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Washington Residential Energy Code Compliance

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1. Executive Summary

1.1. Background

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

This report describes the study of Washington residential compliance with the revised state energy code: 2009 Washington State Energy Code (WSEC). Builders can choose from three approaches to demonstrate compliance: prescriptive, component performance, and systems analysis. The prescriptive approach sets minimum requirements for each building component. The component performance approach allows the builder to tradeoff efficiencies of different components, as long as the overall component thermal performance (UA) meets requirements. The systems analysis approach requires the modeled energy use of a house to not exceed the modeled usage of the house, if built to just meet the prescriptive requirements (the reference house).

1.2. Objectives and Approach

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

- Analyze and report current rate of energy code statewide compliance in new residential construction in Washington, based on the 2009 WSEC.
- Review and comment on the various approaches for assessing code compliance.
- Determine aspects of current energy code in which enhanced code compliance would lead to the largest reductions in home energy consumption.
- Assess an approach to analyze code compliance based on the most significant items in determining energy impacts.

The compliance rate analysis in this study assesses actual compliance of homes built to the current standard. It is important to distinguish between the **compliance rate analyses** conducted for this study and the **compliance demonstration approach** used by builders to show compliance with the code for individual houses. The two methods used to analyze, or assess, code compliance in this study were developed specifically to research observed code compliance for a sample of houses and should not be confused with the compliance demonstration approaches available to builders.

1.2.1. Data Collection

The first step in the study approach was developing a sample frame and sample of newly constructed homes. The approach was patterned after one developed by the Pacific Northwest National Laboratory (PNNL) as part of 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 a three-stage approach to select a sample of new homes to include in site visits. The three stages were:

- County selection
- Jurisdiction selection
- Building selection

Because of the challenges expected in trying to conduct site visits and multiple visits to each home, the study team expanded the sample to sixty-six homes, instead of the forty-four generated by the PNNL methodology.

Cadmus staff conducted the site visits, and obtained building department permit information. The building characteristics were compiled in a checklist designed by PNNL for assessing code compliance. Based on fifty-four criteria, the study organized the checklist into five distinct construction stages, and a Washington state code-specific section. Additional data collected allowed building energy simulation runs.

1.2.2. Data Analysis

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

1. PNNL checklist method: This approach was used to demonstrate and test the method developed by PNNL and made available for compliance analysis studies. It analyzed how well the studied homes complied with each process and efficiency requirement of the code.
2. Significant item methodology: This approach analyzed compliance based on only measures that were considered to have the most significant impact on energy use. It was evaluated as a less complex alternative to the complete checklist method.

The PNNL checklist method produces a compliance rate using site visit data analyzed based on the approach used by the builder to comply with the code. Each item on the checklist is assigned a weight used to calculate compliance points. The checklist incorporates all code requirements, including process and documentation requirements, as well as energy-efficiency requirements. In some cases, the team used available data from homes to fill gaps in the data for other homes. Compliance was calculated 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 issue, in collaboration with NEEA, Cadmus developed an alternate, less complex methodology that encompasses only items with the most significant effect on compliance and energy use. Nine items were included in this analysis and compliance was determined as the ratio of the number complying to the total number observable. All items were weighted equally. The nine items encompassing this analysis are:

1. Window glazing U-factor,
2. Duct sealing,
3. Ducts located away from building cavities,
4. Floor insulation R-value,
5. Wall insulation R-value,
6. Ceiling insulation R-value,
7. Air sealing,
8. High-efficiency lighting, and
9. WSEC Chapter Nine credit options.[1]

In the third analysis, 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 method was applied to provide an estimate of the energy effects of code compliance in terms of an energy compliance index. The analysis was based on the approach specified by the 2009 WSEC. The code specifies lighting requirements, but the software does not model detailed lighting characteristics. To address effects of lighting energy, Cadmus conducted a side calculation accounting for lighting efficiency. In addition, a separate calculation was conducted to analyze water heating energy use. For each home, the effect of compliance on energy consumption was calculated based on the sum of the space conditioning, water heating, and lighting energy used in the reference home and the as-built home.

[1] Chapter Nine credits relate to a requirement to meet all other code requirements and achieve an additional credit based on pre-assigned credits for options such as installing high-efficiency HVAC equipment, high-efficiency water heating, or renewable energy. Chapter Nine also includes a penalty for dwellings larger than 5000 square feet.

1.3. Major Findings

Assessing code compliance through field data collection proved to be challenging because of the difficulty observing all measures covered by the code in a single visit. To fill gaps in the data collected, this study relied on building plans, data from other homes, and code default values, when necessary. The data gaps introduced uncertainty in the compliance estimates; however, when the effect of data gaps was investigated for the two code requirements for which the least data were available, the uncertainty introduced was relatively small—on the order of ten percent.

The two methods to estimate compliance rates produced similar compliance estimates as shown in Table 1.

Table 1. Code Compliance Levels Determined by Two Methods

Methodology	Statewide Weighted Compliance Rate	90% Confidence Level Precision
Checklist	96%	2%
Significant Item	97%	2%

Both methods indicated high compliance with the residential code in Washington. The ARRA legislation establishes that states should strive to reach at least ninety percent compliance overall by 2017. Using the method developed by PNNL, compliance in Washington currently exceeds that level.

The energy modeling approach indicated that the impact of compliance overall is at a level where residential energy use for space heating, cooling, lighting, and water heating is about four percent less than if homes just met the code. High-efficiency heating equipment contributed the most to beyond-code savings.

The compliance estimates from the checklist and significant item methods were highly correlated (at better than the 0.0001 significance level). This suggested it should be possible to estimate checklist compliance reasonably accurately by determining compliance of a subset of only the nine items used in the significant item method. However, data were difficult to obtain for several of these items, which created uncertainty in the estimates. In contrast to the checklist method, there was no statistically significant relationship between the compliance estimates from the significant item method and energy use modeling. Consequently, it was not possible to conclude that the significant item method provided reliable information about the energy impacts of compliance.

Although the overall compliance results were positive, the team identified some areas that should receive attention.

- On the average, compliance was relatively low with the floor and foundation insulation requirements.
- The final lighting installed in the homes was not observable very frequently (observable at only thirty-five percent of the homes), but when it was the compliance rate was 100 percent and lighting energy use was a significant component of total energy consumption.

2. Project Background

As part of its mission, the Northwest Energy Efficiency Alliance (NEEA) commits to achieving 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 the State of Washington. This effort to measure compliance has roots in the 2009 American Recovery and Reinvestment Act (ARRA), which provided funding to states, contingent upon a commitment to adopt the latest model energy codes, and to develop and implement a plan, including active training and enforcement provisions, to achieve at least ninety percent compliance overall with target codes by 2017.

As the governors of all fifty states pledged to meet the ninety percent compliance target, studies across the country are being conducted to examine code compliance. To support these efforts, the U.S. Department of Energy (DOE) requested 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 Washington residential new construction compliance with the revised state energy code—2009 Washington State Energy Code. In Washington, building codes fall under the Washington State Building Code Council's jurisdiction by default. Local city and county governments, however, may choose to enforce state building codes, including the energy code, using their own building officials.

There are three different approaches builders can use to demonstrate compliance with the energy code: prescriptive, component performance, and systems analysis. 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 overall component thermal performance (UA) is at least as efficient as a building meeting all the prescriptive requirements. The systems analysis approach requires the modeled energy use of a house to not exceed the modeled usage of a house built to just meet the prescriptive requirements (the reference house).

In addition to requirements directly related to energy efficiency, the code establishes requirements intended to document information related to compliance. For example, a compliance certificate must be posted and insulation must be installed according to manufacturers' directions, regardless of the approach followed.

To ensure the study is representative of current statewide building patterns, Cadmus and NEEA conducted a webinar meeting on Friday, June 1, 2012, with Washington stakeholders. The meeting allowed these stakeholders to learn the study's purpose and steps, and to provide input on the methodology used to analyze compliance. The meeting produced a key result: the group determined construction data compiled by the U.S. Census Bureau was the best available for sampling, and, if sampled, local jurisdictions could provide permit numbers for recent construction. On Wednesday June 20, 2012, stakeholders received a draft sampling plan, and were asked to respond with comments by Friday June 22, 2012. Stakeholders received a response to all comments on June 28, 2012.

2.1. Study Objectives

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

- Analyze and report current rate of energy code statewide compliance in new residential construction in Washington, based on the 2009 WSEC.
- Review and comment on the various approaches for assessing code compliance.
- Determine aspects of the current energy code in which enhanced code compliance would lead to the largest reductions in home energy consumption.
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The study team analyzed the compliance rate related to meeting code requirements and the energy impacts of code compliance. The team used two different approaches to assess the degree to which homes in Washington complied with the new code:

1. PNNL checklist method: This approach was used to demonstrate and test the method developed by PNNL and made available for compliance analysis studies. It analyzed how well the studied homes complied with each process and efficiency requirement of the code.
2. Significant item methodology: This approach analyzed compliance based on only measures that were considered to have the most significant impact on energy use. It was evaluated as a less complex alternative to the complete checklist method.

The PNNL checklist method produces a compliance rate using site visit data analyzed based on the approach used by the builder to comply with the code. Each item on the checklist is assigned a weight used to calculate compliance points. The checklist incorporates all code requirements, including process and documentation requirements, as well as energy-efficiency requirements. In some cases, the team used available data from homes to fill gaps in the data for other homes. Compliance was calculated 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 issue, in collaboration with NEEA, Cadmus developed an alternate, less complex methodology that encompasses only items with the most significant effect on compliance and energy use. Nine items were included in this analysis and compliance was determined as the ratio of the number complying to the total number observable. All items were weighted equally. The nine items encompassing this analysis are: glazing U-factor, duct sealing, ducts located away from building cavities, floor insulation R-value, wall insulation R-value, ceiling insulation R-value, air sealing, high-efficiency lighting, and WSEC Chapter Nine credit options. Chapter Nine credits relate to a requirement to meet all other code requirements and achieve an additional credit based on pre-assigned credits for options such as installing high-efficiency HVAC equipment, high-efficiency water heating, or renewable energy. Chapter Nine also includes a penalty for dwellings larger than 5000 square feet.

In the third analysis method, Cadmus assessed the energy impacts of code compliance by using a building simulation model, SEEM94, to determine the relative energy use of each home as-built compared to the energy use of a reference home built to meet the prescriptive code. The analysis was based on the approach specified by the 2009 WSEC. The code specifies lighting requirements, but the software does not model detailed lighting characteristics. To address effects of lighting energy, Cadmus conducted a side calculation accounting for lighting efficiency. In addition, a separate calculation was conducted to analyze water heating energy use. For each home, the effect of compliance on energy consumption was calculated based on the sum of the space conditioning, water heating, and lighting energy used in the reference home and the as-built home.

3. Sample Development and Selection

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

3.1. Data Sources for New Construction Activity

In developing the sample of new residential construction in Washington, the process began by utilizing U.S. Census Bureau Building Permits Survey (U.S. Census Bureau 2012a) data for 2009, 2010, and 2011. 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.

Though PNNL used the same data source to develop its sample generator (U.S. DOE 2012b) for code compliance studies, the PNNL calculator only used data for 2008 through 2010, as 2011 data were unavailable at that time. Use of 2009 through 2011 construction data maintained use of a three-year average to minimize bias resulting from unusually high or low construction years in specific counties, but improved the sample's representation of construction activity since implementation of the current code.

However, gaps exist in the Census data. The Bureau fills these gaps by: using data obtained through the Survey of Construction (U.S. Census Bureau 2012a); or by 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.[2]

3.1.1. Estimating Washington's Residential Construction Population

Table 2 shows the Washington climate zone, and the number of construction starts for all thirty-nine Washington counties. Cadmus calculated the three-year average annual starts shown, and the percentage of statewide activity.

3.2. 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 suggests 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 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 sixty-six to provide sufficient data to address the study's research objectives.

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.

3.2.1. Stage 1: Selecting Counties

The first stage randomly allocated sixty-six sampling points to counties within the state, using a probability proportional to size methodology. This resulted in selection of twenty-two unique counties. Cadmus then removed six counties representing the smallest amount of construction activity, and redistributed their sample points to any county with only one sample point originally allocated. The redistribution controlled research costs, with minimal impacts on final study results, given the limited construction activity represented by the counties affected.

3.2.2. 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,

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[2] To check the reasonableness of compiled data, Cadmus attempted to use data compiled within the state by different 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 research team decided the Census Bureau data provided the best available representation of construction activity in the state.

Table 2. Washington Construction Activity by County, 2009–2011

FIPS Code	County Name	WA CZ	Average Annual Starts	Average Percent of Statewide Activity
1	Adams	2	39	0.28
3	Asotin	1	25	0.18
5	Benton	1	764	5.40
7	Chelan	2	200	1.41
9	Clallam	1	140	0.99
11	Clark	1	793	5.61
13	Columbia	1	4	0.03
15	Cowlitz	1	128	0.91
17	Douglas	2	101	0.71
19	Ferry	2	19	0.13
21	Franklin	1	581	4.11
23	Garfield	1	3	0.02
25	Grant	2	203	1.44
27	Grays Harbor	1	139	0.98
29	Island	1	194	1.37
31	Jefferson	1	92	0.65
33	King	1	2,596	18.36
35	Kitsap	1	507	3.59
37	Kittitas	2	176	1.24
39	Klickitat	1	75	0.53
41	Lewis	1	121	0.86
43	Lincoln	2	39	0.28
45	Mason	1	143	1.01
47	Okanogan	2	125	0.88
49	Pacific	1	95	0.67
51	Pend Oreille	2	58	0.41
53	Pierce	1	1,563	11.05
55	San Juan	1	138	0.98
57	Skagit	1	213	1.51
59	Skamania	1	30	0.21
61	Snohomish	1	1,893	13.39
63	Spokane	2	885	6.26
65	Stevens	2	69	0.49
67	Thurston	1	1,031	7.29
69	Wahkiakum	1	11	0.08
71	Walla Walla	1	86	0.61
73	Whatcom	1	430	3.04
75	Whitman	2	58	0.41
77	Yakima	1	375	2.65

Source: Survey of Construction (U.S. Census Bureau 2012a)

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 twenty-two original counties and sixteen final counties selected for the study. The table includes the number of jurisdictions sampled within each county.[3] As shown, selected counties represented the majority of estimated housing starts (after removing the six counties with the least construction), targeting sixteen jurisdictions for sampling.

Table 4. Stage 1 and 2 Sampling

County	WSEC CZ	Percent of Statewide Construction	Original Sample Size	Final Sample Size	Jurisdictions Sampled
King	1	18.4	9	9	2
Snohomish	1	13.4	9	9	2
Pierce	1	11.1	9	9	2
Thurston	1	7.3	6	6	2
Spokane	2	6.3	3	3	1
Clark	1	5.6	4	4	1
Benton	1	5.4	1	3	1
Franklin	1	4.1	3	3	1
Kitsap	1	3.6	3	3	1
Whatcom	1	3.0	4	4	1
Yakima	1	2.7	2	3	1
Skagit	1	1.5	1	2	1
Grant	2	1.4	1	2	1
Kittitas	2	1.2	1	2	1
Mason	1	1.0	1	2	1
Grays Harbor	1	1.0	1	2	1
Okanogan	2	0.9	2	Removed	
Douglas	2	0.7	1	Removed	
Jefferson	1	0.7	1	Removed	
Walla Walla	1	0.6	2	Removed	
Pend Oreille	2	0.4	1	Removed	
Skamania	1	0.2	1	Removed	
Total Represented by Selected Counties		87.0	66	66	20

Of the eight sample points originally allocated between the six removed counties, seven were reallocated equally to seven counties with an original sample size of either one or two: Benton, Yakima, Skagit, Grant, Kittitas, Mason, and Grays Harbor counties. The remaining sample point was reallocated to Benton county due to its relatively small sample given its percent of total statewide construction.

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

3.2.3. Stage 3: Selecting Specific Homes

In selecting specific homes from within a jurisdiction, the study first gathered all new permit data supporting new residential construction.[4] Upon receiving permit data for each home being built in the jurisdiction, the study team could create a randomly ordered list of homes for site visits. For each jurisdiction, the list included a greater number of sites than the number of sites needed for visitation.

4. Data Collection

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

4.1. Site Visit Process

The site visit team worked down the list of selected homes to schedule site inspections. In some cases, the team deviated from the original list when unable to perform site visits to homes selected in the sample, due to the following reasons:

- Occupants in a fully constructed home would not permit a site visit.
- The builder could not be reached.

Developing a substitution procedure addressed these circumstances. In order of preference, the study adopted the following process, selecting:

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.

Overall, the Cadmus field team used this approach to make substitutions for a little over one-half of cases.[5]

4.2. Data Collection Forms

4.2.1. PNNL Form

Cadmus reviewed Washington code requirements for compliance and the compliance workbooks developed for prescriptive and component approaches by Washington State University (WSU Extension Energy Program, Building Efficiency 2012). These workbooks assisted permit applicants in documenting compliance with the WSEC (but they were not required by all jurisdictions).

[4] A contract established with Ms. Mary Kate McGee, a recently retired building official in Washington, facilitated collection of the necessary permit data in each selected jurisdiction. Ms. McGee contacted each jurisdiction, and requested provision of permit data to the research team.

[5] The field team made every effort to maintain the sample's randomness, such as avoiding clusters of homes due to their ready accessibility.

