the software did not model detailed lighting characteristics. To address the effects of lighting energy, Cadmus conducted a side calculation, accounting for lighting efficiency. In addition, a separate calculation analyzed water heating energy use.[1] For each home, calculation of the effect of compliance on energy consumption used the sum of space conditioning, water heating, and lighting energy used in the reference home and the as-built home.

Major Findings

Assessing code compliance through field data collection proved challenging due to the difficulty in using a single visit to observe all measures addressed by the code. To fill gaps in the data collected, this study relied on building plans, data from other homes, and, when necessary, code default values.

[1] The appendices present both calculations.

As shown in Table 1, the two methods to estimate compliance rates produced similar compliance estimates.

Table 1. Code Compliance Levels Determined by Two Methods

Methodology	Statewide Weighted Compliance Rate	90% Confidence Level Precision
Checklist	91%	2%
Significant Item	96%	2%

Both methods indicated high compliance with the Oregon residential code. The ARRA legislation established that states should strive to reach at least ninety percent compliance overall by 2017. Using the method developed by PNNL and the significant item method, compliance in Oregon currently exceeds that level. The data shows a relationship between the checklist and significant items compliance levels, but due to the fact that compliance based on the significant items approach is one-hundred percent for a large proportion of homes, the estimates exhibited little variation, and a statistically significant correlation could not be found.

The energy modeling approach indicated a residential energy use level (for space heating, cooling, lighting, and water heating) about eleven percent less than expected in homes just meeting the 2011 code. High-efficiency envelopes contributed the most to beyond-code savings.

In contrast to the checklist method, no statistically significant relationship existed between the compliance estimates from the significant item method and the energy use modeling. Consequently, the study team could not conclude whether the significant item method provided reliable information about the energy impacts from compliance.

Although relatively high overall compliance resulted and the average as-built energy use was less than the average code requirement, eight percent of homes used more energy than the code level. The study team identified the following areas that should receive attention:

- Air sealing
- Lighting

Project Background

As part of its mission, the Northwest Energy Efficiency Alliance (NEEA) seeks to achieve energy savings by strengthening building energy codes in the Northwest, and, as part of this commitment, has assumed a leadership role in advocating for compliance with new energy codes.

To benchmark statewide compliance, NEEA contracted with Cadmus to conduct a study of residential energy code compliance in Oregon. This effort to measure compliance arises from the 2009 American Recovery and Reinvestment Act (ARRA), which provided funding to states, contingent upon a commitment to adopt the then-latest (2009) model energy codes, and to develop a plan (including active training and enforcement provisions) to achieve at least ninety percent compliance with those codes by 2017.

As the governors of all fifty states pledged to meet the ninety percent compliance target, studies conducted across the country have sought to examine code compliance. To support these efforts, the U.S. Department of Energy (DOE) requested that the Pacific Northwest National Laboratory (PNNL) develop a common methodology for assessing compliance (U.S. DOE 2012a). PNNL's methodology provided the basis for the approach Cadmus used in this study.

This report describes the study of Oregon new construction compliance with the revised Oregon Residential Specialty Code (2011 ORSC). In Oregon, building codes fall under the Oregon Building Codes Division's jurisdiction. Local city and county governments, however, may choose to enforce state building codes, including the energy code, using their own building officials.

Builders can use three different approaches to demonstrate compliance with the energy code: prescriptive, component performance, and alternative systems. Each approach establishes specific requirements for demonstrating compliance:

- The prescriptive approach sets minimum requirements for each building component.
- The component performance approach allows the builder to make selections less efficient than the prescriptive requirements for different components as long as other components exceed their prescriptive requirements, and the homes achieve a component thermal performance (UA) at least fifteen percent better than a building fully complying with all prescriptive requirements listed in ORSC Table N1104.1(1). The component performance approach is considered a separate approach, although it is an Envelope Enhancement Measure option under the prescriptive approach.
- The alternative systems approach requires the modeled energy use of a proposed house to not exceed the modeled usage of a house built to just meet the prescriptive requirements (the reference house).

To ensure the study represented current statewide building patterns, Cadmus and NEEA conducted a webinar meeting on Tuesday, July 9, 2013, with a group of Oregon residential code stakeholders. The meeting allowed the stakeholders to understand the study's purpose and steps, and to provide input regarding the methodology used to analyze compliance. The meeting produced a key result: the group confirmed construction data, compiled by the U.S. Census

Bureau, as the best data available for sampling, and, if sampled, local jurisdictions could provide permit numbers for recent construction. During this meeting, stakeholders received and were asked to comment upon a draft sampling plan.

Study Objectives

Based on discussions at the stakeholder meeting and on NEEA's research goals, Cadmus and NEEA defined the following project objectives:

- Analyze and report the current rate of energy code statewide compliance in new residential construction in Oregon, based on 2011 ORSC.
- Review and comment on the various approaches for assessing code compliance.
- Assess an approach to analyze code compliance, based on the most significant items in determining energy impacts.
- Determine which energy code aspects would lead to the largest reductions in energy consumption through enhanced code compliance. Analyze and report the current rate of statewide energy code compliance in Oregon new residential construction, based on the 2008 ORSC.

The study's compliance rate analysis assessed actual compliance of homes built to the current standard. The study team analyzed the compliance rate related to meeting code requirements and the energy impacts of code compliance. Two different approaches assessed the degree to which Oregon homes complied with the new code:

1. The modified PNNL checklist method: This demonstrated and tested the method developed and made available by PNNL for compliance analysis studies. The checklist, updated to assess compliance with 2011 ORSC, analyzed how well studied homes complied with each process and efficiency requirement of the code.
2. Significant item methodology: This approach analyzed compliance based on only measures considered having the most significant impact on energy use; our team evaluated it as a less complex alternative to the complete checklist method.

The PNNL checklist method produced a compliance rate using site visit data based on the approach builders used to comply with the code. Each item on the checklist received a weight for calculating compliance points. The checklist incorporated all code requirements, including process, documentation, and energy-efficiency requirements. In some cases, the study team used available home data to fill data gaps for other homes. The study team calculated compliance as the ratio of points for measures complying with code to points possible for all observable measures[2].

Many PNNL checklist items have little direct effect on a home's energy consumption. Consequently, in collaboration with NEEA, Cadmus developed an alternate, less complex methodology that addressed only items that most significantly affected compliance and energy

---

[2] This is in accordance with PNNL's established approach.

use.[3] The analysis included ten items, with compliance determined as the ratio of the number complying with the total number observable. Cadmus weighted all items equally.

Cadmus' third analysis method assessed the energy impacts of code compliance using a building simulation model, based on SEEM94, to determine the relative energy use of each home, as built, compared to the energy use of a reference home, built to the prescriptive code. The analysis drew upon the approach specified by the 2011 ORSC.

[3] The items were selected based on prior analyses and experience; analysis suggested the items provided good proxies for the total checklist. Future studies may, however, find value in conducting comparative assessments of alternative subsets of items.

Sample Development and Selection

This chapter describes Cadmus' process for developing the project's evaluation sample.

Data Sources for New Construction Activity

The process for developing the sample of new residential construction in Oregon began by utilizing U.S. Census Bureau Building Permits Survey (U.S. Census Bureau 2012a) data for 2010, 2011, and 2012. PNNL used the same data source, and project stakeholders agreed these data best represented construction activity in the state, and provided the best available data source for statewide sampling.[4]

The Census data, however, exhibited gaps, which the Census Bureau filled by:

- Using data obtained through the Survey of Construction (U.S. Census Bureau 2012a); or
- Estimating activity levels, using the previous periods' level and the ratio of current month authorizations to the prior annual total for reporting locations.

The Bureau's Website (U.S. Census Bureau 2012b) provides more information on compilation of permit data.[5]

Estimating Oregon's Residential Construction Population

Table 2 shows the number of construction starts for all Oregon counties. Six of these counties are aggregated into the "Oregon Balance of State" category due to their respectively low number of building starts across the three-year period. Cadmus calculated the three-year average annual starts shown, and the percentage of statewide activity.

[4] Though PNNL used the same data source (U.S. DOE 2012b) to develop its sample generator for code compliance studies, the PNNL calculator (developed in 2010) used data from 2008 to 2010. This study used relied on the latest construction data (2010 to 2012) while maintaining a three-year average to minimize bias resulting from unusually high or low construction years in specific counties. This improved the sample's representation of construction activity since implementation of the current code

[5] To check the reasonableness of compiled data, Cadmus attempted to use data compiled within the state by organizations suggested by the stakeholder group. Unfortunately, none of the suggested data proved sufficiently comprehensive to use as a comparison. Based on experiences in other states, the team decided the Census Bureau data provided the best available representation of construction activity in the state.

Table 2. Oregon Construction Activity by County, 2010–2012

County Code	County Name	Average Annual Starts	Average Percent of Statewide Activity
000	Oregon Balance of State	78	1.42%
001	Baker County	29	0.53%
003	Benton County	76	1.39%
005	Clackamas County	856	15.61%
007	Clatsop County	99	1.81%
009	Columbia County	37	0.67%
011	Coos County	17	0.31%
013	Crook County	57	1.04%
015	Curry County	22	0.40%
017	Deschutes County	521	9.50%
019	Douglas County	110	2.01%
025	Harney County	6	0.11%
027	Hood River County	60	1.09%
029	Jackson County	305	5.56%
031	Jefferson County	22	0.40%
033	Josephine County	80	1.46%
035	Klamath County	62	1.13%
037	Lake County	10	0.18%
039	Lane County	411	7.49%
041	Lincoln County	107	1.95%
043	Linn County	148	2.70%
045	Malheur County	17	0.31%
047	Marion County	320	5.84%
049	Morrow County	8	0.15%
051	Multnomah County	581	10.59%
053	Polk County	74	1.35%
057	Tillamook County	74	1.35%
059	Umatilla County	53	0.97%
061	Union County	28	0.51%
067	Washington County	1065	19.42%
071	Yamhill County	151	2.75%

Staged Sample Selection

This study used the basic sampling methodology PNNL developed for code compliance studies, as described in *Measuring State Energy Code Compliance* (U.S. DOE 2010a). PNNL's method suggested sampling forty-four homes, the minimum number required to test ninety percent compliance with a one-sided ninety-five percent confidence interval (and the standard deviation of thirteen percent assumed by PNNL). Drawing upon experience from conducting previous compliance studies, the study team knew limited data could be collected from single visits to homes, and the study scope did not permit multiple visits to each home.

Consequently, in consultation with NEEA, the study expanded the sample of homes visited to eighty-eight to provide sufficient data to address the research objectives. Forty-four of the eighty-eight planned site visits were reserved for finished homes, where a majority of the significant items could be inspected, and where blower door testing for air sealing could be performed.

The sampling procedure required three stages to select individual buildings for analysis:

1. County selection
2. Jurisdiction selection
3. Building selection

The following sections describe each of these stages.

Stage 1: Selecting Counties

The first stage randomly allocated forty-four sampling points to counties within the state, using a probability proportional to size (PPS) methodology. This selected fifteen unique counties. Cadmus distributed forty-four additional sampling points to the fifteen counties, sampled so each county attained at least four sampling points. The redistribution controlled research costs, with minimal impacts on final study results, given the limited construction activity within the affected counties.

Stage 2: Selecting Jurisdictions

The second stage determined jurisdictions sampled within each county. Before sampling, the study team created a basic rule-set to determine the number of jurisdictions visited in one county, based on sample points allocated to that county. The methodology also equally distributed sample points within each county across the selected jurisdictions. These rules controlled data collection costs.

Table 3 shows the basic rule-set created to establish the number of jurisdictions selected within a county, based on the number of homes (sample points) required.

Table 3. Jurisdiction Sampling Rules

Number of Sample Points	Number of Jurisdictions
1–5	1
6–10	2
11–15	3
16–30	4

Table 4 shows the fifteen counties selected for the study, and the number of jurisdictions sampled within each county.[6] Selected counties represented the eighty-two percent of estimated housing starts, targeting nineteen jurisdictions for sampling.

Table 4. Sampling

County	Percent of Statewide Construction	Sample Size	Jurisdictions Sampled
Baker County	0.53%	4	1
Benton County	1.39%	4	1
Clackamas County	15.61%	12	2
Clatsop County	1.81%	4	1
Deschutes County	9.50%	5	1
Douglas County	2.01%	4	1
Hood River County	1.09%	4	1
Lane County	7.49%	8	2
Marion County	5.84%	5	1
Multnomah County	10.59%	8	1
Polk County	1.35%	4	1
Tillamook County	1.35%	4	1
Umatilla County	0.97%	4	1
Washington County	19.42%	14	3
Yamhill County	2.75%	4	1

Stage 3: Selecting Specific Homes

In selecting specific homes from within a jurisdiction, the study gathered new permit data associated with new residential construction when provided by a jurisdiction.[7] Upon receiving permit data for each home being built in the jurisdiction, the study team created a randomly ordered list of homes for site visits. For each participating jurisdiction, the list included a greater number of sites than the number of sites needed for visitation. The study team drew upon additional methods when sufficient home sites could not be visited through use of permit data.

[6] Jurisdictions sampled and their individual results remain confidential.

[7] A contract established with Mr. Alan Seymour, a contractor familiar with energy code development and code enforcement offices in Oregon, facilitated collection of the necessary permit data in each selected jurisdiction. Mr. Seymour contacted each jurisdiction, and requested provision of permit data to the research team.

Data Collection

After completing the sample design procedure, Cadmus provided the field data collection team with a roster of ongoing construction projects for use as potential site visits.

Site Visit Process

The data collection team scheduled site inspections using the list of selected homes. In some cases, the team deviated from the original list when unable to perform site visits to homes selected in the sample, for the following reasons:

- Occupants in a fully constructed home would not permit a site visit;
- The builder could not be reached; or
- The builder elected to not participate in the study.

Developing a substitution procedure addressed these issues, with the study adopting the following process, selected in the order of preference:

1. Another home farther down the provided list.
2. A home located near the one that could not be recruited.
3. A home by the same builder.
4. A home selected at random by driving around the jurisdiction.
5. A home suggested by a contact familiar with residential construction the jurisdiction.

Overall, the field team used this approach to substitute for over one-half of cases.[8]

Data Collection Forms

PNNL Form

To enhance consistency with the PNNL method and the prior NEEA studies in Idaho, Montana, and Washington, Cadmus used modified PNNL checklists to document compliance information. PNNL provided a series of checklists for analyzing compliance of residential new construction with the 2009 IECC (U.S. DOE 2010a). As Oregon state code does not follow the 2009 IECC code, Cadmus modified the checklist to include information required to document compliance under Oregon's energy code.[9]

The resulting, modified PNNL checklist included the following eleven component sections[10] to determine compliance with sixty criteria:

---

8 The field team made every effort to maintain the sample's randomness, such as avoiding clusters of homes offering ready accessibility.

9 See Appendix C.

10 The PNNL form for IECC 2009 separated the checklist criteria into seven sections designed to be used for different construction stages of a home. This was designed under the assumption that site visits would be conducted to each home at each of its construction stages. Since this study did not visit homes multiple times, the study team opted for an alternative design using component sections.

1. Wall insulation
2. Air sealing
3. Ceiling insulation
4. Doors
5. Windows
6. Floor insulation
7. Foundation insulation
8. Domestic hot water
9. Heating, ventilation, and air conditioning (HVAC)
10. Lighting
11. Other[11]

For each item, compliance reviewers recorded one of the following entries:

- Yes (complies).
- No (does not comply).
- N/A (does not apply to a given house, such as skylights).
- Not observable (applies but cannot be verified, often because it could not be observed during the visit, or applies to items when selected measures from Table N1101.1(2)[12] from ORSC could not be determined).

