Final Report

Residential Building Energy Efficiency Field Studies: Low-Rise Multifamily

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EXECUTIVE SUMMARY

In recent years, the U.S. Department of Energy (DOE) has conducted a series of research studies to validate the prevalence of energy efficient building technologies in the field. Much of the work has focused on single-family construction, and some has also addressed commercial energy codes. The work detailed in this DOE-funded study (EE0007616) is part of that effort but focuses on low-rise[1] multifamily buildings in various regions of the United States, and reports on how state-level building codes are being implemented, both in terms of observed characteristics and also in terms of estimated energy impacts.

Nearly 100 buildings across four states—Illinois, Minnesota, Oregon, and Washington—were sampled, which represent a range of climate types from mild temperature to very cold continental. Both common entry and outdoor entry ('garden style') buildings were included in the work, and a parallel research project evaluated envelope air tightness and current still-evolving air tightness testing methods[2]. Finally, a set of structured interviews of building designers and other relevant professionals was carried to out to gain more insight into this market.

To the greatest extent possible, the methodology developed under the project for low-rise multifamily buildings mirrored the approach established by Pacific Northwest National Laboratory (PNNL) for single-family residential buildings.[3] This included the general approach to sampling, recruitment, and data collection, as well as data analysis and presentation.

The range of permitting dates for the sites encompassed two energy code cycles in most regions. All states in the study had adopted a variation of the International Energy Conservation Code (IECC) for the structure of their state code[4]. The low-rise multifamily occupancy presents a hybrid building type: most of the building's conditioned floor area was covered by the residential chapter of the code while portions of the building (such as corridors and common spaces) fell under the commercial code chapter.

The key items that were assessed in this work are shown in Table 1, along with the concordance to parts of the IECC. A few items were not assessed in detail (that is, evaluated for overall energy impacts), given their relative paucity in this occupancy type; these included duct leakage, pipe insulation, and hot water circulation controls. Duct leakage is not included in the low-rise study since ductwork, if present, is typically located within conditioned spaces in these buildings. Pipe insulation and hot water circulation controls are typically covered by commercial parts of the code; the latter, in particular, was only present in a very limited number of cases in this study. The low-rise multifamily data collection protocol also includes several additional items (marked with an asterisk in Table 1) that are directly relevant to considerable energy usage in low-rise multifamily buildings.

Table 1. Key Characteristics for Low-Rise Multifamily Study

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[1] For this project low-rise buildings are defined as three stories or fewer above grade

[2] *Commercial Buildings and Energy Code Field Studies: Low-Rise Multifamily Air Leakage Testing*. 2020. D. Bohac, Olson, C., Davis, R., Nelson, G. Sweeney, L.

[3] Residential Building Energy Code Field Study. May 2018. R. Bartlett, M. Halverson, V. Mendon, J. Hathaway, Y. Xie https://www.energy.gov/eere/buildings/downloads/residential-building-energy-code-field-study

[4] Each state amended the IECC in various forms through its internal rulemaking process to formulate its own code.

Component	Data Collected	Code Reference†
Building		
Exterior wall insulation	R-value	Tables R402.1.2, R402.1.4
Ceiling insulation	R-value	Tables R402.1.2, R402.1.4
Foundation insulation	F-factor	Tables R402.1.2, R402.1.4
Window	U-factor	Tables R402.1.2, R402.1.4
Window	SHGC	Tables R402.1.2, R402.1.4
Exterior lighting	Wattage	Section C405.5
HVAC system (living units and common areas)*	Efficiency rating	Section C403, (referenced by IECC section R403.8)
Pipe insulation*	R-value	Section C403.2.10
Domestic hot water (units and common areas)*	Efficiency rating	Section C403
Circulating system*	Pump controls	Section C404.6
Envelope tightness**	Air changes per hour (ACH)	Section R404.4.1.2
Common Areas		
Lighting (also see HVAC, domestic hot water references, above)	Lighting power density	Section C405.4.2
Living Units		
Lighting	Percent high efficacy	Section R404.1
Ventilation	Flow rating	Section M1507 (IRC), (referenced by IECC section R403.6)
Envelope tightness**	Air changes per hour (ACH)	Section R404.4.1.2

† - IECC reference. Individual state energy code references vary.
* Additional items added for low-rise multifamily study not included in DOE single-family studies
**Evaluated as part of parallel air tightness study

Building characteristics were collected via a combination of architectural, mechanical, electrical, and plumbing plan reviews and field inspections, and entered into a spreadsheet-based tool that was later queried to build a database. Data went through quality control both upon arrival and via a later semi-automated review and assurance process. Most of the data are presented graphically so that the reader can quickly assess compliance with the applicable energy codes (both by state and by code year).

As a final step, EnergyPlus™ simulations were created for all buildings in the study to estimate both the as-found energy use intensity (EUI) and the energy and environmental factors that could be saved if features that were found to not meet code minimums were brought up to code. The savings estimates were tabulated for each of the four states in the study.

Findings

This project's primary objectives were to 1) adapt and extend a methodology that has been used to assess single-family building energy performance to low-rise multifamily buildings; and 2) provide a catalog of building characteristics and also discuss the implications of these characteristics in terms of EUI and room for improvement.

The research team found that the single-family approach was largely applicable to low-rise multifamily buildings. This applies to both the data collection and the prototype EUI analysis. Most of the occupied space is living units and falls under residential energy codes, and many characteristics use similar envelope construction and relatively straightforward mechanical systems and lighting. Where there were diversions, such as the heating systems and lighting employed in common areas, components could still be evaluated, and summaries and energy analyses were prepared for these elements.

One of the most challenging aspects of this work was to build a spreadsheet-based data collection instrument that could allow efficient collection of both building plan and field data. The instrument was effective in performing this task. The research team is not convinced, however, that such an approach is essential to success in this sort of project. Other methods, even such as the pencil and paper methods traditionally used for code studies, could be equally effective if the work is done carefully and quality control is performed diligently. The latter approach does add an extra step of data transfer from paper to digital form.

The primary findings for the work center around the thermal envelope and mechanical systems and lighting at the sites:

- For thermal envelope components, in each state, the majority of buildings met or were often better than the prescriptive code. This suggests that building designers and builders are aware of code requirements. In some cases, surveyed buildings were designed to qualify for energy efficiency certification programs[5]. These buildings made up at least 20% of sampled buildings in each state.
- Almost all buildings met mechanical system efficiency requirements (for both living units and common areas). In some cases, sites employed systems that were considerably more efficient than required by the applicable energy code.
- Dwelling units had a majority of high-efficacy lighting, often in excess of the state's residential code requirements. While high-efficacy fixtures were also typical in common areas (corridors and stairwells), lighting power densities (LPDs) in these areas were sometimes higher than levels dictated by the applicable part of the state commercial energy code.
- The simulation models run on a series of low-rise multifamily prototypes, informed by a composite of the field data collected, calculate annual EUIs of between 20 and 50 kBtu/ft2-yr, with the range representing the effects of both building characteristics and building location (climate zone).
- Recent work on energy codes for single-family buildings has included a detailed process (based on simulations of prototype buildings) to estimate the amount of avoided energy use that would occur if 100% adherence to energy codes were attained. This process was extended to low-rise multifamily buildings in this study. The results indicated modest

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[5] Buildings participating in energy efficiency certification programs (including those with above-code requirements) were included in the study when they were selected as a natural part of the sampling and recruiting process so as to achieve an average representation of building characteristics within a given state.

savings are attainable for items such as window thermal performance and common area lighting. The result is overall only a modest potential for additional energy savings, averaging about 10% of EUI.

1 INTRODUCTION

1.1 Purpose/Scope

Over the last several years, state, regional, and national code agencies and other parties have trained their eye on energy efficiency codes. Rather than the just 'checking the box' for prescriptive requirements, the renewed focus concerns the actual energy impacts of these codes on a whole-building basis. Further, if the effect of non-compliance can be estimated accurately, the overall impact of the code on expected new building performance can be placed in context of all new buildings (commercial, multifamily residential, and single-family residential), which is of primary interest to industry education and training programs, as well as to states seeking to validate the impacts of their building energy codes. Another potential audience/client for such studies are electricity and natural gas utilities or utility consortia since they have historically been interested in (and have underwritten) studies on single family building characteristics to inform energy efficiency programs and incentives.[6]

The subject of this study is new construction, low-rise (one-to-three story above grade), apartment buildings (flats) containing five or more living units, designed for occupants who are primarily permanent in nature.[7] Almost 100 buildings, permitted under state energy codes enacted between 2011 to 2015, were evaluated in four states—Illinois, Minnesota, Oregon, and Washington—that represent a cross-section of climate types. The evaluation included review of building energy systems: thermal shell, mechanical systems, water heating, and lighting. The results provide an increased understanding of the energy performance in this sector.

Results include both characteristics summaries (by state) and an analysis of the opportunities associated with increased code compliance on building energy use in the different climate zones. As well, the process of collecting and processing building data so that these estimates can be prepared is described in detail, with the intent that others could employ this process in future studies. This report also includes a market research component that describes interviews with key actors in the multifamily sector (building designers, developers, and builders) that focuses on various aspects of the code, including specific code details relevant to code education and training, and overall energy performance.

Described in a separate report, a simultaneous study of building air tightness occurred using several of the main study buildings and additional sites that met the building type criteria[8]. There is great interest in how this building type can be tested to show compliance with modern air tightness standards, and what methods might be employed to enable testing to be completed in a timely manner. Overall, 26 sites were evaluated this way using semi-automated testing equipment (blower doors). The tests have

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[6] *Residential Building Stock Assessment: Single-Family Home Characteristics and Energy Use*. 2012. Baylon, D., P. Storm, K. Geraghty, and B. Davis. Prepared for Northwest Energy Efficiency Alliance.

[7] The Illinois amendment to the adopted IECC explicitly includes buildings up to 4 stories above grade in the residential code for municipalities having a population of 1,000,000 or more (i.e. City of Chicago). In that locality, the study included buildings up to 4 stories.

[8] *Energy Code Field Studies: Low-Rise Multifamily Air Leakage Testing.* 2020. Bohac, D., Sweeney, L., Davis, R., Olson, C., Nelson, G.

included a measurement of whole building envelope leakage along with the total and exterior leakage of 10 to 12 individual units. Most of the buildings tested were “common entry”, meaning there is a common hallway adjoining living units, but some are also “outside entry” (or "garden style”), a configuration that means individual units must be tested (vs opening unit doors to the hallway). Note that the sites in the main study were also a combination of these building types. These are some of the findings and recommendations from that work:

On a whole building basis, results could be tabulated for 24 buildings (as one garden-style building could not be completely tested due to time constraints and the configuration of another precluded calculation of whole-building results) and all but one building came in below 4.0 ACH_{50}, thereby meeting most states’ air tightness limit. (Note the metric here, ACH_{50}, indicates the amount of exterior air leaking through the building shell at a test pressure of 50 Pascals, normalized by the building’s volume. This is the most commonly used metric, although another, which normalizes leakage by overall building area (all sides) is expressed as CFM_{50}/ft^2 and is also used in this report (and in similar research.)) Overall, the leakiest buildings were in Washington and Oregon, which had the least stringent exterior leakage limits; Oregon does not require air leakage testing for this type of construction.

Also, of note, 21 buildings had measured exterior leakage of below 3.0 ACH_{50}, which was the tightest state-mandated requirement (Minnesota), and within this group, the average air leakage rate was less than 1.5 ACH_{50}. A total of 83% of the buildings had a whole building surface-area-normalized leakage rate less than 0.30 CFM_{50}/ft^2, and 58% were below the USACE requirement of 0.19 CFM_{50}/ft^2.The volume-normalized results are shown in Figure 1.

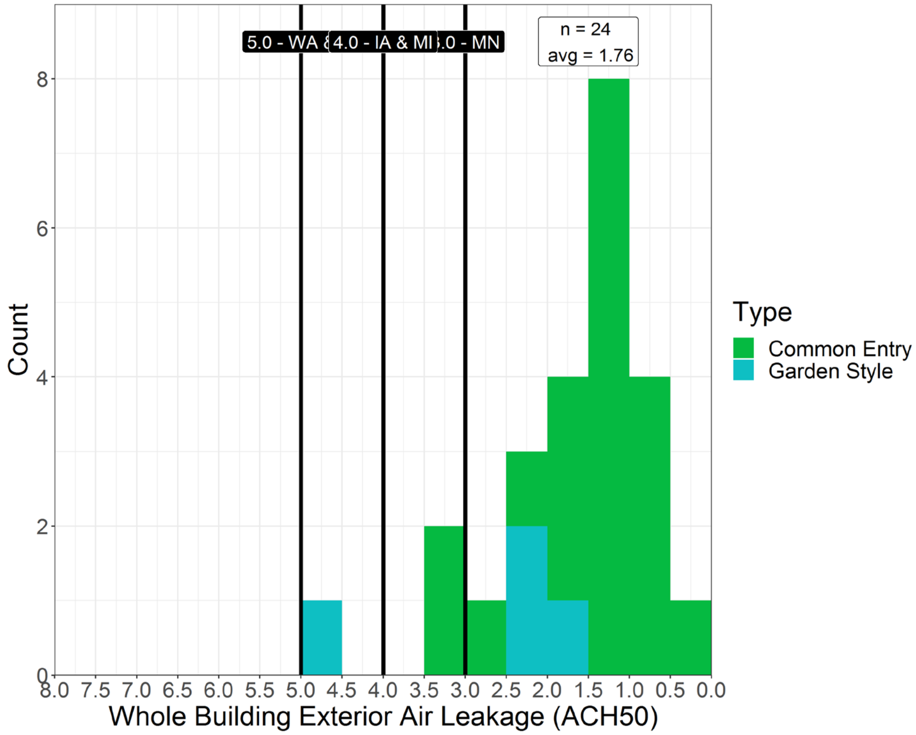

Figure 1. Whole Building Exterior Air Leakage (ACH50)

On a living unit basis, which is particularly relevant to most testing scenarios outside of a research setting (since whole-building tests, especially for garden-style buildings, are extremely labor and equipment intensive, and there is great interest in methods that could allow limited unit testing to be extrapolated to whole-building air tightness), 88% of all units (n = 274) had volume-normalized exterior leakage of less than 3.0 ACH_{50}; 95% were tighter than 4.0 ACH_{50}; and 97% were tighter than 5.0 ACH_{50}. Unit exterior leakage followed the pattern of whole building exterior leakage, with the leakiest units found in Oregon and Washington. Figure 2 shows the distribution of volume-normalized exterior leakage in individual living units.

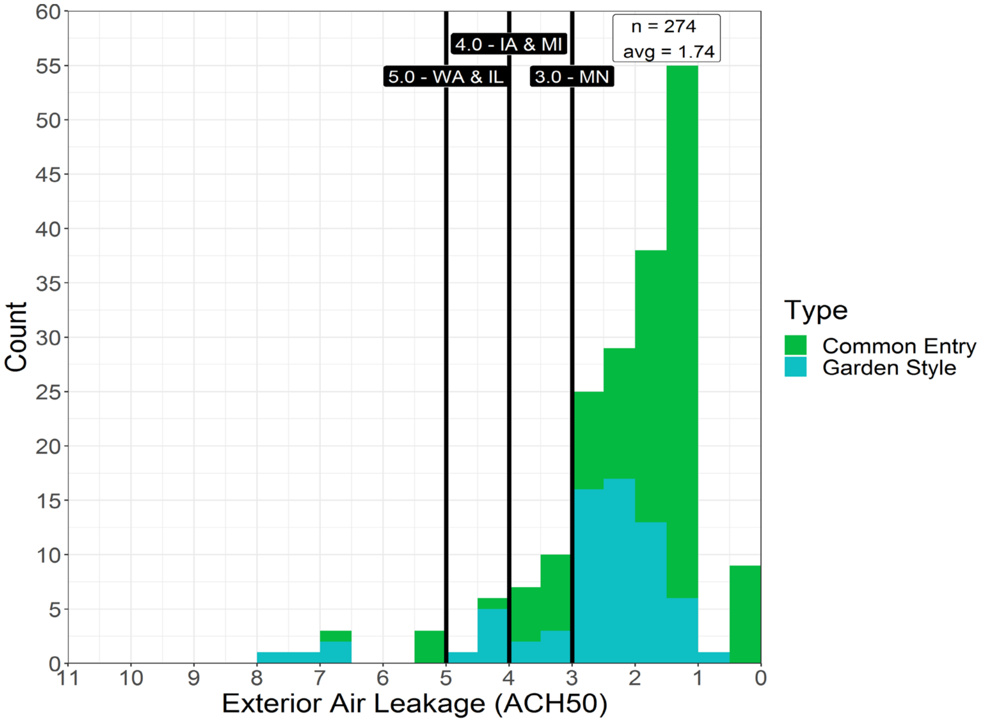

Figure 2. Exterior Air Leakage (ACH50)

- A total of 49% of the living units had a total surface-area-normalized exterior leakage rate less than 0.20 CFM50/ft2; 62% had leakage less than the State of Illinois requirement of 0.25 CFM50/ft2; and 88% were below the proposed State of Washington maximum leakage of 0.40 CFM50/ft2. The average for all of the units was 0.24 CFM50/ft2.
- When the more common compartmentalization test (i.e., pressurization fan set up in a single unit) was used to measure total unit volume-normalized leakage (which includes both interior and exterior leakage), 75% of the common-entry units and 54% of the garden-style units complied with a leakage requirement of 5.0 ACH50. The average was 4.10 ACH50 for the common-entry units and 5.13 ACH50 for the garden-style units. The average for all of the units was 4.53 ACH50. The average total leakage was 2.91 times greater than the exterior leakage for the common-entry buildings and 1.88 times greater for the garden-style

buildings. Adding the interior leakage to the exterior leakage significantly reduces the rate of compliance with the leakage requirement for individual living units.

- Buildings with vented attics displayed higher than average exterior leakage, especially from the top living units in the stack. Exterior wall sealing details made no significant difference in exterior leakage.
- Leakage to and from common areas is typically much larger per ft2 of leakage surface than the living unit leakage to/from outside. More attention should be paid to the construction detailing in these zones in common entry buildings.
- Various methods were evaluated to estimate exterior leakage from total leakage. One method which has been proposed is to use the ratio of a living unit's exterior surface area to the unit's total surface area as the multiplier to get from total leakage to exterior leakage. This method proved to be somewhat useful, but the unit's location in the building (level above grade) had significant bearing on the accuracy of this approach, and the results presented in this report have to be viewed as limited to this set of buildings pending further research.
- In general, living units with a higher amount of interior leakage produced larger adjacent living unit pressure changes during a compartmentalization (single living unit) test. In addition, the larger interior leakage increases the overall total leakage of the unit. That causes a higher calculated exterior leakage which, in turn, causes a positive percentage difference between the surface-area-ratio method calculated exterior leakage and measured leakage. These are notable findings because there are promising methods (discussed in the report) that might be useful in estimating living unit leakage rates from compartmentalization tests.
- Combined air leakage and energy modeling showed that energy savings from reducing exterior air leakage range from modest to considerable (about 5-15% of total living unit heating energy) depending on the starting leakage and amount of improvement. The methodology used for these estimates can be applied to existing (older) low-rise multifamily buildings, as well.
- The energy modeling also showed that a balanced ventilation strategy provides incremental benefits for energy savings if the exterior envelope is tightened below code-required levels, as compared with an exhaust-only system.

1.2 Timing/Code Versions

This project's planning phase began in late 2016, with site recruiting underway in 2018 and fieldwork fully underway in mid-late 2018. In order to attain enough buildings to meet the sampling requirements (see Section 2.1 Sampling), building permit dates typically spanned 5-6 years which often comprised two state code cycles. This can lead to an added analytical complication when a certain building component requirement changes across code cycles but was nevertheless necessary in order to find enough buildings to study. In most of these states, the International Energy Conservation Code (IECC) was substantially adopted for that state's purposes (often with amendments), and the adoption cycle typically meant a specific edition of the IECC was used about 3 years after its nominal release date. Table 2 displays the code versions in question.

Table 2. Sampled State code and IECC code cycles

State	State Code Year	IECC Code Version	Sites (n)
Illinois	2012	2012	6
Illinois	2015	2015	15
Minnesota	2015	2012	25
Oregon	2011	2009	9
Oregon	2014	2012	15
Washington	2012	2012	12
Washington	2015	2015	13

Applicable IECC climate zones in the Pacific Northwest and Illinois are 4 and 5; and Minnesota sites encompass Zones 6 and 7. There were only small differences between newer and older codes in most cases. But the characteristics assessment was always careful to compare a site to the applicable code.

1.3 State-by-State Approach

The project was structured so that a cross-section of climate zones, energy codes, building designers, and builders would be represented. The sampling frame represented a distribution of climate zones encompassing the milder and colder parts of the Pacific Northwest (Zones 4C and 5B), a typical Midwest continental climate (Illinois, Zone 5A), and much colder continental climates (Minnesota, Zones 6A and 7A). The IECC code requirements are calibrated to the severity of the climate, including humidity sub-designations A-C, which correspond to Moist, Dry, and Marine categories, respectively. The compliance and energy analyses in this report follow along with these requirements.

State-by-state results are reported in separate chapters of the report. Section 3 includes detailed accounting of building characteristics such as thermal envelope R-values, mechanical system efficiency, and lighting characteristics. Chapter 4 combines actual building characteristics and prototype modeling to estimate the energy use intensity (EUI) of each building. Chapter 5 extends this analysis to estimate the overall energy savings opportunity of bringing less-than-code measures up to full code, often described as the savings potential or 'savings left on the table'.

In addition, average statewide energy use, as well as the average statewide savings potential, is reported based on a variety of metrics of interest to states, particularly energy savings, cost savings, and environmental benefits. This approach, combined with other recent research efforts across the country, enables several desirable outcomes: providing states a consistent and replicable methodology for assessing code implementation and associated value, increased understanding of high-impact energy-efficiency measures and their ability to inform industry education and training programs, and aligning interests across affected stakeholders, commonly including states, local building departments, builders, designers, manufacturers and utilities, among others.

2 DATA COLLECTION AND ANALYSIS

This chapter describes the processes used to find study sites, including the sample design and recruiting, and then proceeds to a discussion of the various approaches employed to gather data, provide quality control, and analyze and present the results. All methods used in the study were deliberately designed to mirror the single-family studies approach wherever possible (DOE 2018). The team started with the single-family approach and then modified it when needed to accommodate the inherent differences between single-family and low-rise multifamily construction. The end result is a process that is adapted to the multifamily sector yet retains comparability to single-family sector findings.

2.1 Sampling

This project employed a building-based sample of low-rise multifamily buildings (five or more units, one to three total floors above grade) and targeted significance for compliance summaries at 90% or higher (meaning that the eventual surveyed percentage of buildings complying with nominal insulation levels would be significant if the mean were 90% or higher). Using these criteria, the target number of buildings for each of the four states was 22 buildings, using calculations from Scheaffer (1986). The sample target was increased to 25 buildings per state to gather more characteristics and account for data attrition. Since the sampling was based on buildings (versus more granular characteristics), not all characteristics of interest would have enough data for significance. Although the team expected to encounter two main types of buildings (common entry and garden style), the sample was not stratified on that variable. Instead, we would include the two building types at the ratio which they occur in the population. For complete details of the sample design, refer to Appendix F – Sample Design Memo. An overview of the process and deviations from that design are presented here.

2.1.1 Sample Frame Construction

The primary source of the target population was the 2014–2016 Dodge data provided by the Pacific Northwest National Laboratory (PNNL).[9] Since PNNL was the source of the data and DOE has contracted PNNL to be a resource for energy code studies, it allows for any state in the future to use the same methods in this study to generate the target population for their own state.

Sampling was conducted in a simple random manner. First, Dodge data were used to identify the total population of multifamily projects in the state. Unlike the Building Permits Survey (BPS)[10] which includes both mid- and high-rise in its counts, the Dodge data has the advantage of clearly identifying low-rise multifamily projects. The American Housing Survey (AHS)[11] does delineate between low-rise and other multifamily but is problematic in another way since it is only available for large metropolitan areas whose boundaries can cross state lines. Therefore, the Dodge data were used to set the statewide sample size.

For the project recruiting period, BPS data—which were more complete and more consistent than the Dodge data—were used to determine how to distribute the 25 buildings across jurisdictions (i.e., which

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[9] Dodge Pipeline data, a product of Dodge Data & Analytics (www.construction.com)

[10] https://www.census.gov/construction/bps/

[11] https://www.census.gov/programs-surveys/ahs.html

building jurisdictions to sample from and how many buildings within each to sample). Sampling was effectively weighted by construction starts, therefore prioritizing data collection in areas with significant construction activity. Once within a jurisdiction, sampling was conducted in a simple random manner.

The building counts obtained from the BPS were adjusted to remove the projected presence of mid- and high-rise buildings. This adjustment was made using the AHS for the primary metropolitan areas within each state and summarizing the number of buildings for the given area within that dataset (suburban), followed by making an assumption for the rural places in the state. This provided a ratio formula for calculating the number of low-rise multifamily buildings within all buildings by creating a continuous function related to the number of buildings in the jurisdiction. In Minnesota, for example, this resulted in only a small adjustment of the ratios, but the difference was more pronounced in other states. To construct the sample frame, the project team then contacted the designated jurisdictions in each state and requested a list of all permit activity that fit the study criteria. The resulting list of buildings then formed the basis for later recruitment efforts by the project team. Refer to the Sample Design Memo in Appendix E for a robust explanation and the state-by-state plans.

As a primary challenge, the project team encountered a lack of eligible buildings under construction during the project timeframe.[12] Combined with typical challenges in recruiting and gaining access to research sites—common to this type of field research—this resulted in exhausting the initial proposed sample pool in several jurisdictions before an adequate quantity of sites could be obtained. In multiple cases, every jurisdiction within a given state was contacted and all potential buildings were exhausted. In these cases, the project team made every effort to leverage additional contacts and data sources in order to maximize the number of potential buildings and fulfill the 25-building target specified in the sampling plan.

In some situations, substitutions were necessary, and a protocol was used to select the next jurisdiction closest in size. If the target for an exhausted jurisdiction was three buildings, then a new jurisdiction of three buildings was selected as a replacement. When the target number could not be found (e.g., buildings did not exist or could not be accessed), the next closest number was selected. Many jurisdictions required targets of 1 based on the sampling plan. In this case, replacement jurisdictions were selected to match on geography (urban, suburban, rural) and other relevant factors (e.g., density, type of housing, demographics).

While implementing our primary sample frame construction method of contacting the building offices and asking for permits, we realized that many offices did not have permits neatly classified as low-rise multifamily (3 stories or less). Therefore, we learned to ask broadly for permits and then sorted them to identify the low-rise buildings. In Illinois and Minnesota, we exhausted the full sample frame sourced by this primary method and had to resort to secondary approaches to augment the frame. In Oregon and

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[12] This differed from the corresponding single-family field study. Fundamentally, there are far fewer multifamily buildings, particularly those which happen to exist during the necessary stage of construction and whose energy efficiency features are concurrently observable.

Washington, there was enough new construction that we were able to make sample quotas using the primary, permit office approach.

Illinois proved the most difficult, with little construction activity outside of the Chicago area. The project team discovered that obtaining buildings from jurisdictions resulted in an incomplete list for the geography, especially considering the combined effect of unresponsive permit offices. To identify additional buildings, the team expanded the approach to include non-traditional sources[13] as well as 2017-2018 Dodge data for Illinois and referrals from the local construction market to get a more complete list of construction activity.

To build upon the short initial lists from contacting targeted cities in Minnesota, the team used 2017-2018 Dodge data, obtained a referral list from the Minnesota Housing Finance Agency, and reached out to local industry contacts to expand the sample frame and to successfully recruit buildings that were identified within the original sample frame.

In the end, although the survey was designed to sample evenly across state geographies, it was generally found to serve as a starting point for what we were likely to find and where we were likely to find it. New multifamily building construction counts are relatively small and, coupled with specific attributes, system types, and the ability to gain access to the site, the available pool to survey gets even smaller. The sampling plan was used to guide the data collection effort throughout, but it often required modification. The result was more of a census-based approach, where the team effectively surveyed every building that could be recruited to participate. In all cases, sampling was implemented in a deliberate manner and every effort was made to preserve a broad and representative sample within a given state. The nature of the approach, starting with targets based on geographic distributions, helped to focus efforts more evenly across a given state instead of concentrating them in one area. If for no other reason than that, the team recommends future studies in other states begin with a similar sample design approach and prepare to be flexible in finding sufficient study sites.

2.1.2 Unit-Level Sampling

Once a building was recruited, there was an additional layer of sampling to account for the units within the building. While all buildings included in the study were new construction, many were at least partially occupied at the time of the field visit[14]. Coordination with site contacts was made to minimize disruption from unit sampling. At each building, three units were visited in comparison to the original sample design plan of five. The change to three was based both in practicality and in observation. For occupied buildings, it meant only having to disturb three units instead of five which was often an easier sell to the building management. It also reduced surveyor time on site.

The research team also discovered that the unit-to-unit variations of the items of interest were small. For instance, the same packaged terminal air conditioner (PTAC) model is most often used in all units. The site survey approach evolved to using the unit-level visits as verification of what was obtained on

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[13] For example, http://zillow.com and http://apartments.com

[14] This is typical in multifamily construction, where buildings are often completed in phases and initial phases become occupied as later phases are completed.

the plan sets. For instance, the most important characteristics to observe were lighting power density (LPD) and the HVAC equipment (in comparison, insulation details were collected at the building level and not through unit-level sampling). These were listed on plans but needed to be verified in the field. Therefore, the approach was to randomly sample one each of the most typical unit layout types (i.e., one each of a studio, 1-bedroom, and 2-bedroom).

2.2 Recruitment

2.2.1 Project Team Planning, Training, and Execution

A training strategy and training materials for the field team were developed prior to recruiting. This collateral included telephone scripts, email templates, and an FAQ sheet for follow-up information.

A SharePoint site was created for internal communication and storage of documents with sections for each of the four states (Illinois, Minnesota, Oregon, and Washington). One of these documents was a template for logging basic site information from recruiting. The template section had fields for basic building information, contacts, and construction status. As building-specific information is potentially sensitive, confidentiality was prioritized and access to this information was limited only to the necessary field team personnel. In no cases was building-specific information transmitted to DOE or PNNL.

At a state level, the teams, guided by the state sampling plan, contacted local building departments of all jurisdictions in each respective state and requested a list of all buildings that fit the study’s criteria (i.e., low-rise multifamily buildings). This information was assembled into a table with headings for basic building characteristics, identification, and contact details, as well as communication notes and applicable follow-up actions for the project team. As recruiting progressed, each site’s status was updated as To Be Determined (TBD), Screened Out, Declined, Tentatively Agreed, and Site Visit Scheduled. Once the date for the site visit was scheduled, the site was handed off from recruiting personnel to the field team.

To aid with recruiting, which is a known challenge facing field-based research, the project team leveraged a combination of internal and external personnel with experience in recruitment and who ideally had existing relationships with the regional/local construction industry. Internally, the team developed telephone scripts to emphasize key project background information and address typical concerns. Once the team was adequately trained and exhibited a level of comfort on technical details and project goals, the recruiters began contacting potential sites.

Overall, recruiting progress started slowly, which the project team had identified upfront as typical and an anticipated risk, and the project team met regularly to discuss challenges and strategies for expanding recruiting as the project ramped up. Some of the challenges expected and mitigated were:

- Long ramp-up time for new recruiters who lacked industry knowledge
- Discouragement among recruiters when they could not secure sites
- Extremely small initial building pool to draw from (as was the case in Minnesota)
- Few eligible buildings in Illinois outside of Chicago and Chicago suburbs

In terms of specific recruitment strategies, “cold calls” were used as the primary approach and were found to have mixed results. In three of the pilot states, the team had moderate success in scheduling site visits through a call-ahead strategy. In the fourth, Minnesota, the team had very little success when reaching out to building owners and managers; approximately 150 calls to potential sites resulted in only two buildings participating in the study. In this case, alternative recruitment strategies, including outreach to industry contacts, was needed to secure participation. The team emphasizes that recruitment and outreach strategies have the potential to bias the study results—teams replicating this methodology in the future should be aware of this and consider what actions can be taken to mitigate the potential for bias.

The project team sometimes attempted a “driving survey” approach to identify active construction sites. The team would then approach the site on-the-spot to obtain access or contact information for connecting later. Similarly, this strategy experienced mixed results.

Recruiters also often emailed a single-page project description to site contacts prior to the initial phone call, indicating they would receive a call to ask for their participation. This document helped convey more detailed information than was possible in a brief phone call.

The team also found that, when talking with a property manager about a building, the property manager would occasionally offer additional buildings in their portfolio. When these met the study criteria, they were considered for the sample. This was used as a strategy in states where limited buildings were available, and ultimately accounted for relatively few buildings in the final set.

Across all strategies, incentive payments were also made available to encourage participation in the project. In many cases, the incentives helped to secure sites (in addition to having knowledgeable recruiters on the phone who could explain the goals of the study and answer detailed questions about the site visit). All these strategies enhanced buy-in from the site contacts, and a robust recruitment plan utilizing a combination of strategies is recommended.

2.2.2 Final Count

The goal was to recruit 100 low-rise multifamily buildings with 25 buildings from each state: Illinois, Minnesota, Oregon, and Washington. Due to the low number of buildings available, the recruiting phase was extended in an attempt to reach the study target. In the end, 95 buildings were successfully recruited and included in the study, falling short of the target by 4 buildings in Illinois and 1 building in Oregon. In the cases where the target was not met, the sample lists were exhausted.

Table 3 provides summary information on sample frame size and recruiting success by state. The data show a success rate ranging from 5-20% which should be used to inform any future studies in terms of necessary sample frame size to achieve the desired number of recruited buildings. The time spent to successfully recruit a building averaged about 8 hours (excluding any of the planning or material preparation described previously). The number of hours per successful building recruited did surprise the team and reflects the difficulty of the task. In IL, the success rate was higher, but the total number of buildings was substantially lower than other states. Interestingly, the time per “yes” did not vary with the sample frame size or the success rate. The time per "yes" is another useful number in planning future studies.

Table 3. Building Recruiting Success Rate

State	Sample Frame Size	Target Sample	Agreed to Participate	Success Rate
IL	105	25	21	20%
MN	250	25	25	10%
OR	249	25	24	10%
WA	463	25	25	5%

2.3 Plan and Field Review Methods

The process of evaluating a recruited site consisted of a careful review of site plans and a field visit. Given that time at a field site would always be limited, careful plan review was essential to beginning the characterization process. Once a site agreed to participate, the recruiter requested architectural and mechanical, electrical, and plumbing (MEP) plans. When those were received, the on-site visit was scheduled.

Field staff collected and reviewed the architectural as well as MEP plans prior to site visits. They entered details from the plans into a spreadsheet-format Data Collection Instrument (DCI) ahead of the on-site assessment, which had the advantage of saving time on-site and flagging any potential building features that needed close scrutiny. The information collected from plan review included floor, wall, and window areas; level of insulation, foundation type, and other envelope details; lighting type and counts. Based on the plan review, a detailed check list was then developed for use in field verification. In most cases, given overall project timing, buildings were mostly complete by the time the field audit was conducted. This meant that most insulation details, especially wall and floor insulation, could not be directly observed in the field.

The on-site assessments included verification of information from the plans; documentation of information that differed from, or was absent from, the plans; and reference photography of utility meters, HVAC and domestic hot water (DHW) systems and equipment nameplates, lighting fixtures, and other notable details. Information was entered directly into the DCI on site or completed following the site visit using notes taken on site.

Quality control was built into the field work, which was overseen by field managers who reviewed the data gathered for each site (drawings, photographs, and field notes) and checked for completeness, consistency, and clarity. The field manager communicated closely with the field staff, from training them prior to their site visits, to communicating and troubleshooting while in the field, to addressing any incomplete or ambiguous information once the DCIs were filled in. This element of the project was essential, especially on more complicated sites, and should be included on all larger scale field assessments.

2.4 Data Analysis

Data analysis in this study was designed, in the main, to mirror the analytical approach of the single-family studies (DOE 2018). Although there are inherent differences between single-family and low-rise multifamily construction, the similar analytical approaches were intended to achieve consistency in methodologies and allow comparisons to single-family findings (when applicable). As with the single-family studies, the analysis was applied through three basic stages. The first stage assembled and summarized the data by state for key energy usage characteristics (such as insulation values, window types, mechanical system efficiencies, and so on). The second stage modeled energy consumption (of the buildings observed in the field); a divergence for the buildings in this study was the use of performance maps, discussed below in Section 2.4.3 Savings Analysis. (Another divergence from single-family construction in this stage was to include characteristics of common area heating and cooling systems, as these are present in many low-rise multifamily buildings.) The third stage then calculated the potential energy savings, consumer cost savings, and avoided carbon emissions associated with increased code compliance.

The following sections provide an overview of the analysis methods applied to the field study data, with the resulting state-level findings presented in 3.2 State Results and 5.3 Results and Notable Findings.