To enhance consistency with the PNNL method and prior studies for NEEA in Idaho and Montana, Cadmus chose to use modified PNNL checklists to document compliance information. PNNL provides a series of checklists for analyzing compliance of residential new construction with the 2009 IECC (U.S. DOE 2010a). As Washington state code does not follow the 2009 IECC code, Cadmus modified the checklist to include information required to document compliance under Washington's state energy code. [6]

The resulting, modified PNNL checklist included the following eight sections (some sections have been designed for different construction stages, similar to PNNL forms for IECC 2009) to determine compliance with fifty-four criteria:

- Building characteristics
- Building mechanical systems
- Pre-inspection/plan review
- Foundation inspection
- Framing/rough-in inspection
- Insulation inspection
- Final inspection
- Washington code-specific

Unlike the IECC, a Washington code-specific section was added. This section listed different glazing-to-floor area options under the prescriptive approach. This section also listed Washington code Chapter Nine credits.

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

- Yes (complies)
- No (does not comply)
- N/A (item does not apply to a given house, such as skylights)
- Not Observable (item applies but cannot be verified, often because it could not be observed during the visit)

4.2.2. 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 this study. To provide inputs required for the SEEM runs, the study added thirty additional data fields to the PNNL form, including:

- Building type
- Foundation details
- Conditioned floor area
- Wall area
- Fenestration areas and orientation

[6] See Appendix C.

- Ceiling type

Because lighting usage cannot be varied in SEEM, Cadmus analyzed lighting separately, as described later.

4.2.3. Data Entry Methodology

Cadmus entered collected data into a SQL server database management system, using a Web-based tool. 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 data: Building blueprints; Construction documents; Builder information provided verbally (in the absence of written sources);
- Field-verified data: All energy-efficiency characteristics observable during site visits

Though most Washington jurisdictions do not maintain code compliance documents in their filings during new home construction, they require building plans and code compliance checklists to remain on the construction site. The majority of plan-verified data came from these on-site documents.

The study marked data points not verified visually during home site visits as “Not Observable” (N/O), and data points not relevant to the home as “Not Applicable” (N/A).

4.3. 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 three compliance demonstration approaches selected by builders. The three approaches are:

- Prescriptive
- Component performance
- Systems Analysis

When collecting compliance information and analyzing the data, Cadmus applied the checklist in accordance with how the builder chose to demonstrate compliance and guidance provided by PNNL on how to apply the checklist (see section 5.1).

This included a hierarchy of the data used for the study:

1. When observed, field-verified values were always used to assess compliance.
2. When field-verified values were not observed, the study used plans-verified values obtained from one of the sources listed above.
3. Only for the energy modeling methodology was a value required if neither a field-verified nor plan-verified value was observed. In this case, the prescriptive code value was assumed.

In cases where field-verified data were not available, checklist compliance assessment could be done by either treating the item as unobservable or using the plans-verified data. The research team elected to use the plans-verified data to improve the accuracy of the results as illustrated in Table 5. The table shows the case where four equally weighted items are in a checklist section. The first row shows the actual compliance rate for that section based on half the items complying and half not. The second row shows the value calculated by treating the fourth item as unobservable. The last row shows the average effect of using the plans-verified value, assuming the plans are correct only half the time. The calculated compliance of 37.5 percent is closer to the actual value, 50 percent, than if the item is excluded from the calculation entirely. Since it is likely the plans are correct more than half the time, the accuracy of the calculated compliance rate using plans-verified data will likely be much closer to the actual value.[7]

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	50% Yes/50% No	37.5%

4.3.1. Prescriptive Approach

For sixty-eight of the sixty-nine homes visited by the study team, the builder followed the prescriptive approach to demonstrate compliance, which specifies minimum requirements each building component must meet, based on climate zones and glazing-to-floor area ratios with no tradeoffs permitted. The approach presents requirements in terms of R-values by envelope component, and requires both a minimum of fifty percent high-efficacy lighting and use of at least one Chapter Nine credit.

Evaluating homes complying by the prescriptive approach using the checklist proved 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, all required measures were not always observed during site visits. In such cases, the team gathered plans information on site, if available at the building site.

4.3.2. Component Performance Approach

No homes inspected used the component performance approach to demonstrate compliance. This approach compares building envelope heat loss rates of the proposed house design to a code-defined reference house. Washington State University designed a spreadsheet that calculates overall UA of the building envelope, and can be used to demonstrate compliance.

[7] This argument is less accurate if the compliance rate is very low, in which case the plans-verified data are likely to be significantly different from the field-verified data. This was not the case in this study, however.

4.3.3. Systems Analysis Approach

Only one home inspected used the systems analysis approach to demonstrate compliance. As defined in the Washington State Energy Code, the systems analysis approach compares an estimate of annual building energy use by the proposed house design to a code-defined reference house. The one home Cadmus found where the builder planned on using the systems analysis approach was in the foundation stage; and documentation could not be provided to confirm compliance, but the Cadmus field engineer confirmed the approach chosen through a conversation with the builder.

4.4. Description of Data

Cadmus collected data from sixty-nine homes, as listed in Table 6. The number of homes visited exceeded the predetermined sample size for two counties[8]. Table 7 shows the distribution of homes by the approach builders used to demonstrate compliance in the selected counties. Of sixty-nine homes inspected: sixty-eight homes visited chose the prescriptive approach, and one chose the systems analysis approach. No homes inspected chose the component performance approach.

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

County	Sampling Plan Site Visits	Completed Site Visits
Benton	3	5
Clark	4	4
Franklin	3	3
Grant	2	2
Grays Harbor	2	2
King	9	10
Kitsap	3	3
Kittitas	2	2
Mason	2	2
Pierce	9	9
Skagit	2	2
Snohomish	9	9
Spokane	3	3
Thurston	6	6
Whatcom	4	4
Yakima	3	3
Total	**66**	**69**

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

Table 7. Distribution of Site Visits by County Area and Compliance Demonstration Approach

County	Prescriptive Approach	Systems Analysis Approach	Total
Benton	5	0	5
Clark	4	0	4
Franklin	3	0	3
Grant	2	0	2
Grays Harbor	2	0	2
King	10	0	10
Kitsap	3	0	3
Kittitas	2	0	2
Mason	2	0	2
Pierce	9	0	9
Skagit	2	0	2
Snohomish	9	0	9
Spokane	2	1	3
Thurston	6	0	6
Whatcom	4	0	4
Yakima	3	0	3
Total	**68**	**1**	**69**

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, not every data point could be gathered through field verification, or even from plans. Further, some construction documents required (and included in the checklist) could not be obtained from building departments. Consequently, all homes visited included some entries recorded as “Not Observable.” Table 8 shows the overall distribution of checklist compliance items. Nearly one-half of items did not apply. Of those applicable checklist items, compliance or non-compliance could be determined for about fifty percent [(28.5%+1.7%)/(28.5%+1.7%+26.8%)].

Table 8. Average Distribution of Compliance Entries

Compliance Entry	Statewide
Yes	28.5%
No	1.7%
Not Observable	26.8%
N/A	43.1%

Figure 1 shows distribution of homes, based on the number of applicable checklist items. For thirty of the sixty-nine homes, about one-half (twenty-four to twenty-nine) of the fifty-four items on the list applied. Figure 2 shows the distribution of homes—based on how many compliance items could be observed and verified—both complying or not complying. Eighteen or more items were observable in just over half (twenty-nine) of the homes.

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

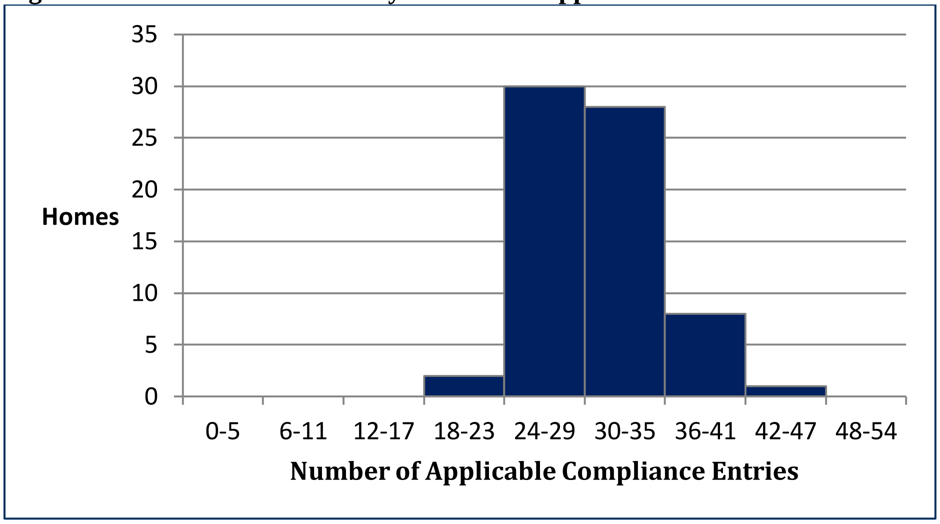


Figure 2. Distribution of Homes by Number of Observed Checklist Items

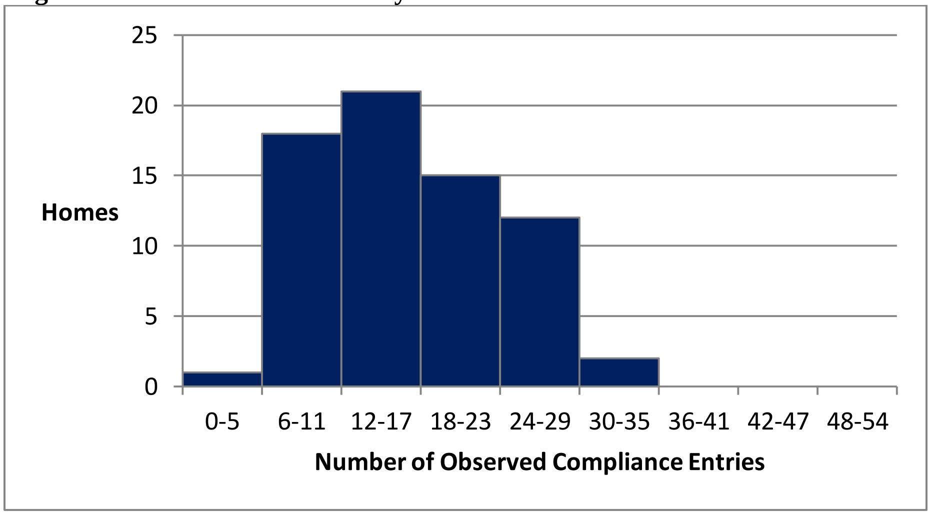
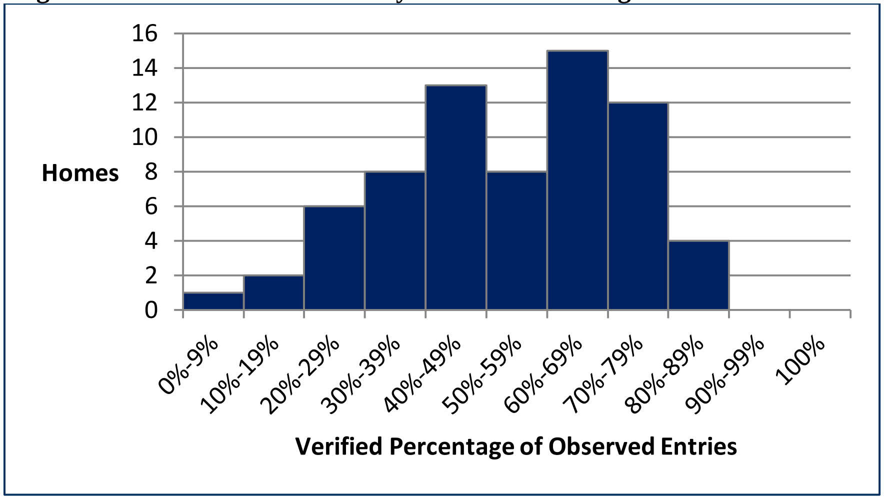


Figure 3 shows distribution of the percentage of observed checklist items, out of the total applicable. About two-thirds of homes fell within forty percent to sixty-nine percent of the observed items. For nine of the sixty-nine homes, fewer than thirty percent of the items could be observed. More than seventy percent of applicable measures could be observed in sixteen homes. Observing measures proved most difficult during the foundation inspection stage.

Figure 3. Distribution of Homes by Verified Percentage



4.5. Data Collection Challenges

The study team obtained permit information from local building departments. Even with Ms. McGee's assistance, several obstacles, however, were encountered in obtaining permit data:

- Although officially public information, convincing building officials to provide permitting information proved very difficult. However, eighteen departments contacted eventually agreed to provide some information. For the two jurisdictions not providing permit data, Cadmus researched new building developments within those jurisdictions, and then contacted builders for permission to perform site visits.
- After Ms. McGee and Cadmus contacted jurisdictions several times, it became clear, for several building departments, that public records requests (PRRs) would be required to obtain permit data. Cadmus completed PRR forms for eight jurisdictions sampled. This postponed field work for several weeks.
- In addition, once jurisdictions received data requests, permit information often was stored in hardcopy. Consequently, permit officials had to photocopy and fax the information, which proved impossible in two cases.
- In some instances, jurisdictions grouped new residential construction permit information with all other permit information. Sorting out residential construction permits had to be done manually, a time-consuming and tedious task.

4.5.1. Supplementing Incomplete Checklist Data

An ideal, complete evaluation following the PNNL protocol requires visiting a home several times to analyze compliance at different construction stages. In practice, few compliance studies, to-date, have had the available resources to conduct the number of site visits implied by this approach; this includes the present study. Expanding the sample size to sixty-six homes helped address this issue by collecting data on more homes from various construction stages that could be combined fill gaps in the information available for individual homes.

For each home, the study calculated the percentage of verified compliance items for each checklist section. Although PNNL recommends making multiple visits to the same home to collect compliance data at each construction stage, the PNNL method allows for data to be combined 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."[9] Since the scope for this project did not permit multiple visits, the study team used this alternate approach to fill in data gaps for the homes visited.

The study team recognized that, when checklist items were not observable, the accuracy of the checklist compliance rate was reduced because no information was included for the unobservable items. The team judged that the alternate approach could be used to apply available data from some homes to fill data gaps of other homes in the same jurisdiction as a way to minimize the effects of unobservable items on accuracy. To do so, the team made the decision that data from homes where more than half the items in a checklist category were observed could be applied to those homes where less than half the items were observed. The selection of one-half as the threshold was somewhat arbitrary, but took advantage of more complete information and minimized the effect of unobservable items on accuracy. Within individual jurisdictions, the study team applied the following rules in line with PNNL's methodology (see section 6.1.2) 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 not be used if only one home where the percent of verified checklist items for a given checklist section was greater than or equal to fifty was present in a given jurisdiction.
- Supplemental data values (for example, the attic R-value) for a home were determined by taking the average of checklist section data from all homes in the same jurisdiction with sufficient data for that section.

Supplemental data were used to replace data only for a given section of the checklist. For example: If a home was considered a candidate for supplemental data for the foundation insulation section, supplemental data were used to replace all checklist items of the section. In other words, supplemental data replaced verified items in addition to missing items of the candidate home's foundation insulation section.

Table 9 shows distributions of homes that were candidates for use of replacement data by checklist section. The table shows how many homes could be adjusted using values from homes with more data available. The most homes adjusted occurred in the Pre-Inspection stage (seventeen of sixty-nine, or twenty-five percent).

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

Table 9. Distribution of Candidate and Adjusted Homes by Checklist Section

Checklist Section	Total Homes	Homes with < 50% Verified	Adjusted Homes
Pre-Inspection	69	26	17
Foundation	69	48	4
Framing/Rough-In	69	26	9
Insulation	69	15	9
Final	69	43	14
Chapter Nine Option	69	10	7

4.5.2. 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 study could observe most data points needed as model inputs. Figure 4 shows, across the entire sample, direct observations in the field collected sixty-three percent of data points. Another eleven percent derived from plans and construction documents, or from information provided by builders. The remaining twenty-six percent of data points could not be obtained using either of the field-verified or plans-verified data.

Information visually collected through field-verified observations varied by home, depending on the home's construction stage. Home characteristics and components with data most often available included: home size, windows, and mechanical systems. As shown in Figure 5, overall infiltration rates and duct system leakage often could not be verified from plans or data gathered in the field.