SEEM Model Input Form

To conduct an energy-usage compliance analysis, Cadmus selected an energy simulation tool—Simple Energy Enthalpy Model (SEEM) Version 94—to model participating homes in the study. To provide inputs required for the SEEM runs, the study added additional data fields to the PNNL form, including:

- Building type
- Foundation details
- Conditioned floor area
- Wall area
- Fenestration areas and orientation
- Ceiling type
- HVAC efficiency
- Water heating efficiency
- Heat pump lockout controls
- Additional measures
- Mechanical ventilation

---

11 This component section includes checklist criteria regarding energy monitoring systems, mechanical ventilation, solar domestic hot water, and solar photovoltaic systems.

12 See Appendix D

As lighting usage cannot be varied in SEEM, Cadmus analyzed lighting separately (discussed below).

Data Entry Methodology

Cadmus entered collected data into a proprietary data collection tool, saving them into a database management system. For each home in the sample, field staff entered as much information as possible into the database. Field visits collected two types of data:

- Plans-verified: Building blueprints; construction documents; builder information provided verbally (in the absence of written sources)[13].
- Field-verified: All energy-efficiency characteristics observable during site visits.

Compliance Determination

The study team used the modified PNNL checklist to determine compliance for each home visited. The checklist provided flexibility in analyzing compliance, based on one of the following three compliance demonstration approaches selected by builders:

- Prescriptive
- Component performance
- Alternative systems

During the study, however, the only compliance path found was the prescriptive so no further mention of the others is made in this report.

Prescriptive Approach

The prescriptive approach specifies minimum requirements that each building component must meet, with no tradeoffs permitted. The approach presented requirements in terms of R-values by envelope component, and required a minimum of fifty-percent high-efficacy lighting and use of at least one Envelope Enhancement Measure and one Conservation Measure from the Additional Measures in Table N1101.1(2).

The study team found using the checklist to evaluate homes complying by the prescriptive approach relatively straightforward. The field team visited the home and filled in information for each item on the compliance checklist. Given that the team did not make multiple visits to each home, they could not always observe all required measures for each home. In such cases, the team gathered plans information on site (if available). If measures from Table N1101.1(2) were not provided, the team attempted to assign appropriate measures from field and plans data.

[13] Though most Oregon jurisdictions did not maintain code compliance documents in their filings during new home construction, they required building plans to remain on the construction site. The majority of plan-verified data derived from these on-site documents.

Since site visits did not follow the recommended PNNL methodology of visiting homes multiple times during the construction process, Cadmus followed the data hierarchy below for the checklist and modeling data:

1. When observed, field-verified values were used to assess compliance.
2. When field-verified values could not be observed, the study used plans-verified values for checklist analysis.
3. In those cases when neither a field-verified nor plans-verified value was available, the energy modeling methodology assumed the prescriptive code value.

Where field-verified data proved unavailable, the team could have assessed checklist compliance by either treating the item as unobservable or by using plans-verified data. Although less reliable than field-verified values, the study team elected to use plans-verified data to improve the accuracy of the results, assuming that the plans-verified data were usually correct and enforced.

The team chose to use plans-verified data in the checklist compliance method rather than exclude observations, as allowed by the PNNL method, because it was likely the plans data were accurate in most cases. To confirm this assumption, envelope data from site visits and plans were compared to determine agreement between the two sources. Efficiency values of measures viewed in the field agreed with or surpassed plans values for over 90% of the cases when both values were available. Table 5 shows, for a simplified example, how using plans data would affect the compliance rate estimate if, on the average, they were accurate seventy percent of the time. In all three cases, using the plans-verified data produces a compliance rate as close or closer to the actual rate as an approach excluding an estimate of the compliance for a single component.

Table 5. Effect of Plans-Verified Data on Compliance Estimate

Approach	Item 1	Item 2	Item 3	Item 4	Compliance Rate
Actual	No	Yes	No	Yes	50%
Treat as Not Observable	No	Yes	No	N/O	33%
Use Plans	No	Yes	No	70% Yes/30% No	43%
Actual	Yes	Yes	No	Yes	75%
Treat as Not Observable	Yes	Yes	No	N/O	67%
Use Plans	Yes	Yes	No	70% Yes/30% No	68%
Actual	No	Yes	No	No	25%
Treat as Not Observable	No	Yes	No	N/O	33%
Use Plans	No	Yes	No	30% Yes/70% No	33%

Description of Data

As shown in Table 6, Cadmus collected data from ninety homes. The actual number of homes visited did not perfectly align with the sampling plan [14]

Table 6. Distribution of Homes in Sample and Completed Site Visits, Local Code Jurisdictions

County	Sampling Plan Site Visits	Completed Site Visits
Baker County	4	4
Benton County	4	2
Clackamas County	12	12
Clatsop County	4	3
Deschutes County	5	5
Douglas County	4	4
Hood River County	4	4
Lane County	8	10
Marion County	5	7
Multnomah County	8	10
Polk County	4	2
Tillamook County	4	2
Umatilla County	4	3
Washington County	14	18
Yamhill County	4	4
Total	**88**	**90**

As anticipated, Cadmus faced difficulties in collecting all checklist data for each home visited. Due to the different construction stages of each home during inspections, the team could not gather every data point through field verification or from plans. Further, building departments did not provide some construction documents required (and included in the checklist). Consequently, all homes visited included some entries recorded as "Not Observable."

Table 7 shows the overall distribution of checklist compliance items. Approximately one-half of the items did not apply[15]. Of applicable checklist items, compliance or noncompliance could be determined for about forty-three percent [(20.2%+1.9%)/(20.2%+1.9%+30.2%)

[14] Cadmus weighted compliance results for the jurisdictions studied to derive a statewide result so the deviation from the predetermined sample sizes only affected the precision of the results, not the statewide estimates.

[15] Items, such as skylights, are included on the checklist of compliance items, but not installed in every home.

Table 7. Average Distribution of Compliance Entries

Compliance Entry	Statewide
Yes	20.2%
No	1.9%
Not Observable	30.2%
N/A	47.7%

Of sixty checklist items, seventeen applied to the options from ORSC Table N1101.1(2) because many of the options are actually composed of bundles of individual measures; depending on the option selected, two to eight of these seventeen items on the checklist might apply to a home. Listing each of these items individually (as opposed to having a single checklist item for the whole option bundle) increased data resolution and avoided showing an entire group of components as not observable if one item in the group could not be observed. This also avoided double-counting of component compliance if Tables N1101.1(1) and N1101.1(2) both listed prescriptive requirements.

The research team found that the number of applicable and observable items of the energy code varied widely by home (see Figure 1 through Figure 3). The home with the highest number of applicable items had fifty-four (out of sixty) and the median number of applicable items was thirty-three. From this base of applicable energy code items, the number of observable items was smaller. The research team was able to observe fifteen items at the average (median) home during its data collection efforts.

Figure 1. Distribution of Homes by Number of Applicable Checklist Items

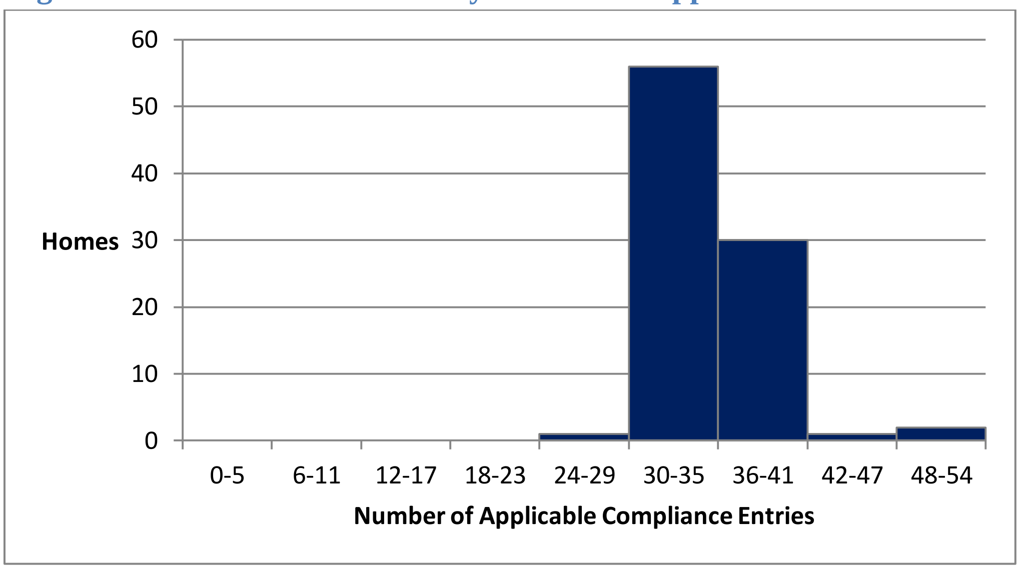


Figure 2 shows the distribution of homes, based on how many compliance items the team could observe and verify, either complying or not complying. Cadmus observed eighteen or more items in about thirty-seven percent (thirty-three) of the homes.

Figure 2. Distribution of Homes by Number of Observed Checklist Items

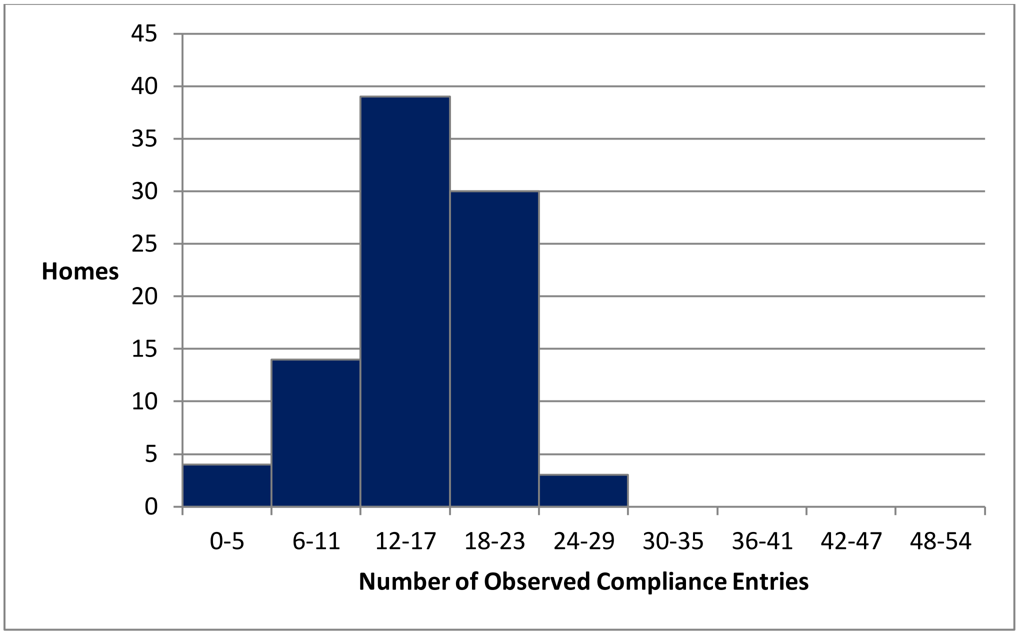
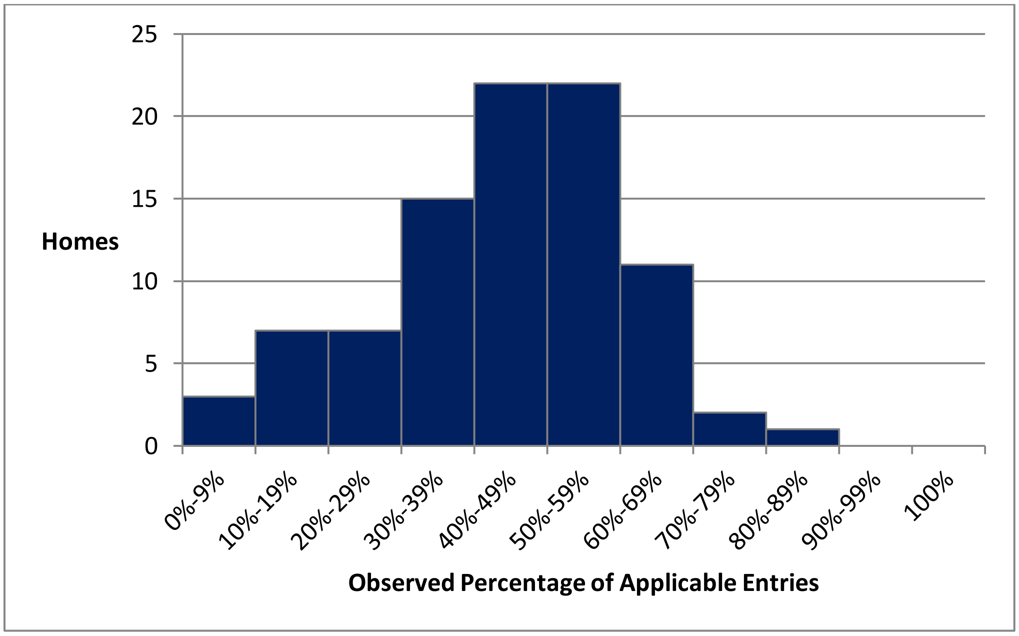


Figure 3 shows the distribution of the percentage of observed checklist items, out of the total applicable.

Figure 3. Distribution of Homes by Percentage of Observable Measures



Data Collection Challenges

The study team obtained permit information from local building departments. Even with the assistance of a consultant very familiar with building departments statewide (Mr. Seymour), the study team encountered the following obstacles in obtaining permit data:

- Although officially public information, obtaining permitting information proved difficult at times. Though most departments and jurisdictions provided assistance, (eighteen departments contacted provided information either before or after site visits), some did not. The study team contacted nineteen jurisdictions in fifteen counties to assist with providing building data. Four of the nineteen jurisdictions did not respond to requests to identify eligible homes for the study. Many jurisdictions identified sites for the team to visit after contact from Mr. Seymour; however, many evidenced limited homes in construction. Five of the nineteen jurisdictions had fewer homes available to inspect than anticipated in the planned sample. In such cases, the team inspected additional homes in the remaining jurisdictions.
- The study team experienced specific difficulties in using permit data and jurisdiction contacts to find builders willing to allow the study team to visit finished homes. A majority of finished homes visited by the study team were identified from heating and insulation contractors, real estate professionals, home inspectors, or other acquaintances residing in jurisdictions. Through these connections, the study team contacted builders for permission to perform site visits, offering $150 gift cards to many connections or builders when homes could not be accessed directly through data from the jurisdictions.
- Plans for finished homes were not available from building departments in some jurisdictions. In many of these cases, the builder provided plans for the study team's review. Some jurisdictions informed the study team that building plans could only be procured for active permits. For some homes without available plans, the builder provided information to the study team concerning information that could not be determined through field inspections.
- Some jurisdictions grouped new residential construction permit information with all other permit information. Sorting out residential construction permits had to be completed manually, which was a time-consuming, tedious task.
- Accessing the requested forty-four finished homes proved difficult within the short time window available between the jurisdiction's final inspection and occupancy by homebuyers. Many builders could not find time in their schedules for the study team's inspection, or did not wish to risk a third party entering the home during that time.

Supplementing Incomplete Checklist Data

A complete evaluation following the PNNL protocol would require visiting a home several times to analyze compliance at different construction stages. In practice, few compliance studies to date have had the resources available to conduct the number of site visits implied by this approach. This includes the present study, which conducted only a single site visit to each sampled home. When visiting a home only once, the proportion of observable checklist items is invariably smaller than when visiting a single home multiple times.

Although PNNL recommended making multiple visits to the same home to collect compliance data at each construction stage, the PNNL method allowed collection and combining of data from different buildings.

> "The checklists can be used to gather data during different stages of construction on different buildings that have the same general attributes in order to yield a resulting single composite building compliance evaluation in lieu of evaluating a single building throughout construction."[16]

As such, expanding the sample size to eighty-eight homes (and visiting ninety) helped address the issue by collecting data on more homes from various construction stages that were combined to fill gaps in the information available from individual homes. Using the PNNL methodology, the compliance rate for a given home is determined only by observable checklist items; the compliance rate is not informed at all by non-observable items. If only two items out of fifty are observable, the only possible rates are zero, fifty, or one-hundred percent. At one extreme, the compliance of the two observable items could be zero percent, yet all other non-observable items could comply (one-hundred percent) but have no effect on the home's compliance rate because they were not observable in the field.