2.4.1 Statistical Analysis

This first stage of analysis involved examination of the data set and distribution of observations for individual building components (such as insulated assemblies, windows, lighting power density). A distribution of each measure was plotted by climate zone to understand the range of the data and the characteristics of low-rise multifamily buildings in each of the states. Distributions portraying the individual values also allowed comparison to code requirements, an understanding of trends in the surveyed buildings, and exploration of areas where there may be potential for improvement (that is, where a given component did not fully make it to the code requirement).

Figure 3 shows a sample distribution and is explained in the paragraph below the graph.

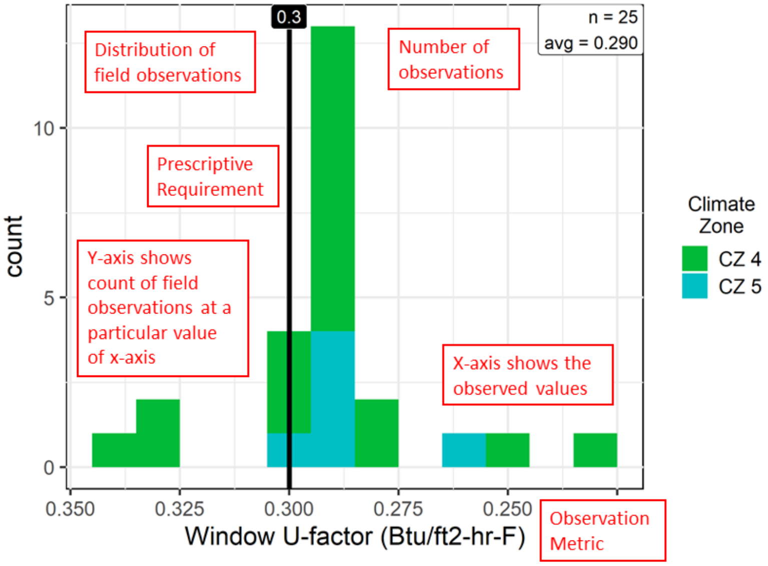

Figure 3. Sample Graph

Each graph (based on the single-family study graphing standard (DOE 2018)) is set up in a similar fashion, identifying the *climate zone*, and specific measure being analyzed. The total *sample size* (n) is displayed in the top left or right corner of the graph, along with the distribution *average*. The *metric* associated with the item is measured along the horizontal axis (e.g., window U-factor is measured in Btu/ft2-hr-F), and a *count* of the number of observations is measured along the vertical axis. The vertical line imposed on the graph represents the applicable code requirement (e.g., the prescriptive requirement in climate zones 4C and 5B is 0.30)—values to the right-hand side of this line are *better than code*. Values to the left-hand side represent areas for improvement.

In most states, multiple prescriptive criteria were assessed either due to differences across code years, or different requirements based on climate zone. When this is the case, the graph will have more than one vertical line representing the applicable code requirements. Differences between code years will be indicated by different color vertical lines (see Figure 59 for an example). In Minnesota, there are two black vertical lines, because a single code year was sampled, but there are differences between the climate zone requirements for some measures (see Figure 14). Each graph is accompanied by a table including climate zone, climate zone by code year, and statewide summaries. The tables provide insights into the overall distribution of the sample, and the specifics (e.g., specific requirement and compliance rate) by climate zone and code year[15].

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[15] Due to the bin-widths for specific characteristics, buildings meeting prescriptive requirements may appear in the bin where the prescriptive requirement falls. Tables that accompany the key characteristics will provide compliance rates by climate zone and by state. For example, the sample graph shows 22 of 25 buildings (88%) meeting the prescriptive requirement.

These graphical representations (and accompanying tables) are provided for the most common measures and characteristics. Where a single building (or subset of buildings) does not fully meet code requirements, those cases are described in the interpretations. For example, wood-framed roof construction was the most commonly encountered ceiling detail. The few cases where metal-framing was used are described and assessed in the text accompanying the ceiling/roof U-factor plot.

In addition, not all summaries aligned well with a graphical presentation. An example of this is mechanical summaries for water and space heating equipment. These results are presented as summary tables to portray the fuels and equipment types used, and narrative discusses observed efficiencies of the most common types.

2.4.2 Energy Analysis

Energy Analysis, described in more detail in *Section 4 Energy Use Analysis (EUI)*, entailed creating EnergyPlus models to represent site energy consumption of surveyed buildings as found (from building plan and field observations), analyzing the modeling outputs, and drawing conclusions about the types of buildings in each state and how they use energy. Each surveyed building is modeled. Table 4 shows a list of starting models, defaults, and variables used. A full list of individual parameters is included in Appendix C – Modeling Workflow. A combined histogram of all buildings in the state visualizes the distribution of building energy use in the state. Energy end-uses are broken out into Cooling, Heating, Fans and Ventilation, Lighting, Hot Water, and Appliances and plotted. Cross referencing system type, lighting and envelope components with end-use energy clarifies how each building component impacts total site energy usage. The site total percentage fuel usage, between fossil fuel (primarily natural gas) and electricity was calculated from the modeled results.

Table 4. List of Seed Models, Defaults and Variables

Starting Models	Defaults	Variables
• Common Basement • Common Slab on Grade (SOG) • Garden Basement • Garden Slab on Grade (SOG)	• Window Wall Ratio (WWR) • Building geometry • HVAC system type • Energy Recovery Ventilation • Residential setpoint temperature • DHW system type • Equipment Power Density (EPD) • Occupancy schedules	• Construction U-values ○ Window U-value ○ Window SHGC ○ Wall U-value ○ Roof U-value ○ Foundation U-value • HVAC features ○ Efficiency (representative COP) ○ Fan power ○ ERV efficiency ○ Basement setpoint temperature • Internal loads ○ LPDs • DHW ○ Efficiency ○ Recirculation heat loss

2.4.3 Savings Analysis

Described in more detail in Section 5 Measure Analysis, savings analysis is an estimation of potential savings from bringing less-than-code building components up to compliance. In this section, energy performance maps for each component were calculated to isolate the component's effect on EUI usage. The exception was mechanical systems, where the inputs for the performance maps used code minimums for representative mechanical system types (such as natural gas furnaces or heat pumps). From the performance maps, EUI delta estimations are made for each building feature where search found a potential for improvement (to meet the code). EUI delta estimations are then extrapolated to estimate savings throughout the whole state and presented in the same format as used in PNNL's single family studies.

A couple of important details need to be mentioned for the performance maps. First, the IECC has for recent code versions required 75% high efficacy fixtures and lamps in living spaces (even though there is no maximum set for residential lighting power density). The 75% requirement applies to Illinois, Minnesota, and Washington for the code years relevant to this study. Oregon's codes for the relevant code cycles did not include a high-efficacy lamp requirement. This requirement was taken into account in the savings analysis.

Second, in DOE's recent single-family studies, summaries of R-value (as a measure of cavity and continuous insulation), and U-factor, considerations of Insulation Installation Quality (IIQ)) were provided for most opaque envelope characteristics. The same approach was not used in this study. Given the stage at which field review was typically done, it was usually impossible to observe insulated assemblies directly and to assign IIQ factors. However, the U-factors used in the analysis here account for both nominal insulation R-value and also framing, void (uninsulated) fraction, and, where applicable, compression[16]. In addition, performance mapping (Appendix E – Performance Maps) indicated that increases in wall U-factor (for example) by as much as ten percent (which could be due to IIQ issues) had a negligible effect on building performance (or EUI).

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[16] WSEC 2015 Table A103.3.1(2)

3 CHARACTERISTICS SUMMARIES

3.1 Methodology

The purpose of the characteristics summaries is to present and analyze information on the key items that influence building energy performance. As described in 2.4.1 Statistical Analysis, the project team used distributions and summary statistics to explore the data range and comparisons to applicable code requirements. This provides a window into both the common characteristics of low-rise multifamily construction and the areas of the energy code requirements that are being met (or even exceeded), as well as areas for improvement.

Because low-rise multifamily buildings commonly have diverse construction assemblies or mechanical components, field-collected data were consolidated to allow 1) summaries of major components and preparation of state-wide characteristics, and 2) energy modelling inputs to conform with the EnergyPlus input format requirements. Data summaries could then be presented in a consistent format (Figure 3 above) and modelling inputs created. This section outlines the summarized key items and methods used to prepare for characteristics summaries and energy modelling. Sections 3.2.1 Illinois through 3.2.4 Washington present the statistical findings for each state (specifically for Envelope and dwelling unit Lighting characteristics). Summaries for mechanical and hot water systems, characteristics that fall under commercial code requirements (e.g., common area, and parking lighting power densities), and ancillary data summaries for each state can be found in Appendix A – Additional State Characteristics Summaries.

- **Ceiling/roof assembly (U-factor)** – To make graphical representation less cumbersome, only the characteristics of the largest area were summarized and assessed for compliance per requirements for that construction type. Most sites were characterized by a single ceiling/roof type. Where more than one ceiling/roof component was characterized, an overall value was calculated as the average U-factor (weighted by ceiling/roof area, regardless of construction-type), and was used solely for modelling inputs.

- **Exterior wall assembly (U-factor)** – Above grade exterior walls were treated similarly to ceiling/roof assemblies. The wall construction-type of the largest area per building was considered representative for this envelope component, expressed in summaries, and assessed for compliance. Although buildings typically had a single construction assembly, more than one wall-type was sometimes characterized. Average U-factor (weighted by wall area), regardless of construction-type, was calculated and used solely for modelling inputs.

Exterior wall U-factors can be correlated with building materials and insulation levels. During compliance screening it was noted that some IECC code years required equivalent insulation levels but listed different U-factor requirements for wood-framed walls. This study used a single U-factor to assess compliance and to define the code-minimum prototype for savings analyses.

Because the construction type was unchanged, the U-factor was selected based on reference tables according to the R-value equivalent for the given code.[17]

- **Window U-factor/SHGC** – Where more than one glazing component was characterized for a surveyed building, overall window U-factor or SHGC was calculated as the average value (weighted by window area). Of the four states examined in this study, only Oregon and Illinois (CZ 4A) have SHGC requirements in the prescriptive code. When there was no state code SHGC requirement, 0.4 (the code minimum in Oregon and Illinois (CZ4A)) was used in modelling inputs.

- **Foundation (F-factor)** – An average F-factor (weighted by slab area) was calculated for each building. Note, the F-factor is heat loss rate per foot of slab perimeter (vs a U-factor, which is heat loss rate per ft^2 of assembly).

- **Percent high efficacy lamps in dwelling units** – Lighting data collected from sampled dwelling units were restricted to interior, installed fixtures for these summaries. Lamps were assigned as either high-efficacy (e.g., compact fluorescent, linear fluorescent, light-emitting diode) or non-high-efficacy (e.g., incandescent, halogen, other, unknown). The proportion of high-efficacy lamps to all installed lamps in the sampled dwelling units represents the percent high-efficacy lamps.

- **In-unit Lighting Power Density (LPD)** – Although not a code-compliance item in residential energy codes, these summaries were prepared as inputs for energy modelling, and are presented in the characteristics summaries. Like high-efficacy lamps summaries, field-collected observations were limited to interior, installed fixtures. The total wattage for these fixtures was then divided by the average dwelling unit square footage for the building to calculate an approximate dwelling unit LPD. This value was used in energy modelling efforts to estimate the dwelling unit lighting loads for the building.

- **Interior Corridor/Stairwell Lighting Power Density** (as applicable by building type) – These summaries apply only to common entry buildings, which have enclosed circulation areas. Total wattage surveyed in these space types was divided by the sum of interior corridor (and/or interior stairwell) square footage to calculate LPD. This characteristic (as well as the Interior/Exterior parking LPD, described next) were assessed against the applicable commercial code (that is, the commercial code version that would apply based on when the building was permitted).

- **Interior/Exterior parking** (as applicable by building) – Parking lighting (interior as well as exterior) falls under commercial code requirements. This differs from the majority of the measures presented in this report, which are assessed through residential prescriptive code. Where parking areas were recorded, lighting wattage serving these areas was summed and

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[17] WSEC 2015 Table A103.3.1(2)

divided by the total gross square footage of the interior parking area or total gross square footage of uncovered driveways and parking areas for exterior parking areas.

- **Mechanical Systems** – IECC code requirements for water heating and space heating/cooling equipment are based on federal minimum efficiency requirements. Substandard equipment should not be available on the market and full compliance is expected. For that reason, the characteristics and compliance summaries for these systems differ from those described up to this point. Mechanical systems are characterized in tables that describe system type, system fuel, and average efficiencies.

  In order to model energy use, the federal minimum efficiency, not the field-observed efficiency, was used in energy modelling. See 4.2 Methodology for additional detail.

  Unlike in single-family construction, where there often is a considerable amount of ductwork that runs in unconditioned buffer spaces such as attics, crawlspaces, and garages there is a very limited amount of that in low-rise multifamily building, so no summaries of duct characteristics are included.

  Common area heating and cooling systems, although addressed by the commercial energy code, are summarized below.

- **Service Hot Water** – Low-rise multifamily buildings typically have a single approach to heating water for use by occupants. Hot water delivery was defined as "In Unit" or "Central" depending on whether equipment served a single unit, or multiple units/areas. Equipment serving only common areas was not assessed. Water heating products were defined as follows:
  - *Boiler/Storage* – typically central systems which have large storage capacities.
  - *Heat pump* – heat pump water heaters move heat (usually from the air) to water, rather than heating the water directly (like conventional storage water heaters). They can, therefore, be much more efficient than typical electric resistance water heaters.
  - *Storage* – individual water heating tanks serving the unit in which they are installed.

  In order to model service hot water energy use, field-reported equipment efficiencies were used as model inputs. See 4.2 Methodology for additional detail.

- **Space conditioning** - Space conditioning for each building is summarized for the dwelling units and common areas. In contrast to water heating, a building may use multiple systems to condition dwelling units. An example of this may be a building using ductless heat pumps to condition open living spaces, and wall heaters to serve the bedroom areas. (See those sections below for additional information on data selection and treatment.)

- **Heating and cooling systems** observed in the field were classified into one of the following categories:
    - *Electric Resistance*: This is typically electric baseboard or wall heaters.
    - *Split system Heat Pump (HP) or Air Conditioner (AC)*: These are usually ducted systems that pair an indoor coil/air handler with an outdoor unit. Heat pumps provide heating or cooling depending on need and typically employ electric resistance coils to supplement compression-cycle heat under colder conditions. The heat pump category also includes residential capacity ductless heat pumps, which usually pair a high wall indoor coil/fan with a small footprint outdoor coil. These systems use direct-current (DC) motor-driven compressor (or compressors). The DC motor means the system has a wide modulation range and this typically increases operating efficiency by at least 30 percent compared to traditional, fixed-RPM equipment.
    - *Variable Refrigerant Flow (VRF) Heat Pump*: This type of technology is increasingly common in both residential and commercial buildings and includes a wide range of distribution options, from a single indoor and outdoor unit to a combination of a larger capacity outdoor unit with multiple indoor distribution points (wall cassettes or short-ducted fan coils).
    - *PTHP/PTAC* (packaged terminal heat pump and packaged terminal air conditioner): These are un-ducted units that are typically installed in wall cut-outs and are relatively common in multifamily living units.
    - *Furnace:* A residential-type system, most commonly using natural gas. Some systems may also employ direct expansion cooling via a ‘split’ system (outdoor condensing unit connected to furnace section by refrigerant lines). Conditioned air is delivered into the space by ducts or may just have a large supply grille (more common in Midwest).
    - *Boiler*: This is typically a larger-capacity (over 500,000 Btu/hr) water heating/distribution system that serves fan coils; all systems in this study were hot water boilers.
    - *Water Source Heat Pump*: This system uses circulating water as the heat source/heat sink; a heat exchanger is used to transfer heat to/from the water to the system refrigerant. Heated (or cooled) air is delivered to the space by ducts.
    - *Window AC units:* These are typically portable units used seasonally for cooling.
- **In-unit Heating/Cooling Capacity** – In order to describe the predominant systems used to condition dwelling units, the highest mean input capacity system from sampled units was considered representative for the building.

- **Common Area Heating/Cooling** – In order to isolate the systems serving common areas (defined as corridors and stairwells), only systems serving multiple spaces (and excluding garage areas) were assessed. The input capacity of this equipment subset was summed, and the highest-capacity equipment type was used to represent the system serving these common areas for a given building. Note that these summaries are specific to common entry building types due to how common areas were defined. That is, garden-style buildings typically did not have common areas. See Section 2.1 Sampling 2.1 for a discussion of building types and their inclusion in this research.

In addition to the measures outlined above, information was collected to inform general characteristics of the sample. Although not the focus of this project, this auxiliary data provides additional insights into low-rise multifamily construction in each of the sample states. These additional data items include:

- Number of buildings sampled by climate zone and by building type
- Number of residential stories and units per building
- Average building size
- Average unit size by number of bedrooms
- The pathway to code compliance (e.g., prescriptive, performance (simulation), UA tradeoff) and energy efficiency certifications, where known. The analysis follows a format that focuses on prescriptive compliance, so in some cases, a site complied with the code via a path other than prescriptive.

3.2 State Results

This section contains individual state results from plan reviews, and field observations and verification. Figures and companion tables summarize the key measures that impact energy efficiency in low-rise multifamily buildings and represent the typical characteristics of this sector of residential new construction for each state. The key measure results for each state are also the basis of the subsequent energy and measure savings analyses. Together they provide insight into challenges to energy code implementation and highlight areas for improvement. Additional summaries for each state can be found in Appendix A – Additional State Characteristics Summaries.

3.2.1 Illinois

Illinois is comprised of two climate zones: zone 4A and zone 5A. Due to recruiting challenges, only zone 5A (referred to as CZ5 for this state's results) was sampled and represented in this analysis. Illinois buildings sampled in this state had construction start dates between 2014 and 2018 and were subject to the 2012 and 2015 energy codes, which correspond to the 2012 and 2015 IECC standards (with amendments), respectively. For many of the key measures summarized in this section, there was little change in the standards between code years (except for specific interior lighting power requirements – those summaries are presented in Appendix A – Additional State Characteristics Summaries).

3.2.1.1 Ceiling U-factor

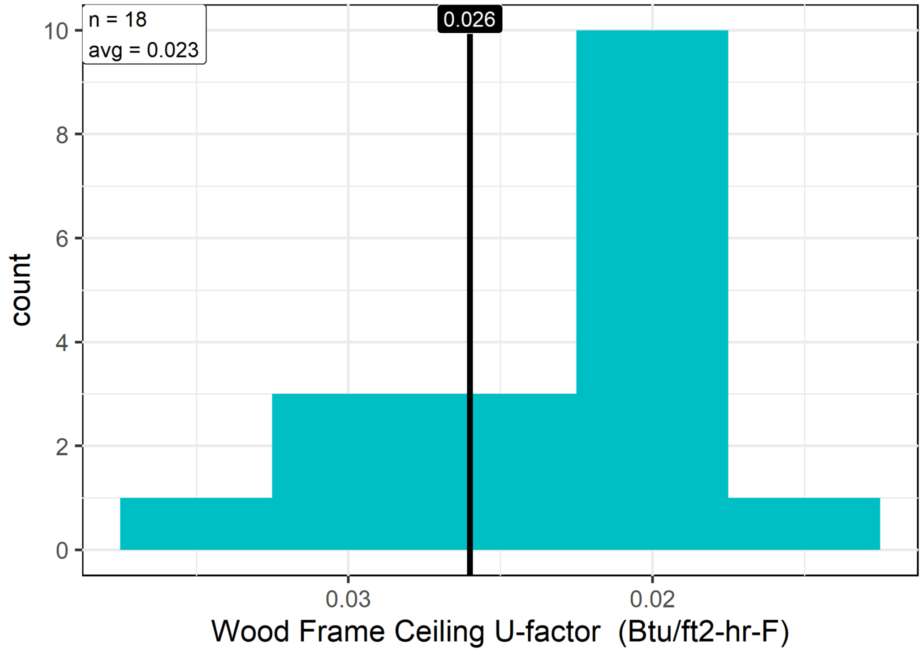


Figure 4. Illinois Wood Frame Ceiling U-factor

Table 5. Illinois Wood Frame Ceiling U-Factor

Climate Zone	CZ5		Statewide
Number	18		18
Range	0.017 to 0.033		0.017 to 0.033
Average	0.023		0.023
Climate Zone and Code	**CZ5 (2012 IL Code)**	**CZ5 (2015 IL Code)**	**Statewide**
Requirement	0.026	0.026	0.026
Compliance Rate	4 of 5 (80%)	10 of 13 (77%)	14 of 18 (78%)

Interpretations:

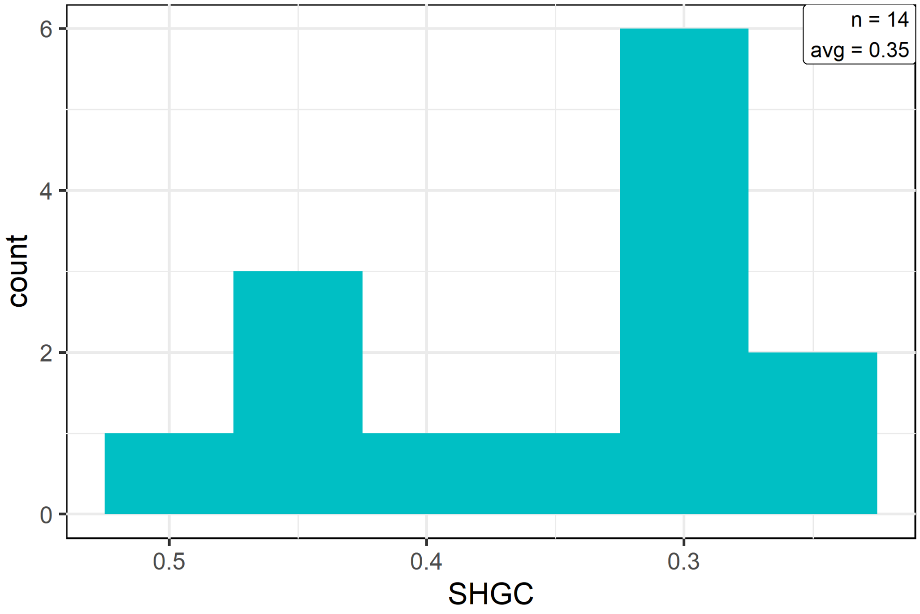
- The most common compliant roofs had R-49 levels of insulation and a U-factor of 0.020. However, approximately twenty percent of Illinois surveyed buildings did not meet the code requirements for ceiling/roof U-factor.
- The higher U-factor buildings were typically flat roofs with wood or concrete roof deck assemblies.

Non-wood frame ceiling/roof construction: Most sites in Illinois had wood-truss roof construction; however, several of the sites had non-wood roof assemblies.

- Two sites had metal truss roof assemblies with U-factors of 0.017 and 0.021. Both sites (CZ5 2015) were compliant with metal truss roof assembly U-factor requirements of 0.035 (IECC 2015).

3.2.1.2 Window SHGC

This key item is not currently included in the Illinois state residential prescriptive code. However, data were collected from two-thirds of the surveyed buildings and are presented here for informational purposes. Unless, field-collected values were available, a default value of 0.4 was used for modelling where specific state prescriptive codes had no SHGC requirement. For additional information on model inputs, see Section 4.2 Methodology.



*Not a code compliance item

Figure 5. Illinois SHGC

Table 6. Illinois SHGC

Climate Zone	CZ5	Statewide
Number	14	14
Range	0.26 to 0.5	0.26 to 0.5
Average	0.35	0.35

Interpretations:

- Most of the recorded fenestration types were residential-style framed, manufactured units. Some storefront types were present mainly in lobby, community, or office areas.
- Although not a code compliance item for Illinois CZ 5, on average Solar Heat Gain Coefficient values met the IECC 2012 and 2015 requirements of 0.4 maximum SHGC for warmer climate zones (CZ 4A and 4B). Few sites (36%) had average SHGC values above that criteria.

3.2.1.3 Window U-factor

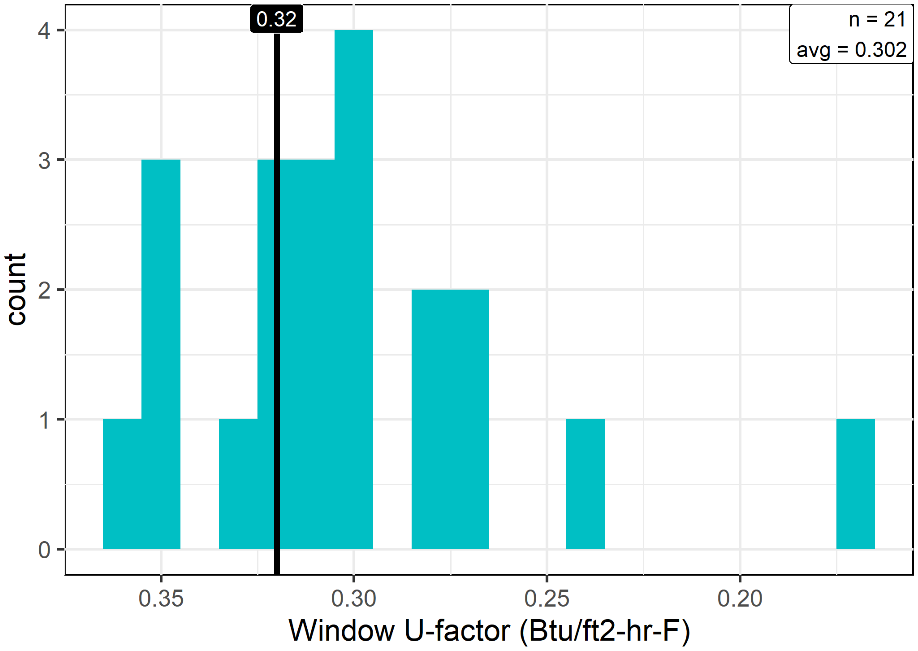


Figure 6. Illinois Window U-factor

Table 7. Illinois Window U-factor

Climate Zone	CZ5	Statewide
Number	21	21
Range	0.17 to 0.36	0.17 to 0.36
Average	0.302	0.302

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.32	0.32	0.32
Compliance Rate	4 of 6 (67%)	11 of 15 (73%)	15 of 21 (71%)

Interpretations:

- Window U-factor values had high compliance rates in Illinois. Nearly three-quarters of the sites met or were better than the code requirements. The five buildings that did not comply had weighted mean U-factors that were close to the prescriptive threshold.

3.2.1.4 Exterior Above-grade Wall U-factor

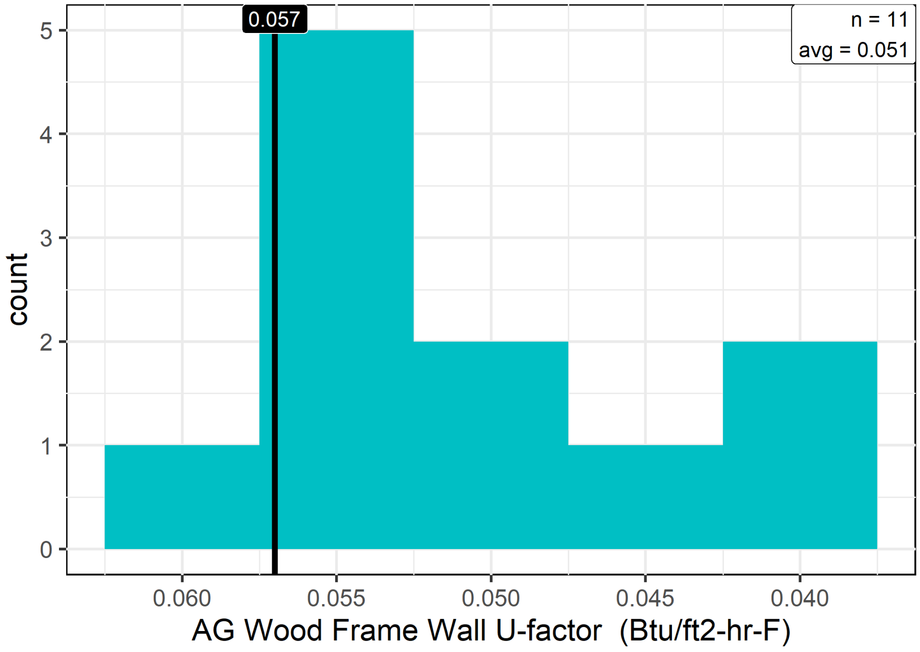


Figure 7. Illinois AG Wood Wall U-factor

Table 8. Illinois AG Wood Wall U-factor

Climate Zone	CZ5	Statewide
Number	11	11
Range	0.039 to 0.059	0.039 to 0.059
Average	0.051	0.051

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.057	0.057	0.057
Compliance Rate	3 of 3 (100%)	7 of 8 (88%)	10 of 11 (91%)

Interpretations:

- The majority of buildings with above-grade wood-frame walls as the predominant assembly met or were better than the prescriptive code requirements.

- Wood 2x6 construction was most common for this category. The site with the lowest U-factor included R-5 or R-10 continuous rigid insulation.

Non-wood above-grade walls: Only approximately half of the surveyed sites had wood-frame walls as the primary construction (by maximum wall area). The remaining sites had either mass walls or metal-frame walls as the largest wall area. Only metal-frame walls are presented graphically.

- Four sites had primarily above-grade mass walls. All had values less than the prescriptive requirement of U-0.082 for CZ5. 75% of them had U-factors < 0.050.

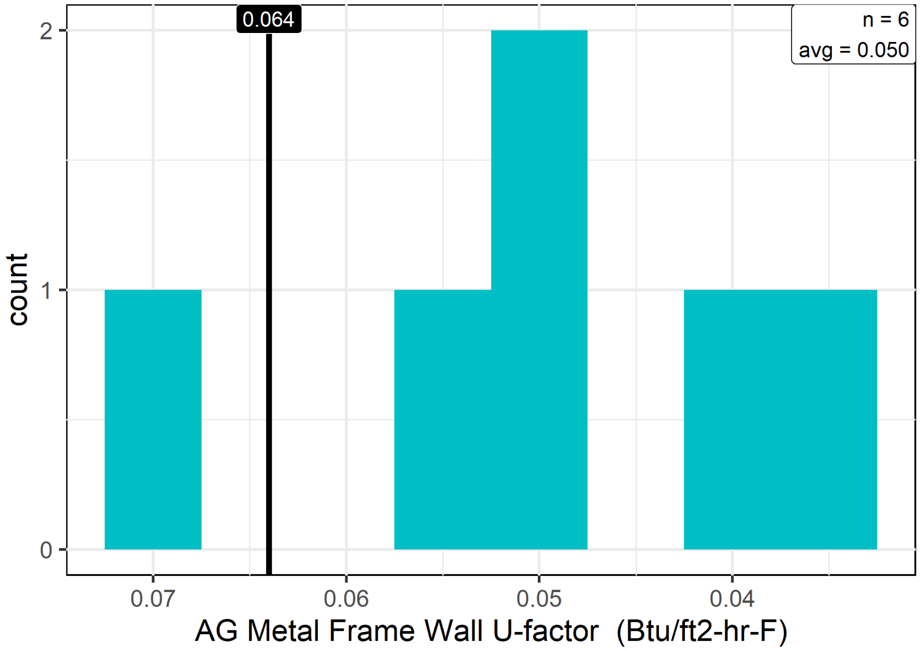


Figure 8. Illinois AG Metal Wall U-factor

Table 9. Illinois AG Metal Wall U-factor

Climate Zone	CZ5	Statewide
Number	6	6
Range	0.034 to 0.069	0.034 to 0.069
Average	0.05	0.05

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.064	0.064	0.064
Compliance Rate	2 of 2 (100%)	3 of 4 (75%)	5 of 6 (83%)

Interpretations:

- 83% of sites with metal-framed walls met CZ 5 requirements of U-0.064. These tended to be 2x4 or 2x6 with varied insulation strategies including batts, insulated sheathing, and/or spray foam. For batt walls, the presence of thermal breaks (which includes continuous insulated sheathing) is essential to meet the code requirement.

3.2.1.5 Slab F-factor

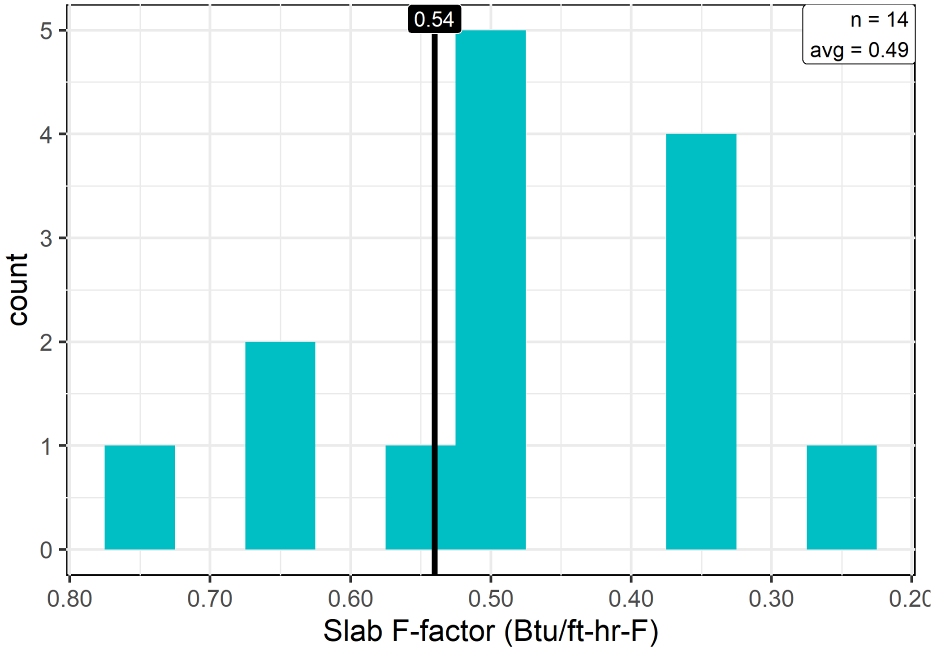


Figure 9. Illinois Slab F-factor

Table 10. Illinois Slab F-factor

Climate Zone	CZ5	Statewide
Number	14	14
Range	0.26 to 0.73	0.26 to 0.73
Average	0.49	0.49

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.54	0.54	0.54
Compliance Rate	4 of 4 (100%)	7 of 10 (70%)	11 of 14 (79%)

Interpretations:

- Almost 80% of slabs met or were better than prescriptive code requirements.
- The highest F-factor slabs typically had uninsulated perimeters.

3.2.1.6 High-efficacy lamps

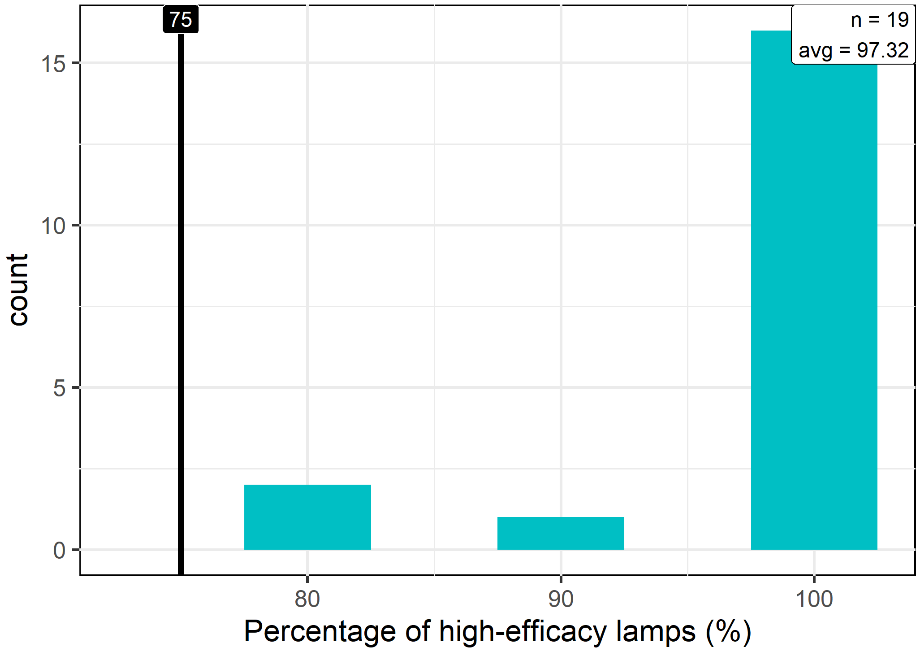


Figure 10. Illinois Percentage of High-Efficacy Lamps

Table 11. Illinois Percentage of High-Efficacy Lamps

Climate Zone	CZ5	Statewide
Number	19	19
Range	80 to 100	80 to 100
Average	97.32	97.32

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	75	75	75
Compliance Rate	6 of 6 (100%)	13 of 13 (100%)	19 of 19 (100%)

Interpretations:

- All buildings with available dwelling unit lighting information were better than the code requirements for high-efficacy lamps. 84% of the compliant sites had 100% high-efficacy lamps installed in the dwelling units.

3.2.1.7 Dwelling unit LPD

LPD of dwelling units is not currently included in the Illinois state residential energy code. Nevertheless, it is an interesting metric, especially given the common characteristic of mostly high efficacy lamps observed in this study.