Figure 4. Information Sources for Modeling

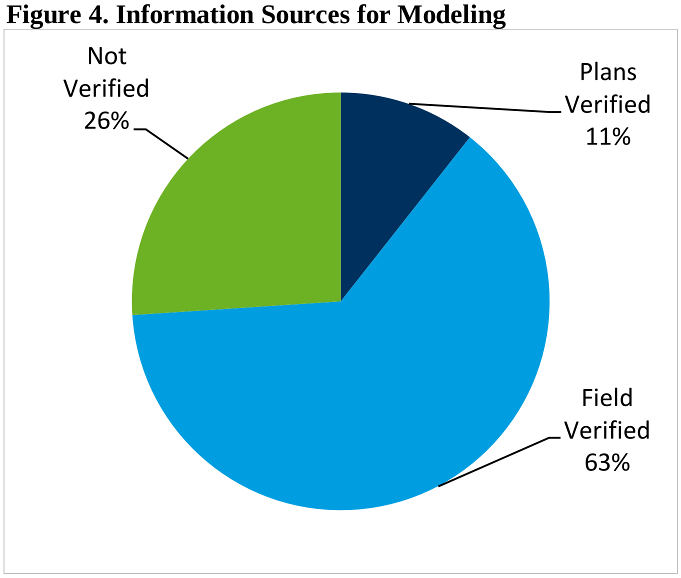
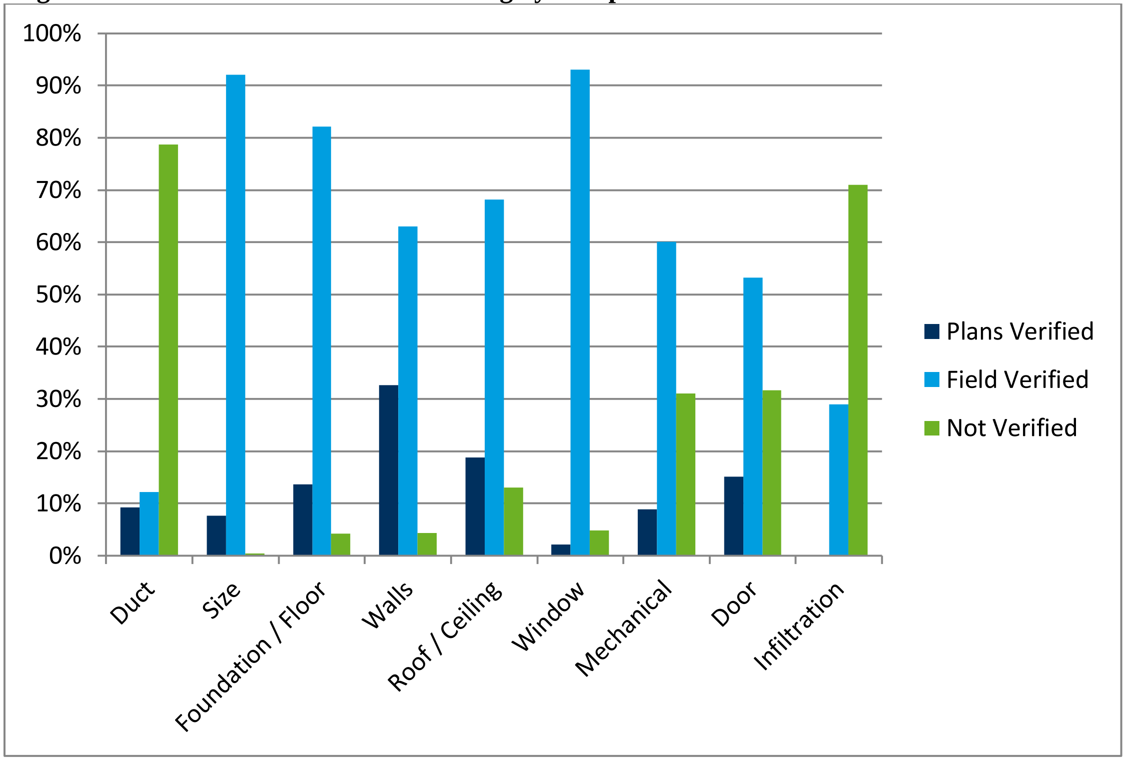


Figure 5. Information Sources for Modeling by Component



Note: "Not Verified" indicates the information was not available from the plans or field visits.

The energy model used in this study requires every parameter to have an associated value. This required 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 data missing due to unobservable components did not factor into the compliance determination.

For each parameter value that could not verified (e.g., floor insulation level, slab insulation) the following hierarchical steps were applied to fill in the missing value:[10]

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

In the first case, the study assumed similarities in construction and code enforcement practices in individual jurisdictions. The PNNL method allows data to be combined from different homes in a development, and the approach extended this basic practice to a broader area, expecting sufficient commonality in practices to prevent significantly biased results. In cases where similar data could not be obtained, the study assumed the specific building component just met the

[10] The regional Residential Building Stock Assessment (RBSA) presented another possible source of current building practice, but only about fifteen Washington homes in the RBSA sample had been built in the last five years; thus this sample size could not provide adequately accurate data for this study.

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, there was no *a priori* reason to assume there was a consistent bias either above or below code requirements and there was no evidence during the study to suggest a bias.

There were two cases where neither of the above approaches could be used, specifically for infiltration and duct system air leakage. This was because those values had to be based on test data, not observable parameters. As testing depended on home size, those values could not be extrapolated to other homes in the sample. For modeling purposes, the study assumed all homes for which test values were not available had natural infiltration rates, just meeting the value required upon performing a blower door test of 0.00030 SLA.[11]

Similarly for duct leakage rates, when values were unknown they were assumed to equal the code requirement of 6CFM50 per 100 square feet of conditioned floor area. The study set duct leakage to zero in the SEEM model runs for homes with all ducts in conditioned spaces[12] since there would be no duct leakage outside the envelope.

As described later, the study team assessed the sensitivity of the results to making these default assumptions.

5. Analysis Methodologies

5.1. PNNL Checklist Methodology

The PNNL method develops a compliance rate for each home using the checklist and site visit data. This rate evaluates each home, based on the approach used by the builder to comply with the code: prescriptive, component performance, or systems analysis.

The checklist methodology assigns each of the items 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 has a total of sixty-one items, which provide a total of 159 possible points when the weights are applied. Since Washington does not use the IECC, the checklist was modified as described later. Detailed data are presented in Appendix A.

Using this method, building-level compliance could be determined by dividing the total points for all items marked as compliant by total points associated with all items marked compliant or non-compliant, with results expressed as a percent. The compliance analysis excluded items marked "Not Applicable" or "Not Observable." For a home considered compliant with this method, the resulting percentage must equal one-hundred percent.

[11] The code states compliance can be achieved: "when tested to have an air leakage less than 0.00030 Specific Leakage Area (SLA) when tested with a blower door at a pressure of 50 Pascals."
[12] All ducts within conditioned space is defined as a duct system with less than 40 linear feet of ducts within conditioned space.

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

5.1.1. Application to Prescriptive Approach

In using the checklist method to evaluate homes complying by the prescriptive approach, verified values are compared against prescriptive code values, which can be found in the Washington code. When field-verified values were available, they were compared to the prescriptive code requirements. If they were not available, the Cadmus team used plans-verified values if they were available.

5.1.2. Application to Component Performance and Systems Analysis Approaches

The checklist method can also be used with homes complying using the component performance or systems analysis approach. For a home complying using the component performance approach, values specified in the provided worksheet or software report could be used to assess compliance. For a home complying using the systems analysis approach, values specified in the performance software analysis could be used to assess compliance.

The values in the worksheet or software report for the component performance approach or in the performance software analysis are known as plans-verified values. To assess compliance, field-verified values are compared against plans-verified values. As long as field-verified values meet or exceed plan-verified values, the respective checklist item is deemed compliant. When a field-verified value does not meet a plans-verified value, the respective checklist item is *not* compliant. For a given checklist item, if a plans-verified value is observed and a field-verified value is not observable, the item is deemed compliant as long as documentation of the tradeoff or performance approach exists and is verified. For a given checklist item, if a field-verified value is observed and a plans-verified value is not observed, the field-verified value is compared against the prescriptive code value.

When a builder used a component performance or systems analysis approach to comply with code, but valid outputs or reports proved unavailable to indicate the building features specified to meet the code, PNNL recommends evaluating homes using the checklist prescriptive approach.

5.1.3. Supplementing Missing Data

In cases of missing data, PNNL suggests combining data from multiple buildings to derive a single building evaluation. This could occur during simultaneous construction of multiple buildings, with construction of different buildings 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, as needed, to create a composite building. When combining data, this study relied on data for homes in the same jurisdiction, preferably by the same builder and in the same development.

5.1.4. Determining Statewide Compliance

For analyzing statewide compliance, PNNL discusses two possibilities[13]:

1. Determine the percentage of homes that achieve 100 percent compliance.

2. Take a simple average of the house-level compliance rates.

PNNL prefers the second method, as it a better indicates a building's proximity to complying and reaching a ninety percent overall compliance level. Cadmus agrees, but finds both metrics informative, and, hence, reports both.

5.2. Adopting PNNL Methodology for Washington

The PNNL checklist did not directly apply in Washington as the code differed from the IECC. For Washington code, Cadmus sought to apply a modified checklist approach as similar to the PNNL IECC checklist approach as possible.

Cadmus mapped Washington code items to relevant compliance items in the PNNL checklist. This included: identifying sunroom requirements and visual inspection requirements in the PNNL checklist that did not apply in the Washington code; and removing these. The only additional compliance item specific to Washington addressed the state's requirement for Chapter Nine credits, which the study team assigned a weight of "3" due to its relatively large effect on home energy consumption. Chapter Nine credits relate to installing high efficiency HVAC equipment, high efficiency water heating, high efficiency envelope, air leakage control, and renewable energy, and include a penalty for large (over 5000 square foot) dwellings.

Although most items on the PNNL checklist could be mapped to requirements in the Washington code, some set different criteria to meet compliance in Washington (due to Washington codes and different Washington climate zones). For example, to determine compliance for the glazing U-factor, PNNL used a U-value requirement of 0.35. In Washington, the required value depended on a home's glazing to floor ratio and WSEC climate zone. In WSEC, homes with a ratio less than thirteen percent had a U-value requirement of 0.34; homes with a ratio up to twenty-five percent had a U-value requirement of 0.32; and homes with a ratio greater than twenty-five percent had a required U-value requirement of 0.30.

After these adjustments, the Washington checklist had fifty-four compliance items with values of one, two, or three points, depending on the PNNL's most relevant assessment of their relative importance. Summing points across the compliance items resulted in 138 possible points.

In addition to these adaptations, Washington uses a component performance and systems analysis approach rather than the IECC's tradeoff and performance approach. The Washington code component performance and systems analysis approaches are essentially equivalent to the IECC tradeoff and performance approaches, respectively. Thus, when evaluating the checklist,

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

the study treated the Washington approaches in the same manner as the corresponding IECC approaches.

5.3. Significant Item Methodology

In the PNNL methodology, each of the fifty-four compliance items receives a weight value ranging from one to three points. Cadmus 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 affect a home's energy consumption little. Some (such as posting a certificate describing energy features on the home's electricity panel) may be important from a procedural perspective, but do not directly contribute to energy savings. To address this issue, Cadmus developed an alternate methodology in conjunction with NEEA, encompassing only items with the most significant effect on compliance and energy use.

This alternative method removed the influence of less-important compliance items by restricting analysis to the nine checklist items deemed most significant in determining energy consumption. The items were selected by the study team in conjunction with NEEA, and the method was employed in a prior study of code compliance in Montana for NEEA (Lee, A., Cook, R., Horton, D. 2012). This method allowed the analysis to consider whether builders complied with the most vital components of the 2009 WSEC affecting energy use, regardless of whether builders complied with other requirements of lesser importance. The nine items in this analysis included:

1. Window glazing U-factor,
2. Duct sealing,
3. Ducts located away from building cavities,
4. Floor insulation R-value,
5. Wall insulation R-value,
6. Ceiling insulation R-value,
7. Air sealing,
8. High-efficiency lighting, and
9. WSEC Chapter Nine option credit.

Other than this change, Cadmus applied the remainder of the PNNL method as designed. Each of the nine items above received a three-point weight in the PNNL checklist, equally weighting them in this alternate analysis. 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" as the PNNL methodology excluded these.)

5.4. SEEM Energy Modeling Methodology

5.4.1. Energy Consumption Methodology

Cadmus used SEEM94[14] to determine the relative energy use of sampled homes compared to energy use of the same homes if they were constructed to exactly meet the code. The model did not have the capability to directly model domestic hot water energy consumption, but the code covers hot water energy use. Domestic hot water energy consumptions was post-processed into the overall energy consumption for each of the as-built and reference home scenarios. Because SEEM does not model lighting in detail, Cadmus also conducted a separate analysis of the lighting energy use impacts, detailed in section 7.2. Overall, the simulation analysis, supplemented with water heating and lighting analyses, was 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. In all cases, the code-compliant reference home was defined using target component values for single-family residential homes, defined in Table 5.1, Table 5-11, Table 5-12, and Table 14 of the Washington State Energy Code. For envelope components, requirements are presented in terms of U-values. Energy use calculated for the reference house could be compared to the calculated energy use of the sampled as-built home. The procedure used a compliant reference home to compare homes in the sample consistently. Builders' compliance approaches proved unimportant as the study sought to compare energy consumption of each home as-built to a minimally-compliant home. If builders had used an approach allowing tradeoffs between prescriptive requirements, the simulation model would account for these in its energy consumption estimate.

Several end uses could not be modeled and they are not addressed by the code. They 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 establishes lighting requirements.

5.4.2. Defining As-Built Homes

As addressed, incomplete data collection results could not be ignored in modeling. This required: combining site visit data and data from plans; cleaning data; and filling remaining gaps. The resulting specifications constituted the as-built home design entered into the model. The SEEM model energy-use estimate based on these inputs provided the estimate of energy consumption of each as-built home.

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[14] 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 it is applied in other residential energy use studies in the Northwest. SEEM94 offers the basic capabilities necessary for this study and is not overly complex. This helped minimize input errors and inconsistent results.

5.4.3. Defining Reference Homes

Reference homes were modeled using, the same size, wall area, roof area, and foundation type as the corresponding as-built homes, but equal window distribution in all directions and a constant fifteen percent glazing-to-floor ratio. In defining the reference home, the code requirements were used to specify insulation values and U-values. Cadmus referred to Table 5-1, Table 5-11, Table 6-1, and Table 6-2 in the Washington State Energy Code to identify prescriptive requirements by component, and modeling parameters to use, consistent with WSEC's approach for systems analysis. Appendix D shows component U-value specifications used, by climate zone.

Homes complying with the prescriptive path must meet the Chapter Six requirements of the Washington State Energy Code, shown in Appendix D. For modeling purposes, the analysis used the Chapter Five requirements as the code specifies for the systems analysis approach. The prescriptive requirements are presented in the appendix to show how prescriptive values vary across climate zones and window areas.

In addition to these prescriptive envelope requirements, the code establishes requirements for duct leakage, ducts in unconditioned space, and whole house tightness. Cadmus used code prescriptive requirements for these measures to determine corresponding inputs for SEEM runs.

One major difference between compliance by systems analysis and by prescriptive path depends on the glazing-to-floor ratio. Compliance by systems analysis uses a glazing target component U-value of 0.30, and the reference home must be modeled with a fifteen percent glazing-to-floor area ratio. Compliance by the prescriptive path specifies a glazing U-value that depends on the building's glazing-to-floor area ratio.

To keep this modeling analysis consistent regardless of the compliance path chosen by the builder, Cadmus applied the systems analysis requirement. While this approach did not vary glazing U-value requirements, depending on the area ratio, it has the effect of making the requirement more stringent for homes with large window areas by maintaining a single target area ratio of fifteen percent in the reference home. This effectively decreases the overall requirements for a home with a low glazing-to-floor area ratio, and increases overall requirements for a home with a high glazing-to-floor ratio.

An energy compliance index for each home could be calculated by dividing energy usage of the as-built home by energy usage of the reference home. To remain consistent with the systems analysis approach, an eight percent adjustment was made to the calculated energy use of the reference home.[15] The code requiring an eight percent reduction in energy use above the reference design is intended to simulate the effect of Washington State Energy Code Chapter Nine: Additional Residential Energy Efficiency Requirements.

$$\frac{Energy\ Usage\ As\ Built\ Home}{Energy\ Usage\ Reference\ Home * (1 - 0.08)} = Energy\ Compliance\ Index\ \%$$

[15] Chapter Four of the Washington State Energy Code defines compliant homes: "…will be deemed as complying with this Code if the calculated annual energy consumption is 8 percent less than a similar building (defined as a "standard design")…."

If this index exceeds 100 percent, it indicates a home uses more energy than if it were built to just meet code. For example, if the index is 120 percent for a specific home, the home exceeds by twenty percent the energy use of the same home built to code.[16]

6. Checklist and Significant Item Analyses Results

In this chapter, Cadmus presents statewide compliance rate results generated from the PNNL checklist and significant item compliance analyses. Chapter 7 presents the compliance results using the simulation analysis.

For these two approaches and the simulation analysis, the study team developed a weighting scheme to address the fact that building codes vary across climate zones. The analysis treated climate zones as a stratification variable. Within each climate zone, the analysis treated counties as level-one sampling units, and individual building starts within counties as level-two sampling units. The resulting weight, calculated as follows, applied to each project-level compliance rate:

$$w_{j,k}^{\text{region}} = \frac{M_i}{\sum_{\substack{\text{sampled } j \\ \text{in zone } i}} N_j} \cdot \frac{N_j}{n_j} \quad (\text{Here, } i \text{ is the climate zone containing county } j.)$$

Appendix B: Derivation of Weights presents details of the weighting approach.

6.1. PNNL Checklist Compliance Results

6.1.1. 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 each component could be verified (that is, it was applicable and observable) and the compliance rate. Table 10 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, and the compliance percentage adjusted as described in Section 4.5.1. Table 22 in Appendix A: Line Item Compliance provides more detailed information. Final compliance was brought down by lower compliance rates observed for attic insulation and display of the compliance certificate.

Table 10. Summary Component Checklist Compliance Statistics

Compliance Item Category	Number of Items	Percent of Items Verified	Average Adjusted Compliance	Variance of Adjusted Compliance
Pre-Inspection	2	40%	93%	4%
Foundation	12	21%	89%	5%
Framing/Rough-In	18	55%	96%	1%
Insulation	13	67%	98%	0%
Final Inspection	16	40%	83%	8%
Chapter Nine Option	1	86%	99%	1%

Note: The Average Adjusted Compliance is based on supplementing the field-verified observations as described in Section 4.5.1. Variance was calculated from the observed adjusted compliance values.

