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Washington 2015 Commercial Construction Code Evaluation Study

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1 Executive Summary

This report presents results of a commercial building construction study conducted in the state of Washington for the Northwest Energy Efficiency Alliance (NEEA). The study covered buildings built under the 2015 energy codes (the statewide Washington State Energy Code [WSEC] and Seattle Energy Code [SEC]) and was performed by a team led by Cadmus.[1] This report is the second in a series supported by NEEA that covers two of the Northwest states.[2]

NEEA funded this study to inform the combined efforts of NEEA and its partners to advance building energy codes in Washington by the following:

- Studying the degree to which code is present in newly constructed buildings
- Providing direction to the development and implementation efforts of the NEEA Codes team and
- Providing guidance to other regional code stakeholders in targeting their energy efficiency work in the commercial new construction sector

The study was planned to provide input to the development process for the Washington 2018 energy codes, but the COVID-19 pandemic disrupted the schedule significantly and increased the difficulty of recruiting participating buildings and collecting data. Nevertheless, the study provides extensive information about the new commercial building market in Washington, building characteristics, and how this sector responds to the energy code. The anonymized database provided to NEEA on all buildings contains much valuable information that could support targeted data mining and further analysis to address other objectives or issues.

1.1 Study Overview

The overriding objective of the study was to identify how buildings were being constructed in response to the code and to provide insights on code compliance; however, this was not primarily a code compliance study. The study included new commercial buildings drawn from a sampling frame comprising multiple databases. Following the approved research design, the sample was intended to be representative of new buildings constructed in the state based on three size categories and multifamily buildings above three stories. Most results are presented for these building groups—small, medium, and large commercial buildings and multifamily buildings over three stories of all sizes. The Cadmus team also addressed how findings varied by building type (such as education and office), but consideration of building type was secondary to building size as a study parameter and building type (other than multifamily) did not influence sample selection.

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[1] Cadmus teamed with McKinstry, Madison Engineering PS, and New Buildings Institute (NBI) to perform this study. We describe roles of the different team members below but generally the term "Cadmus" can refer to the team as a whole.

[2] The first report was entitled *2019 Oregon New Commercial Construction Code Evaluation Study, Report #E19-392*, 2019, prepared by Ecotope.

Table 1 presents the distribution of buildings in our sample and in the sample frame. The sample frame contained 2,211 buildings, and we sampled 76 buildings from the sample frame. We intended to have 108 buildings in our sample, but the COVID-19 pandemic struck early in the study and caused us to eventually reduce the sample size.

Table 2 shows the floor area represented by each size category and multifamily buildings in the sample and sample frame and the percentage captured, which ranged from 2% to 4.8%.

Table 1. New Commercial Buildings in Sample Frame and Sample

Stratum	Floor Area, Sq.Ft.	Sample Frame Population*		Target Number of Site Visits		Site Visits Completed	
		Count	%	Count	%	Count	%
Multifamily	Mix of mid- and high-rise**	527	24%	33	26	15	20%
Small Commercial***	<25,000	1,090	51%	52	41	40	53%
Medium Commercial***	25,000 – 100,000	412	17%	17	13	16	21%
Large Commercial***	>100,000	181	8%	6	5	5	7%
New Construction Total	-	**2,211**	**100%**	**108**	**85**	**76**	**100%**

* Note that one building categorized initially as medium had a floor area that was slightly under the floor area maximum for small buildings based on the field data. Because the analysis was under way, we did not reclassify it, but the correct floor area was applied in all the calculations.
**Mid-rise multifamily buildings are defined as those from four to six stories; high-rise buildings are seven stories and higher.
*** Population sizes within strata are estimated because floor areas were missing for some buildings. Cadmus assumed that square footage data was missing randomly such that the distribution of buildings with unknown square footage across the floor area bins followed that of the buildings with known square footage.

Table 2. Floor Areas in Sample and Sample Frame

Category	Building Category				
	Small	Medium	Large	Multifamily	Total
Sample, Sq.Ft.	262,051	1,040,871	897,759	2,006,200	**4,206,881**
Sample Frame, Sq.Ft.	8,520,887	21,681,072	44,438,911	61,838,462	**136,479,332**
Sample Percentage	3.1%	4.8%	2.0%	3.2%	**3.1%**

After recruiting each building for the study, we obtained and reviewed project drawings and code compliance documents then performed a site visit to collect and confirm construction characteristics. We also conducted an interview with the building representative on code process issues. The COVID-19 pandemic caused us to consider and then start using remote site visits in place of in-person site visits for many of the buildings.

Following the approved study approach, we gathered building characteristics and analyzed data organized by major building system: envelope, mechanical/heating, ventilation, and air-conditioning (HVAC), lighting, and service water heating. We also focused on code commissioning and the choice of code options (see Section C406 of the codes[3]). We compiled data in a comprehensive Excel workbook containing all information collected from documentation, site visits, and interviews.

This study provided a thorough characterization of the new commercial building population in Washington, which can inform other studies and future commercial building and code research. We extrapolated from the sample frame to estimate the total number of buildings covered by the 2015 codes by building size, type, and location. We also used sample frame data to develop building characterizations to compare rural and urban areas and Seattle to the rest of the state. We analyzed findings by three building size categories—small (less than 25,000 square feet), medium (25,000 to 100,000 square feet), and large (more than 100,000 square feet)—and multifamily buildings greater than three stories of all sizes. We also reviewed findings by building type (such as education, office, and retail/service) and presented them if informative patterns were evident.

This study also provided information on the distribution of natural gas service and data on the presence of renewable energy generation, sustainable design features, and participation in programs such as LEED.

To address how buildings complied with the 2015 energy codes, we first documented the code compliance path each building employed. To characterize how building designs satisfied the code and to provide an estimate of code compliance rates, we used a method applied in prior NEEA studies, which relied on documenting quantification of binary (yes/no) compliance with specific code requirements. To reflect the impact of compliance on energy consumption, we weighted the binary results by building floor areas and, to extend the sample results to the building population, we applied post-stratification weights to the sample estimates.

The compliance analysis produced findings at the building level and at the building system level. We identified how various building categories (such as small buildings or office buildings) responded to the code and how different systems and system components performed with respect to the energy code. We explored if findings varied by building size, building type, and location and identified compliance patterns and relationships.

The study scope also includes an analysis of the actual energy performance of sampled buildings and a comparison to their code characteristics. This analysis will be completed in late 2022 when sufficient utility billing data are available to make a valid assessment.

1.2 Major Findings

The following subsections highlight the key study findings, curated according to key study objectives.

[3] Most sections of the codes are numbered the same in the WSEC and SEC, except for those sections that were added in the SEC.

1.2.1 New Commercial Building Characteristics

Based on data for the 2,211 buildings in the sample frame, Cadmus estimated that 4,251 commercial buildings totaling almost 300 million square feet were permitted under the 2015 WSEC and SEC. As Table 1 shows, the largest number of buildings were in the small size category (less than 25,000 square feet), but the largest category in terms of floor area was multifamily buildings greater than three stories.[4] Statewide, offices and education buildings were tied for second place in floor area, followed by retail/service buildings. In urban areas, multifamily buildings were the most common type as well as having the most total floor area. Buildings in Seattle represented slightly more than half of total new commercial floor area in the state.

For the most important characteristics for which we collected primary data, we used the data for the 76 buildings in the sample with appropriate weights (see Appendix D[5]) to derive estimates for the same characteristics of buildings in the population. For other, less important, characteristics, we estimated and reported only the values for the sample and did not derive population estimates.

From the sample, we estimated that 72% of the population of new commercial building floor area in the state used natural gas as well as electricity. Medium buildings had the largest share of natural gas available. Natural gas was least common in small buildings.

Regarding construction assemblies, we estimated the sample characteristics only. Above-grade walls in small and multifamily buildings were most often constructed of wood, whereas metal was most common in medium and large commercial buildings. Roofs of sample buildings were typically constructed of wood or metal except for multifamily buildings where concrete was most common. Slabs were the predominant floor assembly type.

In the population, the window-to-wall ratio averaged between about 17% and 30% across the building size and multifamily categories. Over half the multifamily floor area in the population was in buildings where the window-to-wall ratio exceeded the code threshold of 30%, which triggered additional requirements.

Almost all lighting was provided by LEDs in sample buildings. Across all building size categories, LED integrated and linear lighting fixtures were predominant. In multifamily buildings, LED integrated fixtures were most common but, unlike the other building groups, other types of LED fixtures (such as screw-in) were the second most common. Fluorescent, CFL, and incandescent fixtures were almost completely nonexistent.

The sample buildings included eight different heating system types. Natural gas was the fuel that provided the most capacity and terminal reheat systems provided the most capacity across all buildings

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4 Multifamily buildings of four stories or more are covered by the commercial energy code; multifamily buildings less than four stories are covered by the residential code.

5 As described in the appendix, we derived separate weights based on building type, building size, and location, taking into account the mix of buildings in our sample and in the population represented by the sample frame.

in the sample. Heat pumps, including air-source, water-source, and variable refrigerant flow units were common.

All types of heat pumps combined were the largest source of cooling. Air handling units in all capacities provided the second largest amount of cooling. Ductless heat pumps constituted about 7% of cooling capacity.

Although most natural gas and propane heating equipment efficiencies were at the minimum required by the code, almost one-third were high efficiency, condensing units.

Most service and potable water heating was provided by natural gas water heaters. Office buildings were the only ones where electricity provided more water heating capacity than natural gas.

1.2.2 Meeting the 2015 Codes

Although the Total Building Performance Path of the WSEC allowed more design flexibility, nearly 90% of commercial buildings in Washington complied with code using the Prescriptive Path. Similarly, envelope compliance was usually demonstrated prescriptively though the component performance path was available.

This study reports code compliance in two ways: unweighted binary for the sample and post-stratification weighted for the population of buildings built under the 2015 codes.[6] Because they are more meaningful, this executive summary presents only the weighted population results.

Overall, compliance with the commercial building energy code was 85%. Compliance rate increased with building size; multifamily buildings had the highest overall compliance rate, 90%, while small buildings had the lowest (79%).

This study assessed envelope compliance with the code based on overall UA, component U-factors,[7] fenestration (glazing) U-factors, glazing solar heat gain coefficients (SHGC), and leakage testing. We found that the population average compliance across four envelope requirements was 76%. Noncompliance with code requirements for floor UAs, leakage testing in larger buildings, and fenestration efficiency in medium and small buildings brought down the average envelope compliance rate.

Buildings have shifted almost completely to installing LED lighting systems, both internally and externally. Despite recent increases in the stringency of lighting efficiency code requirements, the adoption of LED lighting technologies led to the average interior lighting power density (LPD) being 29%

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6 For population weighting, the analysis accounts for floor area in the sample, floor area in the population, and differences between rural and urban locations.

7 The U-factor (or U-value) is a measure of the ability of a material per unit surface area to allow the flow of heat from a warmer to cooler surface. UA is a measure of the overall thermal performance of a building's envelope based on multiplying the U-factor of each component times its area. Higher values indicate more heat transfer.

less than the maximum the code allowed. Similarly, the exterior lighting power installed was between 42% less for large buildings and 80% less for other buildings than the maximum allowed by code. Installation of required external occupancy sensors and timer controls was widespread.

Nearly all heating and cooling equipment units in the study sample complied with code equipment efficiency requirements; population compliance was 98% for heating and 98% for cooling. Compliance with HVAC controls was also nearly 100% across all building sizes. Compliance with two other HVAC requirements differed: only two-thirds of floor area required to meet limits on fan power met the requirement but 86% of floor area required to have modulating fans met this requirement. Almost 100% of buildings that were required to have DOAS units did. On the other hand, only 54% of the floor area that had to have an economizer met this requirement.

The codes specify minimum efficiencies for water heating systems and require insulation on inlet and outlet piping. All water heaters met the efficiency requirements and the efficiency of most gas water heating equipment indicated that condensing units were almost universal. Most buildings satisfied the piping insulation requirement, but a large portion of small and retail/service buildings did not.

Compliance of small buildings with the commissioning requirement was very low, but all larger buildings that required commissioning did do so.

The code required buildings to incorporate at least two efficiency options from a list provided in code Section C406. We found that documentation about these options was often incomplete, and many building contacts were uncertain which options were chosen. The main finding was that small buildings were the most likely to not satisfy the requirement.

2 Overview

This report presents results of a commercial building construction study conducted in the state of Washington for the Northwest Energy Efficiency Alliance (NEEA) by the Cadmus team.[8] This report is the second in a series supported by NEEA that covers two Northwest states.[9] The study focused on buildings constructed under the 2015 Washington State Energy Code (WSEC), an amended version of the 2015 International Energy Conservation Code (IECC) model code that went into effect July 1, 2016. The study also covered the Seattle Energy Code (SEC), an amended version of the 2015 state code.[10] Seattle buildings were assessed relative to the SEC for requirements where that was feasible within the scope.

The study was intended to provide input to the development process for the Washington 2018 energy codes (effective February 1, 2021, for the state code and March 15 for the Seattle code), but the COVID-19 pandemic disrupted the schedule significantly and increased the difficulty of recruiting participating buildings and collecting data. Nevertheless, the study provides extensive information about the state's new commercial building market, building characteristics, and how this sector responds to the energy code.

2.1 Study Objectives and Context

Commercial building energy codes have the potential to affect energy consumption substantially. NEEA collaborates with state code bodies and other regional stakeholders to identify promising code measures, works to get them adopted, and supports their implementation. NEEA funded this study to assess the effectiveness of these combined efforts in Washington by the following:

- Studying the degree to which the energy code influenced design and construction of newly constructed buildings
- Providing direction to the development and implementation efforts of the NEEA Codes team
- Providing guidance to other regional code stakeholders in targeting their energy efficiency work in the commercial new construction sector.

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8 Cadmus teamed with McKinstry, Madison Engineering PS, and New Buildings Institute (NBI) to perform this study. We describe roles of the different team members in this report, but generally the term "Cadmus" can refer to the team as a whole.

9 The first report was entitled *2019 Oregon New Commercial Construction Code Evaluation Study, Report #E19-392*, 2019, and was prepared by Ecotope.

10 In Seattle, the code became mandatory on January 1, 2017, and between November 6, 2016, and January 1, 2017, applicants could choose to use the 2012 or the 2015 codes.

2.1.1 Study Objectives

The study objectives NEEA defined in its Request for Proposals (RFP) included evaluating the presence and effectiveness of the Washington commercial new construction code through review of construction market practices in the following areas:

- **Building characteristics.** Catalog the primary current design and engineering practices by major building type; particular attention should be paid to primary characteristics of the envelope, mechanical, lighting, and building service water systems.
- **Compliance**. Assessment of compliance of each building in a sample of the Washington commercial new construction market. The primary analysis of compliance will focus on the four major systems.
- **Energy use.** Analysis of the energy performance of each building using billing data that has been normalized, summarized, and disaggregated by end use.

NEEA selected the Cadmus team to conduct the study and awarded the contract in late-2018. Our evaluation approach was shaped by the RFP, other studies, and ongoing input from NEEA and members of work groups that NEEA created. NEEA had funded a precursor commercial building code pilot study in Washington in 2015-2016,[11] and that report also informed Cadmus' approach to the study.[12] Memos documenting outcomes of each work group are presented in Appendix A, Appendix B, and Appendix C.

2.1.2 The 2015 Codes

The 2015 IECC commercial building model code was estimated to produce about 11% energy savings over the 2012 IECC in the Washington state climate zones.[13] The 2015 IECC included mostly incremental changes to the 2012 IECC and a few significant changes including providing leakage testing standards, requiring lighting system controls, lowering the allowable lighting power, and reducing the amount of glazing allowed. The 2015 IECC provided the basis for the Washington code with several differences, including these significant ones:[14]

- The WSEC did not include an option to use the ANSI/ASHRAE/IESNA 90.1 approach to demonstrate compliance.
- The WSEC required dedicated outside air systems (DOASs) in five building types with some exceptions (C403.2.6.1).
- The WSEC had lighting power density (LPD) requirements (C405.4) that were about 20% more efficient than the IECC.

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11 Ecotope. 2016. *Commercial Code Evaluation Pilot Study Final Report, Report #E16-329.* Prepared for NEEA.

12 An Oregon study (cited above) was a companion to Cadmus' Washington study, but it had not been completed in time to provide much guidance to this study.

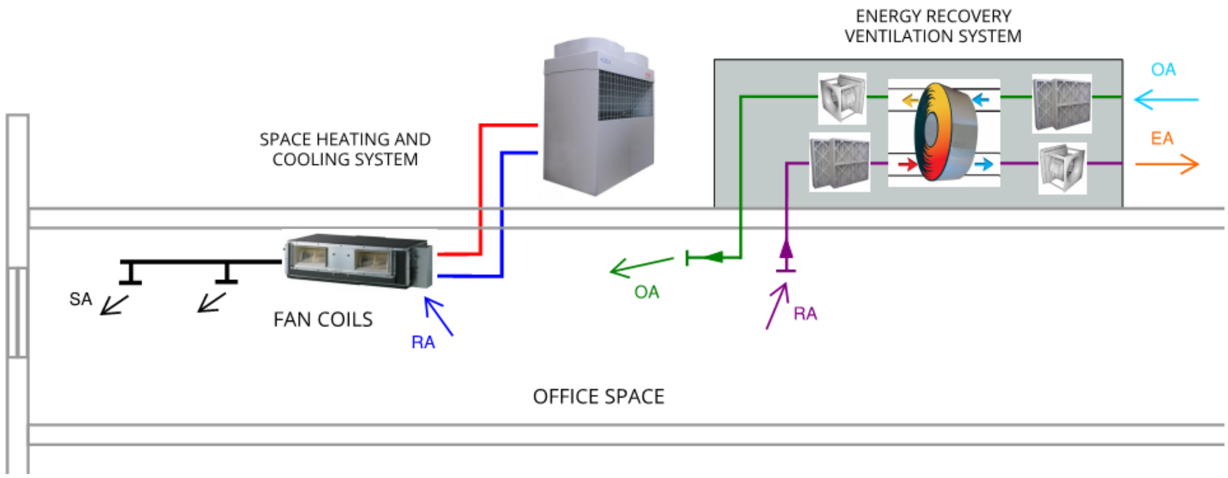
13 Pacific Northwest National Laboratory. August 2015. *Energy and Energy Cost Savings Analysis of the 2015 IECC for Commercial Buildings*, PNNL-24269 Rev.1.

14 Vander Mey, Eric. October 13, 2015. *2015 Washington State Energy Code.* For NAIOP. Accessed November 11, 2021. https://www.naiopwa.org/assets/images/Sustainable_Development/2015%20wsec-naiop-rushing-2015-10-13.pdf

- The WSEC required two C406 options instead of one to be included in the building, and these options were more stringent.
- The WSEC included some additional modeling requirements in the Total Building Performance Path (C407).

Because it was a notable addition to the IECC, Figure 1 is presented to illustrate how a DOAS is incorporated in a building. It provides an air flow system separate from the standard heating/cooling system and incorporates energy recovery to minimize energy loss or consumption.

Figure 1. Illustration of a DOAS



Vander Mey, Eric. October 13, 2015. *2015 Washington State Energy Code.* For NAIOP. Accessed November 11, 2021. https://www.naiopwa.org/assets/images/Sustainable_Development/2015%20wsec-naiop-rushing-2015-10-13.pdf

The features of the energy codes affected data collection, analysis, and reporting. The energy codes are organized around the major building systems identified in the NEEA RFP. Key sections of the code that address the building systems are shown in Table 3.

Table 3. WSEC and SEC Key Systems Sections

Code Section	Description
C401.2	Defines the alternative compliance approaches
C402	Presents the envelope requirements
C403	Focuses on the mechanical and HVAC system
C404	Presents requirements for service water systems
C405	Covers lighting and other electrical system requirements
C406	Presents a menu of additional efficiency package options of which at least two must be included to comply with the code
C407	Presents the procedure to use the Total Building Performance Path
C408	Presents the commissioning requirements
C409	Presents energy use metering requirements
C411	Describes requirements for renewable energy generation system (SEC only)

The alternative compliance approaches were the following for the 2015 codes:[15]

- **Prescriptive Path**, which includes required R-values in C402.1.3 or required U-factors in C402.1.4 and C402.4 fenestration requirements
  - Component performance, C402.1.5,[16] can be applied in lieu of meeting the C402.1.4 prescribed U-factors
- **Total Building Performance Path**, C407
- **Target Performance Path,** C401.3, available only in the Seattle code.

Each path also required satisfaction of numerous mandatory minimum requirements.

2.2 *Study Approach and Constraints*

An interactive planning process with NEEA, in conjunction with the project kickoff meeting and the RFP requirements, provided details that shaped our study approach. We developed the following key research elements to guide study planning:

- Focus on cataloging the characteristics of commercial buildings and their relationship to the energy code
- Select a representative sample of buildings to study to provide insights into how construction varies by building size and type
- Review construction with respect to code requirements in the four systems areas—envelope, mechanical, lighting, and water heating systems
- Identify which code requirements are met relatively easily and those that are more challenging to meet
- Identify the code compliance pathways selected and characteristics of buildings built under different paths
- Obtain building owner/occupant approval to access billing data to support energy performance analysis and conduct the analysis
- Identify any unique findings for the SEC.

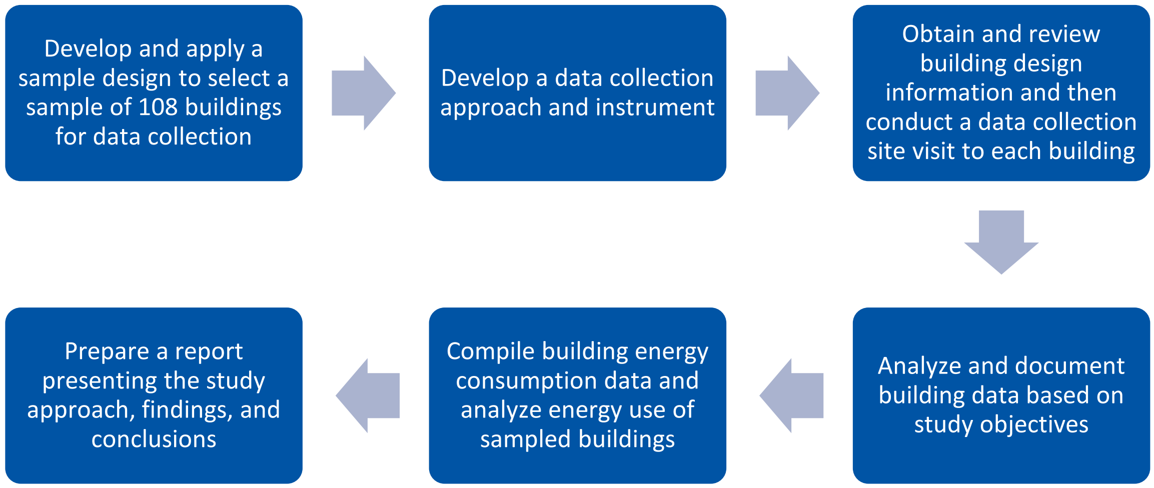
2.2.1 Approach

Cadmus developed an initial work plan based on its study proposal. NEEA designated three work groups—sample design, data collection, and reporting—comprising NEEA staff and external stakeholders to provide input at different stages of the study. We developed an initial study approach consisting of the steps shown in Figure 2.

15 For the 2018 codes, the ASHRAE 90.1 Appendix G was included in C407.

16 Component performance allows trading off the efficiency of envelope components as long as the combined thermal performance is equal to or better than it would be if all components met the prescriptive requirements.

Figure 2. Study Steps



The project started in late-2018 and was intended to take a little more than 24 months. In the initial schedule, field data collection was to be completed by the beginning of 2020 and the final report delivered by December 2020. The work plan allowed for a gap of about one year between the end of field data collection and report submission, during which Cadmus would analyze building characteristics and compliance data. The schedule provided one year after final field data collection to compile at least one year of billing data on each sampled building.

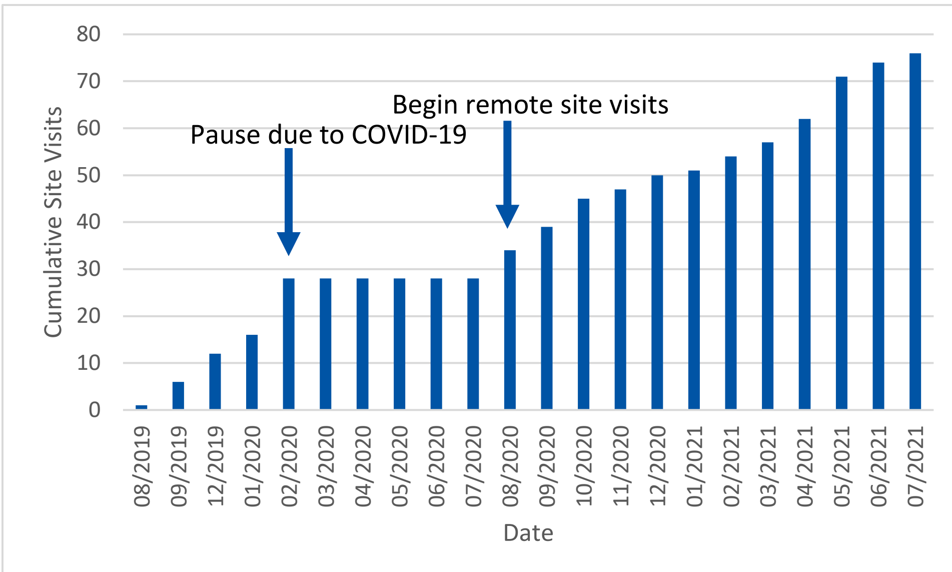
Several events affected the actual schedule and study progress. Contracting activities delayed the initial study tasks by about three months. An extended review of the data collection approach delayed data collection about six months.

As in many similar prior studies, recruiting buildings to participate in the study proved challenging. We designed a recruitment approach based on our review of available data to develop an initial estimate of the number of new buildings constructed under the 2015 WSEC and SEC and were confident we could recruit 108 buildings for this study. Several factors, including the effects of the COVID-19 pandemic discussed below, impacted our recruitment process.

Another significant issue that affected recruitment involved when buildings were permitted. Most of the available data sources rarely included the permit application date, which is the date that determines what energy code the building must meet. This created uncertainty about which buildings in our data sources were permitted under the 2015 energy code. Because we anticipated this uncertainty, we minimized the likelihood of recruiting buildings permitted under an earlier code by starting with buildings that had dates about one year after the code effective date. Nevertheless, when we reached out to building contacts, we still found that some buildings had been permitted under the 2012 code. We used the percentage of recruited buildings that were permitted under the prior code to estimate the share of buildings in our compiled population database that were permitted under the prior code rather than the 2015 code. Of 103 buildings that agreed to participate, we rejected 12 that were permitted under the 2012 code. We then adjusted the counts in our population sampling frame by multiplying by 0.88 (91/103), a reduction of 12%.

The largest effect on the recruiting schedule was from a nearly complete project shutdown when the COVID-19 pandemic struck. The pandemic started affecting the project in February 2020. As shown in Figure 3, by February we had completed 28 site visits and had a pipeline of 33 recruited buildings for future visits.

Figure 3. Completed Site Visits



In March 2020, Washington started limiting building access, and we agreed with NEEA to suspend our field data collection. We began investigating options for conducting site visits remotely and identified a platform developed by Streem that allowed facility staff to use a cell phone camera to stream a video while they conducted a walkthrough of their site. We informed NEEA about the technology and possibility of conducting remote data collection and negotiated an agreement with Streem.[17]

The technology allowed us to continue data collection remotely for sites where the building contact agreed to participate. We asked the contact to walk through the building with cell phone and live camera, record the same information we would have collected on site, then transmit this back to the Cadmus engineer. The technology also allowed us to take stills of specific information such as equipment labels. We revised our data collection process and trained our staff on how to use the system.

[17] Streem, a subsidiary of Frontdoor, developed an AR and AI powered communication platform and Frontdoor provides a portfolio of home service brands. More information can be found at https://www.streem.com/about.

Although we could continue data collection, the pace was slow because not all buildings were accessible even by the building contact. This major disruption to our study caused a significant schedule extension and imposed added costs, largely due to increased recruitment and overhead costs. Cadmus negotiated with NEEA an extension to the schedule and a reduction in the sample size target to 85 buildings. We also extended the billing data collection and analysis into 2022.

Cadmus analyzed the data and presents the findings by three building size categories—small (less than 25,000 square feet), medium (25,000 to 100,000 square feet), and large (more than 100,000 square feet)—and multifamily buildings greater than three stories of all sizes. We also reviewed findings by building type (such as education, office, and retail/service) and presented them if informative patterns were evident. The current report covers all research and findings prior to the billing data analysis; the billing data analysis will be added to an amended version of the report issued in late 2022.

2.2.2 Analysis Constraints and Qualifications

Our study covered most sections of the codes, as shown in Table 3. Although data collection was very comprehensive, the complexity of the codes, interactions among requirements, gaps in available data, and numerous exceptions or alternatives that could apply in lieu of the code requirement affected how accurately we could analyze compliance. For example, we assessed compliance with the economizer requirements (C403.3), but when an economizer was not present, we could not always confirm that none of the 10 exceptions or alternatives applied. Another example is that we were not able to assess compliance with the metering requirements of C409 because most buildings were not fully constructed with metering equipment installed for observation, and the time required to fully review the electrical plans was prohibitive.

Another consequence of the pandemic's disruption was a reduction in the statistical significance associated with sample size. Our proposed approach was designed around providing 10% precision and 90% confidence for population estimates of key variables such as average floor area and compliance rates. As seen in Table 4, our sample size was sufficient to meet this requirement for population estimates, but the precision of estimates for building size and type categories was larger for the size and type categories. The sample sizes for small buildings and education buildings were large enough to achieve precisions less than 20%.

Table 4. Typical Precision Level for Sample Percentages by Building Category, 90% Confidence Level

Small (n=40)	Medium (n=16)	Large (n=5)	Multifamily (n=15)	Education (n=23)	Office (n=7)	Total (n=76)
13%	21%	37%	21%	17%	31%	9.3%

In addition to limits on the statistical significance of results derived for subgroups (such as offices) due to small sample sizes, other features of the data make it important to acknowledge certain cautions when interpreting the study findings. Because the disruption caused by COVID-19 reduced our sample size and limited data collection, results from the study were not as robust and generalizable as originally planned. We alert the reader to these cautions to ensure that findings presented for subgroups should be understood to be indicative, rather than statistically significant, of trends and relationships. This qualification applies less to results derived for the overall building population because the sample size (76) is relatively large, and the sample mirrors the population well.

Table 5 summarizes several key features of the sample and their implications for interpreting the findings. The information highlights the substantial influence of small and education buildings on the findings.

Table 5. Features of Sample and Implications

Features	Implications
Sample includes only five large buildings; four of the five are education buildings, one is an office	• Findings for large buildings should be considered directional at best • Education buildings drive the findings for large buildings
Education buildings constitute 75% of medium buildings in the sample	• Education buildings drive the findings for medium buildings
Six of seven office buildings are small	• Small buildings drive the findings for office buildings
All retail/service buildings are small	• Small buildings drive the findings for retail/service buildings
Sample includes only 10 Seattle buildings; nine are multifamily	• Multifamily buildings drive findings for Seattle buildings • Seattle sample contains enough multifamily buildings to compare findings to multifamily buildings in rest of state • Seattle sample is too homogeneous to derive general findings for Seattle buildings
Sample includes only nine buildings complying under the Total Building Performance Path	• Sample is too small to compare results with buildings complying under the two different compliance paths

2.3 Population Description and Sample Design

The eligible population for this study included all commercial buildings in Washington, with some exceptions, permitted under either the 2015 WSEC or SEC. Buildings included in our sample needed to be sufficiently completed so that all installed equipment could be visually observed. We developed a sample frame by combining data from the following sources:

- Dodge Data & Analytics (Dodge data)
- Construction Monitor
- Selected building departments[18]
- Developer data from team members' networks and other contacts

The initial sample frame consisted of Dodge and Construction Monitor data obtained at the beginning of the study. We supplemented these data with two additional data pulls from these sources over the

[18] We acquired building permit data from Seattle, Spokane, and Tacoma. These sources typically provided information on individual buildings in addition to what was in the other sources (such as number of stories). This allowed us to better characterize each building, but it also required additional work to ensure that we avoided duplications.

course of the project, merging the data pulled each time, to ensure that our population included as many buildings as possible that were permitted while the 2015 codes were in effect.

Combining these sources produced an integrated snapshot of the population of new commercial buildings in the state. These data sources contained many variables that were the same or similar and others that differed. They covered slightly different time periods and some buildings appeared in multiple sources. To avoid double-counting buildings and floor area, we conducted a thorough process of merging data for individual buildings from the different sources; this required eliminating duplicates while preserving the essential information from each source. We started this process using the building addresses that were in the different sources. In most cases, the addresses matched across the sources, but a small share of buildings required manual review because of minor differences in how the addresses were recorded (for example, "first street" vs. "1st street") or errors in the data. Once we had matched all buildings in the sample frame, we combined information from similar fields in the different sources. This required identifying fields that provided similar information (such as building type) in the different sources and merging the data from each source into a single entry. We used the functionality of Excel to manage this step. The resulting database contains the merged data for all the buildings in the Washington sample frame for the timeframe covered.

To create the best estimate possible of the population of buildings permitted under the 2015 energy codes we took the following steps:

1. Determine the number of days the state and Seattle 2015 energy codes were in effect: 1,676 days (4.6 years) for the Washington code and 1,534 days (4.2 years) for the Seattle code.
2. Divide the number of days the code was in effect by the number of days covered by the data sources (853) to provide a ratio to multiply by the building count to estimate buildings affected by the 2015 code.[19] The ratio for the state is 1.96 and for Seattle is 1.80.
3. Combine the building list and data from each source.
4. Use the building address to identify specific buildings.
5. Identify buildings that appear in more than one source.[20]
6. Count individual buildings and combine relevant data from the different sources.
7. Multiply the building count times the ratio from step 2 to estimate the total number of buildings in the population for different categories such as building type and size.

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19 The sources covered almost, but not exactly, the same time period so we used the dates covered by the largest data source, Construction Monitor, as the basis for this adjustment.

20 We note that avoiding duplication was challenging and labor intensive because some buildings appeared multiple times in a single source or were difficult to identify accurately across different sources because of discrepancies or errors in recorded addresses and other parameters.

As recommended by the Sample Design Work Group (see Appendix A) assembled by NEEA,[21] we designed our initial sample based on building floor area with three categories ranging from small to large and a fourth category of multifamily buildings covered by the commercial building energy codes. This report refers to these groupings as categories by building size and multifamily. Throughout this report, multifamily buildings include only those with more than three stories but without any floor area limitations; these are covered by the commercial energy code. The target sample sizes in each category were proportional to the building count in the population estimated based on the raw data in the sources we compiled. With additional input from the Reporting Work Group (see Appendix C),[22] we ensured that our sample also captured the distribution of buildings by building type such as retail, education, multifamily, and office. This report refers to these groupings as building types; note that multifamily buildings are in both the size and type groupings.

We note that determining building type of each building in the population was challenging because the various sources did not use consistent fields to define building type or even consistent terminology. Our team reviewed all the terms used to identify the type for each building in the population then developed the most appropriate categorization possible. In conjunction with NEEA and the Sample Design Work Group, we used a criterion of 75% of floor area to assign a building type to buildings comprising multiple space types (e.g., office and retail).[23] Buildings where no type exceeded 75% of the floor area were classified as mixed-use. In the end, no sampled buildings fell into this category.

As mentioned earlier, our proposed sample size of 108 buildings was adjusted to a target of 85 buildings after COVID-19 disrupted recruitment and data collection. However, we were able to collect data on only 76 buildings.