In addition, the PNNL methodology gives equal weight to each home in determining the statewide compliance. Thus, the results for homes where little information is obtained have the same influence as results for homes where many measures are observable and the results can be biased by homes with fewer observable data points.

To improve upon this, the study team developed a methodology to impute data for a given home leveraging data from the larger sample of homes. For each home, the study team calculated the percentage of verified compliance items for each checklist section. The team established a rule that data from homes with more than one-half of the items in a checklist category could be observed would be applied to homes where less than one-half of the items could be observed (candidate homes).Given the study scope, within individual jurisdictions the study team applied the following rules to operationalize PNNL's methodology in deciding how to fill data gaps:

- Supplemental data could *not* be used for homes in jurisdictions where only one or two homes were sampled;
- Supplemental data could only be used if there was more than one home where the percent of verified checklist items for a given checklist section was greater than or equal to fifty within a given jurisdiction;
- In cases where there was not more than one home that met the second criteria above, the study team treated the candidate homes as is without supplementing data.

Supplemental data replaced data only for a given component section of the checklist. For example, if the team considered a candidate home for use of supplemental data for the wall insulation component, supplemental data from other homes replaced all checklist items of the component section. In other words, supplemental data replaced verified items in addition to missing items of the candidate home's wall insulation component section.

16 Please see page 6.2 of PNNL's *Measuring State Energy Code Compliance* document.

Table 8 shows distributions of candidate homes for use of replacement data, per component. The table indicates how many homes could be adjusted using values from homes with more data available.

Table 8. Distribution of Candidate and Adjusted Homes by Component Section

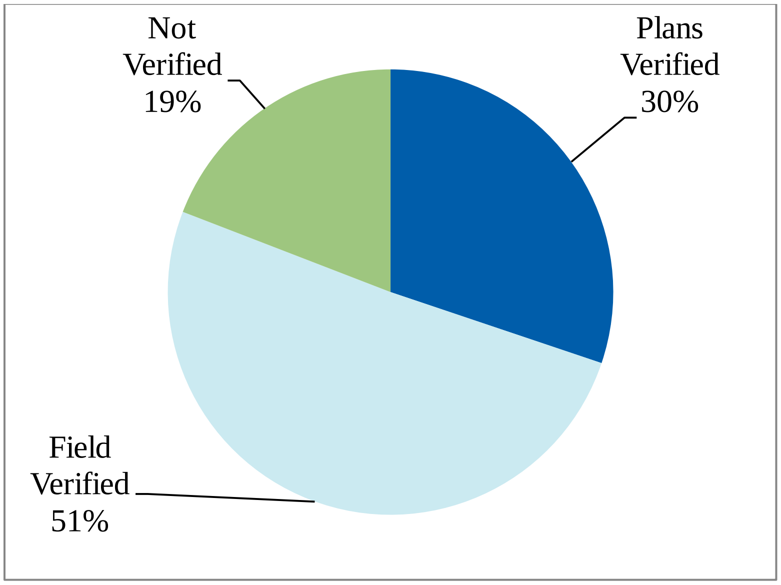
Checklist Section	Total Homes	Homes with < 50% Verified	Adjusted Homes
Wall Insulation	90	65	31
Air Sealing	90	52	29
Ceiling Insulation	90	38	18
Doors	90	55	26
Windows	90	67	25
Floor Insulation	90	37	17
Foundation	90	46	25
Domestic Hot Water	90	77	15
HVAC	90	47	20
Lighting	90	40	14
Other	90	21	5

Supplementing Incomplete Modeling Data

Energy modeling required collecting basic building characteristics data (such as insulation R-values), but did not require the paperwork or some supplementary data required in the PNNL checklist. For modeling energy consumption, the team was able to verify most characteristics needed as model inputs.

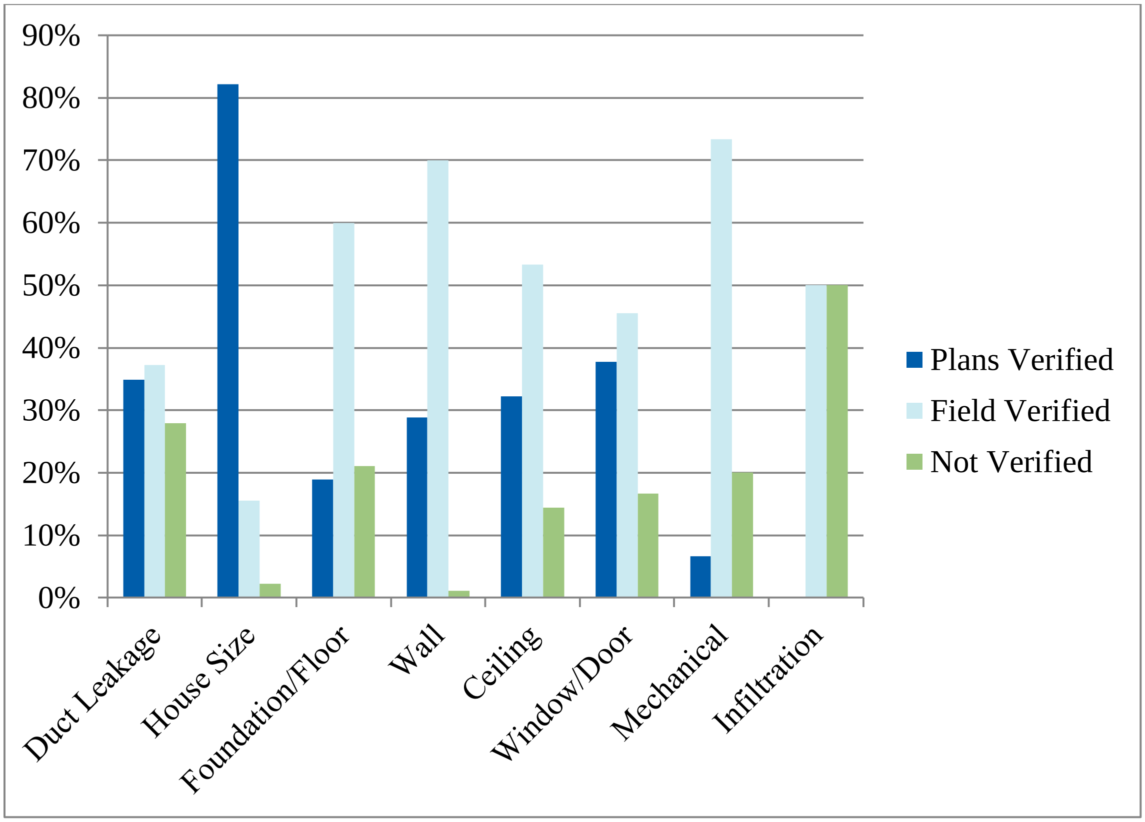
As shown in Figure 4, across the entire sample, direct observations in the field collected fifty-one percent of data points. Plans and construction documents from builders provided another thirty percent of data points. The study team was unable to obtain the remaining nineteen percent of data points using the field-verified or plans-verified data.

Figure 4. Information Sources for Modeling



Information visually collected through field-verified observations varied by home, depending on that home's construction stage. Home characteristics and components documented in the field data most often included: wall insulation, underfloor insulation, and mechanical systems, as shown in Figure 5.

Figure 5. Information Sources for Modeling by Component



Note: "Not Verified" indicates the information unavailable from the plans or field visits.

The energy model used in this study required that every parameter have an associated value. This necessitated developing an approach to deal with parameters when values could not be obtained through inspections or documentation reviews. This differed from the checklist approach, where a compliance value is generated even when some components were unobservable.

For each parameter value that could not verified (e.g., floor insulation level, slab insulation) the following hierarchical steps filled in the missing value:

1. For parameters with data available from similar homes in the jurisdiction, Cadmus calculated the mean of those available values and used it for the not-verified data.
2. For parameters without data available from similar homes in the jurisdiction, the team used code minimum values.

In the first case, the study assumed similarities in construction and code enforcement practices within individual jurisdictions. The PNNL method allowed data to be combined from different homes in a development, and the approach extended this basic practice to a broader area, assuming sufficient commonality in practices to prevent significantly biased results.

Where the team could not obtain similar data, the study assumed a specific building component just met the prescriptive code requirement, a method chosen because:

1. No basis existed for choosing a different value; and
2. Using this value had no net effect on energy use, compared to the reference building modeled for comparison (as described below).

Although this approach could bias the results, no *a priori* reasons existed to assume a consistent bias, either above or below code requirements, and no evidence emerged during the study to suggest a bias.

In two cases, neither of these approaches could be used, specifically for infiltration and duct system air leakage. Those values had to be based on test data, not observable parameters. As testing was only performed on completed homes and results depended on home size, the values could not be extrapolated to other homes in the sample. For modeling purposes, homes for which the team did not measure infiltration, the study assumed test values just meeting the value required by Envelope Enhancement Measure Five (at 6.0 air changes at 50 Pascals).[17]

Similarly, for duct leakage rates, when the team did not conduct leakage tests, they assumed values equaling code requirements of 6 CFM50[18] per one-hundred square feet of conditioned floor area, if an Envelope Enhancement Measure requiring duct sealing and testing was followed. If duct testing was not required, Cadmus used 12 CFM50 per one-hundred square feet of conditioned floor area. This value was consistent with assumptions for Northwest ENERGY STAR Homes model inputs.[19] The study set duct leakage to zero in the SEEM model runs for homes with all ducts in conditioned spaces,[20] as duct leakage would not occur outside the envelope. As described below, the study team assessed the results' sensitivity to making these default assumptions.

---

17 The code states compliance can be achieved when the dwelling is: "tested with a blower door and found to exhibit no more than 6.0 air changes per hour" at a test pressure of 50 Pascals.

18 CFM50 refers to cubic feet per minute at 50 Pascals pressure.

19 Code assumptions for duct leakage are provided in RTF SEEM analysis data files. http://rtf.nwcouncil.org/measures/support/files/Default.asp

20 All ducts within conditioned space are defined as: a duct system with less than 5% of total duct length outside conditioned space.

Analysis Methodologies

PNNL Checklist Methodology

The PNNL method develops a compliance rate for each home using the checklist and site visit data. The checklist methodology assigns each item on the checklist a value of one, two, or three points, depending on PNNL's assessment of the relative importance of each. The PNNL checklist, based on the IECC, cites sixty-one items, for 159 possible points upon applying weights. As Oregon does not use the IECC, Cadmus modified the checklist, as described later. Appendix A presents the detailed data.

Using this method, building-level compliance can be determined by dividing the total points for all items marked as compliant by total points associated with all items marked as compliant or noncompliant, with results expressed as a percentage.

The compliance analysis excludes items marked "Not Applicable" or "Not Observable." For a home considered compliant with this method, the resulting percentage must equal one-hundred percent.

$$Compliance\ Rate\ \% = \frac{\sum Compliant\ Measure\ Points}{\sum Compliant\ Measure\ Points + \sum Non-compliant\ Measure\ Points}$$

Application to Prescriptive Approach

In using the checklist method to evaluate homes complying by the prescriptive approach, one compares verified values against prescriptive code values, as found in the Oregon code. When field-verified values were available, the Cadmus team compared them to the prescriptive code requirements. If they were not available, the study team used plans-verified values if they were available.

Supplementing Missing Data

To adjust for missing data, PNNL suggests combining data from multiple buildings to develop a single building evaluation. For example, this could be used during simultaneous construction of multiple buildings, with construction at different stages. PNNL recommends using the same building for at least one complete inspection stage (e.g., plan review, foundation, framing, insulation, or final inspection). Additionally, buildings must be of the same type and be located in the same jurisdiction.

During data collection and analysis, this study combined data from multiple buildings to create a composite building. The study used data for homes in the same jurisdiction, preferably by the same builder and in the same development.

Determining Statewide Compliance

For analyzing statewide compliance, PNNL discusses two possibilities:[21]

1. Determine the percentage of homes that achieve one-hundred percent compliance.
2. Use a simple average of the house-level compliance rates.

[21] Please see section 5.4 of PNNL's *Measuring State Energy Code Compliance* report.

PNNL prefers using the second method, as it better indicates a building's proximity to compliance (and to reaching a ninety percent overall compliance level). As both metrics prove informative, this report examines both.

Adapting a PNNL Methodology for Oregon

The PNNL checklist does not directly apply in Oregon, as the code differs from the IECC. For Oregon code, Cadmus applied a modified checklist approach, as similar to PNNL's IECC checklist approach as possible.

The study team mapped Oregon code items to relevant compliance items in the PNNL checklist. These steps included identifying requirements and visual inspection requirements in the PNNL checklist that did not apply in the Oregon code, and removing them. The only additional compliance item specific to Oregon addressed the state's requirement for Additional Measures in Table N1101.1(2) of ORSC. The additional measures related to installing high-efficiency HVAC equipment, high-efficiency water heating, high-efficiency envelopes, air leakage controls, and renewable energy. The study team assigned a weight of three points to each table component due their potentially large impact on home energy consumption.

Following these adjustments, the Oregon checklist included sixty compliance items with values of one, two, or three points. At most, fifty-four compliance items could be applicable, depending on the pathways selected in Table N1101.1(2) of ORSC. Summing points across these compliance items resulted in 146 possible points.

Significant Item Methodology

In the PNNL methodology, each of the compliance items receives a weight value ranging from one to three points. The study team finds this small range insufficient to capture the relative effects of checklist measures on energy consumption (the ultimate impact of code compliance). Many checklist items produce little impact upon a home's energy consumption. Some (such as posting a certificate describing the energy features on the home's electricity panel) may prove important from a procedural perspective, but do not directly contribute to energy savings.

To address this issue, the study team developed an alternate methodology in conjunction with NEEA, only addressing items that most significantly affected compliance and energy use.

This alternative method removed the influence of less-important compliance items by restricting analysis to the ten checklist items deemed most significant in determining energy consumption. The study team selected items in conjunction with NEEA, using a method originally employed in a prior study of code compliance in Montana for NEEA (Lee, A., Cook, R., Horton, D. 2012). This method allowed analysts to consider whether builders complied with the most vital 2011 ORSC components affecting energy use, regardless of whether builders complied with other requirements of lesser importance. The analysis included the following ten items:

1. Window glazing U-factor.
2. Duct sealing.
3. Heating equipment.
4. Water heating equipment.

5. Under-floor insulation R-value.
6. Wall insulation R-value.
7. Ceiling insulation R-value.
8. Slab insulation R-value.
9. Air sealing.
10. High-efficiency lighting.

Other than this change, Cadmus applied the remainder of the PNNL method as designed. The ten items above each received a three-point weight in the PNNL checklist. As with the PNNL method, the compliance rate calculated for each home reflected the percentage of items deemed code-compliant, averaging these to estimate a statewide compliance level. (Analysis excluded items rated "Not Applicable" or "Not Observable" per the PNNL methodology.)

SEEM Energy Modeling Methodology

Energy Consumption Methodology

Cadmus used SEEM94[22] to determine the relative energy use of sampled homes as compared to energy use of the same homes, if constructed to exactly meet two reference codes: 2008 ORSC and 2011 ORSC.

The model could not directly model domestic hot water energy consumption and lighting, but the code covered hot water energy use and lighting. Cadmus post-processed the domestic hot water and lighting energy consumptions into the overall energy consumption for each as-built and reference home scenario. Assumptions used for lighting and hot water usage are detailed in Appendix F and Appendix G. Overall, the simulation analysis, supplemented with water heating and lighting analyses, proved very consistent with the code's scope.