[16] This index is comparable to the HERS Index.

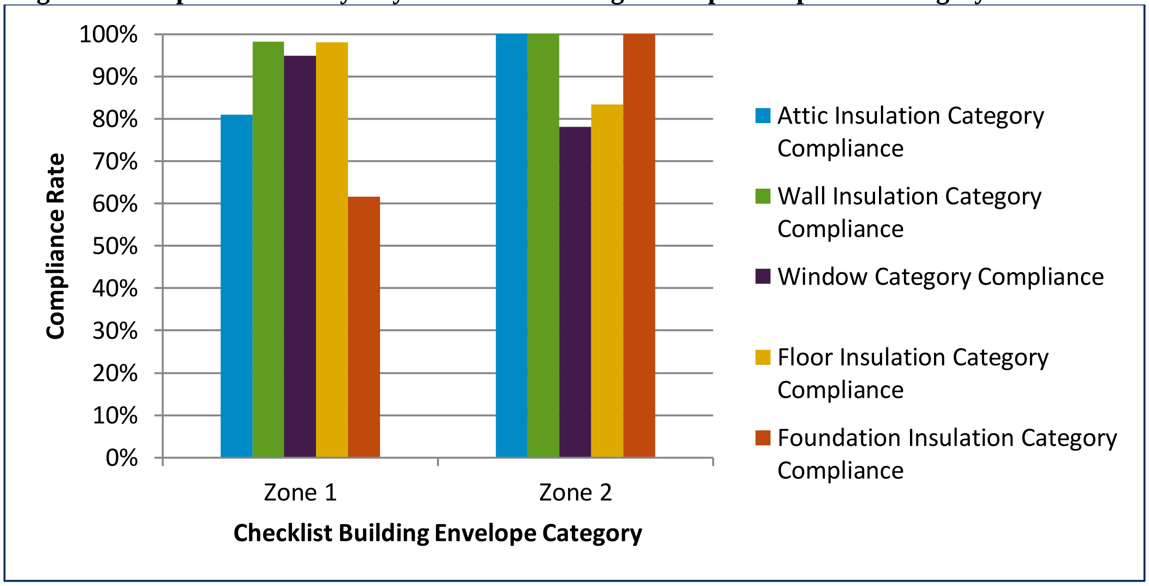
The adjusted average compliance of the Final Inspection checklist category is the lowest of all checklist categories at eighty-three percent. The variance of the adjusted compliance is the highest for this category, however, due to a number of homes with very low compliance rates. Consequently, the confidence interval around the average value is largest for the final inspection category.

Figure 6 graphically displays information on checklist compliance rates by different building component category and climate zone. 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.

This produces results notable for two reasons. First, unlike many other results, they differ significantly between climate zones. For example, the foundation insulation category shows a compliance rate of one-hundred percent in Climate Zone 2, but only just over sixty percent in Climate Zone 1.

Second, these compliance rates are not necessarily good indicators of the effect of specific checklist categories on energy consumption. Figure 10 (presented later) shows that, on the average, the walls, windows, and attics were more efficient than required by code. However, because of other items included in the checklist categories that did not affect energy performance, the compliance for the corresponding categories was less than 100 percent in each case. The results in Figure 6 are interesting in the context of the PNNL checklist, but do not reliably indicate energy effects of compliance variations in different building components because of the inclusion of items in each category that do not affect energy use.

Figure 6. Compliance Rate by Key Checklist Building Envelope Component Category



Homes complying through the prescriptive approach also had to meet a requirement that at least fifty percent of lighting was high-efficacy. Even though many of the sampled homes were observed late in the construction process, the installed lighting could be determined for only thirty-five percent of homes in the sample due to lighting not installed at the time of the visit. However, for those homes where lighting was installed at the time of the site visit, 100 percent met the requirement (see Table 15).

6.1.2. Adjustments for Missing Data

Table 9 shows the number of sampled homes where data from other homes were used to fill data gaps. Table 11 summarizes the effects of the adjusted data by checklist section. In all cases save foundation inspection, using values from other houses with more complete data increased or did not change the estimated compliance rate at the checklist section level and, for most checklist sections, the change was relatively small. Overall, filling the gaps where possible increased the average checklist compliance rate from ninety-three percent to ninety-four percent without any weighting applied. However, the impact of these adjustments did not significantly impact the overall compliance rate.

Table 11. Compliance Rate Effect of Filling Data Gaps, Unweighted

Checklist Section	Unadjusted Average Compliance	Adjusted Average Compliance
Pre-Inspection	88%	93%
Foundation	90%	89%
Framing/Rough-In	96%	96%
Insulation	98%	98%
Final	83%	83%
Chapter Nine Option	97%	99%
Total	**93%**	**94%**

6.1.3. Checklist Compliance of Homes Complying Under Two Approaches

For all but one home in the sample, builders complied under the prescriptive approach (with the one exception complying under the systems analysis approach). No homes complied under the component performance approach. For the home using the systems analysis, Cadmus determined checklist compliance by using plan-verified values to establish the reference values against which field-verified values were compared. This is consistent with the approach recommended in the PNNL checklist approach. When no field-verified value could be determined for the one home using the systems analysis compliance demonstration approach, the study deemed the corresponding item compliant.[17] Table 12 shows the average checklist compliance score for homes that used the two different compliance approaches. Given that only one house complied using the systems analysis approach, no precision can be calculated.

Table 12. Checklist Compliance Rate by Builder Compliance Demonstration Approach and Precision at 90% (Unweighted)

Builder Compliance Approach	Average Checklist Compliance	90% Confidence Level Precision
Prescriptive	94%	2%
Component Performance	N/A	N/A
Systems Analysis	95%	N/A

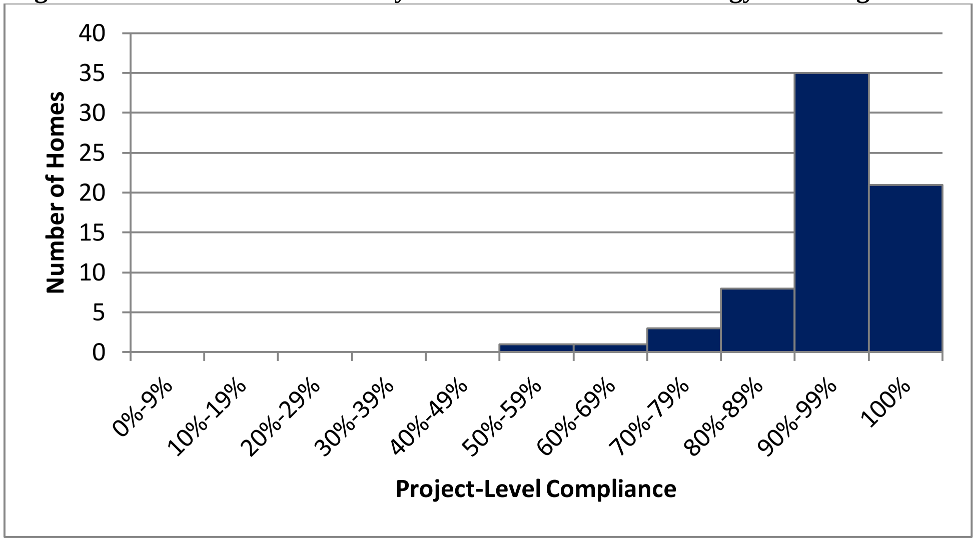
Note: Only one home used the systems analysis approach to demonstrate compliance.

[17] This process assumed that the approved plans met the code and that items that could not be verified in the field neither exceeded nor did not meet code consistently.

6.1.4. Aggregate Results

With the data gaps filled as described in Section 6.1.2, the adjusted data resulted in one home having the lowest compliance rate of fifty-four percent with the checklist analysis method. The highest rate was one-hundred percent, and the mean was ninety-four percent. Figure 7 shows distributions of adjusted project-level compliance rates without geographic weighting. Twenty-one homes fully complied under the checklist method, based on code requirements that could be verified either through plans or field observation.

Figure 7. Distribution of Homes by PNNL Checklist Methodology—Unweighted



Analysis of statewide compliance estimates produced the following results:

- The percentage of homes achieving one-hundred percent compliance.
- Average home-level compliance rates:
  - Without weights applied
  - With climate zone weights applied (as discussed in Appendix B: Derivation of Weights)

Table 13 presents these statewide results. Overall, after adjusting for missing data, thirty percent of homes fully complied with the code requirements using the checklist. A weighted average compliance rate of ninety-six percent resulted across the state.

Table 13. Summary of PNNL Checklist Results for Statewide Compliance

Scenario	Unadjusted Statewide Result	Adjusted Statewide Result
Percentage of homes achieving 100% compliance (unweighted)	42%	30%
Average compliance rate (unweighted)	93%	94%
Average compliance rate (weighted)	96%	96%

6.2. Significant Item Results

Using the Significant Item analysis method resulted in fifty-one homes of the sixty-nine exhibiting a one-hundred percent compliance rate, and the mean compliance rate was ninety-six percent. Figure 8 shows distributions of project-level significant item compliance rates without climate zone weighting.

Figure 8. Distribution of Houses by Significant Item Checklist Methodology—Unweighted

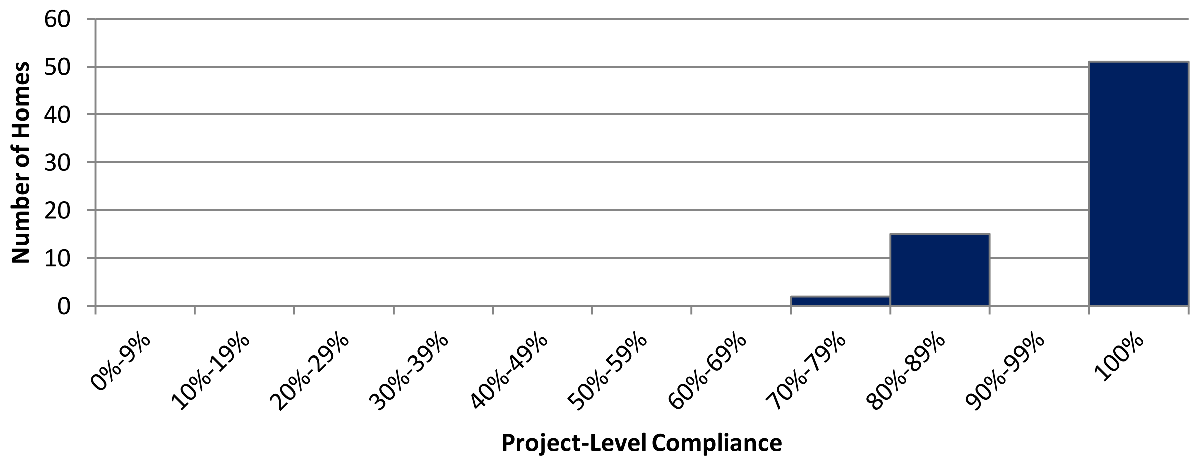


Table 14 presents the statewide results using the significant item approach. Overall, seventy-five percent of homes fully complied with the code requirements using the significant item method. A weighted average compliance rate of ninety-seven percent resulted across the state.

Table 14. Summary of Significant Item Results for Statewide Compliance

Scenario	Statewide Result
Percentage of homes achieving 100% compliance (unweighted)	75%
Average compliance rates (unweighted)	96%
Average compliance rates (weighted)	97%

Compared to the PNNL checklist results reported in Table 13, the share of homes rated one-hundred percent compliant is substantially larger using the significant item approach. There are fifty-one homes that fully comply using this method compared to twenty-one using the full checklist method. This is not surprising given the smaller number of items considered in this method. In addition, as only two homes exhibited a compliance rate less than eighty percent (compared to five with the checklist method), a greater average compliance rate resulted than with the PNNL checklist method.

Table 15 summarizes the compliance rates of the nine significant items, with the compliance rate for ceiling insulation lower than the other eight items. As this rate drew upon sixty observations, ceiling insulation may be an area where Washington could seek improvements. The compliance rate for air sealing must be qualified due to its derivation from only ten verified homes from a total of sixty-nine.

Table 15. Summary of Significant Item Results for Statewide Compliance (Unweighted)

Item	Number of Verified Homes	Statewide Compliance
Lighting efficacy	24	100%
Duct sealing	36	100%
Building cavities not used for supply ducts	42	100%
Floor insulation R-value	52	100%
Air sealing	10	100%
Wall insulation R-value	63	98%
Glazing U-value	63	97%
Chapter Nine option	61	97%
Ceiling insulation R-value	60	80%
Overall	**69**	**96%**

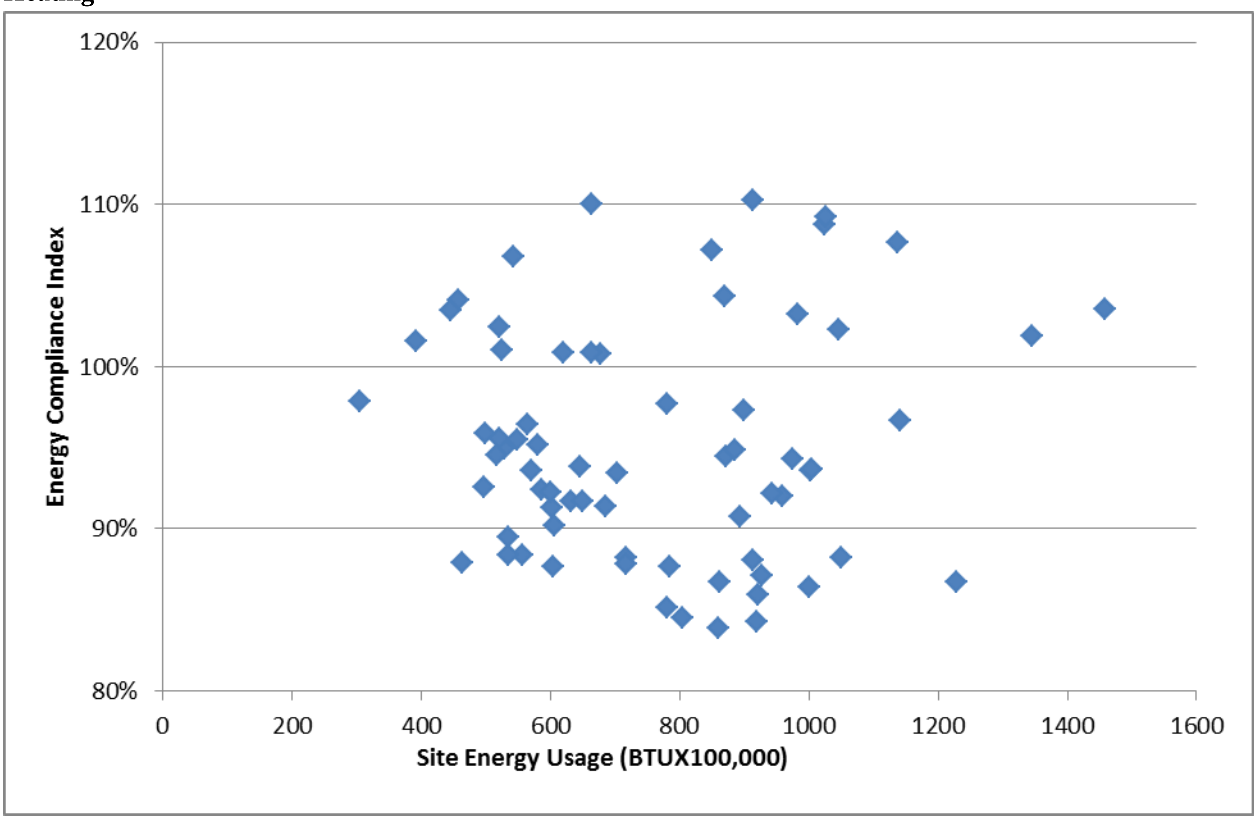
7. SEEM Modeling Results

This chapter presents results of the compliance assessment conducted in this study using the modeling methodology.

7.1. Space Heating and Cooling and Water Heating Results

Of sixty-nine homes modeled, SEEM modeling results for space heating and cooling combined with water heating estimates produced energy compliance indexes ranging from eighty-four percent (sixteen percent less than code) to 112 percent (twelve percent more than code), with an unweighted mean of 94.3 percent, or about six percent less than code. As shown in Figure 9,

Figure 9. Energy Compliance Index vs. Energy Consumption: Space Heating, Space Cooling, and Water Heating



the index was uncorrelated with energy usage. While the 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. Of the sample, seventy-one percent (or forty-nine out of sixty-nine homes) are expected to use less energy than the reference home.

Weighting results to extrapolate to the average for the population of new homes in Washington resulted in a 95.6 percent energy compliance index, or just slightly higher than the unweighted average, indicating statewide energy use of new homes about four percent less than that resulting if all new homes just met the code (including the eight percent adjustment).

HVAC and water heater efficiencies also affect energy consumption. The majority of homes are heated with natural gas, forced air furnaces. Table 16 shows average HVAC efficiencies exceeded code baseline values and water heater efficiencies met or exceeded code requirements.