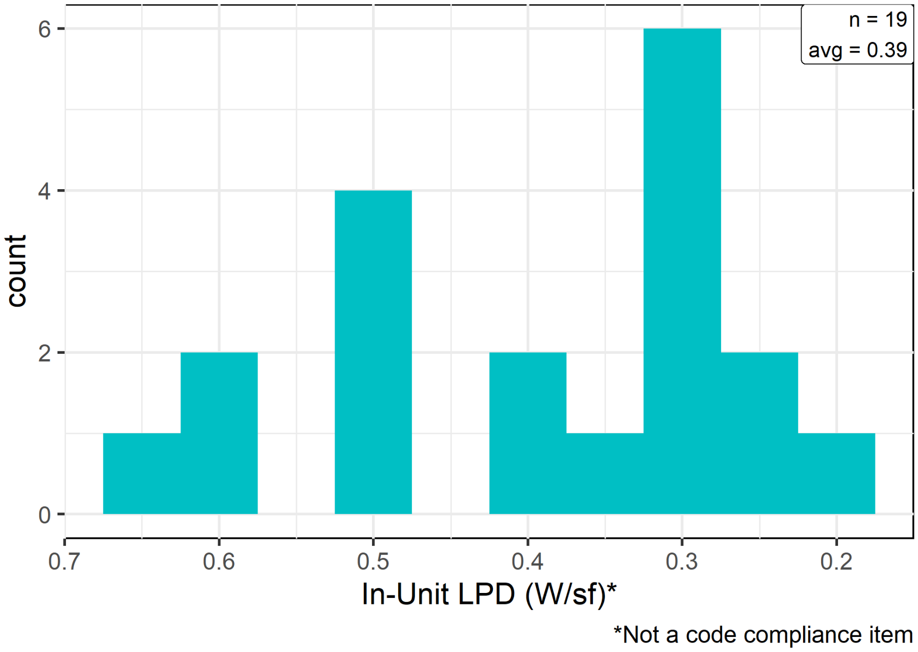


Figure 11. Illinois In-Unit LPD (W/sf)

Table 12. Illinois In-Unit LPD (W/sf)

Climate Zone	CZ5	Statewide
Number	19	19
Range	0.21 to 0.65	0.21 to 0.65
Average	0.39	0.39

Interpretations:

- Average LPDs (based on installed fixtures) in dwelling units ranged from 0.21 to 0.65 W/sf.
- PNNL low-rise multifamily prototype models based on IECC 2012 values use hard-wired LPD values of 0.736 W/sf. Levels in Illinois dwelling units were approximately 50% lower.

3.2.2 Minnesota

Minnesota is comprised of two climate zones: zone 6A and zone 7A. Both zones were sampled and are represented in this analysis. Minnesota buildings sampled in this state had construction start dates between 2015 and 2018 and all were subject to 2015 energy codes, which correspond to the 2012 IECC (with amendments). For many of the key measures summarized in this section, zones 6A and 7A, referred to as CZ6 and CZ7 for the Minnesota State results section, there was no change in standards between climate zones (except for some thermal envelope requirements). Additional summaries can be found in Appendix A – Additional State Characteristics Summaries.

3.2.2.1 Ceiling U-factor

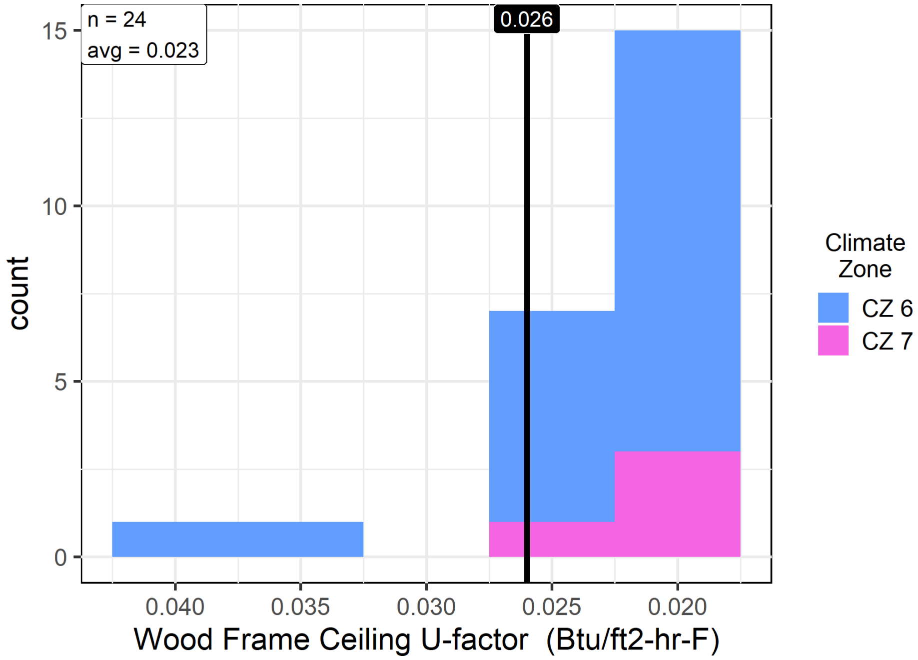


Figure 12. Minnesota Wood Frame Ceiling U-factor

Table 13. Minnesota Wood Frame Ceiling U-factor

Climate Zone	**CZ6**	**CZ7**	**Statewide**
Number	20	4	24
Range	0.019 to 0.041	0.02 to 0.025	0.019 to 0.041
Average	0.023	0.022	0.023
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.026	0.026	0.026
Compliance Rate	18 of 20 (90%)	4 of 4 (100%)	22 of 24 (92%)

Interpretations:

- The majority of buildings met or were better than the code requirements for ceiling/roof U-factor.

- One non-compliant site had R-30 insulation (U-factor of 0.033), while more typical insulation levels were R-40 or higher.
- Two sites had roof deck assemblies. One of these represents the other non-compliant site (U-factor of 0.041). This building had R-23 sheathing.

Non-wood frame ceiling/roof construction: Most sites in Minnesota had wood-truss roof construction; however, several buildings had non-wood roof assemblies.

- A single site had a metal truss roof assembly with a U-factor of 0.045. Even though the attic space was highly insulated, the U-factor did not meet IECC requirements for this assembly (0.031 in CZ 6).

3.2.2.2 Window SHGC

This key item is not currently included in the Minnesota state residential prescriptive code. As a result, data were not collected from a representative sample of buildings and are not summarized in this report. A default value of 0.4 was used for modelling where specific state prescriptive codes had no SHGC requirement. For additional information on model inputs, see Section 4.2 Methodology.

3.2.2.3 Window U-factor

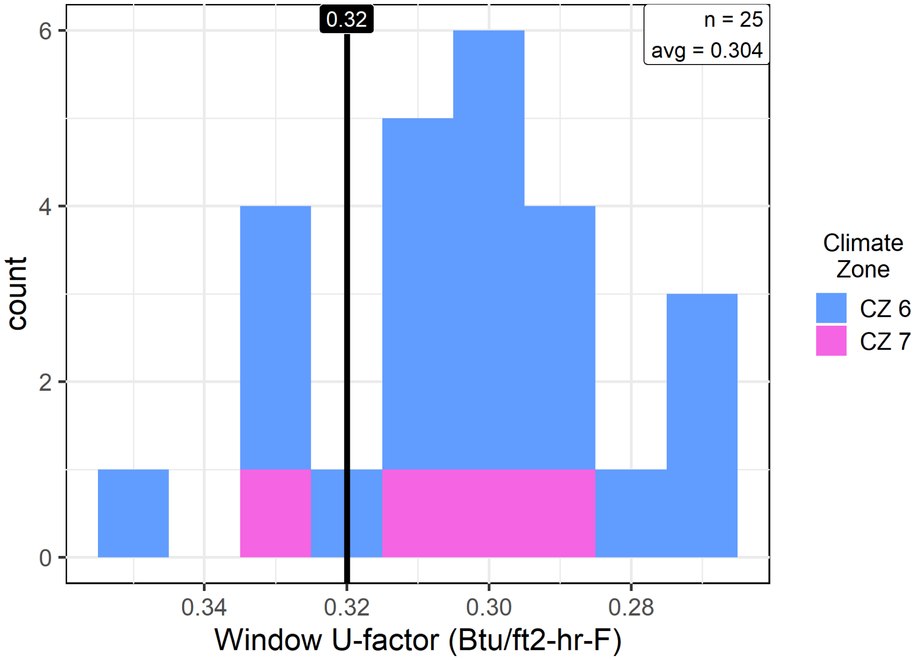


Figure 13. Minnesota Window U-factor

Table 14. Minnesota Window U-factor

Climate Zone	CZ6	CZ7	Statewide
Number	21	4	25
Range	0.27 to 0.351	0.29 to 0.33	0.27 to 0.351
Average	0.303	0.306	0.304
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.32	0.32	0.32
Compliance Rate	17 of 21 (81%)	3 of 4 (75%)	20 of 25 (80%)

Interpretations:

- The majority of surveyed buildings had window U-factors better than prescriptive code requirements.

3.2.2.4 Exterior Above-grade Wall U-factor

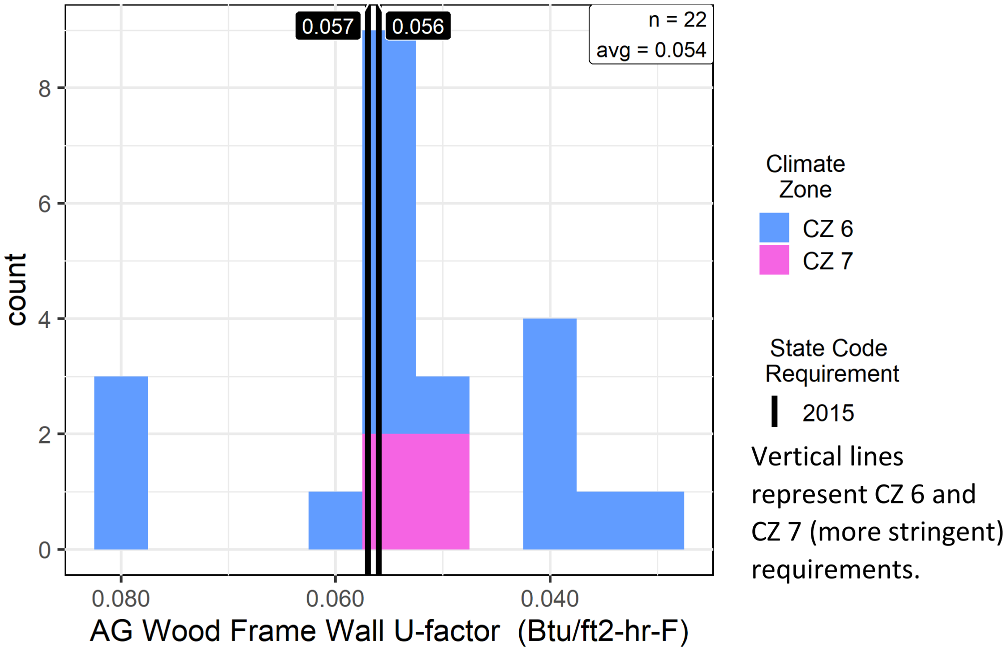


Figure 14. Minnesota Above Grade Wall U-factor (Wood-Frame Walls)

Table 15. Minnesota Above Grade Wall U-factor (Wood-Frame Walls)

Climate Zone	CZ6	CZ7	Statewide
Number	18	4	22
Range	0.029 to 0.080	0.050 to 0.056	0.029 to 0.080
Average	0.054	0.053	0.054
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.057	0.056	0.057 / 0.056
Compliance Rate	14 of 18 (78%)	4 of 4 (100%)	18 of 22 (82%)

Interpretations:

- Most buildings met or were better than wood-framed wall U-factor requirements. The most common construction was 2x6 wood-framed walls with R-21+ insulation and no insulative sheathing.
- The highest U-factor walls were 2x4 wood-framed walls with R-10 insulation, and no sheathing insulation.
- All non-compliant buildings were identified as following the prescriptive path, rather than a performance or trade-off pathway to code compliance.
- Field teams did not have access to buildings in early stages of construction and therefore did not have a way of assessing the quality of insulation installation. It is worth noting, however, that wall insulation U-values include adjustments for framing elements and compression.
- **Non-wood above-grade walls**: A single site had an above-grade mass wall (U-factor of 0.080) as the predominant wall type. This wall did not meet prescriptive requirements for CZ6 (U-0.060). Additionally, two of the surveyed sites were constructed with structural insulated panel (SIP) materials, which achieved a U-factor of 0.038. SIPs are composed of a rigid core of insulation (typically foam) that is sandwiched between two structural skins. They reduce thermal-bridging and increase possible air tightness, leading to highly energy efficient thermal envelopes.

3.2.2.5 Slab F-factor

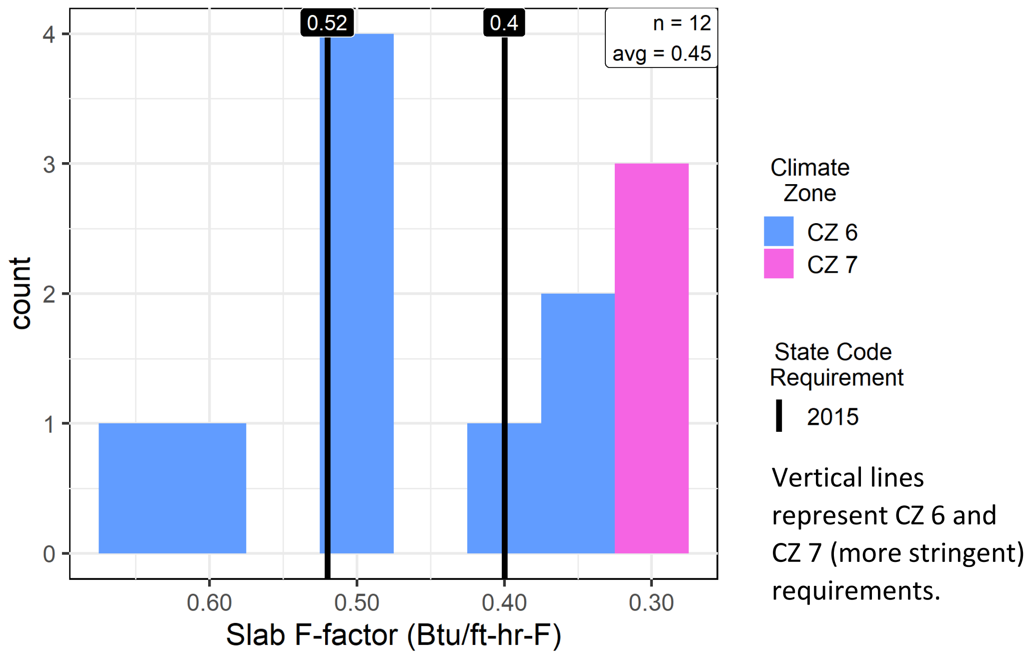


Figure 15. Minnesota Slab F-factor

Table 16. Minnesota Slab F-factor

Climate Zone	CZ6	CZ7	Statewide
Number	9	3	12
Range	0.36 to 0.65	0.30 to 0.32	0.30 to 0.65
Average	0.49	0.31	0.45
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.52	0.40	0.52 / 0.40
Compliance Rate	7 of 9 (78%)	3 of 3 (100%)	10 of 12 (83%)

Interpretations:

- The majority of surveyed buildings met or were better than prescriptive requirements.
- The highest F-factor building used a performance pathway to meet prescriptive code requirements.

3.2.2.6 Below grade walls

Forty-four percent of Minnesota low-rise multifamily buildings had some below-grade space. These were all encountered in CZ 6. Note these were all were semi-conditioned interior parking areas, which require at least R-10 wall insulation versus the usual requirements for fully conditioned space.

Table 17. Minnesota Below-Grade Walls (semi-conditioned space)

Climate Zone	CZ6
Requirement (CZ6 2015 MN Code)	R-10
Number	10
Range	R-10 to R-21
Average	R-12
Compliance Rate	10 of 10 (100%)

Interpretations:

- All sites with semi-conditioned below-grade space met or exceeded the insulation requirements.

3.2.2.7 High-efficacy lamps

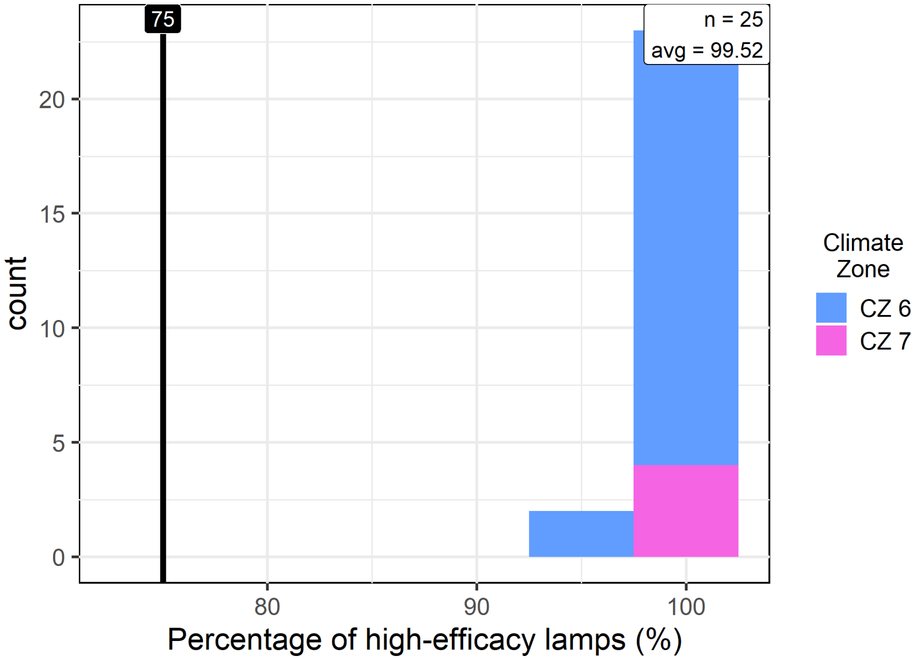


Figure 16. Minnesota Percentage of High-Efficacy Lamps

Table 18. Minnesota Percentage of High-Efficacy Lamps

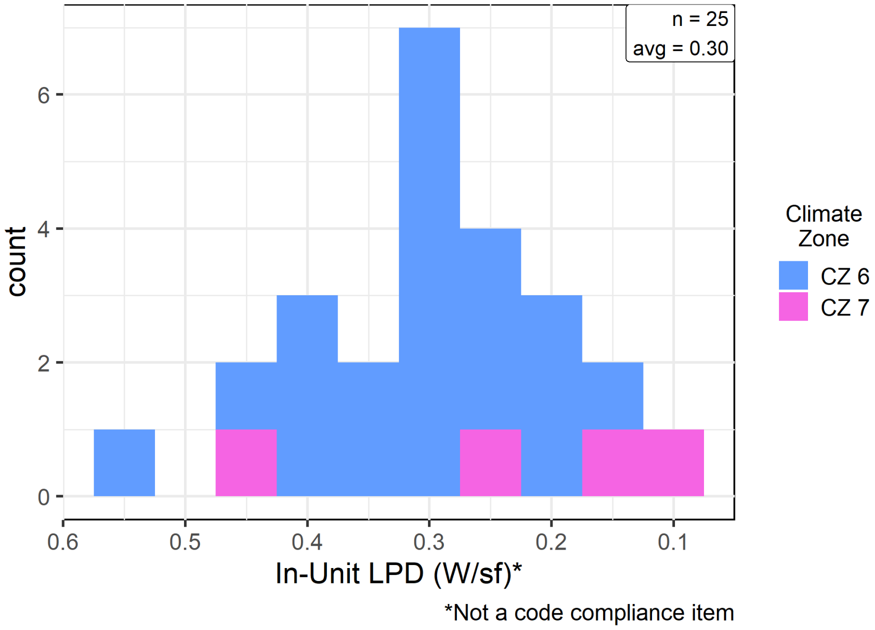
Climate Zone	CZ6	CZ7	Statewide
Number	21	4	25
Range	94 to 100	100 to 100	94 to 100
Average	99.43	100.00	99.52
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	75	75	75
Compliance Rate	21 of 21 (100%)	4 of 4 (100%)	25 of 25 (100%)

Interpretations:

- All surveyed buildings were better than the code requirements for high-efficacy lamps, with over 90% of buildings having all high-efficacy lamps in the dwelling units.
- This code criterion appears well-integrated into current low-rise multifamily construction practices in Minnesota.

3.2.2.8 Dwelling unit LPD

LPD of dwelling units is not currently included in the Minnesota residential energy code. Nevertheless, it is an interesting metric, especially given the common characteristic of mostly high-efficacy lamps observed in this study.



*Not a code compliance item

Figure 17. Minnesota In-Unit LPD (W/sf)

Table 19. Minnesota In-Unit LPD (W/sf)

Climate Zone	CZ6	CZ7	Statewide
Number	21	4	25
Range	0.17 to 0.56	0.09 to 0.46	0.09 to 0.56
Average	0.32	0.24	0.31

Interpretations:

- Average LPDs (based on installed fixtures) in dwelling units ranged from 0.09 to 0.56 W/sf.
- PNNL low-rise multifamily prototype models based on IECC 2012 use hard-wired LPD values of 0.736 W/sf. Levels in Minnesota dwelling units were approximately 60% lower.
- Unlike the measures described to this point, which are subject to residential energy efficiency requirements, lighting power allowances are assessed through commercial energy efficiency requirements. The following lighting summaries were conducted on a subset of the surveyed buildings. Interior corridor and stairwell LPD were calculated for common entry buildings where interior circulation areas are present. Interior and exterior parking LPDs were calculated as applicable to the parking arrangements for a given building. Prescriptive values for interior areas are based on space-by-space interior lighting power allowances.

3.2.3 Oregon

Oregon is comprised of two climate zones: zone 4C and zone 5B. Both zones were sampled and are represented in this analysis. Oregon buildings had construction start dates between 2015 and 2019[18] and were subject to the 2011 and 2014 energy codes, which correspond to the 2009 and 2012 IECC standards (with amendments), respectively. It is also worth noting that for low-rise apartments in Oregon, defined as having three stories or less above grade and an exterior door for each dwelling unit, the convention has been to use the commercial code for prescriptive compliance. For many of the key measures summarized in this section, zones 4C and 5B, referred to as CZ4 and CZ5 for the Oregon State results section, have equivalent standards, and there was no change in the standards between code years (except for interior parking power density requirements ; those summaries are presented in Appendix A – Additional State Characteristics Summaries).

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[18] One Oregon building had a construction start date of 2019; this site was characterized by a plan review only due to construction timing.

3.2.3.1 Ceiling U-factor

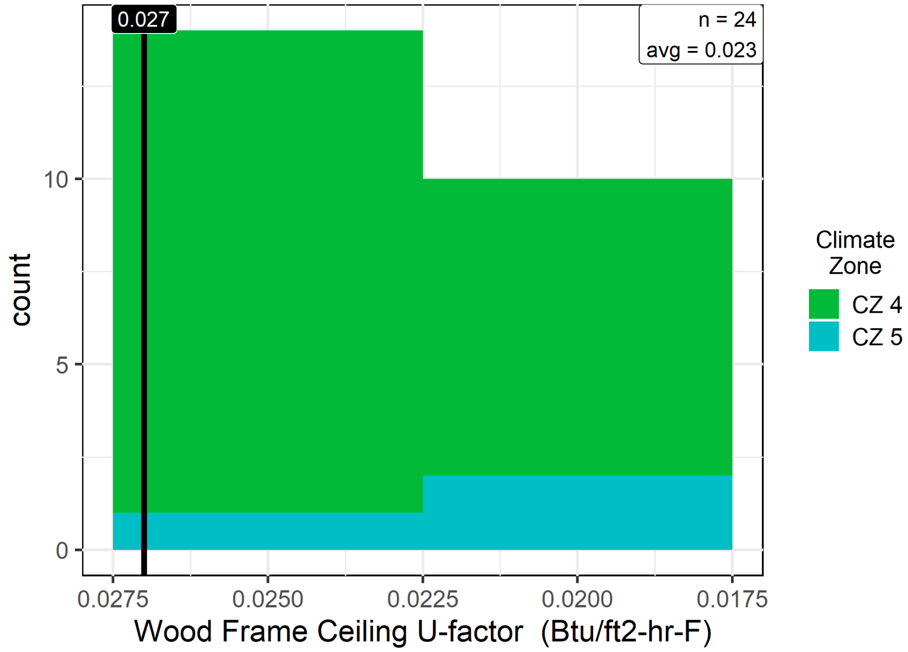

Figure 18. Oregon Wood Frame Ceiling U-factor

Table 20. Oregon Wood Frame Ceiling U-factor

Climate Zone	**CZ4**	**CZ5**	**Statewide**
Number	21	3	24
Range	0.019 to 0.027	0.019 to 0.025	0.019 to 0.027
Average	0.023	0.021	0.023

Climate Zone and Code	**CZ4 (2011 OR Code)**	**CZ4 (2014 OR Code)**	**CZ5 (2011 OR Code)**	**CZ5 (2014 OR Code)**	**Statewide**
Requirement	0.027	0.027	0.027	0.027	0.027
Compliance Rate	8 of 8 (100%)	13 of 13 (100%)	1 of 1 (100%)	2 of 2 (100%)	24 of 24 (100%)

Interpretations:

- All buildings met or were better than the code requirements for ceiling/roof U-factor.
- Typical construction is wood trusses and either batt or blown insulation. A U-factor of 0.025 corresponds to nominal R-38 insulation.

3.2.3.2 Window SHGC

Unlike the other states included in this report, Oregon does have an SHGC requirement for low-rise multifamily. This is because some parts of the commercial energy code apply to low-rise apartments in this state; see especially Table 502.3 of the Oregon 2014 Energy Efficiency Specialty Code.

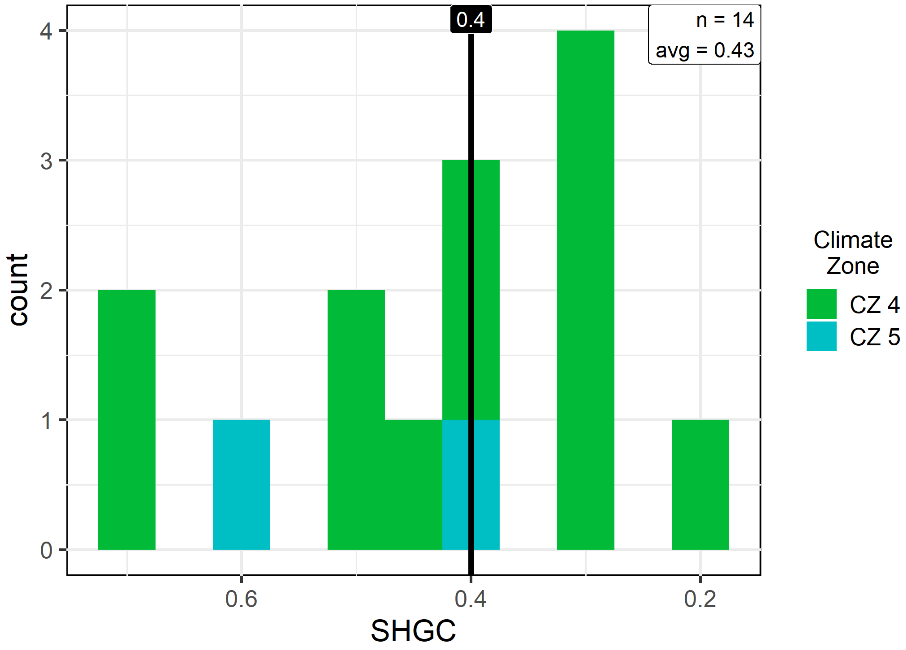

Figure 19. Oregon SHGC

Table 21. Oregon SHGC

Climate Zone	CZ4	CZ5	Statewide
Number	12	2	14
Range	0.22 to 0.7	0.39 to 0.6	0.22 to 0.7
Average	0.42	0.50	0.43

Climate Zone and Code	CZ4 (2011 OR Code)	CZ4 (2014 OR Code)	CZ5 (2011 OR Code)	CZ5 (2014 OR Code)	Statewide
Requirement	0.4	0.4	0.4	0.4	0.4
Compliance Rate	6 of 7 (86%)	1 of 5 (20%)	0 of 1 (0%)	1 of 1 (100%)	8 of 14 (57%)

Interpretations:

- This information was not readily available through architectural drawings nor during site visits. Based on a subset of the buildings, where SHGC information could be obtained, 57% complied with SHGC rating requirements.

- Fenestration was complete commercial units including frame and insulated glazing units rather than site-built or curtain walls, and also included manufactured doors where glazing was greater than 50%.
- Although most buildings met or were better than code requirements, there is opportunity for installation of windows with higher low-e ratings.

3.2.3.3 Window U-factor

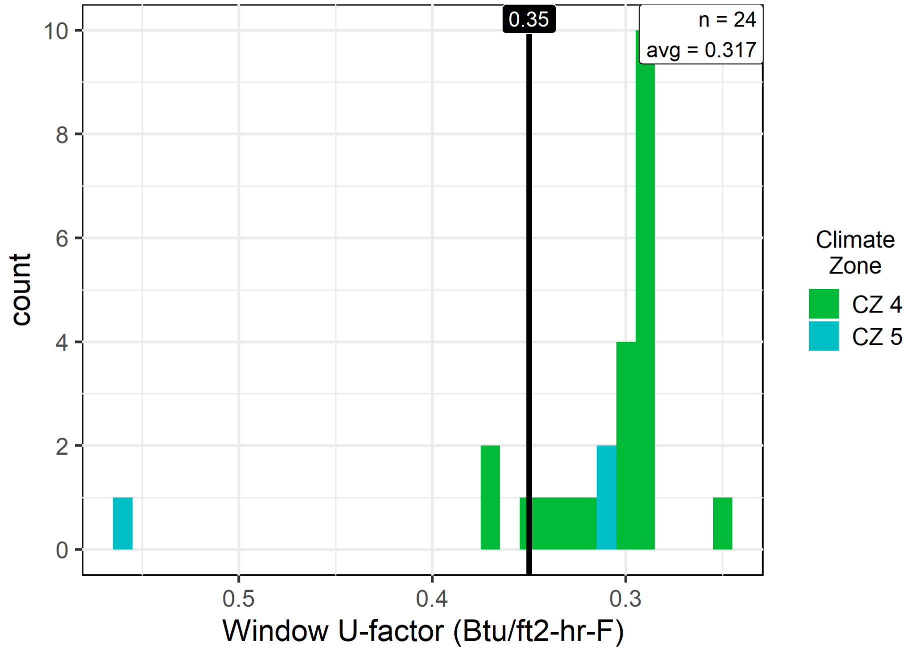

Figure 20. Oregon Window U-factor

Table 22. Oregon Window U-factor

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	0.247 to 0.37	0.305 to 0.559	0.247 to 0.559
Average	0.307	0.392	0.317

Climate Zone and Code	CZ4 (2011 OR Code)	CZ4 (2014 OR Code)	CZ5 (2011 OR Code)	CZ5 (2014 OR Code)	Statewide
Requirement	0.35	0.35	0.35	0.35	0.35
Compliance Rate	7 of 8 (88%)	12 of 13 (92%)	0 of 1 (0%)	2 of 2 (100%)	21 of 24 (88%)

Interpretations:

- Most buildings met or were better than the prescriptive code requirements for fenestration U-factor.
- Typical windows had vinyl frames and the newest low-e coatings, so whole-assembly U-factors were at 0.30 or lower.
- The building with the highest window U-factor used a component trade-off pathway to code compliance.

3.2.3.4 Exterior Above-grade Wall U-factor

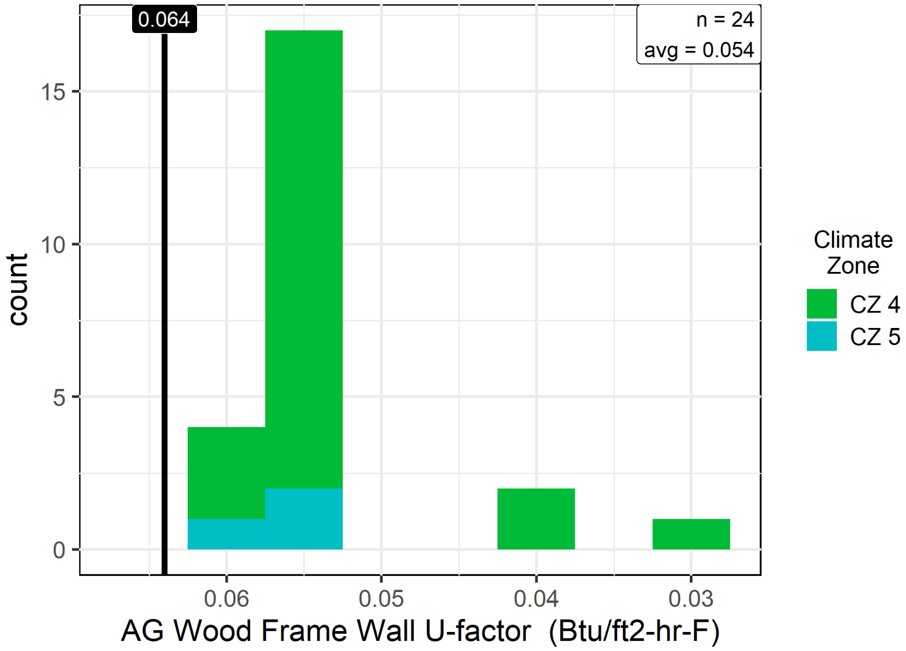

Figure 21. Oregon Above Grade Wall U-factor (Wood-Frame Walls)

Table 23. Oregon Above Grade Wall U-factor (Wood-Frame Walls)

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	0.03 to 0.062	0.053 to 0.061	0.03 to 0.062
Average	0.054	0.057	0.054

Climate Zone and Code	CZ4 (2011 OR Code)	CZ4 (2014 OR Code)	CZ5 (2011 OR Code)	CZ5 (2014 OR Code)	Statewide
Requirement	0.064	0.064	0.064	0.064	0.064
Compliance Rate	8 of 8 (100%)	13 of 13 (100%)	1 of 1 (100%)	2 of 2 (100%)	24 of 24 (100%)

Interpretations:

- All above-grade wood walls exceed the code requirements for this envelope component. These were predominantly 2x6 construction with R-21 insulation. The code requirement is an R-13 batt with an additional R-3.8 continuous rigid insulation.
- The wall construction with the lowest U-factor (0.030) was 2x8 construction with R-30 blown fiberglass in the cavity and R-10 sheathing.
- Field teams did not have access to buildings in early stages of construction and therefore did not have a way of assessing the quality of insulation installation. It is worth noting, however, that wall insulation U-factors include adjustments for framing elements and compression.

3.2.3.5 Slab F-factor

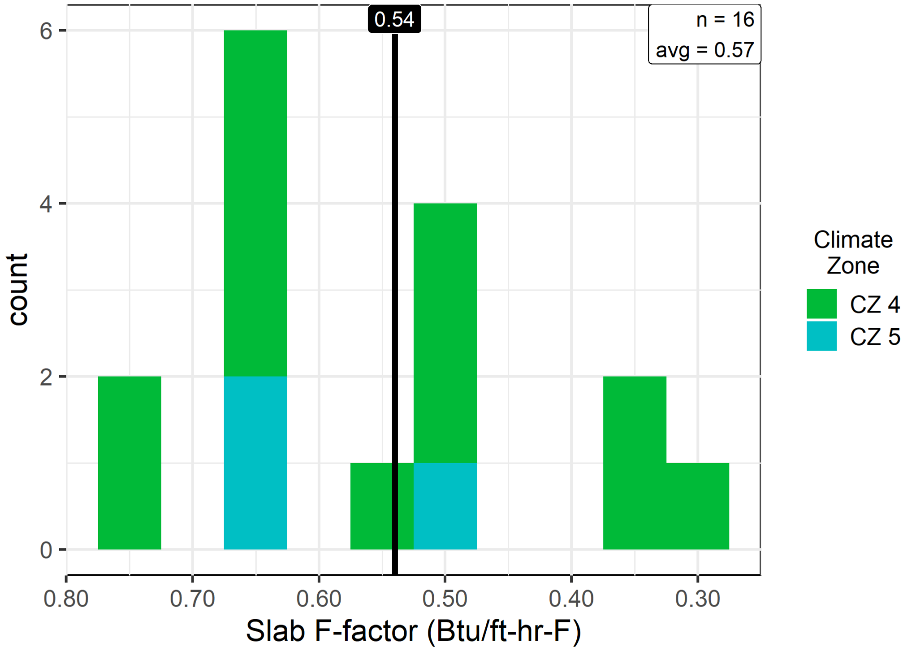

Figure 22. Oregon Slab F-factor

Table 24. Oregon Slab F-factor

Climate Zone	CZ4	CZ5	Statewide
Number	13	3	16
Range	0.32 to 0.73	0.52 to 0.67	0.32 to 0.73
Average	0.56	0.62	0.57
Climate Zone and Code	**CZ4 (2011/2014 OR Code)**	**CZ5 (2011/2014 OR Code)**	**Statewide**
Requirement	0.54	0.54	0.54
Compliance Rate	6 of 9 (67%)	1 of 1 (100%)	7 of 16 (44%)

Interpretations:

- Less than half the surveyed buildings with slabs met F-value prescriptive requirements.
- Most insulated slabs had a F-factor of 0.65 and had R-10 insulation extending horizontally from near the footing edge and no thermal break.
- Approximately 20% of buildings with slabs that didn't meet the prescriptive requirement used the UA tradeoff pathway for code compliance.