Cadmus modeled each home, based on its observed, as-built characteristics, and compared it to a code-compliant reference home, defined using target component values for single-family residential homes, per the ORSC. For envelope components, requirements are presented in terms of U-values[23]. The team compared energy use calculated for the reference house to the calculated energy use of the sampled, as-built home. The procedure used a prescriptive compliant reference home to compare homes in the sample consistently. The code does not address several end uses that Cadmus could not model. These include appliances, swimming pool equipment, and sunrooms. Although these home end uses contribute to energy consumption, code does not specify their requirements. As noted, the Cadmus engineers analyzed lighting energy use separately, but only the prescriptive compliance approach established lighting requirements.

[22] Ecotope developed SEEM94 for the Northwest Power and Conservation Council and NEEA, primarily to model heating and cooling energy consumption and savings for utility planning purposes. Cadmus adopted the model as applied in other residential energy use studies in the Northwest. SEEM94, which offers the basic capabilities necessary for this study, is not overly complex. This helped minimize input errors.

[23] U-Values were used because they represent the insulation and framing of an entire wall or ceiling systems independent of framing type used.

Defining As-Built Homes

As noted earlier, modeling required complete data. Adjustments required combining site visit data and data from plans; cleaning data; and filling remaining gaps. When gaps remained in the building data, the analysis applied data derived from other homes in the same jurisdiction under the assumption that code enforcement would be consistent across homes in the same jurisdiction. The resulting specifications constituted the as-built home design entered into the model. The SEEM model, based on these inputs, provided an energy consumption estimate for each as-built home.

Defining Reference Homes

The study team modeled reference homes using the same size, wall area, roof area, window area, and foundation type as corresponding as-built homes. In defining the reference home, the code requirements specified insulation values and U-values. Cadmus referred to Table N1101.1(1) in ORSC to identify prescriptive requirements by component and Table N1104.1(2) for U-value specifications. Homes complying with the prescriptive path must also meet the ORSC Table N1101.1(2) requirements, shown in Appendix D.

In addition to these prescriptive envelope requirements, code additional measures established requirements for duct leakage, ducts in unconditioned space, and whole house tightness. Cadmus used 2008 ORSC and 2011 ORSC Additional Measure options and assumptions for these measures to determine corresponding inputs for the SEEM runs.

The study team calculated an energy compliance index for each home by dividing energy usage of the as-built home by energy usage of the reference home under each code. This produced a relative comparison between homes, independent of home size:

$$\frac{Energy\ Usage\ As\ Built\ Home}{Energy\ Usage\ Reference\ Home} = Energy\ Compliance\ Index\ \%$$

If this index exceeded one-hundred percent, the home used more energy than if built to just meet code. For example, if a specific home achieved an index of 120 percent, the home exceeded, by twenty percent, the energy use of the same home built to code.[24]

[24] This index proves comparable to the HERS Index.

Checklist and Significant Item Analyses Results

In this section, Cadmus presents statewide compliance rate results, generated from the PNNL checklist and significant item compliance analyses.

To accommodate these two approaches and the energy use simulation analysis, the study team developed a weighting scheme to address building codes varying across counties. The analysis treated counties as a stratification variable. Within each county, the analysis considered building starts as the sampling units. Appendix B: Derivation of Weights presents details of the weighting approach.

PNNL Checklist Compliance Results

Component-Level Results

To gain insights into compliance at the component level, Cadmus summarized compliance information for each measure on the checklist, determining the frequency that could be verified for each component (i.e., proved applicable and observable) and the compliance rate. Each component category represents multiple code requirements in the checklist. For example, the window category includes: window U-value, window SHGC, window labeling, and other code requirements. Table 9 presents results for each compliance item category, including: the number of items on the checklist contributing to the category's compliance level; the percent verified; the average compliance rate of all homes in the sample, adjusted as described in Supplementing Incomplete Checklist Data; and the variance of the compliance rate between the homes in the sample. Table 19 in Appendix A provides more detailed information.

Table 9. Summary Component Checklist Compliance Statistics

Compliance Item Component Category	Number of Items	Percent of Items Observed	Average Adjusted Compliance	Variance of Adjusted Compliance
Wall Insulation	3	51%	94%	3%
Air Sealing	7	44%	90%	3%
Ceiling Insulation	4	63%	98%	~0%
Doors	3	31%	94%	5%
Windows	8	28%	93%	5%
Floor Insulation	4	63%	92%	4%
Foundation	6	48%	98%	2%
Domestic Hot Water	2	14%	85%	7%
HVAC	11	43%	91%	4%
Lighting	2	47%	87%	8%
Other	4	58%	100%	~0%

Note: The Average Adjusted Compliance is based on supplementing the field-verified observations. Variance was calculated from the observed adjusted compliance values.

Adjustments for Missing Data

Table 8 shows the number of sampled homes where data from other homes filled data gaps. In cases where using values from other houses with more complete data decreased the estimated compliance rate at the component section level, the change was relatively small. The wall insulation component section was the exception, where two of the three checklist items have either no impact (R-value labeling) or an unknown impact (contact with the warm surface) on energy consumption, but were often found to not be in compliance. Overall, filling the gaps where possible slightly decreased the average checklist compliance rate from ninety-one percent to ninety percent without applying weighting. The impact of these adjustments, however, did not significantly affect the overall compliance rate.

Checklist Compliance of Homes

Table 10 summarizes the effects of adjusting the checklist category compliance. The section on Supplementing Incomplete Checklist Data details the methodology behind the adjustments.

Table 10. Compliance Rate Effect of Filling Data Gaps

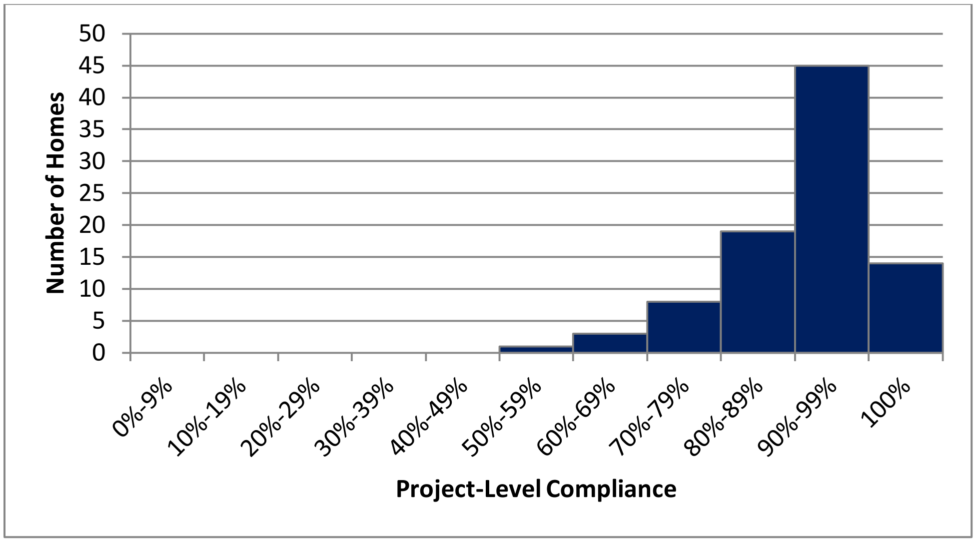
Checklist Section	Unadjusted Average Compliance	Adjusted Average Compliance
Wall Insulation	94%	87%
Air Sealing	90%	88%
Ceiling Insulation	98%	98%
Doors	94%	92%
Windows	93%	91%
Floor Insulation	92%	92%
Foundation	98%	97%
Domestic Hot Water	85%	93%
HVAC	91%	90%
Lighting	87%	87%
Other	100%	100%
Total	**91%**	**90%**

Aggregate Results

With the data gaps filled as described above, adjusted data resulted in one home having the lowest compliance rate (fifty-seven percent) with the checklist analysis method: the highest rate achieved was one-hundred percent, with a mean of ninety percent.

Figure 6 shows distributions of adjusted project-level compliance rates without geographic weighting. Fourteen homes fully complied under the checklist method, based on code requirements that could be verified through plans or field observations.

Figure 6. Distribution of Homes by PNNL Checklist



Analysis of statewide compliance estimates produced the following results:

- The percentage of homes achieving one-hundred percent compliance.
- Average home-level compliance rates.

Table 11 presents these statewide results. Overall, after adjusting for missing data, sixteen percent of homes fully complied with the code requirements using the checklist.

Table 11. Summary of PNNL Checklist Results for Statewide Compliance

Scenario	Unadjusted Statewide Result	Adjusted Statewide Result
Percentage of homes achieving 100% compliance	33%	16%
Average compliance rate	91%	90%

Significant Item Results

Results from using the Significant Item analysis method are shown in Figure 7. As shown in Table 12, this method resulted in seventy-one homes (seventy-nine percent) with a one-hundred percent compliance rate and a mean compliance rate of ninety-five percent.

Figure 7. Distribution of Houses by Significant Item Checklist

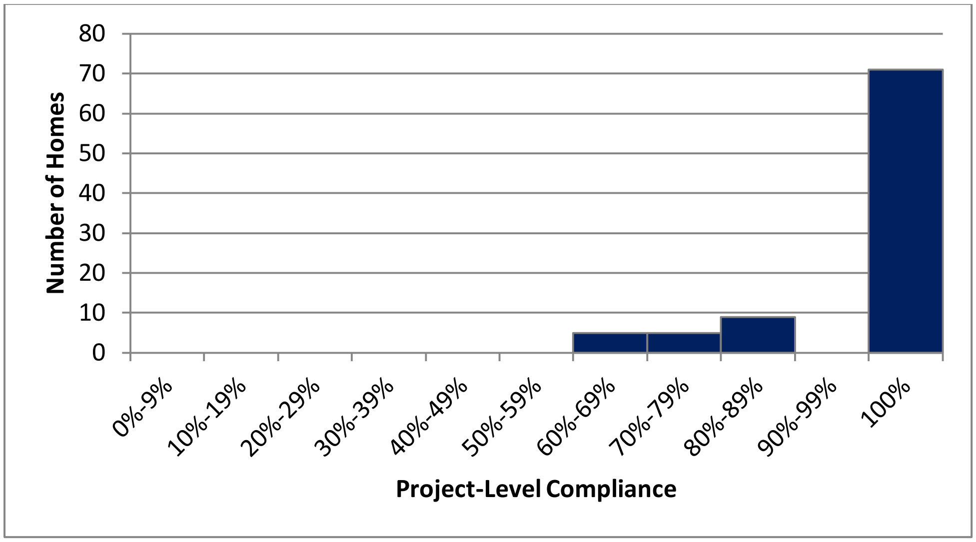


Table 12. Summary of Significant Item Results for Statewide Compliance

Scenario	Statewide Result
Percentage of homes achieving 100% compliance	79%
Average compliance rate	95%

A substantially larger number of homes rated one-hundred percent compliant using the significant item approach (seventy-one) compared to the PNNL checklist approach reported in Table 11 (fourteen).

Table 13 summarizes compliance rates of the ten significant items. Though the compliance rate for high-efficiency lighting is lower than the other nine items, it must be qualified due to its derivation from only thirty-eight verified homes from a total of ninety. Builders used no conservation measures from ORSC Table N1101.1(2) requiring improved water heating equipment in the sample of visited homes, resulting in zero verified homes.

Table 13. Summary of Significant Item Results for Statewide Compliance

Item	Number of Verified Homes	Statewide Compliance
Ceiling insulation R-value	79	100%
Heating equipment	53	100%
Air sealing	30	100%
Slab insulation R-value	21	100%
Duct sealing	33	97%
Wall insulation R-value	90	97%
Under-floor insulation R-value	61	92%
Window glazing U-factor	73	97%
High-efficiency lighting	38	76%
Water heating equipment	0	N/A
Overall	**90**	**95%**

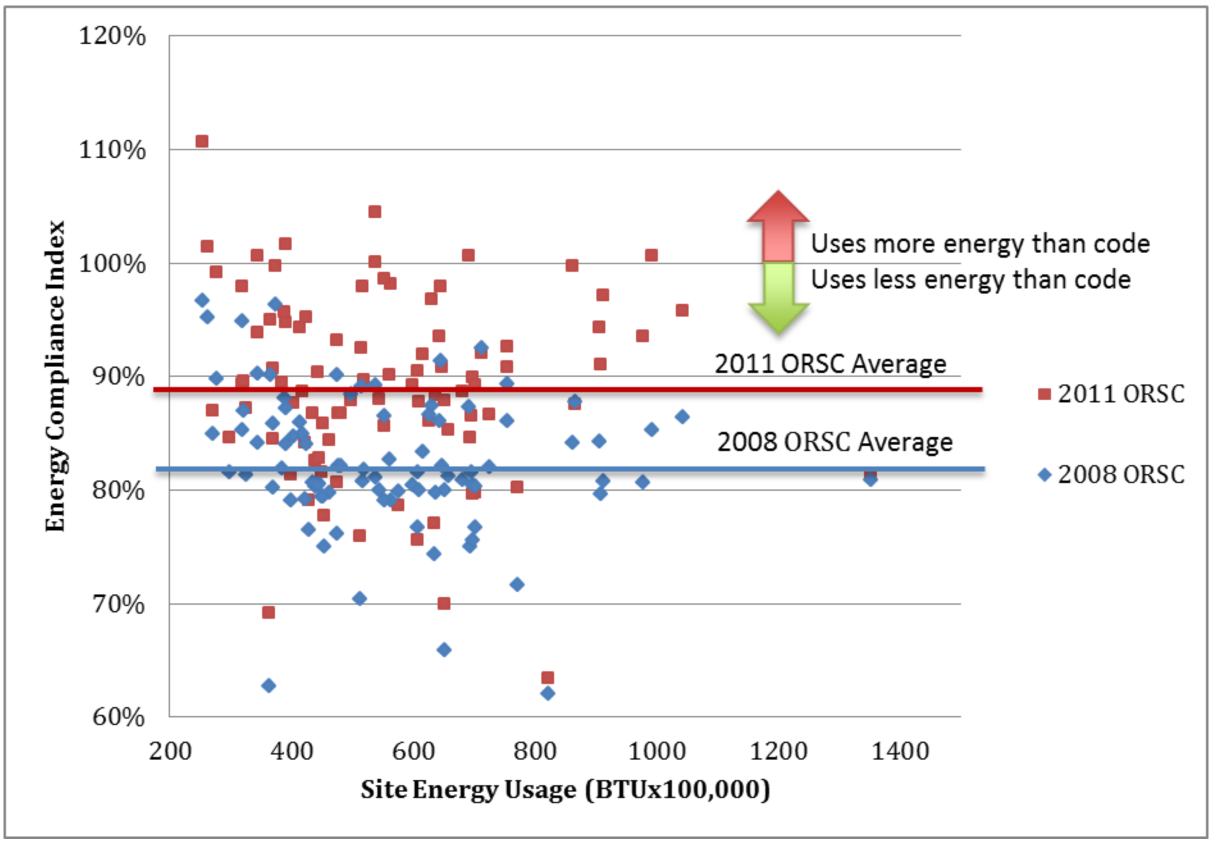
SEEM Modeling Results

This chapter presents results of the compliance assessment conducted in this study using the modeling methodology. This methodology utilizes the energy compliance index: a measure of the relative energy usage of a built home compared to a code equivalent home.

Space Heating and Cooling and Water Heating Results

Figure 8 illustrates each home's relative energy use against the energy compliance index calculated for both 2008 ORSC and 2011 ORSC. Homes receive a higher index when compared to 2011 ORSC than 2008 ORSC because of the more stringent requirements of the code. SEEM modeling results produced energy compliance indexes relative to the ORSC 2011 ranging from sixty-three percent to 110 percent with an un-weighted mean of eighty-nine percent, or about eleven percent better than ORSC 2011. The sampled homes consume approximately seventeen percent less energy than the previous code 2008 ORSC on average. While index values fell within a relatively narrow range (with a sample standard deviation of eight percent), energy usage varied by nearly a factor of five. Ninety-two percent (or eighty-three out of ninety homes) use less energy than the 2011 ORSC reference home.