2.4 Recruitment and Data Collection

2.4.1 Recruitment and Data Collection Approach

Once the sample frame was assembled, Cadmus began randomly selecting buildings then attempted to recruit them to participate. Cadmus' recruiters contacted individuals associated with each building by email and phone to confirm the building was permitted under the 2015 code, obtain documentation such as building plans, and schedule a site visit (either in person or remote). During the final months of the project, we compiled a list of architects in Washington and contacted them to recruit buildings they had designed. The project offered a financial incentive ranging from $50 for small buildings to $250 for

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[21] The Sample Design Work Group included Bing Liu, Dulane Moran, John Jennings, and Steve Phoutrides from NEEA and Allen Lee, Jennifer Huckett, and Tolga Tutar from Cadmus.

[22] The Reporting Work Group comprised Steve Phoutrides and Bing Liu from NEEA; Duane Jonlin from the City of Seattle; Chuck Murray from Washington State Department of Commerce, State Energy Office; Mike Kennedy from Mike Kennedy, Inc.; Lisa Rosenow, Evergreen Technology; Allen Lee from Cadmus; and Kevin Madison formerly from Madison Engineering, P.S.

[23] This was the same approach used in the NEEA Commercial Building Stock Assessment study.

large buildings; however, recruiting was the most challenging and time-consuming step, primarily due to the disruption of the COVID-19 pandemic.

The study's approach to data collection was guided by input from the Data Collection Work Group (see Appendix B).[24] Cadmus developed a data collection spreadsheet and trained several staff to conduct the in-person or remote site audits. Prior to the site visit, the auditor reviewed materials, such as building plans, for each project and recorded building characteristics according to the standardized data collection instrument. During the site visit, the auditor interviewed the building contact about specific topics, such as whether the building participated in an energy efficiency program, and had the contact sign an authorization form and provide approval to collect billing data, if willing. Only 49 building representatives provided permission to obtain their billing data, so this will be the maximum number of buildings for which we can conduct the billing data analysis.

A Cadmus engineer reviewed the data collection form for each building and returned the form to the auditor to resolve any missing information or quality issues.

2.4.2 Recruitment and Data Collection Outcomes

Finding a building contact person to speak with and collect data from was challenging. We sought to speak to the building representative who was most knowledgeable about design, construction, and code compliance. Representatives' titles ranged from fire chief to owner to energy analyst. We classified respondents as management, facility operations/construction, or energy/analysis professionals. Table 6 shows the distribution of these professionals in our sample. The information we were able to obtain was dependent on the respondent's role and level of knowledge about the codes and how the buildings were designed in accordance with the energy code. Many respondents were in senior management and often limited in the technical detail they could provide but were helpful in gaining us access to supporting documentation.

Table 6. Professions of Building Respondents

Primary Category	Example Titles	Percentage
Management	Manager, School Head, Director of Finance and Human Resources	58%
Facility Operations/Construction	Director of Facilities, Maintenance Supervisor, VP Facilities	35%
Energy/Analysis	Energy Analyst, Resource Conservation Manager	7%

Supporting documentation varied across sample buildings. We were usually able to obtain code documentation (usually the compliance spreadsheet forms) and construction documents. However, code compliance forms were often missing specific information such as which C406 options were selected, and there seemed to be some lack of understanding about these requirements and the need to document them. As-built plans were available on about one-third of the projects. Surprisingly, the

[24] Members of the Data Collection Work Group included Steve Phoutrides, Bing Liu, NEEA; Duane Jonlin, City of Seattle; Mike Kennedy, Mike Kennedy, Inc.; Lisa Rosenow, Evergreen Technology; and Tolga Tutar, Allen Lee, Heidi Javanbakht, and Christie Amero, Cadmus.

permit application date was available on only about a third of the buildings; this date was important because it determined which code version applied to the building. In addition, both codes had some requirements that were phased in over time. Through discussions with various building contacts and reviews of additional documentation, we were able to confirm that all buildings in our final sample were built to the 2015 codes; inconsistencies in the information provided by the initial building contacts led us to reject several buildings from the study after we obtained more information.

In several cases, we found specific types of documents were unavailable. For example, leakage test reports were available for only about 15% of the sample. Building representatives often could not provide documentation on who conducted commissioning and, in a few cases, indicated that someone associated with the building conducted commissioning rather than a third party.

In addition to building characteristics information, we gathered some data that was informative for related purposes and might be useful to mine in the future. Examples of this information included:

- **Comfort and HVAC control problems.** Ten respondents mentioned problems such as issues balancing and conditioning spaces when not occupied and zones with lots of glazing overheating and motorized shades not operable.
- **Lighting and lighting control problems.** Ten respondents indicated problems occurred and several were about occupancy controls not working properly
- **Hours of operation.** Most respondents provided the operating schedules that could inform building analyses

2.5 Sampled Buildings

The final sample consisted of 76 buildings of an original sample size target of 108 buildings. The attrition stages are shown in Figure 4.

Figure 4. Attrition from Original Sample Size Target

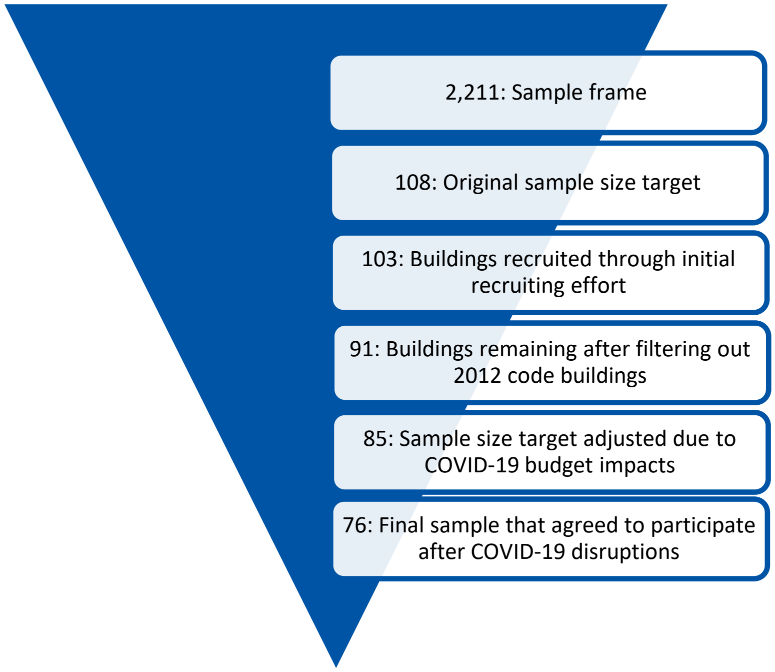


Figure 5 shows the distribution of nonresidential buildings by size category (small, medium, and large) and multifamily separately. Multifamily buildings constituted 20% of our sample (15 buildings). Small buildings constituted a little more than half the sample (40 buildings). Figure 6 shows that the most common building type was education buildings (23) followed by retail/service buildings (19). The sample contained 15 multifamily buildings—10 mid-rise (four to six stories) and five high-rise (seven stories and above). Because all buildings had at least one type of use that occupied at least 75% of the space, our sample did not include any commercial buildings classified as mixed-use.

Figure 5. Sample Distribution by Building Size and Multifamily (Count, %)

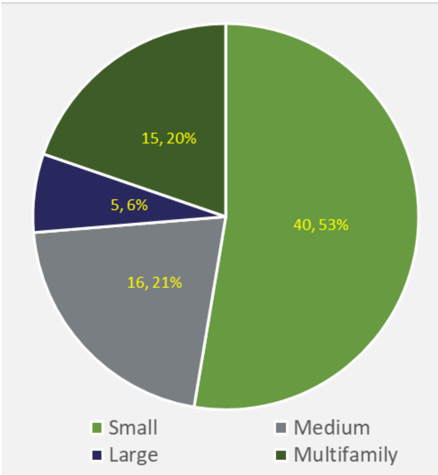
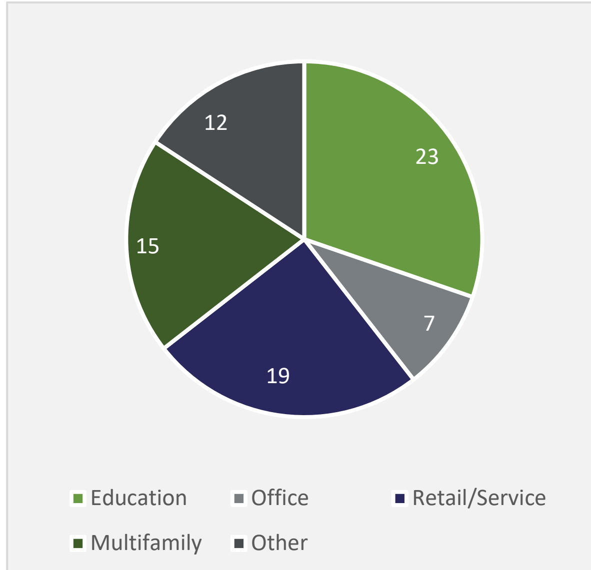


Figure 6. Sample Distribution by Building Type



2.6 Analysis Approach

We analyzed building characteristics primarily by quantifying the frequency of different key characteristics, measures, and features in the sample. At the highest level, we determined the proportion of buildings that complied with the energy code by following alternative paths allowed in the code. At the system level, we determined the relative prevalence of different system types (e.g., gas and electric heating systems) and how the buildings met the respective code requirements for the system. We analyzed and presented these results by building type and building size categories. Our analysis used appropriate weights to extend the sample results to the building population. See Appendix D for a discussion of the weighting approach.

Although determining code compliance rates was not the primary objective of this study, we assessed compliance with the code requirements that applied to each component within the four major building systems. Component data obtained from field or remote observations was the preferred and most reliable data for assessing compliance. The second most reliable source was from plans, drawings, and compliance documentation. In the case of some components with performance characteristics set by the code (such as glazing U-factors), when data were not readily available from direct observations or in building project documentation, we assumed the component performance characteristics were at exactly the code level. In other cases where data were missing, we recorded the observation as missing and did not include it in the compliance assessment. This situation occurred for a few buildings where we could not determine whether economizers were required or whether they were present.

We defined two compliance rate metrics to provide insights into how well the commercial building market was doing overall in complying with the code and to identify code requirements, building types, and other characteristics where compliance was problematic.

To calculate one value of code compliance we used a binary method similar to the approach used in the 2016 Ecotope report (see Study Objectives and Context). That approach identified several key code requirements for each of the four building systems and used the prescriptive code as the reference for evaluating whether each requirement was met in a building. If any one requirement was unmet, the system was deemed to not comply with the code. If any system in a building did not comply using this definition, then the building was deemed to not comply with the code. This method relied on a very strict test of compliance. We used this as one method here because prior studies have used it and, because it required fairly simple analyses, we could compare the results with the more thorough method described next.

To provide a compliance estimate that was more indicative of the magnitude of possible impacts of noncompliance, Cadmus applied a slightly modified version of the method used in the Ecotope study. For most code requirements, we calculated a percentage compliance level that accounted for the floor area of the building, whether the measure complied, and a post-stratification weight to expand each sample building to the building population. For example, we calculated whether the glazing UA was less than the maximum allowed by code (thus it complied) in each building and assigned it a value of 1 if it complied and 0 if it did not. We multiplied these values times each building's floor area and the post-stratification weight, summed the values, and then divided by the total floor area of all buildings in the same category. This produced a compliance value weighted by the building sizes and the post-stratification weights. For some measures, such as presence of economizers when required by code, we used the proportion of the required economizers that were present (such as 0.4) instead of a binary value of 1 or 0 as the compliance value for each building. We calculated the building compliance value as the average of these system values. Buildings for which there were data gaps, or the code requirement did not apply were excluded from the analysis. Because our approach removed the bias toward zero compliance if a single requirement were not met, it provided a compliance estimate that was more representative of the overall building's performance and compliance with code requirements.

We note that while our approach provided a qualitative indication of how compliance affected energy consumption it did not provide a quantitative measure of that effect. Other studies have used simulation models to estimate a building's energy consumption based on how it was constructed. However, from the beginning, the scope and objectives of this study focused on the more descriptive approach.

We calculated compliance metrics for the sample and applied building weights to produce estimates by building type and size categories and for the population.

We used the prescriptive code requirements as the benchmark for assessing compliance of measures and equipment across all buildings that used the Prescriptive Path to comply with the code. For the envelope, we assessed compliance based on the overall UA value calculation.

We treated the small number of buildings (9) that complied using the Total Building Performance Path slightly differently. If the building used this path to demonstrate compliance, we assumed it complied with the individual Prescriptive Path requirements, even though it did not have to. This allowed the analysis to account for the fact that these buildings demonstrated code compliance but did not use the prescriptive approach.[25] This method also highlighted which components should be considered for improvement without requiring extensive building modeling. The analysis did assess whether buildings that used the Total Building Performance Path met the various mandatory requirements and found that not all buildings did satisfy the mandatory requirements.

The last quantitative analysis step in this study will use utility bills to determine the energy use intensity (EUI) for each building, compare the values to benchmarks, then investigate any relationship between the EUIs and level of code compliance. Because of the time required to acquire sufficient billing data, this analysis will be conducted in 2022 and documented in a supplemental report.

Finally, we summarized findings from interviews of building owners and other stakeholders to provide qualitative insights into how designers and developers viewed the energy code and how they satisfied it. This information helped identify potential challenges in the code and provided insights into how the code could be made more effective.

2.7 Building Database and Report Contents

We compiled data collected from each sample building's data collection form in an Excel database. We removed all data that would identify a specific site (such as contact name, address, etc.) and made this anonymized version of the database available so NEEA and stakeholders could access the raw data.

The remainder of this report focuses on the study findings in the following categories:

- Building level
- Envelope systems
- Lighting systems
- HVAC systems
- Service water heating systems and other code requirements

The final report section presents key study conclusions. The appendices present memos prepared at key junctures in the study to report essential information on sample design, recruitment, and data collection procedures.

[25] In most cases, we compared the findings for the Prescriptive Path buildings alone with the findings if we included the buildings complying under the Total Building Performance Path and found they were consistent.

3 Building-Level Findings

This section describes the building population, the targeted sample, achieved sample, and representation of the building population. It also summarizes key findings from the data at the building level.

3.1 Building Population and Sample Characteristics

The following subsections present descriptions and comparisons of the buildings in the study sample and population.

3.1.1 Building Population

To provide the basis for estimating population construction characteristics under the 2015 WSEC and SEC, we developed estimates of the building counts and floor areas in the population. As described in the Population Description and Sample Design section, to estimate the number of buildings affected by the codes we started with the sample frame developed from our integrated database then adjusted the building counts based on the length of time the codes were in effect.

To allow analysts or policymakers to calculate the annual effects of the 2015 codes, Figure 7 provides the estimated average number of buildings permitted under the 2015 codes each year in Seattle and in the rest of Washington during the period when the 2015 codes were in effect.[26] The WSEC was in effect from July 1, 2016, until February 1, 2021, and the SEC was in effect from January, 1, 2017, until March 15, 2021.[27] Energy savings from these codes accrued as the permitted buildings were constructed. The graph also shows what percentage of each building type was permitted in Seattle and the rest of the state. More multifamily buildings were permitted each year in Seattle than in the rest of the state, but more buildings in each size range were permitted outside of Seattle. The number and proportion of small buildings permitted outside of Seattle far exceeded those permitted in the city.

To permit analysts or policymakers to calculate the total effects of the 2015 codes, Figure 8 shows the number of buildings and percentage by size and multifamily category permitted during the entire period the 2015 codes were in effect. These codes established the efficiency requirements and cumulative energy consumption impacts of all buildings covered by the 2015 codes. The same relationships held as

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[26] Because floor areas and building type were not available in the integrated sample frame database for all buildings, we made some assumptions about allocating such buildings. The primary decision was to assume we had identified all multifamily buildings (i.e., none of the unknown buildings were multifamily buildings) then to multiply the building count in each size category by the ratio between the population count of nonresidential buildings to the count of buildings categorized by size. We believe this was appropriate because in most cases the population database identified whether a building was a multifamily building or not. We made this adjustment in all cases where we developed population estimates.

[27] Buildings in Seattle could choose whether to comply with the 2012 or 2015 code between November 6, 2016, and January 1, 2017.

in the annual counts, but the number of buildings affected was about four times the annual permit volume.

Figure 7. Annual Average Permit Counts under 2015 Codes, Population Total=943

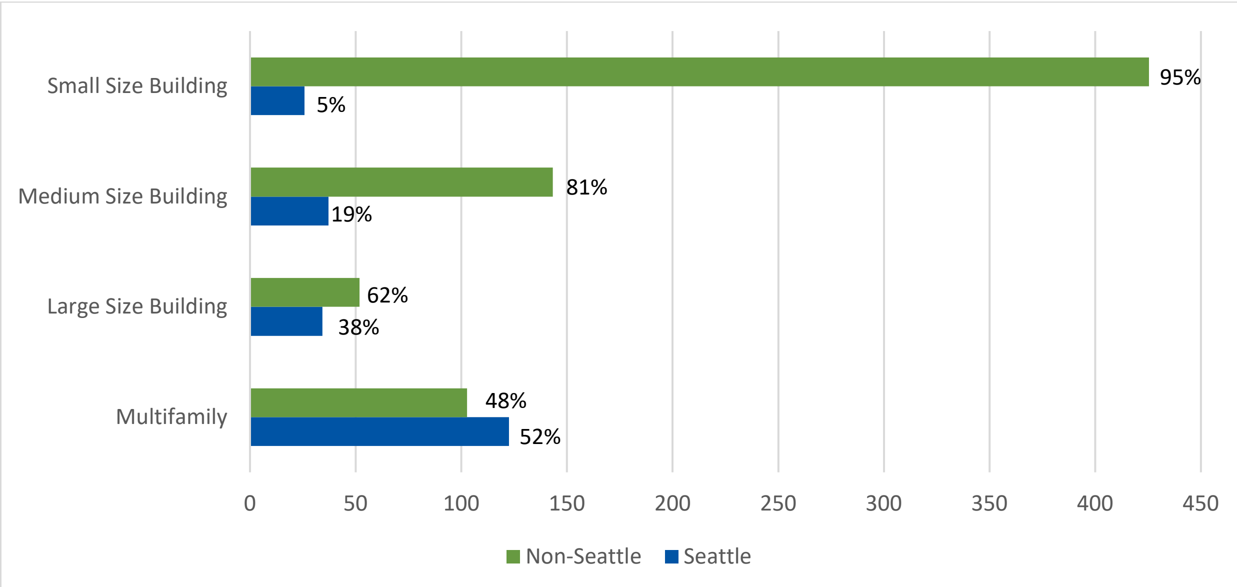


Figure 8. Permit Counts under 2015 Codes, Population
WSEC Effective July 1, 2016 – February 1, 2021
SEC Effective January 1, 2017 – March 15, 2021
Total=4,251

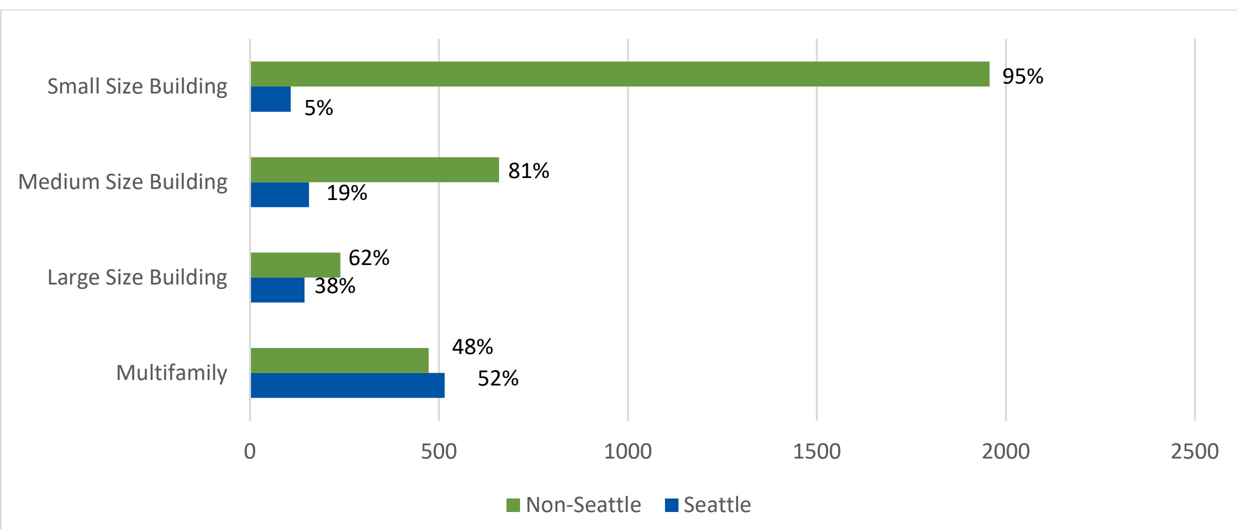


Table 7 presents the same information but based on floor area in each building size and multifamily category.[28] On an annual basis, about 20% more floor area was permitted in Seattle than outside the city. Over the time the 2015 codes were in effect, about 289 million square feet of new commercial floor space were permitted with about 7% more in Seattle than the rest of the state (this percentage is less than the 20% annual amount because the 2015 code was in effect a shorter time in the city). Multifamily buildings constituted the largest category of building floor area, 43% of the total statewide and 53% in Seattle. Although the fewest buildings were in the large building category, this category was the second largest in floor area, representing almost seven times the statewide floor area of small buildings, which had the largest number of buildings.

Table 7. Total Floor Areas Permitted under 2015 Codes

Category	Floor Area Permitted by Category				
	Multifamily	Large	Medium	Small	Total
Annual Average					
Seattle	19,014,074	14,177,955	2,185,993	356,162	35,734,184
Outside Seattle	9,761,562	10,175,630	7,404,331	2,792,611	30,134,134
Washington Total	28,775,636	24,353,585	9,590,324	3,148,773	65,868,318
Under 2015 Codes					
Seattle	79,859,111	59,547,410	9,181,172	1,495,879	150,083,573
Outside Seattle	44,903,185	46,807,899	34,059,921	12,846,012	138,617,016
Washington Total	124,762,296	106,355,309	43,241,094	14,341,891	288,700,589

Another useful comparison is between urban and rural areas in Washington. For analysis purposes, we selected the 10 largest cities as the urban area and compared the permit data for these cities with the rest of the state. We classified the rest of the state as rural.

Figure 9 shows the percentage of total floor area by building size and multifamily buildings in rural and urban areas. The patterns are like those in the comparison of Seattle to the rest of the state. About two-thirds of total floor area and about three-fourths of multifamily floor area are in urban areas. On the other hand, the amount of floor area in medium and small buildings is more in rural areas than urban areas.

28 To maintain consistency, we adjusted the building floor areas by size category to match the totals calculated from the building type data. This compensated for any error introduced in the floor areas by the necessary allocation of buildings for which size data were unavailable.

Figure 9. Distribution of Floor Area between Rural and Urban Areas, Population

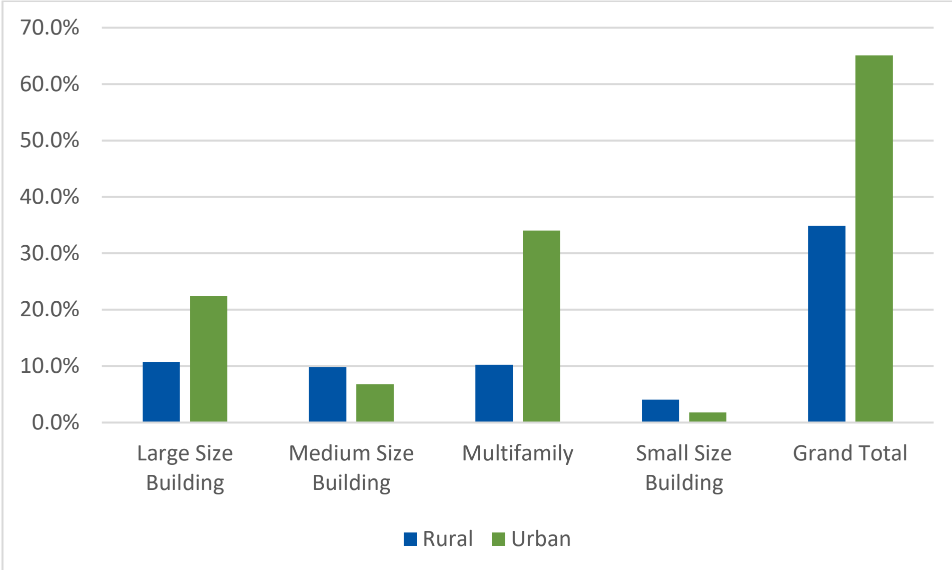
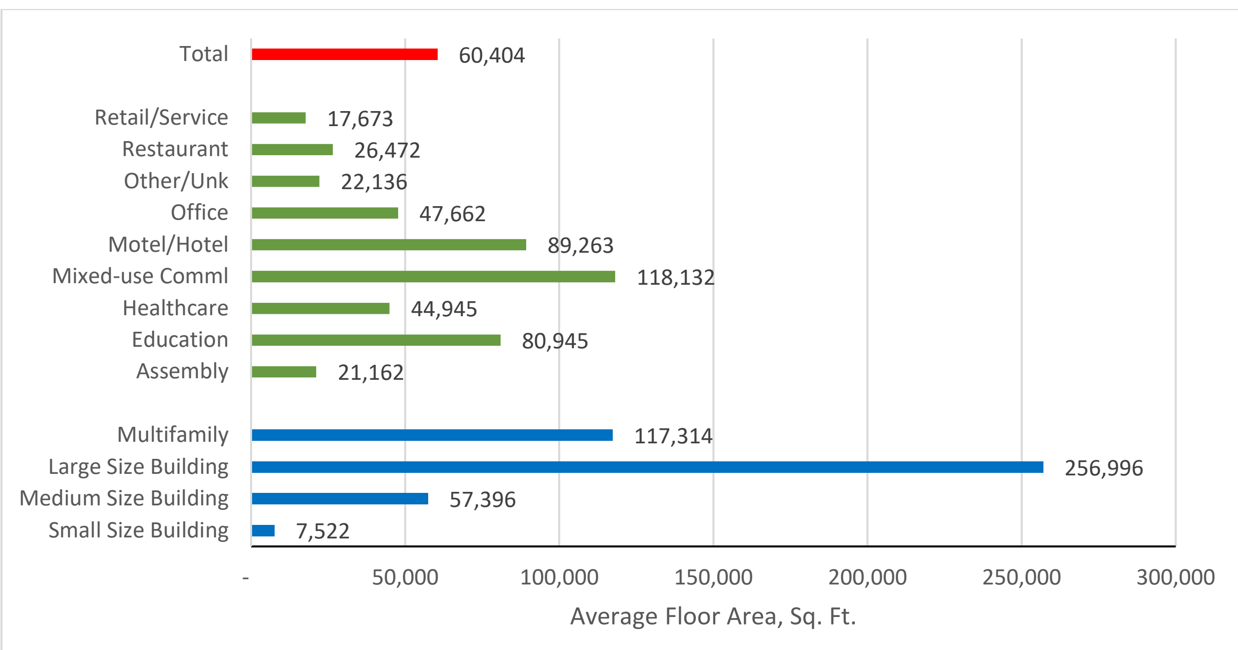


Figure 10 presents the average floor area of building categories in the population. The overall average size of all buildings in the population is 60,404 square feet. The average ranges from 7,522 square feet for small buildings to nearly 257,000 for large buildings. Mixed-use commercial buildings averaged 118,132 square feet, with multifamily buildings a close second at 117,314 square feet. The smallest buildings were retail/service, averaging 17,673 square feet.

Figure 10. Average Floor Area by Building Type, Population



3.1.2 Population and Sample Descriptions and Comparisons

To estimate population values of interest (such as compliance rates), we define population here and in the rest of the report as all the buildings in the combined database sample frame from which we drew our sample but reduced by the 12% to account for buildings permitted under the preceding energy code. Because this study's sample frame covered only part of the time when 2015 codes were in effect, this population is not all buildings eventually permitted under the 2015 codes. We used the relevant time intervals to extrapolate sample frame data to the full period when 2015 codes were in effect to estimate total population of buildings permitted under these codes, as presented above in Table 7.

Table 8 summarizes the distribution of nonresidential buildings by size and multifamily buildings in our sample frame population and reduced by 12% for the proportion of buildings permitted under the 2012 code. Our sample frame contains 2,211 buildings, of which we completed site visits to 76 buildings. Multifamily buildings are treated as a separate category so are not included in the building counts by size. We designed our original sample to be approximately proportional to the population distribution by size and the estimated share of multifamily buildings based on the population data available at the beginning of the project. As the table shows, the final distribution of buildings in our sample that agreed to site visits matched very closely the actual population distribution calculated at the end of the project based on the complete integrated population sample frame database.

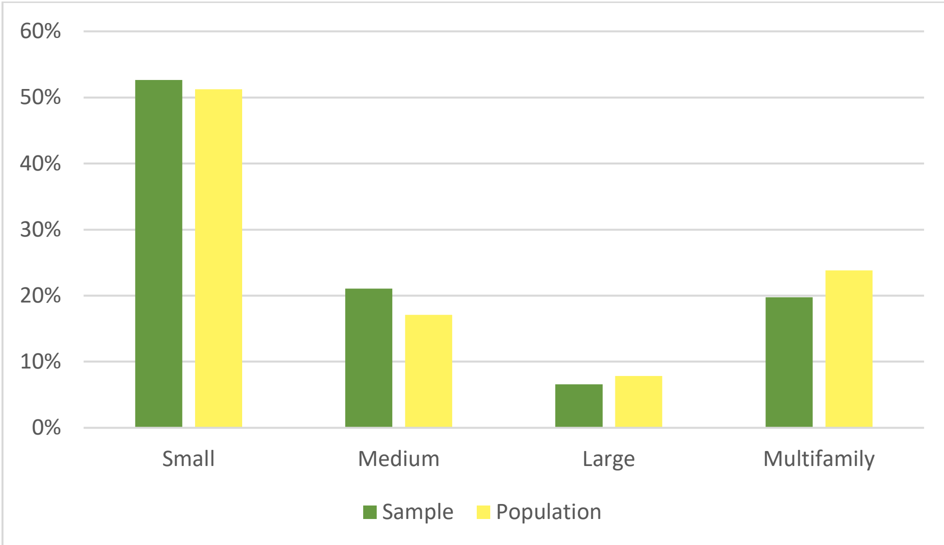
Table 8. New Buildings in Sample Frame and Sample

Stratum	Floor Area, sq.ft.	Sample Frame Population*		Target Number of Site Visits		Site Visits Completed	
		Count	%	Count	%	Count	%
Multifamily	Mix of mid- and high-rise**	527	24%	33	26	15	20%
Small Commercial***	<25,000	1,090	51%	52	41	40	53%
Medium Commercial***	25,000 – 100,000	412	17%	17	13	16	21%
Large Commercial***	>100,000	181	8%	6	5	5	7%
New Construction Total	**-**	**2,211**	**100%**	**108**	**85**	**76**	**100%**

* Note that one building categorized initially as medium had a floor area that was slightly under the floor area maximum for small buildings based on the field data. Because the analysis was under way, we did not reclassify it, but the correct floor area was applied in all the calculations.
**Mid-rise multifamily buildings are defined as those from four to six stories; high-rise buildings are seven stories and higher.
*** Population sizes within strata are estimated because floor areas were missing for some buildings. Cadmus assumed that square footage data was missing randomly such that the distribution of buildings with unknown square footage across the floor area bins followed that of the buildings with known square footage.

Figure 11 compares the distribution of our nonresidential sample by building size and multifamily separately with the population distribution. In both the sample and the population, almost exactly half the buildings are in the small category. The other categories agree closely between the sample and population, as Table 8 shows.

Figure 11. Sample (n=76) and Population (n=2,211) Count Distribution by Size and Multifamily



Energy usage is proportional to the floor area, so it is important to consider the amount of floor area in each size category as well as the building count. Figure 12 shows that this distribution differed considerably from the distribution by building counts. The distribution by building size is the inverse of the distribution based on counts: in the population, the small category constituted only 6% of the distribution and large buildings constituted 37% of the distribution. Multifamily buildings made up 43% of the population floor area, about twice their share by count. The floor area distribution in our sample was similar to the population in two cases and different in two: the shares of small and multifamily building floor areas were almost the same as in the population. The share of medium building floor area, however, was larger (24% vs. 15%) and the share of large building floor area was smaller (21% vs. 37%).

Figure 12. Sample (n=76) and Population (n=2,211) Floor Area Distribution by Size and Multifamily

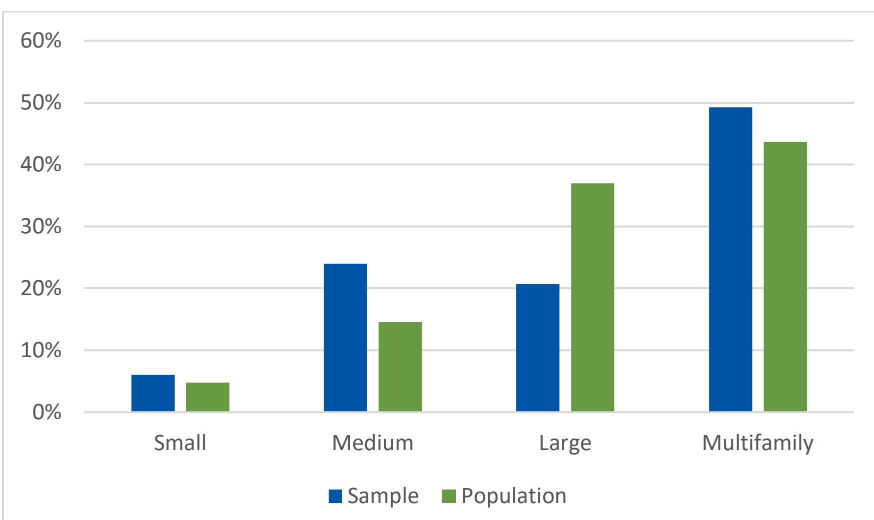


Figure 13 and Figure 14 illustrate the distribution of building types and sizes in the sample and population, respectively. The most noteworthy difference between our sample and the building population is the relatively large share of buildings in our sample that were in the education category compared to the population—30% vs. 7.2%. During data collection, we recognized that education buildings were taking a large share of the sample because owners were more willing to participate. We therefore stopped recruiting education buildings. Even so, the proportions of other building types in our sample were typically smaller than in the population because education buildings had already taken the larger share. The share of multifamily buildings, an important building type in this study, was close to the population share. Our sample included only one motel/hotel and one restaurant. About 23% of buildings in the population fell into other categories, or we were unable to identify their type.

Within the building types, the distributions of building size were similar between the sample and population in most cases. For example, retail/service buildings were primarily small; education buildings were mostly medium, followed by small buildings, and then large buildings. However, for some building types our sample did not include any buildings in certain size categories, which was to be expected given the small sample sizes. No buildings in our sample were designated as mixed-use because all buildings sampled had at least 75% of the floor space occupied by a specific building type.