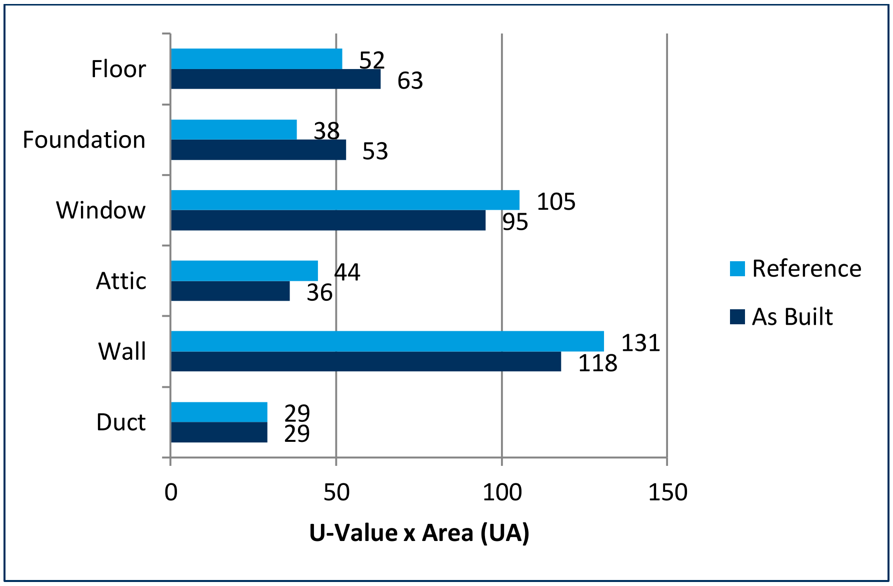
Table 16. Space Heating and Water Heating System Efficiency

	Number of Homes	Percent Of Sample	As Built Efficiency	Reference Efficiency	Percent Improvement
Natural Gas Forced Air Furnace	53	77	91.7	80	15
Air Source Heat Pump	11	16	8.7	7.7	13
Ground Source Heat Pump	1	1	12.3	12.3	0
Electric Resistance	4	6	N/A	N/A	N/A
Gas Conventional Water Heater	26	81	0.62	0.58	7
Gas Tank-less Water Heater	1	3	0.82	0.58	41
Electric Conventional Water Heaters	5	16	0.91	0.91	0

Note: Heat pump efficiencies are in HSPF and furnace efficiency is in AFUE; water heater efficiencies are in EF (Energy Factor). Water heater sample percents are based on the number of homes for which water heater efficiency data were available.

The overall effect of compliance on energy use depends on the magnitude of each component's impact on energy use. Figure 10 displays the UA (U-value times area) for each component, and the difference between the average value for the reference and as-built homes. The UA value difference directly relates to energy consumption differences, with as-built UA less than the reference UA indicating savings relative to the code requirement. The largest UA improvement occurred for walls. Windows more efficient than those required by code made the second-largest contribution, with attic insulation the third-largest contributor to overall enhanced energy performance. The as-built foundation and floor UA, on the other hand, exceeded the value for the reference by a relatively large amount (thus were less efficient), but not enough to offset the more efficient values for the other components. Component level compliance is based on the component energy performance characteristics alone, and does not take into account the other factors included in the prescriptive path compliance outlined in the PNNL checklist method.

Figure 10. Component UA Difference between As-Built and Reference Homes

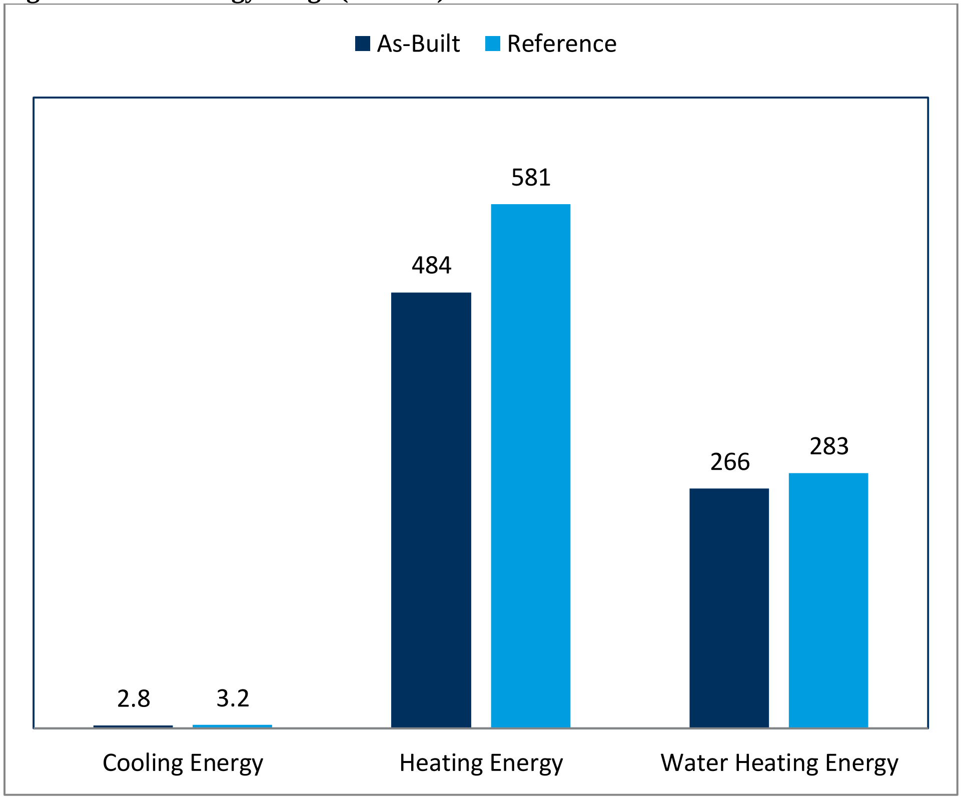


It is important to point out differences between results from the systems analysis modeling and significant item methodologies. Comparing Table 15 with Figure 10, the significant item method suggests a higher floor insulation compliance and lower ceiling insulation compliance than the modeling method indicates. The reason for these different findings is the difference in how the reference home is defined by the two methods. The significant item method applies the prescriptive approach, which specifies R-values, to define the reference home, whereas the modeling approach uses component U-values. To illustrate the difference, a ceiling with R-49 (or R-38 advanced framing) is required in the prescriptive approach, while a U-value of 0.027 is required in the modeling approach and can be satisfied with R-37 insulation.

Energy modeling indicated energy savings of as-built homes compared to minimally code-compliant new homes came primarily from reduced space heating energy use. Overall, high-efficiency heating systems contributed the most savings, constituting about ten percent of the overall savings relative to reference homes. Based on the values shown in Figure 11, new homes in Washington saved, on average, about 9.8 million Btu (98 therms)[18] per year for heating compared to homes just meeting the code. Cooling energy consumption impacts proved less significant, due to internal loads (lighting, occupants, and appliances) serving as major drivers of annual cooling loads and unaffected by envelope efficiency. Only twenty-nine percent of sampled homes contained cooling systems. Water heating was included in this analysis because of the Chapter 9 credits in the energy code. While there is no prescriptive requirement for water heating other than the federal minimum standard, Chapter 9 has two options for gaining credits from high efficiency water heating. Water heating accounts for an average annual reduction of 1.7 million Btu (17 therms). The calculation is described in Appendix E: Water Heating Calculation.

[18] The study calculated 9.8 MMBtu by taking the difference between heating energy for baseline and as built models and accounting for the 8 percent reduction in energy usage code required for the home to show compliance.

Figure 11. Site Energy Usage (Therms)



7.2. Lighting and Other Component Compliance Effects on Energy Consumption

The code's performance compliance demonstration approach did not require lighting to be included in the energy modeling. As a result, when the study team used the simulated energy consumption analysis, the results did not account for compliance levels for the prescriptive approach's lighting efficacy requirements. To understand the impact of lighting on energy consumption, the study team separately estimated lighting energy consumption for both non-compliant and compliant homes. Section 505.1.1 of the Washington State Energy Code reads:

> **Interior Lighting**: Fifty percent of all interior lighting luminaires (fixtures) are required to be high efficacy luminaires.[19]

The annual lighting kBtu was estimated using data from the 2012 Residential Building Stock Assessment (RBSA), and from the Regional Technical Forum (RTF). For high-efficacy lamps, Cadmus assumed compliant homes installed fifty percent CFLs, and non-compliant homes installed only incandescent lighting; this is the most conservative assumption. Table 17 shows

[19] The code requires those luminaries (fixtures) to be non-medium screw base fixtures however the State Building Code Council later published an interpretation NO.11-02. The interpretation states that Code Council allows medium screw based fixtures to comply after it was shown that those fixtures can meet or beat the efficacy standard. The interpretation also states those fixtures are likely to be replaced with new high efficacy lamps after end of lamp life.

the annual average modeled home space heating and cooling consumption, kBtu lighting energy consumption, and the energy compliance index including lighting.

Table 17. Modeling Results with Lighting Energy, Unweighted, Site Energy, kBtu

					Total Energy with Lighting	
Model	Space Heating/ Cooling & Water Heating	Lighting Non-Compliant Annual	Lighting Compliant Annual	Lighting Compliance Rate	Without Chapter Nine Adjustment	With Chapter Nine Adjustment
Average Reference Home	86,731	23,913	14,519	100%	101,250	93,150
Average As-Built Home	75,208	23,913	14,519	100%	89,727	89,727
					Adjusted Energy Compliance Index	96.3%

The reference home is assumed to be one-hundred percent compliant with the lighting requirements, or fifty percent of the lighting is high-efficacy. For the homes visited, Cadmus found one-hundred percent to be compliant. It should be noted the study team was able to verify lighting compliance in only thirty-five percent of the homes inspected because lighting was not often fully installed at the time of the site visit. The calculation is presented in Appendix F: Lighting Consumption Calculation.

As the table shows, the lighting impact on annual energy consumption is significant. Adding lighting energy use to the space heating and cooling and water heating energy consumption increases estimated energy consumption of as-built homes nineteen percent (14,519/75,208). The calculated unweighted average compliance index increases from 95.1 percent to 96.3 percent when lighting is included with the other end-uses. The index increases because, at 100 percent compliance, the lighting energy use just meets the code level, whereas the remaining end-uses consume less energy than if they just met the code

It was possible to estimate the contribution of various building component efficiencies to the overall energy savings compared to the code. Table 18 shows how the savings were distributed, on the average, among the various components used to meet the code. The largest contribution came from the installation of high-efficiency furnaces. Lighting contributed no savings, on the average, beyond those resulting from the code.

Table 18. Contribution to Beyond-code Savings

Component	Contribution, Percent
Furnace	59
Shell	26
Water Heater	15
Lighting	0

7.3. Effects of Assumed Data Points on Modeled Results

Because assumptions had to be made in the modeling analysis when field-verified data were not available, the study team investigated the uncertainty introduced to the results by these assumptions. Since data from blower door and duct leakage testing were the least available and both duct leakage and infiltration have large impacts on energy consumption, this study examined impacts of the assumptions used to fill gaps in these values. When data were missing, the modeling analysis assumed that both infiltration and duct leakage just met the code requirements.

The best data available for comparison purposes derived from the 2012 RBSA (Ecotope2012), a study characterizing residential building energy use and the current building stock across the Northwest. The current study modeled the sixty-nine sampled homes using SEEM with the default assumption of just meeting code, and then applying the upper and lower bounds from the RBSA data, and comparing the results. The effects are shown in Table 19.

Table 19. Compliance Rate Variability

Input	Assumption	RBSA 2012 Mean	Upper Error Bound Of RBSA Data	Lower Error Bound Of RBSA Data	Upper Bound Effect On Compliance Rate	Lower Bound Effect On Compliance Rate
Infiltration	0.00036 SLA* (Approx. 7ACH50)	6.33 ACH50***	8.09 ACH50	4.57 ACH50	-3%	4%
Duct Leakage	6CFM/100sq-ft**	35.4% Duct Leakage****	41.7% Duct Leakage	29.1% Duct Leakage	-7%	-4%

**SLA (Specific Leakage Area)
** Assuming 10.7% duct leakage as modeled input.
***Mean of 20 homes built between 2006-2010 across MT, ID, WA, and OR.
**** Mean of 74 homes in Washington all vintages.

The variation in the RBSA infiltration data provides an error band around this study's estimated space heating and cooling compliance rate of about plus or minus ten percent. This is a relatively small uncertainty and, since it is approximately equal on either side of the average value estimated in the study, it does not provide any evidence the study value would be increased or decreased by incorporating measured infiltration. The best available data for infiltration and duct leakage shows that these assumed values are reasonable.

Figure 12 presents the effects of the upper and lower bounds on the compliance rates for each home analyzed. In the majority of cases, the study value falls within the error band.
As shown in Figure 13, modeled results showed slightly higher compliance rates than RBSA data bounds for duct leakage. This would be expected because the RBSA data are for homes of all vintages in Washington and newer homes should have tighter duct systems than the average home in the existing housing stock.[20] Given the small difference between the duct leakage compliance calculated using the assumption in this study and the fact that all homes analyzed were new, the Cadmus team believes the evidence supports the assumptions made in this study.

[20] The figure only contains homes with duct systems outside of conditioned spaces.

Figure 12. Infiltration Effect on Compliance Rate

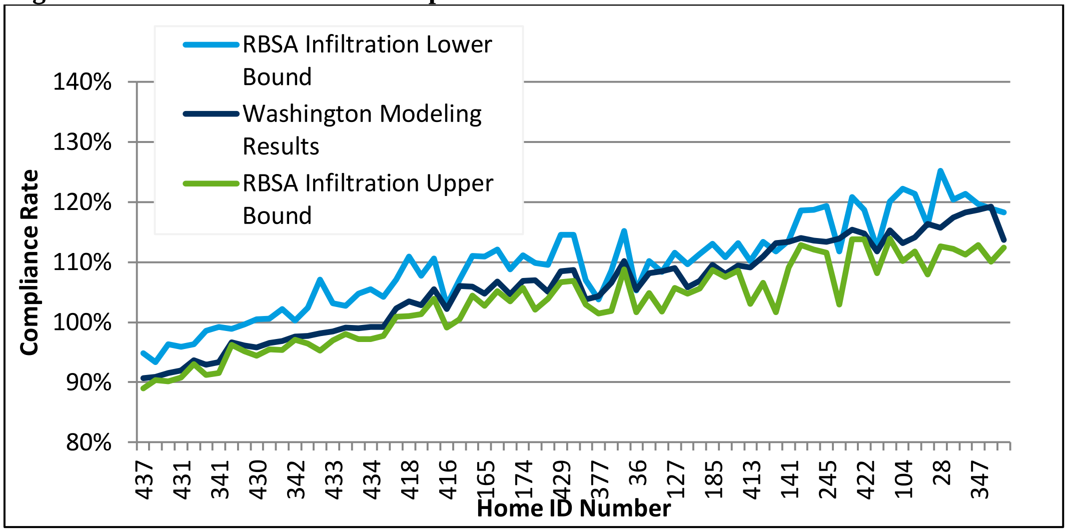
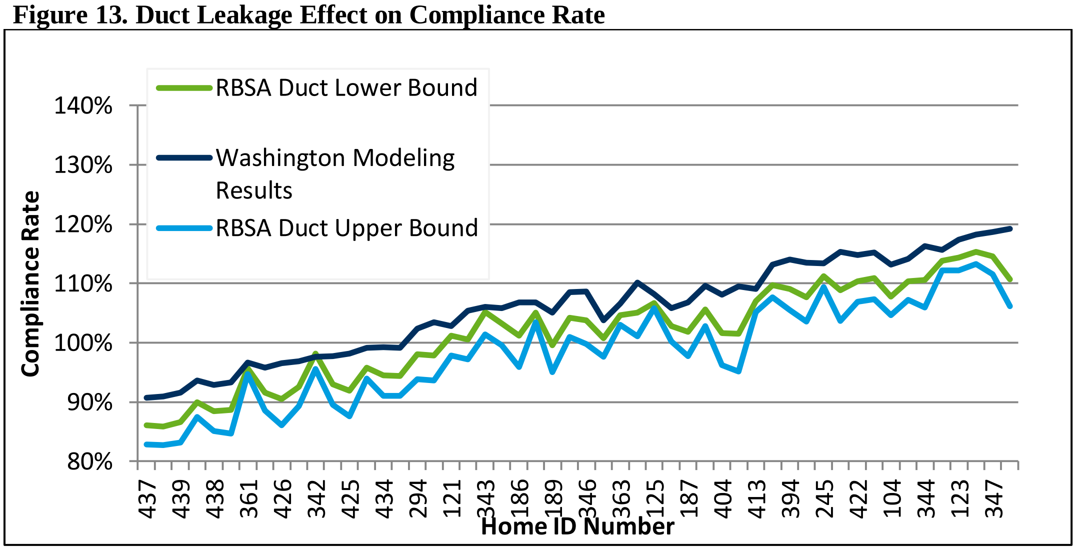


Figure 13. Duct Leakage Effect on Compliance Rate



8. Findings and Recommendations

Study objectives included the following:

- Analyze and report current rate of energy code statewide compliance in new residential construction in Washington, based on the WSEC 2009.
- Review and comment on the various approaches for assessing code compliance.
- Determine aspects of current energy code in which enhanced code compliance would lead to the largest reductions in home energy consumption.
- Assess an approach to analyze code compliance based on the most significant items in determining energy impacts.

The study collected field data on sixty-nine Washington homes permitted since the current residential code took effect and plans data from many of the same homes. Based on these data, Cadmus analyzed compliance using: the PNNL checklist approach (modified to apply to the Washington code); the significant item approach, which measured compliance based on the checklist items most significant to energy use; and a simulation model, providing an estimate of the impact of code compliance on energy use.