Figure 8. Energy Compliance Index vs. Home Energy Consumption



Weighting results to extrapolate to the average for the population of new homes in Oregon resulted in an eighty-nine percent energy compliance index, indicating statewide energy use of new homes about eleven percent less than that resulting if all new homes just met the code. Using 2008 ORSC as a baseline the weighted average is eighty-two percent.

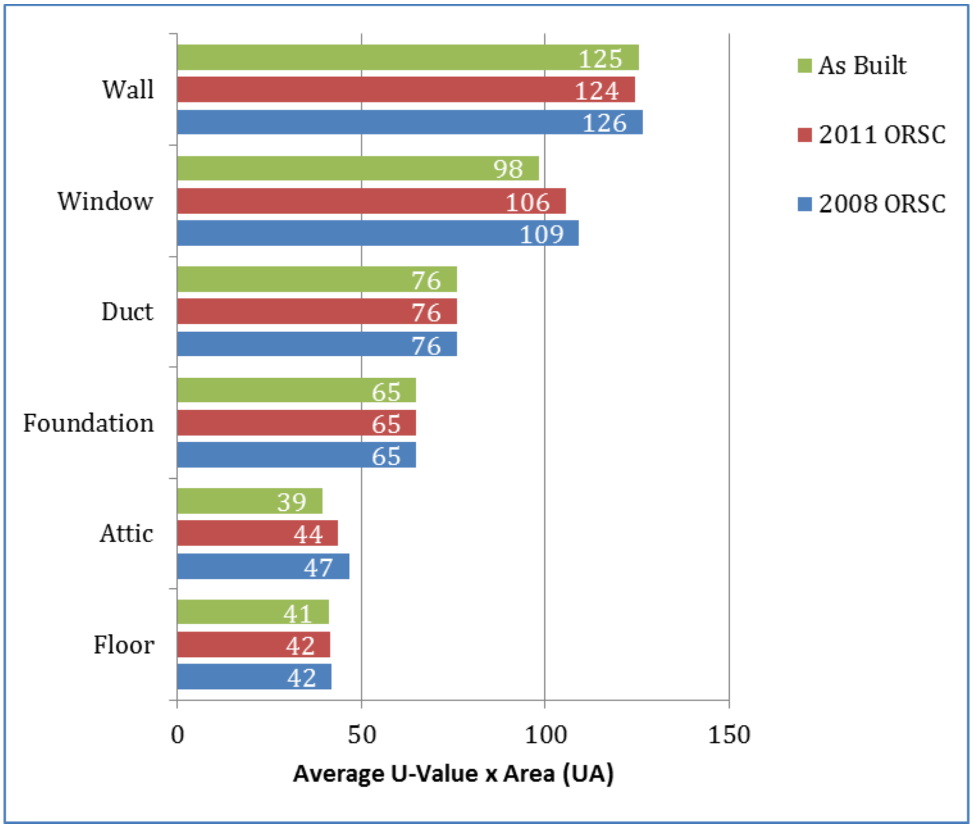
Table 14 shows the per home weighted average of component contribution to energy savings The largest individual contributor to energy savings beyond code requirements is improvement to the building shell followed by increased HVAC efficiency, water heating, lighting, and improved ductwork tightness.

Table 14. Average Contribution to Energy Savings by Component – Amount and Percent

	2008 Code		2011 Code	
Component	BTU x100,000	Contribution, %	BTU x100,000	Contribution, %
HVAC Efficiency	20	16%	19	26%
Shell Efficiency	58	45%	27	37%
Duct Sealing	20	15%	2	3%
Water Heating Efficiency	15	12%	15	20%
Lighting Efficiency	15	11%	10	14%
Total	128	100%	75	100%

Focusing on envelope improvements, Cadmus calculated the average component UA values for as-built and for baseline homes. The UA value represents unit area conductive losses (U-value) times the area. The larger the UA the more the conductive losses; smaller UAs mean homes are better insulated and/or smaller. Figure 9 shows that the largest losses were through the walls of the building and, on the average, as-built homes had slightly higher losses through the walls than if they just met the prescriptive 2011 ORSC. An additional SEEM analysis showed that if homes were built beyond code requirements with ducts installed inside conditioned space, heating consumption would be reduced by about eleven percent.

Figure 9. Envelope UA Values



Windows showed the largest improvement over 2011 ORSC requirements. Many homes were only required to install 0.35 U-value windows; however, most homes installed 0.30 U-value windows. As with UA values, lower U-values mean less heat transfer.

Duct insulation showed little improvement over code. Because most common ductwork sold comes pre-insulated with R-6 or R-8 insulation and these values appear to have become standard practice, this was not surprising.

Foundations also showed little improvement over code. Much of the data collected on foundation insulation was from plans or imputed, and could not be verified during site inspections. Attic losses are relatively small due to the high R-values installed. Many sampled homes needed only to insulate attics to R-38 under the code, yet most insulated attics are rated at R-49 or better. This resulted in a small decrease in attic UA value over code.

Floor insulation levels were generally at code or slightly better. Crawl spaces are very common in Oregon and most were insulated adequately.

Component-level compliance solely drew upon the component energy performance characteristics, and did not account for other factors outlined in the PNNL checklist method.

Examining heating equipment efficiency for the homes built following the optional approaches in Table N1101.1(2) Conservation Measure A, requiring efficiencies better than federal standards, shows a significant increase in gas furnace efficiency over Measure A requirements. Table 15 shows the increases over 2011 and 2008 ORSC codes. For modeling the 2008 ORSC, Cadmus' analysts assumed that every home would take the high efficiency heating path. That assumption was very likely to be valid given the current efficiency of installed furnaces. Air-source heat pumps are less common and had an average HSPF slightly below the requirement of Conservation Measure A and the 2008 High Efficiency HVAC Additional Measure Path. Our analysis always assumed electric resistance systems to be one-hundred percent efficient.

Table 15. Heating Efficiency

			As Built	2011 ORSC		2008 ORSC	
Heating System	Number of Homes	Percent Of Sample	Efficiency	Reference Efficiency	Percent Improvement	Reference Efficiency	Percent Improvement
Natural Gas Furnace (AFUE)	67	74%	94.6	89.2	6%	90	5%
Air Source Heat Pump (HSPF)	10	11%	8.4	8.5	-1%	8.5	-1%
Electric Resistance	13	14%	N/A	N/A	N/A	N/A	N/A

While no homes followed a Conservation Measure requiring the installation of high efficiency water heating systems, many of these systems were installed. Shown in Table 16, conventional gas water heaters averaged ten percent better than the federal standard. Tank-less water heaters with efficiencies exceeding the requirement of Conservation Measure D were installed in many homes. Conventional electric water heaters were marginally better than the reference water heating efficiency.

Table 16. Water Heating Efficiency

			As Built	2011 ORSC		2008 ORSC	
Water Heating System	Number of Homes	Percent Of Sample	Efficiency	Reference Efficiency	Percent Improvement	Reference Efficiency	Percent Improvement
Gas Conventional Water Heater(EF)	55	61%	0.65	0.59	10%	0.59	10%
Gas Tank-less Water Heater(EF)	10	11%	0.86	0.59	46%	0.59	46%
Electric Conventional Water Heaters(EF)	25	28%	0.92	0.9	2%	0.9	2%

Typical sampled homes had sixty-two percent high-efficacy or compact fluorescent (CFL) lighting[25] installed. The code requirements for installation of efficient lighting vary from fifty percent to sixty-five percent high efficacy, depending on the compliance path taken. The team verified the amount of high-efficacy lighting at forty-seven percent of homes. This provides high confidence to assign the mean value of sixty-two percent efficient lighting to homes where lighting was not observable. Several individual homes did not meet the minimum requirements, but on average they were offset by homes installing more than the required percentage of high-efficacy lighting. Shown in Figure 10, twenty-five homes installed more than seventy-five percent high-efficacy lamps.

Figure 10. Lighting

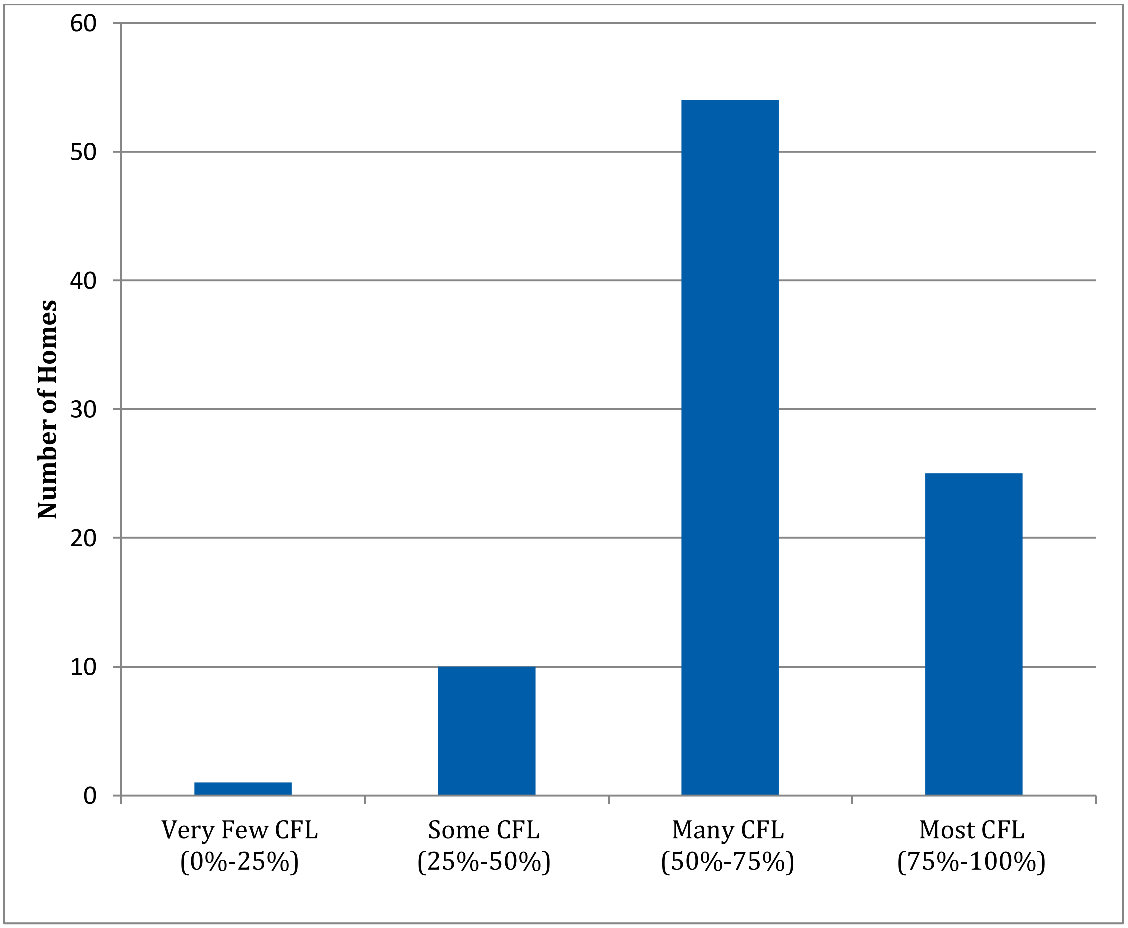
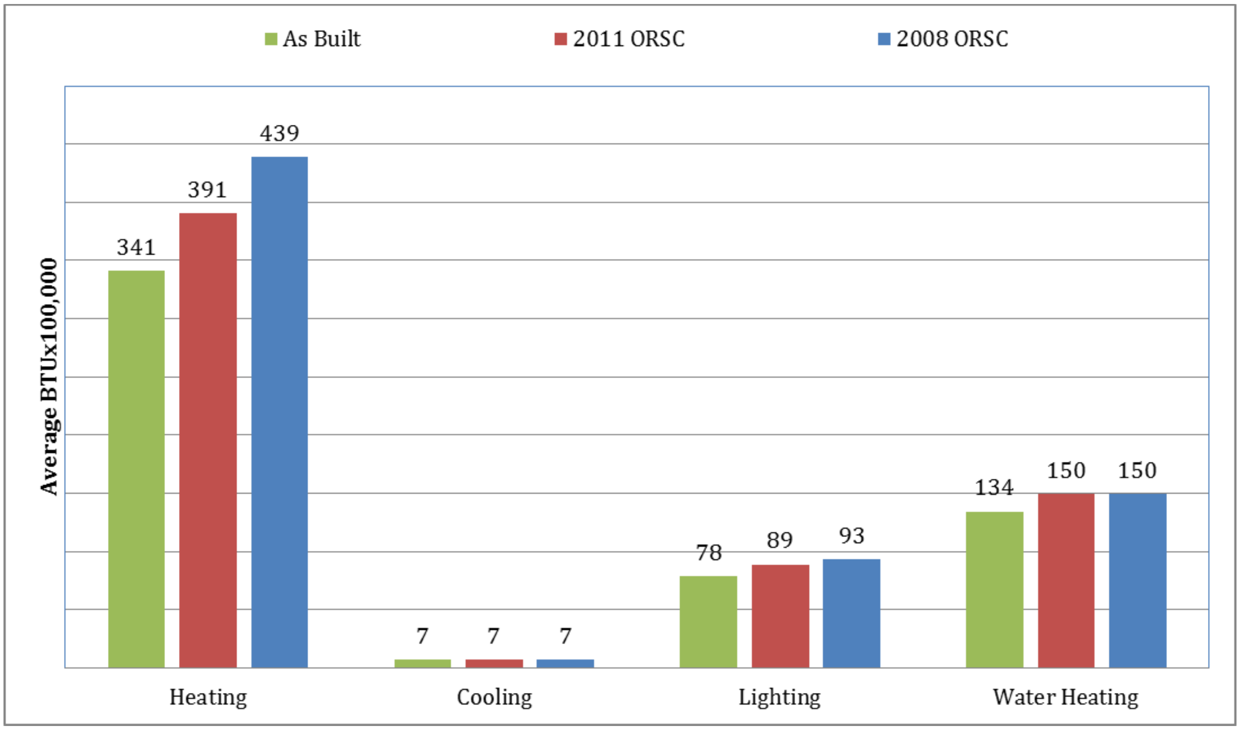


Figure 11 shows the relative energy consumption of each end-use examined in this section compared to Oregon code requirements or federal standards in the case of water heating. For each end-use (except air conditioning), the average home studied in this analysis used less energy than its reference code equivalent counterpart. Heating savings are significant, and

[25] The 2011 ORSC defines CFL's as complying with the high efficacy lighting requirement.

assisted by improved envelope and high-efficiency furnaces. Lighting and water heating savings are moderate. Cooling savings are small due to the low cooling loads across much of the state.

Figure 11. Relative Energy Usage



Findings and Recommendations

Discussion of Findings

Code Compliance

All homes included in this study followed the prescriptive approach. Over ninety percent of homes followed and complied with the Conservation Measure A requirement of installing gas heating equipment with a minimum Annual Fuel Utilization Efficiency (AFUE) of ninety percent or an air-source heat pump with minimum Heating Season Performance Factor (HSPF) of 8.5. Improved insulation (Measures One, Two, and Three) was used to meet code requirements at forty-five percent of homes, while building tightness and duct sealing (Measure Five) from Table N1101.1(2) was used at over one-half of homes.

Table 17 shows statewide code compliance levels, determined using these two different methods. The PNNL checklist method and the significant item method both provided an average compliance rate above ninety percent. Based on these results, Oregon achieved the ARRA legislation requirement for states to reach a minimum of ninety percent compliance.