Figure 13. Sample Building Type Count and Size Distribution (n=76)

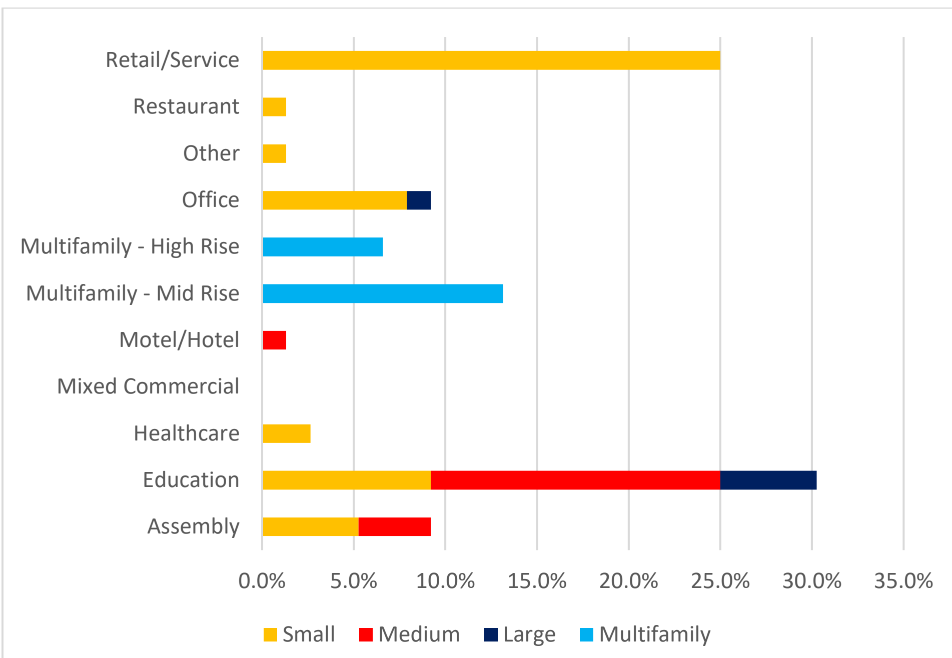
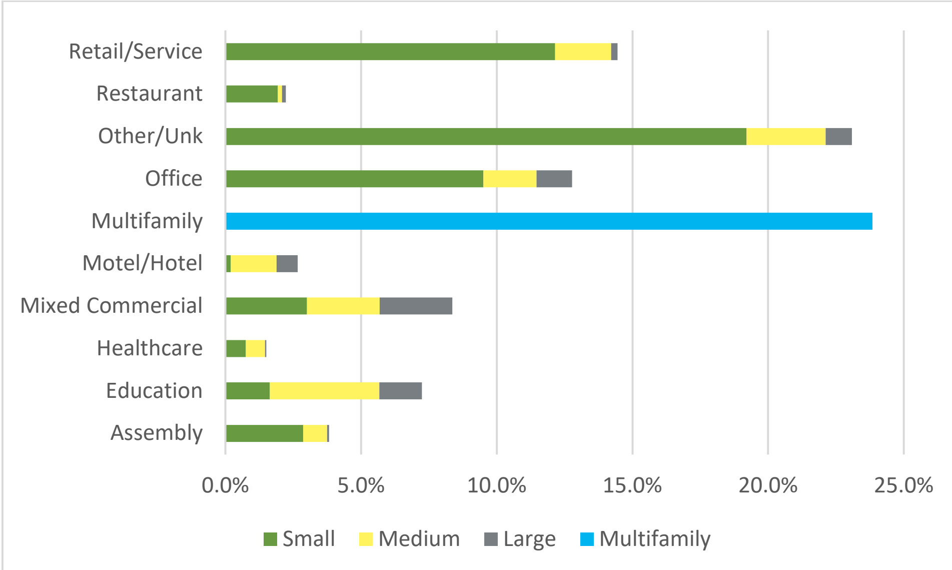


Figure 14. Population Building Type Count and Size Distribution (n=2,211)



3.1.3 Urban vs. Rural Areas

One hypothesis is that the way buildings are built to meet the energy code varies between urban and rural jurisdictions. The diversity of building size and type in the population and our sample and in urban and rural jurisdictions allowed us to investigate possible differences in how buildings in urban and rural areas complied with the energy code.

Table 9 provides additional details about the buildings included in our sample. Slightly more than half the sample buildings were in rural areas (defined as cities smaller than the 10 largest in the state). Table 10 provides the same information for the building population. The split in sample and population between rural and urban locations agreed closely by building size category. Average floor areas by size category agreed closely between the population and sample except for large buildings where the average size of sample buildings was about 30% smaller than the population average.

Table 9. Sample Distribution Details

Building Category	Building Type, Counts	Location		Average Floor Area, Sq.Ft.	Floor Area Range, Sq.Ft.
		Rural	Urban		
Small	Education=7 (9%) Office=6 (8%) Retail/Service=19 (25%) Other=8 (11%) Total=38 (50%)	24 (32%	14 (18%)	6,551	594-16,100
Medium	Education=12 (16%) Office=0 Retail/Service=0 Other=4 (5%) Total=18 (24%)	10 (13%)	8 (11%)	65,054	23,753-95,729
Large	Education=4 (5%) Office=1 (1%) Retail/Service=0 Other=0 Total=5 (7%)	3 (4%)	2 (3%)	179,552	125,121-305,556
Multifamily	High-rise=5 (7%) Mid-rise=10 (13%) Total=15 (20%)	4 (5%)	11 (14%)	142,361	20,819-380,932
All	Education=23 (30%) Office=7 (9%) Retail/Service=19 (25%) Other=12 (16%) Multifamily=15 (20%) Total=76	41 (54%	35 (46%)	55,537	594-380,932

Table 10. Population Distribution Details

Building Category	Building Type, Counts	Location		Average Floor Area, Sq.Ft.	Floor Area Range, Sq.Ft.
		Rural	Urban		
Small	Education=2% Office=10% Retail/Service=12% Other=27% Total=51%	35%	14%	7,522	93-24,953
Medium	Education=4% Office=2% Retail/Service=2% Other=9% Total=17%	11%	8%	57,396	25,000-98,500
Large	Education=2% Office=1% Retail/Service=0.2% Other=5% Total=8%	3%	5%	256,996	100,400-1,149,400
Multifamily	Total=24%	6%	18%	117,314	477-1,316,100
All	Education=7% Office=13% Retail/Service=14% Multifamily=24% Other=42%	56%	44%	60,404	93-1,316,000

To provide more detail, Table 11 displays the counts, average floor area, and total floor area by building type in urban and rural areas. More buildings were in the rural areas, but they tended to be smaller than their urban counterparts so the floor areas in urban areas were larger than in rural areas for most building types. The distribution of buildings in our sample followed a similar pattern, with more buildings located in rural areas but constituting total floor area less than those in urban areas. These data illustrate the diversity in building characteristics between urban and rural areas, which justified developing weights accounting for building location.

Table 11. Population New Building Counts and Floor Areas by Building Type

Building Type	Rural			Urban		
	Count	Avg. Floor Area, Sq.Ft.	Total Floor Area, Sq.Ft.	Count	Avg. Floor Area, Sq.Ft.	Total Floor Area, Sq.Ft.
Education	112	69,686	7,788,069	48	111,455	5,394,410
Multifamily	139	104,849	14,578,207	388	124,414	48,282,597
Office	179	16,212	2,896,182	104	99,366	10,318,164
Retail/Service	227	15,934	3,617,558	92	22,142	2,045,919
Other	577	28,460	16,429,619	344	90,224	31,044,314
Total	1,234	36,725	45,309,634	977	99,391	97,085,403

3.1.4 Seattle vs. Rest of Washington

Because the Seattle code differed some from the state code, we compared results for Seattle to those for the rest of Washington. Seattle's 2015 code had the following notable differences from the WSEC:

- Included a third compliance option, the Target Performance Path, section C401.3, that establishes modeled EUI targets for each building type and requires demonstration of complying energy use
- Set slightly more stringent envelope requirements in a few areas
- Had slightly more stringent fenestration performance requirements
- Limited the maximum window-to-wall ratio to 45%, with some exceptions
- Set additional requirements for some air systems
- Prohibited certain water recirculation distribution systems
- Added lighting control requirements in certain spaces
- Set more stringent interior lighting power allowances and lighting power densities (LPDs)
- Eliminated the high-activity commercial exterior lighting zone
- Set a slightly more stringent air infiltration requirement
- Required different HVAC systems under certain conditions in the total building performance compliance path analysis
- Added some commissioning testing requirements and required commissioning in the Total Building Performance Path (C407)
- Required installation of renewable energy generation (C411), with some exceptions.

Above, Figure 7, Figure 8, and Table 7 present summary information on building counts and floor areas permitted under the 2015 codes combining the buildings in Seattle and outside of the city. To compare Seattle with the rest of the state, Table 12 presents building type distributions and floor areas when the 2015 codes were in effect in Seattle and the rest of the state. In Seattle, the most common building type was multifamily, with mixed commercial a distant second. Building types outside Seattle were distributed over many different categories, with the most common those in the other/unknown category, followed by retail/service.

We wanted to examine how building characteristics affected by the energy codes differed between Seattle and the rest of the state implementing the WSEC. However, only 10 of the 76 buildings in our sample were in Seattle,[29] and all were multifamily buildings with one exception, a medium education building. Given the small sample size and lack of diversity in the Seattle sample, we were unable to provide substantial findings comparing Seattle construction to the rest of the state.

[29] Although the proportion of buildings in Seattle was slightly less in our sample than in the population, the urban-rural distribution was very similar between the sample and population. Also, the total floor area of Seattle buildings in the sample was substantial.

Table 12. Population Permitted under 2015 Codes: Building Type Statistics, Seattle vs. Rest of State

Building Type	Seattle					Outside Seattle				
	Buildings		Floor Area			Buildings		Floor Area		
	Count	% of Seattle	Square Feet	% of Seattle	% of State	Count	% of Outside Seattle	Square Feet	% of Outside Seattle	% of State
Assembly	11	1.2%	618,306	0.4%	0.2%	154	4.6%	3,051,732	2.2%	1.1%
Education	29	3.1%	2,722,041	1.8%	0.9%	283	8.5%	22,505,432	16.2%	7.8%
Healthcare	3	0.3%	997,920	0.7%	0.3%	62	1.9%	2,212,521	1.6%	0.8%
Mixed Commercial	177	19.2%	40,620,642	27.1%	14.1%	169	5.1%	16,845,554	12.2%	5.8%
Motel/Hotel	14	1.5%	2,216,095	1.5%	0.8%	100	3.0%	8,213,902	5.9%	2.8%
Multifamily	515	55.7%	79,859,111	53.2%	27.7%	473	14.2%	44,903,185	32.4%	15.6%
Office	70	7.5%	15,552,534	10.4%	5.4%	478	14.4%	11,143,470	8.0%	3.9%
Other/Unk	59	6.3%	4,837,277	3.2%	1.7%	937	28.1%	18,523,812	13.4%	6.4%
Restaurant	5	0.5%	35,402	0.0%	0.0%	91	2.7%	2,500,779	1.8%	0.9%
Retail/Service	41	4.5%	2,624,244	1.7%	0.9%	581	17.5%	8,716,630	6.3%	3.0%
Total	923	100.0%	150,083,573	100.0%	52.0%	3327	100.0%	138,617,016	100.0%	48.0%

3.1.5 Other Sample Building Characteristics

Fifty-seven (75%) of the buildings in our sample had natural gas service in addition to electricity. Taking floor area into account and estimating for the population, natural gas was available for buildings constituting 72% of the floor area. Natural gas was less common in urban buildings (66% of floor area) and least common in small buildings (71%); it was only slightly more available in multifamily buildings (73%). Natural gas was available to the largest share of floor area for medium buildings. None of the buildings on Bainbridge Island had gas service because there is no provider. Four buildings listed propane as a fuel source.

Seventeen (22%) indicated they had installed renewable energy generation. Seven of 10 buildings in Seattle indicated they had installed renewable energy generation as the SEC required. The three that did not satisfied exceptions (higher equipment efficiencies and heat recovery) so met the code. The renewable generation documentation available for most projects was not sufficient to analyze the systems in detail but indicated that many of the systems were small.

Several participated in a variety of programs supporting energy efficiency:[30]

- Seven participated in programs provided by utilities
- Two were LEED certified
- Three schools participated in the Washington Sustainable Schools Protocol (WSSP)
- One was WELL certified[31]

LEED, WSSP, and the WELL program required sustainable building features in addition to energy efficiency.

We also asked all building contacts if their building had any notable sustainable design features. Five multifamily buildings had green roofs. One high school had a roof rainwater drainage and filtration pond system. An elementary school included several sustainable design features: ground source heat pumps and wind-assisted natural ventilation integrated with the building management system.

3.2 Building-Level Compliance Findings

This section summarizes compliance approaches and findings at the building level.

3.2.1 Compliance Approaches Selected

We reviewed the overall compliance approach each building in our sample used to comply with the energy code. Of 76 buildings, nine used the total building performance approach (10% of the floor area), 61 used the prescriptive approach, and six were indeterminate.[32] We had no evidence that the buildings where the compliance path was not indicated were more or less likely to comply, but the fact that the information was not always readily available was a gap in the overall compliance documentation process.

Of the buildings in the sample with confirmed overall compliance approaches:

- Statewide, 87% followed the Prescriptive Path
  - Multifamily buildings were the most likely to use the Prescriptive Path—92%
  - Large buildings were the least likely to use the Prescriptive Path—75%
- Statewide, 13% used the Total Building Performance Path
- In Seattle, eight of 10 buildings used the Prescriptive Path and two were indeterminate
- The Target Performance Path was an option unique to Seattle, but no buildings in our sample used it

[30] We did not have state data on the population of buildings that participated in these programs for comparison.

[31] The WELL certification for healthy buildings is provided by the International WELL Building Institute.

[32] For several more buildings, we did not find information confirming the overall compliance approach used, but we were able to review information on individual building system compliance that suggested the building followed the prescriptive approach and so assigned it to that category.

Table 13 summarizes the percentages of different compliance options selected by the projects in the sample and estimated for the population.[33]

Table 13. Compliance Options

Compliance Requirement	Option	Sample Percent	Population Percent
Envelope	Component Performance	26%	35%
	Prescriptive	74%	65%
Lighting	Area Lighting	64%	61%
	Space-by-Space	36%	39%
Overall	Total Building	13%	14%
	Prescriptive	87%	86%

For the envelope, about three-fourths of sampled buildings took the prescriptive approach, and the rest chose the component performance approach. However, 64% of sampled multifamily buildings used the component performance approach. For the population, we estimated the choice of the prescriptive approach at about two-thirds. For lighting, 64% of sampled buildings used the area lighting method and about one-third selected the space-by-space method. The population weighted estimate showed that a smaller share, 61%, used the area lighting method.

As noted above, 87% of the buildings in the sample used the Prescriptive Path to demonstrate overall compliance and only 13% selected the Total Building Performance Path based on building modeling. The estimate for the population was almost identical.

More buildings complying using the Total Building Performance Path were in the small building category than in any other size category; however, they represented only 13% of the small building sample. The percentage of large buildings using this compliance approach was 25%, but this was based on only one of four large buildings for which we determined the compliance approach. Multifamily buildings were the least likely to use the Total Building Performance Path approach: only one multifamily building in our sample used this option.

The only notable difference between Seattle and the rest of the state was in the options selected to demonstrate envelope compliance. Buildings in Seattle used the envelope component performance approach (63%) three times as often as buildings in the rest of the state (20%). The data suggested that multifamily buildings were more likely to use the envelope component performance approach and, given that multifamily buildings represented 90% of the Seattle sample, this may be more related to the predominance of multifamily buildings in the Seattle sample than anything unique about the location. We did not observe any relationship between building size and envelope compliance method.

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33 Percentages shown in the table are calculated for those cases where we were able to determine which compliance option was selected. We note that for several buildings we could not determine the compliance option selected with certainty after reviewing all the available information.

3.2.2 Unweighted Binary Compliance Results

The simplest approach for assessing code compliance across building systems is to assess whether all code requirements for a system are met; to assess compliance no credit would be given if some, but not all, requirements are met. This binary approach is a strict test that does not account for how many individual requirements are met. It is an informative metric, however, to identify how compliance varies across building systems, sizes, and types.

Figure 15 summarizes the binary compliance results for individual small, medium, and large buildings. Figure 16 presents similar results for the three building types for which we had the largest samples. Each column represents the sample building labeled by the ID at the bottom of the figure. The results are color coded to indicate whether the building complied completely with the specific code requirement shown on the left. Blue indicates the building complied and red indicates it did not comply because at least one of the building components did not meet the specific code requirement. The grey shading indicates that the requirement either did not apply or insufficient data were available on one or more components to determine binary compliance.

Figure 15 shows that almost all buildings complied with the HVAC and water heating equipment efficiency requirements or compliance could not be determined. Exterior lighting power, interior LPD, and HVAC controls also showed high binary compliance although a few buildings failed to comply with these requirements. For the Section C406 requirements, we used the most stringent criteria to assess compliance, and this showed compliance was low for small buildings using this metric.

Figure 16 shows the results for multifamily, education, and retail/service buildings. The figure shows the multifamily buildings complied more often with the binary total envelope and glazing UA and glazing SHGC requirements than other buildings. Retail/service buildings often did not comply with the C406 requirements, but this overlaps with the findings for small buildings because most the retail/service buildings were usually small.

Figure 15. Binary Compliance Results by Building Size

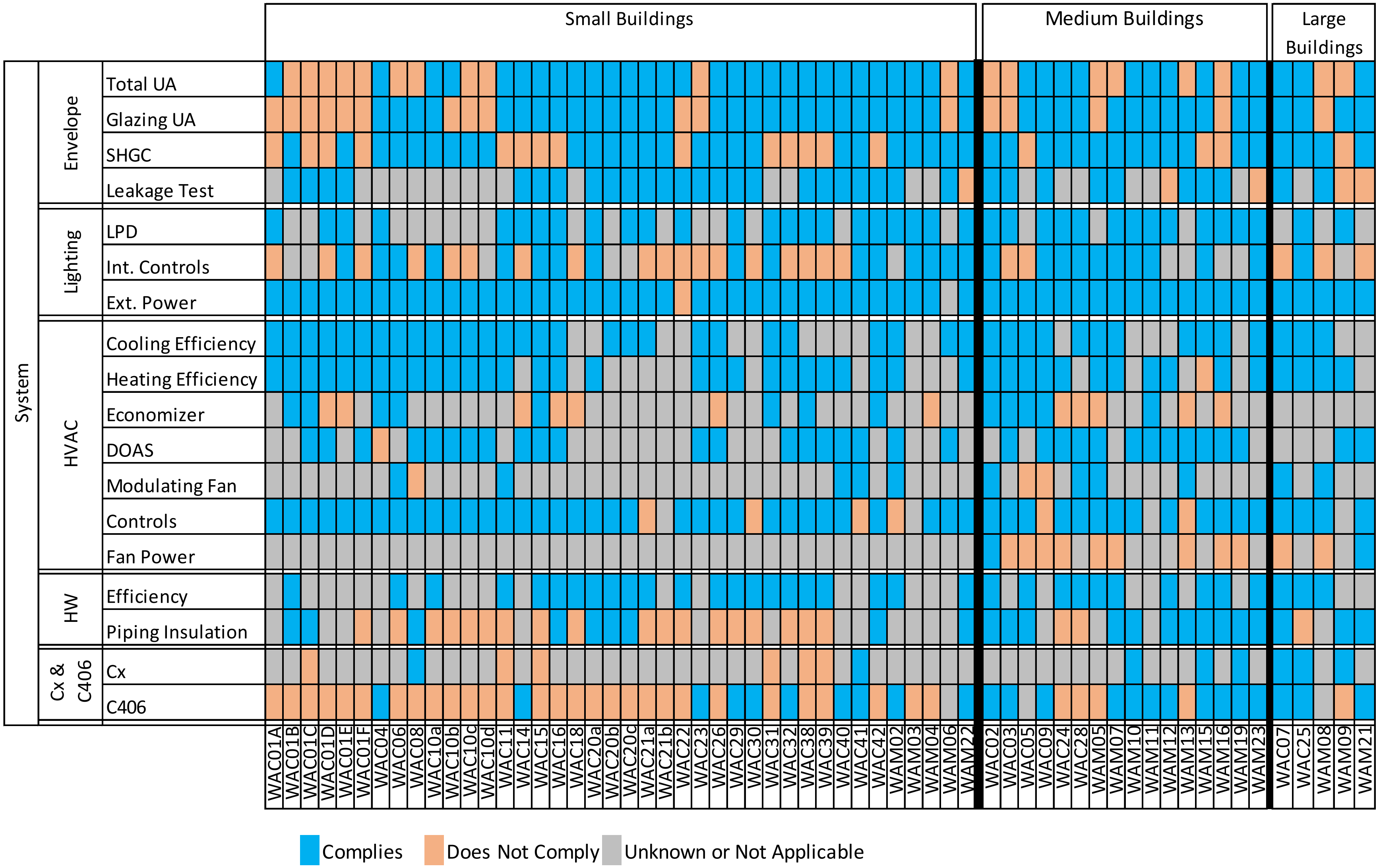


Figure 16. Binary Compliance Results for Three Building Types

Table 14 presents disaggregated compliance results for each system category and subcategory. The table presents the count for each subcategory of whether it complied or did not comply with the requirement and if the requirement was not applicable or we were not able to determine compliance. The compliance rate is the ratio of “yes” to the sum of “yes” and “no” findings; no weights were applied to these results.

In the envelope system category, we included the total building UA (C402.1.5), fenestration UA (C402.1.5, C402.4.1), glazing SHGC (C402.4.1), and leakage test conducted (C402.5) code requirements. The compliance by code requirement subcategory ranged from 71% for total UA to 84% for satisfying the leakage test requirement. The average of the subcategory values was 75%. Generally, multifamily buildings had higher compliance rates than other buildings and small buildings tended to have the lowest compliance rates. The one exception was compliance with the leakage test requirement—96% of small buildings met this requirement.

The lighting system category included requirements for interior lighting controls (C405.2), exterior lighting controls (C405.2.5), interior lighting power (C405.4), and exterior lighting power (C405.5). Based on the count of controls in each building, compliance by subcategory ranged from 25% to 100%. Compliance with the lighting power requirements was high in all cases. Compliance with internal controls was relatively low for small and large buildings.

The HVAC system category included several code requirements: heating equipment efficiency (C403.2.3), cooling equipment efficiency (C403.2.3), modulating cooling fan (C403.2.11.5), fan power limit (C403.2.11.1), economizer presence (C403.3), and DOAS presence (C403.6). We determined compliance only for those units that were required to meet the code. Table 14 shows that compliance was high with the efficiency requirements and inclusion of modulating fans. We assessed compliance with the modulating fan, fan power, economizer, and DOAS requirements by counting how many of the units covered by the code met it. Our estimate of compliance with the fan power requirement was likely an underestimate because many exceptions were potentially applicable, and documentation was inadequate to review all the possible exceptions. Nevertheless, this was an area where compliance appeared to be problematic. Compliance with the fan power and economizer requirements were the lowest rates of any measure included in this study.

Section C404 of the codes specifies water heating system efficiency requirements. Similar to HVAC equipment efficiency, compliance was high with this requirement—every system for which we obtained data complied. The codes also require piping insulation on hot water lines (C404.6) and compliance with this requirement was low in small buildings.

Section C408.1 presents commissioning requirements for buildings complying through the Prescriptive Path in the WSEC and the SEC also requires commissioning under the Total Building Performance Path. Many buildings were exempted from the commissioning requirement because their system capacities fell below triggering thresholds; buildings covered by the commissioning requirement in the sample all complied.

Section C406 requires all buildings complying under the Prescriptive Path to include two efficiency options chosen from a list of eight. Compliance with this requirement was low in small buildings.

Table 14. Detailed Compliance Results, Unweighted

Building System	Requirement Subcategory	Compliance Counts			Compliance Rate*				
		Yes	No	Unk/ N/A	Small	Medium	Large	Multi-family	Total
Envelope	Total UA	57	19	0	73%	63%	60%	100%	**75%**
	Fenestration UA	59	17	0	70%	75%	80%	100%	**78%**
	SHGC	58	18	0	65%	81%	80%	100%	**76%**
	Leakage Test	42	8	26	96%	80%	50%	73%	**84%**
	Combined	216	62	26					**78%**
Lighting	Interior LPD	34	0	42	100%	100%	100%	100%	**100%**
	Interior Controls	37	25	14	47%	83%	25%	83%	**60%**
	Exterior Lighting Power	73	2	1	95%	100%	100%	100%	**97%**
	Combined	144	27	57					**84%**
HVAC	Heating Efficiency	56	1	19	100%	92%	100%	100%	**98%**
	Cooling Efficiency	54	1	21	100%	91%	100%	100%	**98%**
	Modulating Cooling Fan	12	4	60	83%	57%	100%	100%	**75%**
	Fan Power	3	11	62	N/A	18%	33%	N/A	**21%**
	Economizers	14	16	46	47%	55%	N/A	25%	**47%**
	DOAS	39	1	36	95%	100%	100%	100%	**98%**
	HVAC Controls	64	6	6	89%	87%	100%	100%	**91%**
	Combined	242	40	250					**86%**
Water Heating	Equipment Efficiency	45	0	31	100%	100%	100%	100%	**100%**
	Pipe Insulation	36	22	18	33%	85%	75%	93%	**62%**
	Combined	81	22	49					**79%**
Commissioning and C406 Options	Commissioning	13	6	57	25%	100%	100%	100%	**63%**
	C406 Options**	32	38	6	26%	73%	75%	67%	**46%**
Overall		728	195	445					**79%**

*"N/A" indicates either that the requirement did not apply, there were no observations, or data were missing.
**The values for C406 Options are the averages between the lower and upper bounds.

3.2.3 Weighted Compliance Results

To better indicate the relative effects of the compliance levels of different buildings and the population, we applied the floor area and post-stratification weights to the raw compliance findings for each building and aggregated across all buildings in the population. Subsequent sections in this report present the detailed results by building size category and location that provide the basis for calculating these aggregated results.

Table 15 presents the results for the same code requirements in Table 14. Most results were similar between the unweighted sample results and the weighted population results. In several cases, including the building floor area and population weights increased the compliance estimate. Notable differences between the two metrics included the following:

- **Leakage testing**. The population estimate for leakage testing compliance was much less than the unweighted estimate because of low compliance in large buildings.
- **Interior lighting controls**. The population compliance estimate was much higher than the unweighted estimated because of high compliance in larger buildings.
- **Fan power**. The population compliance estimate was much higher than the unweighted binary estimate because the binary estimate strictly required all units to comply in a building for the building to comply.
- **Commissioning**. The population commissioning rate was higher because of the effect of floor area weighting.
- **C406 options**. The population weighted compliance estimate for C406 options is much larger than binary estimate because the population estimate took the upper bound into account.

Table 15. Detailed Compliance Results, Population Weighted

Building System	Requirement Category	Compliance Rate
Envelope	Total UA	82%
	Fenestration UA	92%
	SHGC	82%
	Leakage Test	53%
	Combined Average	76%
Lighting	Interior LPD	100%
	Interior Controls	88%
	Exterior Lighting Power	99%
	Combined Average	96%
HVAC	Heating Efficiency	98%
	Cooling Efficiency	98%
	Modulating Cooling Fan	86%
	Fan Power	66%
	Economizers	54%
	DOAS	99%
	HVAC Controls	99%
	Combined Average	86%
Water Heating	Equipment Efficiency	100%
	Pipe Insulation	63%
	Combined Average	82%
Commissioning and C406 Options	Commissioning	82%
	C406 Options*	84%
	Combined Average	83%
Combined Overall Average		85%

*The value for C406 Options is the average between the lower and upper bounds.

Table 16 presents the weighted average compliance rates for all buildings in the sample categorized by size and multifamily and by location, urban vs. rural. The results for the state and for all building categories by location are estimates for the building population based on the sampling weights (see Appendix D). Overall, multifamily buildings achieved the highest compliance rate and compliance rate increased with building size. For the population on the whole, the population weighted compliance rate was slightly less in rural areas.

Table 16. Overall Average Compliance Rates by Building Size, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	77%	80%	79%
Medium	83%	85%	84%
Large	91%	85%	89%
Multifamily	96%	92%	92%
All	88%	83%	86%

4 Envelope System Findings

This section presents findings on the envelope design and code requirements. Findings include the following:

- Overall envelope thermal performance based on the normalized UA[34]
- Assembly types and thermal characteristics
- Glazing solar heat gain coefficient (SHGC)
- Window-to-wall ratio
- Leakage testing.

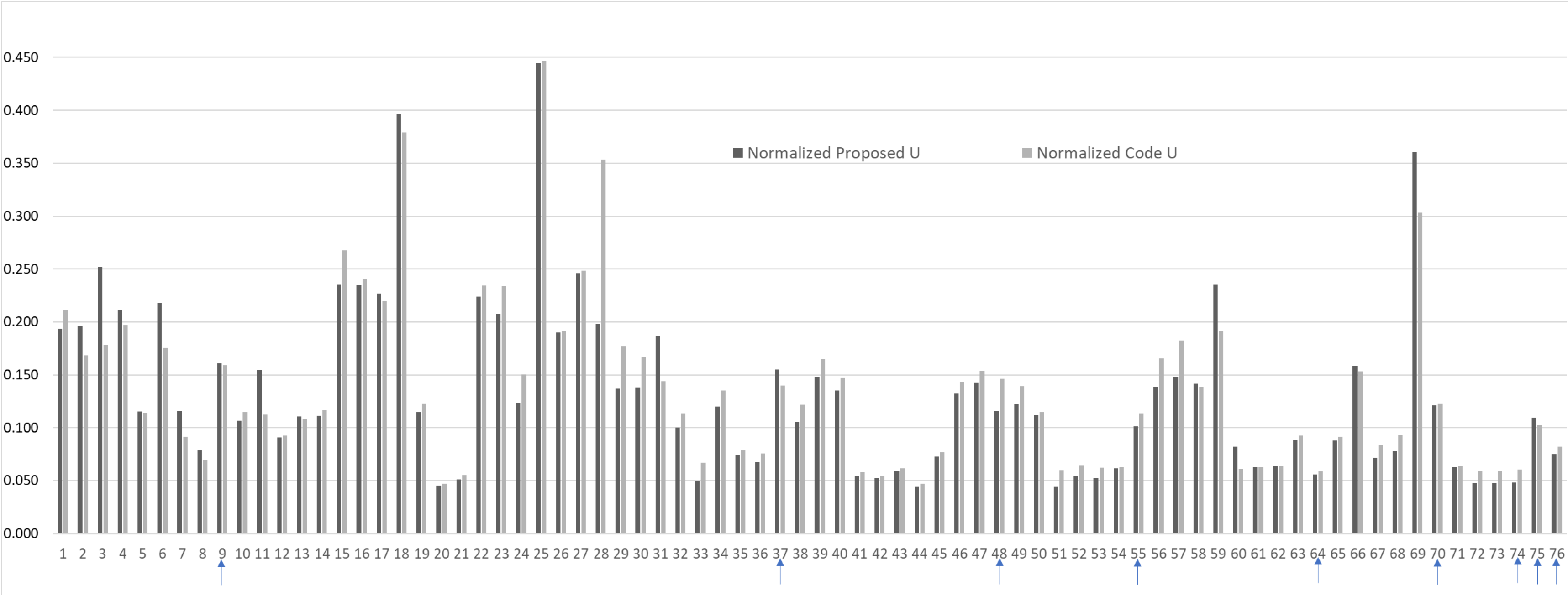
4.1 Envelope Thermal Performance

Figure 17 presents the calculated overall U-factor normalized by building floor area for each building in our sample compared to the value required by the code based on the prescriptive requirements. To cover all buildings in our sample, the nine buildings that complied using the Total Building Performance Path (and buildings for which we could not determine the compliance approach) are included in the graph; buildings complying under the Total Building Performance Path are marked by arrows below the axis. Those buildings exhibited results similar to the remainder of the sample.

Fifty-four (71%) of the 76 buildings in the sample had normalized U-factors that were less than or equal to the maximum allowed by the code, so they complied with the code envelope prescriptive requirement. Six of the nine buildings that used the Total Building Performance Path had more efficient envelopes than the prescriptive approach required. All of the sampled buildings in Seattle had envelopes more efficient than required by the prescriptive approach. Twenty-two (29%) buildings in the sample had values that exceeded the code maximum so did not comply with the prescriptive envelope requirement; however, only 11 had values that exceeded the code maximum by more than 10%. Five buildings had values that exceeded the code level by more than 25%, with one building having a value 41% larger than the code level. On the other hand, 16 buildings had proposed normalized U-factors that were less than 85% of the level required by the code so were more energy-efficient.

[34] The UA is a measure of the overall thermal performance of a building's envelope calculated as the product of the thermal transmittance (U-value or U-factor) of a component and its area (A). The total UA for a building envelope is the sum of the values of all envelope components. The units are Btu/hour-deg F.

Figure 17. Envelope Normalized U-factor Comparison by Building in Sample*



*Arrows indicate buildings that complied using the Total Building Performance Path.

Table 17 presents the percentage of buildings in the sample, by various categories, that complied with the UA requirement and includes buildings that followed both the Prescriptive Path and the Total Building Performance Path to demonstrate compliance. As noted earlier, the analysis assumed that buildings that used the Total Building Performance Path to comply had envelopes that met the Prescriptive Path requirement, and these were included in the analysis to account for the entire population.

The data did not show a clear relationship between size and compliance rate; medium buildings had the smallest compliance rate. Multifamily buildings had a much higher compliance rate, at 100%, than other commercial buildings categorized by size. The table also compares the rates across the building types. Education buildings had the lowest compliance rate, at 52%.

Table 17. Envelope UA Compliance Rates, Sample Unweighted

Building Category	Compliance Rate
Size	
Small	74%
Medium	60%
Large	75%
Multifamily	100%
Type	
Education	52%
Multifamily	100%
Office	86%
Retail/Service	79%
Other	82%

We used post-stratification weights to take into account floor areas and the regional distribution of buildings to estimate the statewide population envelope compliance rates. Table 18 presents these estimates by building size and multifamily in urban and rural areas and for Washington overall.

Table 18. Envelope UA Compliance Rates, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	71%	85%	80%
Medium	74%	46%	58%
Large	100%	51%	78%
Multifamily	100%	100%	100%
Total	93%	72%	84%

Large and multifamily buildings had the highest envelope compliance rates in both the unweighted sample and the population estimates in Table 18. However, both the unweighted sample results and the population estimates indicated that medium education buildings in the rural areas tended to have lower envelope compliance rates. Although we did not investigate any contributing factors in detail, it appeared that this building category, as well as small buildings, tended to have less efficient glazing overall than required by the codes (see Fenestration U-Factor).

4.2 Assembly Types and Performance

Table 19 presents the distribution of assembly types by envelope component in our sample by building size and multifamily. These types include metal, wood, mass, concrete, slabs, and other. Except for floors, the table shows the percentages the specific assembly type constituted of the total area of the envelope component in each building weighted across all buildings by the building floor area. For floors, the percentages are the total occurrences of each assembly type in a building category divided by the total number of floor types for buildings in the category. We used this approach for floors because only the perimeter values were available for slabs rather than their total area.

Table 19. Envelope Assembly Types, Sample

Building Category	Wall Assembly*		Roof Assembly, %*	Floor Assembly, %**
	Above Grade, %	Below Grade, %		
Small	Metal 36% Wood 45% Mass 7% Other 12%	Metal 0% Wood 0% Mass 100% Other 0%	Metal 39% Wood 60% Mass 0% Other 1%	Metal 3% Wood 5% Slab-on-grade 93% Concrete-no earth contact 0% Other 0%
Medium	Metal 76% Wood 14% Mass 10% Other 0%	Metal 0% Wood 0% Mass 88% Other 12%	Metal 81% Wood 16% Mass 1% Other 2%	Metal 4% Wood 8% Slab-on-grade 67% Concrete-no earth contact 21% Other 0%
Large	Metal 69% Wood 14% Mass 0% Other 17%	Metal 0% Wood 0% Mass 100% Other 0%	Metal 35% Wood 65% Mass 0% Other 0%	Metal 0% Wood 13% Slab-on-grade 63% Concrete-no earth contact 13% Other 13%
Multifamily	Metal 0% Wood 59% Mass 3% Other 38%	Metal 0% Wood 0% Mass 100% Other 0%	Metal 4% Wood 37% Mass 59% Other 0%	Metal 0% Wood 5% Slab-on-grade 52% Concrete-no earth contact 29% Other 14%

*Note that percentages may not add to 100% due to rounding.
**Floor assembly percentages are calculated from the ratio of each assembly type to total floor types for each building category.

For above-grade-wall assemblies, the predominant type was wood for small and multifamily buildings and metal for medium and large commercial buildings. The 38% of walls in multifamily buildings categorized as "other" were curtain walls. Below-grade wall assemblies were mass[35] except for 12% of medium buildings. Just under 40% of roof assemblies were metal for all commercial buildings except multifamily for which only 4% were metal. More than half the roof assemblies were wood for small and large commercial buildings, but the most common roof assembly type for medium commercial buildings was metal. For multifamily buildings, 59% of the roof assembly type was mass.