Cadmus' research also identified code requirements offering the most opportunity for increased energy savings, given enhanced compliance.

This chapter summarizes key findings addressing these issues, presenting recommendations for: improving code compliance; and conducting future compliance studies.

8.1. Discussion of Findings

8.1.1. Code Compliance

Washington builders may select among three different approaches to demonstrate compliance with energy codes: prescriptive, component performance, and systems analysis. Each approach establishes specific requirements for demonstrating compliance. There are several differences in the approaches that have significant impact in the results each generate. One is in how they handle lighting. The prescriptive approach requires homes to have at least fifty percent high-efficacy lighting, while the systems analysis approach does not. Another difference involves the window efficiency requirements. The prescriptive approach has different glazing U-value requirements depending on the glazing-to-floor area ratio. The systems analysis approach, on the other hand, sets a specific U-value and glazing-to-floor area ratio for the reference homes.

Washington builders most commonly used the prescriptive compliance approach. Ninety-nine percent of the builders used the prescriptive approach, and only one builder used the systems analysis approach. Cadmus did not inspect any home using the component performance approach.

To assess the degree to which homes in Washington complied with the new code, this study used two alternative methods to analyze compliance:

1. The PNNL checklist method: It analyzed how well the studied homes complied with each process and efficiency requirement of the code.
2. The significant item method: This approach analyzed compliance based on only measures that were assumed to have the most significant impact on energy use. It was evaluated as a less complex alternative to the complete checklist method.

Table 20 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, Washington has achieved the ARRA legislation requirement for states to strive to reach at least ninety percent compliance.

Table 20. Code Compliance Levels Determined by Two Methods

Methodology	Statewide Weighted Compliance Rate	90% Confidence Level Precision
Checklist	96%	2%
Significant Item	97%	2%

Using the modeling approach, the energy compliance index showed that homes, on average, performed better than homes just meeting the code minimum requirements. When the effect of lighting is included, new homes in Washington consume 3.7 percent less energy than if they just met code.

The ninety percent minimum target in ARRA draws upon applying the PNNL checklist method, taking into account all code requirements, including those without direct effects on building energy use. Considering the relatively strict nature of the Washington code, the compliance level estimated with the PNNL method provided a positive finding.

The precision (with a ninety percent confidence level) for estimated average compliance rates is shown in Table 20. The values are based on 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 believes the effects of unobservable items are not very large for the following reasons:

- When field-verified data were not available, but plans-verified data were, the study used the plans-verified data. As illustrated, the plans-verified values improve the accuracy of compliance rate estimates under the assumption that they are correct at least half the time.
- In reviewing the checklist items that were unobservable, the team found that many were code requirements that were not clearly linked to energy use (such as labeling on insulation). In many cases, the lack of visibility resulted from the timing of the site visit and had no effect on energy use.
- When data were not available for a specific home, but were available for other homes in the same jurisdiction, the study used data from the other homes. Assuming building practices and code enforcement were fairly consistent within a jurisdiction, this approach helped fill data gaps accurately.

Based on the PNNL checklist compliance analysis:

- About thirty percent of homes received a one-hundred percent compliance rate, based on observable checklist items.
- Significant differences occurred between climate zones in the compliance rates of specific checklist measure categories.
- All the homes where installed lighting was observable met the lighting efficacy requirement, but installed lighting could not be observed in sixty-five percent of homes.

Based on the significant item compliance analysis:

- About forty-two percent of homes received a one-hundred percent compliance rate, based on the observable checklist items.
- A ninety-seven percent average weighted compliance score resulted, slightly larger than the PNNL checklist average score of ninety-six percent.
- On the average, attic insulation shows a relatively low level of compliance based on observed R-values; however, when analyzed with the modeling approach, attics exceed the code requirements.

The compliance estimates from the checklist and significant item methods were highly correlated (the correlation coefficient was 0.45, which is significant at better than the 0.0001 significance level). This suggested it should be possible to estimate checklist compliance reasonably accurately by determining compliance of a subset of only nine items.

As the simulation modeling analysis requires 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 make this assessment, the study team calculated the percent savings for each home as-built compared to the modeled reference home. This value was regressed against the significant item checklist compliance rate for the same home. There was only a very small positive correlation between the measures, and the relationship was not statistically significant. Consequently, the study team cannot conclude that the significant item compliance method can be used to assess compliance energy impacts.

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

- High efficiency furnaces and heat pumps had the greatest impact on beyond-code energy savings, accounting for over half the additional savings
- Higher efficiency envelope components, including wall insulation and windows, provided the second largest beyond-code savings
- High efficiency water heating contributed the third largest amount to beyond-code savings.
- Overall, floors and foundations exhibited higher U-values than the code reference requirements and, thus, reduced energy savings.

The modeling results also showed the energy compliance index and percent energy savings were remarkably consistent, regardless of a home's energy consumption. Several qualifications must be cited regarding the simulation model compliance analysis results:

- Data required to run the models were missing in many cases and Cadmus assumed components just met minimum code requirements in these cases. This assumption was made to avoid introducing either a positive or negative bias in the analysis.
- Due to a lack of data, actual duct leakage and infiltration rates could not be used in the analysis, though both can significantly affect energy use. The study sensitivity analysis based on available duct leakage and infiltration data, however, showed that assuming both just met the code requirement was reasonable and did not bias the results.

8.1.2. Compliance Benchmarking

It is informative to compare Washington compliance rates found in this study with energy code compliance rates from other studies. As this study illustrates, however, there are many ways to measure compliance and no standard metric has been widely adopted. Some of the alternative ways to measure compliance include the following:

- Pass/fail criteria for individual requirements or the code as a whole
- Percentage of requirements met
- Energy consumption relative to a building complying with the code.

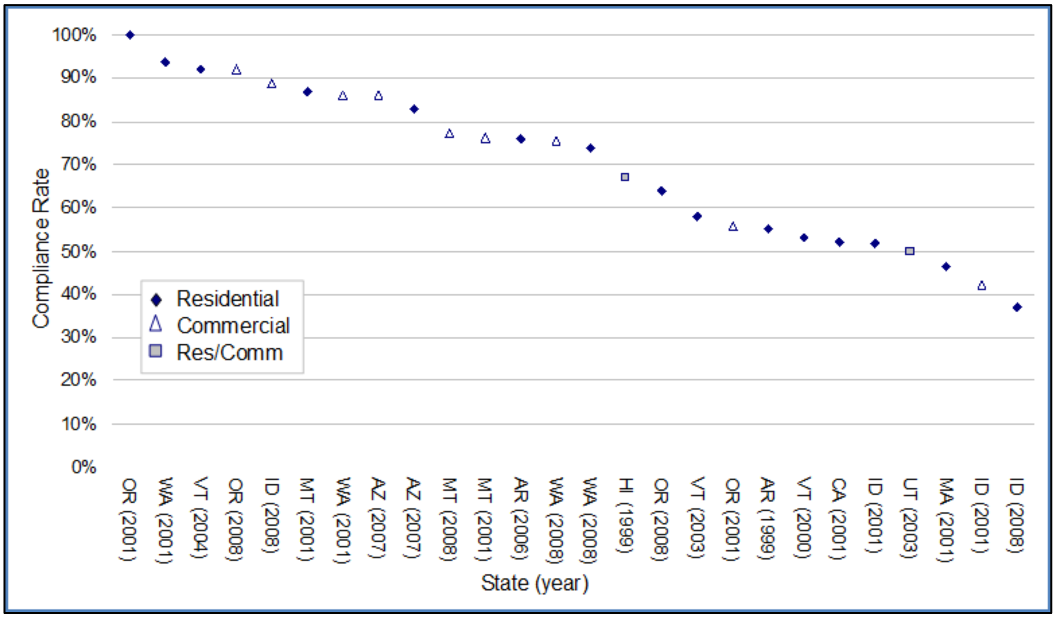
Using energy consumption to measure compliance rates also can be further delineated based on a range of approaches such as these:

- Energy consumption as a percent of the consumption of a building just meeting the code
- The amount of energy a building uses that is more or less than a building built to code, calculated as the percent difference
- Percent a building saves of the amount of energy a building built to the current code would save relative to the prior code

In addition to these variations, assessment of compliance is confounded by the need to define what measures and energy impacts are included. As this study shows, lighting efficiency may or may not be a factor under the 2009 WSEC depending on which approach a builder chooses to demonstrate compliance.

Despite these complexities and lack of consistency, compliance results from other studies provide context for the findings in this study. Figure 14 shows results of twenty-six prior studies for several states and residential and commercial buildings. The report noted that nine different compliance rate metrics had been used. The rates range from 100 percent to thirty-seven percent. Although the differences in methodology and metrics make meaningful comparisons challenging, it is informative to note the compliance rates for Northwestern states: Oregon, Idaho, and Washington in particular. In addition, compliance rates above ninety percent have been measured in three studies in Oregon and Washington. Compliance rates in Washington have been relatively high historically, and this study's results indicate that Washington continues to perform well in residential code compliance and enforcement.

Figure 14. Compliance Rates from Prior Studies, by State and Building Type



Notes: From Misuriello, Kwatra, Kushler, Nowak (2012)

As mentioned before, NEEA sponsored a recent study of residential code compliance in Montana using methods similar to those used in this study, but without any energy impact estimates. The results from the Montana study and two other recent studies are shown in Table 21. They illustrate the diversity of methods used and the large compliance rate range observed in very recent studies.

Table 21. Recent 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%
California	2008	Electricity space heating/cooling savings as percent of savings expected from code change—120%	--	--
Rhode Island	2012	PNNL checklist—58%	Prescriptive—38%	Energy cost— -26%

Notes: Montana results are from Lee, A., Cook, R., Horton, D. (2012); California results are from Cadmus (2010); Rhode Island results are from NMR Group, Inc., KEMA, Inc., The Cadmus Group, Inc., Conant (2012). Negative energy cost compliance for Rhode Island means the energy consumed by the average house exceeded what it would if the average home just met the code by twenty-six percent.

8.2. Recommendations

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

8.2.1. Code Implementation

NEEA and other organizations have been active in the region supporting code compliance. This study finds relatively high statewide compliance levels in Washington using two different methods. The high compliance rates are likely due in part to these efforts, so Cadmus recommends continuing these activities. With the change in the residential code and integration with the IECC, there may be an increase in the number of homes complying using a tradeoff approach. REScheck[21] has been developed to facilitate compliance using a UA tradeoff approach and builders may start using this approach and tool. Cadmus recommends NEEA continue its ongoing 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. Builders and code officials should be educated and trained in code requirements, especially those regarding floor and foundation insulation.
3. Efforts should seek to improve code compliance documentation provided to code officials. REScheck may become a viable option and has proven to be heavily used across the country and is intuitive for builders.

8.2.2. Compliance Assessments

In conducting this code compliance assessment, challenges emerged, and several steps can facilitate and enhance future studies. These steps, increasing the ease of conducting compliance assessments, will simultaneously increase energy simulation analyses' accuracy and completeness, based on the PNNL checklists. The following recommendations seek to facilitate future compliance studies:

1. Steps should be taken to reduce the difficulty of locating and visiting newly constructed homes.
    a) The state should investigate development of a statewide repository of code compliance data to facilitate code compliance tracking and future research.
    b) Building departments should be discouraged from discarding completed permits, and should be encouraged to assist in the evaluation process.
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. Cadmus recommends conducting future compliance study inspections in conjunction with building officials' final inspections, to allow the most data to be gathered for each home. Duct testing and HVAC efficiencies—both high-energy impact components—could be verified at each home.
4. To assess whether the assumptions made about items that were unobservable when homes were visited in this study, the study team recommends conducting a pilot study that follows a small number of homes through the entire construction cycle as described in the PNNL approach. This study could provide evidence about the validity of the assumptions made regarding compliance of unobservable items.

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[21] REScheck was developed for U.S. DOE by PNNL to demonstrate residential code compliance (U.S. DOE 2010b).

5. 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.[22] Weighting a sample heavily toward finished homes and inspecting items not observable with infrared technology could allow for a more efficient use of field personnel.[23]

8.2.3. 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 nine 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 importance between various compliance items.
3. The current method for estimating compliance makes no adjustment to account for the number of items applicable and observable and this gives equal weight to homes for which less data were gathered. Cadmus suggests calculating statewide compliance with a weighted average that gives more weight to compliance rates of homes with a larger number of applicable and observable checklist items.
4. An energy-modeling component should be incorporated in 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 robust view of compliance.

8.3. Final Observations

Cadmus finds Washington has made progress in implementing the latest residential energy code effectively to achieve high compliance rates. Although our analysis indicates ARRA's ninety percent target is being met, data gaps create some uncertainties in the results. The energy modeling analysis showed, on the average, homes were using less energy than if they just met the code. However, nearly thirty percent of the homes in the study sample used more energy than they would if they met the code. Since the ultimate benefit of code compliance is energy savings, the state should strive to achieve full compliance in all homes, and even exceed the code requirements.

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

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

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10. Appendix A: Line Item Compliance

This Appendix presents results of sixty-nine Cadmus site visits for sixty-two compliance items on PNNL's checklist. For each checklist item, the following have been provided:

1. Construction phase (checklist 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 22. 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
Pre-Inspection	Construction drawings and documentation available. Documentation sufficiently demonstrates energy code compliance, with the exception of HVAC loads, addressed in PR2. Systems serving multiple dwelling units must demonstrate compliance with the commercial code	3	43	4	21	1	99%	69%	91%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	HVAC equipment correctly sized per ACCA Manual J and S, or other approved methods: Heating system size(s): Cooling system size(s):	2	12	4	53	0	100%	23%	75%
Foundation	Slab edge insulation R-value.	3	8	0	1	60	13%	89%	100%
	Slab edge insulation installed per manufacturer's instructions.	3	0	0	26	43	38%	0%	-
	Slab edge insulation depth/length.	3	4	0	2	63	9%	67%	100%
	Conditioned basement wall exterior insulation R-value. If the insulation is located on the wall interior, use IN5 and mark this N/A. Not required in warm-humid locations in Climate Zone 3.	3	1	0	1	67	3%	50%	100%
	Basement wall exterior insulation installed per manufacturer's instructions.	3	1	0	3	65	6%	25%	100%
	Basement wall exterior insulation depth.	3	1	0	3	65	6%	25%	100%
	Crawl space wall insulation R-value.	3	0	0	3	66	4%	0%	-
	Crawl space	3	0	0	21	48	30%	0%	-

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 installed per manufacturer's instructions.								
	Crawl space continuous vapor retarder installed with joints overlapped by 6” and sealed, and extending at least 6" up the stem wall.	3	25	0	21	23	67%	54%	100%
	Crawl space wall insulation depth (total vertical plus horizontal distance).	3	0	0	26	43	38%	0%	-
	Exposed foundation insulation protection.	2	0	5	33	31	55%	13%	0%
	Snow melt controls.	2	0	1	3	65	6%	25%	0%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
Framing/ Rough-In	Door U-factor. One side-hinged door up to 24 ft^2 can be exempted from the prescriptive requirements.	3	21	5	43	0	100%	38%	81%
	Glazing U-factor (area-weighted average). 15 ft^2 of glazed fenestration, including skylights, may be exempted from the prescriptive requirements.	3	61	2	6	0	100%	91%	97%
	Glazing labeled for U-factor and SHGC (or default values used).	3	57	4	7	1	99%	90%	93%
	Skylight U-factor. 15 ft^2 of glazed fenestration may be exempted from the prescriptive requirements.	3	1	0	2	66	4%	33%	100%
	Skylights labeled for U-factor and SHGC (or default values used).	3	1	1	0	67	3%	100%	50%
	Mass wall exterior insulation R-value. If more than ½ of insulation is on the wall interior, use IN3 and mark this N/A.	3	18	0	1	50	28%	95%	100%
	Mass wall	3	6	0	16	47	32%	27%	100%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	exterior insulation installed per manufacturer's instructions.								
	Duct insulation. If all ducts are in conditioned spaces, mark this compliant. If all systems are ductless, mark this N/A.	3	42	1	25	1	99%	63%	98%
	Duct sealing complies with listed sealing methods.	3	36	0	26	7	90%	58%	100%
	Duct tightness via rough-in. For post-construction tests, use FI4 and mark this N/A.	3	13	0	25	31	55%	34%	100%
	Building cavities NOT used for supply ducts.	3	42	0	22	5	93%	66%	100%
	IC-rated recessed lighting fixtures meet infiltration criteria.	2	49	0	17	3	96%	74%	100%
	HVAC piping insulation.	2	17	0	50	2	97%	25%	100%
	Circulating hot-water piping insulation.	2	12	0	57	0	100%	17%	100%
	Dampers Installed on all outdoor Intake and exhaust openings.	2	48	0	18	3	96%	73%	100%
	Fenestration that is not site built is listed and labeled as meeting AAMA	1	16	0	5	48	30%	76%	100%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	/WDMA/CSA 101/I.S.2/A440 or has infiltration rates per NFRC 400 that do not exceed code limits.								
Insulation	Floor insulation R-value.	3	52	0	5	12	83%	91%	100%
	Floor insulation installed per manufacturer's instructions, and in substantial contact with the subfloor.	3	43	3	19	4	94%	71%	93%
	Wall insulation R-value. If this is a mass wall with at least ½ of the wall insulation on the wall exterior, use FR10 and mark this N/A.	3	62	1	6	0	100%	91%	98%
	Wall insulation installed per manufacturer's instructions.	3	20	0	48	1	99%	29%	100%
	Conditioned basement wall interior insulation R-value. If the insulation is located on the wall exterior, use FO4 and mark this N/A. Not required in warm-humid locations in Climate Zone 3.	3	4	0	1	64	7%	80%	100%
	Basement wall interior insulation	3	2	0	3	64	7%	40%	100%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	installed per manufacturer's Instructions.								
	Basement wall interior insulation depth.	3	1	0	3	65	6%	25%	100%
	All installed insulation labeled or installed R-value provided.	2	40	1	21	7	90%	66%	98%
Final	Ceiling insulation R-value. Where >R-30 is required, R-30 can be used if insulation is not compressed at eaves. R-30 may be used for 500 ft^2 or 20% (whichever is less) where sufficient space is not available.	3	48	12	9	0	100%	87%	80%
Final	Ceiling insulation installed per manufacturer's instructions. Blown insulation marked every 300 ft^2.	3	25	2	40	2	97%	40%	93%
Final	Duct tightness via post construction. For rough-in tests, use FR14 and mark this N/A.	3	9	0	24	36	48%	27%	100%
Final	Heating and cooling equipment type and capacity as per	3	26	2	38	3	96%	42%	93%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	plans.								
	Lighting: 50% of lamps are high efficacy.	3	24	0	44	1	99%	35%	100%
	Compliance certificate posted.	2	31	10	27	1	99%	60%	76%
	Wood burning fireplace; gasketed doors and outdoor air for combustion.	2	0	1	2	66	4%	33%	0%
	Programmable thermostats installed on forced air furnaces	2	22	0	35	12	83%	39%	100%
	Heat pump thermostat installed on heat pumps.	2	6	0	10	53	23%	38%	100%
	Circulating service hot water systems have automatic or accessible manual controls.	2	13	1	24	31	55%	37%	93%
	Automatic or accessible manual controls for heated swimming pools.	2	0	0	3	66	4%	0%	-
	Air sealing complies with sealing requirements via blower door test. If evaluated via visual inspection, use IN14 and mark this N/A.	3	10	0	59	0	100%	14%	100%
	Manufacturer manuals for mechanical and water heating	1	29	0	29	11	84%	50%	100%