3.2.3.6 High-efficacy lamps

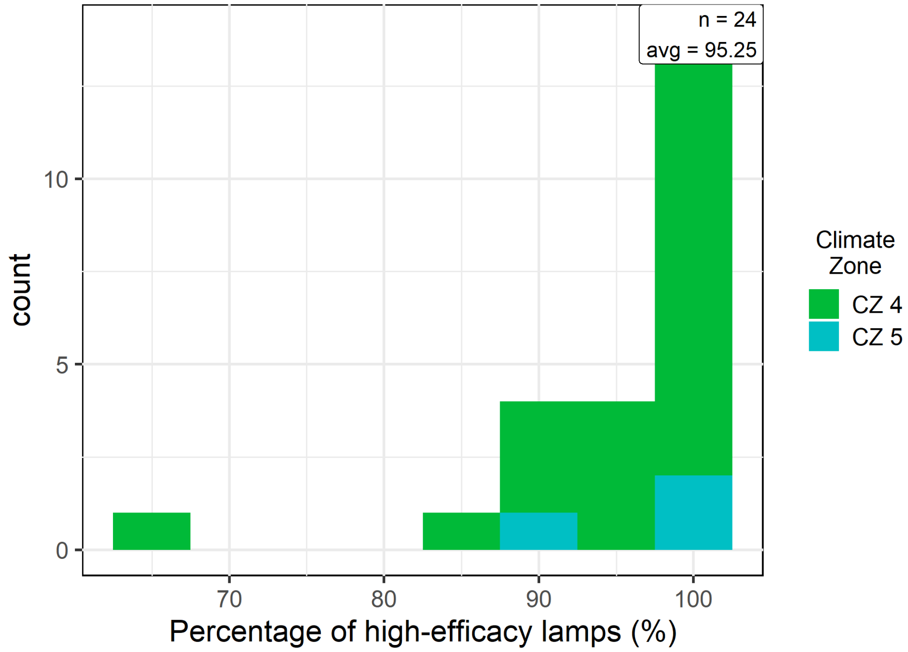

Figure 23. Oregon Percentage of High-Efficacy Lamps

Table 25. Oregon Percentage of High-Efficacy Lamps

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	65 to 100	88 to 100	65 to 100
Average	95.14	96.00	95.25

Interpretations:

- There is no state requirement for high-efficacy lamps in the Oregon state residential energy code. Nevertheless, surveys suggest that buildings generally do better than the IECC suggested levels of 75%. Note 60% of Oregon buildings had 100% high-efficacy lamps installed in dwelling units.

3.2.3.7 Dwelling unit LPD

- Lighting power density of dwelling units is not currently included in the Oregon state residential energy code. Nevertheless, it is an interesting metric, especially given the common characteristic of mostly high efficacy lamps observed in this study.

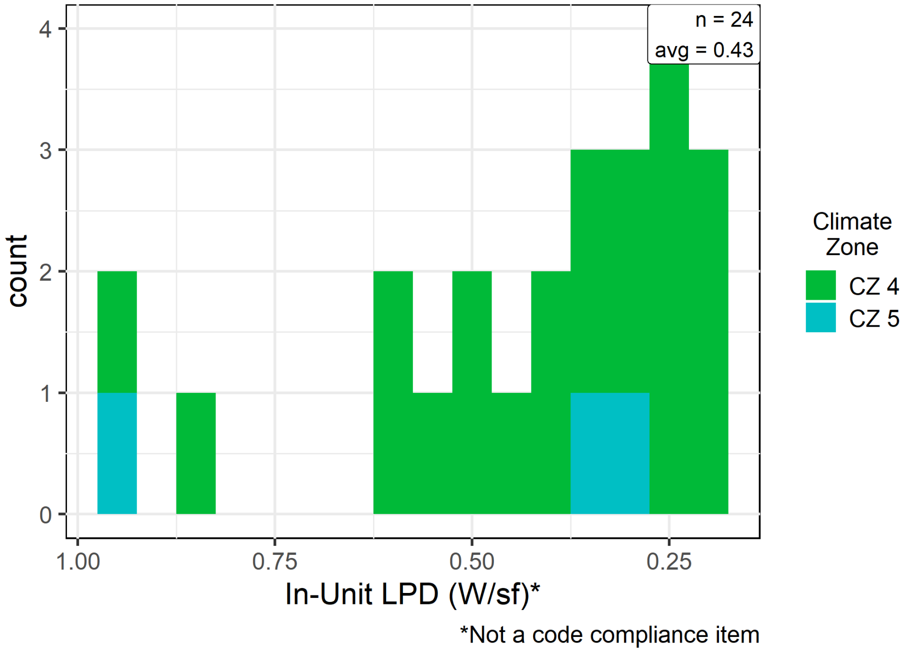

Figure 24. Oregon In-Unit LPD

Table 26. Oregon In-Unit LPD

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	0.2 to 0.94	0.31 to 0.93	0.2 to 0.94
Average	0.42	0.53	0.43

Interpretations:

- Average LPDs (based on installed fixtures) in dwelling units ranged from 0.2 to 0.94 W/sf.
- PNNL low-rise multifamily prototype models based on IECC 2012 use hard-wired LPD values of 0.736 W/sf. Levels in Oregon dwelling units were approximately 60% of these levels.

3.2.4 Washington

Washington is comprised of three climate zones: zone 4C, zone 5B, and zone 6B. The majority of the state's population (and therefore new construction) is in zones 4C and 5B, so only those climate zones were sampled and are represented in this analysis. Buildings sampled in Washington State had construction start dates between 2015 and 2018 and were subject to the 2012 and 2015 residential energy codes, which correspond to the 2012 and 2015 IECC standards (with amendments), respectively. For many of the key measures summarized in this section, zones 4C and 5B, referred to as CZ4 and CZ5 for the Washington State results section, have equivalent standards, and there was no change in the standards between code years (except for specific lighting power density requirements, e.g., common areas and interior parking – those summaries are presented in Appendix A – Additional State Characteristics Summaries).

3.2.4.1 Ceiling U-factor

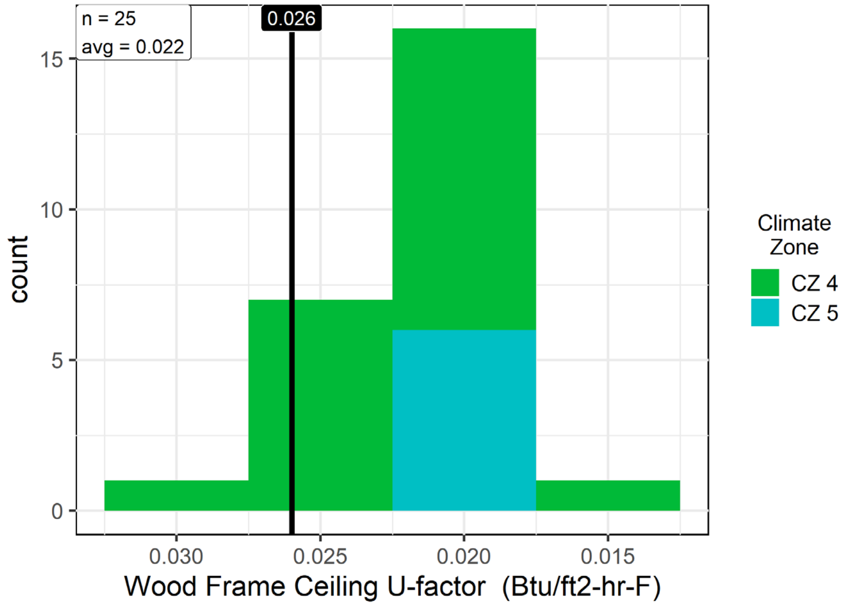

Figure 25. Washington Ceiling/Roof U-factor

Table 27. Washington Ceiling/Roof U-factor

Climate Zone	CZ4	CZ5	Statewide
Number	19	6	25
Range	0.017 to 0.029	0.019 to 0.021	0.017 to 0.029
Average	0.023	0.021	0.022

Climate Zone and Code	CZ4 (2012 WA Code)	CZ4 (2015 WA Code)	CZ5 (2012 WA Code)	CZ5 (2015 WA Code)	Statewide
Requirement	0.026	0.026	0.026	0.026	0.026
Compliance Rate	10 of 11 (91%)	8 of 8 (100%)	1 of 1 (100%)	5 of 5 (100%)	24 of 25 (96%)

Interpretations:

- The majority of buildings met or were better than the code requirements for ceiling/roof U-factor.
- Typical construction is wood trusses and either batt or blown insulation. A U-factor of 0.025 corresponds to nominal R-38 insulation and nominal R-49 corresponds to U-0.021.

3.2.4.2 Window SHGC

This key item is not currently included in the Washington state residential prescriptive code. As a result, data were not collected from a representative sample of buildings and are not summarized in this report. A default value of 0.4 was used for modelling where specific state prescriptive codes had no SHGC requirement. For additional information on model inputs, see Section 4.2 Methodology.

3.2.4.3 Window U-factor

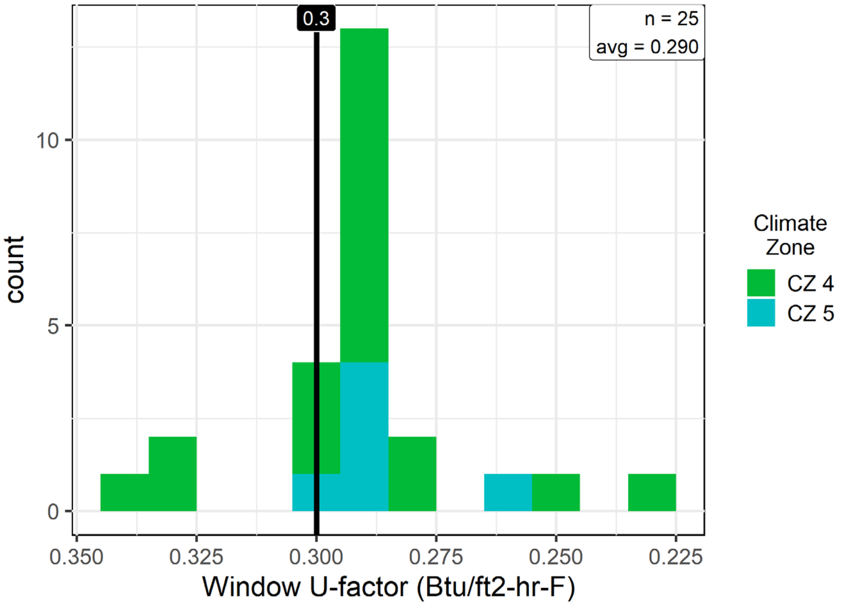

Figure 26. Washington Window U-factor

Table 28. Washington Window U-factor

Climate Zone	**CZ4**	**CZ5**	**Statewide**
Number	19	6	25
Range	0.225 to 0.337	0.256 to 0.299	0.225 to 0.337
Average	0.291	0.287	0.290

Climate Zone and Code	**CZ4 (2012 WA Code)**	**CZ4 (2015 WA Code)**	**CZ5 (2012 WA Code)**	**CZ5 (2015 WA Code)**	**Statewide**
Requirement	0.30	0.30	0.30	0.30	0.30
Compliance Rate	9 of 11 (82%)	7 of 8 (88%)	1 of 1 (100%)	5 of 5 (100%)	22 of 25 (88%)

Interpretations:

- Most buildings were better than the prescriptive code requirements for fenestration U-factor.
- Although uncommon, windows with U-factors above the code minimum tended to have no low-e coating or a single low-e coating. More typically, vinyl double pane windows with multiple low-e coatings were present in surveyed buildings. Modern low-e treatments offer much more energy-saving advantages versus treatments available five or ten years ago.

3.2.4.4 Exterior Above-grade Wall U-factor

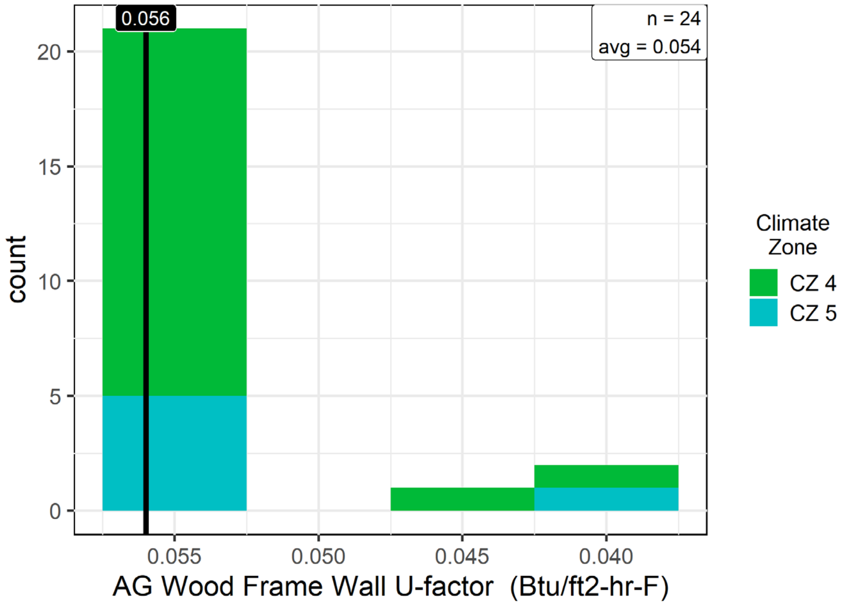

Figure 27. Washington Above Grade Wall U-factor (Wood-Frame Walls)

Table 29. Washington Above Grade Wall U-factor (Wood-Frame Walls)

Climate Zone	**CZ4**	**CZ5**	**Statewide**
Number	18	6	24
Range	0.042 to 0.056	0.042 to 0.056	0.042 to 0.056
Average	0.055	0.054	0.054

Climate Zone and Code	**CZ4 (2012 WA Code)**	**CZ4 (2015 WA Code)**	**CZ5 (2012 WA Code)**	**CZ5 (2015 WA Code)**	**Statewide**
Requirement	0.056	0.056	0.056	0.056	0.056
Compliance Rate	10 of 10 (100%)	8 of 8 (100%)	1 of 1 (100%)	5 of 5 (100%)	24 of 24 (100%)

Interpretations:

- All above-grade wood-framed walls met or exceed the code. These were predominantly 2x6 stud construction with nominal R-21 insulation in cavities, which corresponds to U-0.056.
- Three sites (12.5% of the statewide sample) had U-factors < 0.050 and all included rigid sheathing insulation in addition to cavity insulation.
- As mentioned above, the project did not have access to buildings in early stages of construction and therefore did not have a way of assessing the quality of installation. (That is, were batts cut properly, fluffed into wall-cavities, and so on.) It is worth noting, however, that wall insulation U-factors include adjustments for framing elements and compression[19].
- **Non-wood above-grade walls**: A single site had an above-grade mass wall as the largest above-grade wall type (U-0.055 in CZ4). Above grade mass walls were also compliant with the code requirement (U-0.056 in CZ4).

3.2.4.5 Slab F-factor

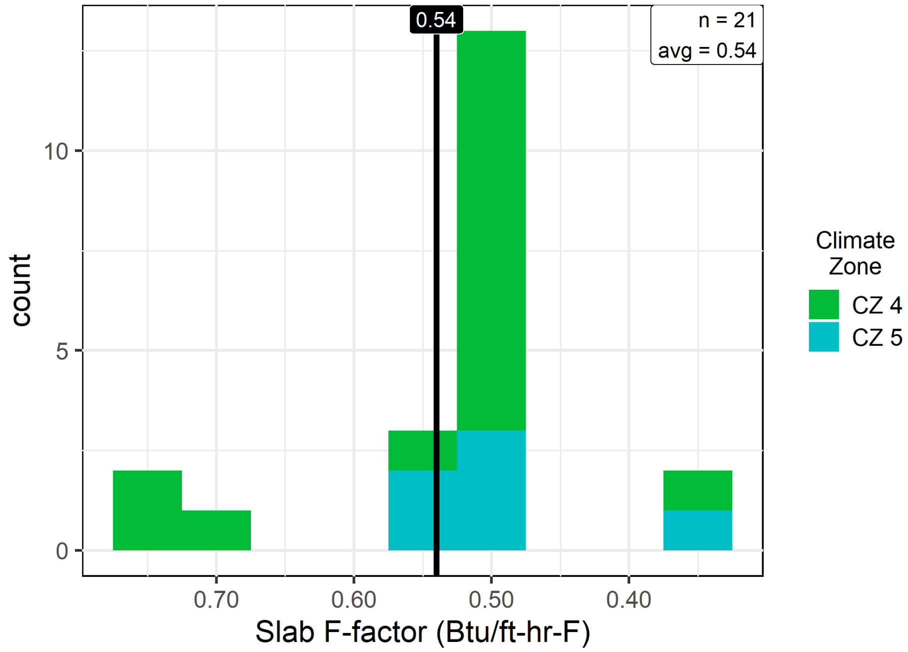

Figure 28. Washington Slab F-factor

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[19] WSEC 2015 Table A103.3.1(2)

Table 30. Washington Slab F-factor

Climate Zone	CZ4	CZ5	Statewide
Number	15	6	21
Range	0.35 to 0.73	0.36 to 0.57	0.35 to 0.73
Average	0.55	0.50	0.54

Climate Zone and Code	CZ4 (2012 WA Code)	CZ4 (2015 WA Code)	CZ5 (2012 WA Code)	CZ5 (2015 WA Code)	Statewide
Requirement	0.54	0.54	0.54	0.54	0.54
Compliance Rate	7 of 9 (78%)	4 of 6 (67%)	1 of 1 (100%)	4 of 5 (80%)	16 of 21 (76%)

Interpretations:

- Approximately three-quarters of the sites with slab foundations met the prescriptive requirement.
- Half of the buildings that did not comply had F-values of 0.55-0.56, narrowly missing the code requirement of 0.54.
- The remaining four buildings with the highest F-values correspond to uninsulated slabs or slabs on grade with R-4 to R-10 insulation, all without thermal breaks.
- The majority of construction was slab on grade (21 of 25 sites). The remaining sites were classified as basements (which includes interior parking). There was only a single heated basement encountered. In this case the basement was the only remaining area of a demolished pre-existing building and was not assessed for compliance.

3.2.4.6 High-Efficacy Lamps

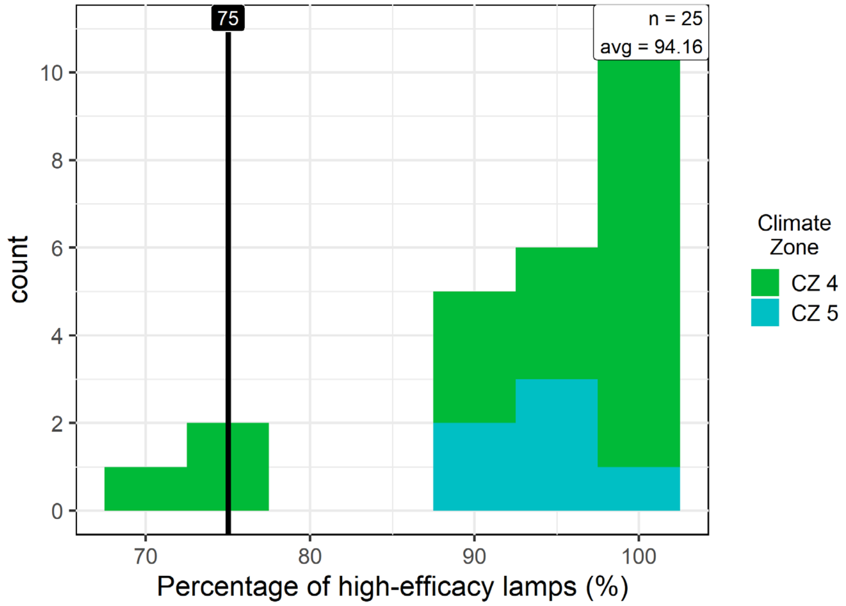

Figure 29. Washington Percentage of High-Efficacy Lamps

Table 31. Washington Percentage of High-Efficacy Lamps

Climate Zone	CZ4	CZ5	Statewide
Number	19	6	25
Range	71 to 100	91 to 100	71 to 100
Average	94.05	94.50	94.16

Climate Zone and Code	CZ4 (2012 WA Code)	CZ4 (2015 WA Code)	CZ5 (2012 WA Code)	CZ5 (2015 WA Code)	Statewide
Requirement	75	75	75	75	75
Compliance Rate	10 of 11 (91%)	8 of 8 (100%)	1 of 1 (100%)	5 of 5 (100%)	24 of 25 (96%)

Interpretations:

- The majority of buildings met or were better than the code requirements for high-efficacy lamps. 92% of the compliant sites had 90% or more high efficacy lamps.
- The single non-compliant building did not fall much below the code requirement.

3.2.4.7 Dwelling unit LPD

Lighting power density (LPD) of dwelling units is not currently included in the Washington state residential prescriptive code. Nevertheless, it is an interesting metric, especially given the common characteristic of mostly high-efficacy lamps observed in this study.

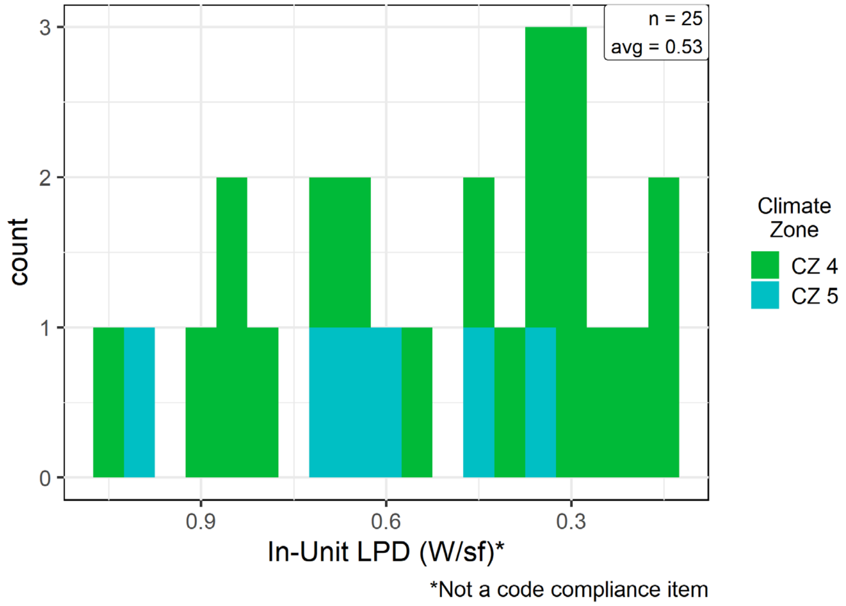

Figure 30. Washington In-Unit LPD (W/sf)

Table 32. Washington In-Unit LPD (W/sf)

Climate Zone	CZ4	CZ5	Statewide
Number	19	6	25
Range	0.13 to 1.06	0.36 to 1.01	0.13 to 1.06
Average	0.50	0.64	0.53

Interpretations:

- Average lighting power densities (based on installed fixtures) in dwelling units ranged from 0.13 to 1.06 W/sf.
- PNNL low-rise multifamily prototype models based on IECC 2012 values use hard-wired LPD values of 0.736 W/sf. Average levels in Washington dwelling units were approximately 30% lower.

4 ENERGY USE ANALYSIS (EUI)

Energy models for each surveyed building were run using the EnergyPlus™ software[20]. The goal was to create a distribution of energy usage that represents the population of low-rise multifamily buildings sampled in the four states. Since this study uses prototype models with identical dimensions, geometry, and window area, the modeled energy use results will differ from the actual energy use. Therefore, the modeled energy use should be considered representative energy consumption from the pseudo low-rise multifamily buildings rather than the actual energy use.

4.1 Context

Sufficient information was collected at each building from the survey to create a representative energy model for each. However, developing individual models with precise geometries for all 95 buildings is time-intensive and was not feasible. Prototype models were used to create seed models where key variables were changed to represent surveyed buildings. Seed models are starting energy models that, when key inputs are adjusted, can represent the wide range of buildings surveyed. Additionally, using seed models reduces variability in non-code driven design, and allows for better comparison of the effect of non-compliant features.

The Pacific Northwest National Laboratory (PNNL) provides 'Residential Prototype Building Models'[21] to simulate both a single-family detached house and a multi-family low-rise apartment building. The multi-family low-rise apartment prototype has 3 floors and 18 units with breezeway ("garden-style") corridors. PNNL has 16 prototype models representing a combination of 4 heating system types (electric resistance, gas furnace, oil furnace, and heat pump) and 4 foundation types (slab-on-grade (SOG), crawlspace, heated basement, and unheated basement).

Seed models were created from PNNL prototype models to better represent two important construction factors: entrance door location and foundation type. The entrance door has two types. A common entry type has indoor corridors and interior entrance doors for each unit. A garden-style type has outdoor corridors and exterior entrances to each unit. The foundation has also two types: a basement type and a slab-on-grade (SOG) type. Four seed models were developed as a combination of entrance and foundation types.

4.2 Methodology

This section provides a brief description of how building surveys are represented as energy simulation models. First, a description of how PNNL prototype models[22] were used to create seed models. Then, how jEplus[23] was used to alter seed models to represent surveyed buildings. The following sections provide a general outline of key details needed to understand the energy modeling methodology. More details are provided in Appendix C – Modeling Workflow and Appendix D – DCI to EnergyPlus.

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[20] https://energyplus.net/

[21] https://www.energycodes.gov/development/residential/iecc_models

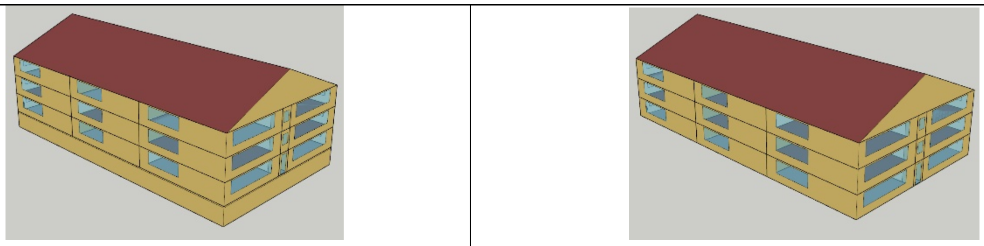
[22] https://www.energycodes.gov/development/residential/iecc_models

[23] jEplus is a graphical user interface for running parametric analysis with EnergyPlus

Appendix C – Modeling Workflow provides more description of the modeling workflow and Python[24] scripts used to manage data. Appendix D – DCI to EnergyPlus provides more description of how surveyed data is processed for energy modeling inputs.

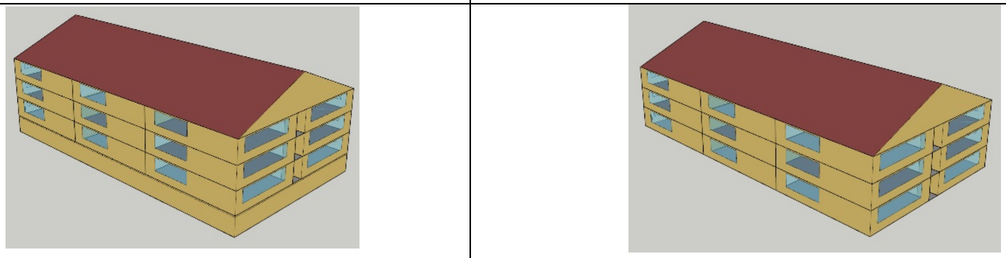
4.2.1 Seed Models

Two garden-style prototype models (heat pump with slab-on-grade and heat pump with heated basement) were downloaded from the PNNL website. Garden-style models have no enclosed corridors. Then, model adjustments were made to the original models to generate common entry prototype models. Corridor geometry and thermal zones were added manually using Euclid[25]. EPPY scripts[26] were used to add the HVAC system, modify ground conditions, add lights, add thermostat controls, adjust constructions, and set ground temperatures. Figure 31 shows the 4 seed models used in this project – the original garden-style prototypes and the adjusted common entry types.



(a) Common entry – Basement

(b) Common entry – Slab on grade



(c) Garden style – Basement

(d) Garden style – Slab on Grade

Figure 31. Seed Models

4.2.2 DCI Data Extraction

Before building-survey information could be input into EnergyPlus, it had to be extracted from building survey data sets and organized to conform to model input requirements. Refer to Section 3.1 Methodology for details on the data extraction and consolidation process.

4.2.3 jEplus – Description and Use

After the seed models were created, jEplus was used to alter select EnergyPlus inputs in order to best represent the buildings surveyed. It allows specific EnergyPlus inputs to be replaced with variables.

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[24] https://www.python.org/

[25] https://bigladdersoftware.com/projects/euclid/

[26] https://github.com/santoshphilip/eppy

Variables were added to seed models using EPPY scripts. See Appendix C – Modeling Workflow for more details.

The approach models variations in HVAC equipment COPs, LPDs, U-factors, service hot water equipment efficiencies, and hot water circulation losses, but it cannot capture changes in building geometry, including window-to-wall ratio. Service hot water was primarily electric resistance and gas heating and field-reported equipment efficiencies were used directly for model inputs. Hot water circulation losses are only based on whether there was a central hot water system because no information was collected on insulation thickness. A representative COP was calculated and used for different mechanical systems; see the next section for more detail. A description of mechanical systems modeled and calculations for their representative COPs is in Section 4.2.4 HVAC Systems Equivalent COP Calculation. In the few cases where U-factors or LPDs were missing from the building survey, they are filled in with code minimums. When missing, SHGC values were filled in with code minimums, or, if no code minimum existed, 0.4.

See Appendix D – DCI to EnergyPlus for more description of how surveyed data are used to construct EnergyPlus Inputs.

4.2.4 HVAC Systems Equivalent COP Calculations

Surveyed mechanical systems were classified into seven heating equipment types and six cooling equipment types. Heating equipment types include electric resistance heater, gas furnace, hydronic baseboard with gas boiler, packaged terminal heat pump (PTHP), split system heat pump, water source heat pump (WSHP) with electric boiler, and water-source heat pump with gas boiler. Cooling equipment types include packaged terminal air conditioner (PTAC), packaged terminal heat pump (PTHP), split system air conditioner, split system heat pump, water-source heat pump, and window air conditioner.

All seed models use the AirLoopHVAC:UnitaryHeatPump:AirToAir EnergyPlus object with a Coil:Cooling:DX:SingleSpeed cooling coil and Coil:Heating:DX:SingleSpeed heating coil.

jEplus is used to adjust COPs and performance curves for both space heating and cooling coils. The COPs for heating and cooling coils are adjusted separately to match the representative COP of the surveyed building's mechanical system type. Similarly, performance curves are adjusted to match the building's mechanical system type.

Table 33 and Table 34 list representative COPs and performances curves for the range of mechanical systems surveyed.

Table 33. Representative Input Values of Heating Equipment

Heating Equipment type	Performance curves	Representative COP
Electric resistance heater	Flat	1.00
Gas furnace	Flat	0.80
Hydronic baseboard (Gas Boiler)	Flat	0.80
PTHP	refrigeration	3.60
Split System HP	refrigeration	3.40
Water Source HP (Elec Boiler)	refrigeration	0.98
Water Source HP (Gas Boiler)	refrigeration	0.83

Table 34. Representative Input Values of Cooling Equipment

Cooling Equipment Type	Performance curves	Representative COP
PTAC	refrigeration	3.20
PTHP	refrigeration	3.20
Split system AC	refrigeration	3.10
Split system HP	refrigeration	3.20
Water source HP	refrigeration	2.14
Win AC	refrigeration	3.20

Each system type has a representative COP derived from the federal regulation (highest COP value out of four states), based on one ton of cooling capacity. Water source heat pumps have cascading equipment effects on COP. An equivalent COP of the entire system was calculated based on the actual system of one arbitrary site and the federal equipment COP requirement (see Appendix B – Equivalent COP Calculations).

Two performance curves are used – flat and refrigeration. The flat performance curve is used for gas and electric resistance heating. Flat curves do not change COP based on load or condenser (heat source/sink) temperature. A generic refrigeration curve is used to represent all systems that use vapor compressor cycles. The refrigeration curve alters COP based on building load and heat source/sink temperature.

4.3 Discussion of Results

This section discusses results for the Energy Use Analysis, which was an exercise in creating representative models of each building survey. Each building was modeled from the four seed models, and an EUI was calculated. Buildings are compared in terms of EUI.

Energy Comparison Metric - EUI

Energy use intensity (EUI) is the industry standard metric for comparing building energy use. EUI is kBtu per square foot per year. It gives an understanding of the energy use per year relative to the size of the building. In a residential building, living space is the floor area that matters the most. This is what determines the number of available units and therefore the occupational capacity of the building. The

highest energy use in a residential building is in the occupied units. Because additional floor area from basement storage or garage space only confuses the EUI calculation, they have been omitted from the EUI calculation. The reason is that both basement storage and garage space use very little energy but have
a large area, so if their areas were included, the EUIs for those buildings would appear artificially low.

Each seed model has the same number of living spaces. Floor area from the common slab on grade model was used in order to compare buildings with corridors, without corridors, with basements, and without basements. Therefore, the EUI presented in these results is not a surveyed building's actual EUI, but it is representative of the energy use per available living space. Basements and semi-heated parking garages are not considered part of the building's floor area, but outdoor corridors are considered part of the building area in garden-style buildings.

Results by State

Results presented below are broken up by state. Two figures are provided for each state studied: an EUI histogram and an end-use stacked bar plot.

Histograms visualize the distribution of data. They show centering, dispersion, and shape of a dataset. The histograms for each state provide a visualization of the EUI distribution of multifamily buildings surveyed in those states. Climate zones are represented as different colors. No baseline EUI was shown since EUIs change so dramatically with mechanical system design choices (all of which meet code) that it did not make sense to include a single baseline EUI for reference.

No state currently requires that a maximum EUI be met, although this has been discussed in Washington state (at least for commercial buildings). For some perspective, new multifamily buildings in Seattle have EUIs that average around 30 kBtu/ft2-yr; it is likely that buildings built to PassivHaus standards could reduce this to around 20 kBtu/ft2-yr in Seattle. Average commercial buildings in Seattle have an EUI of about 70 kBtu/ft-yr and the most efficient commercial buildings have EUIs of less than 25 kBtu/ft2-yr.[27] The same building sited in a continental climate such as Illinois or Minnesota would be expected to have an EUI somewhat higher.

End-use stacked bar plots provide a way to compare both total EUI and EUI by end-use. End-uses included are cooling, heating, fans and ventilation, lighting, hot water, and appliances and equipment. In all buildings in all states, appliances and equipment account for just over 10 EUI points in each building surveyed. However, surveys gave little information on appliances and equipment and it is not regulated by code, so PNNL prototype model assumptions were used for all models.

Hot water, heating, and cooling are the three largest variable end-uses. Larger EUIs are driven by these three end-uses. Lighting is secondary to hot water, heating, and cooling. LED lighting is now so common that most buildings have an energy-conscious lighting design. Energy usage from fans and ventilation is small.

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[27] https://data.seattle.gov/dataset/2018-Building-Energy-Benchmarking/7rac-kyay

Weather Files

Weather Files used for each state and climate zone are shown in Table 35. EnergyPlus™ Weather Files (EPW) were downloaded from the internet[28].

Table 35. Weather Files used for Energy Modeling by Climate Zone

State	Climate Zone	Weather File
IL	5A	USA_IL_Chicago-OHare.Intl.AP.725300_TMY3.epw
MN	6A	USA_MN_Minneapolis-St.Paul.Intl.AP.726580_TMY3.epw
MN	7A	USA_MN_Bemidji.Muni.AP.727550_TMY3.epw
OR	4C	USA_OR_Portland.Intl.AP.726980_TMY3.epw
OR	5B	USA_OR_Redmond-Roberts.Field.726835_TMY3.epw
WA	4C	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMY3.epw
WA	5B	USA_WA_Spokane.Intl.AP.727850_TMY3.epw

4.3.1 Illinois

None of the Illinois buildings participating in the survey fell into climate zone 4A. Chicago, the largest city in Illinois, falls in climate zone 5A and most of the Illinois population is in 5A (Figure 32).