35 Mass includes concrete masonry unit (CMU) assemblies.

Slabs were the predominant floor type across building sizes, ranging from 52% for multifamily buildings to 97% for small commercial buildings. Concrete floor assemblies below grade or not in earth contact were also common in all except small buildings.

Table 20 presents the average U-factors and F-factors in our sample of the different envelope components compared to the code requirement for each building size category and multifamily buildings. The values were calculated by taking into consideration the code requirement for the different assembly types in our sample, summing the UA values for all the buildings in a category, and dividing by the sum of the component areas. The main finding was that wall and roof U-factors were typically more efficient than required by code. Floors were typically less efficient, which suggests that buildings often traded off higher efficiency wall and roof systems for less efficient floor systems.

Table 20. Envelope Component Compliance with Prescriptive Requirements, Sample

Building Category	Wall, Above Grade U-factor		Roof U-factor		Floor U-factor		Slab F-factor	
	As-built	Code	As-built	Code	As-built	Code	As-built	Code
Small	0.053	0.058	0.026	0.027	0.034	0.029	0.53	0.54
Medium	0.052	0.058	0.027	0.025	0.065	0.030	0.60	0.54
Large	0.047	0.055	0.021	0.028	0.036	0.029	0.56	0.54
Multifamily	0.051	0.053	0.025	0.027	0.029	0.028	0.57	0.54

4.3 Fenestration U-Factor

Section C402.1.5 requires that buildings using the Prescriptive Path demonstrate compliance by having a total area-weighted UA of fenestration that does not exceed the value calculated based on the prescriptive component values.[36] We calculated the total glazing UA for each building as built and compared it to the code requirement.[37] Table 21 compares the average prescriptive fenestration U-factors for the buildings as built to the average code requirement for the same buildings. The table shows that the average as-built U-factor for medium buildings was slightly larger than the average prescriptive code value; for the other size categories, the as-built average was less than or equal to the code average. For multifamily buildings, the as-built value was nearly 20% less than the code value.

Table 21. Average Fenestration U-Factor Comparison, Sample

Value	Building Category			
	Small	Medium	Large	Multifamily
As-built	0.36	0.38	0.35	0.26
Code	0.36	0.36	0.37	0.32

[36] As noted before, we included buildings that complied under the Total Building Performance Path and assumed that their fenestration complied.

[37] As mentioned before, for characteristics such as glazing U-factor and SHGC, if the data were not available from observation of documentation, we assumed the characteristic just met the level required by code.

Table 22 presents the compliance rate for the population by building size and multifamily and urban vs. rural.

Table 22. Fenestration UA Compliance Rate, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	69%	90%	82%
Medium	74%	72%	73%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	**93%**	**91%**	**92%**

Overall, the compliance rate was high, which would be expected given recent advances in efficient glazing. Fifty-one percent of buildings complying prescriptively had glazing with a U-factor less than required by code, therefore more efficient than the prescriptive requirement. Compliance of all large and multifamily buildings was 100%. A large proportion of buildings had fenestration that was more efficient than the code prescriptive requirement; 53% of buildings had glazing that was on the average 16% more efficient than required by code (that is, the UA was 16% less than the amount allowed by the code).

However, the overall fenestration compliance rates for small and medium buildings were unexpectedly low. Medium buildings and small urban buildings had the lowest average compliance rate; six of the small urban buildings had fenestration UA values that exceeded code by 17% or more, with one having a UA twice the prescriptive code allowance. Although overall compliance of small buildings in rural areas was higher than in urban areas, four buildings in this group had glazing UA values between 15% and 87% larger than the code allowed UA level. The overall compliance rate for medium buildings was the lowest at 73%; however, the four buildings that did not comply exceeded the code UA value by only 4% to 34%. The low fenestration compliance rates in medium buildings contributed to the low envelope UA compliance rate of these buildings.

Considering building type, fenestration in education buildings exceeded the maximum UA allowed by code more often than in other buildings; about 40% of education buildings exceeded the code limit on fenestration UA. On the average, the education buildings that did not comply with the fenestration requirement exceeded the code UA level by 14%. Fenestration that did not comply with the UA requirement occurred in 26% of the retail/service buildings, but these buildings exceeded the maximum allowed UA by a much larger average, at 42%.

4.4 Solar Heat Gain Coefficient

Section C402.1.5.2 requires that the overall SHGC be no more than the values prescribed in Table C402.4, with different limits prescribed for glazing oriented toward the north and glazing facing all other directions. This requirement did not apply to buildings that used the Total Building Performance approach, but we included them in the analysis as described.[38]

We calculated the population weighted SHGC for buildings taking all fenestration into account and compared its value to the maximum value allowed by the codes. Prescriptive code compliance required the as-built value to be less than or equal to the code value. Table 23 compares the average SHGC values by building size and multifamily category. The average as-built value for small buildings exceeded the code average; the as-built value was 10% less than the code value for the medium and large building categories. For multifamily buildings, the average SHGC was 41% less than the prescriptive code value.

Table 23. Average SHGC Comparison, Sample

Value	Building Category			
	Small	Medium	Large	Multifamily
As-built	0.42	0.36	0.36	0.23
Code	0.40	0.40	0.40	0.39

Table 24 presents the code compliance results by building size and multifamily category and location.

Table 24. SHGC Compliance Rates, Population

Building Category	Location		
	Urban	Rural	State
Small	54%	49%	51%
Medium	100%	73%	85%
Large	100%	51%	78%
Multifamily	100%	100%	100%
Total	94%	66%	82%

Although the overall compliance rate was relatively high, the compliance rates were surprisingly low for some building categories. Small buildings had a statewide compliance rate of only 51%. Generally, compliance was lower in rural buildings than urban buildings. Multifamily buildings complied in all cases, and all medium and large buildings in urban areas complied.

We also examined compliance across building types, as shown in Table 25. Values in the table were not weighted by floor area but gave an indication of the relative compliance rates. The smallest compliance rate was for buildings in the retail/service category. As noted earlier, buildings in this category were all categorized as small, so this finding is related to the building size as well as building type.

38 Only one of the nine buildings using the Total Building Performance Path did not meet the SHGC requirement.

Table 25. SHGC Compliance Rates by Building Type, Sample Unweighted

Education	Multifamily	Office	Retail/Service	Other
86%	100%	86%	47%	73%

4.5 Window-to-Wall Ratio

Under the Prescriptive Path, the window-wall-ratio (WWR) cannot exceed 30% unless certain other conditions are met.[39] Table 26 presents information on the WWR ratio for the different building size and multifamily categories for all buildings.[40] Values in the table were estimated based on the post-stratification weights for the population. The average WWR was the least for small buildings at just under 20%. For the other categories, the average was slightly larger, ranging between 25% and 28%.

Table 26. Window-Wall Ratio Findings for Prescriptive Compliance Buildings, Population Weighted[41]

Building Category	Average WWR, %	% Greater than 30%		Compliance Strategies
		% Buildings	% Floor Area	
Small	18%	8%	6%	Daylighting, DOAS, component performance alternative
Medium	25%	19%	18%	Component performance alternative
Large	28%	20%	17%	Total Building Performance Path
Multifamily	26%	27%	48%	Component performance alternative
All*	28%	15%	35%	

*The results in the row labeled "All" are calculated by applying population weights; all other results are based on the sample alone.

Because the code required the WWR to be less than 30% unless specific conditions were met, the table also presents the share of buildings in each size category that exceeded the 30% limit. Less than 10% of small buildings exceeded 30%, and between 19% and 27% of other buildings exceeded the code limit. Taking building size into account, the floor area of buildings where the WWR exceeded the limit ranged from 6% for small buildings to 48% for multifamily buildings.

Table 26 also shows what other conditions were met in those cases where the WWR exceeded the 30% limit. All buildings that had a WWR larger than the 30% limit met one of the alternative conditions that allowed the building to exceed this limit. The table indicates that four of the possible alternatives were

39 Under the Total Building Performance Path, the 30% ceiling does not apply. The WWR can be as large as 45% for buildings using this path if specific conditions are met.

40 We limited this analysis to buildings complying under the Prescriptive Path because the Total Building Performance Path allowed more flexibility.

41 Four of the five large buildings were education buildings and this likely affected the observation that no large buildings exceeded the 30% limit. The fact that no large buildings exceeded the 30% limit was likely related to

used in the sample buildings.[42] Of the three small commercial buildings that exceeded the limit, one used the daylighting alternative (at least 25% of net floor area in a daylight zone, C402.4.1.1), one used a dedicated outside air system (DOAS) to comply, and the third used the component performance alternative approach (C402.1.5).[43] One medium commercial building complying under the Prescriptive Path had a WWR larger than the limit and used the component performance alternative approach. All four multifamily buildings that exceeded the limit also used the component performance alternative, and one installed a DOAS that would also have provided an alternative.

One large building and one medium commercial building that complied with the code under the Total Building Performance Path had a WWR greater than 40%. The Total Building Performance Path allowed WWR values larger than 40% and required the modeled standard reference design to use the same WWR as the proposed design.[44] Two other medium buildings using the Total Building Performance Path had a WWR greater than 30%. One motivation for buildings to comply using the Total Building Performance Path was the flexibility allowed for larger WWR values.

4.6 Leakage Test

Section C402.5.1.2 of the codes requires that a whole building leakage test shall be conducted and, if the leakage exceeds the amount allowed by the code, corrective actions must be taken and documented, but no retest is required. The requirement applies to all buildings regardless of their overall compliance approach. Table 27 summarizes the findings on compliance with the leakage testing requirement.

The table reports the percentage of buildings that complied with the testing requirement out of those buildings for which we could determine compliance; we were unable to determine compliance for about one-third of buildings.[45] Overall, 84% of the buildings conducted leakage testing and the percentage varied across the size and multifamily categories, ranging from 96% for small buildings to 50% for large buildings. Given the apparent relationship between testing and building size, we calculated the average floor area of compliant and non-compliant buildings. As shown in the table, the average size of complying buildings was about one-third of non-complying buildings.

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42 We note that the data collected did not always make it possible to confirm the approach used. In some cases, we found based on our UA analysis that the envelope thermal performance was better than required by code so assumed that the component performance alternative applied.

43 We include one small building that barely exceeded the 30% limit based on our analysis but note that it was just under 30% according to the compliance submittal and is within the error band so may not have actually exceeded the threshold.

44 The Seattle code limits the WWR to 45% but allows an exception if the modeled energy consumption meets specific requirements.

45 We relied on interviews with the building representative to confirm that the testing was done. In several cases, the representative did not know, and, in some, the projects documents said testing was intended but the building representative could not confirm; in these cases, we marked this requirement as “unknown.”

Table 27. Leakage Testing, Sample

Building Category	Percent of Buildings Conducting Leakage Test
Small	96%
Medium	80%
Large	50%
Multifamily	73%
Total	84%
Did Building Perform Leakage Test?	**Average Floor Area, Sq.Ft.**
Yes	49,602
No	156,073

We examined whether compliance with the testing requirement varied between rural and urban jurisdictions and by building type. Based on building counts in our sample, with no weighting, leakage testing occurred most frequently in rural areas (87%) compared to urban areas (29%). Retail/service buildings complied more frequently with this requirement than other building types, but this was probably attributable in part to the fact that these buildings were all in the small category.

Table 28 presents the population weighted leakage testing frequency for the population based on the sample data using our post-stratification weights. For each size category and multifamily buildings, the compliance rate was less in urban areas. Overall, the difference between the rates for rural (87%) and urban (29%) areas was much larger than in the unweighted results. This was because the only large building in an urban area for which we had data did not comply and its large floor area heavily weighted the results. The results for small and medium buildings did not vary much from the results based on the unweighted sample (not shown). They also supported the unweighted findings that compliance declined as building size increased.

Table 28. Leakage Testing Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	88%	100%	96%
Medium	75%	89%	83%
Large	0%	78%	17%
Multifamily	44%	77%	59%
Total	29%	87%	53%

5 Lighting System Findings

Section C405 of the codes specifies lighting efficiency requirements that apply to buildings following the Prescriptive Path and the Total Building Performance Path.[46] The Reporting Work Group noted that lighting was rapidly shifting to high-efficiency technologies, particularly LEDs, and that new commercial buildings likely met the codes' lighting power density (LPD) requirements. Consequently, the group recommended that the study deemphasize analyzing LPD. Following the group's recommendations, we confirmed that almost all lamps or fixtures sampled in Washington commercial buildings used LEDs (which are substantially more efficient than other typical lighting technologies), but we did not conduct detailed LPD analyses. However, we were able to analyze lighting power according to the planning documents and compare the proposed LPD to code requirements. We did not include analysis of daylight responsive controls (C405.2.4).

Our lighting system analyses focused on the following:

- Shares of lighting following different compliance paths
- Interior lighting power, fixture types, and controls
- Exterior lighting power levels, fixture types, and controls

In addition, we identified which buildings chose options C406.3 (reduced lighting power) and C406.4 (enhanced lighting controls), and these results are discussed in the Commissioning and C406 Option Findings section. We did account for cases where C406.3 applied when we assessed compliance with the LPD requirement.

Table 29 presents results of the lighting system analysis for urban and rural areas and the state, applying post-stratification population weighting. Across the state, the Building Area Method was used most often to demonstrate interior lighting compliance; however, it was used much less frequently in rural than urban areas. All large commercial buildings in our sample used the Building Area Method, whereas only 50% of multifamily buildings did. Interior and exterior lighting complied with the code in almost all cases. The internal lighting controls compliance rate was high but only 80% for rural buildings.

Table 29. Lighting Compliance Results, Population Weighted

Location	% Interior Lighting using Building Area Method	Compliant Interior Lighting	Compliant Interior Lighting Controls	Compliant Exterior Lighting
Rural	45%	100%	80%	98%
Urban	81%	100%	93%	100%
State	61%	100%	88%	99%

46 Section C405.4, interior lighting power requirements, does not apply to buildings following the Total Building Performance Path under the SEC. However, we included Seattle buildings in our analysis because all Seattle buildings met the C405.4 requirements.

Based on data for the sample buildings, we estimated full compliance with the interior LPD requirements for the population as shown in Table 30.[47]

Table 30. Interior LPD Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	100%	100%	100%
Medium	100%	100%	100%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	100%	100%	100%

In all buildings for which we had data, the interior lighting had an installed LPD that was less than allowed by the codes and therefore complied with the code lighting power requirement. Table 31 presents the reported code and installed average LPDs for the sample buildings, weighted by building floor area. The average installed LPD was less than the average code LPD across the three building size categories, with the largest difference for medium buildings (-36%). Multifamily buildings had the smallest code and installed average LPDs. The largest difference between code and installed LPDs was for buildings in the "other" category, driven mostly by a hotel with an installed LPD much less than the code requirement. Conclusions based on building type, however, were not very robust given the small sample sizes. Overall, the average weighted installed LPD was 29% less than the average code level.

Table 31. Interior LPD, Sample Weighted by Floor Area

Building Category	LPD	
Size	Code	Installed
Small	0.75	0.54
Medium	0.73	0.47
Large	0.70	0.58
Multifamily	0.36	0.25
Type	Code	Installed
Education	0.73	0.52
Multifamily	0.36	0.25
Office	0.69	0.64
Retail/Service	0.77	0.57
Other	0.73	0.30
Overall	0.61	0.44

Exterior installed lighting power also was substantially less than the amount allowed by code for most

47 This table is included for consistency with all other code requirement compliance tables.

buildings. Table 32 shows that the only case where compliance was less than 100% was in small rural buildings (one small retail/service building).[48]

Table 32. Exterior Lighting Power Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	100%	95%	97%
Medium	100%	100%	100%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	100%	98%	99%

Table 33 presents the total exterior lighting power for sample buildings, broken down by building size category and building type. The table also shows the percentage that the installed power was less than the allowed power for each building group. The exterior lighting power installed in medium, office, and other type buildings was at least 70% less than allowed by the codes. The difference between the installed and allowed exterior lighting power was the least in large and retail/service buildings.

Table 33. Exterior Total Lighting Power (Watts), Sample

Power	Building Size			Building Type				
	Small	Medium	Large	Multi-family	Education	Office	Other	Retail/ Service
Allowed, Watts	97,333	72,492	22,318	31,075	65,693	7,708	43,776	74,965
Installed, Watts	47,725	20,536	13,042	11,998	30,320	1,730	8,937	40,316
Percent Installed Is Less Than Allowed	51%	72%	42%	61%	54%	78%	80%	46%
Installed Power, Watts/Sq.Ft. Floor Area	0.18	0.02	0.01	0.01	0.02	0.01	0.03	0.30

The table also shows the total installed wattage per square foot of building floor area. For most building types and sizes, these values are an order of magnitude less than the interior LPD (see Table 31). In the case of small and retail/service buildings, however, the values are between about a third and half of the respective interior LPDs.

Table 34 and Table 35 present estimates of the distribution of interior lighting fixture types across the size and multifamily categories and by building type. In small commercial buildings, LED integrated fixtures provided almost three-fourths of the lighting power. For the other building size categories,

48 Table C405.5.2(1) lists the zones that determine the exterior lighting power requirements. When we evaluated exterior lighting power requirements, we used the zone 2 requirements to simplify the analysis. Zones 3 and 4 have higher allowances and the SEC eliminates zone 4. Given that all buildings in urban areas met the zone 2 requirements they also satisfied the zone 3 and 4 requirements. It was unlikely that the building that did not meet the standard in rural areas would have been in locations that would have qualified as zone 3 or 4.

these fixtures provided from about 44% to about 54%. LED linear fixtures provided almost as much lighting power as LED integrated fixtures in medium buildings. Multifamily buildings relied on other LED types (such as screw-in bulbs) for almost 40% of their lighting power. T8s, CFLs, and incandescent lighting were almost nonexistent in new commercial buildings.

Table 34. Interior Lighting Fixture Shares by Building Size, Sample

Lighting Type	Small	Medium	Large	Multifamily
LED Integrated	73.4%	47.4%	43.6%	53.7%
LED Linear	12.0%	39.4%	30.5%	9.6%
LED other	14.1%	13.2%	26.0%	36.7%
T8	0.3%	0.0%	0.0%	0.0%
CFL	0.2%	0.0%	0.0%	0.0%
Incandescent	0.0%	0.0%	0.0%	0.0%

Table 35 shows that LED integrated fixtures provided the most lighting power across all the building type categories, ranging from 43% in education buildings to about 71% in buildings in the other category. LED linear fixtures provided the second most lighting power in education and office buildings. Other LED types provided the second largest amount of lighting power in retail/service and other buildings, as well as multifamily buildings as noted before.

Table 35. Interior Lighting Fixture Shares by Building Type, Sample

Lighting Type	Education	Office	Multifamily	Retail/Service	Other
LED Integrated	43.1%	53.0%	53.7%	66.2%	71.3%
LED Linear	37.8%	27.8%	9.6%	13.2%	14.3%
LED other	19.1%	19.1%	36.7%	19.7%	14.4%
T8	0.0%	0.1%	0.0%	0.5%	0.0%
CFL	0.0%	0.0%	0.0%	0.4%	0.0%
Incandescent	0.0%	0.0%	0.0%	0.0%	0.0%

Table 36 and Table 37 present estimates of the distribution of exterior lighting fixture types across the size and multifamily categories and by building type.[49] LED integrated fixtures were the most common for all building sizes. In large commercial buildings, LED integrated fixtures provided nearly all the lighting power. For the other size categories, these fixtures provided from 62% to 85% of the lighting power. LED fixtures classified as other types were the second most common. Small quantities of incandescent and CFL fixtures were present, including incandescents providing more than 7% of the lighting power in multifamily buildings.

[49] We had type information for 2,209 fixtures but did not have sufficient information to determine the fixture type for others constituting 1.3% of the estimated total power. There were additional fixtures that we were unable to classify or estimate their wattage, but this missing information was unlikely to affect the percentage estimates.

Table 36. Exterior Lighting Fixture Shares by Building Size, Sample

Lighting Type	Small	Medium	Large	Multifamily
LED Integrated	62.1%	82.1%	98.4%	85.0%
LED Other	36.6%	12.5%	0.0%	6.2%
LED A-lamp	0.2%	5.4%	0.0%	0.8%
LED Linear	0.0%	0.0%	1.6%	0.7%
Incandescent	0.0%	0.0%	0.0%	7.2%
CFL	1.1%	0.0%	0.0%	0.0%

Table 37 shows, by building type also, LED integrated fixtures provided the most lighting power except for other buildings, which mostly had LED fixtures classified as other types. A large share of retail/service buildings also had other types of LED fixtures.

Table 37. Exterior Lighting Fixture Shares by Building Type, Sample

Lighting Type	Education	Office	Multifamily	Retail/Service	Other
LED Integrated	77.8%	95.4%	85.0%	59.1%	49.2%
LED Other	0.0%	0.6%	6.2%	39.6%	50.8%
LED A-lamp	8.3%	3.9%	0.8%	0.0%	0.0%
Incandescent	0.0%	0.0%	7.2%	0.0%	0.0%
CFL	0.0%	0.0%	0.0%	1.3%	0.0%
LED Linear	13.9%	0.0%	0.7%	0.0%	0.0%

Section C405 of the WSEC and SEC provides mandatory code requirements for interior lighting controls. Section C405.2.1.1 identifies building areas in which occupancy controls are required (such as conference rooms, lounges, and private offices). Section C4.5.2.2 identifies areas in which time switch controls are required; these are most areas not required to have occupancy controls. Daylit areas are required to have daylight responsive controls presented in Section C405.2.4.

We analyzed compliance with the interior lighting occupancy and timer controls. Table 38 shows unweighted, binary compliance rates, based on the number of controls, by building size and building type. The rates are relatively low for most building categories, but especially low for large buildings and retail/service buildings. The binary test was very strict—a single non-complying control would make the building non-compliant so these results, as all the binary results, overstate the effect of partial non-compliance.

Table 38. Interior Lighting Controls Compliance, Unweighted Sample

Building Size			Building Type				
Small	Medium	Large	Multi-family	Education	Office	Other	Retail/ Service
47%	83%	25%	83%	76%	33%	55%	38%

Table 39 presents the compliance data but takes into account building size and population distribution; this estimate is weighted by floor area so gives a better indication of the lighting power controlled. For all building sizes and multifamily buildings, the rates are higher than the unweighted binary estimates. The difference suggests that compliance was typically higher in larger buildings, however the lowest rate occurred in large rural buildings.

Table 39. Interior Lighting Controls Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	80%	70%	74%
Medium	91%	100%	96%
Large	94%	58%	78%
Multifamily	98%	100%	99%
Total	93%	80%	88%

Despite the cases of noncompliance with the interior controls requirements, it was surprising that many buildings installed more occupancy sensors or timer controls than code required. For all buildings in the sample, the combined controls installed that were not required were almost 160% of the number installed that were required. Occupancy sensor controls installed that were not required were an additional 50% of the required quantity installed; the number of lighting timers installed that were not required far exceeded the number required. The percentage of such controls that were not required by code increased with building size (from 105% to 166%) and was the most for buildings in the other category (234%).

We compiled the wattage controlled by the different control types for each building. We did not analyze compliance in detail for exterior controls, however, because of some cases where the relationship between areas and the control type was uncertain. A few buildings had manual controls, which are not permitted under the code in most exterior areas; however, the code does allow manual controls and 24/7 lighting in some areas (primarily for safety and security), so we could not accurately assess whether these controls complied. The data indicated that compliance was very high based on the total power controlled by compliant technologies as shown in Table 40. The “Other” category included unknown controls, central controllers, and manual controls; it is likely most complied based on the area controlled but, even if they did not, the wattage included is only about 5% of the total. Section C405.2.7 requires, for most lighting that controls "automatically turn off lights as a function of available daylight" or "automatically shut off the lighting as a function of dawn/dusk and a set opening and closing time." We observed many astronomical timeclocks where no photocells were installed. We did not investigate the programming logic of any of these controls and we assumed that these controls were compliant and had the capability to both turn off lights based on daylight and also be programmed to coincide with open and closing times.

Table 40. Exterior Lighting Controls by Power Controlled (Watts), Sample

Control Type					
Astronomical Timeclock	Photocell	Daylight Sensor	Occupancy Sensor	Luminaire Level Control	Other
44,017	52,466	123	114	10,841	6,079

6 HVAC System Findings

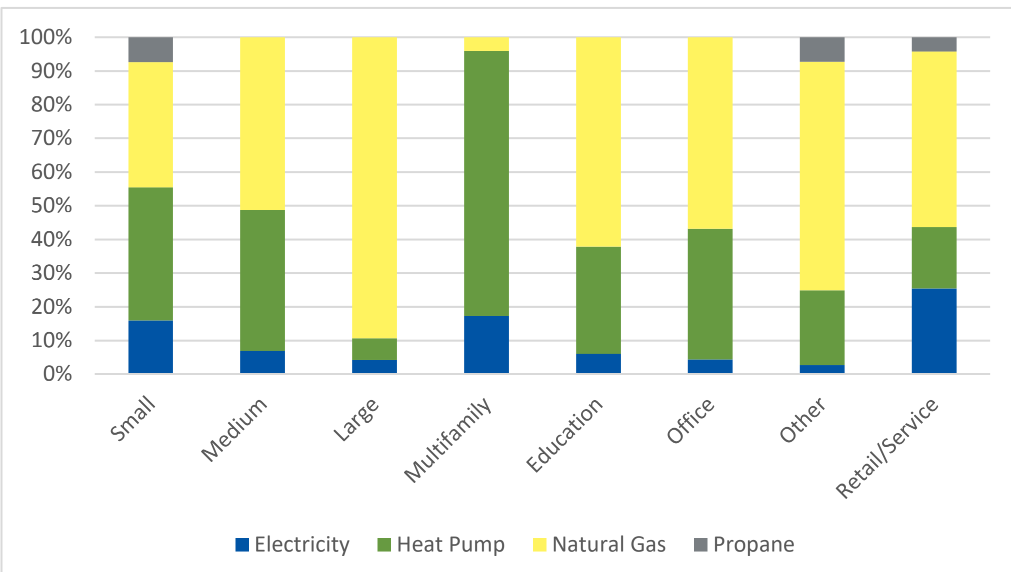
This section presents findings on the HVAC systems. It includes the following information on these systems and the relevant code requirements:

- Proportion of fuel, HVAC, and distribution system types
- Equipment efficiencies
- Fan power and speed modulation
- Economizers and DOAS
- HVAC controls.

6.1 Space Heating Fuel, Heating and Cooling System Type, and Distribution Types

Heating fuels included natural gas, electricity, and propane. We separated electric resistance heating from heat pumps and determined the distribution of fuel type capacity by building size and type as shown in Figure 18.[50] Across the sample, heat pumps and natural gas constituted nearly equal shares. Natural gas heating provided about as much capacity (a little less than 40%) as heat pumps in small buildings, but the natural gas share increased, and heat pump share decreased substantially as building size increased. Electric resistance also decreased as building size increased. Propane was used in only small buildings in the sample. Heat pumps were the major source of heat in multifamily buildings and natural gas was the primary source in all other building types.

Figure 18. Heating Fuel Type Distribution, Sample



50 We did not have sufficient data to determine the fuel type for a few buildings and for several terminal units, primarily in multifamily and education buildings. We excluded those units from the analysis, which introduced some uncertainty in the fuel shares for the affected buildings.

We compiled data on the heating system types in each building and totaled the capacity (in Btu-hour) for different building groups. The systems found in the sample buildings included the following:

- Water-source Heat Pump (WSHP): This system uses circulating water as the heat source/heat sink and a heat exchanger transfers heat to/from the water to the system refrigerant. The systems can provide both heated and cooled air by ducts.
- Air-source Heat Pump (ASHP): Same as WSHP but the heat source/sink is the air surrounding the outdoor unit.
- Variable Refrigerant Flow (VRF): VRFs transfer heat (and cooling) via a refrigerant and can provide heating in one zone and cooling in another simultaneously. VRF systems can either be a heat pump system or a heat recovery system
- Split Heat Pump Variable Refrigerant Flow (Split HP VRF): This is a VRF that is served by a heat pump split system.
- Packaged Rooftop Unit (PRTU): This type includes the evaporator and condenser coils in a single enclosure. Heated air is distributed through ducts and can be provided by natural gas or a heat pump.
- Furnace: These are generally smaller systems that provided heated air via ducts. They can be combined with direct expansion cooling systems.
- Boiler: These are usually large, central units that provide heat through fan coils.
- Terminal Reheat: These systems supply heat to ducted air at the delivery point usually through a hot water coil or electric heat strips.

In terms of total installed capacity, boilers provided the most capacity across all sample buildings, followed closely by ASHPs. WSHPs provided the third largest capacity, followed by PRTUs. Small and medium buildings in the sample had a wide variety of heating equipment types as shown in Figure 19. The most common type in small buildings was PRTUs, followed by wall heaters, with ASHPs and VRFs tied for third common. The mix in medium buildings was very different; WSHPs provided the most capacity, followed closely by boilers. Terminal reheat systems were the third most common. Boilers provided the most capacity, by far, in large buildings providing 80% of capacity, driven by their predominance in education buildings.

Figure 19. Primary Heating Equipment Type Capacities by Building Size, Sample

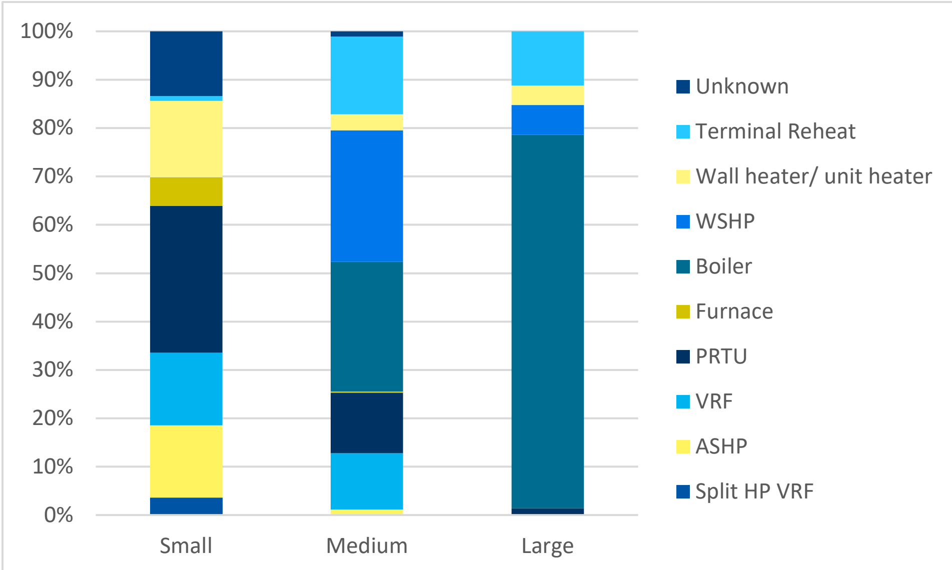
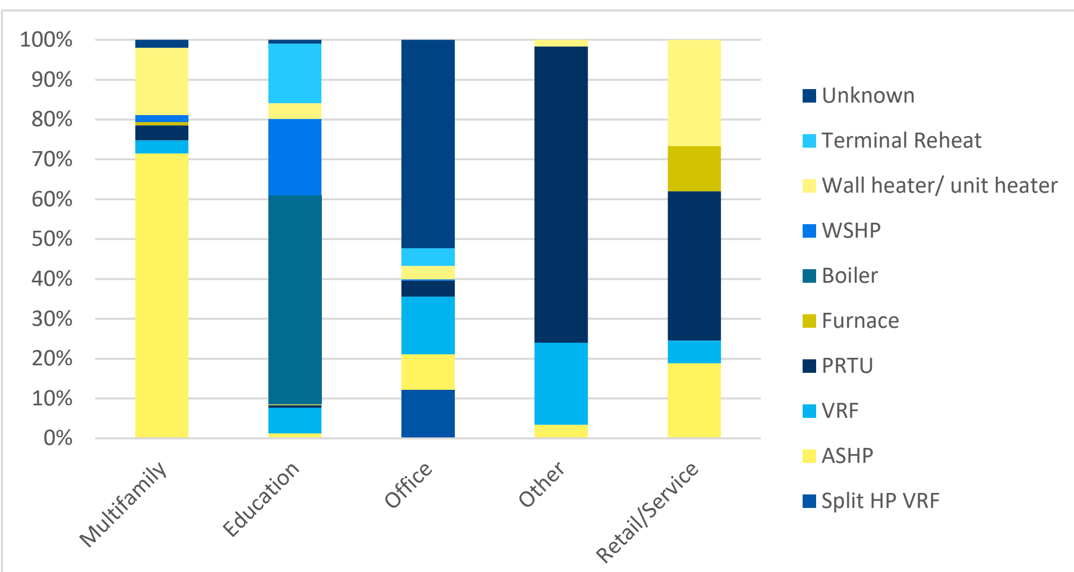


Figure 20 presents the same data by building type. ASHPs were the predominant type in multifamily buildings, followed by wall heaters at 17%. Boilers provided the most capacity in education buildings. PRTUs provided the most capacity in retail/service and other buildings. We were unable to identify the system type for about half the capacity in office buildings; in office buildings where we identified the system type, VRFs and split heat pumps were most common.

Figure 20. Primary Heating Equipment Type Capacities by Building Type, Sample



We collected data on the capacity of each sample building's heating and cooling distribution system; Table 41 presents the results for heating systems. The most common systems in small and large buildings were air handling units (AHUs). These units are prefabricated and consist of fans, heating and/or cooling coils, filters, dampers, and other equipment. They were the most common type in education, retail/service, and other building types. VRFs were common in medium and education buildings. We were unable to determine the unit type in a large share of office buildings, but, in those buildings where the information was available, VRFs were the most common type.

Table 41. Heating Distribution Systems by Building Size and Type, Sample

System Type	Small	Medium	Large	Multi-family	Education	Office	Retail/ Service	Other
AHU (single or multi-zone)*	40%	23%	78%	4%	43%	0%	57%	75%
Hydronic (boiler)	0%	24%	11%	0%	19%	0%	0%	0%
Package Heat Pump	2%	0%	0%	0%	0%	4%	3%	1%
Split Heat Pump	4%	0%	0%	62%	0%	0%	6%	0%
Ductless Heat Pump VRF	4%	0%	0%	0%	0%	13%	0%	0%
Ductless Heat Pump	5%	1%	0%	10%	1%	9%	1%	2%
Ground Source Heat Pump	0%	5%	0%	0%	3%	0%	0%	0%
Water Source Heat Pump	0%	28%	7%	2%	20%	0%	0%	0%
VRF	15%	14%	0%	3%	8%	15%	6%	21%
Zonal Electric	3%	3%	5%	17%	4%	4%	3%	2%
Hydronic Zonal (boiler)	0%	0%	0%	0%	0%	0%	0%	0%
Zonal Unknown Source	13%	1%	0%	0%	1%	0%	23%	0%
Unknown	14%	1%	0%	2%	1%	55%	0%	0%

*Note that AHUs include units with furnaces.

Table 42 presents the shares of cooling capacity provided by different systems across the building sizes and types. AHUs were the most common type in small and large buildings. The table breaks out the AHU capacities into three capacity ranges: for small and retail/service buildings the capacities were mostly less than 65 kBtu-hour and for large buildings they were mostly in the largest capacity range, greater than 240 kBtu-hour. The most common cooling systems in medium buildings were WSHPs. Split system heat pumps were the most common cooling distribution system in multifamily buildings.