Construction Phase	Compliance Item	Item Weight	Number Compliant	Number Not Compliant	Number Not Observed	Number Not Applicable	Percent Applicable	Percent Observed	Percent Compliant
	equipment have been provided.								
	Timer switches on pool heaters and pumps.	1	0	0	1	68	1%	0%	-
	Heated swimming pool covers.	1	0	0	1	68	1%	0%	-
Chapter Nine Option	Chapter Nine options applied.	1	59	2	8	0	100%	88%	97%

11. Appendix B: Derivation of Weights

As building codes vary significantly across climate zones, Cadmus treated climate zones as a stratification variable in analyzing results. Within each climate zone, Cadmus treated counties as level-one sampling units, and individual building starts within counties as level-two sampling units.

This section utilizes the following notation:

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

Cadmus estimates the compliance rate for the *j*th sampled county as:

$$\overline{x}_j = \sum \frac{x_{j,k}}{n_j} \text{ (The sum is over sampled buildings } k \text{ within county } j\text{.)}$$

For each climate zone, Cadmus estimated the compliance rate as the weighted mean of rates for sampled counties within that zone. For example, zone *i* is:

$$\overline{\text{Zone}}_i = \frac{\sum N_j \cdot \overline{x}_j}{\sum N_j} \text{ (Both sums are over sampled counties } j \text{ within zone } i\text{.)}$$

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

$$w_{j,k}^{\text{climate}} = \frac{N_j}{n_j}$$

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

$$\overline{\text{Region}} = \frac{\sum M_i \cdot \overline{\text{Zone}}_i}{\sum M_i} \text{ (Both sums run over the four regional climate zones.)}$$

In terms of weighting, this means, in estimating the regional compliance rate, the weight attached to the sample point $x_{j,k}$ as:

$$w_{j,k}^{\text{region}} = \frac{M_i}{\sum_{\substack{\text{sampled } j \\ \text{in zone } i}} N_j} \cdot \frac{N_j}{n_j} \text{ (Here, } i \text{ is the climate zone containing county } j.\text{)}$$

12. Appendix C: PNNL Checklists

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

Building ID:_______ Date:_________ Name of Evaluator(s):______

Building Contact (optional): Name:____________ Phone:___________ Email:_____________________________

Building Name & Address:____

Subdivision:__________________________________ Lot #:_____________

State:___________ County:____________________ Jurisdiction:____

IECC Climate Zone: ___________________________

NW Climate Zone: ____________________________

Compliance Approach (check all that apply): ☐ Prescriptive

☐ Trade-Off (IECC)

☐ Performance (IECC)

☐ Component Performance (WA)

☐ System Analysis (WA)

Compliance Software Used:_____________________

Green Building/Above-Code Program:____________

	Building Characteristics	Units	Plans Verified Value	Field Verified Value	Comply?	Options
BC1	Project Type					New Building Existing Building Addition Existing Building Renovation
	Building Type					1 or 2-Family, Detached 1 or 2-Family, Modular

						1 or 2-Family, Townhouse Multifamily, Apartment Multifamily, Condominium
	Foundation Type					Basement, Conditioned Basement, Unconditioned Slab Crawl Space, Conditioned Crawl Space, Unconditioned Floor Over Unconditioned Space
Added	Perimeter of foundation (ft)					#INPUT
Added	Sq-ft of footprint (ft^2)					#INPUT
	Number of Floors Above Grade					#INPUT
	Conditioned Floor Area	*Square feet*				#INPUT
	Ceiling Height					#INPUT
	Number of Bedrooms					#INPUT
	Number of floors above					#INPUT

	grade					
	Attached Garage					Y/N
	Garage Wall Area					
	Conditioned Floor Area above Garage					Y/N
	If yes, Garage Ceiling Area					
	Number of Exterior Doors					
	Window VLT(Visible Light Transmittance)					
	Window Frame Type					Wood/Metal/Vinyl /Fiberglass/Other
	North Window Area					
	West Window Area					
	South Window Area					
	East Window Area					
	Skylight Area					
	Above Grade Wall Area (ft^2)					
Added	Basement/Crawl Wall Height (ft) [If applicable]					
Added	Basement/Crawl Wall Depth Below Grade (ft) [If applicable]					
Added	Basement/Crawl Wall Area (ft^2) [If applicable]					

Added	Floor Area Over Unconditioned Space (ft^2) [If applicable]					
Added	Flat Ceiling Area (ft^2)					
	Vaulted Ceiling Area (ft^2)					
	Vaulted Ceiling R-Value					

IECC Section #	Building Mechanical Systems	Dropdown Menu	Plans Verified Value	Field Verified Value	Complies?	Options
Added	**Heating System Type**					Furnace - Central Forced Air Boiler Hot Water Boiler Steam Resistance (Electric Only) ASHP GAHP Fireplace Stove

						Portable Units Other
Added	**Heating System Fuel**					Wood Heating Oil Natural Gas Propane Electricity Wood/ Corn Pellet Kerosene Other
Added	**Heating System Capacity (BTU/hr)**					
Added	**Heating System Efficiency(AFUE , HSPF)**					
Added	**Cooling System Type**					Room Unit Central Forced Air Heat Pump Ductless Split System Evaporative Cooler Other
Added	**Cooling System Capacity (BTU/hr)**					
Added	**Cooling System Efficiency(SEER)**					

Added	**DHW Fuel**					
Added	**DHW System Type**					**Conventional,** **On Demand(Tankless),** **Indirect,** **Other**
Added	**DHW System EF**					
Added	**Mechanical Ventilation System**					**Exhaust Fan,** **Energy Recovery Ventilation,** **Inlet Fan,** **Other**
Added	**Mechanical Ventilation System Recover Efficiency**					
Added	**Mechanical Ventilation System CFM Rate**					
Added	**Alternative Energy Source**					
Added	**Alternative Energy Output and Notes**					

IECC Section #	Pre-Inspection/Plan Review	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Comply?	Comments/Assumptions[24]
103.2, 403.7 [PR1][1]	Construction drawings and documentation available. Documentation sufficiently demonstrates energy code compliance, with the exception of HVAC loads, addressed in PR2. Systems serving multiple dwelling units must demonstrate compliance with the commercial code				☐Y ☐N/A ☐N ☐N/O	
403.6 [PR2][2]	HVAC equipment correctly sized per ACCA Manual J and S, or other approved methods: Heating system size(s): Cooling system size(s):		Heating: kBtu: ______ Cooling: kBtu: ______	Heating: kBtu: ______ Cooling: kBtu: ______	☐Y ☐N/A ☐N ☐N/O	

Additional Comments/Assumptions: ______________________________

[24] Use Comments/Assumptions to document code requirements that pass due to exceptions, and specify the exception. Also use Comments/Assumptions to document multiple values observed for a given code requirement, such as multiple equipment efficiencies.

General building information only required if different than above Building ID:________

Date:__________ Name of Evaluator(s): ________________________________

Building Name & Address:________________________________ Conditioned Floor Area:________________________________ft²

Building Contact (optional): Name:__________ Phone:__________ Email:________________

Compliance Approach (check all that apply): ☐ Prescriptive ☐ Trade-Off ☐ Performance

Compliance Software Used:__________________ Green Building/Above-Code Program: __________________

IECC Section #	Foundation Inspection	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
402.1.1 [FO1][1]	Slab edge insulation R-value.	Unheated: R-10 Heated: R-15	R-_____ ☐ Unheated ☐ Heated	R-_____ ☐ Unheated ☐ Heated	☐Y ☐N/A ☐N ☐N/O	
303.2, 402.2.8 [FO2][1]	Slab edge insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐N/A ☐N ☐N/O	
402.1.1 [FO3][1]	Slab edge insulation depth/length.	2 ft.	_____ ft.	_____ ft.	☐Y ☐N/A ☐N ☐N/O	
402.1.1 [FO4][1]	Conditioned basement wall exterior insulation R-value. If the insulation is located on the wall interior, use IN5 and mark this N/A. Not required in warm-humid	Continuous: R-10	R-_____	R-_____	☐Y ☐N/A ☐N ☐	

	locations in Climate Zone 3.				N/O	
303.2 [FO5][1]	Basement wall exterior insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.2.7 [FO6][1]	Basement wall exterior insulation depth.	10 ft. or to bsmt. floor	_____ ft.	_____ ft.	☐Y ☐ N/A ☐N ☐ N/O	
402.2.9 [FO7][1]	Crawl space wall insulation R-value.	Continuous: R-10 Cavity: R-13	R-_____ R-_____	R-_____ R-_____	☐Y ☐ N/A ☐N ☐ N/O	
303.2 [FO8][1]	Crawl space wall insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.2.9 [FO9][1]	Crawl space continuous vapor retarder installed with joints overlapped by 6 inches and sealed, and extending at least 6" up the stem wall.				☐Y ☐ N/A ☐N ☐ N/O	
402.2.9 [FO10][1]	Crawl space wall insulation depth (total vertical plus horizontal distance).					

303.2.1 [FO11][2]	Exposed foundation insulation protection.				☐Y ☐ N/A ☐N ☐ N/O	
403.8 [FO12][2]	Snow melt controls.				☐Y ☐ N/A ☐N ☐ N/O	

Additional Comments/Assumptions: ____

General building information only required if different than above Building ID:________

Date:__________ Name of Evaluator(s): ____

Building Name & Address:________________________________ Conditioned Floor Area:________________________________ft²

Building Contact (optional): Name:__________ Phone:__________ Email:____________________

Compliance Approach (check all that apply): ☐ Prescriptive ☐ Trade-Off ☐ Performance

Compliance Software Used:__________________ Green Building/Above-Code Program: ________________________________

IECC Section #	Framing / Rough-In Inspection	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
402.1.1, 402.3.4 [FR1][1]	Door U-factor. One side-hinged door up to 24 ft^2 can be exempted from the prescriptive requirements.	U-0.35	U-_____	U-_____	☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.1, 402.3.3 [FR2][1]	Glazing U-factor (area-weighted average). 15 ft^2 of glazed fenestration, including skylights, may be exempted from the prescriptive requirements.	U-0.35 (0.48 max)	U-_____	U-_____	☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.2, 402.3.3, 402.5 [FR3][1]	Glazing SHGC value (area-weighted average). 15 ft^2 of glazed fenestration may be exempted from the prescriptive requirements.	N/A	SHGC: _____	SHGC: _____	☐Y ☐N/A ☐N ☐N/O	

303.1.3 [FR4][1]	Glazing labeled for U-factor and SHGC (or default values used).				☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.3 [FR5][1]	Skylight U-factor. 15 ft^2 of glazed fenestration may be exempted from the prescriptive requirements.	U-0.6 (0.75 max)	U-_____	U-_____	☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.3, 402.5 [FR6][1]	Skylight SHGC value, including sunrooms. 15 ft^2 of glazed fenestration may be exempted from the prescriptive requirements.	N/A	SHGC: _____	SHGC: _____	☐Y ☐N/A ☐N ☐N/O	
303.1.3 [FR7][1]	Skylights labeled for U-factor and SHGC (or default values used).				☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.5 [FR8][1]	Sunroom glazing U-factor. New windows and doors separating the sunroom from conditioned space must meet code requirements.	U-0.5	U-_____	U-_____	☐Y ☐N/A ☐N ☐N/O	
402.1.1, 402.3.5 [FR9][1]	Sunroom skylight U-factor.	U-0.75	U-_____	U-_____	☐Y ☐N/A ☐N ☐N/O	

402.1.1 [FR10][1]	Mass wall exterior insulation R-value. If more than ½ of the insulation is on the wall interior, use IN3 and mark this N/A.	R-13	R- _____	R- _____	☐Y ☐N/A ☐N ☐N/O	
303.2 [FR11][1]	Mass wall exterior insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐N/A ☐N ☐N/O	
403.2.1 [FR12][1]	Duct insulation. If all ducts are in conditioned spaces, mark this compliant. If all systems are ductless, mark this N/A.	Attic Supply: R-8 Other: R-6	R- _____ R- _____	R- _____ R- _____	☐Y ☐N/A ☐N ☐N/O	
403.2.2 [FR13][1]	Duct sealing complies with listed sealing methods.				☐Y ☐N/A ☐N ☐N/O	
403.2.2 [FR14][1]	Duct tightness via rough-in. For post-construction tests, use FI4 and mark this N/A.	Across System: 6 cfm No Air Handler:: 4 cfm	_____ cfm	_____ cfm	☐Y ☐N/A ☐N ☐N/O	
402.4.4 [FR20][1]	Fenestration that is not site built is listed and labeled as meeting AAMA /WDMA/CSA 101/I.S.2/A440 or has infiltration rates per NFRC 400 that do not exceed code				☐Y ☐N/A ☐N ☐N/O	

	limits.					
402.4.5 [FR16][2]	IC-rated recessed lighting fixtures meet infiltration criteria.				☐Y ☐ N/A ☐N ☐ N/O	
403.3 [FR17][2]	HVAC piping insulation.	R-3	R-_____	R-_____	☐Y ☐ N/A ☐N ☐ N/O	
403.4 [FR18][2]	Circulating hot-water piping insulation.	R-2	R-_____	R-_____	☐Y ☐ N/A ☐N ☐ N/O	
403.5 [FR19][2]	Dampers Installed on all outdoor Intake and exhaust openings.				☐Y ☐ N/A ☐N ☐ N/O	
403.2.3 [FR15][3]	Building cavities NOT used for supply ducts.				☐Y ☐ N/A ☐N ☐ N/O	

Additional Comments/Assumptions: ____

General building information only required if different than above Building ID:________

Date:___________ Name of Evaluator(s): ____

Building Name & Address:____ Conditioned Floor Area:____ft²

Building Contact (optional): Name:___________ Phone:___________ Email:____________________________

Compliance Approach (check all that apply): ☐ Prescriptive ☐ Trade-Off ☐ Performance

Compliance Software Used:_____________________ Green Building/Above-Code Program: ____

IECC Section #	Insulation Inspection	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
402.1.1, 402.2.5, 402.2.6 [IN1][1]	Floor insulation R-value.	Wood: R-30 (or sufficient to fill cavity, R-19 minimum) Steel: R-19+R-6 in 2x6 or R-19+R-12 in 2x8 or 2x10	R-______ ☐ Wood ☐ Steel	R-______ ☐ Wood ☐ Steel	☐Y ☐N/A ☐N ☐N/O	
303.2, 402.2.6 [IN2][1]	Floor insulation installed per manufacturer's instructions, and in substantial contact with the subfloor.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐N/A ☐N ☐N/O	
402.1.1 402.2.5 402.2.4 [IN3][1]	Wall insulation R-value. If this is a mass wall with at least ½ of the wall insulation on the wall exterior, use FR10 and mark this N/A."	Wood: R-20 or R-13+R-5 Mass: R-17 Steel:R-13+R-10; R-19+R-9; R-25+R-8	R-______ ☐ Wood ☐	R-______ ☐ Wood ☐	☐Y ☐N/A ☐N ☐N/O	