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[28] https://energyplus.net/weather

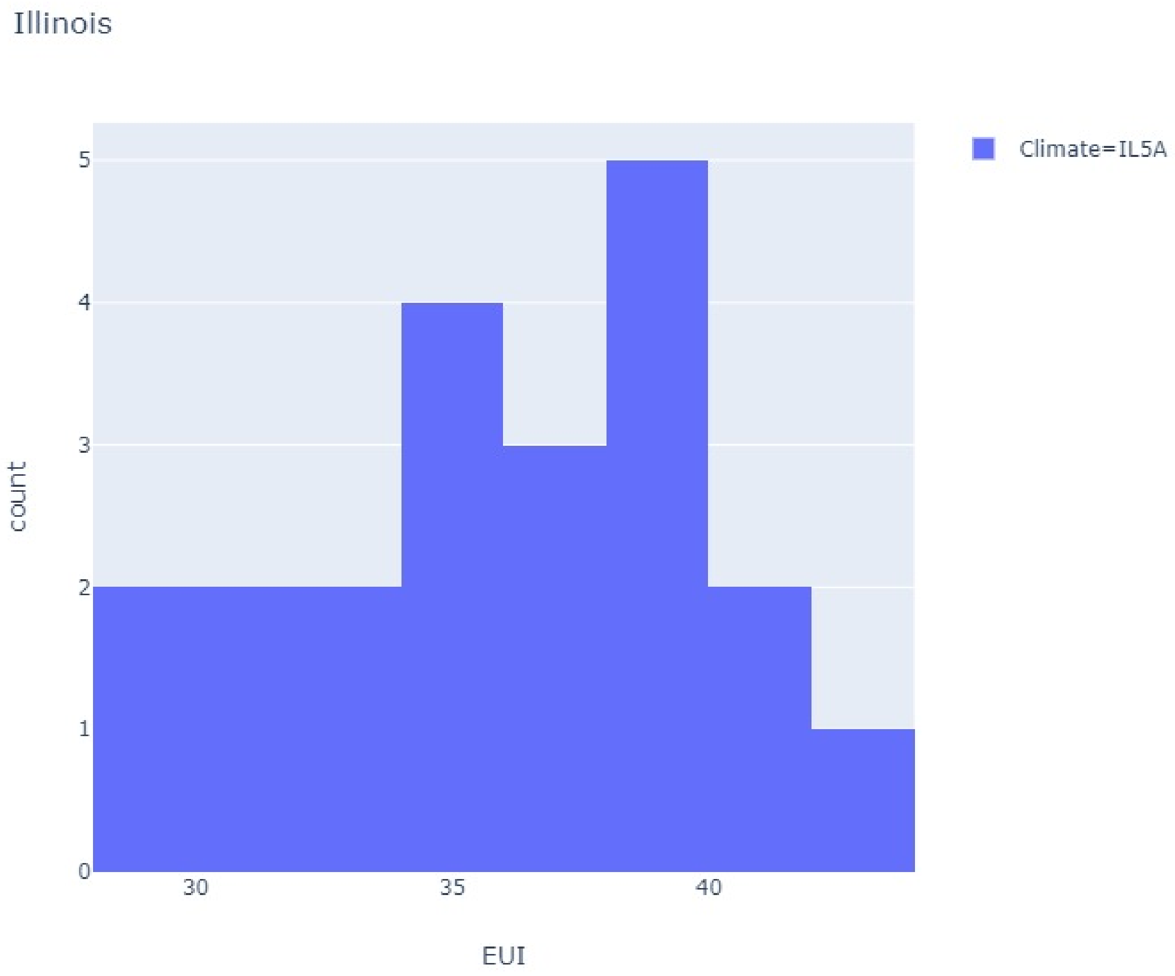

Figure 32. Illinois EUI Histogram

Figure 33 shows the EUI from each surveyed site in Illinois broken out by end-use.

The largest modeled EUI of the buildings surveyed in Illinois was 50. Mechanical design contributed to its high energy use. This building uses gas furnace heating, PTAC cooling, and central gas boiler hot water.

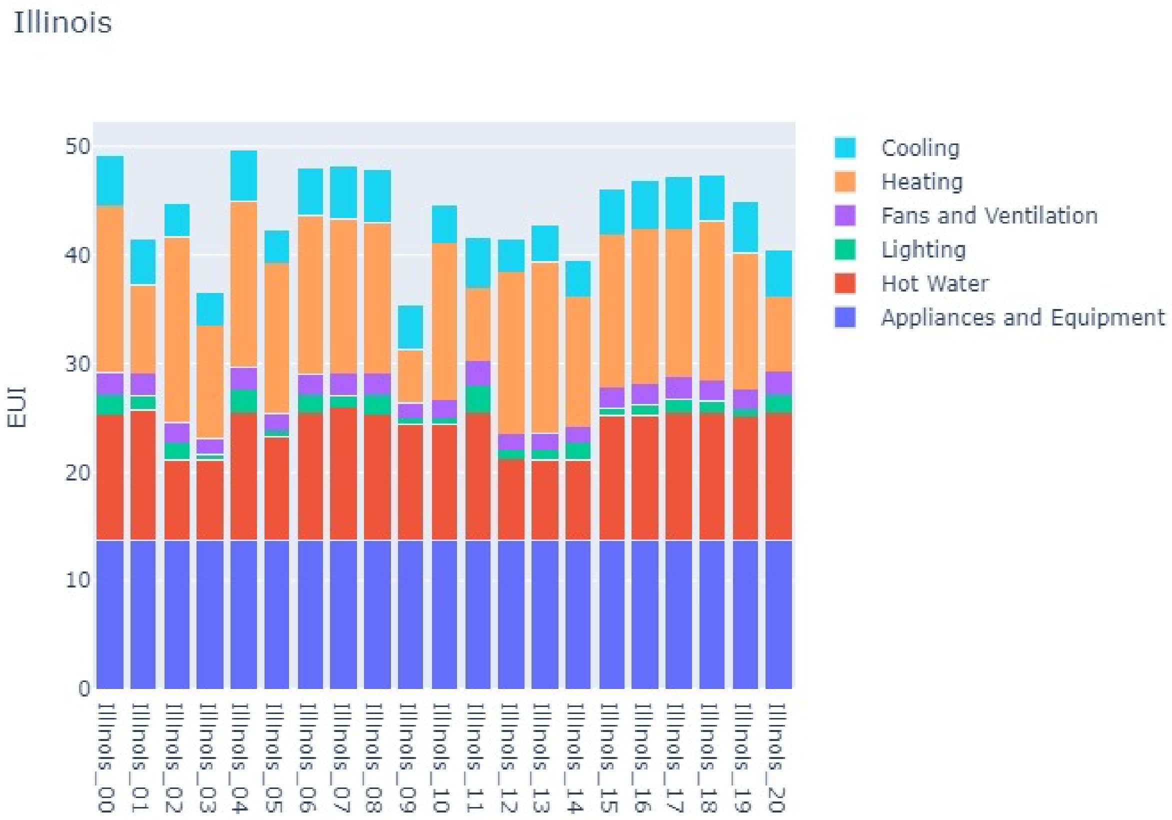

Figure 33. Illinois EUI end-use stacked bar plot

According to energy modeling results, gas furnace heating used more energy than any other mechanical heating system. Gas furnaces operate with natural gas at 80% efficiency, which is lower than electric resistance heating, and much lower than heat pump heating. Of the buildings surveyed in Illinois, a majority used gas furnace heating. In buildings that used gas furnaces, 11-16 EUI was from heating energy.

Hot water energy use is driven most significantly by whether the system is central or in-unit. Central systems require hot water to be circulated throughout the building in pipes to ensure water at a desirable temperature is always near the fixtures. Recirculating hot water through pipes increases the amount of heat lost when compared to in-unit systems as the surface area of a piping system is much greater than the surface area of an individual tank. As a result, central hot water systems typically account for about 11 EUI, whereas in-unit hot water systems typically account for about 7 EUI.

The lowest modeled EUI of the buildings surveyed in Illinois was 35. It accomplished this low EUI with both its mechanical design and a high-performance envelope. (It was built to PHIUS standards). It used PTHPs for heating and cooling and had low window U-factor and exterior wall U-factors. The combination of efficient mechanical equipment and high-performance envelope drive both the heating and cooling EUI down to 5 and 4 EUI respectively. For buildings in Illinois with heat pumps and lower performing envelopes, heating accounted for 6-7 EUI and cooling accounted for 4-5 EUI.

Apartment-weighted split of fuel use (at the site level across the state) was calculated. Natural gas and electricity usage are as follows:

- 43.9% Natural Gas
- 56.1% Electricity

The buildings surveyed suggest that Illinois uses only a slightly higher percentage of electricity than natural gas. Most buildings used natural gas for space heating and hot water heating.

4.3.2 Minnesota

As Figure 34 shows, far fewer surveys were done in the Minnesota 7A climate zone; this is related to the lower number of eligible buildings in this zone leading up to the study period. Climate zone 7A has slightly colder winters than Zone 6A, and we would therefore expect to see more heating in those buildings, but not by a lot.

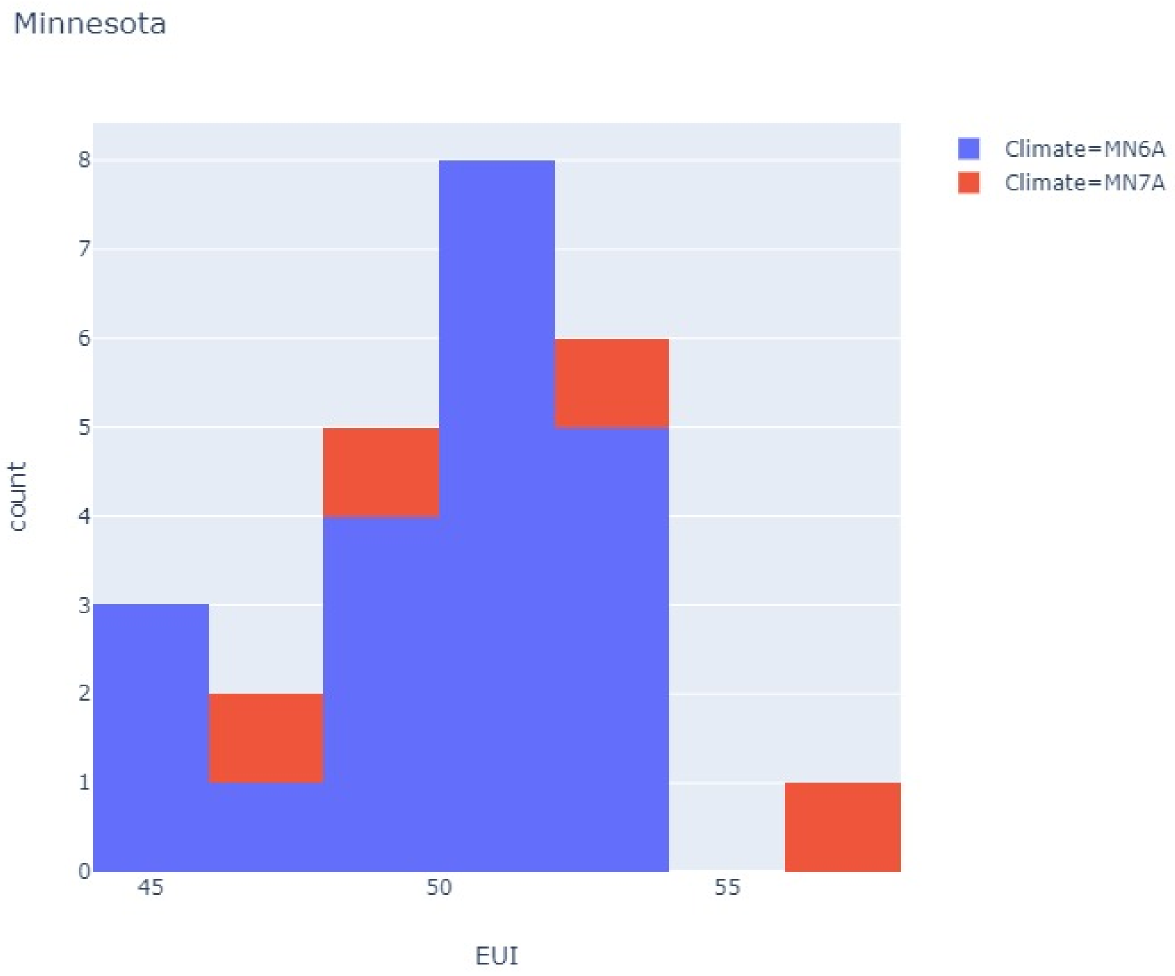

Figure 34. Minnesota EUI Histogram

Figure 35 shows the EUI from each surveyed site in Minnesota broken out by end-use.

The largest modeled EUI of the buildings surveyed was 60. The building's mechanical design contributes most significantly to its high energy use. It used gas furnace heating and PTAC cooling.

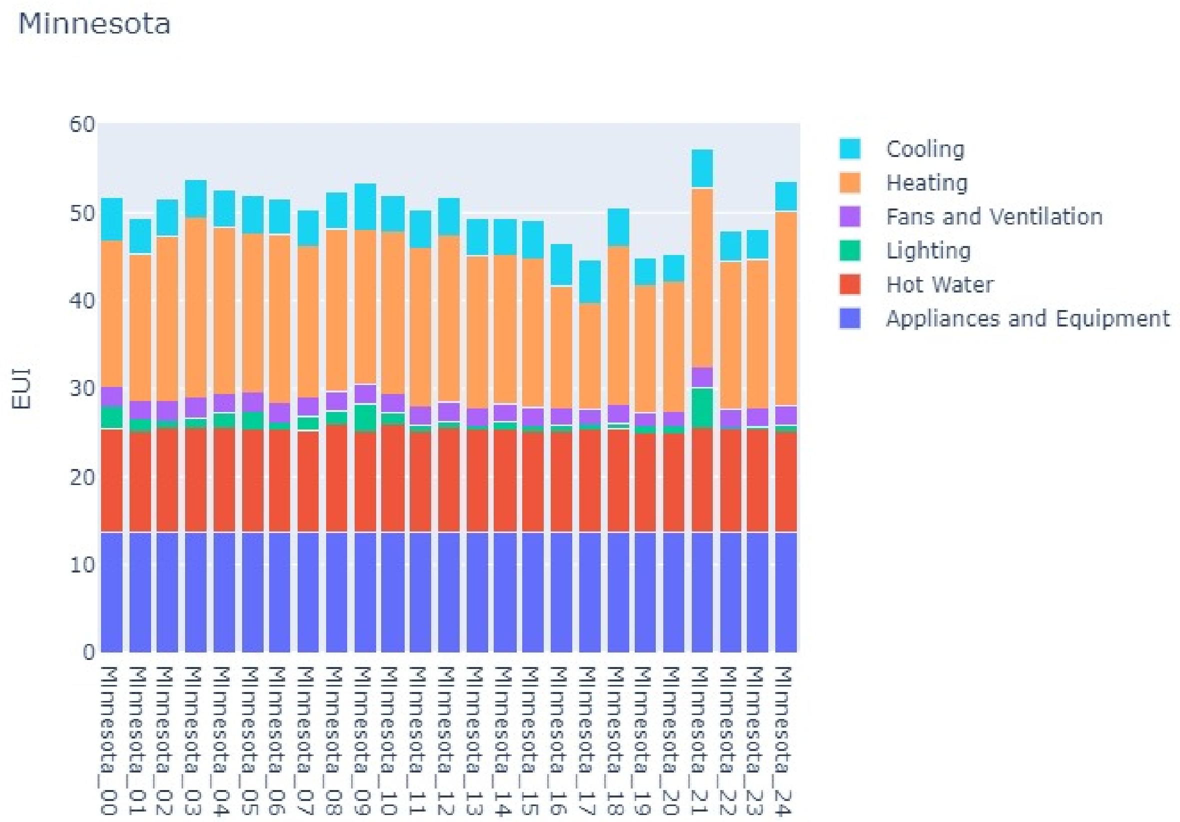

Figure 35. Minnesota EUI end-use stacked bar plot.

Some sites in Minnesota used water-source heat pumps for heating and cooling. The water is heated with a gas boiler, circulated through the building, then heat pumps extract heat from the water loop and use it for space heating. In this mechanical design, energy is spent twice to get heating: first through the natural gas boiler, and then with electricity by the heat pump. Additionally, during the heating season energy is lost through heat transfer as hot water is circulated throughout the building.

Water-source heat pumps can provide savings in buildings with a significant amount of simultaneous heating and cooling, all pulling from the same water loop. However, very little simultaneous heating and cooling is present in the EnergyPlus models run for this study. In general, simultaneous heating and cooling is low in residential buildings.

A handful of buildings surveyed in Minnesota had relatively low modeled EUIs considering Minnesota's cold climate. Buildings were heated predominately with gas furnaces, accounting for 12-17 EUI points or central plant systems accounting for 14-18 EUI points. Cooling was predominately PTAC, the least efficient cooling source, accounting for 3-5 EUI points. Because there was little alteration between mechanical systems used in Minnesota, relatively low modeled EUIs were achieved with improved thermal envelopes.

Apartment-weighted split of fuel use (at the site level across the state) was calculated. Natural gas and electricity usage are as follows:

- 42% Natural Gas
- 58% Electricity

The buildings surveyed suggest that Minnesota uses only a slightly higher percentage of electricity than natural gas. Most buildings used natural gas for space heating and hot water heating.

4.3.3 Oregon

As seen in Figure 36, fewer surveys were done of buildings in the Oregon 5B climate zone, where the population is much lower. 5B has far colder winters, and we would therefore expect to see more heating in those buildings. However, all three buildings sampled in 5B had heat pump heating and therefore heating energy is significantly reduced in those buildings, so no significant energy usage difference is observed in the heating end-use category.

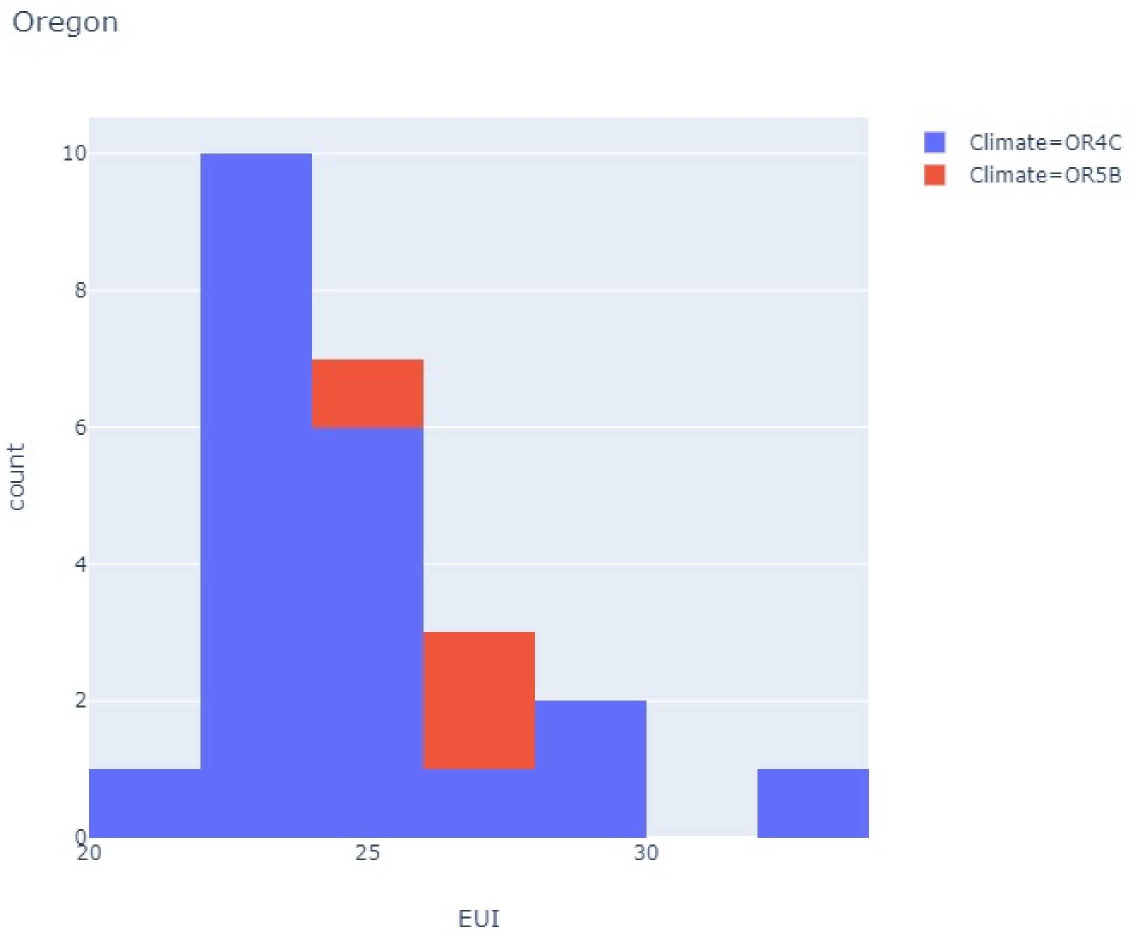

Figure 36. Oregon EUI Histogram

Figure 37 shows the EUI from each surveyed site in Oregon broken out by end-use.

Oregon's highest EUI site was almost 40 EUI. The site had high energy use due mostly to an inefficient mechanical design. The mechanical system included a gas furnace, split system air conditioner. The hot water system was a central plant, natural gas system.

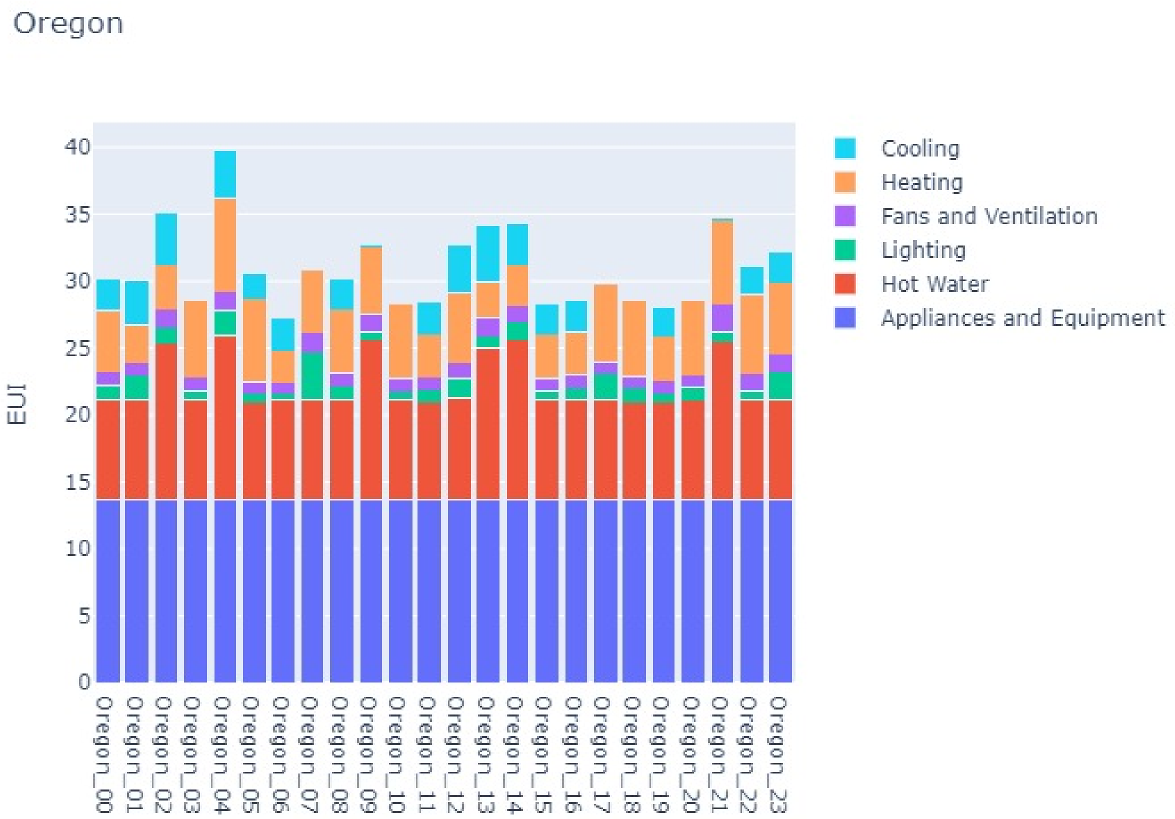

Figure 37. Oregon EUI end-use stacked bar plot

Not all buildings in Oregon included cooling, but buildings in Oregon that included cooling also had heat pump heating because most heat pump systems allow for both heating and cooling.

Hot water energy use is driven most significantly by whether the system is central or in-unit. Central systems require hot water to be circulated throughout the building in pipes to ensure water at a desirable temperature is always near the fixtures. Recirculating hot water through pipes increases the amount of heat lost when compared to in-unit systems. The surface area of a piping system is much greater than the surface area of an individual tank. As a result, central hot water systems typically account for about 11 EUI, whereas in-unit hot water systems typically account for about 7 EUI.

Of the buildings surveyed in Oregon, the lowest EUI was about 25. This was the most efficient building surveyed primarily due to its mechanical design – heating, cooling, and hot water.

Modeling suggests that the choice of mechanical system, all of which meet code, has the largest impact on energy usage. The energy code focuses on architectural components and lighting because savings from these features is easier to understand and still gives mechanical engineers flexibility in their designs. However, if energy codes are to continue improving energy efficiency in buildings, the issue of regulating mechanical systems more intensively will have to be addressed.

Apartment-weighted split of fuel use (at the site level across the state) was calculated. Natural gas and electricity usage are as follows:

- 17.5% Natural Gas
- 82.5% Electricity

The buildings surveyed suggest that Oregon uses a significantly higher percentage of electricity than natural gas usage. All but one building used electricity for space heating. The 17.5% natural gas is mostly from central hot water systems with gas boilers.

4.3.4 Washington

As shown in Figure 38 below, fewer surveys of buildings were done in the Washington 5B climate zone, where the population is smaller. Climate Zone 5B has far colder winters, and we would therefore expect to see higher heating EUIs in those buildings. In 5B, heating accounted for 7-13 EUI points; whereas in 4C, heating accounted for 3-7 EUI points. The difference in heating energy explains why buildings in climate zone 5B have higher EUIs.

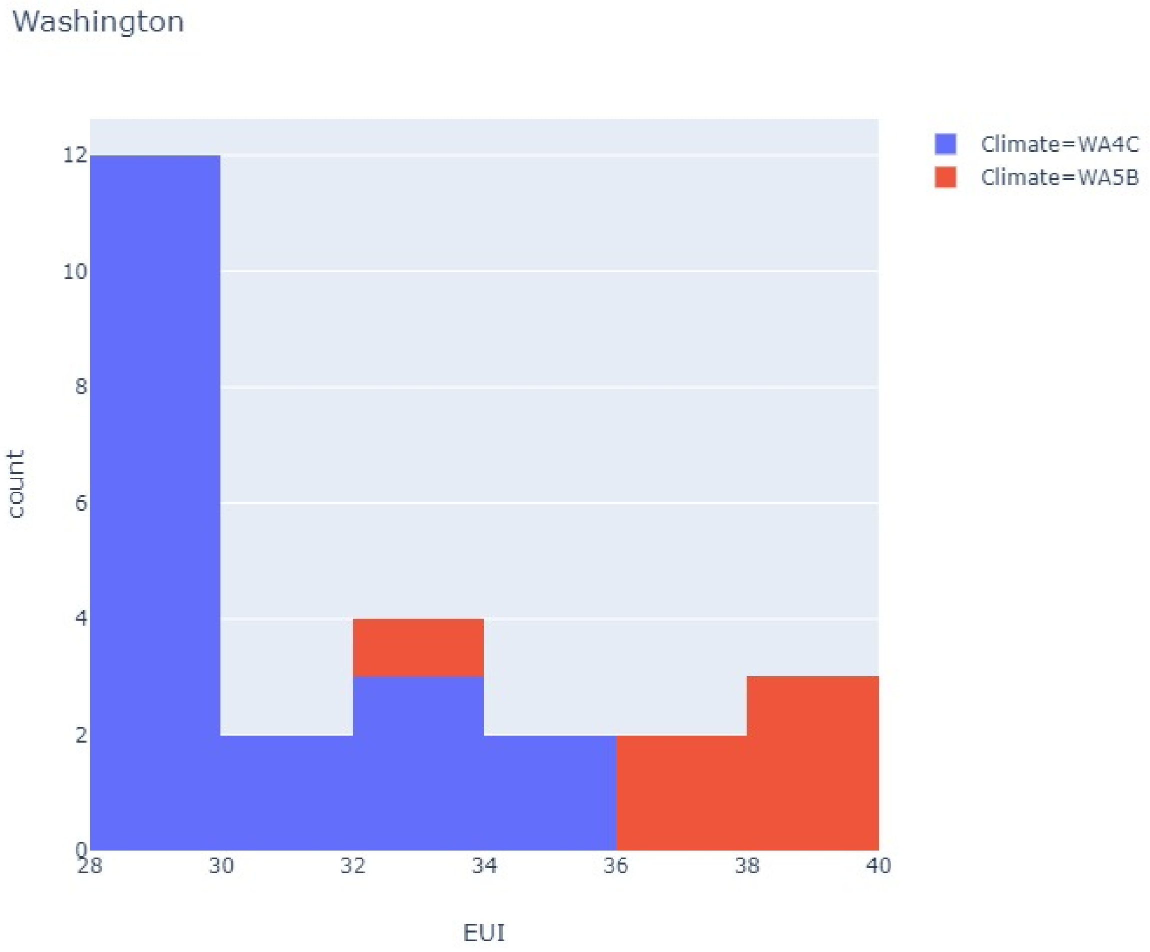

Figure 38. Washington EUI Histogram

Figure 39 shows the EUI from each surveyed site in Washington broken out by end-use.

The largest modeled EUI of the buildings surveyed in Washington had almost 40 EUI. It used more energy due to its location in Washington's colder climate zone 5B and gas furnace heating system type.

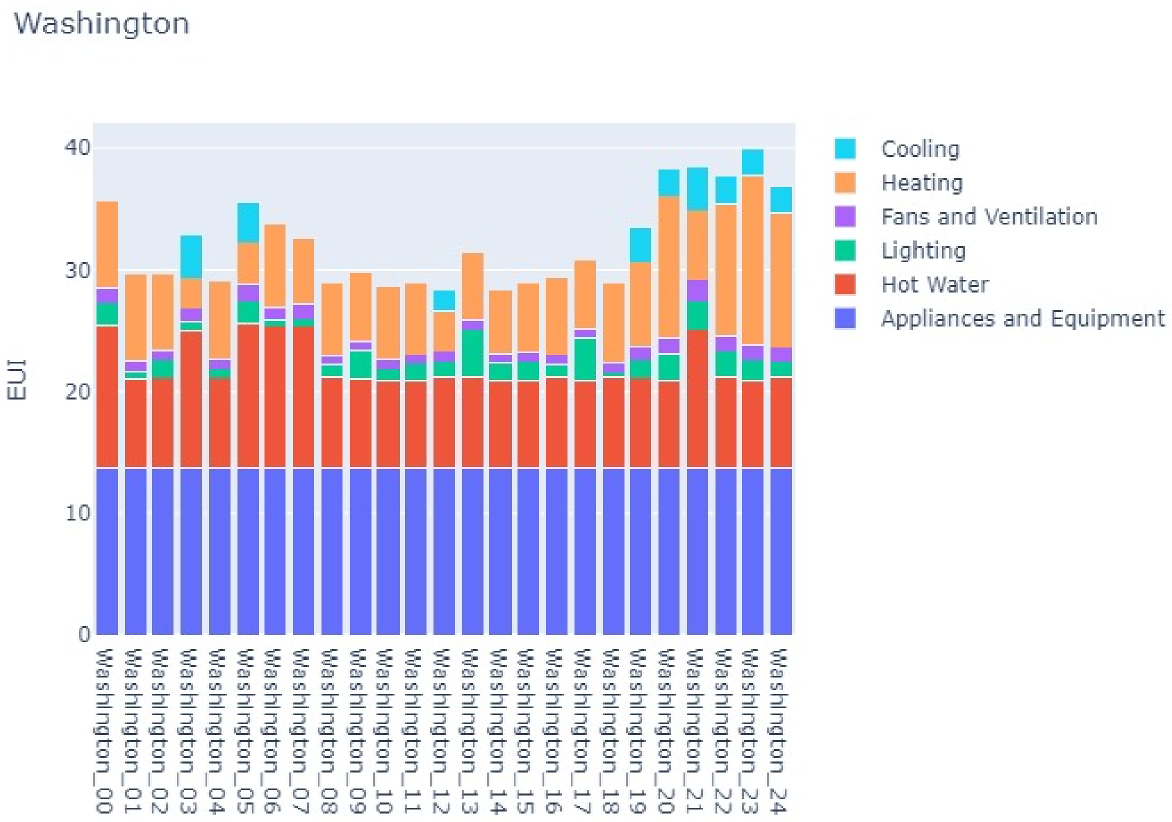

Figure 39. Washington EUI end-use stacked bar plot

According to energy modeling results, gas furnace heating uses the most site energy. Gas furnaces operate with 80% efficiency, which is lower than electric resistance heating, and much lower than heat pump heating. For buildings heated by gas furnace, heating accounted for almost 14 EUI. For similar buildings heated by heat pumps, less than 7 EUI was used for heating.

Not all buildings in Washington included cooling. The climate in western Washington (zone 4A) is such that cooling is not always installed, but some buildings still have cooling for comfort. Many buildings surveyed in Washington that included cooling also have heat pump heating. Typically heat pump systems allow for both heating and cooling.

Apartment-weighted split of fuel use (at the site level across the state) was calculated. Natural gas and electricity usage are as follows:

- 20.3% Natural Gas
- 79.7% Electricity

The buildings surveyed suggest that Washington uses a significantly higher percentage of electricity than natural gas. All but one building used electricity for space heating. The 20.3% natural gas is mostly from central hot water systems with gas boilers. Central hot water systems use almost twice as much energy as in-unit tanks and are more common in larger apartment buildings.

5 MEASURE ANALYSIS

The goal of measure analysis simulation is to quantify the excess energy usage from non-compliant building components identified in the Characteristic Summaries. Here measure analysis focuses on envelope and lighting.

5.1 Context

Envelope components included Basement Wall U-Factor, Ceiling U-Factor, Exterior Wall U-Factor, Slab F-Factor, Window U-Factor, and Window SHGC. Lighting components included Stair LPD, Corridor LPD, and In-Unit LPD.

HVAC is not included since federal standards preclude distribution of below-minimum equipment. It was assumed that all the HVAC equipment used in the buildings surveyed was code-minimum compliant. (The characteristics review found only a tiny number of systems that were non-compliant and other systems that greatly exceeded code minimums).

An energy performance map was created for each component in question in each climate zone studied. The map was created by taking an average code-compliant building and running a parametric analysis of only the component in question. Results were then plotted, with the y-axis as EUI, and the x-axis as values of the building component in question.

The same data used to create component performance map plots was used to estimate extra energy use from non-compliance at a statewide level. For each feature that did not comply, excess EUI was calculated through interpolation of calculated performance maps. The excess EUI was then used to extrapolate potential savings, at a state-wide level, in bringing out-of-compliance components up to code.

5.2 Methodology

To isolate the effect on EUI that each component in question had, a standard code-compliant building (based on the common entry basement seed model) was used. The common entry basement model was chosen because it included all building features that needed to be analyzed.

jEplus was used to run a parametric analysis model on the standard code-compliant building in order to create a baseline for each climate zone, then the component in question was looked at to create a performance map. Over 1,500 EnergyPlus™ models were performed in jEplus in order to create performance maps for all features in question.

After runs were performed in jEplus, Python was used to extract, organize, and plots results. Plots in Section 5.3 Results and Notable Findings have an x-axis to show the building component value and two y-axes. The first y-axis is a line plot of the EUI delta from the baseline building, as the building component performance is varied. The second y-axis shows a histogram, similar to the histograms in the Section

3 Characteristics Summaries, with a count of buildings corresponding with the performance value of the building component. For additional description and a figure showing an example performance map, see section 2.4.3 Savings Analysis.

A two-step process was used to quantify the excess energy usage from non-compliant building components: (1) calculate the excess energy use per apartment unit; (2) convert per unit savings to a statewide energy delta.

Performance maps were used to calculate the excess energy usage from non-compliant building components. Figure 40 provides a visual aid for the description in the following paragraph.

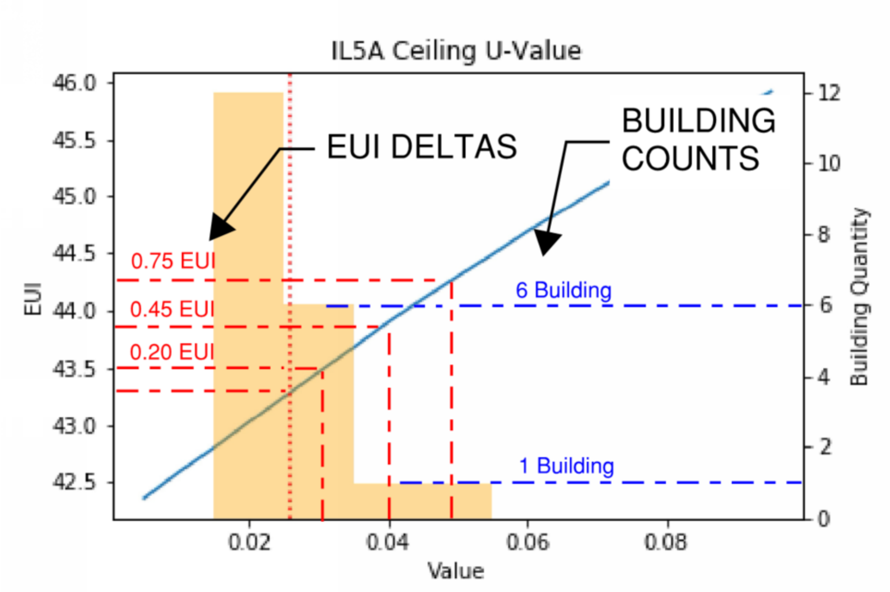

Figure 40. Performance Map Savings Calculations

For each building component that had non-compliant features, the excess energy usage was quantified using performance maps. First a modeled EUI delta is calculated between the baseline value and non-compliance values, shown in red in Figure 40. Each modeled EUI delta is multiplied by the number of corresponding buildings, shown in blue. In the example above a total of 2.4 modeled EUI is calculated for non-compliance.