Table 42. Cooling Distribution Systems by Building Size and Type, Sample

System Type		Small	Medium	Large	Multi-family	Education	Office	Retail/ Service	Other
AHU (single or multi-zone)	<65kBtuh	30%	7%	1%	2%	1%	0%	45%	36%
	65kBtuh-240kBtuh	11%	9%	16%	0%	11%	0%	22%	25%
	>240kBtuh	0%	8%	58%	0%	37%	0%	0%	0%
Package Heat Pump		4%	0%	0%	0%	0%	10%	5%	2%
Split Heat Pump		11%	0%	0%	73%	0%	0%	11%	7%
Split AC		5%	2%	10%	7%	6%	1%	5%	4%
Split AC VRF		0%	14%	0%	0%	7%	0%	0%	0%
Ductless Heat Pump VRF		7%	1%	0%	0%	1%	37%	0%	0%
Ductless Heat Pump		9%	2%	1%	12%	2%	18%	3%	2%
Water Source Heat Pump		0%	38%	9%	2%	24%	1%	0%	0%
VRF		23%	16%	0%	3%	7%	33%	9%	25%
Ground Source Heat Pump		0%	3%	0%	0%	2%	0%	0%	0%
Chilled Beam		0%	0%	5%	0%	3%	0%	0%	0%

6.2 Equipment Efficiencies

The codes' HVAC system equipment efficiency requirements apply to all buildings regardless of the overall compliance approach used. We reviewed the heating and cooling equipment efficiencies of all systems in every building and compared the values to the code levels. Across the 76 buildings in our sample, we had data on 387 HVAC units. The heating equipment in only two buildings and cooling equipment in one building did not comply with the efficiency requirements. Due to data gaps or inconsistencies in how efficiencies were reported, we could not determine compliance for 19 heating units and 21 cooling units.

Table 43 presents the population-weighted results for heating equipment. Overall statewide compliance was 98%. Noncompliance of heating efficiency occurred in one medium building in rural areas in our sample. Noncomplying systems in one building were only 4% less efficient than the code required.[51]

[51] Noncomplying heating equipment consisted of several water source heat pumps with a COP of 4.1 where the code required a COP of 4.3.

Table 43. Heating System Equipment Efficiency Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	100%	100%	100%
Medium	100%	81%	89%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	100%	96%	98%

Although most natural gas and propane heating systems had equipment efficiencies close to the minimum code levels (78% AFUE or 80% combustion efficiency), almost one-third had efficiencies exceeding 90% AFUE. These units were in a variety of buildings, and this suggested that condensing units are becoming relatively common in commercial buildings.

Table 44 presents the results for cooling systems. Statewide, compliance with cooling equipment efficiency requirements was 98%. The one building in our sample that did not comply had an overall weighted efficiency only about 2% less than the code requirement.[52]

Table 44. Cooling System Equipment Efficiency Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	100%	100%	100%
Medium	77%	100%	90%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	97%	100%	98%

6.3 Fan Power and Speed Modulation

Code Section C403.2.11 specifies requirements for fan horsepower and provides two metrics for demonstrating compliance determined by the air flow rate, nameplate horsepower, and brake horsepower. The requirements apply to all buildings regardless of overall compliance approach. Because we were able to obtain nameplate horsepower more often than brake horsepower, we used this value to assess compliance.

Table 45 presents the compliance rates estimated for the building population. The table shows that no fans in multifamily buildings met the threshold horsepower level that trigger the code requirements. The requirement applied to only one unit in a small building, but we did not have data to determine

52 The noncomplying equipment was a large package HVAC with an EER of 9.8 where code required an EER of 10.8.

compliance. Compliance was less than 30% for medium buildings, and two large schools in rural areas had low compliance.

Table 45. Fan Power Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	N/A	N/A	N/A
Medium	21%	35%	29%
Large	100%	9%	80%
Multifamily	N/A	N/A	N/A
Total	87%	22%	66%

Section C403.2.11.5 of the code specifies single-zone system requirements for variable speed cooling or staged volume fans regardless of the overall compliance approach. Table 46 shows that compliance with this requirement was generally high; however, three of four medium buildings in urban areas had low compliance with the requirement.

Table 46. Modulating Cooling Fan Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	100%	78%	86%
Medium	28%	100%	69%
Large	N/A	100%	100%
Multifamily	100%	N/A	100%
Total	81%	91%	86%

6.4 Economizer and DOAS Requirements

Section C403.3 presents requirements for economizers integrated with the mechanical cooling systems to provide outside air for partial cooling. These requirements do not apply to buildings that complied with the code using the Total Building Performance Path.[53] However, to calculate compliance with the economizer requirement, we assumed that all buildings using the Total Building Performance Path to demonstrate compliance complied with the prescriptive code requirement. This approach was consistent with the compliance analysis of all other prescriptive requirements.

The sampled buildings had 1,235 systems where economizers were required, with a little less than half the total in a single multifamily building. Table 47 shows that compliance with this requirement was low

53 Section C407 requires any building that installs economizers and uses the Total Building Performance Path include the economizers in the standard reference building as well. As noted before, we did not have the resources to thoroughly review all the building simulations so were unable to verify the standard reference building designs included economizers in the three cases they might have been required.

for all building size categories and multifamily buildings. For the total population, compliance was 54%; most of the systems in the multifamily building that had about half the covered systems did not comply.[54] We did not assess compliance in large buildings because their systems were either not required to have economizers or data were not available.

Table 47. Economizer Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	58%	74%	68%
Medium	72%	59%	64%
Large	N/A	N/A	N/A
Multifamily	N/A	<1%	0%
Total	65%	49%	54%

Section C403.6 requires DOAS systems in buildings that use the Prescriptive Path to demonstrate compliance.[55] The compliance rate was almost 100% in all cases where the systems were required. The only exception was in one small urban building; that building used the Total Building Performance Path, which does not require a DOAS, but the compliance documents indicated a DOAS was to be included under option C406.6 and it was not.

Table 48. DOAS Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	86%	100%	95%
Medium	100%	100%	100%
Large	100%	100%	100%
Multifamily	100%	N/A	100%
Total	98%	100%	99%

6.5 HVAC System Controls

Section C403.2.4 specifies the controls required for HVAC systems by building zone. This requirement applies to all buildings regardless of the overall compliance approach selected.

54 Section C403.3 Exception 6 allows units serving Group R occupancies to have no economizers provided the cooling efficiency is 15% better than the code minimum equipment efficiency. For this building, nearly all the package terminal and split system units serving the dwelling units did not meet this requirement and were therefore identified as non-complying.

55 As noted before, this requirement was optional until July 1, 2017. Because of gaps in the permit application date for several projects, we assumed that all projects were permitted after this date and the requirement applied. Given the high compliance rate, this did not bias the findings.

Sampled buildings included a total of nearly 5,000 controls that were primarily programmable thermostats and direct digital controls (DDCs).[56] We did not verify the thermostat settings or DDC programming, but the data showed the controls were present and able to provide the required capability. The number of controls ranged from one to nearly 700 in one large multifamily building.

Table 49 shows that compliance with this requirement was very high overall. Small and medium buildings were the only ones where controls did not meet the code, and noncompliance occurred in isolated cases in those buildings. Although in some buildings data did not allow us to verify the controls requirement was met, this occurred in only about 6% of the cases so the effect on compliance rate accuracy was minimal.

Table 49. HVAC Controls Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	98%	97%	98%
Medium	99%	99%	99%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	100%	99%	99%

56 We checked for controls listed in Sections C403.2.4.1, C4033.2.4.2, C403.2.4.10, C403.2.4.11, and C403.2.4.12. These included thermostatic, off-hour, and DDC controls.

7 Water Heating Systems

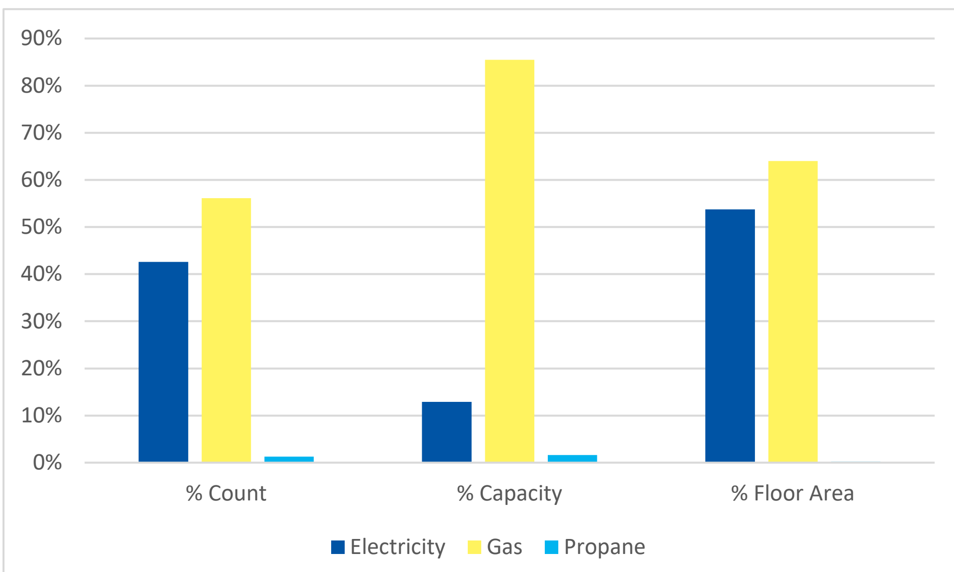
This section presents findings for service water heating systems. We obtained some data on 175 water heating systems in 66 of the 76 buildings in the sample; 10 buildings had no water heating system. Information presented includes these characteristics:

- System fuel types and capacities
- Equipment efficiencies
- Piping insulation.

7.1 Water Heating System Fuel Types and Capacities

Three fuels heated water in the sample buildings: electricity, natural gas, and propane. Figure 21 shows the distribution of fuel types in three ways: percentage by the system count, capacity, and building floor area. In all three cases, natural gas was the predominant fuel, and the distribution was similar for the system count and building floor area, with the natural gas share about ten percentage points more than the electricity share.[57] The distribution by capacity shows that the system capacity (in Btu/hour) provided by natural gas is much larger—almost eight times—than the electricity capacity. The share of capacity provided by propane is only about 2%.

Figure 21. Water Heating Fuel Types, Sample Buildings*



*Percentages can add to more than 100% because some buildings use more than one fuel.

Figure 22 presents the distribution of water heating fuels by building size and building type. The percentages are based on system capacities and demonstrate the predominance of natural gas. However, office buildings differ from the other categories because electricity is the predominant fuel

[57] The floor area distribution is based on assigning the entire floor area to a fuel type if any of a building's water heating systems used that fuel.

type, 52% compared to 48% for natural gas. The only buildings using propane are in the small group, consisting of retail/service and other buildings.

Figure 22. Water Heating System Fuel, Capacity by Building Category, Sample Buildings

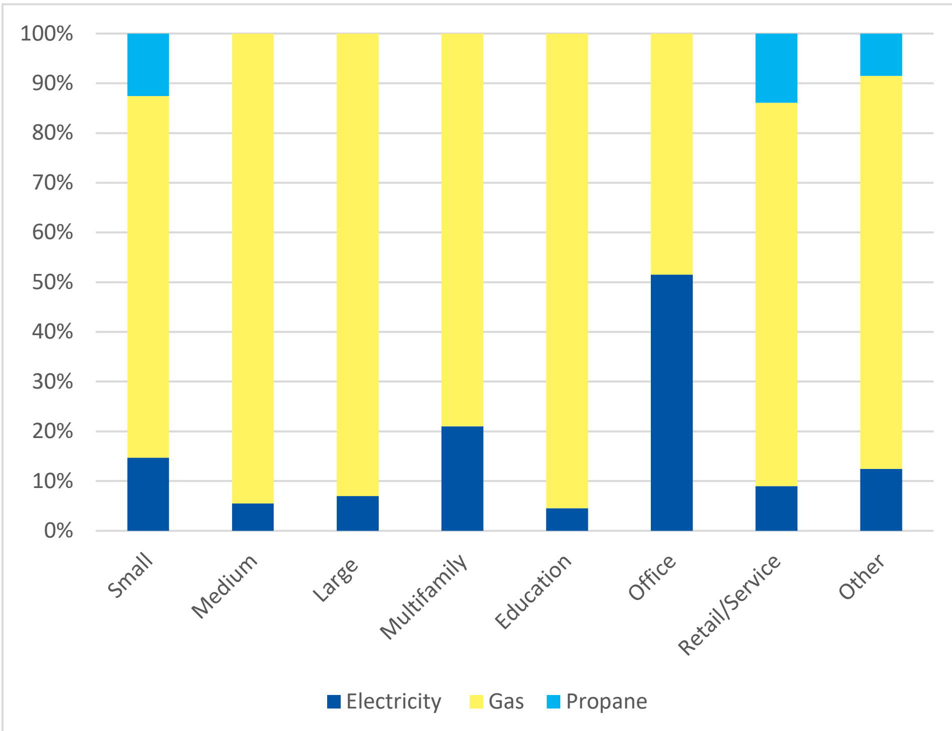
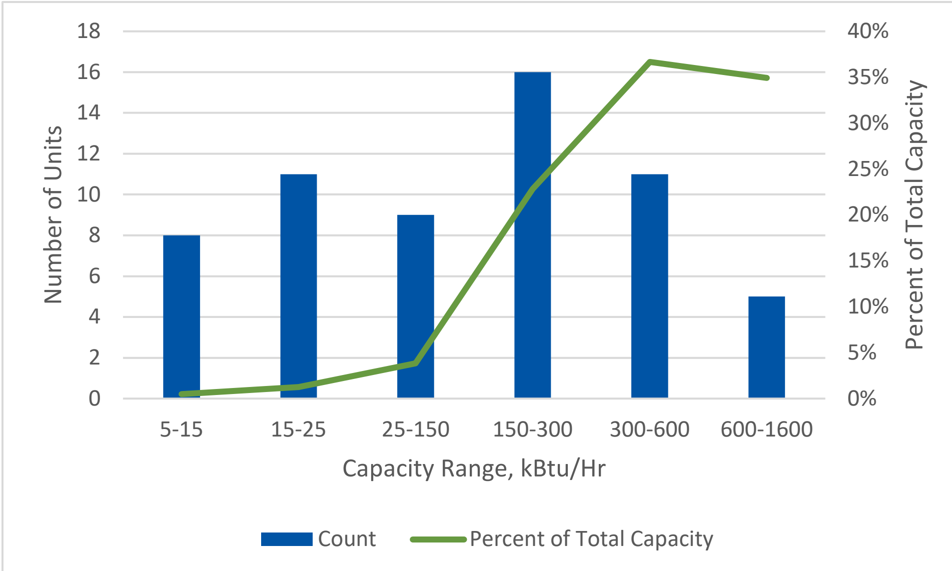


Figure 23 shows the distribution of water heater systems by capacity. Bins used in the figure were chosen to provide a fairly uniform distribution of quantities across the bins. Using the selected bins, 16 units were in the range of 150 to 300 kBtu/hour and 27 were between 5 and 150 kBtu/hour. The median capacity in the sample was 184 kBtu/hour and 16 systems were larger than 300 kBtu/hour. The figure also shows what share of total capacity was in each bin. The largest share of capacity was in the 300-600 kBtu/hour bin and only 5% of combined capacity was in the three bins from 5 to 150 kBtu/hour.

Figure 23. Distribution of Water Heaters by Capacity



We classified 22 systems as on-demand and three units were heat pumps—one small system and two medium size systems.

7.2 Equipment Efficiencies

Section C404 specifies the efficiency requirements for water heating equipment that apply to buildings regardless of the overall compliance method. The water heating equipment in the sample buildings included both residential and commercial units. The federal standards for residential water heaters were effective April 2015 and expressed in terms of the energy factor, EF. Beginning June 12, 2017, EF ratings were replaced with a new industry metric for measuring energy efficiency in water heaters called the Uniform Energy Factor (UEF). The timing and equipment mix complicated determining the appropriate efficiency requirements and documentation indicated that some units were rated with the EF and others with the UEF.

Based on the available data, we concluded the following:

- **All water heating equipment met the building code requirements**
- **Washington commercial buildings have almost universally adopted condensing flue gas heat exchanger technologies**
    - Most gas water heaters exceed the code minimum requirement
    - Out of 64 gas water heaters, only one using natural gas and one using propane had efficiencies less than 92%

7.3 Piping Insulation

In all compliance paths, the codes require the first 8 feet of inlet and outlet piping from the storage tank to be insulated (C404.6) with insulation thickness depending on the pipe size and water temperature.

We recorded whether any insulation was applied to the piping and found good compliance overall as shown in Table 50. Compliance was very high in multifamily buildings, but only about one-fourth of small buildings, including retail/service buildings, complied. Data suggested that small buildings (including many retail/service buildings) had relatively large water heating capacity per square foot, so noncompliance in these buildings could be of concern. One large urban building did not comply, which lowered the overall rate for large buildings.

Table 50. Water Heating Piping Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	26%	28%	27%
Medium	77%	85%	82%
Large	45%	100%	70%
Multifamily	99%	100%	99%
Total	56%	73%	63%

8 Commissioning and C406 Option Findings

8.1 Commissioning Findings

The 2015 codes require commissioning of mechanical, water heating, electrical and lighting, metering, and refrigeration systems (C408.1).[58] There are threshold exceptions to this requirement for each system. During our interviews with the building representatives, we asked whether commissioning had been conducted and, if not, whether it was planned.[59] We also inquired about who performed the commissioning and whether the commissioning report was onsite.

We asked building representatives if commissioning was performed but did not inquire about each system. We used the HVAC capacity thresholds to assess whether commissioning was required (cooling capacity greater than 240 kBtu-hour and heating capacity greater 300 kBtu-hour). [60]

Table 51 shows that commissioning was fully compliant in all but small buildings. Eight small buildings required commissioning and only two were commissioned. Of the six that were not commissioned, three were in the other type category and three were retail/service buildings. On the positive side, seven of the nine buildings that demonstrated code compliance using the Total Building Performance Path were commissioned although not required by code.

Table 51. Commissioning Compliance, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	0%	28%	18%
Medium	100%	100%	100%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	87%	76%	82%

[58] The 2015 WSEC does not require buildings following the Total Building Performance Path to satisfy the commissioning requirement but the SEC does. Unlike for the other code requirements, we exclude buildings outside Seattle that complied under the Total Building Performance Path from the assessment because commissioning refers to a process rather than a technology requirement.

[59] Note that we asked a question about commissioning overall but not about each system.

[60] Whether commissioning is required at all if a single system does not meet the triggering requirement is somewhat ambiguous in the code. The code language regarding this exception states: "*Buildings, or portions thereof, which are exempt from Sections C408.2 through C408.6 may be excluded from the commissioning process*."

8.2 C406 Options Findings

The 2015 WSEC and SEC required that all buildings that comply under the Prescriptive Path include at least two of the following options in addition to the other code requirements:

- More efficient HVAC performance in accordance with Section C406.2.
- Reduced lighting power in accordance with Section C406.3.
- Enhanced lighting controls in accordance with Section C406.4.
- On-site supply of renewable energy in accordance with Section C406.5.
- Provision of a dedicated outdoor air system for certain HVAC equipment in accordance with Section C406.6.
- High-efficiency service water heating in accordance with Section C406.7.
- Enhanced envelope performance in accordance with Section C406.8.
- Reduced air infiltration in accordance with Section C406.9.

We compiled information on which of these options applied to each building during our interviews with building representatives and our review of compliance documents and plans. We found cases where the building did not have to meet this requirement, yet the building documents indicated one or more options had been selected. In some cases, more than the required two options were shown in the documentation. We also encountered many cases of missing data or were unable to confirm which options had been selected, so it proved to be challenging to make an accurate assessment of which options were chosen.

Consequently, we determined the lower and upper bounds on how many buildings met the requirement for at least two options implemented; the lower bound was based on cases where we confirmed from the documentation or site visit that each option was selected and the upper bound was based on an assumption that the option was selected in all cases where we were uncertain whether it was selected.

Table 52 shows how many buildings included each of the options under the tightest criteria (lower bound) and loosest criteria (upper bound). The two-option requirement did not apply to all buildings that complied under the Total Building Performance Path, but consistent with the analysis of other non-mandatory requirements, we assumed that buildings complying under the Total Building Performance Path included the minimum number of C406 options.[61]

[61] There is a requirement in the Total Building Performance Path for buildings to incorporate one or two of these options if the energy performance target is more than 87% of the standard reference design building energy consumption. We did not examine this requirement separately.

Table 52. C406 Option Selections

Condition	Met Two Option Requirement	C406 Option Selection							
		C406.2: Efficient HVAC	C406.3: Reduced LPD	C406.4: Lighting Controls	C406.5: Renew-able Energy	C406.6: DOAS	C406.7: Efficient HW	C406.8: Efficient Envelope	C406.9: Infiltra-tion
Lower Bound	30	10	19	8	4	13	3	6	5
Upper Bound	61	44	54	40	51	49	40	37	33

Under the loosest criteria, 61 buildings (or 87% of the buildings for which we could determine the overall compliance approach) would meet the C406 requirement to include at least two options. Because the criteria were very loose, this would likely overstate the actual compliance level. Under the tightest criteria, only 30 buildings (40%) met the requirement.

We considered the distribution of the C406 options under the lower bound to be more reliable. It indicated that reduced LPD (C406.2) was the most often selected option. The DOAS (C406.7) option and efficient HVAC (C406.2) were the second and third most often selected. After these, efficient lighting controls (C406.4) and efficient envelope (C406.8) were chosen most frequently. The least often selected options were high-efficiency water heating (C406.7) and renewable energy (C406.5).

Finally, we assessed compliance of the building population with the C406 requirements by building size and location, based on the two criteria. Table 53 presents estimates of compliance with the C406 requirements in the population under the strictest interpretation of missing data. Overall, small buildings were the least likely to meet the requirement and had an overall compliance rate of only 34%, but compliance overall was 74%.

Table 53. C406 Compliance, Lower Bound, Population Weighted

Building Category	Location		
	Urban	Rural	State
Small	46%	27%	34%
Medium	75%	75%	75%
Large	100%	51%	89%
Multifamily	70%	100%	83%
Total	84%	59%	74%

Table 54 presents the same results but based on the loosest interpretation of the data. Even with this interpretation a few small and medium buildings were determined to not comply with the requirement. Most notably, 26% of small buildings were still deemed to not comply with the requirement. Given the uncertainties in these data, we reported the average between the lower and upper bound values to assess overall compliance in Table 14.

Table 54. C406 Compliance, Upper Bound, Population Weighted

Building Category	C406 Compliance		
	Urban	Rural	State
Small	79%	71%	74%
Medium	100%	86%	92%
Large	100%	100%	100%
Multifamily	100%	100%	100%
Total	97%	87%	93%

9 Conclusions

This report presents the results of a review of the characteristics of new buildings constructed under the 2015 Washington State Energy Code and Seattle Energy Code based on a statewide sample of 76 buildings. The study's purpose was to provide insights to NEEA and its regional partners about the new commercial building market and how buildings were complying with the codes. The study was planned to provide input to the development process for the Washington 2018 energy codes, but the COVID-19 pandemic disrupted the schedule and delayed the study. Nevertheless, the study provides extensive information about the new commercial building market in Washington, building characteristics, and how this sector responds to the energy code.

This section provides conclusions addressing the following key research questions about new commercial buildings in Washington built under the 2015 energy codes:

- What were primary characteristics of the new commercial building population in Washington?
- What were overall code compliance rates and how did new commercial buildings demonstrate compliance?
- How did compliance vary by building system?
- What code requirements were less difficult and more difficult to meet?
- How did building size and type affect building design and what differences occurred between compliance with the SEC and WSEC?
- What lessons were learned about conducting similar studies in the future?
- What insights did the study provide for future energy codes?

9.1 What Were Characteristics of the Washington Commercial Building Market?

Our sample and sample frame provided the basis for estimating key characteristics of new buildings constructed under the WSEC and SEC as shown in Figure 24.

Figure 24. Key New Building Characteristics

About 4,250 new buildings were permitted under the 2015 codes	• They constituted almost 300 million square feet
Most buildings were small, <25,000 square feet	• But were only 5% of total floor area
Multifamily buildings were the most common type and occupied 43% of total floor area	• Retail/service buildings were second most common, but only 4% of floor area • Office buildings were third most common and 9% of floor area • Education buildings were fourth most common and 5% of floor area
Almost 21% of new buildings were in Seattle	• They represented more than half of new floor area
Almost three-fourths of new floor area had natural gas	• It was least common in small buildings

Construction characteristics varied by building type and size. Figure 25 summarizes information on building assembly materials.

Figure 25. Building Assembly Materials

Above-grade Walls	Below-grade Walls	Roofs	Floors
• Wood walls were most common in small and multifamily • Metal walls were most common in medium and large	• Below-grade walls were almost all concrete	• Wood roofs constituted more than half the roof area in small and large buildings • Metal roofs constituted about 80% of medium building roof areas and about 40% in small and large buildings	• Slabs were predominant floor assembly

Figure 26 presents highlights on the types of lighting and fixtures found in new Washington commercial buildings we sampled.

Figure 26. Lighting and Fixture Types

LEDs provided by far the most interior and exterior lighting power

- LEDs provided more than 99% of interior lighting power
- LEDs provide 98.5% of exterior lighting power
- Occurrences of T8s, CFLs, and incandescent were negligible

LED integrated lighting fixtures were most common interior and exterior fixture type

- Provided 43% of interior lighting power in large and education buildings
- Provided 73% of interior lighting power in small buildings
- Provided 95% of exterior lighting power in offices

LED linear fixtures were second most common

- Provided about 40% of lighting power in medium size and education buildiings

Other LED types were common in multifamily building interiors

Interior occupancy sensor and timer controls were in common use

Exterior timer and light sensitive controls were prevalent

Figure 27 summarizes key characteristics of HVAC systems in the sample buildings.

Figure 27. HVAC Systems Characteristics

Heating fuel

- Buildings used natural gas, propane, and electricity for heating
- Natural gas provided the most heat in medium and large buildings and all building types except multifamily
- Heat pumps provided about 40% of heating in small and medium buildings
- Heat pumps were the main heating type in multifamily buildings

Heating systems

- AHUs were the most common heating distribution systems in small and large buildings and most buildings types
- WSHPs were the most common heating distribution systems in medium buildings

Cooling systems

- AHUs provided most cooling in small, large, and retail/service buildings
- WSHPs were the most common cooling system in medium buildings
- Split system heat pumps were the most common cooling systems in multifamily buildings
- VRFs were very common in office buildings

Key characteristics about water heating included the following:

- **Natural gas water heating equipment was the most common overall.**
  - Gas water heating capacity was eight times the capacity of electric water heating.
  - Electric water heating was slightly more common in office buildings.
  - Propane water heaters were rare.

- **The median capacity was 184 kBtu/hour.**
- **Only three of 175 systems were heat pumps**.

Although 70% of Seattle respondents said they had installed renewable energy systems, many systems appeared to be small. Outside of Seattle, 15% of respondents said they installed renewable generation. About 20% of the buildings in our sample participated in a rating program (such as LEED) or utility energy-efficiency program. About 10% of the buildings included some sustainability features such as green roofs.

9.2 What Were Overall Compliance Rates and How Was Compliance Demonstrated?

Using the binary compliance assessment method applied in this study, we found the following overall compliance rates:

- Statewide population weighted compliance rate**: 85%**
- Sample unweighted compliance rate**: 79%**

Figure 28 presents key conclusions about how buildings demonstrated code compliance.

Figure 28. How Code Compliance Was Demonstrated

The Prescriptive Path was the most popular overall compliance approach

- 86% of buildings in population used this approach
- Multifamily buildings used it most frequently
- Flexibility to have more glazing likely resulted in large buildings using the Total Building Performance Path
- Seattle's unique Target Performance Path was not used by any sample buildings

Envelope compliance was demonstrated most often with the prescriptive approach than the component performance approach

- Two-thirds of buildings in population used the prescriptive approach
- But 64% of multifamily buildings used the envelope component performance approach to gain some compliance flexibility

Lighting most often used buildng area method to demonstrate compliance

- 61% of population used this method

9.3 How Did Compliance Vary by Building Systems?

We assessed system compliance based on the prescriptive code and mandatory requirements. The assessment applied this same method to systems in buildings that complied using the Total Building Performance Path.[62]

The following sections identify the characteristics of major building systems using the most typical approach to comply with the code and then highlight significant variations from the typical approach. In some cases, variations were related to building size, type, or location.

9.3.1 Envelope Compliance

Figure 29 summarizes key conclusions about typical commercial building envelopes and code compliance. The conclusions were based on the area of building envelopes in the population.

Figure 29. Conclusions about Envelope Systems Compliance

Compliance of envelopes was usually demonstrated prescriptively

- Using Total Building Performance Path compliance allowed some buildings to exceed 40% WWR

More than 80% met prescriptive UA requirement

- Walls and roofs usually met component U-factor requirement
- Many buildings traded off less efficient floors for more efficient walls and roofs

80% to 90% of glazing met SHGC and UA requirements, respectively

- Half the buildings had glazing UA more efficient than code by average of 12%
- Windows were usually about 25% of gross wall area

Walls and roofs were usually more efficient than prescriptive requirement

- Floors were often less efficient than prescriptive requirement

Leakage testing requirement was met most often in small buildings

- Compliance declined with building size

We drew additional conclusions about the characteristics of building envelopes from observed patterns in the envelope data and substantial differences noted by building size and other features. The following conclusions provided useful insights into envelope characteristics and how they complied with the code:

- **Large differences occurred in compliance with the prescriptive UA requirement**
  - All multifamily and large urban buildings complied.

[62] We assumed that buildings complying under the Total Building Performance Path complied with the design energy use target and implicitly satisfied the prescriptive requirements; however, we evaluated mandatory requirements that applied to buildings using this path and included them in our findings on those requirements.

    - Medium buildings were less likely to comply than were buildings of other sizes.
    - Education buildings were least likely to meet the UA requirement.
    - Buildings in rural areas were less likely to comply.
- **Multifamily buildings exhibited several unique characteristics**
    - Multifamily buildings used prescriptive envelope compliance most frequently and met the UA requirement most often.
    - Multifamily buildings had the largest window areas.
    - Multifamily buildings rarely had metal wall assemblies and had concrete roof assemblies more often than other buildings.
- **Small and medium buildings were least likely to meet glazing UA and SHGC requirements**
    - Only about half the small buildings complied with SHGC requirement.
- **More efficient envelopes were rarely chosen as a C406 option**
- **Compliance with leakage testing requirement was inversely related to building size**

9.3.2 Lighting

The average installed LPD was less than the average LPD allowed by the code across the three building size categories with the largest efficiency increase in medium buildings (36% reduction over code allowed level). Overall, the average weighted installed LPD was 29% more efficient than the code level. Exterior lighting power was also much less than allowed by the codes.

Although compliant lighting controls were common, interior controls were not compliant in 12% of the population. Exterior controls complied for about 95% of the controlled lighting power.

Figure 30. Conclusions about Lighting Systems Compliance

Building Area Method was used most often to demonstrate interior lighting compliance

- Area method was used in 61% of population

All sampled buildings complied with the code interior lighting power requirement

- Average installed interior LPD was 29% less than the maximum allowed by code

Interior controls

- Compliance with interior lighting control requirements varied from 58% to 100% by building size and location

All but one building complied with the exterior power requirements

- Installed exterior power was between about 40% and 80% less than allowed by code

Code compliance of exterior lighting controls was very high

- 99% of the population complied

The sample buildings provided additional insights about lighting systems and code compliance in commercial buildings. Supplemental conclusions about lighting included the following:

- **The mix of LED fixtures varied by building category**
  - By size, small buildings were most likely to have LED integrated fixtures.
  - By building type, retail/service and buildings in the "other" category were most likely to have LED integrated fixtures.
  - LED linear fixtures were generally the second most common except in multifamily buildings where other LED fixture types were.
- **Space-by-space LPD method was common in certain building categories**
  - 55% of rural buildings used the space-by-space method.
  - 50% of multifamily buildings used the space-by-space method.
- **LPD efficiency margin over code varied by building type**
  - The average LPD in offices was only 8% less than the code allowance.
- **Lighting and controls**
  - Compliance of lighting controls was higher for exterior than interior lighting

9.3.3 HVAC

Figure 31 presents key conclusions from this study about the code compliance of HVAC systems in new Washington commercial buildings.

Figure 31. Conclusions about HVAC Systems Compliance

Heating and cooling equipment compliance with efficiency requirements was over 90%

- 98% of heating systems complied
- 98% of cooling systems complied

Compliance with fan requirements was high where they applied

- Two-thirds of floor area met fan power requirements
- Modulating cooling fan compliance was nearly 90%

Economizer and DOAS compliance differed

- DOAS requirement compliance was nearly 100%
- Overall compliance with economizer requirement was only 50%

Compliance with HVAC controls requirements was nearly 100%

- A few systems in small and medium buildings did not comply

The sampled buildings provided additional insights about HVAC systems and compliance with the 2015 commercial building codes. Further conclusions about HVAC systems included the following:

- **Non-complying heating and cooling efficiencies were only slightly less efficient than the code requirement.**
- **Many buildings were eligible for exceptions to the fan power requirements.**
- **Lack of economizers in multifamily buildings reduced the overall compliance rate.**[63]
  - Two multifamily buildings with hundreds of small air conditioners did not have economizers.

9.3.4 Water Heating

Because it was mandatory, all buildings had to comply with the water heating efficiency requirement regardless of the overall compliance path. The primary conclusions regarding water heating compliance included these:

- **Equipment efficiencies complied overall.**
- **Although overall compliance with piping insulation requirements was high, piping in small and retail/service buildings was often uninsulated and did not comply.**

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63 We note that this conclusion should not be generalized to all multifamily buildings because it was based on only these buildings that had a large number of air conditioners.

9.3.5 Commissioning and C406 Options

Major conclusions regarding compliance with the commissioning and the Section C406 options requirements included the following:

- **In most buildings where commissioning was required it was performed.**
  - **Small buildings were a notable exception** because compliance was very low.
- **Certain C406 options were selected more frequently**
  - **Reduced lighting power** (C406.3) was most common
  - **More efficient HVAC and DOAS** (C406.2, C406.6) were second most common
  - **More efficient water heating (C406.7) and envelope (C406.8) were chosen least often**

9.4 What Code Requirements Were Less Difficult and More Difficult to Meet?

The commercial building design and construction industry is very experienced with energy code requirements and generally knows what equipment and materials are required to satisfy the codes. Both the 2015 IECC and the 2015 WSEC incorporated mostly incremental changes to their precursor codes, so these codes were unlikely to change building design and construction dramatically. Nevertheless, some typical code requirements have been and continue to be challenging to meet and, as the codes introduce new requirements, it is important to get feedback on how this industry responds.

Figure 32 lists several of the more significant changes that occurred in the 2015 IECC, along with additions to the code that were adopted in the WSEC and in the SEC. This study provided insights into the code requirements that were relatively easy for the commercial building industry to meet and some that were more difficult to meet. The study also provided information about how new commercial buildings responded to the 2015 code changes.

Figure 32. Significant Code Requirement Changes

The data collected on sampled buildings across the state suggested that the industry had little difficulty meeting the following code requirements:

- **Roof and wall U-factors.** The codes required some modest increases in envelope efficiency and buildings typically met the requirements through increased roof and wall insulation.
- **Reduced WWR allowances.** Despite the WWR limits in the codes, several buildings were able to increase their window areas by implementing an alternative approach that allowed for more window area; this included using the Total Building Performance Path to demonstrate compliance.
- **Lighting power levels.** More stringent interior lighting power requirements were easily met through widespread adoption of LEDs. Both interior and exterior installed lighting was substantially more efficient than the minimum code requirements.
- **Lighting system controls.** Widespread compliance with occupancy sensor and timer lighting controls and installation not required by code suggested these controls were becoming standard practice in all except small buildings.
- **HVAC efficiency.** The codes referenced the Federal equipment standards that regulate HVAC equipment efficiency so virtually all available equipment met the code. Condensing gas-fired units were about one-third of the heating units.
- **Commissioning.** Compliance with the commissioning requirements was very high in larger buildings.
- **DOAS.** DOAS systems have been integrated into commercial building practices.
- **Water heating efficiency.** Essentially all water heating equipment met the code requirements, likely because of regulation through federal equipment standards. Condensing gas-fired water heaters are industry standard practice.
- **Renewable energy generation.** The sampled Seattle buildings all indicated they had installed renewable energy generation systems, except for three that applied exceptions.[64]

Compliance with some of the code requirements was limited, suggesting that the specific requirements were more difficult to meet. These included the following:

- **Floor U- and F-factors.** Although a majority of building envelopes complied with the overall building prescriptive UA requirement, floors in several buildings were not sufficiently insulated to meet the floor prescriptive U-factor requirement. Although these buildings usually complied with the overall UA requirement, it appeared designers were choosing to increase the efficiency of other components, rather than meet the floor prescriptive requirements; anecdotal evidence suggested that some builders have found slab insulation challenging to install.
- **Glazing performance.** Despite the availability of high-performance glazing, one-fourth of the medium buildings did not meet the glazing UA requirement and half the small buildings did not

[64] The building representatives informed our team during interviews that they included renewable energy generation systems and system characteristics, but we did not conduct a thorough analysis to confirm the systems satisfied the specific requirements of the code.

meet the SHGC requirement. All the medium buildings that did not meet the UA requirement were education buildings.