			Mass ☐ Steel	Mass ☐ Steel		
303.2 [IN4][1]	Wall insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.1.1 [IN5][1]	Conditioned basement wall interior insulation R-value. If the insulation is located on the wall exterior, use FO4 and mark this N/A. Not required in warm-humid locations in Climate Zone 3.	Continuous: R-10 Cavity: R-13	R- _____ R- _____	R- _____ R- _____	☐Y ☐ N/A ☐N ☐ N/O	
303.2 [IN6][1]	Basement wall interior insulation installed per manufacturer's Instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.2.7 [IN7][1]	Basement wall interior insulation depth.	10 ft or to basement floor	_____ ft	_____ ft	☐Y ☐ N/A ☐N ☐ N/O	
402.2.1 1 [IN8][1]	Sunroom wall insulation R-value. New walls separating the sunroom from conditioned space must meet code	R-13	R- _____	R- _____	☐Y ☐ N/A ☐N ☐ N/O	

	requirements.					
402.2.11 [IN9][1]	Sunroom wall insulation installed per manufacturer's Instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.2.11 [IN10][1]	Sunroom ceiling insulation R-value.	R-24	R- ______	R- ______	☐Y ☐ N/A ☐N ☐ N/O	
303.2 [IN11][1]	Sunroom ceiling insulation installed per manufacturer's instructions.			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
402.4.1, 402.4.2 [IN14][1]	Air sealing complies with sealing requirements via visual inspection. If evaluated via blower door test, use FI17 and mark this N/A."			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐ N/A ☐N ☐ N/O	
303.1 [IN13][2]	All installed insulation labeled or installed R-value provided.				☐Y ☐ N/A ☐N ☐ N/O	

Additional Comments/Assumptions: ______________________________

General building information only required if different than above Building ID:________

Date:__________ Name of Evaluator(s): ____

Building Name & Address:____________________________________ Conditioned Floor Area:____ft²

Building Contact (optional): Name:__________ Phone:__________ Email:___________________

Compliance Approach (check all that apply): ☐ Prescriptive ☐ Trade-Off ☐ Performance

Compliance Software Used:___________________ Green Building/Above-Code Program: ____

IECC Section #	Final Inspection Provisions	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
402.1.1 402.2.1 402.2.2 [FI1][1]	Ceiling insulation R-value. Where >R-30 is required, R-30 can be used if insulation is not compressed at eaves. R-30 may be used for 500 ft² or 20% (whichever is less) where sufficient space is not available.	Wood: R-38 Steel Truss: R-49; R-38+R-3 Steel Joist: R-49	R-_____ ☐ Wood ☐ Steel	R-_____ ☐ Wood ☐ Steel	☐Y ☐N/A ☐N ☐N/O	
303.1.1.1, 303.2 [FI2][1]	Ceiling insulation installed per manufacturer's instructions. Blown insulation marked every 300 ft².			If complies: ☐ Good ☐ Fair ☐ Poor	☐Y ☐N/A ☐N ☐N/O	
402.2.3 [FI3][1]	Attic access hatch and door insulation.	R-38	R-_____	R-_____	☐Y ☐N/A ☐N ☐N/O	

403.2.2 [FI4][1]	Duct tightness via postconstruction. For rough-in tests, use FR14 and mark this N/A.	To Outdoors: 8 cfm Across System: 12 cfm	______ cfm	______ cfm	☐Y ☐ N/A ☐N ☐ N/O	
403.6 [FI5][1]	Heating and cooling equipment type and capacity as per plans.				☐Y ☐ N/A ☐N ☐ N/O	
404.1 [FI6][1]	Lighting - 50% of lamps are high efficacy.				☐Y ☐ N/A ☐N ☐ N/O	
402.4.2, 402.4.2.1 [FI17][1]	Air sealing complies with sealing requirements via blower door test. If evaluated via visual inspection, use IN14 and mark this N/A.	ACH 50 ≤ 7	ACH 50 = ______	ACH 50 = ______	☐Y ☐ N/A ☐N ☐ N/O	
401.3 [FI7][2]	Compliance certificate posted.				☐Y ☐ N/A ☐N ☐ N/O	
402.4.3 [FI8][2]	Wood burning fireplace - gasketed doors and outdoor air for combustion.				☐Y ☐ N/A ☐N ☐ N/O	

403.1.1 [FI9][2]	Programmable thermostats installed on forced air furnaces.				☐Y ☐ N/A ☐N ☐ N/O	
403.1.2 [FI10][2]	Heat pump thermostat installed on heat pumps.				☐Y ☐ N/A ☐N ☐ N/O	
403.4 [FI11][2]	Circulating service hot water systems have automatic or accessible manual controls.				☐Y ☐ N/A ☐N ☐ N/O	
403.3 [FI18][3]	Manufacturer manuals for mechanical and water heating equipment have been provided.				☐Y ☐ N/A ☐N ☐ N/O	
403.9.1 [FI12][3]	Automatic or accessible manual controls for heated swimming pools.				☐Y ☐ N/A ☐N ☐ N/O	
403.9.2 [FI19][3]	Timer switches on pool heaters and pumps.				☐Y ☐ N/A ☐N ☐ N/O	
403.9.3 [FI20][3]	Heated swimming pool covers.				☐Y ☐ N/A ☐N ☐ N/O	

Additional Comments/Assumptions: ______________________________

KEY	1	High Impact (Tier 1)	2	Medium Impact (Tier 2)	3	Low Impact (Tier 3)

IECC Section #	Washington Code Specific	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
WSEC	Chapter 9 Options Applied	1 Credit			☐Y ☐N/A ☐N ☐N/O	
	Continuous Radiant Slab Insulation	R-10			☐Y ☐N/A ☐N ☐N/O	

WSEC	Prescriptive Requirements	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
	Glazing area in sqft				☐Y ☐N/A ☐N ☐	

					N/O	

WSEC	Prescriptive Requirements	Prescriptive Code Value	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
Option 1	Glazing area: % of floor	*13%*			☐Y ☐ N/A ☐N ☐ N/O	
Option 2	Glazing area: % of floor	25%			☐Y ☐ N/A ☐N ☐ N/O	
Option 3	Glazing area: % of floor	unlimited			☐Y ☐ N/A ☐N ☐ N/O	

WSEC	Credit type	Number of Credits	Plans Verified Value	Field Verified Value	Complies?	Comments/Assumptions
Chapter 9	High Efficiency HVAC Equipment: You can obtain 1	1			☐Y ☐	

table 9-1[25]	credit if you install a 92 percent or higher Annual Fuel Utilization Efficiency (AFUE) gas, propane or oil-fired furnace or boiler or an air source heat pump with a minimum Heating Season Performance Factor (HSPF) of 8.5. There is no minimum Seasonal Energy Efficiency Ratio (SEER) requirement for heat pumps to claim this credit.				N/A ☐N☐ N/O	
Chapter 9 table 9-1	High Efficiency HVAC Equipment:: 2 credits are obtained for installing a closed loop ground source heat pump with a minimum Coefficient of Performance (COP) of 3.3 or better. Even though the WSEC calls out a ground source	2			☐Y☐ N/A ☐N☐ N/O	
Chapter 9 table 9-1	High Efficiency HVAC Equipment: 1 credit can be taken for installing a ductless split system heat pump with zonal control. To satisfy the Requirements for this credit, it has to be installed in a house with zonal electric heat and the heat pump must supply heat to at least one zone. For example, the ductless heat pump could be installed in the main living area of the house with electric resistance heat (baseboard or wall units) in the bedrooms.	1			☐Y☐ N/A ☐N☐ N/O	

[25] The 2009 Washington State Energy Code (WSEC) now requires that all International Residental Code (IRC) defined occupancies develop one credit from Chapter 9, Table 9-1, if complying prescriptively or when using the component performance approach. If complying with IRC Chapter 4, Systems Analysis, compliance is accomplished by demonstrating that the proposed building's annual energy use is 8 percent less than the target building.

Chapter 9 table 9-1	High Efficiency HVAC Distribution System: 1 credit is obtained when all HVAC components, including both the furnace and ductwork, are installed inside the conditioned space. Combustion equipment must be direct vent or sealed combustion. This credit is not allowed if ductwork or the air handler is located in a conditioned crawl space. Also, this credit cannot be taken for a structure heated with an electric resistance system such as baseboards or electric wall heaters. Direct combustion equipment cannot be less than 80 percent AFUE to claim this credit.	1			☐Y ☐ N/A ☐N ☐ N/O	
Chapter 9 table 9-1	Efficient Building Envelope 1: .5 credits are allowed if the building envelope is improved in Climate Zone 1 to: – Windows U-.28 (area weighted average) – Floor R-38 – Slab-on-grade R-10 fully insulated – Below grade slab R-10 fully insulated	.5			☐Y ☐ N/A ☐N ☐ N/O	
Chapter 9 table 9-1	Efficient Building Envelope 2: 1 credit is gained by improving the building envelope in Climate Zone 1 to: – Windows U-.25 (area weighted average) – Floor R-38 – Slab-on-grade R-10 fully	1			☐Y ☐ N/A ☐N ☐ N/O	

	insulated – Below grade slab R-10 fully insulated – R-21+R-5 below grade basement walls. This measure requires R-21 cavity insulation with R-5 foam sheathing on the exterior of the below grade wall.					
Chapter 9 table 9-1	Super-Efficient Building Envelope 3: 2 credits are allowed for improving the building envelope in Climate Zone 1 to: – Windows U-.22. – Walls R-21+R-12. This measure requires R-21 cavity insulation and R-12 exterior foam sheathing. – Floor R-38. – Slab-on-grade R-10 fully insulated. – Below grade slab R-10 fully insulated. – R-21+R-12 below grade basement walls. This measure requires R-21 cavity insulation with R-12 foam sheathing on the exterior of the below grade wall.	2			☐Y ☐ N/A ☐N ☐ N/O	
Chapter 9 table 9-1	Air Leakage Control and Efficient Ventilation: .5 credit If the specific leakage area (SLA) of the house is reduced to .00020 from the standard code maximum SLA of .00030, .5 credits are obtained.	.5			☐Y ☐ N/A ☐N ☐	

	Documentation of the test results are recorded on the certificate posted at the house (See Figure 5-7 in Chapter 5). An HRV must also be installed to claim this credit.				N/O	
Chapter 9 table 9-1	Additional Air Leakage Control and Efficient Ventilation: 1 credit is allowed if the SLA of the house is further reduced to .00015. As with the previous credit, documentation of the test results are recorded on the certificate posted at the house. An HRV must also be installed to claim this credit.	1			☐Y ☐ N/A ☐N ☐ N/O	
Chapter 9 table 9-1	Efficient Water Heating: .5 credits are given when installing a minimum .62 Energy Factor (EF) gas, propane or oil water heating equipment. If installing an electric water heater, a minimum EF of .93 or higher is required for this credit. In addition, all showerheads and kitchen sink faucets need to be rated for 1.75 gallons per minute (GPM) or less. All other lavatory faucets need to be rated at 1.0 GPM or less.	.5			☐Y ☐ N/A ☐N ☐ N/O	
Chapter 9 table 9-1	High Efficiency Water Heating: 1.5 credits are given if one of the following is met: – The water heating system includes a minimum of .82 EF gas, propane or oil water heater. This is likely going to be an on-demand or ‘tankless’ type of system. – Solar water heating can be installed to supplement a standard	1.5			☐Y ☐ N/A ☐N ☐ N/O	

	water heater. It must provide a rated minimum savings of at least 85 therms or 2,000 kWh. Savings are based on the Solar Rating Certification Corporation (SRCC) Annual Performance of OG-300 Certified Solar Water Heating Systems. Their website is: www.solarrating.org/ratings/ratings.htm Credits for an electric heat pump water heater are allowed if the unit has a minimum EF of 2.0.					
Chapter 9 table 9-1	Small Dwelling Unit: 1 credit is given to houses less than 1,500 square feet. And with a maximum window and door area of 300 square feet. This credit also applies to additions less than 750 square feet.	1			☐Y ☐ N/A ☐N ☐ N/O	
	Large Dwelling Unit: -1 credit is assessed as a deficit for houses exceeding 5,000 square feet. This means that houses over 5,000 square feet need to get two credits from Chapter 9 to satisfy Chapter 9 requirements.					
Chapter 9 table 9-1	Renewable Electric Energy: .5 to 3 credits are allowed for every 1,200 kWh of annual electrical generation for on-site solar or wind. A documentation method is outlined in Chapter 9 of the WSEC, see Option 8 in Table 9-1.	.5-3			☐Y ☐ N/A ☐N ☐ N/O	

13. Appendix D: Washington Code Requirements

This appendix presents the residential code requirements by climate zone.

Table 23. Reference Home U-Values

CZ	Fenestration U-Factor	Skylight U-Factor	Ceiling U-Factor	Frame Wall U-Factor	Mass Wall U-Factor	Floor U-Factor	Basement Wall U-Factor*	Crawlspace Wall U-Factor
1	15% of Floor Area 0.30	0.5	0.027	0.056	0.060	0.029	2' BG 0.042 3.5' BG 0.041 7' BG 0.037	2' BG 0.042 3.5' BG 0.041 7' BG 0.037
2	15% of Floor Area 0.30	0.5	0.0.27	0.056	0.060	0.029	2' BG 0.042 3.5' BG 0.041 7' BG 0.037	2' BG 0.042 3.5' BG 0.041 7' BG 0.037

*BG (Below Grade).

Table 24. Prescriptive Requirements for Single-Family Residential Climate Zone 1

Glazing Area % of Floor	Glazing U-Factor Vertical	Glazing U-Factor Overhead	Door U-Factor	Ceiling	Vaulted Ceiling	Wall Above Grade	Wall Interior Below Grade	Wall Exterior Below Grade	Floor	Slab on Grade
13%	0.34	0.50	0.20	R-49 or R-38 adv	R-38	R21 int	R-21 TB	R-10	R-30	R-10 2'
25%	0.32	0.50	0.20	R-49 or R-38 adv	R-38	R21 int	R-21 TB	R-10	R-30	R-10 2'
Unlimited	0.30	0.50	0.20	R-49 or R-38 adv	R-38	R21 int	R-21 TB	R-10	R-30	R-10 2'

Table 25. Prescriptive Requirements for Single-Family Residential Climate Zone 2

Glazing Area% of Floor	Glazing U-Factor Vertical	Glazing U-Factor Overhead	Door U-Factor	Ceiling	Vaulted Ceiling	Wall Above Grade	Wall Interior Below Grade	Wall Exterior Below Grade	Floor	Slab on Grade
12%	0.32	0.50	0.20	R-49 or R-38 adv	R-38	R21 int	R-21 TB	R-12	R-30	R-10 2'
15%	0.32	0.50	0.20	R-49 or R-38 adv	R-38	R-19 + R5	R-21 TB	R-12	R-30	R-10 2'
Unlimited	0.30	0.50	0.20	R-49 or R-38 adv	R-38	R-19 + R5	R-21 TB	R-12	R-30	R-10 2'

14. Appendix E: 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 was used to determine 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[26] 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 Washington State Energy Code 2009 assumed water heater outlet temperature.

Inlet H20 °F: 58°F from RTF assumptions for water heating measures.[27]

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

[26] IECC 2009 assumption for hot water consumption per person.

[27] RTF document "*RTF Water Heaters rResDHW_v2_3.xls*"

15. Appendix F: Lighting Consumption Calculation

Estimated lighting energy consumption was calculated using secondary data sources for the 2012 RBSA, RTF data and from primary site visit data. The following factors were used to estimate lighting energy consumption:

- Heating and Cooling Enegy Consumption (HCEC) – This is the average per home heating and cooling energy consumption from the SEEM model outputs.

- Non - Compliant Lighting Energy Consumption (ncLEC) –This factor is calculated from RBSA data for Washington and adjusted for average home floor area.[28] A typical distribution of incandescent lamp wattages from RTF data[29] was used to determine the average installed lighting load of a home lit by incandescent lights. Hours-of-use was determined using RTF calculator data.[30] A factor of 3.16 was applied to the result to adjust accordingly for the source energy factor required by the code compliance methodology.

- Compliant Lighting Energy Consumption (cLEC) –This factor is calculated from RBSA data from Washington.[31] A typical distribution of fifty percent incandescent and fifty percent CFL lamp wattages from RTF data[32] was used to determine the average installed lighting load of a home complying with the code. Hours-of-use was determined using RTF calculator data.[33] A factor of 3.16 was applied to the result to adjust accordingly for the source energy factor required by the IECC compliance methodology.

- Lighting Compliance Rate (LCR) – The LCR is the proportion of homes in this study with at least fifty percent high efficacy lighting fixtures installed. In Washington, the observed compliance was 100 percent, so LCR equals 1.

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

$$HCEC + [(ncLEC \times (1 - LCR)) + (cLEC \times LCR]) = Total\ Energy\ with\ Lighting$$

The total energy compliance index was then calculated using the following equation:

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

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[28] Ecotope. 2012. *(RBSA)Residential Building Stock Assessment: Single-Family Characteristics and Energy Use*. Ecotope Inc. Presented to: Northwest Energy Efficiency Alliance.

[29] Northwest Council. 2012 (RTF) *Regional Technical Forum: Residential Lighting - CFL*

[30] Northwest Council. 2012 (RTF) *Regional Technical Forum: Residential Lighting - CFL*

[31] Ecotope. 2012. *(RBSA)Residential Building Stock Assessment: Single-Family Characteristics and Energy Use*. Ecotope Inc. Presented to: Northwest Energy Efficiency Alliance.

[32] Northwest Council. 2012 (RTF) *Regional Technical Forum: Residential Lighting - CFL*

[33] Northwest Council. 2012 (RTF) *Regional Technical Forum: Residential Lighting - CFL*