The total modeled EUI for non-compliance is the total EUI delta across all the buildings surveyed. To normalize the modeled EUI delta to a single building, the total across all buildings surveyed is divided by the total number of buildings surveyed in each state. It is then multiplied by the area of a single apartment unit to get the kBtu per unit for non-compliance.

The non-compliance EUI estimation is then used to calculate electricity, natural gas, and total savings on a statewide basis. For each building component, other than heating, a single fuel, electricity or gas, is considered. Lighting components use electricity; architectural components that contribute to increased cooling (such as window SHGC) use electricity; architectural components that contribute to increased heating (such as window and wall U-factors) can use electricity or gas.

For architectural components that contribute to increased heating, heating systems used in each state and their efficiencies were used to create a ratio of natural gas to electricity usage for space heating. The ratio is used to determine how much electricity and natural gas are accounted for by the heating EUI delta.

The method for calculating excess energy use per apartment unit and assigning fuel usage assumes building component deficiencies are independent of building size. All surveyed buildings, regardless of the number of units, are weighted equally in the calculation.

To convert per-unit savings to a statewide energy delta, census data are used to estimate the number of new apartment units built in the state. The surveyed buildings are considered as a representative sample.

The following values were used in all states to calculate energy costs and green-house gas (GHG) emissions:

- 1.22 \$/Therm of natural gas[29]
- 0.11 \$/kWh of electricity[30]
- 1.63E-02 metric tons CO_2 per Therm of natural gas[31]
- 4.49E-04 metric tons CO_2 per kWh of electricity[32]

5.3 Results and Notable Findings

Measure analysis results are provided in two parts, starting with this overview of performance maps. Some building components have a greater impact on EUI than others, and some components depend more on climate than others. Those characteristics are discussed for each component in a non-compliant building. A description of each building characteristic for which a component map was created is included below. See Appendix E – Performance Maps for the full set of maps.

> **Exterior Wall U-Value** has a nearly linear correlation with modeled EUI. The modeled EUI delta was driven by the heating season, and therefore colder climate zones had more dramatic EUI differences for differences in Exterior Wall U-Value.
>
> **Basement Wall U-Value** has a negligible impact on modeled EUI.

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[29] https://www.eia.gov/dnav/ng/NG_SUM_LSUM_A_EPG0_PRS_DMCF_M.htm
[30] https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_6_a
[31] https://www.eia.gov/conference/2015/pdf/presentations/skone.pdf
[32] https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

Slab F-Factor has a negligible affect on modeled EUI using the garden slab-on-grade seed model. In a single family home, with a smaller footprint and one story, Slab F-Factor is likely much more impactful on energy usage.

Ceiling U-Value has a nearly linear correlation with modeled EUI. The modeled EUI delta was driven by the heating season, and therefore colder climate zones had more dramatic EUI differences for differences in Ceiling U-Value.

Window U-Value has a strong correlation with modeled EUI. The correlation between Window U-Value and EUI was driven by heating and is therefore stronger in colder climates. The correlation between Window U-Value and EUI would also be driven significantly by window-to-wall ratio (WWR). The higher the WWR, the more glass on the building and the bigger an effect Window U-Value has on EUI. However, as discussed in section 3.1 Methodology, all models have the same WWR, so the effect of WWR was not captured.

Window SHGC represents the amount of total solar insolation that is admitted through an insulated glazing unit. Lower SHGCs reduce cooling load and can also reduce heating load, depending on where the window treatment is located. Window SHGC had a weaker correlation with EUI than Window U-Value, and its correlation was driven by cooling instead of heating. SHGC typically does more to mitigate high peak loads than to reduce EUI. The correlation between Window SHGC and EUI would also be driven significantly by WWR. The higher the WWR, the more glass on the building and the bigger an effect Window SHGC has on EUI. However, as discussed in section 3.1 Methodology, all seed models have the same WWR, so the effect of WWR was not captured.

Corridor LPD has a nearly linear correlation with EUI. Most LPDs have a nearly linear correlation with EUI; the interaction between LPD and heating load can create a non-linear characteristic. Corridor LPD does not have as strong of a correlation with EUI as Exterior Wall, Window, and Ceiling characteristics, but it does have an impact.

Stair LPD has a nearly linear correlation with EUI. Most LPDs have a nearly linear correlation with EUI, the interaction between LPD and heating load creates a small non-linear characteristic. Stairwell area is a small percentage of building area, and it therefore takes a large Stair LPD change to significantly impact EUI.

Exterior Parking LPD has a linear correlation with modeled EUI.

Interior Parking LPD has a linear correlation with EUI. LPDs are expected to have linear correlations with EUI. The interaction between LPD and heating energy can create small non-linear characteristics.

The second part of the measure analysis results is the following discussion on statewide excess energy use from non-compliance. For each state, a Statewide Annual Measure Level Savings table is included to illustrate the effect of bringing building components up to code. The four states surveyed in this study had high compliance and, as a result, relatively low amounts of savings for bringing components up to compliance. For this reason only the top three components that show excess energy are included.

The **Savings Measure** column shows the out-of-compliance component that could be brought up to compliance. **Electricity Savings** and **Natural Gas Savings** columns show the per-apartment savings in electricity or natural gas usage. **Total Savings** was the total excess energy use for all surveyed buildings divided by the number of buildings. Natural gas or electricty was chosen based on which energy source was more commonly in excess based on the non-compliant component. **Total Number of Units Built in State** is the statewide number of apartments. The number of apartments per climate zone was unavailable, so all savings for the state are lumped together. Finally, **Total Energy Savings**, **Total Energy Cost Savings**, and **Total State Emissions Reduction** are per year.

5.3.1 Illinois

When each building component is brought up to code, Ceiling U-Value, Exterior Wall U-Value, and Corridor LPD show savings and are included in Table 36.

Table 36. Statewide Annual Measure Level Savings for Illinois

Savings Measure	Electricity Savings (kWh / unit)	Natural Gas Savings (Therms / unit)	Total Savings (kBtu / unit)	Total Number of Units Built in State	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Ceiling U-Value	4	0.83	98	17,789	1,742	26,545	276
Exterior Wall U-Value	4	1.11	126	17,789	2,238	32,745	356
Corridor LPD	6	0.00	19.06	17,789	339	10,935	45

5.3.2 Minnesota

When each building component is brought up to code Exterior Wall U-Value, Window SHGC, Exterior Parking LPD, and Interior Parking LPD show significant savings and are included in Table 37.

Table 37. Statewide Annual Measure Level Savings for Minnesota

Savings Measure	Electricity Savings (kWh / unit)	Natural Gas Savings (Therms / unit)	Total Savings (kBtu / unit)	Total Number of Units Built in State	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Exterior Wall U-Value	4	3.83	396	14,225	5,631	72,351	912
Window U-Value	1	1.82	186	14,225	2,651	33,676	430
Exterior Parking LPD	31	0.00	106.71	14,225	1,518	48,967	200

5.3.3 Oregon

When each building component is brought up to the code Window U-Value, Window SHGC, Exterior Parking LPD, and Interior Parking LPD, the building shows significant savings (Table 38).

Table 38. Statewide Annual Measure Level Savings for Oregon

Savings Measure	Electricity Savings (kWh / unit)	Natural Gas Savings (therms / unit)	Total Savings (kBtu / unit)	Total Number of Units Built in State	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Window SHGC	33	0.00	111	14,480	1,610	51,922	212
Exterior Parking LPD	23	0.00	77.81	14,480	1,127	36,346	148
Interior Parking LPD	24	0.00	83	14,480	1,207	38,942	159

5.3.4 Washington

When each building component is brought up to code, Exterior Window U-Value, Exterior Parking LPD, and Interior Parking LPD show significant savings and are included in Table 39.

Table 39. Statewide Annual Measure Level Savings for Washington

Savings Measure	Electricity Savings (kWh / unit)	Natural Gas Savings (Therms / unit)	Total Savings (kBtu / unit)	Total Number of Units Built in State	Total Energy Savings (MMBtu)	Total Energy Cost Savings ($)	Total State Emissions Reduction (MT CO2e)
Window U-Value	23	0.05	82	33,799	2,769	86,256	369
Exterior Parking LPD	34	0.00	117	33,799	3,967	127,983	522
Interior Parking LPD	6	0.00	21.34	33,799	721	23,270	95

6 MARKET RESEARCH

6.1 Low-rise Multifamily Building Market

The study included a market research component to better understand the market for low-rise multifamily new construction so that effective energy-code compliance education and training could be delivered to designers and contractors. There were two specific goals of this market research:

- Gain a better understanding of the nature of the firms that work in this market, the range of buildings that they design and construct, and how they approach the design/construction process.
- Understand how these firms stay current on code requirements and gather information about preferred methods for code education and training.

The market research was implemented through interviews with market actors and key stakeholders and through an online survey designed to reach active multifamily building developers, architects, and contractors.

The market research approach was designed to leverage contacts made during the sampling and recruiting for the field study, and to reach stakeholders not involved with the study directly. Contacts from the study sampling and recruiting process were asked to complete the online survey in order to paint a broad picture of the firms involved in this market. Interviews with stakeholders outside the study allowed us to explore in more detail issues and topics that arose as the field study progressed.

6.2 Interviews with Market Actors and Key Stakeholders

The market actors and key stakeholder interviews targeted individuals from Washington, Oregon, Minnesota, and Illinois including state government employees responsible for oversight of the codes or code training, local building code officials or plan inspectors, and energy rating consultants and evaluators. Study leads for each state (Ecotope in Washington and Oregon, CEE in Minnesota and Slipstream in Illinois) identified individuals to be interviewed.

Slipstream, with input from Ecotope and CEE, designed an interview guide and conducted the in-depth interviews with at least five individuals in each state.[33] The interview guide was designed to capture information about market trends in an interviewee's jurisdiction, their understanding of code requirements for low-rise multifamily construction, and the availability of and need for training on low-rise multifamily codes. Following is a compilation of the results of the interviews.

6.2.1 Market Characterization

Within all four states, there were regions with growth in the low-rise multifamily market as well as regions with little to no growth. In general, interviewees indicated that mid-size cities and suburbs had more new low-rise buildings, while larger cities and rural areas had lower overall new low-rise growth. Interviewees stated that in larger cities such as Seattle, Portland, Minneapolis, and Chicago, apartment developers tended to opt for taller buildings when they were able to get a parcel of land. However, they

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[33] We interviewed five individuals in each of Washington, Minnesota, and Illinois and six individuals in Oregon.

also mentioned that low-rise buildings were more common for affordable housing development and, as that need has increased, the cities have seen some growth in this market. In rural areas or smaller suburbs, the interviewees stated that abundant land lends itself to large townhome or duplex developments rather than low-rise apartment buildings.

In general, the developers of low-rise multifamily buildings included market-rate builders and affordable housing developers. In most places, individuals estimated that market-rate builders make up most of the market. As for characteristics of the buildings, there was wide variation among building size, prevalence of mixed-use construction, and type of entry. In general, buildings with fewer units typically have separate entrances whereas buildings with more units have corridor entrances. In Oregon, the interviewees suggested that most low-rise multifamily construction includes commercial or retail space on the lower level ('mixed-use') while in Washington and Minnesota, they suggested that most low-rise multifamily construction is strictly residential. In Illinois, the interviewees stated that Chicago and the nearby suburbs relied on mixed-use construction due to land constraints while rural areas and suburbs outside of the main city center did more strictly residential buildings.

6.2.2 Code

In Illinois, Minnesota, and Washington, low-rise multifamily buildings, defined as three stories or less, fall under the residential energy code. However, Chicago[34] and Seattle count buildings up to five stories and four stories, respectively, as low-rise multifamily construction. Multifamily buildings in Chicago that are four stories follow the residential code, while buildings in Seattle that are higher than three stories follow the commercial code. In Minnesota, there seems to be some confusion around which code to follow as two interviewees stated that low-rise buildings fall under the commercial code book. Additionally, in Illinois, an energy efficiency consultant stated that buildings are not always classified correctly. For example, if a building has an underground garage and three stories of residential space above it, it would fall under the residential code, but it often gets classified as commercial.

There is also confusion in Oregon regarding which code low-rise multifamily buildings fall under. One city building code official stated that only 1- to 2-unit residential buildings (including townhomes) follow the residential code; all others follow the commercial code which has provisions for residential construction. Other interviewees indicated that some projects could fall under the residential code and others might follow the commercial code. One interviewee indicated that there are currently a lot of changes in Oregon, where new code provisions went into effect on October 1, 2019.

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[34] Administrative Code. TITLE 71: PUBLIC BUILDINGS, FACILITIES, AND REAL PROPERTY CHAPTER I: CAPITAL DEVELOPMENT BOARD SUBCHAPTER D: ENERGY CODES PART 600 ILLINOIS ENERGY CONSERVATION CODE SECTION 600.100 DEFINITIONS. "Residential Building" means a detached one-family or 2-family dwelling or any building that is 3 stories or less in height above grade that contains multiple dwelling units…when applied to a building located within the boundaries of a municipality having a population of 1,000,000 or more, the term "residential building" means a building containing one or more dwelling units, not exceeding 4 stories above grade…" http://www.ilga.gov/commission/jcar/admincode/071/071006000A01000R.html

Air Leakage Testing

Recent energy codes in several states have required new buildings to meet a maximum air tightness level (typically expressed in air changes per hour at a pressure differential of 50 Pa between the building's interior and exterior, expressed as ACH_{50}). The primary reason for establishing standards and requiring testing is to reduce the amount of conditioning energy needed for heating or cooling outside air that enters the building through unintentional leakage pathways. Illinois, Minnesota, and Washington require air leakage testing for these buildings while Oregon does not. However, individuals stated that even if the state requires air leakage testing, enforcement of the testing is non-existent or very weak. For example, in Illinois interviewees stated that no formal enforcement or review process for the testing exists. In Washington, interviewees suggested that air leakage testing is rarely implemented or enforced, but individuals are trying to push for stricter enforcement and have introduced a proposal to require the use of a geo- or time stamp to certify that air leakage testing has been completed.

Each state has slightly different requirements for the air leakage test, and it was often noted that there was little clarity around testing requirements.[35] In Washington, common-entry buildings could be tested on a whole building basis while buildings with outside entry required the use of a unit-by-unit test. In contrast, in Illinois, the requirements vary by jurisdiction. An energy evaluator in the state mentioned that he telephones the jurisdiction before a site visit to determine whether whole building or unit-by-unit testing will be required. In Minnesota, the respondents had different answers on this subject, with some stating that whole building testing is required and others mentioning that unit-by-unit testing is required.

Compliance Issues

In each of the states, most respondents mentioned that code is generally well-followed and compliance issues are not widespread. However, at least one respondent in Minnesota, Illinois, and Washington mentioned that compliance issues stem from a skillset gap or lack of education or knowledge on the topic.

The most commonly mentioned compliance issues were related to air leakage requirements, particularly meeting air sealing and duct testing and leakage requirements. Other common compliance issues were related to meeting envelope insulation requirements and implementing adequate and well-performing ventilation strategies.

In Washington, another commonly mentioned issue surrounded the section of the code where developers or builders must pick a certain number of measures to implement from a larger list of measures. Respondents mentioned that this checklist approach can lead to confusion over which items can be combined and how to apply the credits from this list.

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[35] A parallel research project evaluated envelope air tightness and current still-evolving air tightness testing methods. *Commercial Buildings and Energy Code Field Studies: Low-Rise Multifamily Air Leakage Testing*. 2020. D. Bohac, Olson, C., Davis, R., Nelson, G. Sweeney, L.

Although not specifically related to low-rise-multifamily construction, an Oregon respondent mentioned the need for a review of the codes governing townhomes and duplexes because mechanical reviews are currently not required, meaning that there is no way to know if heating/cooling units are undersized. On this point, several interviewees mentioned that townhome and duplex construction were much more prevalent than the low-rise multifamily structures that are the subject of this study.

Another issue mentioned was the lack of consistency between the building codes and the energy codes, specifically in terms of the current year adopted for each code. For example, a building code official in Illinois stated that it is difficult to abide by the 2018 IECC requirements for a tighter building if the current building code still follows the 2012 International Building Code. Illinois does not have a statewide building code for either residential or commercial new construction. For the residential code, units of local government have authority to adopt and enforce building codes, zoning ordinances, and other instruments related to construction. However, if the unit of local government has not adopted a residential building code, compliance with 815 ILCS 670. Illinois Residential Building Code Act is required. The Residential Building Code Act references the International Residential Code.

6.2.3 Training

The availability of training on low-rise multifamily codes was relatively consistent across the states. Each state had an organization responsible for providing training on all applicable energy codes. The organizations commonly offered fact sheets, a helpline, online webinars, and some in-person training sessions. Several respondents also mentioned the existence of utility-run construction assistance programs.

When asked about how low-rise multifamily code training could be improved, most respondents did not have recommendations for additional training resources. However, respondents commonly expressed that there was a need for more resources for all building types at the time of a code change, especially because codes are changing more rapidly and drastically now. For example, every individual in Oregon mentioned the upcoming code change and how there will be an immediate need for resources and training on the new code, as large changes are expected. Similarly, respondents in other states mentioned that because the code changes every three years, more robust resources and training are needed to keep all relevant stakeholders up to date. One interviewee mentioned that the release of new resources often lags several months behind the release of a new code, which causes difficulties in designing and enforcing buildings to code.

6.3 Online and Phone Survey

Slipstream developed a closed-ended survey instrument to query developers, architects, general contractors, HVAC contractors, and property managers. The survey sample was drawn from contacts made during the sampling and recruiting for the field study and included firms that participated in the field study as well as those that did not.

While the goal for this survey was 50 responses per state to allow for potential cross-state analysis, the reality fell far short. Due to a combination of recruiting hurdles, timeline challenges, and an inherently difficult population to reach (despite multiple contact attempts), we received only 44 survey responses out of a total starting sample pool of 819 individuals. Most of these respondents were in the Pacific Northwest. Of the 36 who completed the entire survey and provided contact information, 13 were based in Oregon, 12 in Washington, 7 in Minnesota, 2 in Illinois and one each in Arizona and California (these respondents were from firms that had completed projects in the Pacific Northwest). Following is a synopsis of the responses.

6.3.1 Market Characterization

Most of the survey respondents work for a building developer or an architectural/engineering company with fewer than 50 employees and an in-state or regional geographic reach (Table 40). While some respondent firms specialize in one building type, the majority work across multiple types, though they tend to be focused on residential construction (Table 41). Most respondents work for firms that are involved with fewer than 10 low-rise multifamily projects annually (Table 42).

Table 40. Firmographics of survey respondents

Which of the following best describes the company you work for? (n=44)	Developer	43%
	A&E firm	32%
	General contractor	14%
	HVAC contractor	5%
	Other	7%
How many people currently work for your company? (n=42)	<10	50%
	10-50	31%
	51-100	7%
	>100	12%
What is your company's gross annual revenue? (n=28)	<$500,000	18%
	$500,000 to $1 million	18%
	$1 million to $5 million	50%
	$5 million to $10 million	11%
	>$10 million	4%
Geographic reach of Company (n=43)	Within state	63%
	Regional	23%
	National	12%
	Other	2%

Table 41. Percent of business by building by type (and number of types cited) for developers, A&E firms, and general contractors (n=34).

Building Type	Mean	Range
Single-family homes	13%	0 to 70%
Multifamily buildings, 2-4 units	20%	0 to 100%
Apartment buildings, 1-3 stories	35%	0 to 100%
Condominiums, 1-3 stories	4%	0 to 15%
Multifamily buildings, 4+ stories	34%	0 to 100%
Mixed-use buildings	22%	2 to 95%
Commercial buildings	21%	0 to 70%
Other (unstated)	2%	0 to 62%
Number of types cited	3.6	1 to 7

Table 42. Number of low-rise multifamily projects per year for developers, A&E firms and general contractors (n=34).

<10	68%
10-50	26%
51-100	3%
>100	3%

The 34 respondents who answered the question on the construction delivery method most often used for low-rise multifamily building projects, nine reported using design-build-bid, eight use design-build, seven use spec-build, three use construction manager-at-risk, and two use integrated property delivery (Table 43). Another five reported using other methods, including guaranteed maximum price, not-to-exceed and self-perform, design-bid-build, and a negotiated construction contract type of design build.

Table 43. Most-often-used construction delivery method for low-rise multifamily projects by developers, A&E firms, and general contractors (n=34).

Design-Build-Bid: Developer/owner contracts with separate firms for the design and construction of the building.	29%
Design-Build: Developer/owner contracts with a single firm for the design and construction of the building.	24%
Spec-Build: Developer/owner constructs the building with the intention of selling it for a profit.	21%
Construction Manager at Risk: Construction manager commits to delivering the building at a guaranteed maximum price.	9%
Integrated Project Delivery: Collaborative process involving, at a minimum, the owner, architect, and contractor, to maximize the benefits from all phases of the design and construction process.	6%
Other	12%

In terms of specifying key components and systems (insulation levels, lighting, windows and HVAC) for low-rise multifamily projects, respondents indicated that architects were most often responsible for specifying insulation levels, lighting and windows and HVAC contractors took care of specifying the HVAC system. Sometimes electrical contractors specified the lighting.

Respondents cited new construction programs offered by utilities or statewide energy efficiency organizations, more stringent municipal codes, energy benchmarking ordinances, and local stretch codes as market dynamics that influence energy efficiency in low-rise multifamily buildings, in addition to the code enforcement process.

6.3.2 Code Knowledge

Survey respondents indicated that they learn about both residential and commercial building code requirements and methods for complying with those requirements primarily by working with code officials and from online resources. This was the case for both building developers and architects, though some building developers rely on the architect to be aware of code requirements. More architects than building developers attend training sessions to learn about code.

When asked about their familiarity with the residential building code, building developers said they are more likely to rely on their contractors and subcontractors to know the code. Only one architect indicated an “inside out” knowledge of the residential code, while the others (12 respondents) said they knew only what applied to their work.

More than half of the respondents—mostly developers—believe there are requirements in the residential building code that are difficult (i.e. complicated) to comply with. Some identified cost as a difficulty too. Fifteen building developers believe there are residential building code requirements that are difficult to comply with while only one architect indicated the same (28 total respondents: 10 architects and 18 building developers). Building developers report that energy, parking, ADA, fire and exits were the challenging portions of the residential building code.

Architects and building developers also have different perspectives on how strictly the residential building code is enforced: more than half of the building developers (11 of 18 building developer respondents) believe that the code is strictly enforced in all jurisdictions. This contrasts with a quarter of the architects (3 of 12 respondents) who stated the same. Most of the architects indicate that enforcement of the residential building code varies by jurisdiction or by individual code requirements.

Most respondents indicated that they receive feedback and/or correction notices on energy requirements, either when applying for building permits or later in the construction process. Most also indicated that technical support is available for improving the building design. This support comes from utility new construction programs, non-profit energy efficiency advocacy organizations, and home building associations. Building developers were more likely than architects to receive assistance from utility energy efficiency programs.

6.3.3 Training

Respondents identified several issues for understanding and complying with the residential building energy code as it pertains to low-rise multifamily buildings: staying current with changes in the code; knowing performance requirements for different design components, knowing which code applies to various dwelling types, and knowing the cost of complying with the code. Some specific comments included:

- There are various options for achieving energy standards, and these change over time. Keeping abreast of these changes is challenging.
- There are so many energy-related products and services available it’s hard to know what works best. There is no rating service like Consumer Reports®.
- It’s difficult to navigate the "point" system to understand which menu items are both affordable and will yield "real" energy savings.
- It would help to know the various R and U ratings for windows, roof, and wall assemblies while designing, instead of just doing a calc at the end for permit submittal.
- We need better/more consistent information from local building departments.

Though several of these issues could be addressed through education and training, 20 out of 39 respondents were not interested in attending residential building energy code training. The 15 respondents who indicated an interest in attending training preferred on-demand webinars or half-day classroom formats. One respondent called out the need for continuing education credits for any training they attend. Respondents listed the following topics that they'd like to learn about:

- specific energy efficiency technologies such as wall assemblies, insulation, water heating, windows, etc.,
- code changes and upcoming changes to existing code,
- energy-efficiency incentives available, and
- cost-effective strategies for improving energy efficiency.

6.4 Market Research Conclusions

Interviews and survey data suggest that while the low-rise multifamily market is diverse, both in terms of location of construction and the companies building these structures, this housing type is most strongly associated with mid-size cities and suburbs and with smaller design and construction firms that focus primarily on multifamily residential construction.

Some of the interesting findings from the market research include:

- Developers, architects, and construction contractors learn about both residential and commercial building code requirements and methods for complying with those requirements primarily by working with code officials and from online resources.
- Building developers are likely to rely on their contractors and subcontractors to know the code.
- Architects primarily know only the code that applies to their work.
- Building developers generally believe there are requirements in the residential building code that are difficult to comply with, while architects generally do not.
- There is a perception that compliance issues stem primarily from a skillset gap or lack of education or knowledge on the topic.
- Respondents identified confusing issues for understanding and complying with the code but are often not interested in attending residential building code training.

Perhaps unsurprisingly for a building type with both residential- and commercial-construction attributes, there are clear signs of confusion on the part of market actors and even code officials regarding what energy code low-rise multifamily construction is subject to and what those code requirements are—particularly regarding air-leakage-testing requirements.

These findings highlight the need for additional code training targeted at this building type.

7. CONCLUSIONS

The project was successful in surveying nearly 100 low-rise multifamily buildings in three geographic regions of the US: Pacific Northwest, Midwest, and Upper Midwest. The sites represent a statistically significant representation of this building type. Data collection and analysis allowed a robust characterization of energy-using characteristics of these sites. For the most part, the states in the study utilized the requirements of the 2012 and 2015 cycles of the International Energy Conservation Code as part of the building permitting process. Both building plan review and field verification were used to catalog and confirm building energy details such as insulation levels, mechanical systems, domestic hot water, and lighting.

The study benefitted from earlier work on energy code compliance that was done by the Pacific Northwest National Laboratory (PNNL) on single-family homes.[36] The templates from this work, most notably the analysis graphical approach, were helpful in summary characterizations. Many characteristics categories overlapped closely. Data collection and handling were built around a spreadsheet-based data collection tool; this approach facilitated a relatively efficient means of performing quality control and also feeding a series of EnergyPlus™ prototype simulations which informed consideration of additional energy benefits that could accrue to improvements in building components.

In addition to the success of the extension of the single-family methodological approach, the major findings from the data review were as follows:

- For thermal envelope components, in each state, the majority of buildings met or were often better than the prescriptive code. This suggests that building designers and builders are aware of code requirements. In some cases, surveyed buildings were designed to qualify for energy efficiency certification programs[37]. These buildings made up at least 20% of sampled buildings in each state.
- Almost all buildings met mechanical system efficiency requirements (for both living units and common areas). In some cases, sites employed systems that were considerably more efficient than required by the applicable energy code, and this resulted in a significant reduction in modeled HVAC usage.
- Dwelling units had a majority of high-efficacy lighting, often in excess of code requirements. While high-efficacy fixtures were also typical in common areas (corridors and stairwells), lighting power densities (LPDs) in these areas were sometimes higher than prescriptive

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[36] Residential Building Energy Code Field Study. May 2018. R. Bartlett, M. Halverson, V. Mendon, J. Hathaway, Y. Xie https://www.energy.gov/eere/buildings/downloads/residential-building-energy-code-field-study

[37] Buildings participating in energy efficiency certification programs (including those with above-code requirements) were included in the study when they were selected as a natural part of the sampling and recruiting process so as to achieve an average representation of building characteristics within a given state.

levels. High-efficacy fixtures and design/installation of fewer fixtures were observed as code-compliance strategies.

- The simulation models run on a series of low-rise multifamily prototypes, informed by a composite of the field data collected, calculate annual energy use intensities of between 20 and 50 kBtu/ft^2-yr, with the range representing the effects of both building characteristics and building location (climate zone).
- Recent work on energy codes for single-family buildings has included a detailed process (based on simulations of prototype buildings) to estimate the amount of avoided energy use that would occur if 100% adherence to energy codes were attained. This process was extended to low-rise multifamily buildings in this study. The results indicated modest savings are attainable for items such as window thermal performance and common area lighting. The result is overall only a modest potential for additional energy savings, averaging about 10% of EUI.
- Interviews with about 21 building developers, architects and construction contractors revealed a wide range of awareness about residential and commercial building energy code requirements and methods for complying with those requirements. Many code details are well-understood by building designers and builders, although there remains room for improvement at the measure level. This seems especially true as regular code updates (typically tied to IECC updates) have become routine.

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GLOSSARY OF TERMS AND ACRONYMS

AC	air conditioning
AFUE	annual fuel utilization efficiency
BPS	Building permits survey
Btu	British Thermal Unit
CEE	Center for Energy and Environment
cfm	cubic feet per minute
CO2	carbon dioxide
COP	coefficient of performance
csv	command separated values
CZ4/CZ5	climate zone X
DC	direct current
DCI	data collection instrument
DOE	U.S. Department of Energy
DHW	domestic hot water
ECD	Energy Conscious Design
EER	energy efficiency ration
EPPY	a Python package for scripting in EnergyPlus
EPW	EnergyPlus Weather
ERV	energy recovery ventilator
E_t	thermal efficiency
EUI	energy use intensity (kBtu/ft^2·yr)
F-factor	a measure heat loss rate around the slab perimeter of a building, expressed as Btu/ft· ^{0}F· hr
ft2	square feet
Gal	gallon
GHG	greenhouse gas
GPM	gallons per minute
HP	heat pump
HSPF	Heating Seasonal Performance Factor
HVAC	heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
IEER	integrated energy efficiency ratio
jEplus	a user interface for running parametric analysis in EnergyPlus
kBtu	thousand British thermal units
kWh	kilowatts
PNNL	Pacific Northwest National Laboratory
PTHP	packaged terminal heat pump
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
m3/s	cubic meter per second
MEP	mechanical, electrical, and plumbing
MHB	thousands of British thermal units per hour
MMBtu	one million British thermal units
MT CO2e	metric tons of carbon dioxide equivalent

N	site
Pa	Pascal
PTAC	packaged terminal air conditioner
PHIUS	Passive Haus Institute, US (organization that writes and oversees above-code building and mechanical standards/specifications in the United States)
PTHP	packaged terminal heat pump
R-value	resistance to heat flow, expressed in ft2·°F·hr/BTU
SEED	starting energy models that, when key inputs are adjusted, can represent the wide range of buildings surveyed
SEER	Seasonal Energy Efficiency Ratio
SHGC	solar heat gain coefficient
SIP	structural insulated panel
SOG	slab-on-grade
Sqft	square feet
Therm	unit of heat equivalent to 100,000 Btu
UA	heat loss (Btu/hr°F)
UEF	Uniform Energy Factor
U-factor	reciprocal of R-value, units are Btu/ft^{2}· °F·hr
VRF	variable refrigerant flow
W/m*K	watts per meter-Kelvin
W/sf	watts per square foot
WSHP	water source heat pump
WWR	window-to-wall ratio

APPENDIX A – ADDITIONAL STATE CHARACTERISTICS SUMMARIES

This Appendix contains additional state characteristics summaries for each of the four states in the study. The appendix is separated into state sections, and sub-sections for additional lighting, service hot water equipment, mechanical equipment, and additional informational summaries.

A.1 Illinois

Additional lighting

Unlike the measures described in 3.2 State Results, which are subject to residential energy efficiency requirements, lighting power allowances are assessed through the applicable state commercial energy efficiency requirements. The following lighting summaries were conducted on a subset of the surveyed buildings. Interior corridor and stairwell LPD were calculated for common entry buildings where interior circulation areas were present. Interior and exterior parking LPD were calculated as applicable to the parking arrangements for a given building. Prescriptive values for interior areas are based on space-by-space interior lighting power allowances.

Interior corridor LPD

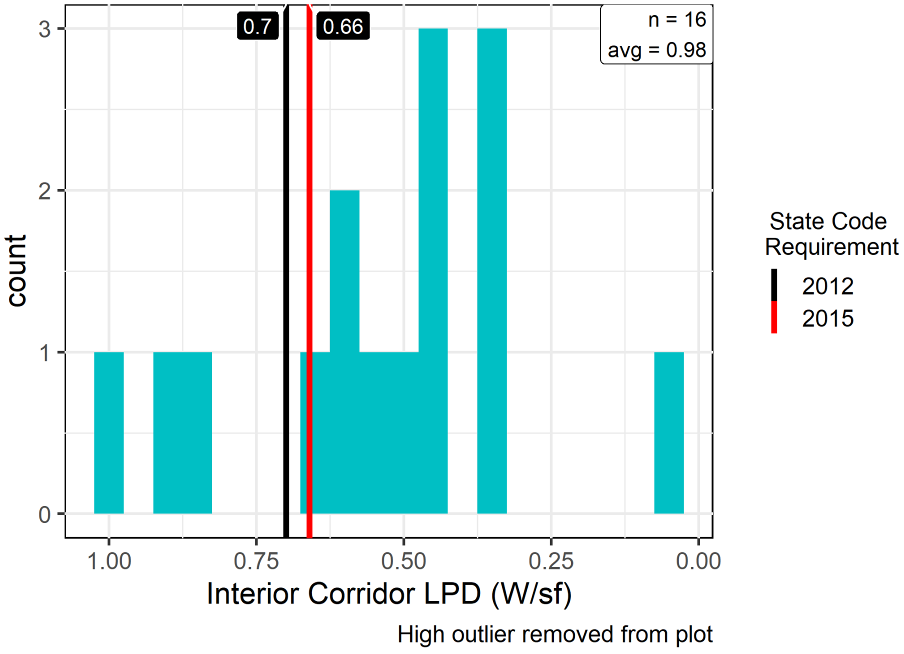


Figure 41. Illinois Interior Corridor LPD (W/sf)

Table 44. Illinois Interior Corridor LPD (W/sf)

Climate Zone	CZ5	Statewide
Number	16	16
Range	0.07 to 7.73	0.07 to 7.73
Average	0.98	0.98

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.7	0.66	0.7 / 0.66
Compliance Rate	3 of 5 (60%)	9 of 11 (82%)	12 of 16 (75%)

Interpretations:

- Most buildings met or were better than interior corridor LPD values. Excluding the outlier site, average interior corridor LPD averaged 0.535 W/sf.
- The building with the highest LPD (which was removed from the plot) had approximately 30% more fixtures installed and observed during field surveys than were detailed on lighting schedule plans.
- A few other sites had LPDs slightly higher than requirements and represent an opportunity for improved compliance.

Interior stairwell LPD

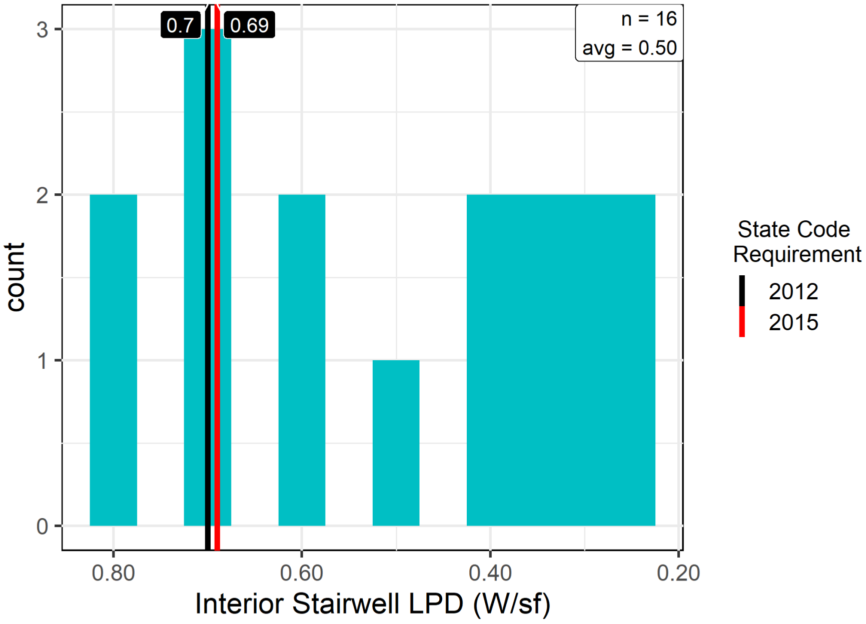


Figure 42. Illinois Interior Stairwell LPD (W/sf)

Table 45. Illinois Interior Stairwell LPD (W/sf)

Climate Zone	CZ5	Statewide
Number	16	16
Range	0.26 to 0.81	0.26 to 0.81
Average	0.5	0.5

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.7	0.69	0.7 / 0.69
Compliance Rate	3 of 5 (60%)	9 of 11 (82%)	12 of 16 (75%)

Interpretations:

- Most buildings met or were better than interior stairwell LPD requirements. The three sites that were higher than required levels fell between 0.72 and 0.81 W/sf.