- **Envelope and glazing UA in education buildings.** Findings for education buildings, especially in rural areas, showed that glazing and the overall envelope UA often did not meet the code prescriptive requirement.
- **Modulating cooling fan:** A large share of fans in medium buildings in urban areas did not meet the variable flow fan requirement.
- **Economizers.** Compliance with the economizer requirements was low across all building sizes.
- **Commissioning.** Commissioning occurred very rarely in small buildings.
- **C406 options.** Even under the most optimistic assumptions, compliance with the two-option requirement was very low in small buildings.
- **Leakage testing.** Even though leakage testing protocols were provided in the code, the leakage testing requirement was not met in several larger buildings.
- **Piping insulation.** Although installing water pipe insulation should not be challenging, it appeared this code requirement was not enforced in a large proportion of small and retail/service buildings.

9.5 How Did Findings Vary by Building Size, Building Type, and Location?

Although the overall sample size was relatively large, groups based on size, type, and location were relatively small, making it difficult to draw statistically significant conclusions about the relationship between these parameters and code compliance. Some relationships between size and building type highighted in Table 5 influenced several findings.

Nevertheless, the analysis suggested the following preliminary findings about differences by building size, type, and location:

- **Smaller window-to-wall ratios:** Small buildings had the smallest average WWR.
- **HVAC system types varied:** Heating and cooling system types varied considerably across building size and type categories.
- **Lower code compliance for smaller buildings:** Compliance with several code requirements tended to be lower for small buildings including fan power, modulating cooling fan, water heater piping insulation, commissioning, and C406 option requirements.
- **Lower code compliance for education buildings:** Education buildings had lower compliance with the prescriptive UA and fenestration U-factor requirements.
- **Lower code compliance in rural areas**: A few specific code requirements demonstrated lower code compliance levels for buildings in rural areas; these included compliance with UA, SHGC, and C406 options requirements.
- **Lower leakage testing compliance:** Large buildings complied less frequently than other buildings with the code leakage testing requirement.

- **Additional lighting controls installed:** Compliance with the interior lighting controls requirements was high for most buildings other than small buildings. In addition, occupancy sensors were often installed even where only a timeclock was required by the code.

9.6 What Lessons Were Learned about Conducting Similar Studies?

Commercial building studies focused on building characteristics and the effects of energy codes across the building population present several challenges. This study's scope was comprehensive—it was not limited to assessing code compliance; it also emphasized characterizing how new commercial buildings statewide were constructed. The study faced the additional challenge of being disrupted by the COVID-19 pandemic. The pandemic made it more difficult to recruit participating buildings and perform data collection, and these effects led to an extended schedule and difficulty maintaining staffing continuity.

Despite these challenges, we offer several suggestions and lessons learned that could inform future studies:

- **Sources of population data**. This study and several predecessors relied on a Dodge Data & Analytics projects database. We also used a database obtained from Construction Monitor (https://www.constructionmonitor.com/) that compiled building permit data and was a very useful complement to the Dodge data. As more building departments move to electronic permit data, they could be a useful source. A significant challenge is removing and/or merging duplicates. Another is that the commercially available databases typically do not provide the permit application date, which is essential for determining the applicable energy code.
- **Sample design**. Based on experiences in prior studies, NEEA chose to use building size as the main sampling parameter. This study's results did show the importance of building size in characterizing building features such as HVAC equipment type and envelope construction. Because some features and code requirements are unique to certain building types, it is also important to capture diverse building types too.
- **Sample selection**. Because the population databases typically did not provide permit application date, we selected buildings for the sample from those for which listed dates (e.g., permit issuance date) were long after the code effective dates. However, that filter was not sufficient, so we tried to confirm permit dates with the building contacts. In many cases, the contact did not know the permit date, and this led to other contacts and more research. Future studies need to be aware of and plan for this eventuality. Building departments would likely be the best source of this information and maybe the services, such as Construction Monitor, could be persuaded to include these dates.
- **Recruiting.** Recruiting buildings has been the most challenging step in this and similar prior studies. We compiled building representatives from the project databases and other sources. Few building representatives were motivated to participate. To encourage participation, we provided a one-time financial incentive, a large monetary financial incentive through a drawing, and a commitment to provide an energy analysis of each building. With these inducements and a dedicated recruiting team, we estimated we were able to recruit about 20% of the buildings we attempted to contact. Near the end of the project, we attempted to recruit buildings through industry organizations, and

this appeared promising, but we could not fully test it. The major lessons from this study were to anticipate this challenge and to have one or two dedicated, skilled recruiters conduct recruiting.

- **Data collection instrument and process**. We based our data collection instrument on one used in a prior study. This project provided the following lessons about data collection:
  - **Tailor data collection instrument to data analysis needs.** The instrument we started with did not document all the data in a structure totally compatible with the analysis needs. Inputs to the instrument need to be as standardized as much as possible to minimize the need for subsequent interpretations. Based on Cadmus' experience, we recommend using a web-based data collection form with a tablet.
  - **Anticipate changes in data collection instrument.** Learning occurred during data collection about data availability, options, etc.; it is important to consider the data collection instrument to be organic and plan for revisions. By aligning the instrument with analysis needs, the revisions should be modest.
  - **Train data collection team thoroughly and educate them on study objectives and analysis needs.** We conducted thorough training for the data collection team. Include training on identify code compliance issues on-site and provide a check-list of items to look out for (which can be implemented in the data collection tool) to determine compliance. It is also important for the data collection team to understand how the data will be used so they can focus their efforts and provide useful feedback on possible changes.
  - **Perform real-time quality control**. We implemented a rigorous QC protocol, but the COVID-19 pandemic disrupted this process, and this led to delays in conducting QC.
  - **Building department data**. We were not able to acquire much data from building departments, however they could provide high quality data in the future. Many building departments are migrating to electronic permitting, and this could be an efficient, quality data source.
  - **Remote data collection**. To continue some data collection when COVID-19 struck, we developed and implemented a remote, "virtual" data collection process. It was very successful and allowed us to complete the majority of site visits we planned. In future studies, this option should be considered. It eliminated travel cost but was not significantly less costly than in-person site visits.[65] Building location, size, and type should be considered before moving forward with a remote site visit. Rural locations may not have strong cellular reception and a reliable connection may be difficult to establish. Very large buildings and building types that may have more complex equipment also may not be ideal for a remote site visit
- **Consider integrating data collection form with database**. For this study, we imported all data from the data collection instruments into a single data table in Excel and then used Excel built-in database

[65] Remote data collection did eliminate travel cost, but for most in-person site visits we were able to use team members located relatively close to the site, so the travel costs typically were not very large. The time required to review, enter, and quality control the data was considerably larger in most cases. For projects where the field data collection team had to travel long distance or fly, the savings from remote data collection could be more substantial.

and analytical functions for each discreet compliance or building characteristic check. This limits some of the analysis capabilities compared to database scripting (e.g., SQL) analysis capabilities. While there were some guidelines, data integrity checks, and constraints in the data collection form used, we recommend that future data collection forms incorporate more complete rules such as datatype and range checks, rigid picklists, etc. as ways to ensure data consistency across all site visits. Additionally, we recommend automating the import of data from the data collection instrument into an existing, pre-designed and constructed database with one-to-one matching of fields in the data collection instrument to fields and tables in the database. Since this study began, Cadmus has implemented an approach like this in other studies.

- **Study design**. Depending on study objectives, we suggest the following study design adjustments:
  - **Focus the study** on those code requirements or building characteristics that are of the most interest because of code or technology changes, potential impacts, or other criteria.
  - **Use simplified compliance metrics** such as unweighted compliance measurements. The unweighted and population adjusted compliance results in this study were similar in most cases; however, when a building had multiple units and a single unit did not comply, the strict binary approach indicated the building did not comply. This result can understate the degree of compliance. We suggest instead basing binary compliance on the count of units across all buildings of the same size or type.
  - **Use an incremental study approach**, producing an early snapshot to provide insights to inform code development, feedback to building departments, and information used to adjust the study approach.

9.7 What Insights Were Provided for Future Codes?

Although COVID-19 limited the final sample size, this study provided a wealth of detailed building information that could inform future code development and implementation. Code development is an incremental process so, even though study completion was delayed, general findings and findings on specific requirements should be useful to future code development activities. The study data also could be useful in commercial building studies in addition to code studies.

Suggestions for areas to pursue in developing future codes include the following:

- **Areas where compliance was high might offer direction for tightening future codes.**
  - Both interior and exterior lighting power requirements in the 2015 codes were met easily in most cases. The 2018 codes tightened requirements for some building types that were consistent with this study's findings.
  - Interior lighting controls that met the code requirements were often installed even when not required by the code. There may be opportunities to expand the requirement for lighting controls, but the issue of only moderate compliance in small buildings needs to be investigated.
  - HVAC and water heating equipment are readily available that are more efficient than code requires. However, federal standards on many types of equipment preempt building codes from requiring higher efficiency. The Section C406 options have provided a way to encourage

adoption of more efficient equipment; it could be useful to explore how to expand the C406 options to promote more use of high efficiency equipment.

- **There may be opportunities to increase savings from water heating systems.**
  - The coverage of the Section C406.7 option could possibly be expanded to include more building types (e.g., retail/service buildings) or provide more credit for higher efficiency equipment.
  - Expanded enforcement of the piping insulation requirement in small buildings could provide additional energy savings.
- **This study could help target research into why certain code requirements were not met by specific building sizes and types.**
  - Education buildings showed low compliance with window and envelope UA.
  - Compliance with leakage testing requirements was low in large buildings.
  - A sizable share of small and medium buildings did not meet glazing UA or SHGC requirements
- **Opportunities to increase compliance may exist in rural, smaller code jurisdictions.**
  - Code compliance in several categories was less in areas classified in this study as rural.
- **Additional ways to increase glazing under the Prescriptive Path might be worth exploring.**
  - The code provides some prescriptive options to exceed current glazing limits, but additional options (such as incremental levels of envelope efficiency) could provide designers more flexibility.
- **Issues limiting the energy efficiency of floors could be investigated.**
  - All floor types tended to be less efficient than the prescriptive code requirements. It could be useful to explore with industry what factors have contributed to limited floor efficiency and identify ways to increase efficiency.
- **Increasing compliance with the commissioning requirement in small buildings and including buildings complying under the Total Building Performance Path in the WSEC could be investigated.**
  - Enforcement of commissioning requirements in small buildings appeared to be limited; the need to clarify or emphasize the requirement could be examined.
  - The costs and benefits of commissioning buildings complying under the Total Building Performance Path could be researched.

In addition to helping develop future codes, this study's findings and data could be useful for other commercial building research. The project's building database provided extensive building characteristics and information on 76 new buildings in Washington. Some of the data were not essential to answer the core research questions or required analysis beyond the study scope but could support other studies. For example, we compiled information on the operating hours of each building that might be useful to define or confirm hours-of-use estimates. Other examples are possible in-depth analysis of daylighting based on a review of collected building plans or detailed analysis of renewable energy systems that building representatives indicated the buildings included. Some of these research areas might require follow-up contacts with the building designers or managers.

Appendix A. Sample Design Work Group Memo

Memorandum

Author: Jennifer Huckett, Shannon Greene, Allen Lee, and Tolga Tutar

Subject: NEEA Washington New Commercial Construction Code Evaluation (WCCE) Study – Sample Design Work Group Memo

Last Update: December 14, 2018

Overview

To better understand the new construction practices and evaluate how the new construction market is affected by the current commercial energy code in Washington, NEEA selected Cadmus to complete the evaluation of the Washington State Energy Code for commercial buildings, the IECC with Washington amendments, effective July 1, 2016. In this evaluation, Cadmus will collect data from a sample of new commercial buildings on the following factors:

- Building characteristics: focused on envelope, mechanical systems, lighting, and service water
- Code pathways and characteristics: corresponding to envelope, mechanical systems, lighting, and service water
- Energy use: normalized total EUI as well as EUI disaggregated by end use

This will not be a compliance checklist study—NEEA is largely focusing efforts on cataloging the characteristics in commercial buildings and understanding compliance pathways, providing direction to its code development and implementation efforts, and sharing results with regional stakeholders to provide guidance in targeting commercial building energy efficiency activities.

In this memo, we describe the population of interest, sampling frame, and sampling plan. We developed these materials through collaboration with the NEEA Sample Design Work Group in two meetings in Fall 2018.

Sample Design Work Group

The primary focus of the Sample Design Work Group was to establish a sample design for collecting data that would meet the study objectives. Cadmus facilitated two meetings with the work group, the first meeting on October 9, 2018, and second meeting on November 14, 2018, which included Bing Liu, Dulane Moran, John Jennings, and Steve Phoutrides, from NEEA and Allen Lee, Jennifer Huckett, and Tolga Tutar from Cadmus. The following points summarize key outcomes that resulted from the meetings:

1. Sample Frame
    - Cadmus will sample commercial buildings from a sample frame that will include all new commercial and new multifamily construction begun after July 1, 2016, in Washington.
    - The final sample frame will exclude the following types of commercial new construction:

        - Commercial Additions[66]
        - Commercial Alterations
        - Warehouses[2]
        - Detached parking structures and garages
        - Large (over 100,000 square feet) hospital buildings
        - Stand-alone data centers
        - Multifamily buildings below four stories above the ground
    - Mixed use buildings will be classified using the NEEA Commercial Building Stock Assessment (CBSA) study formula, i.e., if 75% or more of the floor space is of a single space type, then the building will be defined as that type.
2. Sample Frame Sources
    - Cadmus will use Dodge and Construction Monitor as the primary data sources for the WCCE sample frame.
    - Cadmus will supplement the Dodge and Construction Monitor data with publicly available building department permit data.
    - Cadmus will reach out to building departments in jurisdictions not covered by Construction Monitor data to obtain additional building department permit data.[67] Cadmus expects to complete this process and include all available building department permit data for the State of Washington in the next sample frame update (April 2019).
3. Sample Frame Source Adjustments
    - Square footage is missing from the Dodge, Construction Monitor, and building department permit data for a large share of buildings. Cadmus will provide summaries of the combined data set and sample size targets, treating buildings with missing square footage as eligible for evaluation. Cadmus expects to fill in most of the missing square footage information through the recruitment calls and additional data obtained for the sample frame updates in April 2019 and October 2019.
    - NEEA expressed an interest in obtaining detailed information on how building envelopes comply with the code. Cadmus will conduct both plan review and field inspection to obtain detailed information on building envelope, mechanical, lighting and service water systems. Because recruiting is challenging, Cadmus will visit any building that agrees to a site visit and will use other sources to fill in envelope data if visual observation during field inspection is not feasible. Cadmus will track the source of each data point, i.e., direct observation, building plans, spec sheets, commissioning report, O&M report etc.

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[66] These will be held in reserve. Individual sample points will be considered for inclusion if insufficient buildings are recruited.

[67] In this memo, Cadmus included a summary of the combined building department permit data for Seattle, Spokane and Tacoma which were available on building departments' websites for download.

4. Confidence and Precision

- Accepting that confidence and precision cannot be determined in advance because of factors including those above, Cadmus will work to make the sample design as representative as possible, within the scope of the WCCE. Cadmus will design the sample to align with the study objectives and to reflect the need to collect data that, when analyzed, will provide NEEA and its stakeholders with insights into how commercial new construction practices and characteristics are affected by code, i.e., it will be designed to inform NEEA and regional code activities, rather than develop precise code compliance estimates.

Below, we provide an overview of the sample frame, sample design, and sample size targets. We plan to update this information over the course of the study, as more buildings enter the population and we collect additional data, until the effective code date of the next code cycle of Washington State Energy Code for commercial buildings.

Sample Frame

The population of interest in this evaluation includes newly constructed commercial buildings in Washington that were permitted under the current Washington State Energy Code for commercial buildings that went into effect on July 1, 2016. Cadmus created a sample frame of buildings in the new construction population as of November 2018, from which we will select the first sample of buildings for the evaluation. We relied on multiple data sources, including Dodge Data and Analytics (Dodge data),[68] Construction Monitor data[69], and building department permit data. Table lists our data sources for the sample frame. Note that we will use McKinstry's market data to supplement the sample frame in future samples (planned for April 2019 and October 2019).

Table A-1. Sample Frame Data Sources

Data Set	Description	Use
Dodge Data	Contractor and builder records for each building start; includes address, square footage (limited), building description and building type	Primary sample frame input; contact information
Construction Monitor	Permit data collected in the metropolitan areas in Washington; includes address, square footage (limited), building description and building type	Primary sample frame input; contact information
Building department permit data	Actual permit data; includes address, square footage (limited), building type and permit description	Primary sample frame input; contact information
Developer data	New construction bid opportunity tracking records and client relationships	Supplement primary sample frame input to complete sample frame; enhanced contact information based on working relationships

68 Dodge Data & Analytics website is available at: https://www.construction.com/

69 Construction Monitor The company website is available at: https://www.constructionmonitor.com/

Each data source has specific strengths and limitations. Together, they provide the most comprehensive set of information on new construction in Washington, but gaps do remain. We summarize the limitations and our planned approaches to overcome them in Table .

Table A-2. Sample Frame Data Limitations

Limitations	Cadmus Approach
None of the data sources identify the energy code under which the building was permitted	Cadmus will confirm which energy code applied during recruitment process and the code documentation review process.
Dodge data tend to omit smaller buildings and design-build buildings	Cadmus will use McKinstry to help identify missing design-build buildings through their new construction and commissioning practice areas and Construction Monitor and building department permit data will provide information on smaller buildings
Construction Monitor data tend to omit buildings in areas where less construction occurs	Cadmus will use Dodge data, permit data from building departments, and McKinstry to help identify missing buildings in areas with low construction volume.
Developer data from a single developer may bias the results	McKinstry is involved with the development of new construction in Washington and the developer is expected to provide data on design-build buildings, a portion of the population that is mostly missing from other data sources. Therefore, we expect the McKinstry recruitment to fill a gap that would otherwise exist in our sample, rather than biasing the result. We expect that the portion of McKinstry buildings in our sample will be similar to the portion of McKinstry buildings in the population. As a precaution, Cadmus will finalize assessing code pathways and characteristics after data from all sampled buildings have been collected to determine if post-stratification will be required to correct for possible bias.
Current data is missing square footage for many buildings	Cadmus will include these in the sample frame and determine the building sizes through the recruitment calls and additional data obtained for the sample frame updates in April 2019 and October 2019.

We will update the sample frame at least twice over the course of the study, in April 2019 and in October 2019, using new data from all sources to ensure that buildings completed after the initial sample frame development are included and eligible to be selected in the sample. We will incorporate additional updates as needed to address gaps and issues revealed by recruitment and site visits up to that point.

Stratification and Sample Sizes

A key outcome of the Sample Design Work Group was to define the population stratification boundaries as follows:

- Multifamily buildings
- Small commercial buildings (<25,000 square feet)
- Medium commercial buildings (25,000 to 100,000 square feet)
- Large commercial buildings (>100,000 square feet)

In Table , we provide a summary of the counts of buildings and total square footage of new construction in each stratum (only including buildings with square footage data).

Table A-3. New Construction Building Counts and Square Footage (buildings with square footage data only)

Stratum	Building Counts	% Building Counts	Total SQFT	% SQFT*
Multifamily	227	20%	25,425,164	44%
Small commercial	641	56%	4,689,620	8%
Medium commercial	204	18%	11,657,003	20%
Large commercial	67	6%	15,571,894	27%
Total	**1,139**	**100%**	**57,343,681**	**100%**

*Percent SQFT in rows do not add to 100% because of rounding in individual rows.

In Table , we provide counts of buildings of new construction in each stratum when we count buildings that currently have missing square footage data.[70]

Table A-4. New Construction Building Counts (buildings with and without square footage data)

Stratum	Building Counts	% Building Counts
Multifamily	872	31%
Small commercial	1,387	49%
Medium commercial	439	15%
Large commercial	147	5%
Total	**2,845**	**100%**

The square footage and counts are based on data merged from all sources, with duplicate addresses removed. As we collect data on buildings over the WCCE study period, the counts and square footage will change as additional new commercial construction is introduced to the market. Cadmus will report on these summaries each time we sample and in the final report.

Cadmus recommends the target number of site visits in each stratum in Table . We calculated the targets by allocating the target number of site visits (n=108) to strata based on the proportion of the population in each stratum. We considered distributions from both sources above, i.e., based on data that included square footage and data where square footage was missing, to provide a range in each stratum. To determine the total sample sizes required to meet the target number of site visits, Cadmus assumed that we will recruit about one in twenty buildings, or 5% of buildings that we attempt to contact and that we will complete about 75% of the site visits that we initially recruit (some buildings are likely to drop out after initially agreeing to participate or some other issues might arise that prevent completion of a full site-visit). We applied those rates to the targets to determine the sample sizes.

70 Counts of *multifamily buildings without square footage data* are directly added to the total building count for multifamily stratum in this table. Cadmus assumed that counts of small, medium and large commercial buildings *without square footage data* have a similar distribution as those *with square footage data* and allocated the buildings *without square footage data* proportionally to the strata.

Based on the revised scope agreed to with NEEA in December 2020, we adjusted the site visit targets to reflect a total of 85 site visits in our sample. These revised targets by category are shown in the table.

Table A-5. Sample Size Targets

Stratum	Current Population Size*	% Population	Target Number of Site Visits**	Target Number of Site Visits. REVISED**	Sample Size
Multifamily	227-872	20%-31%	22-33	17-26	560-861
Small Commercial	641-1,387	56%-49%	53-61	42-48	1,369-1,580
Medium Commercial	204-439	18%-15%	17-19	13-15	433-500
Large Commercial	67-147	6%-5%	5-6	4-5	145-168
New Construction Total	**1,139-2,845**	**100%**	**108**	**85**	**2,507-3,109**

*Ranges in the number of buildings are based on considering only buildings with square footage data (smaller number) and considering all data (larger number).
**The total number of site visits is fixed at n=108, and n=8
5 in the revised targets, even though the number of site visits in strata may vary.

- Cadmus will select an initial sample in December 2018 and then two additional samples in April and October 2019.

Sampling

Cadmus will use two methods to select the sample of buildings for recruitment—random sampling and convenience sampling. We recommend using convenience sampling to supplement the random sampling effort because response rates tend to be low among randomly sampled buildings (i.e., number of successful recruitments out of total number of attempts is small). We will leverage the following resources for convenience sampling:

- McKinstry developer contacts to gain additional access into recently completed and upcoming new construction.
- NEEA code stakeholder relationships with new and existing customers in new buildings to gain access to the right contact person.

Although convenience sampling introduces potential bias, it will also reduce the risk that recruitment results in the target number of site visits within the scheduled study period and budget. Further, the degree of potential bias is reduced by the fact that developers and builders associated with McKinstry are building a portion of the new construction in Washington and that they fill a gap that exists in the Dodge data (i.e., design builds). The Sample Design Work Group supports the conclusion that benefits of combining the convenience sample with the random sample outweigh potential drawbacks. We expect the distribution of sampled buildings to be similar to the distribution in the current sample frame, i.e., that:

- The concentration of buildings will be highest in specific counties.
  - King, Snohomish, Pierce, and Spokane counties will have the highest concentrations of commercial new construction.

  - King county will have the highest concentration of multifamily new construction.
- The concentration of buildings will be lowest in the area to the west of the Puget Sound and in counties in northern, central and eastern Washington.
  - Counties to the west of the Puget Sound will include less than 5% of the total new construction population and sample.
  - We currently have no data for multifamily new construction in counties on the Pacific coast, in northeast Washington, or for most of southern Washington—new data from building departments in those regions could reveal new construction there, but we currently do not expect to sample multifamily sites from these regions.
- Figures that show the geographic distribution of buildings in the current sample frame are provided in *Attachment A*.

Sampling Weights

Cadmus will use sampling weights to aggregate data from different strata and calculate overall commercial and multifamily results. We will review the results from buildings recruited through convenience and random sampling to determine if additional stratification and weighting should be used to correct for potential biases. For example, if all buildings recruited through McKinstry are design-build and we do not recruit this type of building through regular recruitment efforts, Cadmus will apply post-stratification to summarize the compliance pathways and compliance metrics for these buildings separately and then combine them with results from the other buildings using weights proportional to the portion of square footage they represent in the population.

Attachment A. Distribution of Small, Medium, and Large New Commercial Buildings in Washington

Figure A-1. New Commercial Building Counts (All Strata)

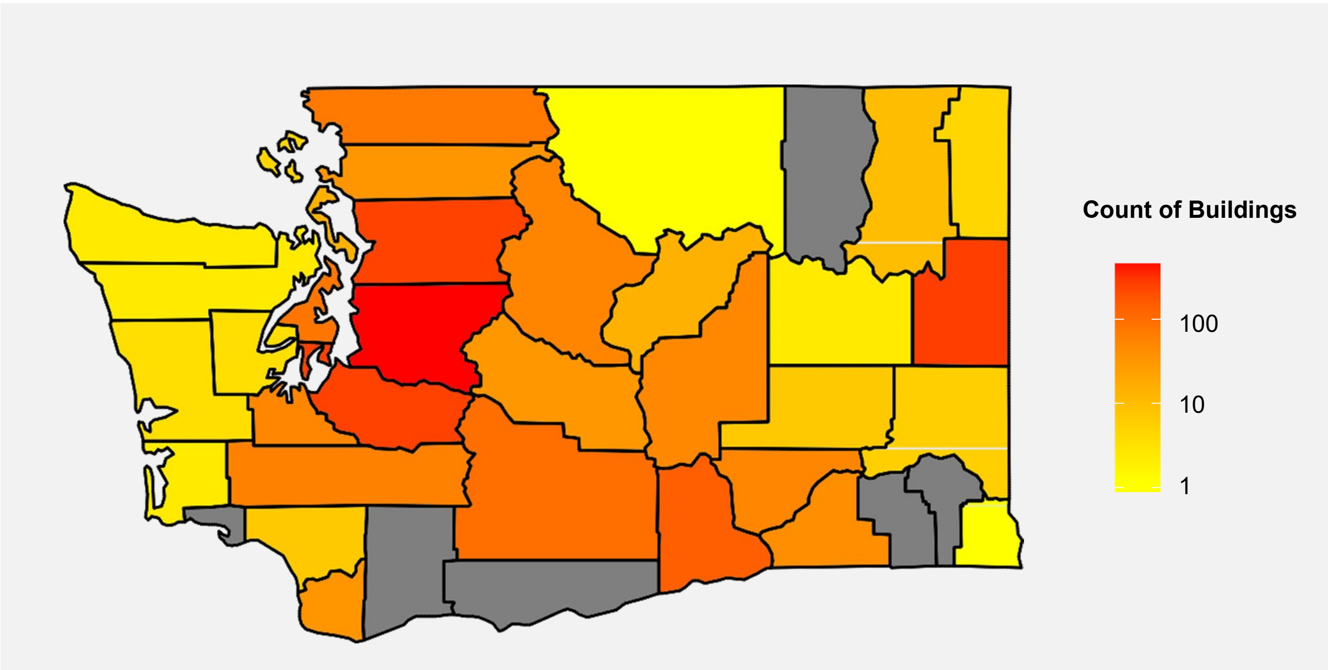


Figure A-2. New Multifamily Building Counts

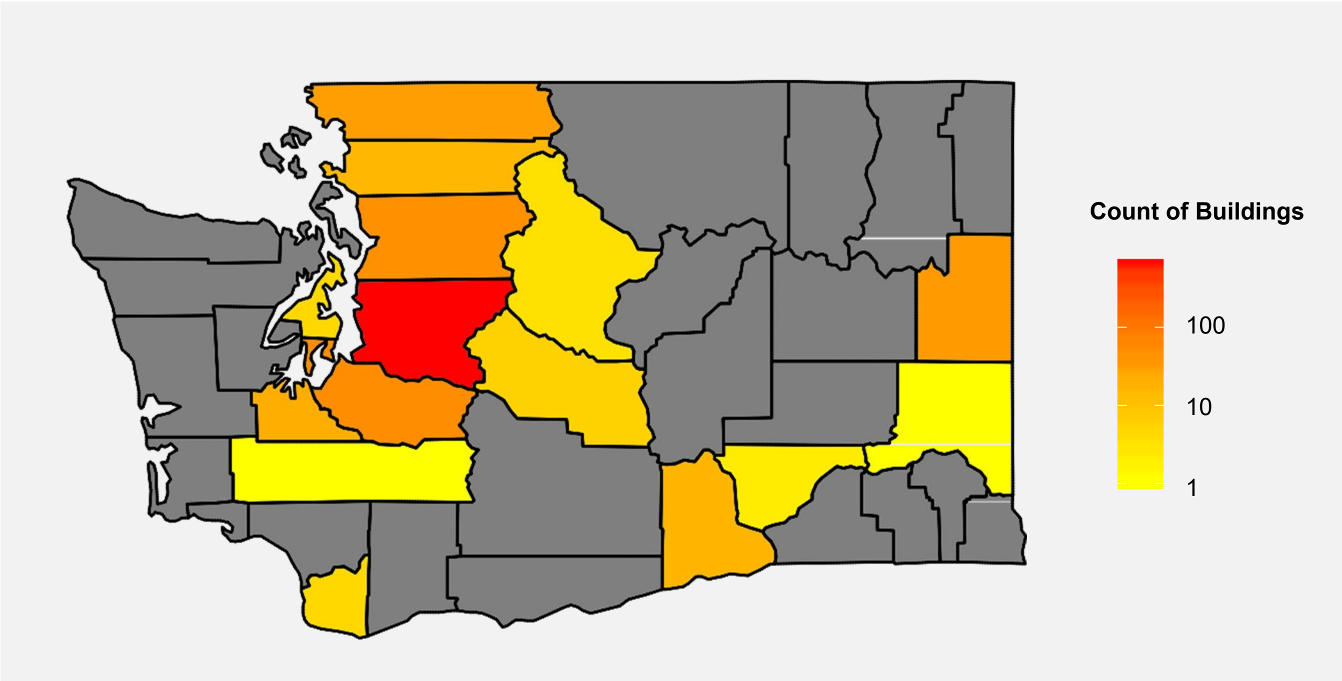


Figure A-3. New Small Commercial Building Counts

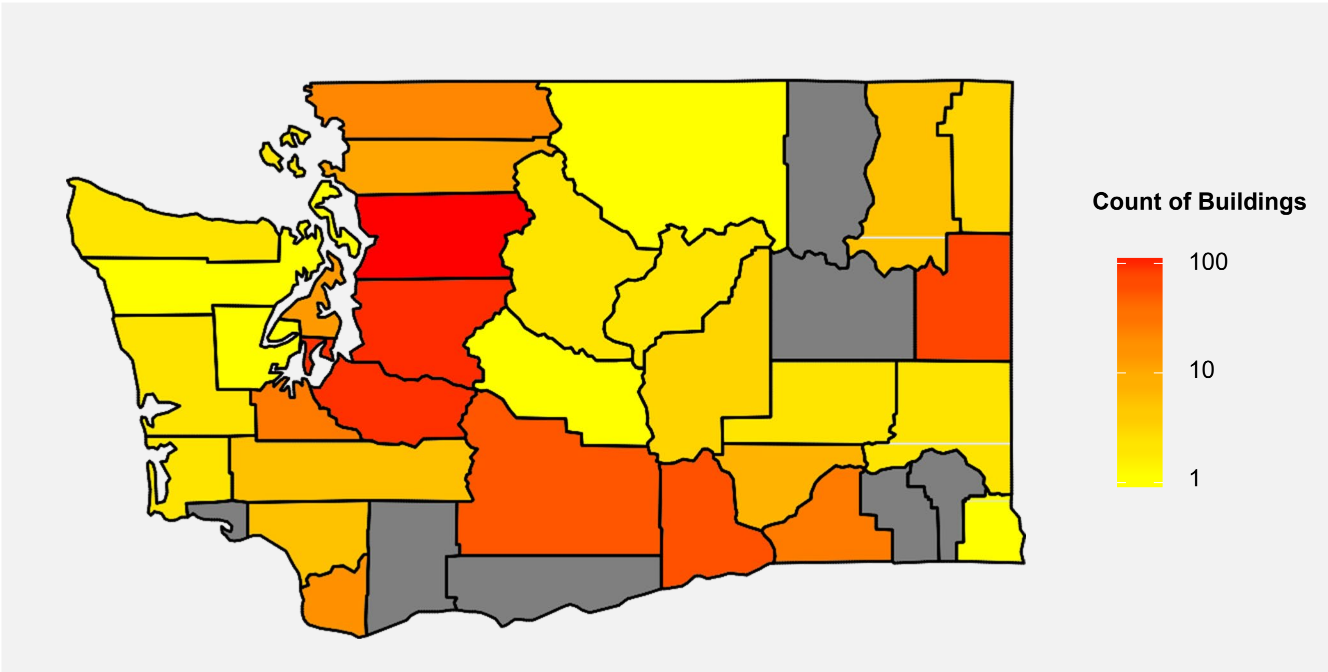


Figure A-4. New Medium Commercial Building Counts

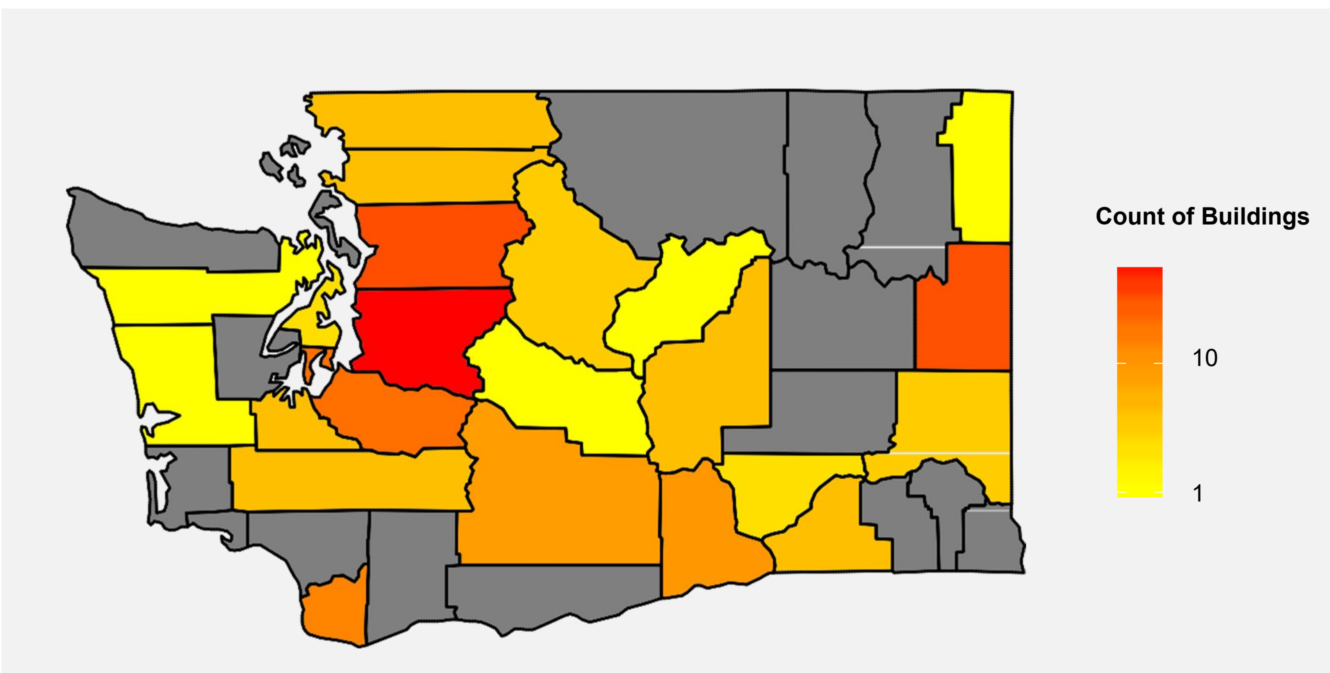
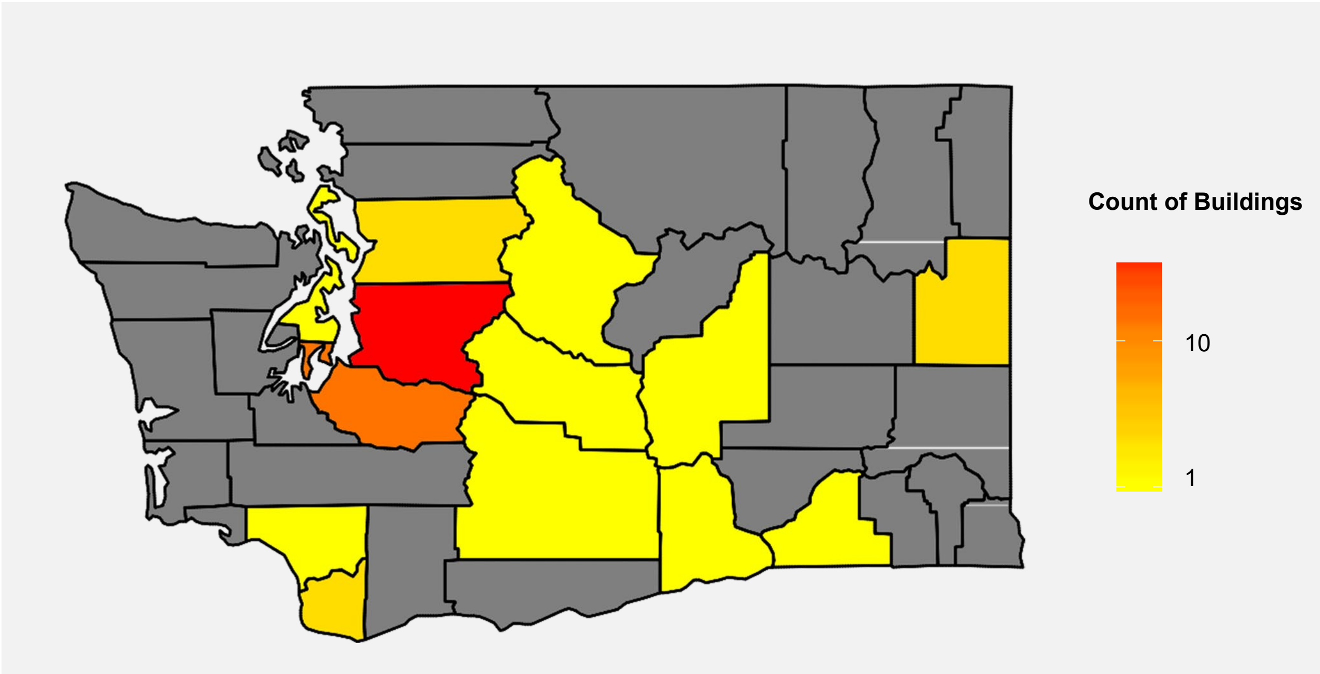


Figure A-5. New Large Commercial Building Counts



Appendix B. Data Collection Work Group Memo

CADMUS

Memorandum

To: Steve Phoutrides, Bing Liu – NEEA

From: Allen Lee, Heidi Javanbakht, Christie Amero – Cadmus

Subject: NEEA Washington Commercial Code Evaluation (WCCE) Study – Response to Stakeholder Comments from the 3^{rd} and 4^{th} Data Collection Work Group Meetings

Date: March 18, 2019

NEEA WCCE Data Collection Work Group held two additional meetings on February 25, 2019 and on March 13, 2019 to review, discuss and finalize the overall objective, sampling approach and building characteristics priorities for WCCE.