Table 17. Code Compliance Levels Determined by Two Methods[26]

Methodology	Statewide Weighted Compliance Rate	90% Confidence Level Precision
Checklist	91%	2%
Significant Item	96%	2%

Using the modeling approach, the energy compliance index showed that homes, on average, performed better than homes just meeting the code minimum requirements. New homes in Oregon consumed eleven percent less energy than if they just met code. Ninety-two percent of homes used less energy than required by 2011 ORSC requirements and eight percent of homes consumed more energy than code requirements. The least efficient home consumed eleven percent more energy than 2011 ORSC requirements. On the average, homes consumed eighteen percent less energy than if they were built to meet 2008 ORSC requirements.

The ninety percent minimum target in ARRA draws upon applying the PNNL checklist method, accounting for all code requirements (including those without direct effects on building energy use). Considering the relatively strict nature of Oregon's code, the compliance level estimated with the PNNL method provided a positive finding.

Table 17 also shows the precision (at a ninety percent confidence level) for estimated average compliance rates. The values draw upon the variance observed in the compliance rates for the sampled homes. The missing data (unobservable measures) introduce some uncertainty in the results; however, the study team considers the effects of unobservable items not very large due to the use of both plans and field verified data.

[26] The confidence level and precision are based on the likely sampling error.

Based on the PNNL checklist compliance analysis:

- About thirty percent of homes received a one-hundred percent compliance rate, based on observable checklist items.

Based on the significant item compliance analysis:

- About sixty-four percent of homes received a one-hundred percent compliance rate, based on observable checklist items.
- A ninety-six percent average resulted—slightly larger than the PNNL checklist average rate of ninety-one percent.

To determine if a relationship exists between the checklist and significant items compliance levels, the team regressed estimates from one compliance assessment method against the other. The data shows a relationship between the checklist and significant items compliance levels, but due to the fact that compliance based on the significant items approach is one-hundred percent for a large proportion of homes, the estimates exhibited little variation, and a statistically significant correlation could not be found. The lack of variance in the significant item compliance data is due to unobservable items not being factored into the rate.

As the simulation modeling analysis required additional labor, the study team explored whether the significant item compliance analysis method could be used to provide an accurate estimate of the energy impacts of the compliance level. To do so, the study team calculated the percent savings for each home as-built, compared to the modeled reference home. Cadmus regressed this value against the significant item checklist compliance rate for the same home. Only a very small positive correlation emerged between the measures, and the relationship did not prove statistically significant. Consequently, the study team cannot conclude that the significant item compliance method can be used to assess compliance energy impacts. This is primarily the result of the upper limit of the significant item checklist being one-hundred percent and a large proportion of homes achieved this compliance level based on the observable items. Cadmus did find that the average of the energy compliance index values was less for homes with one-hundred percent significant item compliance than homes with less than one-hundred percent significant item compliance so the results were consistent, but not highly correlated.

The energy modeling analysis provided a more direct measure of compliance effects on energy consumption. Modeling results indicated as-built homes performed better than those built to just comply with the code. The following observations draw upon results from the simulation analysis and the lighting compliance analysis:

- Higher-efficiency envelope components, including infiltration and windows, provided the largest beyond-code savings.
- High-efficiency furnaces and heat pumps had the second greatest impact on beyond-code energy savings.
- High-efficiency water heating and lighting contributed the third largest amount of beyond-code savings.
- Overall, walls exhibited slightly higher U-values than the code reference requirements when following Envelope Enhancement Measure One, thus reducing energy savings.

- Of the few homes where ducts were installed inside conditioned space when not required by Table N1101.1(2), Cadmus' analysis demonstrated they produced significant[27] energy savings.

The modeling results also showed the energy compliance index and percent energy savings remained consistent, independent of a home's energy consumption. Cadmus notes several qualifications that must be applied regarding the simulation model compliance analysis results:

- In many cases, data required to run the models could not be obtained, thus Cadmus assumed components matched other homes in the jurisdiction or statewide average values for the missing data.
- While the aggregate data show average energy use was less than the code level, some of the sampled homes used more energy than the code level and they were offset by homes more efficient than code.

Compliance Benchmarking

Comparing Oregon compliance rates found in this study with energy code compliance rates from other studies proved informative. Although the differences in methodology and metrics make it difficult to drawn meaningful comparisons, it can be informative to note the compliance rates for Northwestern states: Idaho, Montana, and Washington. Historically, Oregon has exhibited relatively high compliance rates, and this study's results indicate Oregon continues to perform well in residential code compliance and enforcement. Table 18 shows the results from the other NEEA studies and two other recent studies.

Table 18. Recent Northwestern States Residential Code Compliance Study Findings

State	Study Date	First Compliance Method and Rate	Second Compliance Method and Rate	Third Compliance Method and Rate
Montana	2012	PNNL checklist—61%	Significant items—81%	Checklist items weighted based on estimated energy consumption impacts—64%
Washington	2012	Modified PNNL checklist—96%	Significant items—97%	Modeling —96.3%
Idaho	2012	PNNL checklist—90%	Significant items—83%	Modeling —100.3%

Notes: Montana results derive from Lee, A., Cook, R., Horton, D. (2012). The compliance metric reported initially for Idaho was the inverse of the compliance index defined in this report so, for consistency, Cadmus revised the original value to be consistent in this table with the compliance index.

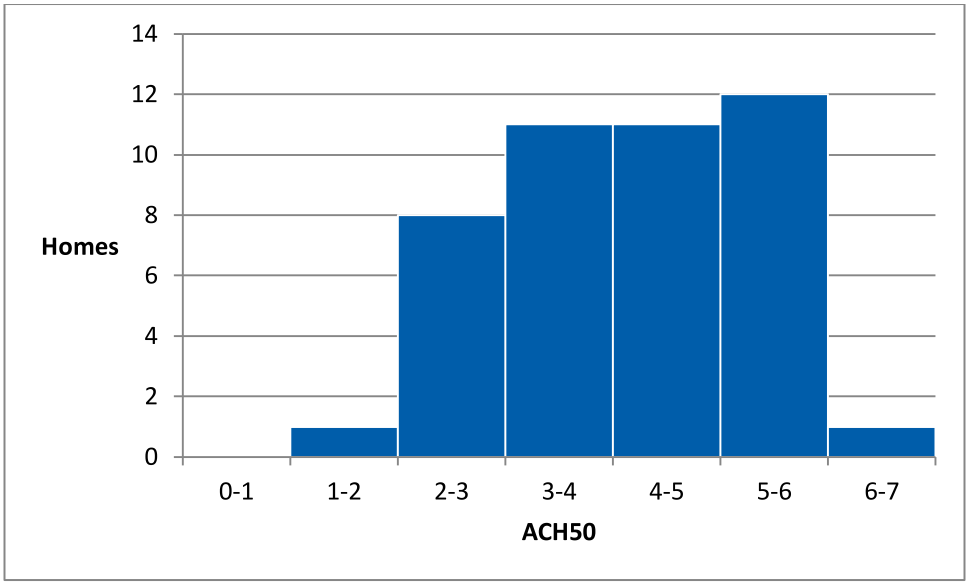
Performance Testing

The study team performed blower door tests on forty-five homes and measured an average result of 4.0 air changes at 50 Pascals (ACH50). Approximately sixty percent of those homes (twenty-

[27] SEEM runs show a reduction of heating energy consumption of approximately eleven percent beyond homes with ducts sealed and not fully inside conditioned space.

eight) followed Envelope Enhancement Measure Five (building tightness testing, ventilation, and duct sealing) to meet an additional measure requirement in Table N1101.1(2). Measure Five requires a blower door value of 6.0 ACH50 or less. As shown in Figure 12, only one of the forty-five homes tested higher than this value.

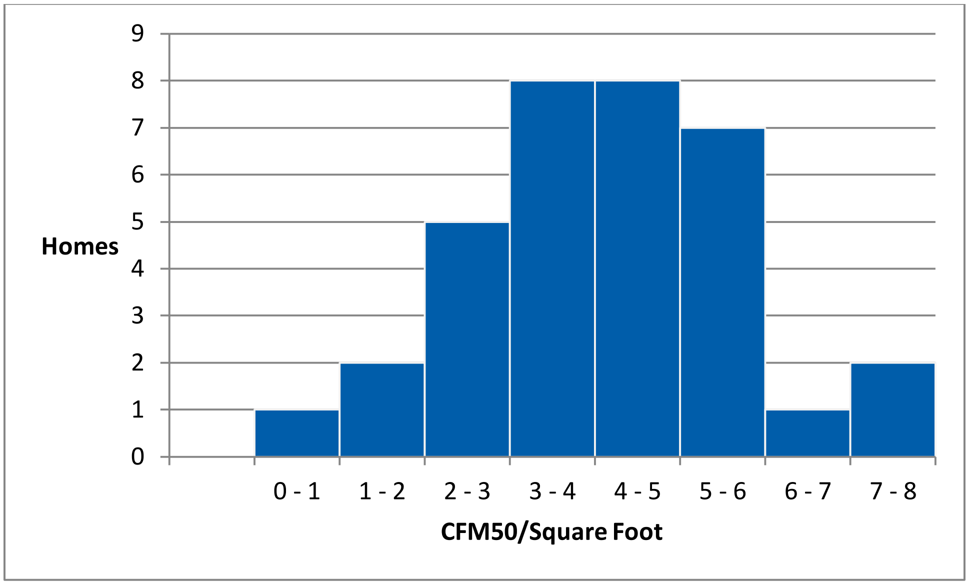
Figure 12. Blower Door Test Values



Builders who allowed the study team to conduct an inspection at the project's finish tended to participate in utility energy-efficiency programs. Of twenty-seven finished homes tested in the Portland Metro area, the study team learned that twenty-one participated in energy-efficiency programs. Additional air sealing measures might be implemented at these homes causing them to be tighter than homes that do not participate in energy-efficiency programs.

The study team also performed duct leakage tests on thirty-four homes and measured an average result of four cubic feet per minute at 50 Pascals (CFM50) per one-hundred square feet of conditioned floor area. All but four of the tests measured duct leakage to outside the conditioned space. Twenty-seven of the tested homes followed Envelope Enhancement Measures Three or Five, requiring duct sealing to meet an additional measure requirement in Table N1101.1(2). Of those twenty-seven homes, twenty-five met the measure requirement of duct leakage less than six CFM50 per one-hundred square feet of conditioned area. As shown in Figure 13, only three of the thirty-four homes tested higher than six CFM50 per one-hundred square feet of conditioned area.

Figure 13. Duct Leakage Test Values



Recommendations

The study team developed the following recommendations addressing three categories: code enhancement, facilitation of code compliance assessments, and the PNNL methodology.

Code Implementation

NEEA and other organizations have actively supported code compliance in the region. This study finds relatively high statewide compliance levels in Oregon, using two different methods. As the high compliance rates likely result in part from these efforts, Cadmus recommends continuing these activities. Cadmus recommends NEEA continue efforts to educate builders and code officials about code and code revisions. Specific recommendations include the following:

1. This study’s findings should be communicated to builders and code officials.
2. Training of builders and code officials on energy code requirements should continue, especially those regarding improved lighting.
3. Develop with Oregon Building Codes Division, a consistent method of documenting chosen code pathways from ORSC Table N1101.1(2).

Compliance Assessments

In conducting this code compliance assessment, challenges emerged. The following steps can facilitate and enhance future studies, increasing the ease of conducting compliance assessments, and simultaneously increasing energy simulation analyses’ accuracy and completeness, based on the PNNL checklists:

1. Take steps to reduce the difficulty of locating and visiting newly constructed homes. The state should investigate development of a statewide repository of code compliance data to facilitate code compliance tracking and future research.
2. Any assistance the state could offer by working with builder organizations to urge builders to allow inspections in future compliance studies would greatly aid such studies.

3. To assess whether the assumptions about unobservable items when visiting homes for this study prove accurate, the study team recommends conducting a pilot study following a small number of homes throughout the entire construction cycle, as described in the PNNL approach. This could provide evidence about the validity of the assumptions.
4. To supplement observable information collected at completed homes, Cadmus recommends infrared inspection of building envelopes to provide information about the quality of insulation installation and air leakage.[28] Weighting a sample heavily toward finished homes and inspecting not observable items with infrared technology could more efficiently use field personnel.[29]

PNNL Methodology

PNNL has sought feedback on its proposed compliance assessment methodology and has made continuous improvements. Using a common methodological approach for demonstrating compliance in all fifty states offers value, and the existing PNNL methodology provides an excellent foundation for further enhancements. The PNNL methodology can be modified to address remaining issues, per the following recommendations:

1. PNNL should investigate the option of using a less comprehensive checklist, such as the "ten significant item" method examined in this study.
2. The weighting system used for PNNL's checklists should be refined to better reflect the greater importance of certain compliance issues. While the checklists currently value items as worth one to three points, a wider range would appropriately capture differences in the relative impact on energy consumption between various compliance items.
3. The current method for estimating compliance makes no adjustment to account for the number of items applicable and observable, equally weighting homes with less data gathered. Cadmus suggests calculating statewide compliance with a weighted average that awards greater weight to the compliance rates of homes with a larger number of applicable and observable checklist items.
4. An energy-modeling component should be incorporated into PNNL's methodology. By combining PNNL's prescriptive checklist with more exact energy consumption metrics for newly constructed homes and individual checklist items, evaluators could present a more an additional view of compliance.

Final Observations

Cadmus finds Oregon has made progress in implementing the latest residential energy codes effectively to achieve high compliance rates. Although the analysis indicates ARRA's ninety percent target has been met, data gaps introduce some uncertainties into the results. The energy modeling analysis indicated, on average, energy efficiency features of homes exceed code requirements. The model results show that ninety-two percent of the homes in the study sample used less energy than they would if they met the code. As energy savings remains the ultimate benefit from code compliance, the state should strive to achieve full compliance in all homes and to even exceed the code requirements.

---

[28] This would likely require winter visits to finished homes to obtain sufficient data, given the need for a large temperature differential between the building and the outdoors.

[29] "RESNET Interim Guidelines for Thermographic Inspection of Buildings." April 2012.

References

Cadmus. 2010. Codes & Standards (C&S) Programs Impact Evaluation, Volume III. Prepared for: California Public Utilities Commission.

Lee, A., Cook, R., Horton, D. 2012. Montana Residential Energy Code Compliance. Cadmus. Prepared for: Northwest Energy Efficiency Alliance.

Lee, A., Standen, B., Donohue, S., Desu, M., Wood, A. 2013. Washington Residential Energy Code Compliance. Cadmus. Prepared for: Northwest Energy Efficiency Alliance.

Lee, A., Standen, B., Donohue, S., Desu, M., Wood, A. 2013. Idaho Residential Energy Code Compliance. Cadmus. Prepared for: Northwest Energy Efficiency Alliance. Misuriello, H.

Kwatra, S., Kushler, M., Nowak, S. 2012. Building Energy Code Advancement through Utility Support and Engagement. American Council for an Energy-Efficient Economy.

NMR Group, Inc.; KEMA, Inc.; The Cadmus Group, Inc.; Conant, D. 2012. Rhode Island 2011 Baseline Study of Single-Family Residential New Construction, Final Report. Submitted to National Grid.

Residential Energy Services Network (RESNET), 2012. “RESNET Interim Guidelines for Thermographic Inspection of Buildings.
http://www.resnet.us/standards/RESNET_IR_interim_guidelines.pdf

U.S. Census Bureau. Accessed 2012a. Building Permits.
http://censtats.census.gov/bldg/bldgprmt.shtml

U.S. Census Bureau. Accessed 2012b. “How the Data are Collected (Survey of Construction).”
http://www.census.gov/construction/nrc/how_the_data_are_collected/soc.html

U.S. Department of Energy (DOE). 2010a. “Compliance Evaluation Checklists.” Energy Efficiency and Renewable Energy.
http://www.energycodes.gov/compliance/evaluation/checklists

U.S. Department of Energy (DOE). 2010b. “REScheck.” Energy Efficiency and Renewable Energy. http://www.energycodes.gov/rescheck/

U.S. Department of Energy (DOE). Accessed 2012a. “Measuring State Compliance.” Energy Efficiency and Renewable Energy.
http://www.energycodes.gov/compliance/evaluation/checklists

Ibid. Section 5.2.