Interior parking LPD

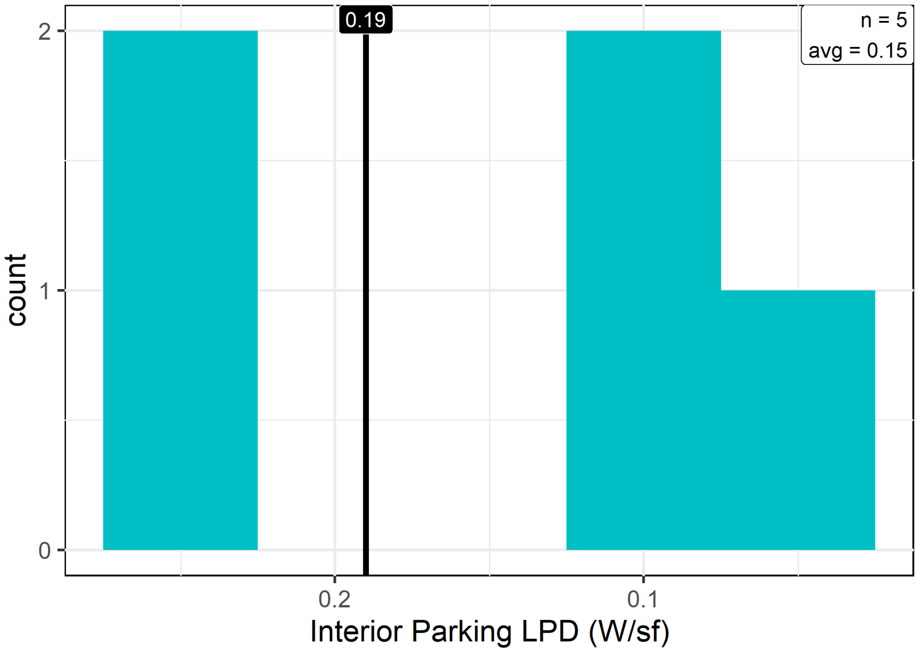


Figure 43. Illinois Interior Parking LPD (W/sf)

Table 46. Illinois Interior Parking LPD (W/sf)

Climate Zone	CZ5	Statewide
Number	5	5
Range	0.07 to 0.27	0.07 to 0.27
Average	0.15	0.15
Climate Zone and Code	**CZ5 (2015 IL Code)**	**Statewide**
Requirement	0.19	0.19
Compliance Rate	3 of 5 (60%)	3 of 5 (60%)

Interpretations:

- Very few surveyed buildings had interior parking areas identified. Just over half of the surveyed interior parking areas had compliant interior parking LPD.

Exterior parking LPD

Uncovered parking areas have increasing allowable thresholds under state commercial code requirements based on the development density of the surrounding area. All buildings in this study were assessed against the criteria for “areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas”. Buildings in major metropolitan commercial districts, as designated by the local land use planning authority, would have higher allowable exterior parking LPD allowances of 0.13W/sf. Base site allowances are not addressed.

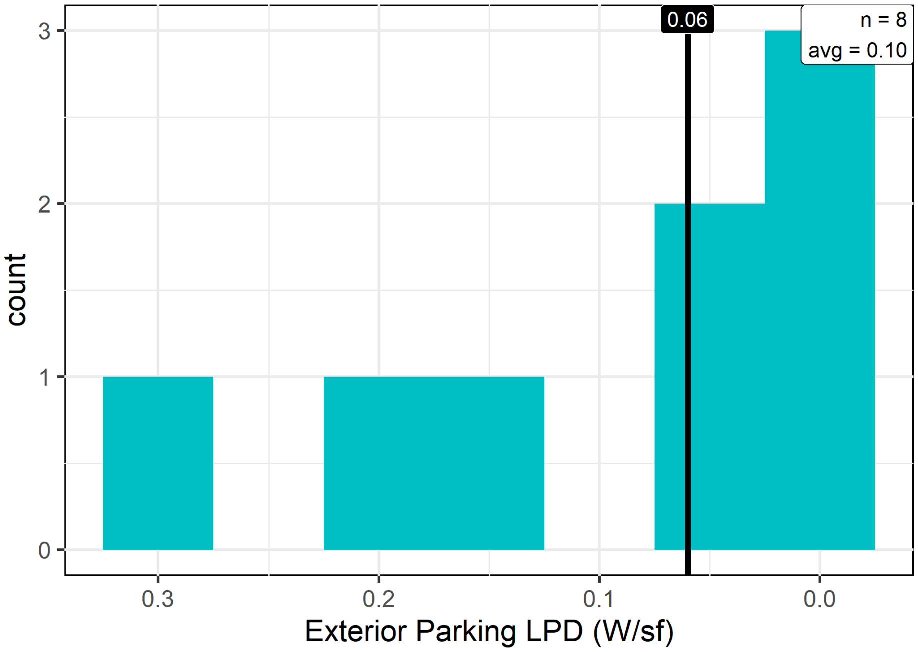


Figure 44. Illinois Exterior Parking LPD

Table 47. Illinois Exterior Parking LPD

Climate Zone	CZ5	Statewide
Number	8	8
Range	0.02 to 0.3	0.02 to 0.3
Average	0.1	0.1

Climate Zone and Code	CZ5 (2012 IL Code)	CZ5 (2015 IL Code)	Statewide
Requirement	0.06	0.06	0.06
Compliance Rate	2 of 4 (50%)	3 of 4 (75%)	5 of 8 (62%)

Interpretations:

- As with interior parking areas, exterior parking areas were infrequently identified. Less than half the buildings had exterior parking areas. However, just over half of the exterior parking areas met the 0.6 W/sf threshold. All the sites with higher LPDs were in metropolitan areas.

Service Hot Water

Water-heating equipment minimum efficiency requirements are subject to federal standards. As a result, equipment below the federal minimums is not available on the market. Instead water- heating strategies are presented to characterize the typical fuels and equipment used to deliver hot water to low-rise multifamily buildings.

Table 48. Illinois Service Hot Water

Delivery	Fuel	Product Class	Units	Avg. Efficiency	Site (n)
Central	Electricity	Boiler/Storage	UEF*	0.942	1
	Natural Gas	Boiler/Storage	EF	0.960	1
		Boiler/Storage	E_t	0.964	12
In Unit	Electricity	Storage	UEF	0.920	5
	Natural Gas	Storage	UEF	0.667	3

*Uniform Energy Factor

Interpretations:

- Natural gas was the primary fuel used for producing hot water in these buildings.
- Approximately two-thirds of the surveyed Illinois low-rise multifamily buildings delivered hot water using central boiler/storage systems.
- When domestic hot water was provided by per-unit individual water heating tanks, both electric and gas systems were encountered about equally.

Mechanical Systems

Similar to service hot water equipment, mechanical heating and cooling equipment efficiencies are required to meet federal standards. The summaries for heating and cooling equipment address the approaches used to condition dwelling units and common areas in surveyed buildings.

Dwelling Unit Heating & Cooling

Heating and cooling strategies can be implemented centrally, such that central systems serve dwelling units and common areas, or via discrete systems serving local areas directly. The in-unit summaries incorporate both strategies. Table 49 and Table 50 summarize the approaches used to provide in-unit heating and cooling. Note that ‘PTHP’ denotes ‘packaged terminal heat pump’, which is typically a through-wall unit. (Also note ‘PTAC’ denotes the same type of system but with only cooling.)

Table 49. Illinois Dwelling Unit Heating

Fuel	In-Unit Heating System	Sites (n)	Percent
Electricity	Electric resistance	2	10%
Electricity	PTHP	1	5%
Electricity	Split system HP	3	14%
Gas	Gas Furnace	14	67%
Gas	Hydronic baseboard (gas boiler)	1	5%

Table 50. Illinois Dwelling Unit Cooling

Fuel	In-Unit Cooling System	Sites (n)	Percent
Electricity	PTAC	4	19%
Electricity	PTHP	1	5%
Electricity	Split system AC	13	62%
Electricity	Split system HP	3	14%

Interpretations:

- Gas was the primary fuel used for space heat, with gas furnaces being the most common system (average efficiency: 93.0 AFUE / 95 E_t).
- Although gas furnaces were the predominant system, almost a third of the buildings used electric space heat (either electric resistance, a split system heat pump, or a PTHP).
- Two central space-heating systems were recorded. One was a gas boiler feeding hydronic baseboards. The other was a split system HP VRF system.
- Unit cooling was present in all surveyed buildings, and largely provided by split systems. Average split system AC efficiencies were 11.7 EER / 14.9 SEER and 12.8 EER for heat pumps.

Common Area Heating & Cooling

Common area conditioning systems serve interior corridors and stairways. Summaries are provided for common entry buildings only (since garden style buildings, by definition, have no enclosed common areas).

Table 51. Illinois Common Area Heating & Cooling Efficiencies

Fuel	Common Area Heating System	Sites (n)	Percent
---	None	1	5%
Electricity	Electric resistance	5	25%
Electricity	Split system HP	1	5%
Gas	Gas Boiler	1	5%
Gas	Gas Furnace	12	60%

Fuel	Common Area Cooling System	Sites (n)	Percent
---	None	7	35%
Electricity	PTAC	9	45%
Electricity	Split system HP	4	20%

Interpretations:

- Gas was the primary fuel used for space heat of common-entry corridors and stairways, with gas furnaces being the most common system (average efficiency: 93.0 AFUE / 95 E_t).
- Cooling was present in 65% of surveyed buildings, with PTACs (average efficiency: 11.6 EER / 13.85 SEER) most regularly being used for cooling of common areas.

Additional Data Items

The following tables and figures serve to describe the sample of surveyed buildings. All Illinois buildings (n = 21) were sampled from climate zone 5A. These were almost all common entry style buildings (Table 52), with most buildings (86%) having three residential floors, rather than two.

Table 52. Illinois Building Type Sampling

Surveyed Building Type	n	Percent
common entry	20	95%
garden style	1	5%

The majority of sampled buildings had fewer than 50 dwelling units (Figure 45), and 50,000 or less square feet of conditioned residential square footage (Table 53).

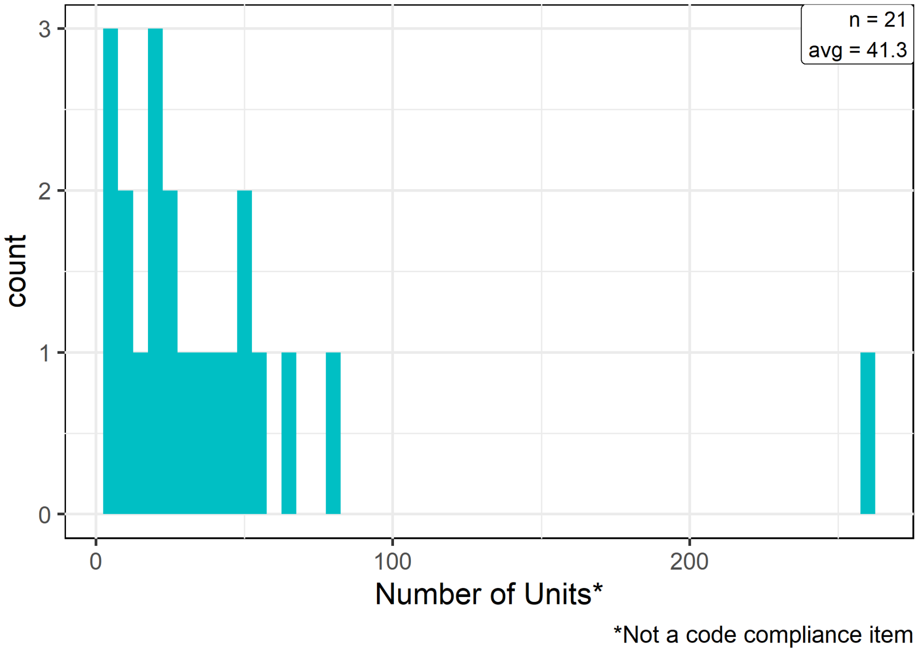


Figure 45. Illinois Number of Units

Table 53. Illinois Number of Units

Climate Zone	CZ5	Statewide
Number	21	21
Range	6 to 260	6 to 260
Average	41.3	41.3

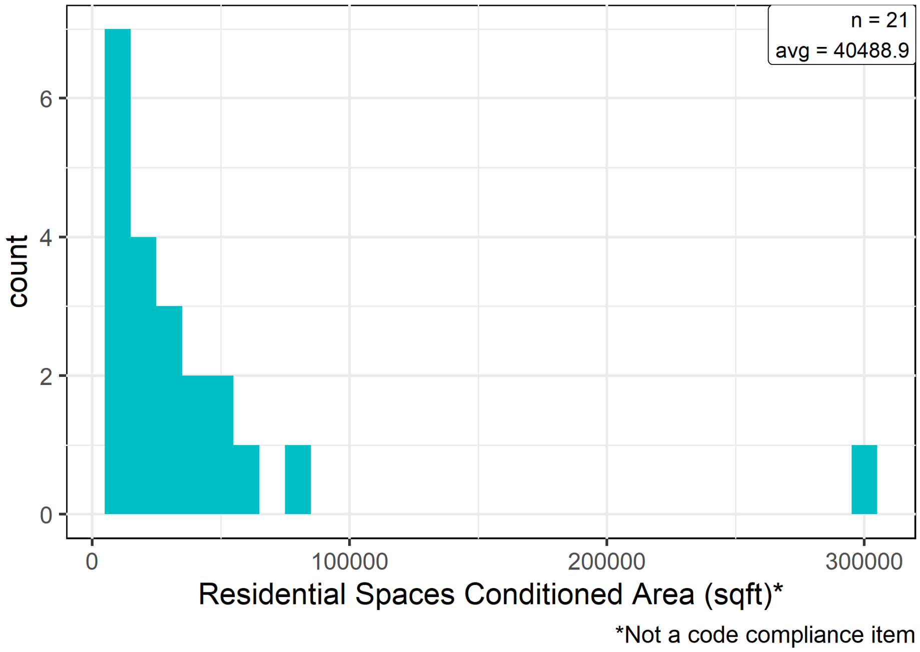


Figure 46. Illinois Residential Spaces Conditioned Area

Table 54. Illinois Residential Spaces Conditioned Area (sqft)

Climate Zone	CZ5	Statewide
Number	21	21
Range	8,000 to 296,000	8,000 to 296,000
Average	40,570	40,570

Average unit sizes by number of bedrooms are presented in Table 55:

Table 55. Illinois Average Unit Area (sqft)

Bedrooms	Average Unit Area (sq ft)
Studio	500
1	845
2	1,016
3	1,173
>3	1,220

The majority of surveyed buildings followed the prescriptive code, while approximately ten percent followed a performance pathway.

Table 56. Illinois Path to Energy Code Compliance

Compliance Path	n	Percent
Performance	2	10%
Prescriptive	19	90%

A little over a third of the sample consisted of Energy Star certified buildings (Table 57). Another 20% were certified under the LEED rating system or other certification programs. The other half of the buildings either had no energy efficiency certification or it was unknown whether the buildings had or were pursuing efficiency certifications. In these cases, this information was unavailable on the plans and on-site contacts were unable to clarify this topic. In some cases, certifications may have above-code requirements for specific components; however, even in instances where energy efficiency programs do not have above-code thresholds, pursuit of a certification indicates some prioritization of energy efficiency in the building design.

Table 57. Illinois Energy Efficiency Certification

Energy Efficiency Certification	n	Percent
Yes	11	52%
No	5	24%
Unknown	5	24%

A.2 Minnesota

Additional lighting

Unlike the measures described in 3.2 State Results, which are subject to residential energy efficiency requirements, lighting power allowances are assessed through the applicable state commercial energy efficiency requirements. The following lighting summaries were conducted on a subset of the surveyed buildings. Interior corridor and stairwell LPD were calculated for common entry buildings where interior circulation areas were present. Interior and exterior parking LPD were calculated as applicable to the parking arrangements for a given building. Prescriptive values for interior areas are based on space-by-space interior lighting power allowances.

Interior corridor LPD

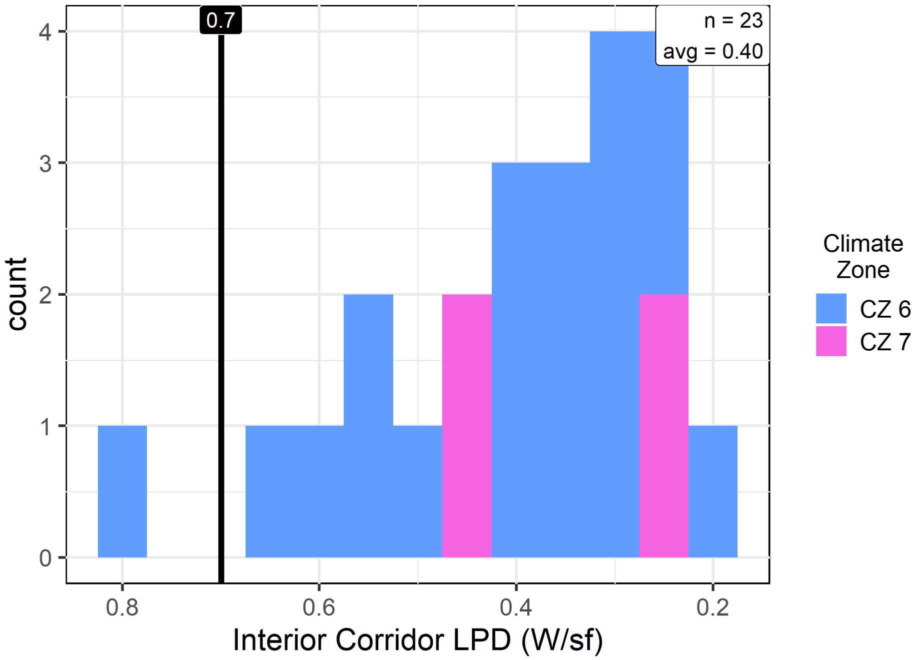


Figure 47. Minnesota Interior Corridor LPD (W/sf)

Table 58. Minnesota Interior Corridor LPD (W/sf)

Climate Zone	**CZ6**	**CZ7**	**Statewide**
Number	19	4	23
Range	0.21 to 0.81	0.25 to 0.47	0.21 to 0.81
Average	0.41	0.36	0.40
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.7	0.7	0.7
Compliance Rate	18 of 19 (95%)	4 of 4 (100%)	22 of 23 (96%)

Interpretations:

- Almost all surveyed buildings had interior corridor LPD values that were better than code requirements.

- Approximately 40% of surveyed buildings had LPD levels that were less than half the level required by prescriptive code.

Interior stairwell LPD

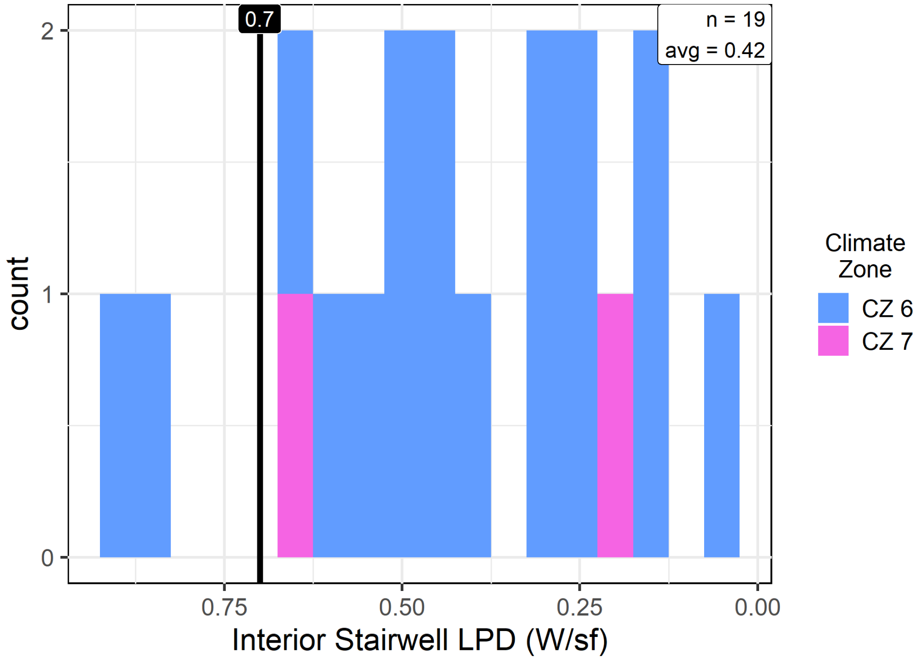


Figure 48. Minnesota Interior Stairwell LPD (W/sf)

Table 59. Minnesota Interior Stairwell LPD (W/sf)

Climate Zone	CZ6	CZ7	Statewide
Number	17	2	19
Range	0.04 to 0.88	0.22 to 0.63	0.04 to 0.88
Average	0.42	0.42	0.42
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0.7	0.7	0.7
Compliance Rate	15 of 17 (88%)	2 of 2 (100%)	17 of 19 (89%)

Interpretations:

- Similar to interior corridor LPD, most buildings were better than the code requirement for interior stairwell LPD. On average, interior stairwell LPD values were 56% of the levels required by prescriptive code.

Interior parking LPD

Unlike the measures described to this point, which are subject to residential energy efficiency requirements, parking lighting levels (interior and exterior) are assessed through commercial energy efficiency requirements.

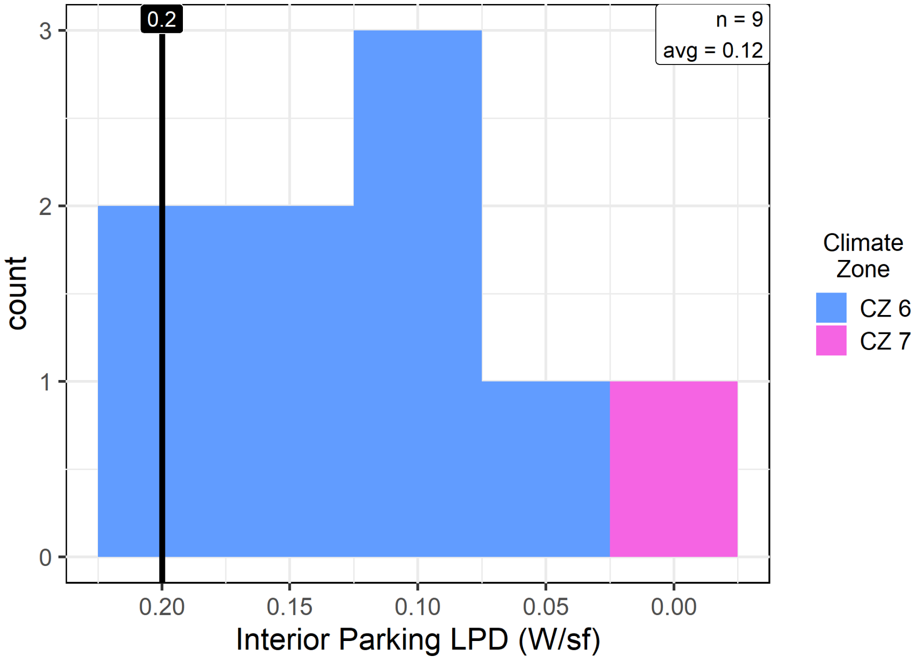


Figure 49. Minnesota Interior Parking (W/sf)

Table 60. Minnesota Interior Parking (W/sf)

Climate Zone	**CZ6**	**CZ7**	**Statewide**
Number	8	1	9
Range	0.06 to 0.2	0.02 to 0.02	0.02 to 0.20
Average	0.13	0.02	0.12
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**
Requirement	0. 20	0.20	0.20
Compliance Rate	8 of 8 (100%)	1 of 1 (100%)	9 of 9 (100%)

Interpretations:

- All buildings with interior parking areas had LPDs that met or were better than code requirements.

Exterior parking LPD

Uncovered parking areas have increasing allowable thresholds under state commercial code requirements based on the development density of the surrounding area. All buildings in this study were assessed against the criteria for “areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas”. Buildings in major metropolitan commercial districts, as designated by the local land use planning authority, would have higher allowable exterior parking LPD allowances of 0.13W/sf. Base site allowances are not addressed.

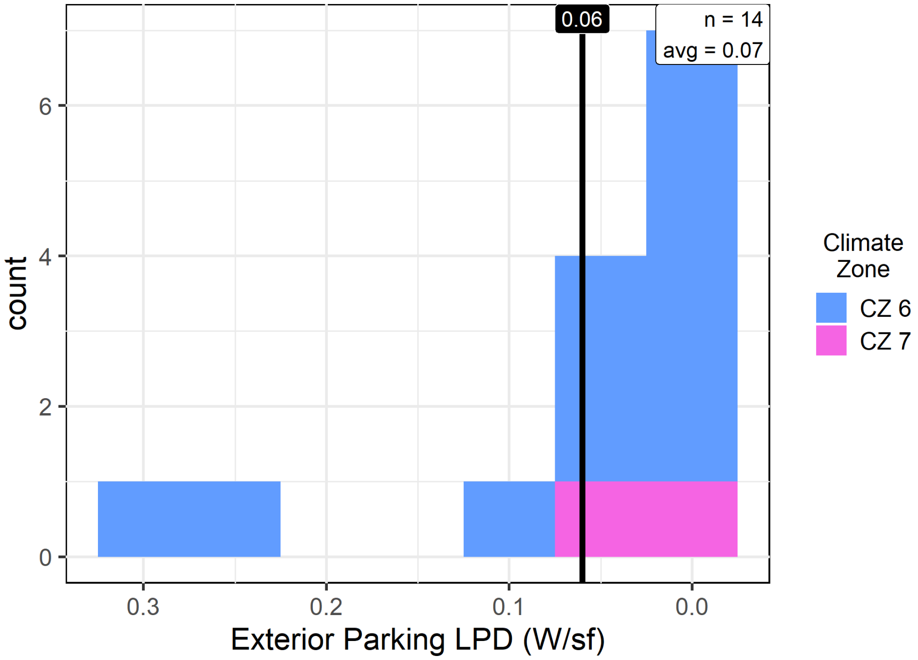


Figure 50. Minnesota Exterior Parking (W/sf)

Table 61. Minnesota Exterior Parking (W/sf)

Climate Zone	CZ6	CZ7	Statewide
Number	12	2	14
Range	0 to 0.31	0.02 to 0.03	0 to 0.31
Average	0.07	0.02	0.07
Climate Zone and Code	**CZ6 (2015 MN Code)**	**CZ7 (2015 MN Code)**	**Statewide**

Climate Zone	CZ6	CZ7	Statewide
Requirement	0.06	0.06	0.06
Compliance Rate	8 of 12 (67%)	2 of 2 (100%)	10 of 14 (71%)

Interpretations:

- Approximately 70% of the sites with surveyed exterior parking areas had LPD levels that met or were better than code requirements. The lowest LPD sites typically had a single security light for the parking area.
- The non-compliant sites had relatively small exterior parking areas of less than 5,500 square feet.

Service Hot Water

Water-heating equipment minimum efficiency requirements are subject to federal standards, as a result, equipment below the federal minimums is not available on the market. Instead water-heating strategies are presented to characterize the typical fuels and equipment used to deliver hot water to low-rise multifamily buildings.

Table 62. Minnesota Service Hot Water

Delivery	Fuel	Product Class	Units	Avg. Efficiency	Site (n)
Central	Natural Gas	Boiler/Storage	EF	0.950	1
		Boiler/Storage	E_t	0.966	22
In Unit		Storage	UEF	0.610	2

Interpretations:

- Gas was used exclusively for heating water for building occupant use in Minnesota.
- Almost all the sites utilized boilers with larger-capacity storage systems to serve dwelling units. Average efficiency was 96.6 E_t.
- 18 of the central-delivery sites (78%) had central circulation loops.

Mechanical Systems

Similar to service hot water equipment, mechanical heating and cooling equipment efficiencies are required to meet federal standards. The summaries for heating and cooling equipment address the approaches used to condition dwelling units and common areas in surveyed buildings.

Dwelling Unit Heating & Cooling

Heating and cooling strategies can be implemented centrally, such that central systems serve dwelling units and common areas, or via discrete systems serving local areas directly. The in-unit summaries incorporate both strategies; central conditioning strategies are highlighted in the interpretations.

Table 63 and Table 64 summarize the approaches used to provide in-unit heating and cooling. Note that 'PTAC' denotes 'packaged terminal air conditioner', which is typically a through-wall cooling unit.

Table 63. Minnesota Dwelling Unit Heating

Fuel	In-Unit Heating System	Sites (n)	Percent
Electricity	Electric resistance	1	4%
Gas	Gas Furnace	17	68%
Gas	Hydronic baseboard (gas boiler)	3	12%
Gas	Water source HP (gas boiler)	4	16%

Table 64. Minnesota Dwelling Unit Cooling

Fuel	In-Unit Cooling System	Sites (n)	Percent
Electricity	PTAC	16	64%
Electricity	Split system AC	2	8%
Electricity	Water source HP	4	16%
Electricity	Window AC	3	12%

Interpretations:

- As with water heating, gas was the primary fuel used for dwelling unit space heat. Gas furnaces mainly served the occupants, although boiler-provided space heat was used in approximately 30% of the buildings.
- A single building had a furnace with AFUE 78. Excluding that site, furnaces typically had 94 AFUE/94 E.
- The gas boiler sites were all central HVAC system buildings. These buildings relied on a variety of cooling methods for dwelling units. Water-source heat pump cooling is discussed

below. The other three buildings predominantly relied on window AC units (EER 10.2/SEER 9.3) or in one case, PTACs.

- Cooling loads were most commonly served by PTAC equipment with an average efficiency of 10.5 EER.
- Water-source heat pump sites were the second most-common cooling strategy and correspond to the water-source heat pump-heated sites. These systems had an average COP of 4.1.

Common Area Heating & Cooling

Common area conditioning systems serve interior corridors and stairways. Summaries are provided for common entry buildings only (since garden style buildings, by definition, have no enclosed common areas).

Table 65. Minnesota Common Area Heating & Cooling Efficiencies

Fuel	Common Area Heating System	Sites (n)	Percent
---	None	2	9%
Electricity	Electric resistance	4	17%
Gas	Gas Boiler	5	22%
Gas	Gas Furnace	12	52%

Fuel	Common Area Cooling System	Sites (n)	Percent
---	None	4	17%
Electricity	PTAC	8	35%
Electricity	Split system AC	1	4%
Electricity	Split system HP	7	30%
Electricity	Water source HP	3	13%

Interpretations:

- As with dwelling unit space heat, gas was also the primary fuel for heating common areas. Although electric resistance was sometimes used (17% of common entry buildings), 74% of these buildings used gas furnaces (average 92.1 AFUE/ 95.5 E_t) or boilers (average 94 AFUE/94.2 E_t).

- The two sites without dedicated corridor/stairwell heating were efficiency apartments with very small corridors surrounded by conditioned space.
- Split system heat pumps and packaged air conditioning equipment were most often used for cooling. Split system heat pumps were commonly fan coils coupled with through-wall furnace units, while packaged air conditioners averaged 14.6 SEER or 11.5 EER.
- Water-source heat pumps use a water loop (typically the return leg of the boiler loop) as the heat source and sink. 60% of the buildings that used boilers for common area conditioning relied on water source heat pumps to provide seasonal cooling to common areas.

Additional Data Items

The following tables and figures serve to describe the sample of surveyed buildings. The majority of buildings were sampled from climate zone 6A with the remaining buildings sampled in climate zone 7A (Table 66).

Table 66. Minnesota Climate Zone Sampling

Climate Zone	n	Percent
6A	21	84%
7A	4	16%

These were almost all common entry style buildings (92% or 23 of 25 buildings), with most buildings (67%) having three residential floors, rather than two.

The majority of sampled buildings had fewer than 50 dwelling units (Figure 51, Table 67). However, there was a higher proportion of larger buildings. Forty-four percent of buildings had more than 50 units. Relatedly, larger buildings (> 50,000 square feet of conditioned residential square footage) were also more common in Minnesota (Figure 52, Table 68).

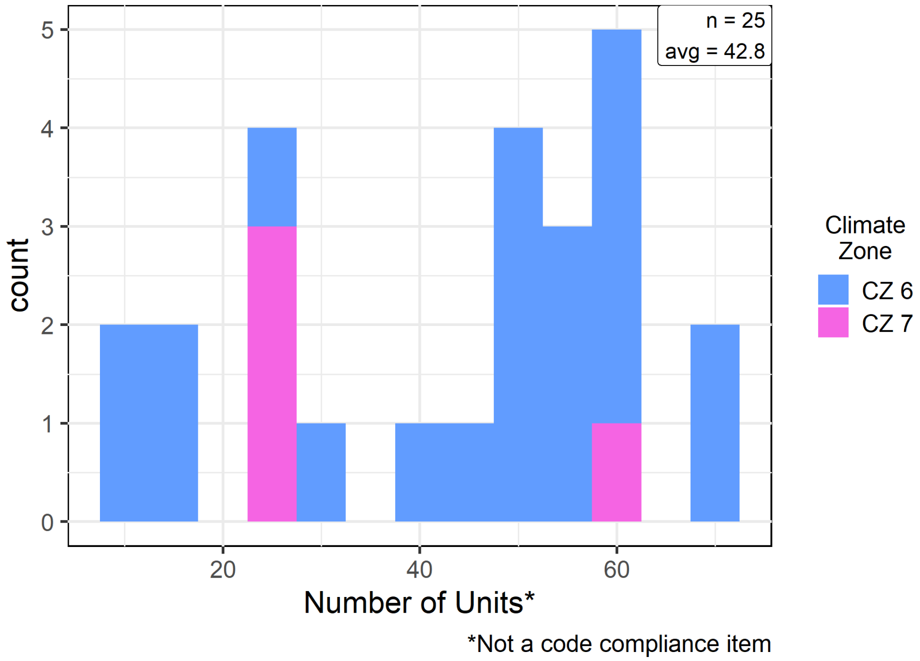


Figure 51. Minnesota Number of Units

Table 67. Minnesota Number of Units

Climate Zone	CZ6	CZ7	Statewide
Number	21	4	25
Range	10 to 71	25 to 60	10 to 71
Average	44.5	34.2	42.8

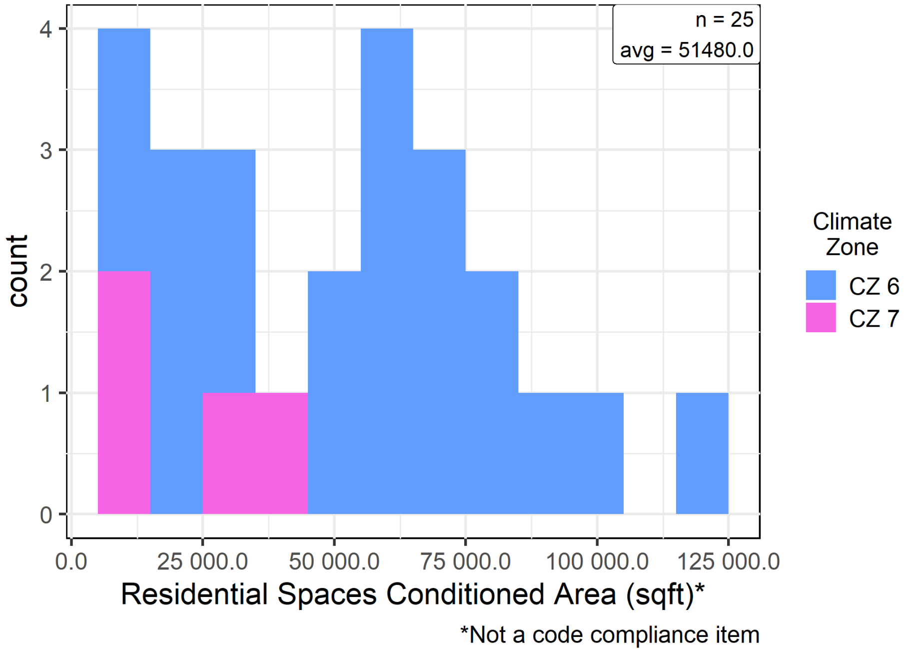


Figure 52. Minnesota Residential Spaces Conditioned Area

Table 68. Minnesota Residential Spaces Conditioned Area (sqft)

Climate Zone	CZ6	CZ7	Statewide
Number	21	4	25
Range	11,000 to 117,000	15,000 to 36,000	11,000 to 117,000
Average	56,470	25,250	51,480

Average unit sizes by number of bedrooms are presented in Table 69:

Table 69. Minnesota Average Unit Area (sqft)

Bedrooms	Average Unit Area (sq ft)
Studio	431
1	716
2	969
3	1,274
>3	1,573

The majority of surveyed buildings followed the prescriptive code, but approximately a third met code requirements by a performance pathway.