3^{rd} Data Collection Work Group Meeting

Data Collection Work Group discussed and finalized the following topics during the 3^{rd} Data Collection Work Group Meeting held on February 25, 2019.

The Objective of WCCE

As Bing described during the meeting on February 25, the objectives of the NEEA WCCE study are different from typical code compliance studies which typically focus on precisely measuring the rates of compliance. Rather than providing a precise estimate of overall code compliance, the study focuses more on compiling qualitative information about how the building industry is responding to the current commercial building energy code. It is intended to provide insights into what paths are selected for code compliance; code requirements that are frequently not being met; and issues such as requirements that are of special interest because they are new or challenging. The early project stages and engagement with stakeholders have presented an opportunity for stakeholders to present their views about priorities for data collection and analysis given the study objectives.

Overall, this study will provide useful qualitative information to NEEA and others that can be used as directional guidance for activities in the future to both improve code effectiveness and code requirements. The types of useful information the study will produce include:

- Code compliance approaches, including options selected
- Building system types
- Requirements that are not being complied with or enforced

Cadmus intends to cross-tabulate the findings by parameters such as building size, building type, compliance path, location (urban vs. rural), and other parameters of interest.

The Sample Frame of WCCE

NEEA decided to develop a building data collection sample design based on building size. The Oregon study (OCCE) targeted building types and sizes, but the study had difficulties recruiting buildings across all types. Consequently, the sample criteria were narrowed down to building size for this study and Cadmus developed a sample plan based on size categories to provide reliable findings. This allowed having a larger sample for the same budget rather than trying to do an in-depth study based on building types.

As a reminder, the population of interest in this study is newly constructed commercial buildings in Washington that were permitted under the current Washington State Energy Code[71] for commercial buildings that went into effect on July 1, 2016. The population stratification boundaries in the sample frame are:

- Multifamily buildings (4+ story multifamily buildings, all sizes)
- Small commercial buildings (<25,000 square feet)
- Medium commercial buildings (25,000 to 100,000 square feet)
- Large commercial buildings (>100,000 square feet)

Cadmus will update the current new construction building counts listed in the Cadmus Clarification Memo[72] in April 2019 and October 2019 when additional sample frame data becomes available to Cadmus. Based on the stakeholder feedback, Cadmus will closely review the sample sizes especially for the multifamily building and large commercial building strata:

- **Multifamily Buildings:** Throughout the sample frame updates, Cadmus will balance the number of multifamily buildings with fewer stories (4-10 stories) vs. high rise multifamily buildings (10+ stories)
- **Large Commercial Buildings:** Per NEEA's request, Cadmus held warehouses as reserve and excluded them in the current new construction building counts. Since warehouses represent a large portion of counts and square footage in WA new construction market, the current eligible new construction building counts listed in the Cadmus Clarification Memo are small for large commercial buildings. If the percentage of the large commercial buildings in the sample does not increase as additional data becomes available in April 2019 and October 2019 sample frame updates, Cadmus will consult with NEEA and stakeholders to determine whether increasing the sample size of the large commercial building stratum would better represent the sample frame.

71 The evaluation will consider the Seattle City Energy code, On-site Renewable, for the sampled buildings located in the city of Seattle.

72 Cadmus. NEEA WCCE Study – Clarification of WCCE Objectives, Data Collection and Analysis Approach. February 12, 2019

Prioritizing Building Characteristics

Based on the stakeholder feedback on February 25, 2019 meeting, Cadmus updated the data collection priorities for **Lighting System** characteristics as shown in the table below.

LIGHTING	Code Characteristics	Key Space and Lighting Characteristics
What to Verify?	• **Compliance Path taken for Lighting** ○ Interior: TCLP building area method ○ Interior: TCLP space-by-space method ○ Exterior: Minimum efficacy and base site LP allowance plus individual area LP allowances • **Were any C406 Lighting Options Chosen** • C406.3 for reduced lighting power • C406.4 for enhanced digital lighting controls	• **Basic Info on Interior Lighting System*** ○ Through plan review and field inspection, identify: ▪ predominant fixture types & technologies (light source type, fixture style, efficacy) ▪ rough percentage of fixture types & technologies • **Detailed Info on Interior Lighting Controls** ○ For a sample of dominant space types within the building, through plan review and field inspection: • verify all types of controls (occupancy, time switch, manual, daylight responsive, or other) • identify what controls were required by the code • if the lighting controls are installed • if the controls function as intended (only if it is feasible not to disturb occupants) • **Detailed Info on Exterior Lighting System** ○ Through plan review; ▪ Verify fixture and lamp types ▪ Verify fixture counts and wattages and calculate LPDs ○ Crosscheck plan review findings through field inspection (if it complies with Cadmus safety requirements. If the exterior lighting covers a large area, only for a sample of dominant exterior space and zone types) • **Basic Info on Exterior Lighting Controls** ○ Through plan review, identify: ▪ predominant exterior lighting control types & technologies ▪ Rough percentage of exterior lighting control types & technologies • **Lighting Commissioning** ○ Verify if commissioning was completed
Data Sources	• Lighting code compliance forms and supporting documentation • Energy Modeling reports • On-site Interview	• full lighting plans and fixture cut sheets • Invoices, product labels, or spec sheets if available • O&M or submittal cut sheets • Electrical as-built or construction drawings • Commissioning documentation
Data Collection Protocol	• Collect copies of relevant documentation from site contacts if available • Note key data on data collection form	• Collect copies of relevant documentation such as full lighting plans and fixture cut sheets from site contacts if available • Note key data on data collection form • Collect photos of predominant fixture types & technologies • Collect photos of predominant lighting controls

* Cadmus will not collect fixture counts or wattage data for interior lighting as stakeholders indicated they are not interested in interior LPDs. Lighting drawings and other supporting documentation will be collected as planned to support any potential future studies on LPDs.

4th Data Collection Work Group Meeting

Data Collection Work Group discussed and finalized the following topics during the 4th Data Collection Work Group Meeting held on March 13, 2019. Based on the stakeholder feedback during the meeting, Cadmus updated the data collection priorities for **HVAC and Domestic Hot Water System**, **Envelope**, **Other** and **Building Level** characteristics as shown in the tables below.

Prioritizing Building Characteristics

HVAC & DHW	Code Characteristics	Key Equipment and Controls Characteristics

What to Verify?	• **HVAC and DHW Compliance Path**
	  ○ Prescriptive
	  ○ Total Building Performance
	• **Were any C406 HVAC or DHW Options Chosen**
	  ○ C406.2 for more efficient HVAC performance
	  ○ C406.6 for a dedicated outdoor air system for certain HVAC equipment
	  ○ C406.7 for high-efficiency service water heating
	• **Was the project required by code to use DOAS? Did the project use DOAS?**
		• **Whole System Type and System Controls**
		  ○ Verify system type and system control type per building space it serves
		  ○ Verify sequence of controls
		• **HVAC and DHW Equipment Sizing and Equipment Efficiency**
		  ○ Airflow rates
		  ○ Unit types and fuel types
		  ○ Unit quantities
		  ○ Unit make and model number
		  ○ Unit heating/cooling capacity
		  ○ Unit heating/cooling performance
		  ○ Motor horsepower and efficiency
		  ○ Space or zone type served by equipment
		  ○ Operating hours
		  ○ Note any exceptions
		  ○ Verify equipment quantities, make/model number onsite for a sample of equipment
		• **HVAC Controls**
		  ○ Verify onsite for a sample of systems
		  ○ Types of controls
		    ▪ BMS or thermostat occupied/ unoccupied space temperature setpoints
		    ▪ Fan speed controls
		      ○ What is the fan speed when heating and cooling are not required (on, off, or % volume)?
		      ○ What is the fan speed during low cooling (on, % volume)?
		    ▪ Economizer and heat recovery use
		  ○ Auto setback and shutdown
		• **HVAC Commissioning (Cx)**
		  ○ Verify if Cx is done?
		  ○ Understand if all of the issues listed in the Cx report are resolved through on-site interview
		• **DHW Circulating and Temperature Maintenance Controls**
		  ○ Verify onsite for a sample of systems
		• **Domestic Water Pressure Booster Systems**
		  ○ Only for high rise buildings check presence/absence and how they are controlled

Data Sources	• HVAC code compliance documentation • On-site Interview	• Full mechanical and plumbing as-built or construction plans • Commissioning reports • Invoices, product labels or spec sheets • Field inspection • On-site interview

Data Collection Protocol	• Collect copies of relevant documentation and conduct plan review
	• Verify plan review findings during on-site visit:
	  ○ If it is a large office, retail or multifamily building with several tenants and time on site is a constraint, focus on-site time in the main mechanical room(s), rooftop, and control rooms
	  ○ In addition, only for a sample of occupied tenant spaces (check vacant tenant spaces if relevant and as accessible) verify terminal units and other in-tenant mechanical systems and controls as accessible
	• Conduct on-site interview with relevant contacts
	• Note key data on data collection form
	• Collect photos of sampled unit ID (e.g. "RTU-2"), manufacturer and model number
	• Collect photos of sampled controls (BMS or thermostat setpoints, fan speed controls, economizer and heat recovery use)	

ENVELOPE	**Code Characteristics**	**Key Envelope Characteristics**

What to Verify?	• **Envelope Compliance Path**
	  ○ Prescriptive
	  ○ Component Performance
	  ○ Total building performance
	• **Was air barrier testing performed per C402.5.1.2**
	If so, what is the actual tested leakage rate and error band?
	• ***Check if building complies with the Minimum Skylight Fenestration Area (C402.4.2)***
		• **Assembly Type, R-value/U-factor and Area for Envelope Components**
		  ○ Roof
		  ○ Above-grade wall
		  ○ Floor
		  ○ Below-grade wall
		• **Specific Details for CMU Walls**
		  ○ The amount of CMU wall as a fraction of the total wall area
		  ○ Details of insulation/finishing applied to CMU walls (core-fill, finished or not, which type of fill, masonry on both sides, etc.)
		• **Assembly Type, Area, U-Factor & SHGC for Fenestration**
		  ○ Windows
		  ○ Skylights
		  ○ Doors
		• **Building Window-to-wall ratio (WWR)**
		  ○ Strategy used to comply when WWR is >30%
		  ○ Whether 25% of the net floor area is in a daylight zone or served by DOAS option

Data Sources	• Envelope code compliance documentation • Building enclosure test results • On-site Interview	• Full envelope as-built or construction plans • National Fenestration Rating Council (NFRC) certificates • Invoices, spec sheets • On-site interview
Data Collection Protocol	• Collect copies of relevant documentation and conduct plan review • Conduct on-site interview with relevant contacts • Note key data on data collection form • Collect photos of facades and fenestration	

OTHER		Code Characteristics	Key Characteristics
Energy Metering	**What to Verify?**	• **Whether energy metering is required** – though it is required for all compliance paths in Washington and Seattle, there are many exceptions	**Fuel types metered** • Verify each energy source is separately metered, including district energy and site-generated renewable energy **End use metering** • WA: Verify HVAC and water heating are separately metered • Seattle: Verify HVAC, water heating, lighting, plug loads, process loads, and tenants are separately metered **Metering system commissioning** • Verify commissioning was completed
	Data Sources	• Metering code compliance documentation • On-site Interview	• Invoice, product label, or spec sheet if available • Field Inspection • Commissioning documentation
	Data Collection Protocol	• Collect copies of relevant documentation from site contacts if available • Note key data on data collection form	• Verify metering system onsite • Verify metering system is operational and commissioning was completed • Collect photos of metering system and displays if possible

On-site Renewable Energy	**What to Verify?**	• **Washington provides an option under C406 for renewable energy**
		• **Seattle Compliance Path**
		  ○ Prescriptive requires PV or SWH and a solar zone
		  ○ Total Building Performance requires solar readiness
		  ○ Was an alternate chosen
		    ○ HVAC equipment is 10% more efficient
		    ○ Heat recovery
		    ○ Envelope UA value is 15% more efficient
			• System type
			• System nameplate capacity
			• For Seattle, if no renewable system was installed, verify the solar zone
			• Note any exceptions such as excessive shading

	Data Sources	• Renewable energy code compliance documentation • On-site interview	• System Invoice, product label, or spec sheet if available • SWH system ratings: Solar Rating and Certification Corporation (SRCC) • PV module ratings: California Energy Commission solar equipment list
	Data Collection Protocol	• Collect copies of relevant documentation from site contacts if available • Note key data on data collection form	• Verify system type and capacity onsite • Verify system is operational • Verify space allocated for solar readiness or that the solar zone was not required • Collect photos of system
Plug Load Controls	**What to Verify?**	• **A portion of controlled receptacles were installed (C405.10)**	• Are occupancy sensors installed? • Are occupancy sensors used or not? • Verify occupant satisfaction with occupancy sensors via on-site interview

	Data Sources	• Full envelope as-built or construction plans • On-site interview	
	Data Collection Protocol	• Collect copies of relevant documentation and conduct plan review • Conduct on-site interview with relevant contacts • Note key data on data collection form • Collect photos of plug load controls	
Refrigeration	**What to Verify?**	• **Do refrigeration systems meet key criteria outlined in C410.2 and C410.3?**	**Refrigeration System Sizing** • Unit types • Unit quantities • Unit make and model number • Unit cooling capacity • Unit cooling performance • Motor horsepower and efficiency • Note any exceptions
	Data Sources	• As-built plans • Field Inspection • Collect photos	
	Data Collection Protocol	• Collect copies of relevant documentation and conduct plan review • Note key data on data collection form	

BUILDING LEVEL	**Code Characteristics**	**Key Project Level Characteristics**
What to Verify?	• **General Compliance Path taken** ○ Prescriptive/Component Performance ○ Total Building Performance • **Were additional efficiency package options chosen per C406** ○ C406.8 Enhanced envelope performance ○ C406.9 Reduced air infiltration ○ C406.5 On-site renewable energy ○ C406.2 More efficient HVAC equipment ○ C406.6 Dedicated outside air systems (DOAS) ○ C406.7 Reduced energy use in service water heating ○ C406.3 Reduced lighting power ○ C406.4 Enhanced digital lighting controls	• Building description and basics • Building operations summary • Project floor area and stories • Occupancy type • Whole Building Commissioning ○ For each building system, verify if performed by an 3rd party, by owner, by design team or did the general contractor or mechanical contractor have someone on staff provided the commissioning?
Data Sources	• Code compliance documentation	• As-built plans • Field Inspection • Collect photos
Data Collection Protocol	• Collect copies of relevant documentation from site contacts if available • Note key data on data collection form	• Collect copies of relevant documentation from site contacts if available • Note key data on data collection form • Photos of building façade

Appendix C. Reporting Work Group Memo

CADMUS

Memorandum

To: Steve Phoutrides, NEEA

From: Allen Lee; Cadmus

Subject: Washington Commercial Code Project Analysis and Reporting Approach

Date: January 26, 2021

Introduction

As discussed at the February 25, 2019, meeting of the Data Collection Work Group, the objectives of the NEEA WCCE study are different from those of typical code compliance studies that are intended to precisely measure code compliance rates. Instead, this study focuses more on compiling qualitative information about how the building industry is responding to the 2015 commercial building energy code in Washington. It is intended to provide insights into what paths are selected for code compliance; code requirements that are frequently not being met; and issues such as requirements that are of special interest because they are new or challenging. These objectives have guided our data collection process and will provide the basis for analyzing the building data collected during the project.

This document presents our proposed data analysis approaches for review by NEEA and the Data Analysis and Reporting Work Group. Based on comments from these entities, Cadmus will revise the proposed data analysis and reporting approaches as needed. We acknowledge that the analysis and reporting approaches may evolve moderately as the data collection process continues and we gain a more complete understanding of how buildings are being constructed under the code.

The analyses described here are based upon the final data analysis approach presented in Cadmus' revised statement of work in contract amendment 3 (approved April 2, 2020), the February 25 Data Collection Work Group memo, the approach used by Ecotope in their Washington pilot study,[73] the approach used in the Ecotope report on Oregon commercial buildings,[74] and what we have learned to date from the data collected on a sample of buildings. This approach also reflects the discussions during the Data Analysis and Reporting Work Group meeting held on October 19, 2020.

Starting in late-February 2020, data collection through building site visits was suspended due to the COVID-19 pandemic. Since March, we have continued recruitment, at a reduced level, and developed and implemented a virtual (remote) data collection process to collect building data. COVID-19 has disrupted the data collection process considerably so our original data collection schedule cannot be met. Cadmus has worked with NEEA to amend our original plan, including extending data collection into mid-2021 and reducing the total sample from 108 to 85 buildings. Other than reducing the sample size,

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[73] Ecotope. 2016. *Commercial Code Evaluation Pilot Study Final Report.* Report E16-329, prepared for Northwest Energy Efficiency Alliance.

[74] Ecotope. 2019. *2019 Oregon New Commercial Construction Code Evaluation Study.* Report E19-392, prepared for Northwest Energy Efficiency Alliance.

the basic analysis approach described in this document is unaffected; however, we will monitor progress closely and will reexamine the scope and schedule at the end of February 2021.

The data collection and analysis approach for this study is structured around four building systems: envelope, lighting, HVAC, and hot water (DHW). This memo consists of the following 10 sections: Database and Analysis Method, Presentation of Results, Building and Code Compliance Characterization, Envelope Analyses, Lighting Analyses, HVAC Analyses, Other Requirements, Billing Data Analysis, and Reporting. This memo presents several tables to illustrate the results that we propose presenting; the report will present a mixture of graphics and tables that best display the study results.

Overview

In response to the guidance provided in the Data Collection Work Group meeting, the analysis will present a mix of qualitative and quantitative results. The qualitative results capture primarily the paths chosen to comply with the code and the main project characteristics, based on interviews with key personnel. The quantitative results are mostly building characteristics, such as floor area, the proportions of buildings with certain equipment or characteristics, and the proportions that comply with specific code requirements.

The data collection sampling approach was designed to compile data primarily based on building size categories (conditioned floor area). The target sample sizes by category are shown in Table . During the first meeting of the Data Analysis and Reporting Group, Cadmus received feedback that the group members would like to see an emphasis on a diversity of buildings. Cadmus had already adjusted the sampling process to ensure that a variety of building types is included in the sample and will continue this throughout the remaining data collection. The table shows the original targets based on a total sample size of 108 buildings and the revised targets based on a sample of 85 buildings.

Table C-1. Sample Size Targets

Stratum	Floor Area, Sq.Ft.	% Population	Population Size	Target Number of Site Visits**	Target Number of Site Visits. REVISED**
Multifamily	Mix of mid- and high-rise***	52%	1,094	22-33	17-26
Small Commercial*	<25,000	33%	1,427	53-61	42-48
Medium Commercial*	25,000 – 100,000	12%	513	17-19	13-15
Large Commercial*	>100,000	4%	173	5-6	4-5
New Construction Total	**-**	**100%**	**3,207**	**108**	**85**

* Population sizes within strata are estimated because some buildings are missing square footage data. Cadmus assumed that square footage data was missing randomly such that the distribution of buildings with unknown square footage across the floor area bins followed that of the buildings with known square footage. One caveat for this assumption is that the square footage data was missing for buildings that were only included in the Spokane and Seattle building permit data. However, most buildings in Seattle and Spokane came from the Construction Monitor and Dodge data and contributed to the distribution of buildings across size categories assumed for the population.

**The total number of site visits is fixed at n=85 even though the number of site visits in strata may vary.

***Mid-rise multifamily building are defined as those from 4 to 7 stories; high-rise buildings are higher than 7 stories.

In most cases, our analysis will present results disaggregated by building size and type categories. We also will often report results disaggregated by region—Seattle and non-Seattle areas—because the Seattle code requirements differ in some ways from the state code requirements. For purposes of discussion, this memo indicates the basic disaggregations we propose for each finding. We welcome feedback from NEEA and the work group on the proposed disaggregations.

As agreed during the Data Collection Work Group process, we will identify code requirements that are frequently not being met and will present results for code requirements identified as of special interest because they are new or challenging. The analysis will examine relationships between these code requirements and other parameters such as building size and correlations with other building characteristics.

Our planned primary data collection relied on a review of all available documents such as design drawings, permit application data, and physical site visits to sampled buildings. Prior to site visits, our data collection team reviewed all the project documentation and recorded all available information. For the building envelope, our data collection relied on drawings only except in those cases where construction details were available on site. We refer to the data collected as as-built information, which we then compared to code requirements.

As noted above, when COVID-19 struck in Washington in March 2020, data collection stopped. During the hiatus, Cadmus investigated options for collecting data via virtual site visits that enlisted the help of facility staff to verify code characteristics through live video transmissions. We identified an effective tool for doing these visits and tested and then employed it on selected sites. As of the writing of this memo, we have conducted several virtual site visits using this technique and have received approval to begin physical site visits in selected areas. The site visit disruption and the shift to virtual visits has affected the type and quality of data collected and may constrain the analyses. The ultimate effect is unknown, however, but we will work closely with NEEA to maximize the quality of data collected and minimize negative effects on the analyses.

Database and Analysis Method

We are transferring data for all building data collection forms to a single Excel workbook for analysis. The workbook includes reference code requirements for each building characteristic so that many compliance determinations can be automated and other calculations can be performed readily. Cadmus will make a version this workbook that excludes site identification information available to NEEA during the course of the project and at the end of the study.

Presentation of Results

The population of interest in this evaluation includes newly constructed commercial buildings in Washington that were permitted under the 2015 Washington State Energy Code (effective July 1, 2016) and Seattle energy code (effective January 1, 2017). Cadmus created an initial sample frame of buildings in the new construction population as of November 2018, from which to select the first sample of buildings for the evaluation. We relied on multiple data sources, including Dodge Data and Analytics

(Dodge data),[75] Construction Monitor data[76], and building department permit data. We updated the sample frame twice over the course of the study, in April 2019 and in October 2019, using new data from all sources to ensure that buildings completed after the initial sample frame development were included and eligible to be selected in the sample. Table lists our data sources for the sample frame.

Each data source had specific strengths and limitations. Together, they provided the most comprehensive set of information on new construction in Washington. However, gaps in the population information remained. We summarize the limitations and our planned approaches to overcome them in Table C-3.

Table C-2. Sample Frame Data Sources

Data Set	Description	Use
Dodge Data	Contractor and builder records for each building start; includes address, square footage (limited), project description and building type	Primary sample frame input; contact information
Construction Monitor	Permit data collected in the metropolitan areas in Washington; includes address, square footage (limited), project description and building type	Primary sample frame input; contact information
Building department permit data (Seattle, Spokane, and Tacoma)	Actual permit data; includes address, square footage (limited), building type and permit description	Primary sample frame input
McKinstry developer data	New construction bid opportunity tracking records and client relationships	Supplement primary sample frame input to complete sample frame; enhanced contact information based on working relationships

Table C-3. Sample Frame Data Limitations

Limitations	Cadmus Approach
None of the data sources identify the energy code under which the building was permitted	Cadmus will confirm which energy code applied during recruitment process and the code documentation review process.
Dodge data tend to omit smaller buildings and design-build buildings	Cadmus will use McKinstry to help identify missing design-build buildings through their new construction and commissioning practice areas and Construction Monitor and building department permit data will provide information on smaller buildings
Construction Monitor data tend to omit buildings in areas where less construction occurs	Cadmus will use Dodge data, permit data from building departments, and McKinstry to help identify missing buildings in areas with low construction volume.
Current data is missing square footage for many buildings	Cadmus will include these in the sample frame and determine the building sizes through the recruitment calls and additional data obtained for the sample frame updates in April 2019 and October 2019.

Cadmus sampled buildings randomly to the extent possible within the study and market constraints from the sample frame for recruitment from each size category. We deviated slightly from this approach

75 Dodge Data & Analytics website is available at: https://www.construction.com/

76 Construction Monitor The company website is available at: https://www.constructionmonitor.com/

by including buildings with unknown square footage in the sample frame and allocating them to the appropriate size category once the recruitment was completed and we gathered the information from the site contact.

Cadmus notes that issues of missing square footage and difficulties recruiting eligible buildings will affect the accuracy of estimates of study parameters for the new commercial building population constructed under the 2015 Washington and Seattle energy codes, such as compliance rates. When presenting population values estimated from the study sample of buildings, we will calculate sample weights for each sampled building to adjust for any inherent bias in the types of buildings ultimately selected into the study sample. Weights will be based on the estimated population sizes and the number of sampled buildings in each size category and in other groupings of interest, such as by urban and rural buildings or for Seattle vs. the rest of the state, as these dimensions are known for the population of buildings. We anticipate limitations in the accuracy of population estimates to be fairly uniform across building categories so should not substantially reduce the validity of observations about patterns and comparisons across size categories and other categorizations of interest.

We will report code compliance using a binary method similar to the approach used in the 2016 Ecotope report cited earlier. That approach identifies several key code requirements for each of the four building systems and uses the prescriptive code as the reference for evaluating whether each requirement was met in a building. If any one of the requirements is unmet, the system is deemed to not comply with the code. If any system in a building does not comply using this definition, then the building is deemed to not comply with the code. To report findings from this study, we propose a modest variation on this method. We will calculate a percentage compliance level for each system based on what share of requirements is met and the building compliance value is calculated as the average of these system values. Within each system, we will account for the relative effects of components (such as the effect of walls versus roofs in the envelope efficiency) but will not account for the impacts across the systems. This will likely provide a compliance estimate that is more representative of the overall building performance and compliance with code requirements, since it removes the bias towards zero compliance if a single requirement is not met. We note that this approach was adopted at the beginning of the project and will not produce results that are directly applicable to estimating code-to-code energy impacts. However, we anticipate the database generated by this project will be very robust and provide extensive raw data to use in such analyses.

We propose to use the prescriptive code requirements to assess compliance of all buildings. For the envelope, we will assess compliance based on the overall UA value calculation. We will include the options required in section C406 in the analysis. For buildings that comply using the performance approach, we will consider measures compliant if the building complies overall, even if individual measures do not meet the prescriptive requirements and we will document these observations.

Building and Code Compliance Characterization

We will analyze and present high-level building and code compliance characteristics data. These data will include:

- Proportion of buildings by size category—small, medium, large
- Proportion of buildings by building type, including multifamily
- Distribution of buildings by urban and rural areas
- Share of buildings complying with the code
- Proportion of buildings complying using the prescriptive/component performance or total building performance method
- Proportion of prescriptive-compliance buildings selecting each C406 option

We will report results for the buildings in our sample and will provide population estimates for most of these parameters. In some cases, it will not be practical to provide population estimates. For example, our sample will likely have too few buildings of a specific type to support an accurate population estimate for that type.

Table shows that the main categorization parameter is building size. We will also present the information with building type as the main parameter. The building type categories will be defined once we have collected the data; the categories shown in the following tables, as well as other tables and figures in this document, are illustrative. these two tables are likely categories but not inclusive.

We propose to report findings for the sample and, where feasible, estimated for the building population. When we report population values, we will use the calculated building weights to derive the population estimates. Table shows how we propose to present findings for the items above for the building sample, as well as aggregated to the population level. Table shows the same information for selections of the C406 options.

Table indicates which of these characteristics we will compare between buildings in Seattle and the remainder of the state. Table shows the same information for selections of the C406 options.

Table C-4. Building and Code Characteristics, Sample and Population Estimates

Building Category	Building Type	Compliance	Location		Compliance Approach		Average Floor Area, sq.ft.
			Rural	Urban	Prescriptive/ Comp. Perf.	Total Building Perf.	
Small	Office % Education % Other %	%	%	%	%	%	
Medium	Office % Education % Other %	%	%	%	%	%	
Large	Office % Education % Other %	%	%	%	%	%	
Multifamily	%	%	%	%	%	%	
All	Office % Education % Multifamily % Other %	%	%	%	%	%	
Population Estimate	All	%	%	%	%	%	

Table C-5. Building and Code Characteristics, Sample and Population Estimates

Building Category	Building Type	C406 Option Selection							
		Efficient HVAC	LPD	Lighting Controls	Renewable Energy	DOAS	Efficient HW	Efficient Envelope	Infiltration
Small	Type 1	%	%	%	%	%	%	%	%
	Type 2	%	%	%	%	%	%	%	%
	Type 3	%	%	%	%	%	%	%	%
Medium	Type 1	%	%	%	%	%	%	%	%
	Type 2	%	%	%	%	%	%	%	%
	Type 3	%	%	%	%	%	%	%	%
Large	Type 1	%	%	%	%	%	%	%	%
	Type 2	%	%	%	%	%	%	%	%
	Type 3	%	%	%	%	%	%	%	%
Multifamily	Mid-Rise	%	%	%	%	%	%	%	%
	High-rise	%	%	%	%	%	%	%	%
All	All	%	%	%	%	%	%	%	%

Table C-6. Seattle vs. Non-Seattle Building and Code Characteristics

Building Category	Building Type	Compliance	Compliance Approach		Average Floor Area, sq.ft.
			Prescriptive/ Comp. Perf.	Total Building Perf.	
Seattle	Office % Education % Other %	%	%	%	
Rest of WA	Office % Education % Other %	%	%	%	

Table C-7. Seattle vs. Non-Seattle Building and Code Characteristics

Building Category	Building Type	C406 Option Selection							
		Efficient HVAC	LPD	Lighting Controls	Renewable Energy	DOAS	Efficient HW	Efficient Envelope	Infiltration
Seattle	Type 1	%	%	%	%	%	%	%	%
	Type 2	%	%	%	%	%	%	%	%
	Type 3	%	%	%	%	%	%	%	%
Rest of State	Type 1	%	%	%	%	%	%	%	%
	Type 2	%	%	%	%	%	%	%	%
	Type 3	%	%	%	%	%	%	%	%

Envelope Analyses

Results for the envelope will include the compliance path, assembly type for each envelope component, component average performance factors (U-, F-, or C-factor), and average performance factor required by code. The average values reported will be for the specific building category across all buildings in that category. We also will calculate the average U-factor for the envelope and compare it to the code-maximum allowable U-factor (including target area adjustments).

We will report the results for the population of commercial buildings and by building size category and selectively by building type. Small sample sizes will limit the precision of the estimates by building size. The compliance paths will be compared between Seattle and the rest of the state. The results presented also will include the average window-to-wall area ratio (WWR), the percentage of buildings and building floor area for which the WWR exceeds 30%, and the distribution of approaches for offsetting the increased WWR if necessary.

Table illustrates how part of the envelope results will be presented. The table shows the distribution of compliance options by envelope component across the building size categories. C401.3 is the target performance path approach, which is available in Seattle only. C402.1.3 uses prescriptive component R-values; C402.1.4 uses prescriptive U-, C-, and F-factors; and C402.1.5 is the component performance UA tradeoff approach. Table also presents the distribution of different assembly types for the envelope components. Our data collection form, modeled on one previously used by NEEA, can collect data on up to four assembly types.

Table C-8. Envelope Assembly Type and Compliance Path

Building Category	Compliance Path	Wall Assembly, Above Grade	Wall Assembly, Below Grade	Roof Assembly	Floor Assembly
Small	C401.3 % C402.1.3/C402.1.4 % C402.1.5 % C407 %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Slab %
Medium	C401.3 % C402.1.3/C402.1.4 % C402.1.5 % C407 %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Slab %
Large	C401.3 % C402.1.3/C402.1.4 % C402.1.5 % C407 %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Slab %
Multifamily	C401.3 % C402.1.3/C402.1.4 % C402.1.5 % C407 %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Slab %
All	C401.3 % C402.1.3/C402.1.4 % C402.1.5 % C407 %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Other %	Metal % Wood % Slab %

Table summarizes additional envelope results. It presents the average performance factors for opaque envelope components by building size category as-built and the value required by code. As noted earlier, we will rely on construction documents and supporting information from site visits to provide the data. This analysis accounts for exceptions required to meet the window-to-wall ratio requirement and timing of the code requirements. We will not adjust for construction quality.