U.S. Department of Energy (DOE). Accessed 2012b. State Sample Generator.
http://energycode.pnl.gov/SampleGen/

Appendix A: Line Item Compliance

This appendix presents results of ninety Cadmus site visits fifty-four compliance items on PNNL's checklist. For each checklist item, the following have been provided:

1. Component section of a compliance item.
2. Description of a compliance item.
3. The compliance item weight, assigned by PNNL.
4. The number of homes in which the compliance item was deemed compliant.
5. The number of homes in which the compliance item was deemed not compliant.
6. The number of homes in which the compliance item was not observed.
7. The number of homes in which the compliance item was not applicable.
8. The percentage of homes in which the compliance item was observed.
9. The percentage of observed homes in which the compliant item was verified.
10. The percentage of verified homes compliant with the item.

Table 19. Rate of Code Compliance by Compliance Criteria, All Homes

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
Wall Insulation	Insulation in contact with warm surface	3	20	5	65	0	100%	28%	80%
	Insulation labeled or R-value provided	2	16	6	68	0	100%	24%	73%
	Wall insulation meets above grade R-value or selected additional measures requirement	3	87	3	0	0	100%	100%	97%
Air Sealing	Attic access hatch sealed and insulated	3	35	13	37	5	94%	56%	73%
	Building tightness test result meets selected additional measures requirement	3	28	0	21	41	54%	57%	100%
	Dampers installed on outdoor intake and exhaust openings	2	65	0	25	0	100%	72%	100%
	Envelope sealed around doors, windows, framing joints, and penetrations	3	39	3	48	0	100%	47%	93%
	Joints and seams sealed checked via visual inspection	3	19	6	65	0	100%	28%	76%
	Openings and penetrations sealed checked via visual inspection	3	24	5	61	0	100%	32%	83%
	Other sources of infiltration sealed	3	15	5	70	0	100%	22%	75%
Ceiling	Flat ceiling insulation meets R-value or selected additional measures requirement	3	78	0	11	1	99%	88%	100%
	Ceiling insulation in contact with warm surface	3	46	1	43	0	100%	52%	98%
	Ceiling insulation labeled or R-value provided	2	43	3	44	0	100%	51%	93%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	Vaulted ceiling insulation meets R-value or selected additional measures requirement	3	12	1	15	61	31%	46%	92%
Doors	Doors meet selected additional measures requirement	3	0	1	28	61	32%	3%	0%
	Exterior doors U-value meets requirement	3	32	2	55	1	99%	38%	94%
	Exterior doors with_2.5 ft^2 glazing and U-value meets requirement	3	5	1	60	24	73%	9%	83%
Windows	Skylights label available	2	0	2	13	75	17%	13%	0%
	Skylights U-value meets requirement	3	0	1	14	75	17%	7%	0%
	Window area limitation meets requirement	3	0	0	2	88	2%	0%	-
	Window area meets selected additional measures requirement	3	0	0	2	88	2%	0%	-
	Windows air leakage meets requirement	3	0	0	90	0	100%	0%	-
	Windows label available	2	22	4	63	1	99%	29%	85%
	Windows U-value or selected additional measures meets requirement	3	71	2	17	0	100%	81%	97%
	Windows and doors labeled for air leakage	2	1	5	84	0	100%	7%	17%
Floor Insulation	Crawl space continuous vapor retarder installed	3	59	1	24	6	93%	71%	98%
	Floor insulation in contact with warm surface	3	47	5	36	2	98%	59%	90%
	Floor insulation labeled or R-value provided	2	49	2	37	2	98%	58%	96%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	Floors insulation meets underfloor R-value or selected additional measures requirement	3	56	5	29	0	100%	68%	92%
Foundation Insulation	Heated slab insulation R-value requirement	3	0	0	2	88	2%	0%	-
	Heated slab interior R-value requirement	3	0	0	2	88	2%	0%	-
	Plans and specifications available	3	45	1	43	1	99%	52%	98%
	Slab edge perimeter insulation extends from top of slab extends 24 inch V or 24 inch H	3	0	0	14	76	16%	0%	-
	Slab edge perimeter insulation R-value meets requirement	3	0	0	14	76	16%	0%	-
	Below grade wall insulation R-value meets requirement	3	2	0	12	76	16%	14%	100%
Domestic Hot Water	Domestic hot water pipe Insulation R-value meets requirement	2	11	2	77	0	100%	14%	85%
	Water heating equipment meets selected additional measures requirement	3	0	0	2	88	2%	0%	-
HVAC	Heating equipment and duct location meets selected additional measures requirement	3	3	1	5	81	10%	44%	75%
	HVAC equipment correctly sized per ACC Manual J and S or other approved methods	2	1	2	83	0	100%	3%	33%
	Outdoor thermostat and heat pump controls installed on heat pumps	2	3	1	28	58	36%	13%	75%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	Duct leakage test result meets selected additional measures requirement	3	28	0	38	24	73%	42%	100%
	Forced air duct insulation R-value meets requirement	3	59	1	16	12	86%	79%	98%
	Heating equipment efficiency meets selected additional measures requirement	3	59	0	24	6	93%	71%	100%
	HVAC load calculations available	2	1	21	68	0	100%	24%	5%
	Outdoor combustion air vented directly from outdoors requirement and combust furnaces installed	2	29	0	20	41	54%	59%	100%
	Outdoor combustion air required for fireplaces and stoves	2	11	0	48	31	66%	19%	100%
	Heating pipe insulation R-value meets requirement	2	0	0	4	86	4%	0%	-
	Programmable thermostats installed	2	46	1	43	0	100%	52%	98%
Lighting	Fixtures installed in envelope	2	30	0	43	17	81%	41%	100%
	Lighting meets minimum of fifty percent of fixtures outfitted with high-efficacy lighting or selected additional measures requirement	3	29	9	52	0	100%	42%	76%
Other	Energy monitoring system meets selected additional measures requirement	3	0	0	2	88	2%	0%	-
	Mechanical ventilation meets selected additional measures requirement	3	29	0	21	40	56%	58%	100%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	Solar DHW system meets selected additional measures requirement	3	0	0	2	88	2%	0%	-
	Solar PV system meets selected additional measures requirement	3	0	0	2	88	2%	0%	-

Appendix B: Derivation of Weights

As building codes compliance varies across counties, Cadmus treated counties as a stratification variable in analyzing results. Within each county, the study team treated building starts as sampling units.

This section utilizes the following notation:

- Counties indexed with the letter *i*.
  - N_i as the population size (i.e., total number of building starts) for county *i*.
  - n_i as the sample size for county *i*.
- Building starts indexed with the letter *k*.
  - $x_{i,j}$ as the compliance rate for the *j*th building in county *i*.

The study team estimates the compliance rate for the *i*th sampled county as:

$$\overline{x}_i = \sum \frac{x_{i,j}}{n_i} \text{ (The sum is over sampled buildings } j \text{ within county } i\text{.)}$$

In terms of weighting, this means, in estimating a county's compliance rate, the weight attached to the sample point $x_{i,j}$ equals:

$$w_i^{\text{county}} = \frac{N_i}{n_i}$$

The regional compliance rate could be estimated as the weighted average of the climate zone compliance rates:

$$\overline{\text{Region}} = \frac{1}{\sum N_i} \cdot \sum \frac{x_{i,j} \cdot N_i}{n_i} \text{ (Sum runs over all sampled counties.)}$$

Appendix C: PNNL Checklists

A sample of the PNNL checklist study team converted to cover the Oregon code is presented in this appendix.

Builder	
Address	
Jurisdiction	
Field Technician	

Building Characteristics	Value
Type of Home	Single-Family Attached
	Single-Family Detached
	Multi-Family
Levels Above Grade	
Thermometer Type	Programmable
	Manual
Year Built	
Number of Bedrooms	
Finished Square Footage	
Total Square Footage	
Number of Light Bulbs	
Number of Efficient Light Bulbs	
Envelope Enhancement Measure	
Conservation Measure	
Door Type	Solid Wood
	Insulated
	Hollow Core
Door Height	
Door Width	
Foundation	

Type	Conditioned Basement
	Unconditioned Basement
	Unconditioned Crawlspace
	Conditioned Crawlspace
	Slab on grade
Wall Area	
Location	Between Conditioned Space and Ground
	Between Conditioned Space and Unconditioned Space
	Between Conditioned Space and Ambient
	Between Unconditioned Space and Ambient/Ground
Depth Below Grade	
Height Above Grade	
Perimeter	
Insulation R-Value	
Foundation Insulation Type	
Slab Floor	
Perimeter	
Slab Floor Area	
Insulation Vertical R-Value	
Insulation Vertical Depth	
Insulation Horizontal R-Value	
Insulation Horizontal Length	
Frame Floor	
Area	
Location	Between Conditioned Space and Crawlspace
	Between Conditioned Space and Garage
	Between Conditioned Space and Outside
Framing Material	Wood

	Metal
Framing Spacing	
Cavity Depth	
Cavity Insulation Material	Fiberglass Batt
	Loose Fill Fiberglass
	Loose Fill Cellulose
	Foam
Cavity R-Value	
Continuous Insulation R-Value	
Frame Floor	
Area	
Location	Between Conditioned Space and Crawlspace
	Between Conditioned Space and Garage
	Between Conditioned Space and Outside
Framing Material	Wood
	Metal
Framing Spacing	
Cavity Depth	
Cavity Insulation Material	Fiberglass Batt
	Loose Fill Fiberglass
	Loose Fill Cellulose
	Foam
Cavity R-Value	
Continuous Insulation R-Value	
Wall	
Area	
Ceiling/Attic Type	Vented Attic
	Unvented Attic

	Vaulted
Framing Material	Wood
	Metal
Framing Spacing	
Cavity Depth	
Insulation Material	Fiberglass Batt
	Loose Fill Fiberglass
	Loose Fill Cellulose
	Foam
R-Value	
Ceiling Insulation Depth	
Air Infiltration	
Blower Door Location	Back Door
	Front Door
Ring Size	Open,A,B,C
House Test Pressure (Pascals)	
Blower Door CFM50	
Fan Pressure (Pa)	
Mechanical Ventilation Type	Exhaust
	Supply
	Balanced
HRV/ERV Efficiency	
Windows	
Pane Type	Single
	Double
	Triple
Frame Type	Wood
	Metal

	Vinyl
	Composite
Direction	
U-Value	
SHGC	
Heating	
Fuel Type	Gas
	Electric
	Propane
	Oil
	Wood
Heating Type	Furnace
	Baseboard
	Boiler
Make	
Model	
Efficiency	
Central Air Conditioning	
Condenser Make	
Condenser Model	
Air Handler Make	
Air Handler Model	
Evaporator Make	
Evaporator Model	
SEER	
Tons	
Heat Pump	
Condenser Make	

Condenser Model	
Air Handler Make	
Air Handler Model	
Evaporator Make	
Evaporator Model	
HSPF	
SEER	
Tons	
Ductless Heat Pump	
Condenser Make	
Condenser Model	
HSPF	
SEER	
Water Heater	
Fuel Type	Gas
	Electric
Type	Tank
	Tankless
Make	
Model	
Energy Factor	
Tank Size	
Ducts	
Location	Crawlspace
	Attic
	Conditioned Space
Supply % Location	
Return % Location	

Duct Sealing	All Sealed
	Some Sealed
	None Sealed
Sealing Material	Mastic
	Tape
R-Value	
Duct Type	Flex
	Metal
Duct Test	
House Pressure WRT Outside	
Duct Pressure WRT Outside	
Fan Pressure (Pa)	
Ring Size	Open, 1, 2, 3
Duct Leakage to Outside (CFM50)	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Wall insulation-below grade	R-Value			Y N/A N N/O	
Slab edge perimeter	R-Value			Y N/A N N/O	
Heated slab interior	R-Value			Y N/A N N/O	
Heated Slab Insulation	R-Value			Y N/A N N/O	
Slab edge perimeter	Insulation extends from top of slab and extends 24" vertical or 24" horizontal			Y N/A N N/O	
Plans & Specifications	Available			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Underfloor R-Value				Y N/A N N/O	
Underfloor	Underfloors Meets Selected Additional Measures requirement			Y N/A N N/O	
Underfloor	Underfloors Crawl space continuous vapor retarder installed			Y N/A N N/O	
Underfloor	Insulation labeled or R-value provided			Y N/A N N/O	
Underfloor	Insulation in contact with warm surface			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Wall insulation-above grade	R-Value			Y N/A N N/O	
Wall Insulation -Above Grade	Meets Selected Additional Measures requirement			Y N/A N N/O	
Insulation	Insulation labeled or R-value provided			Y N/A N N/O	
Insulation	Insulation in contact with warm surface			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Windows	U-Value			Y N/A N N/O	
Window area limitation	% Floor Area			Y N/A N N/O	
Skylights	U-Value			Y N/A N N/O	
Exterior doors	U-Value			Y N/A N N/O	
Exterior doors w/>2.5 ft2 glazing	U-Value			Y N/A N N/O	
Windows	Meets Selected Additional Measures requirement			Y N/A N N/O	
Window Area	Meets Selected Additional Measures requirement			Y N/A N N/O	
Doors	Meets Selected Additional Measures requirement			Y N/A N N/O	
Windows	Label available			Y N/A N N/O	
Windows	Air leakage meets requirement			Y N/A N N/O	
Windows and doors	Labeled for air leakage			Y N/A N N/O	
Skylights	Label available			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Flat ceilings	R-Value			Y N/A N N/O	
Vaulted ceilings	R-Value			Y N/A N N/O	
Flat ceilings	Meets Selected Additional Measures requirement			Y N/A N N/O	
Vaulted ceilings	Meets Selected Additional Measures requirement			Y N/A N N/O	
Flat ceilings	Insulation labeled or R-value provided			Y N/A N N/O	
Flat ceilings	Insulation in contact with warm surface			Y N/A N N/O	
Vaulted ceilings	Insulation labeled or R-value provided			Y N/A N N/O	
Vaulted ceilings	Insulation in contact with warm surface			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Air Sealing	Building tightness test result meets selected Additional Measures requirement			Y N/A N N/O	
Air Sealing	Dampers installed on outdoor intake and exhaust openings			Y N/A N N/O	
Air Sealing	Openings and penetrations sealed via visual inspection			Y N/A N N/O	
Air Sealing	Joints and seams sealed via visual inspection			Y N/A N N/O	
Air Sealing	Other sources of infiltration sealed			Y N/A N N/O	
Air Sealing	Attic access hatch sealed and insulated			Y N/A N N/O	
Air Sealing	Envelope sealed around doors, windows, framing joints, and penetrations.			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
Lighting	Minimum 50% of Fixtures Outfitted With High Efficiency Lighting			Y N/A N N/O	
Lighting	Meets Selected Additional Measures requirement			Y N/A N N/O	
Recessed Lighting	Fixtures installed in envelope either: 1) No penetrations in recessed fixture 2) Rated in accordance with ASTM E283 3) Installed in air-tight construction			Y N/A N N/O	
Energy Monitor	Energy Monitoring System meets selected Additional Measures requirement			Y N/A N N/O	
Solar PV	Solar PV System meets selected Additional Measures requirement			Y N/A N N/O	
Solar DHW	Solar DHW System meets selected Additional Measures requirement			Y N/A N N/O	