Table C-9. Envelope As-built and Prescriptive Code Performance Factors

Building Category	Wall, Above Grade U-factor		Wall, Below Grade F-factor		Roof U-factor		Floor U-factor		Slab F-factor	
	As-built	Code	As-built	Code	As-built	Code	As-built	Code	As-built	Code
Small										
Medium										
Large										
Multifamily										
All										

Figure C-1 summarizes information on the building envelope thermal performance comparing the average envelope overall U-factor of the as-built (proposed) building to the required value to meet the code. Proposed values less than the code value correspond to buildings that complied with the code. We will report the results by building size and type.

Of the 36 buildings analyzed to date, 15 had average U-factors exceeding the value required by code, most by only a small amount but several by 30% or more. For comparison, 13 of 46 buildings analyzed in the Oregon study by Ecotope had building U-factors that exceeded the strict code requirement. We note that we made conservative assumptions when data were missing; for example, in the cases when there was lack of clarity in the description of an assembly type, such as whether the glazing is operable or where the wall construction type was listed as “unknown,” we assumed the most stringent baseline and the associated code requirement.

We note that the Data Collection Work Group did not identify window performance characteristics as one of the features to report on in this study. We collected window characteristics including frame type, SHGC, and U-factors. However, when we did not have detailed information (such as whether the window was operable) we used conservative code requirements to assess compliance. We will use the observed window characteristics to calculate overall envelope thermal performance but have not planned to report window characteristics separately. These data, as well as all other data collected, will be provided in the study database for possible future analysis by NEEA.

Figure C-1. Building U-Factor Comparison by Building

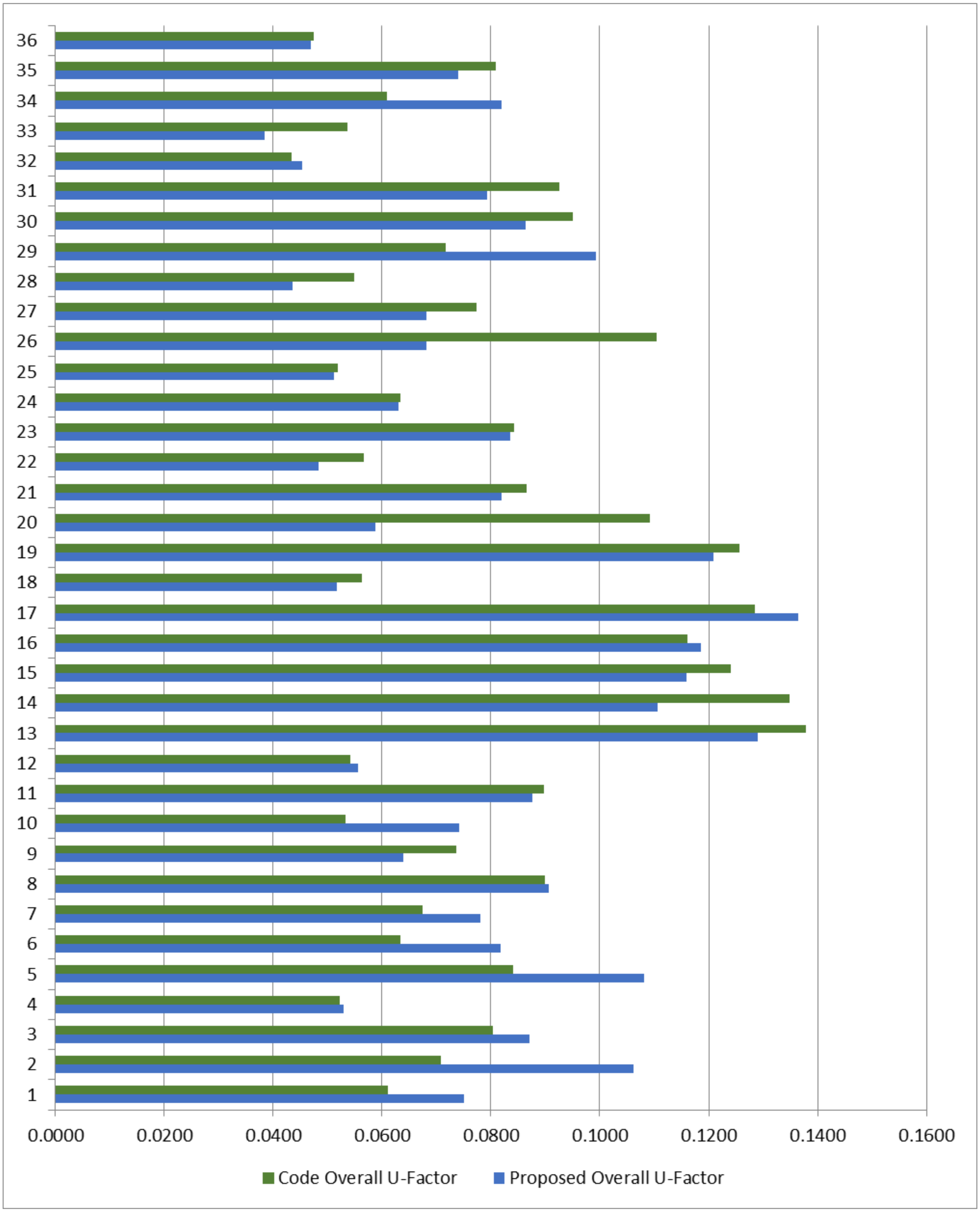


Table shows for each building size category the average window-to-wall ratio (WWR) as a percentage (for the first 33 buildings studied). It also shows what share of buildings in each category exceed the 30% WWR threshold by the percentage of buildings and percentage of floor area in that category. For each category, the table summarizes what share of buildings exceeding 30% WWR in each category used different methods to compensate for the excess glazing under the code. The final report will include all strategies used to comply with the WWR threshold requirement.

Table C-10. Window-Wall Ratio Findings

Building Category	Average WWR, %	% Greater than 30%		Compliance Strategies
		% Buildings	% Floor Area	
Small	18%	4%	0.4%	None
Medium	28%	17%	12%	Target area adjustment
Large	27%	0%	0%	
Multifamily	37%	100%	100%	Target area adjustment
All	21%	9%	20%	

One glazing requirement relates to the minimum skylight fenestration area (C402.4.2). We will report on compliance with this requirement. Out of the first 33 buildings reviewed only one had a skylight.

We will summarize information collected on air leakage requirements. In our experience to date, however, information on compliance with air leakage requirements is very limited in compliance documents and we will report this as a finding if it holds up in the sample.

Lighting Analyses

One outcome of the Data Collection Work Group process was a consensus that lighting results should be deemphasized. This reflected the opinions and observations of the Group regarding lighting equipment and trends. The Group's guidance was to minimize the emphasis on lighting power density (LPD) analysis given expectations that both interior and exterior lighting was likely to be primarily LEDs and code compliant. Instead of LPD, the analysis was to focus on:

- shares of lighting following different compliance paths
- proportion of projects that chose options C406.3 (reduced lighting power) and C406.4 (enhanced lighting controls)
- interior lighting power fixture and control types
- exterior lighting power levels, fixture types, and controls

Our data collection to date has shown expectations about the lighting types installed were correct: nearly every lamp or fixture is an LED. There is consensus among the work group that buildings with all or nearly all LED fixtures will likely comply with the LPD requirement. We will record the lighting types but will not conduct detailed analyses of LPDs. However, we will document the reported LPDs and whether they meet the code requirement. We will highlight any cases where lighting does not meet code and will look for patterns if any exist. The group also expected that lighting controls were likely to comply so we will summarize information on controls but not conduct detailed analyses. Table C-11. Lighting Results summarizes the lighting system results we propose presenting.

Interior lighting power compliance can be demonstrated using either the building area or space-by-space method. We will present the percentage of buildings using the building area method to demonstrate compliance. For buildings that comply with the code overall using the C407 total building performance method, the interior lighting requirements appear to vary between the Seattle and state codes. We will report the lighting results for buildings that comply via C407 if the data are available. Our results will include the share of buildings in the different size categories that meet the interior lighting LPD and interior lighting controls requirements.

We are collecting data on exterior lighting too and virtually all exterior lighting we have recorded so far is LEDs and would meet the code requirements. Verifying compliance of exterior lighting requires fairly detailed calculations and we will perform these calculations when sufficient data are available. We have found that LED lighting is very common, so exterior lighting usually meets existing code requirements., . We are collecting exterior lighting controls data and observations to date also indicate that appropriate lighting controls are being installed in most projects.

We also will determine the shares of buildings that comply with the code using option C406.3 (reduced LPD) and C406.4 (advanced controls). We note that 20% of the first 33 buildings analyzed used both of these options to demonstrate compliance.

Table C-11. Lighting Results

Location	% Interior Lighting using Building Area Method	Compliant Interior Lighting				Compliant Interior Lighting Controls				Compliant Exterior Lighting	Compliant Exterior Controls
		Small	Med	Large	Multi-family	Small	Med	Large	Multi-family		
Seattle	%	%	%	%	%	%	%	%	%	%	%
Rest of State	%	%	%	%	%	%	%	%	%	%	%
State	%	%	%	%	%	%	%	%	%	%	%

HVAC Analyses

The HVAC analyses will identify the share of buildings following different compliance paths and will compare the results for Seattle and non-Seattle jurisdictions. We will report other system information such as the:

- proportion of system types and fuel types
- shares of different control types
- proportion with automatic setback and shutdown controls.

Compliance results will include what share of equipment met efficiency standards, the share with a DOAS installed if required, and the share with economizers when they were required.

Our analysis will base the shares on the total number of units and capacity in each building and all buildings in the category of interest. We also will report what proportion of projects included the C406.2 (higher efficiency HVAC and fan equipment) or C406.6 (DOAS presence) options.

Table illustrates the information that will be presented on the heating equipment types. It shows the split between heating fuel and system types. The types are categorized in the same way they were in the 2019 Ecotope Oregon code report cited earlier.

Table C-12. Heating System Results

Building Category	Heating Fuel		Heating System Type							
	Electric	Fossil Fuel	Mini/Multi-Split HP	PRTU	PTHP/PTAC	Boiler	Wall/Unit Heater	Furnace	WSHP	ASHP
Small	%	%	%	%	%	%	%	%	%	%
Medium	%	%	%	%	%	%	%	%	%	%
Large	%	%	%	%	%	%	%	%	%	%
Multifamily	%	%	%	%	%	%	%	%	%	%
All	%	%	%	%	%	%	%	%	%	%

Table and Table , respectively, summarize key heating and cooling distribution system type results by building size category. The systems are categorized the same way they were in the 2019 Ecotope report. Additional detail will be provided on the type of reheat.

Table C-13. Key Heating Distribution System Results

Building Category	Heating System Distribution Type									
	Zonal Electric Resistance	Single-zone Ducted	VRF	Two/Four Pipe	Hydronic	Minisplit	VAV with reheat	Multi-zone VAV	WSHP	Other
Small	%	%	%	%	%	%	%	%	%	%
Medium	%	%	%	%	%	%	%	%	%	%
Large	%	%	%	%	%	%	%	%	%	%
Multifamily	%	%	%	%	%	%	%	%	%	%
All	%	%	%	%	%	%	%	%	%	%

Table C-14. Key Cooling Distribution System Results

Building Category	Cooling System Distribution Type							
	Zonal	Single-zone Ducted	VRF	Two/Four Pipe	Minisplit	Multi-zone VAV	WSHP	Other
Small	%		%	%			%	%
Medium	%		%	%			%	%
Large	%		%	%			%	%
Multifamily	%		%	%			%	%
All	%		%	%			%	%

Table presents a summary of HVAC controls data that will be presented.

Table C-15. Key HVAC System Controls

Building Category	BMS	Thermostat with Setback	Simple Thermostat	Other
Small	%	%	%	%
Medium	%	%	%	%
Large	%	%	%	%
Multifamily	%	%	%	%
All	%	%	%	%

We propose quantifying HVAC system compliance through a combination of code requirements. Table C-16 shows the requirements we propose to use to determine the degree of compliance; the overall compliance percentage will be based on the proportion of requirements met by the sampled buildings.

Table C-16. HVAC Compliance

Building Category	Overall Compliance	Fan Speed Controls	Heating Efficiency	Cooling Efficiency	Economizer Requirement	DOAS Requirement	Heat Recovery Requirement
Small	%	%	%	%	%	%	%
Medium	%	%	%	%	%	%	%
Large	%	%	%	%	%	%	%
Multifamily	%	%	%	%	%	%	%
All	%	%	%	%	%	%	%

Service Water Heating System Analyses

For service water heating, we will document system types and determine compliance with the code efficiency, flow control, and pipe insulation requirements. Of the first 31 buildings studied to date, we have data on 13 have service water systems. Results comparing central and distributed systems will be presented.

Other Requirements

Other code requirements that will be assessed include:

- Energy metering
- Renewables
- Plug load controls
- Refrigeration

So far, information on energy metering is not very complete and this requirement will be difficult to assess. Of the first 31 projects reviewed, three have included photovoltaic generation to satisfy the code requirement. Data on plug load controls is difficult to collect; we have verified load controls in seven of 31 buildings to date and will note for all buildings whether we could not determine whether controls were present and whether they were not but were required by code. For buildings with refrigeration equipment, our team has found limited information. Condenser fan data have been limited as has information on motor horsepower.

Performance Path Compliance

Of the first 31 buildings studied, three demonstrated compliance using the performance path approach (C407). None of these buildings were in Seattle.

Billing Data Analysis

Cadmus has been obtaining signed forms from the site contacts to allow us to collect all available billing data for each site and put it in the format required for FirstView. FirstView is an NBI software tool that estimates end-use energy consumption for commercial buildings based on the billing data. We will obtain at least 12 months of the most recent billing data available. Our plan was to get permission from building contacts to obtain billing data for all buildings for which we conducted site visits. Only 49 building representatives provided permission to obtain the billing data as of November 2021.

NBI will analyze the billing data to provide the standardized whole-building EUI for each building. We will compare the results for each building and groups of buildings to various benchmarks, the whole-building zEPI score (a score that indicates relative performance compared to a zero-net energy building) and end-use energy consumption. We will explore the EUI estimates from FirstView with the compliance results for each building to explore relationships between the degree of compliance and energy use.

Generating a meaningful estimate of building energy use requires accounting for non-routine events that could have affected energy use. The COVID-19 pandemic started affecting buildings in February 2020 and our plan was to analyze one-year of billing data in 2021. This non-routine event has greatly disrupted the energy use of the buildings included in our study, and an accurate estimate of “typical” energy use will have to wait until a year has passed after this event has no longer affected energy use. At this point, we cannot predict when that will be, but it will certainly push the analysis of billing data out beyond 2021.

Reporting

As indicated earlier, our report will focus on qualitative results and observed patterns related to building construction and energy code compliance. Compliance results will be presented at the system and building level.

The report will highlight insights about systems that do not meet the code and about compliance with new code requirements including DOAS. The 2015 code required the new construction to incorporate two options from section C406 and we will investigate how frequently this requirement is met and with what options.

Other new requirements we will explore include those for controlled receptacles and minimum skylight areas. We will identify compliance with these requirements to the extent possible.

Some requirements pose special verification challenges. Our report will identify common gaps in compliance documentation and requirements that are difficult to verify because they have to be observed at specific times.

Although we have had success with virtual site visits that our team started implementing in response to COVID-19, the quality and scope of data collection can be affected. For example, when a technician is on site, he or she can take more time to verify lighting installations than it is reasonable to ask a facility person to do remotely. However, still photographs and videos can be reviewed after the virtual site visit to perform fairly complete reviews.

Appendix D. Sample Weights

To develop population estimates of the key parameters estimated in the building sample we calculated post-stratification weights. The weights were calculated for each group reported on to account for differences in representation of each group of buildings in the sample as compared with the population. Because energy consumption and other important quantities are dependent on buildings size, we used building floor areas, rather than counts, as the basis for calculating the weights.

Each post-stratification weight is equal to the proportion of the population square footage represented by the group of interest divided by the proportion of the sample square footage represented by that group in our sample. For instance, Urban Large Commercial buildings represent 22.5% of the population square footage, but only 7.77% of the sample square footage. Thus, the post-stratification weight for Urban Large Commercial buildings is 0.225/0.0777 = 2.89. We developed these weights for each building for all combinations of building location—urban vs. rural—and building size category and for combinations of building location and type. The following tables present the post-stratification weights calculated and then applied to the relevant estimates for each building in our sample.

Table D-1. Post-stratification Weights, Building Location and Size Category

Location	Size Category	Weight
Rural	Large	0.833
	Medium	0.792
	Small	1.175
	Multifamily	0.768
Urban	Large	2.889
	Medium	0.588
	Small	0.677
	Multifamily	0.949

Table D-2. Post-stratification Weights, Building Location and Type

Location	Type	Weight
Rural	Education	0.230
	Multifamily	0.732
	Office	6.053
	Other	3.594
	Retail/Service	1.093
	Education	0.259
	Multifamily	0.904
Urban	Office	1.621
	Other	8.529
	Retail/Service	1.505

Appendix E. Billing Data Analysis Addendum

To:	Chris Cardiel; Northwest Energy Efficiency Alliance
From:	Aaron Huston, Brandon Kirlin, and Romeo Michael; Cadmus
Subject:	Washington 2015 Commercial Construction Code Evaluation Study – Billing Data Analysis
Date:	December 22, 2022

9.7.1 Billing Data Analysis

Consumption histories, which form the basis for calculating energy use intensity (EUI) indices, were one of the key data elements in the Washington 2015 commercial construction code evaluation study. This addendum is part of a larger effort to assess compliance with the 2015 Washington State Energy Code (WSEC) in newly constructed buildings, and focuses on energy consumption outcomes for building systems that complied to the 2015 WSEC against those that did not.

Cadmus conducted a billing data analysis on electric and gas consumption for nine building types to compare energy use intensity (EUI) against the buildings' compliance to five energy code categories—exterior lighting power, interior lighting control, total UA[77], heating system efficiency, and HVAC controls.

Cadmus obtained signed forms from the site contacts to collect all available billing data for each site and put these data into the format required for FirstView. FirstView is a New Buildings Institute (NBI) software tool that estimates end-use energy consumption for commercial buildings based on the billing data. Building representatives provided permission to obtain the billing data for 48 of 76 buildings.

Cadmus submitted billing data requests to utilities in batches, then matched the data to each building. In some cases, one meter from the utility billing data represented the entire site. In other cases, multiple meters were associated with the site. Where applicable, we matched the specific meter to the audited building. In some cases, we visited more than one building at a single site and aggregated the meter data for the entire site.

Cadmus was unable to obtain gas information for 30 of the 48 buildings for which utility billing data were received. According to information provided in the billing release, natural gas was listed as not applicable or none for 14 buildings, not listed for six buildings, and blank for one building. Despite several attempts, we could not reach an appropriate contact for one gas utility that represented nine buildings. We were unable to collect billing data (a) for buildings that had new tenants and had changed account numbers since the release form was signed, (b) for buildings for which contact with the

[77] Total UA is defined as a building envelope's overall U-value over its gross area. This is calculated by summing the product of the U-value, also referred to as thermal transmittance, and the area of each component of the envelope.

servicing utility could not be established, or (c) in cases in which tenants filled out the release form incorrectly or were unable to provide the requested information.

Table 1 and Table 2 show the final number and proportion of buildings that have histories of electric and natural gas consumption, respectively, by building type for the region.

Table E-55. Proportion of Electric Billing Data Obtained By Building Type

Building Type	Buildings with Electric Billing Data	Total Buildings	Proportion of Total
Assembly	4	7	57%
Education	12	23	52%
Health Care	1	2	50%
Motel/Hotel	0	1	0%
Multifamily	5	15	20%
Office	6	7	86%
Other	1	1	100%
Restaurant	0	1	0%
Retail/Service	11	19	58%
Total	**40**	**76**	**53%**

Table E-56. Proportion of Gas Billing Data Obtained By Building Type

Building Type	Buildings with Gas Billing Data	Total Buildings	Proportion of Total
Assembly	1	4	25%
Education	8	18	44%
Health Care	0	2	0%
Motel/Hotel	0	1	0%
Multifamily	3	13	23%
Office	1	1	100%
Other	0	1	0%
Restaurant	0	1	0%
Retail/Service	5	16	31%
Total	**18**	**57**	**32%**

Cadmus compiled the billing data into a Microsoft Excel template containing building address, building type, size, and a minimum of a year's worth of electrical and gas consumption for 29 buildings. We could not compile data for any buildings served by natural gas but that were missing natural gas billing data. We then aggregated the data to the site level where applicable for a total of 25 sites. It should be noted that the relatively small number of buildings included in the final analyzed sample necessarily limits the generalizability of findings articulated below, with these findings consequently considered exploratory rather than conclusive. Table 3 shows the proportion of sampled buildings by building type.

Table E-57. Proportion of Sampled Buildings By Building Type

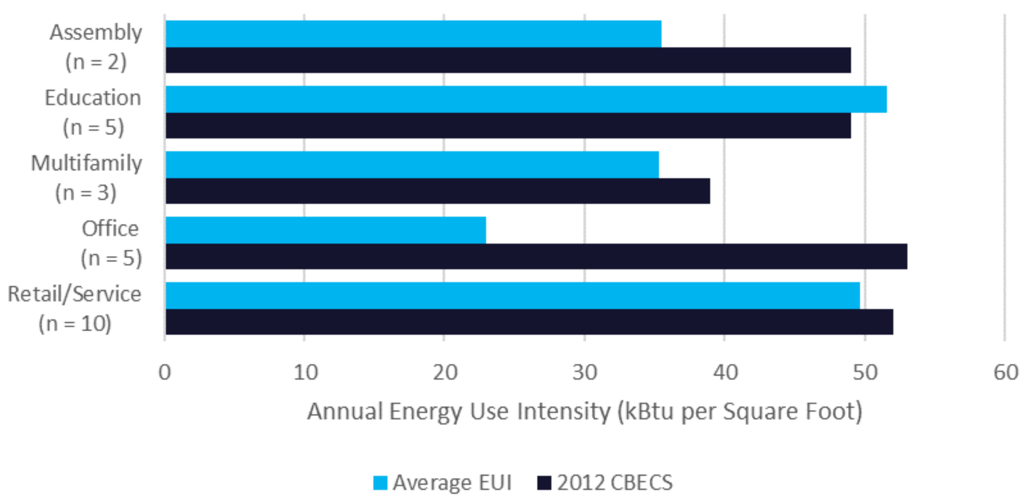
Building Type	Number of Sampled Buildings	Total Buildings	Proportion of Total
Assembly	2	7	29%
Education	5	23	22%
Multifamily	3	15	20%
Office	5	7	71%
Retail/Service	10	19	53%
Total	**25**	**71**	**35%**

Cadmus sent the compiled utility billing data to NBI, a subcontractor on this study task, to generate FirstView reports of each site for benchmarking.

Cadmus and NBI screened energy use intensity (EUI) values to check for reasonableness. NBI compared the EUI of the selected buildings to the 2012 Commercial Buildings Energy Consumption Survey (CBECS) median and ASHRAE Standard 100 target EUIs for similar building type. For buildings with anomalous EUIs relative to the 2012 CBECS median or to the ASHRAE Standard 100 target, we conducted additional research into the matched meter or meters or the square footage. The purpose was to check if the meter included other buildings in the site that were not audited or if the building's total square footage did not accurately represent the meter data. We dropped any EUIs for which we were not confident of the accuracy.

Figure 1 shows the average EUI for each building type on a combined fuel basis (in kBtu per square foot) compared to the 2012 CBECS for that building type.

Figure E-33. Combined Annual Energy Use Intensity by Building Type (n = 25)



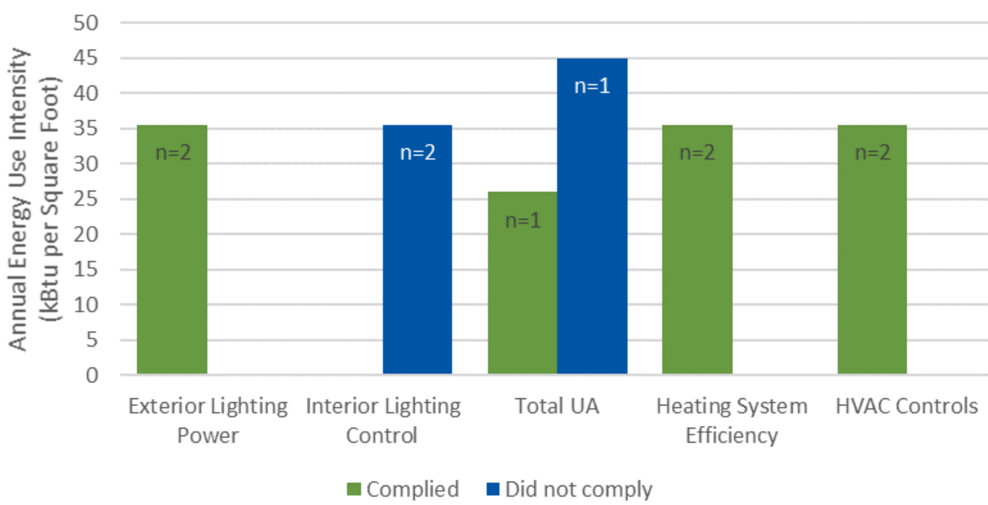
Compared to the 2012 CBECS, average annual EUI for the study buildings was lower for assembly, multifamily, office, and retail/service building types and higher for the education building type.

For the subset of 25 buildings with FirstView reports, we then compiled binary compliance rates to the WSEC or the Seattle Energy Code (SEC) for exterior lighting power (C405.5), interior lighting control (C405.2), total UA (C402.1.5), heating equipment efficiency (C403.2.3), and HVAC controls by building type. We excluded compliance rates in other categories due to either 100% compliance or a high frequency of unknown compliance across all buildings in this subset.

The following discussion and figures compare the average EUI of buildings based on their compliance with each of the five categories reviewed.

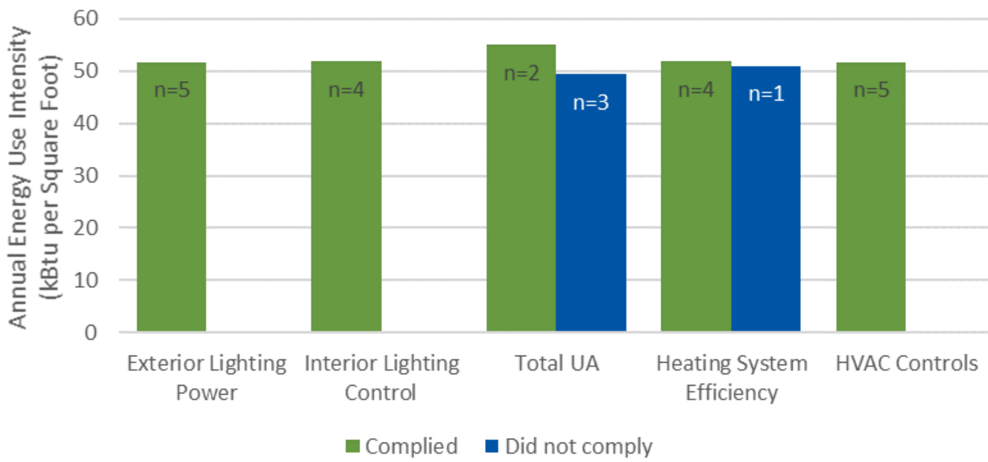
The two assembly buildings complied with exterior lighting power, heating system efficiency, and HVAC controls requirements, as shown in Figure 2, but neither complied with interior lighting control requirements. One assembly building did not comply with overall total UA requirements and had a higher annual combined EUI than the other (45 kBtu/sqft and 25.5 kBtu/sqft, respectively, for an average EUI of 35.5 kBtu/sqft).

Figure E-34. Average Combined Annual EUI by Binary Compliance of Assembly Buildings (n = 2)



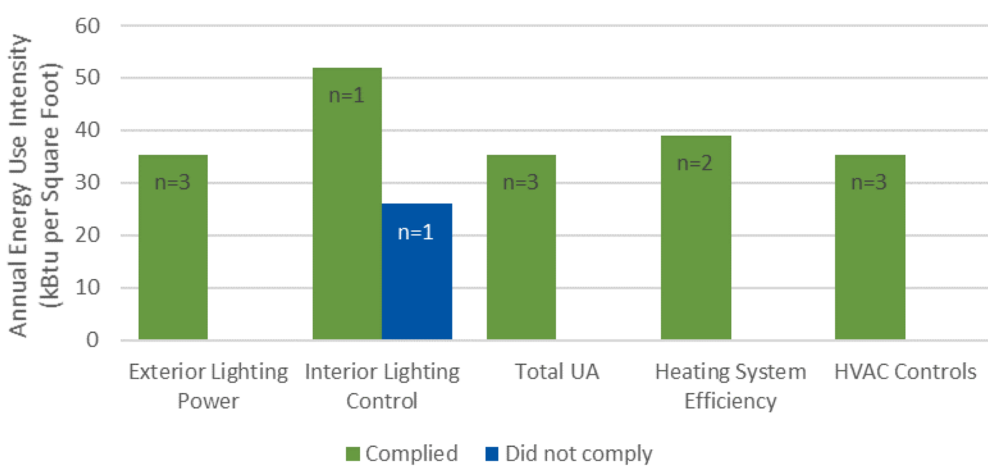
The five education buildings complied with most of the reviewed categories, as shown in Figure 3. Three did not comply with the total UA requirement. One building did not comply with the heating system efficiency requirement. The EUIs for these buildings were very similar and did not appear to be influenced by compliance in any of these categories.

Figure E-35. Average Combined Annual EUI by Binary Compliance of Education Buildings (n = 5)



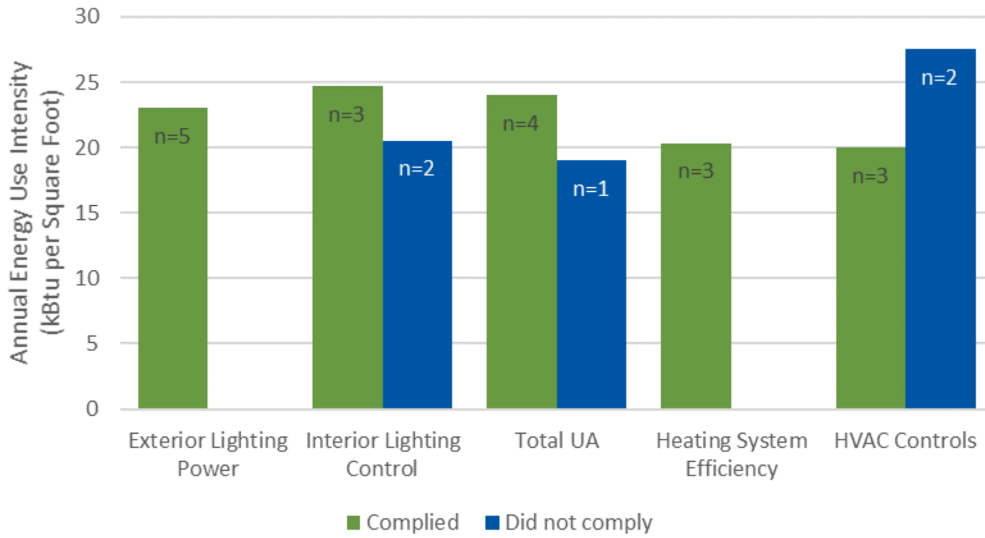
Of the three multifamily buildings, one did not comply with interior lighting controls requirements. This building did not have the required occupancy sensors in many spaces and instead had installed manual switches. Figure 4 shows the average EUI of multifamily buildings based on compliance to the five categories. Some buildings' compliance to some categories were unknown and were not included in the EUI averages in this figure.

Figure E-36. Average Combined Annual EUI by Binary Compliance of Multifamily Buildings (n = 3)



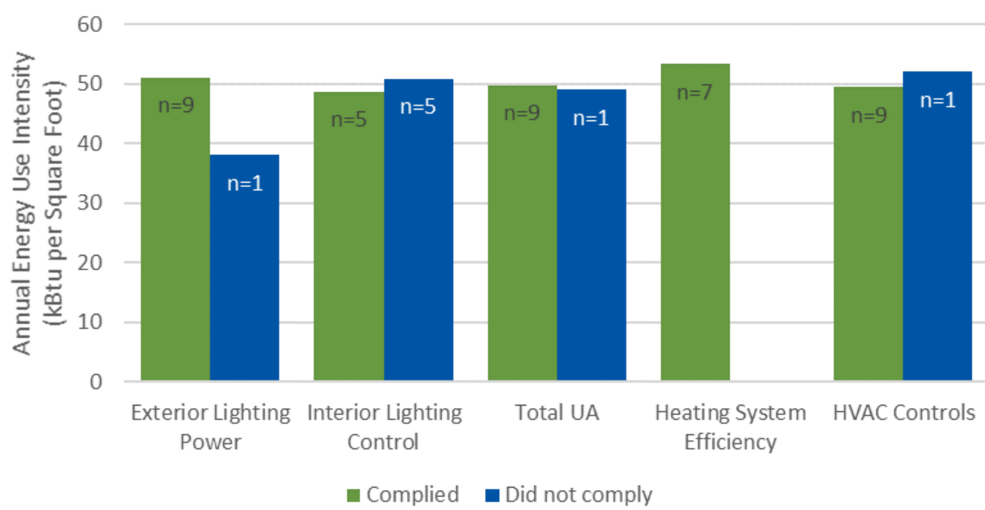
All five office buildings complied with exterior lighting power and heating system efficiency requirements, as shown in Figure 5. Two did not comply with the HVAC controls requirements, and they had higher EUIs, on average, than the other three office buildings; however, they had partial compliance to HVAC controls, meaning some but not all systems in the building complied with control requirements. Two office buildings did not comply with interior lighting control requirements, and one did not comply with total UA requirements.

Figure E-37. Average Combined Annual EUI by Binary Compliance of Office Buildings (n = 5)



All 10 retail/service buildings complied with heating system efficiency requirements, as shown in Figure 6. With the exception of interior lighting control compliance, only one building in each category did not comply. Five buildings did not comply with interior lighting control requirements and had a higher average EUI than the buildings that did comply. EUIs did not differ much between retail/service buildings that did or did not comply in each of these categories.

Figure E-38. Average Combined Annual EUI by Binary Compliance of Retail/Service Buildings (n = 10)



The low number of buildings for which Cadmus could capture complete billing data hindered the ability to make meaningful conclusions regarding a building's annual EUI and its compliance in the five categories. In addition, comparing EUIs of buildings based on binary compliance does not provide sufficient granularity because this method does not account for the degree of compliance, such as the number of units in a building that do not comply or how much higher a system's efficiency is than the requirement. However, with a larger sample, comparing EUIs based on binary compliance may be an informative metric to identify the most impactful energy code requirement on energy use.

9.7.2 Conclusion

Cadmus requested historical utility consumption data for buildings and sent forms requesting signed consent from the site contacts to allow the release of all available billing data. We received utility data for a total of 48 buildings but were unable to obtain gas information for 30 of these 48 buildings, leaving a total of 25 buildings for which all required billing data (gas and electric or electric-only) were available for analysis.

Cadmus worked with NBI to analyze the utility bills of the 25 buildings in the final sample, then compared the building EUI against the binary compliance rates to the Washington State Energy Code (WSEC) or Seattle Energy Code (SEC), as applicable, for exterior lighting power, interior lighting control, total UA, heating equipment efficiency, and HVAC controls by building type.

Cadmus found that for an assembly building type, the building that did not comply with envelope code had higher EUI in comparison to the other building that complied. For education and retail buildings, the average EUIs were very close among buildings that complied with codes and those that did not. For multifamily buildings, the EUI of a building that lacked interior lighting controls was not higher than that of the average EUI of buildings that complied. For office buildings, complying with HVAC controls showed lower EUIs in comparison to buildings that did not comply with this category.

Developing meaningful conclusions on the most impactful energy code requirement on energy use was not feasible due to the small sample size of buildings and the insufficient granularity of the binary compliance method.