Building Component	Compliance Requirement	Plans Verified Value	Field Verified Value	Component Complies	Comments/Assumptions
HVAC	Forced air duct insulation			Y N/A N N/O	
HVAC	Pipe Insulation Heating			Y N/A N N/O	
DHW	Pipe Insulation DHW			Y N/A N N/O	
HVAC	Heating equipment efficiency meets selected Additional Measures requirement			Y N/A N N/O	
DHW	Water heating equipment meets selected Additional Measures requirement			Y N/A N N/O	
HVAC	Duct leakage test result meets selected Additional Measures requirement			Y N/A N N/O	
HVAC	Heating equipment and duct location meets selected Additional Measures requirement			Y N/A N N/O	
Whole-Home Mechanical Ventilation	Mechanical Ventilation meets selected Additional Measures requirement			Y N/A N N/O	
HVAC	Outdoor thermostat and heat pump controls required on Heat Pumps			Y N/A N N/O	
HVAC	Outdoor combustion air required for fireplaces and stoves			Y N/A N N/O	
HVAC	Outdoor combustion air vented directly from outdoors required for combustion furnaces installed in building envelope			Y N/A N N/O	
HVAC	HVAC loads calculations available			Y N/A N N/O	
HVAC	HVAC equipment correctly sized per ACCA Manual J and S, or other approved methods:			Y N/A N N/O	
HVAC	Programmable thermostats installed			Y N/A N N/O	

Appendix D: 2011 Oregon Code Requirements

This appendix presents the 2011 residential code 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-0.060	R-21 [c]	[d]	[d]
Wall insulation-below grade [e]	F-0.565	R-15	F-0.565	R-15
Flat ceilings [f]	U-0.031	R-38	U-0.025	R-49
Vaulted ceilings [g]	U-0.042	R-38[g]	U-0.027	R-38A[h]
Underfloors	U-0.028	R-30	U-0.028	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-0.35	U-0.35	U-0.35	U-0.35
Window area limitation [k]	n/a	n/a	n/a	n/a
Skylights [l]	U-0.60	U-0.60	U-0.60	U-0.60
Exterior doors [m]	U-0.20	U-0.20	U-0.54	U-0.54
Exterior doors w/>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 N1101.1(2)
ADDITIONAL MEASURES

Envelope Enhancement Measure (Select One)		
	1	**High efficiency walls & windows:** Exterior walls – U-0.047 / R-19+5 (insulation sheathing) / SIPS, and Windows – Max 15% of conditioned area; or Windows-U-0.30
	2	**High efficiency envelope:**
		Exterior walls – U-0.058 / R-21 Intermediate framing, and Vaulted ceilings – U-0.033 / R-30A [d, e], and Flat ceilings – U-0.025 / R-49, and Framed floors – U-0.025 / R-38, and Windows – U-0.30; and Doors- All doors U-0.20, or Additional 15 percent of permanently installed lighting fixtures as high-efficacy lamps or Conservation Measure D and E
	3	**High efficiency ceiling, windows & duct sealing:** (Cannot be used with Conservation Measure E)
		Vaulted ceilings – U-0.033 / R-30A [d,e], and Flat ceilings – U-0.025 / R-49, and Windows-U-0.30 Windows- U-0.30, and Performance tested duct systems [b]
	4	**High efficiency thermal envelope UA:**
		Proposed UA is 15% lower than the Code UA when calculated in Table N1104.1(1)
	5	**Building tightness testing, ventilation & duct sealing:** (Cannot be used with Conservation Measure E)
		A mechanical exhaust, supply, or combination system providing whole-building ventilation rates specified in Table 1101.1(3), or ASHRAE 62.2, and The dwelling shall be tested with a blower door and found to exhibit no more than: 1. 6.0 air changes per hour [f], and Performance tested duct systems [b]
	6	**Ducted HVAC systems within conditioned space:** (Cannot be used with Conservation Measure B or C)
		All ducts and air handler are contained within building envelope [i]

Conservation Measure (Select One)		
	A	**High efficiency HVAC system:** Gas-fired furnace or boiler with minimum AFUE of 90% [a], or Air-source heat pump with minimum HSPF of 8.5 or Closed-loop ground source heat pump with minimum COP of 3.0
	B	**Ducted HVAC systems within conditioned space:** All ducts and air handler are contained within building envelope [i]
	C	**Ductless heat pump:** Replace electric resistance heating in at least the primary zone of dwelling with at least one ductless mini-split heat pump having a minimum HSPF of 8.5. Unit shall not have integrated backup resistance heat, and the unit (or units, if more than one is installed in the dwelling) shall be sized to have capacity to meet the entire dwelling design heat loss rate at outdoor design temperature condition. Conventional electric resistance heating may be provided for any secondary zones in the dwelling. A packaged terminal heat pump (PTHP) with comparable efficiency ratings may be used when no supplemental zonal heaters are installed in the building and integrated backup resistant heat is allowed in a PTHP.
	D	**High efficiency water heating & lighting:** Natural gas/propane, on-demand water heating with min EF of 0.80, and A minimum 75 percent of permanently installed lighting fixtures as CFL or linear fluorescent or a min efficacy of 40 lumens per watt as specified in Section N1107.2 [c]
	E	**Energy management device & duct sealing:** Whole building energy management device that is capable of monitoring or controlling energy consumption, and Performance tested duct systems [b], and A minimum 75 percent of permanently installed lighting fixtures as high-efficacy lamps.
	F	**Solar photovoltaic:** Minimum 1 watt / sq ft conditioned floor space [g]
	G	**Solar water heating:** Minimum of 40 ft^2 of gross collector area [h]

For SI: 1 square foot = 0.093 m, 1 watt per square foot = 10.8 W/m.

a. Furnaces located within the building envelope shall have sealed combustion air installed. Combustion air shall be ducted directly from the outdoors.
b. Documentation of Performance Tested Ductwork shall be submitted to the building official upon completion of work. This work shall be performed by a contractor certified by the Oregon Department of Energy's (ODOE) Residential Energy Tax Credit program and documentation shall be provided that work demonstrates conformance to ODOE duct performance standards.
c. Section N1107.2 requires 50 percent of permanently installed lighting fixtures to contain high efficacy lamps. Each of these additional measures adds an additional percent to the Section N1107.2 requirement.
d. A = advanced frame construction, which shall provide full required ceiling insulation value to the outside of exterior walls.
e. The maximum vaulted ceiling surface area shall not be greater than 50 percent of the total heated space floor area unless vaulted area has a *U*-factor no greater than *U*-0.026.
f. Building tightness test shall be conducted with a blower door depressurizing the dwelling 50 Pascal's from ambient conditions. Documentation of blower door test shall be submitted to the Building Official upon completion of work.
g. Solar electric system size shall include documentation indicating that Total Solar Resource Fraction is not less than 75 percent.
h. Solar water heating panels shall be Solar Rating and Certification Corporation (SRCC) Standard OG-300 certified and labeled, with documentation indicating that Total Solar Resource Fraction is not less than 75 percent.
i. A total of 5 percent of an HVAC systems ductwork shall be permitted to be located outside of the conditioned space. Ducts located outside the conditioned space shall have insulation installed as required in this code.

TABLE N1104.1(2)— APPROVED DEFAULT U-FACTORS

FLAT CEILINGS[a]		
Insulation	**Type**	**U-Factor**
R-38	Conventional framing	0.031
R-38	=>8/12 roof pitch	0.028
R-38	Advance framing[c]	0.026
R-49	Conventional framing	0.025
R-49	=>8/12 roof pitch	0.024
R-49	Advance framing[c]	0.020
VAULTED CEILINGS[a]		
Insulation	**Type**	**U-Factor**
R-21	Rafter framings	0.047
R-30	Rafter framing	0.033
R-38	Rafter framing	0.027
R-21	Scissors truss	0.055
R-30	Scissors truss	0.046
R-38	Scissors truss	0.042
R-49	Scissors truss	0.039
R-30	Advance scissors truss[c]	0.032
R-38	Advance scissors truss[c]	0.026
R-49	Advance scissors truss[c]	0.020
EPS FOAM CORE PANEL VAULTED CEILINGS		
Insulation	**Type**	**U-Factor**
R-29	8-1/4" EPS foam core panel	0.037
R-37	10-1/4" EPS foam core panel	0.030
R-44	12-1/4" EPS foam core panel	0.025
FLOORS[a]		
Insulation	**Type**	**U-Factor**
R-21	Underfloor	0.035
R-25	Underfloor	0.032
R-30	Underfloor	0.028
SLAB-ON-GRADE		
Insulation	**Type**	**F-Factor[f]**
R-10	Slab edge	0.54
R-15	Slab edge	0.52
EPS FOAM CORE PANEL EXTERIOR WALLS		
Insulation	**Type**	**U-Factor**
R-14.88	4-1/2" EPS foam core panel	0.065
R-22.58	6-1/4" EPS foam core panel	0.045
R-29.31	8-1/4" EPS foam core panel	0.035

EXTERIOR WALLS[a]			
Insulation	**Insulation Sheathing**	**Framing**	**U-Factor**
R-15	0	Conventional framing	0.080
R-15	0	Intermediate framing[b]	0.075
R-19	0	Conventional framing	0.065
R-19	0	Intermediate framing[b]	0.063
R-19	0	Advance framing[d]	0.061
R-21	0	Conventional framing	0.060
R-21	0	Intermediate framing[b]	0.058
R-21	0	Advance framing[d]	0.055
R-11	3.5[e]	Conventional framing	0.069
R-11	5[e]	Conventional framing	0.063
R-11	7[e]	Conventional framing	0.055
R-11	3.5[e]	Advance framing[d]	0.067
R-11	5[e]	Advance framing[d]	0.061
R-11	7[e]	Advance framing[d]	0.054
R-13	3.5[e]	Conventional framing	0.064
R-13	5[e]	Conventional framing	0.058
R-13	7[e]	Conventional framing	0.052
R-13	3.5[e]	Advance framing[d]	0.062
R-13	5[e]	Advance framing[d]	0.056
R-13	7[e]	Advance framing[d]	0.050
R-15	3.5[e]	Conventional framing	0.060
R-15	5[e]	Conventional framing	0.055
R-15	7[e]	Conventional framing	0.049
R-15	3.5[e]	Advance framing[d]	0.057
R-15	5[e]	Advance framing[d]	0.052
R-15	7[e]	Advance framing[d]	0.047
R-19	3.5[e]	Conventional framing	0.052
R-19	5[e]	Conventional framing	0.047
R-19	7[e]	Conventional framing	0.043
R-19	3.5[e]	Advance framing[d]	0.049
R-19	5[e]	Advance framing[d]	0.045
R-19	7[e]	Advance framing[d]	0.041
R-21	3.5[e]	Conventional framing	0.048
R-21	5[e]	Conventional framing	0.044
R-21	7[e]	Conventional framing	0.040
R-21	3.5[e]	Advance framing[d]	0.044
R-21	5[e]	Advance framing[d]	0.042
R-21	7[e]	Advance framing[d]	0.038

Appendix E: 2008 Oregon Code Requirements

This appendix presents the 2008 residential code requirements.

Measure[A]	Effective 04/01/08
Underfloor insulation	**R-30**
Slab-on-grade insulation	R-15
Heated slab, i.e., hydronic heat – underneath entire slab	**R-10**
Windows & sliding glass doors	**U-0.35**
Skylights≤2% heated space floor area[B, C]	**U-0.75[B, C]**
Skylights>2% heated space floor area[C]	**U-0.60[C]**
Exterior Door ≤24 ft^2	U-0.54
Exterior Door >24 ft^2	U-0.20
Exterior doors with >2 ft^2 glazing[D]	U-0.40[D]
Above grade wall insulation	R-21
Below grade wall insulation	R-15
Flat ceiling insulation	R-38
Vaulted ceilings – limited to ≤50% heated space floor area	**R-38[E]**
Vaulted ceilings – >50% heated space floor area	R-38[F]
High efficiency lighting[G]	**50% fixtures[G]**
Forced air duct insulation	R-8

	Additional Measure Path	Description
1	High efficiency HVAC	90% AFUE furnace or boiler, or 8.5 HSPF heat pump, or 3.0 COP ground-source heat pump
2	High efficiency ducts	Performance Tested Ductwork performed by a contractor certified by ODOE Residential Energy Tax Credit program, or All ducts within the conditioned space and air handler must be sealed combustion-air unit with air supply ducted from outdoors and is located within the conditioned space
3	High efficiency building envelope	R-24 exterior walls, R-30 advanced framing vaulted ceilings, R-49 flat ceilings, and U-0.32 windows and sliding glass doors
4	Zonal electric heat, or ductless furnace/heat pump and one of the high efficiency measures described	75% of permanently-installed lighting fixtures are fitted with energy efficient lamps, or U-0.32 windows and sliding glass doors, or R-30 advanced framing vaulted ceilings and R-49 flat ceilings, or R-24 exterior walls
5	High efficiency windows/ceiling/lighting	R-30 advanced framing vaulted ceilings, R-49 flat ceilings, U-0.32 windows and sliding glass doors, and 75% of permanently-installed lighting fixtures are fitted with energy efficient lamps
6	High efficiency windows/ceiling/water heating	R-30 advanced framing vaulted ceilings, R-49 flat ceilings, U-0.32 windows and sliding glass doors, and natural gas/propane, on-demand water heating with minimum EF of 0.80.
7	High efficiency water heating/lighting	Natural gas/propane, on-demand water heating with min EF of 0.80 and 75% of permanently-installed lighting fixtures have efficient lamps
8	Solar photovoltaic	Minimum 1 Watt / sq ft. conditioned floor space with documentation indicating that Total Solar Resource Fraction is not less than 75%.
9	Solar water heating	Panels shall be Solar Rating and Certification Corporation (SRCC) Standard OG-300 certified and labeled, with documentation indicating that Total Solar Resource Fraction is not less than 75%.

Appendix F: Water Heating Calculation

Water heating energy consumption was estimated using the average water heating efficiency by systems type for as-built homes and the minimum code efficiency factor for reference homes. The following equation provided water heating energy consumption:

$$\frac{1}{Water\ Heater\ EF} \times \frac{Gallons}{Day} \times 365 \times 8.3 \times \frac{Outlet\ H2O\ °\mathrm{F} - \ Inlet\ H20\ °\mathrm{F}}{100{,}000} = Annual\ Energy\ Use, 100{,}000 BTU$$

With the following factors defined:

Gallons/Day: Gallons per day is assumed to be 20 gallons per person per day[30] and the number of occupants is determined as the number of bedrooms plus one occupant.(Example: 3 bedroom house = 3 occupants + 1 occupant = 4 occupants)

Outlet H2O °F: 120°F from Oregon State Energy Code 2009 assumed water heater outlet temperature.

Inlet H20 °F: 58°F from RTF assumptions for water heating measures.[31]

The as-built and reference energy consumptions were added to the respective energy consumption for each as-built and reference home.

30 IECC 2009 assumption for hot water consumption per person.

31 RTF document "*RTF Water Heaters rResDHW_v2_3.xls*"

Appendix G: Lighting Consumption Calculation

Estimated lighting energy consumption was calculated using secondary data sources for the RTF data and from primary site visit data. The following factors provided estimates of lighting energy consumption:

- Lamps Per Home(LPH): This data point was determined from lighting audit data during the site visits. Homes with an unknown number of lamps were assumed to follow the same number of lamps per square foot(0.0296 lamps/ft^2) as the known homes.
- % High Efficacy (%HE): This data point was determined from lighting audit data during the site visits. Homes with an unknown percentage of high efficacy lamps were assumed to follow the same % of high efficacy lamps as home that did not follow Envelope Enhancement measure 2 or Conservation measure D(59.3% high efficacy) as the known homes.
- Hours of Use (HOU): Hours of use were assumed to be 3 hours per lamp per day.
- Watts baseline(b_{watts}): Wattage of a 60 watt incandescent lamp
- Watts efficient(e_{watts}): Wattage of a 13 watt CFL lamp

The equation used to calculate total energy consumption with lighting installed follows:

$$\frac{LPH * HOU * 356 * \%HE * e_{watts} + (1 - \%HE) * b_{watts}}{1000} = Annual\ Home\ Lighting\ kWh$$