Table 70. Minnesota Path to Energy Code Compliance

Compliance Path	n	Percent
Performance	7	28%
Prescriptive	17	68%
Unknown	1	4%

A little over a third of the sample consisted of Energy Star certified buildings (Table 71). In 20% of the cases, it was unknown whether the buildings had or were pursuing efficiency certifications. Frequently this information was unavailable on the plans and on-site contacts were unable to clarify this topic. The remaining buildings were not certified through an energy efficiency program. In some cases, certifications may have above-code requirements for specific components; however, even in instances where energy efficiency programs do not have above-code thresholds, pursuit of a certification indicates some prioritization of energy efficiency in the building design.

Table 71. Minnesota Energy Efficiency Certification

Energy Efficiency Certification	n	Percent
Yes	9	36%
No	11	44%
Unknown	5	20%

A.3 Oregon

Additional lighting

As with the Oregon measures described in 3.2 State Results, lighting power allowances are also assessed through the applicable state commercial energy efficiency requirements. The following lighting summaries were conducted on a subset of the surveyed buildings. Interior corridor and stairwell LPD were calculated for common entry buildings where interior circulation areas were present. Interior and exterior parking LPD were calculated as applicable to the parking arrangements for a given building. Prescriptive values for interior areas are based on space-by-space interior lighting power allowances.

Interior corridor LPD

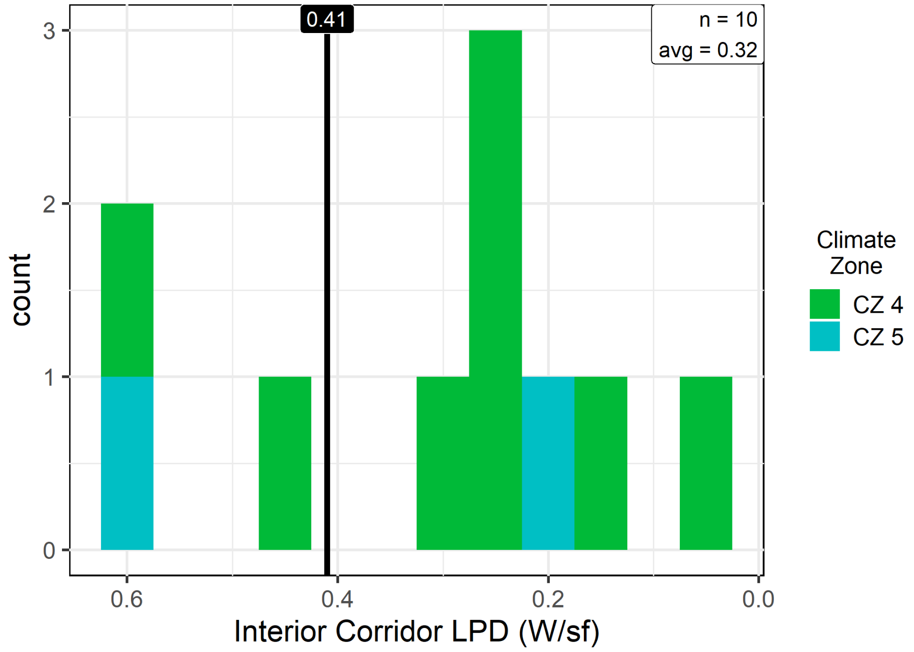


Figure 53. Oregon Interior Corridor LPD

Table 72. Oregon Interior Corridor LPD

Climate Zone	**CZ4**	**CZ5**	**Statewide**
Number	8	2	10
Range	0.06 to 0.61	0.22 to 0.6	0.06 to 0.61
Average	0.30	0.41	0.32

Climate Zone and Code	**CZ4 (2011 OR Code)**	**CZ4 (2014 OR Code)**	**CZ5 (2011 OR Code)**	**CZ5 (2014 OR Code)**	**Statewide**
Requirement	0.41	0.41	0.41	0.41	0.41
Compliance Rate	3 of 4 (75%)	3 of 4 (75%)	0 of 1 (0%)	1 of 1 (100%)	7 of 10 (70%)

Interpretations:

- 70% of surveyed buildings met or were better than the code requirements for interior corridor LPD.

Interior stairwell LPD

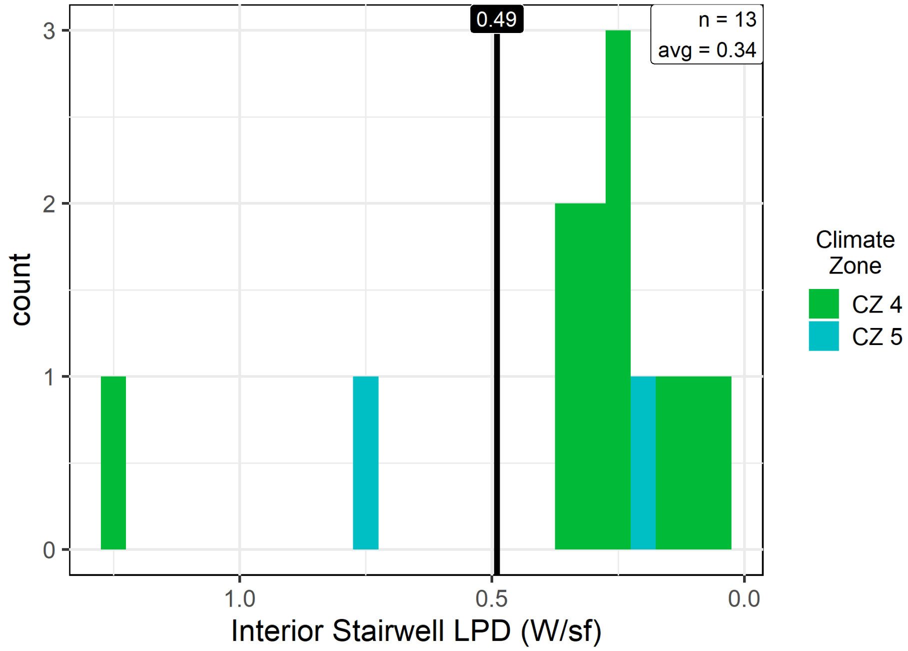


Figure 54. Oregon Interior Stairwell LPD

Table 73. Oregon Interior Stairwell LPD

Climate Zone	CZ4	CZ5	Statewide
Number	11	2	13
Range	0.03 to 1.25	0.21 to 0.75	0.03 to 1.25
Average	0.32	0.48	0.34

Climate Zone and Code	CZ4 (2011 OR Code)	CZ4 (2014 OR Code)	CZ5 (2011 OR Code)	CZ5 (2014 OR Code)	Statewide
Requirement	0.49	0.49	0.49	0.49	0.49
Compliance Rate	4 of 4 (100%)	6 of 7 (86%)	0 of 1 (0%)	1 of 1 (100%)	11 of 13 (85%)

Interpretations:

- 85% of surveyed buildings were better than the code requirements for interior stairwell LPD.
- The sites with interior stairwell LPD levels above code requirements are two of the three sites that were also non-compliant for interior corridor LPD.

Interior parking LPD

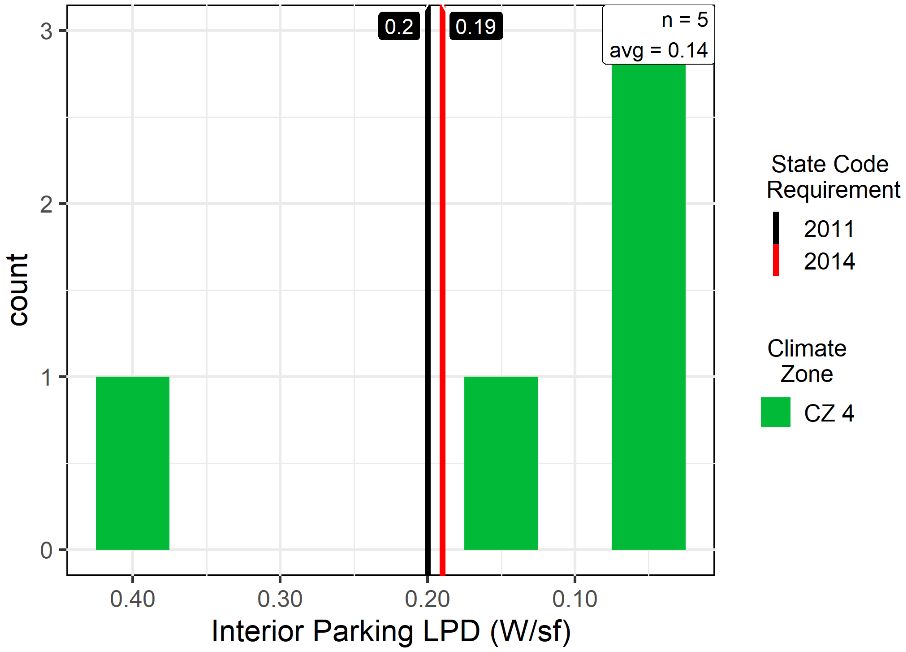


Figure 55. Oregon Interior Parking LPD

Table 74. Oregon Interior Parking LPD

Climate Zone	CZ4		Statewide
Number	5		5
Range	0.03 to 0.42		0.03 to 0.42
Average	0.14		0.14
Climate Zone and Code	**CZ4 (2011 OR Code)**	**CZ4 (2014 OR Code)**	**Statewide**
Requirement	0.2	0.19	0.2 / 0.19
Compliance Rate	3 of 3 (100%)	1 of 2 (50%)	4 of 5 (80%)

Interpretations:

- Few buildings had interior parking areas. This sub-sample consists of 5 buildings, 80% of which met or were better than code requirements for interior parking LPD.

Exterior parking LPD

Uncovered parking areas have increasing allowable thresholds under state commercial code requirements based on the development density of the surrounding area. All buildings in this study were assessed against the criteria for "areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas". Buildings in major metropolitan commercial districts, as designated by the local land use planning authority, would have higher allowable exterior parking LPD allowances of 0.13W/sf. Base site allowances are not addressed.

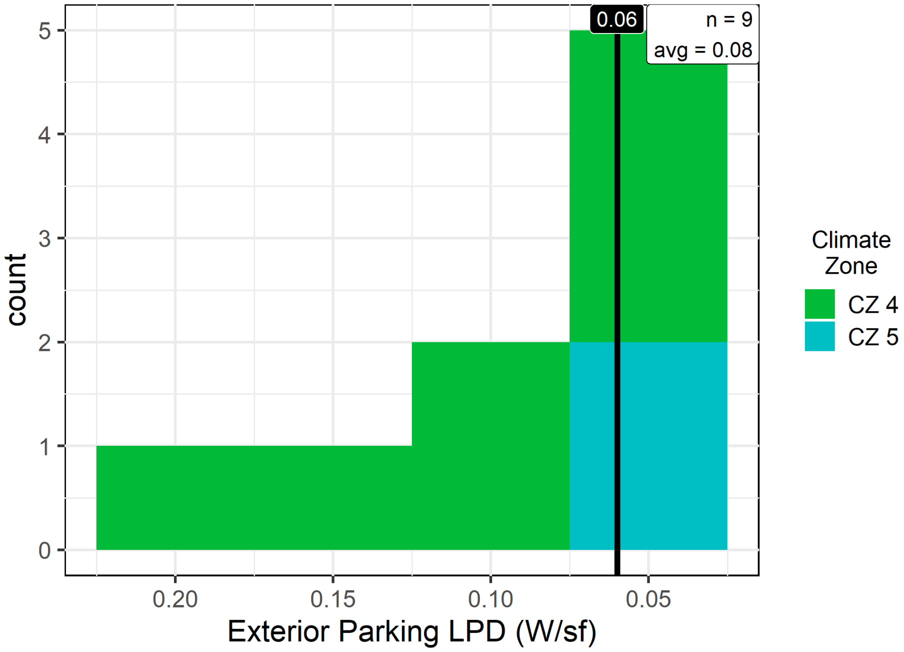


Figure 56. Oregon Exterior Parking LPD

Table 75. Oregon Exterior Parking LPD

Climate Zone	CZ4	CZ5	Statewide
Number	7	2	9
Range	0.03 to 0.18	0.03 to 0.06	0.03 to 0.18
Average	0.09	0.04	0.08

Climate Zone and Code	CZ4 (2011 OR Code)	CZ4 (2014 OR Code)	CZ5 (2011 OR Code)	CZ5 (2014 OR Code)	Statewide
Requirement	0.06	0.06	0.06	0.06	0.06
Compliance Rate	1 of 2 (50%)	2 of 5 (40%)	1 of 1 (100%)	1 of 1 (100%)	5 of 9 (56%)

Interpretations:

- 56% of surveyed buildings met or were better than the code requirements for exterior parking LPD.
- Exterior parking lighting represents an opportunity for improvement within the state and should be given increased attention in future training and enforcement.

Service Hot Water

Water-heating equipment minimum efficiency requirements are subject to federal standards; as a result, equipment below the federal minimums is not available on the market. Instead water- heating strategies are presented to characterize the typical fuels and equipment used to deliver hot water to low-rise multifamily buildings.

Table 76. Oregon Service Hot Water

Delivery	Fuel	Product Class	Units	Avg. Efficiency	Site (n)
Central	Electricity	Heat pump	UEF	3.340	1
	Natural Gas	Boiler/Storage	E_t	0.957	3
		Boiler/Storage	UEF	0.960	2
In Unit	Electricity	Storage	UEF	0.927	18

Interpretations:

- Electricity is the primary fuel used for producing hot water in these buildings.

- The majority of Oregon low-rise multifamily buildings deliver hot water using small residential-capacity storage tanks distributed in the individual units.
- Natural gas is used in larger commercial-capacity applications, usually with larger storage volumes to deliver hot water from central systems serving multiple units. In one case, a boiler was coupled with a passive solar pre-heating system.
- The highest efficiency system encountered during building surveys was a heat pump water heater that served 5 units. The site was comprised of several clustered buildings each with a dedicated heat pump water heater, such that this strategy supplies the hot water for a total of 16 units.

Mechanical Systems

Similar to service hot water equipment, mechanical heating and cooling equipment efficiencies are required to meet federal standards. The summaries for heating and cooling equipment address the approaches used to condition dwelling units and common areas in surveyed buildings.

Dwelling Unit Heating & Cooling

Heating and cooling strategies can be implemented centrally, such that central systems serve dwelling units and common areas, or via discrete systems serving local areas directly. Only a single central heating and cooling system was encountered in Oregon surveys. This was a split system heat pump with variable refrigerant flow (VRF).

Table 77 and Table 78 summarize the approaches used to provide in-unit heating and cooling. Note that ‘PTHP’ denotes ‘packaged terminal heat pump’, which is typically a through-wall unit. (Also note ‘PTAC’ denotes the same type of system but with only cooling.)

Table 77. Oregon Dwelling Unit Heating

Fuel	In-Unit Heating System	Sites (n)	Percent
Electricity	Electric resistance	10	42%
Electricity	PTHP	6	25%
Electricity	Split system HP	7	29%
Gas	Gas Furnace	1	4%

Table 78. Oregon Dwelling Unit Cooling

Fuel	In-Unit Cooling System	Sites (n)	Percent
---	None	8	33%
Electricity	PTAC	1	4%
Electricity	PTHP	7	29%
Electricity	Split system AC	2	8%
Electricity	Split system HP	6	25%

Interpretations:

- Electricity is the primary fuel used for heating and cooling dwelling units in these buildings.
- Heating and cooling are provided mainly by heat pump equipment, with electric resistance also being commonly used for space heat. PTHP average efficiencies were 3.5 COP, whereas split system heat pumps averaged 9.6 HSPF / 3.6 COP.
- In-unit cooling was documented in over 60% of surveyed buildings. Where present, it is primarily provided by packaged equipment or split-system heat pumps. PTHP average efficiencies were 11.2 EER, whereas split system heat pumps averaged 20.0 SEER. The majority of the electric resistance sites were also the sites with no cooling.
- A single surveyed building was served by a central split system HP / VRF with an average efficiency of 3.34 COP / 12.5 HSPF.

Common Area Heating & Cooling

Common area conditioning systems serve interior corridors and stairways. Summaries are provided for common entry buildings only (since garden style buildings, by definition, have no enclosed common areas).

Table 79. Oregon Common Area Heating

Fuel	Common Area Heating System	Sites (n)	Percent
---	None	1	8%
Electricity	Electric resistance	3	25%
Electricity	Split system HP	7	58%
Gas	Gas Furnace	1	8%

Table 80. Oregon Common Area Cooling

Fuel	Common Area Cooling System	Sites (n)	Percent
---	None	4	33%
Electricity	PTAC	1	8%
Electricity	Split system HP	7	58%

Interpretations:

- Split system heat pump equipment was primarily used for common area heating and cooling. Average efficiencies are shown in Table 81. (Note both SEER and IEER are reported for some categories since larger-capacity equipment uses IEER vs SEER.)

Table 81. Oregon Common Area Heating & Cooling Efficiencies

Service	System	Efficiency Unit	Avg. Efficiency Rating
Heating	Split system HP	HSPF	10.9
	Split system HP	COP	3.6
Cooling	Split system HP	EER	9.7
	Split system HP	SEER	23.78
	Split system HP	IEER	19.8

Additional Data Items

The following tables and figures serve to describe the sample of surveyed buildings. The majority of buildings were sampled from climate zone 4C, with the remaining buildings sampled in climate zone 5B (Table 82).

Table 82. Oregon Climate Zone Sampling

Climate Zone	n	Percent
4C	21	88%
5B	3	12%

These were split between common entry and garden style buildings (where all living units have entry doors to a non-enclosed corridor or outside) (Table 83) with most (88%) of sampled buildings having three residential floors, rather than two.

Table 83. Oregon Building Type Sampling

Surveyed Building Type	n	Percent
common entry	12	50%
garden style	12	50%

The majority of sampled buildings had fewer than 50 dwelling units (Figure 57, Table 84), and less than 50,000 square feet of conditioned residential square footage (Figure 58, Table 85).

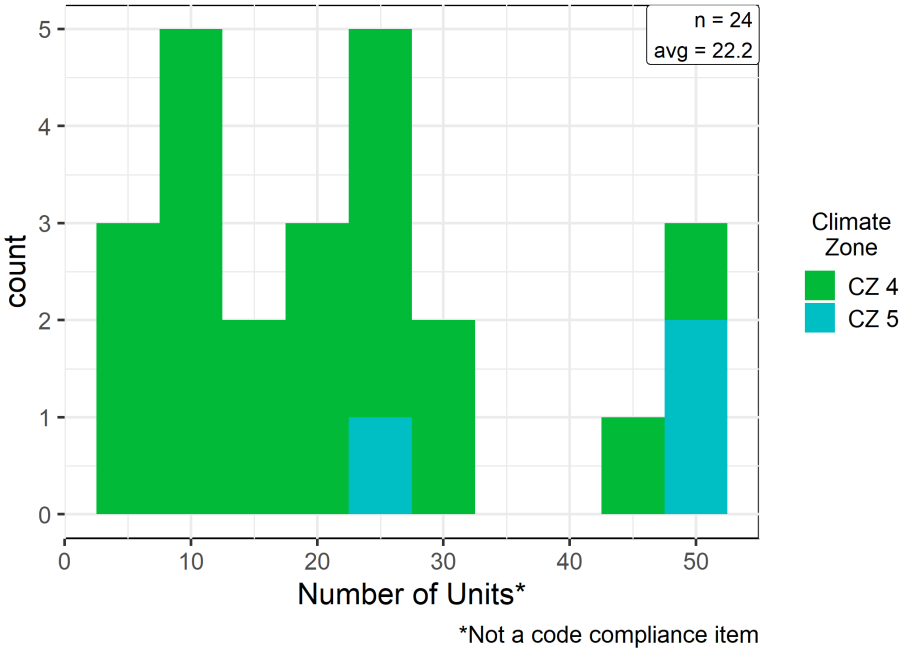
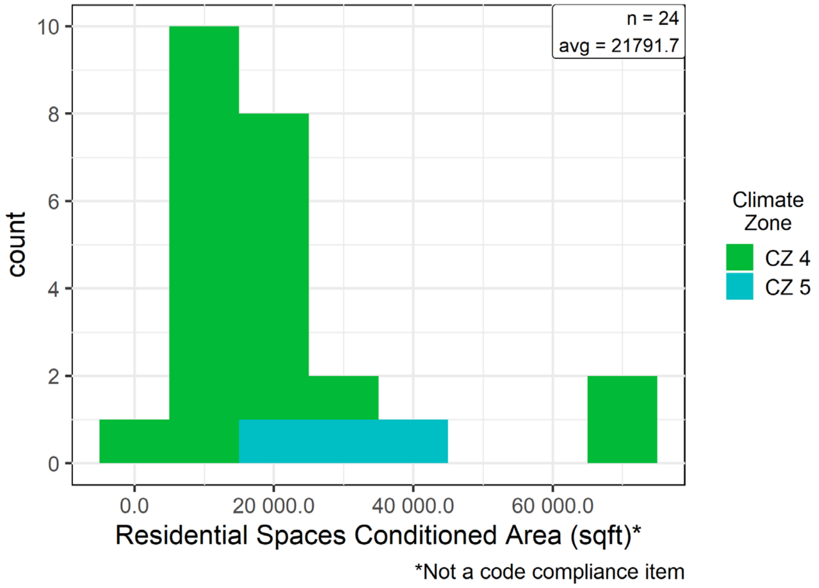


Figure 57. Oregon Number of Units

Table 84. Oregon Number of Units

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	5 to 52	24 to 50	5 to 52
Average	19.5	40.7	22.2



*Not a code compliance item

Figure 58. Oregon Residential Spaces Conditioned Area

Table 85. Oregon Residential Spaces Conditioned Area (sqft)

Climate Zone	CZ4	CZ5	Statewide
Number	21	3	24
Range	4,000 to 70,000	17,000 to 45,000	4,000 to 70,000
Average	20,290	32,330	21,790

Average unit sizes by number of bedrooms are presented in Table 86:

Table 86. Oregon Average Size Unit by Number of Bedrooms

Bedrooms	Average Unit Area (sqft)
Studio	537
1	654
2	994
3	1,423
>3	1,506

The majority of surveyed buildings followed the prescriptive code, while approximately 25% followed a UA (component) tradeoff pathway (Table 87).

Table 87. Oregon Path to Energy Code Compliance

Compliance Path	n	Percent
Prescriptive	14	58%
UA tradeoff	6	25%
Unknown	4	17%

Most surveyed buildings had not received any energy efficiency certification (Table 88). However, it was unknown whether roughly 30% of the buildings had or were pursuing efficiency certifications. In these cases, this information was unavailable on the plans and on-site contacts were unable to clarify this topic. A single surveyed building was LEED certified, but 20% had other energy efficiency certifications from either local (Earth Advantage) or international programs (e.g., Green Globe, Living Future Institute). In some cases, certifications may have above-code requirements for specific components; however, even in instances where energy efficiency programs do not have above-code thresholds, pursuit of a certification indicates some prioritization of energy efficiency in the building design.

Table 88. Oregon Energy Efficiency Certification

Energy Efficiency Certification	n	Percent
Yes	6	25%
No	10	42%
Unknown	8	33%

A.4 Washington

Additional lighting

Unlike the measures described in 3.2 State Results, which are subject to residential energy efficiency requirements, lighting power allowances are assessed through the applicable state commercial energy efficiency requirements. The following lighting summaries were conducted on a subset of the surveyed buildings. Interior corridor and stairwell LPD were calculated for common entry buildings where interior circulation areas were present. Interior and exterior parking LPD were calculated as applicable to the parking arrangements for a given building. Prescriptive values for interior areas are based on space-by-space interior lighting power allowances.

Interior corridor LPD

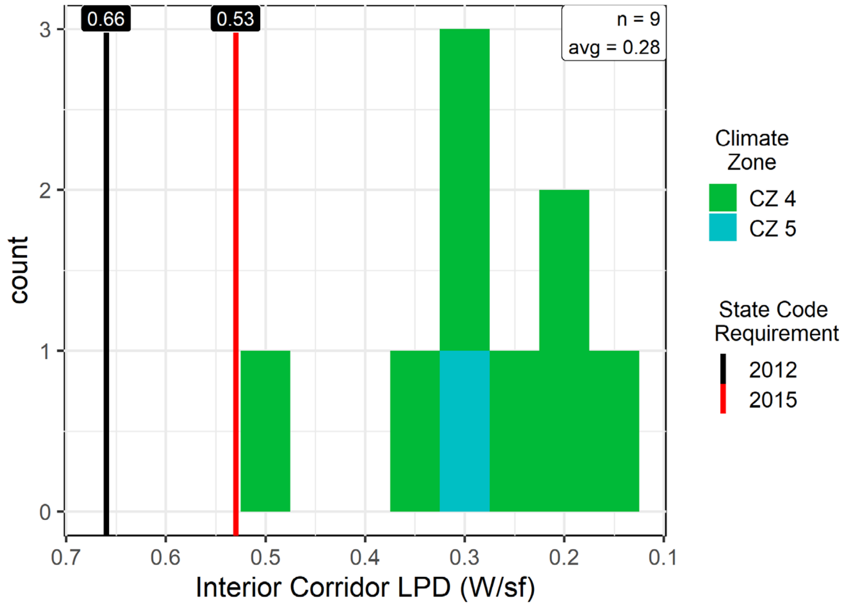


Figure 59. Washington Interior Corridor LPD (W/sf)

Table 89. Washington Interior Corridor LPD (W/sf)

Climate Zone	CZ4	CZ5	Statewide
Number	8	1	9
Range	0.14 to 0.49	0.28 to 0.28	0.14 to 0.49
Average	0.28	0.28	0.28

Climate Zone and Code	CZ4 (2012 WA Code) [38]	CZ4 (2015 WA Code)	CZ5 (2015 WA Code)	Statewide
Requirement	0.66	0.53	0.53	0.66 / 0.53
Compliance Rate	4 of 4 (100%)	4 of 4 (100%)	1 of 1 (100%)	9 of 9 (100%)

Interpretations:

- All surveyed buildings met or were better than the code requirements for interior corridor LPD.
- On average, surveyed buildings were approximately 52% of the maximum allowable LPD levels.

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[38] Because this is a sub-sample of surveyed Washington buildings, there were no buildings subject to CZ5 (2012 WA Code) requirements.

Interior stairwell LPD

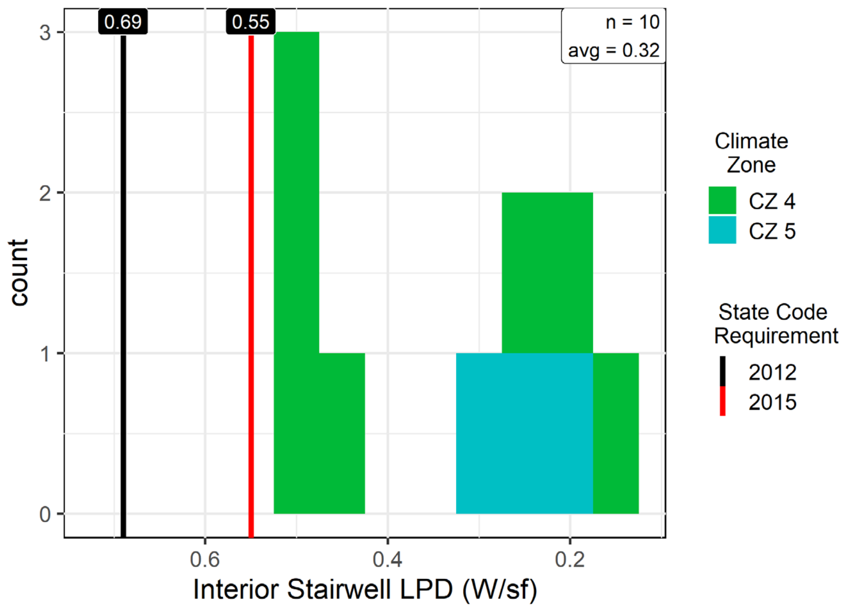


Figure 60. Washington Interior Stairwell LPD

Table 90. Washington Interior Stairwell LPD

Climate Zone	CZ4	CZ5	Statewide
Number	7	3	10
Range	0.14 to 0.49	0.21 to 0.29	0.14 to 0.49
Average	0.36	0.25	0.32

Climate Zone and Code	CZ4 (2012 WA Code)[38]	CZ4 (2015 WA Code)	CZ5 (2015 WA Code)	Statewide
Requirement	0.69	0.55	0.55	0.69 / 0.55
Compliance Rate	3 of 3 (100%)	4 of 4 (100%)	3 of 3 (100%)	10 of 10 (100%)

Interpretations:

- Similar to interior corridor LPD, all surveyed buildings were better than the code requirement for interior stairwell LPD.

Interior parking LPD

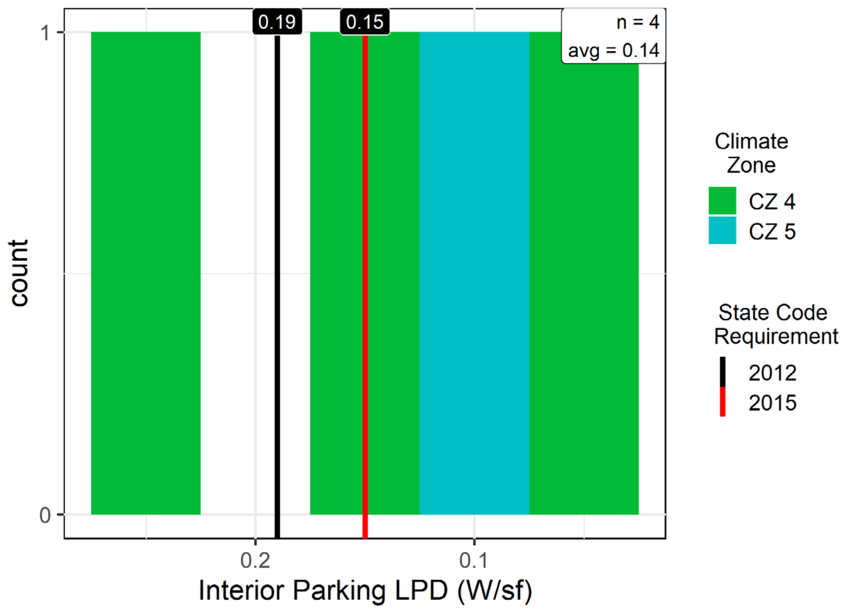


Figure 61. Washington Interior Parking LPD

Table 91. Washington Interior Parking LPD

Climate Zone	CZ4	CZ5	Statewide	
Number	3	1	4	
Range	0.04 to 0.27	0.12 to 0.12	0.04 to 0.27	
Average	0.15	0.12	0.14	
Climate Zone and Code	**CZ4 (2012 WA Code)[38]**	**CZ4 (2015 WA Code)**	**CZ5 (2015 WA Code)**	**Statewide**
Requirement	0.19	0.15	0.15	0.19 / 0.15
Compliance Rate	2 of 2 (100%)	0 of 1 (0%)	1 of 1 (100%)	3 of 4 (75%)

Interpretations:

- Few buildings were characterized by interior parking areas. This sample consists of 4 buildings, 75% of which met or were better than code requirements for interior parking LPD.

Exterior parking LPD

Uncovered parking areas have increasing allowable thresholds under state commercial code requirements based on the development density of the surrounding area. All buildings in this study were assessed against the criteria for “areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use and residential mixed-use areas”. Buildings in major metropolitan commercial districts, as designated by the local land use planning authority, would have higher allowable exterior parking LPD allowances of 0.13W/sf. Base site allowances are not addressed.

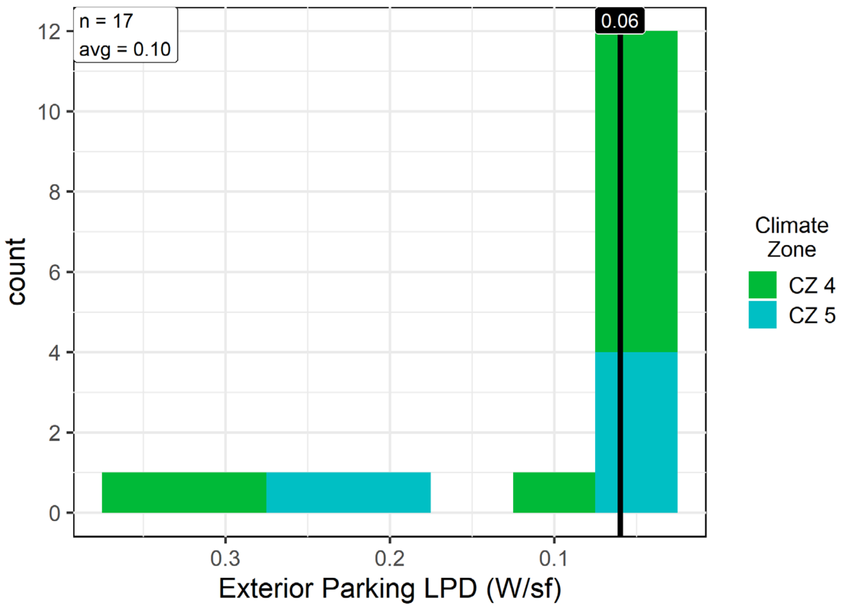


Figure 62. Washington Exterior Parking LPD

Table 92. Washington Exterior Parking LPD

Climate Zone	**CZ4**	**CZ5**	**Statewide**
Number	11	6	17
Range	0.03 to 0.37	0.04 to 0.24	0.03 to 0.37
Average	0.10	0.11	0.10

Climate Zone and Code	**CZ4 (2012 WA Code)**	**CZ4 (2015 WA Code)**	**CZ5 (2012 WA Code)**	**CZ5 (2015 WA Code)**	**Statewide**
Requirement	0.06	0.06	0.06	0.06	0.06
Compliance Rate	3 of 6 (50%)	5 of 5 (100%)	1 of 1 (100%)	3 of 5 (60%)	12 of 17 (71%)

Interpretations:

- Exterior parking areas were more common at surveyed buildings than interior parking areas. Exterior parking LPD showed one of the lower compliance rates for prescriptive code key items examined in this study.

- Exterior parking lighting represents an opportunity for improvement within the state and should be given increased attention in future training and enforcement.

Service Hot Water

Water heating equipment minimum efficiency requirements are subject to federal standards; as a result, equipment below the federal minimums is not available on the market. Water-heating categories characterize the typical fuels and equipment used to deliver hot water to low-rise multifamily buildings.

Table 93. Washington Service Hot Water

Delivery	Fuel	Product Class	Units	Avg. Efficiency	Site (n)
Central	Electricity	Heat pump	COP	4.100	1
		Storage	E_t	0.980	1
	Natural Gas	Boiler/Storage	EF	0.965	1
		Boiler/Storage	E_t	0.967	3
		Boiler/Storage	UEF	0.970	1
In Unit	Electricity	Storage	UEF	0.933	19

Interpretations:

- In-unit electric storage water heaters were most commonly used for producing hot water. Centralized systems were most commonly natural gas storage.
- The majority of Washington low-rise multifamily buildings deliver hot water using small, residential-capacity storage tanks (45-55 gal) distributed in the individual units.
- Natural gas systems typically have larger storage volumes to deliver hot water to multiple units. However, gas was not used exclusively in central water heating.
- The highest efficiency system encountered during building surveys was a heat pump water heater that was centrally serving the hot water needs of 18 units.
- At one site, a condensing tankless gas water heater was used in conjuncture with solar thermal pre-heating and multiple storage tanks.

Mechanical Systems

Similar to service hot water equipment, mechanical heating and cooling equipment efficiencies are required to meet federal standards. The summaries for heating and cooling equipment address the approaches used to condition dwelling units and common areas in surveyed buildings.

Dwelling Unit Heating & Cooling

Heating and cooling strategies can be implemented centrally, such that central systems serve dwelling units and common areas, or via discrete systems serving local areas directly. No central heating or cooling systems were found in surveyed buildings in Washington State.

Table 94 and Table 95 summarize the approaches used to provide in-unit heating and cooling. Note that 'PTHP' denotes 'packaged terminal heat pump', which is typically a through-wall unit. (Also note 'PTAC' denotes the same type of system but with only cooling.)

Table 94. Washington Dwelling Unit Heating

Fuel	In-Unit Heating System	Sites (n)	Percent
Electricity	Electric resistance	20	80%
Electricity	PTHP	2	8%
Electricity	Split system HP	2	8%
Gas	Gas Furnace	1	4%

Table 95. Washington Dwelling Unit Cooling

Fuel	In-Unit Cooling System	Sites (n)	Percent
---	None	16	64%
Electricity	PTAC	2	8%
Electricity	PTHP	2	8%
Electricity	Split system AC	1	4%
Electricity	Split system HP	2	8%
Electricity	Window AC	2	8%

Interpretations:

- Electricity is the primary fuel used for heating and cooling dwelling units in these buildings.
- Heating is provided predominantly by electric resistance equipment, with heat pump equipment used in approximately one-fifth of the buildings.
- In-unit cooling was documented in less than 40% of surveyed buildings. Where present, it is primarily provided by in-unit packaged equipment or split-system heat pumps. Window air conditioning units were also used.

- Table 96 summarizes average efficiencies for the most common in-unit cooling systems.

Table 96. Washington Dwelling Unit Cooling Efficiencies

In-Unit Cooling System	Efficiency Unit	Avg. Efficiency Rating
Split system HP	SEER	23.5
PTAC	EER	10.2
PTHP	EER	11.4
Window AC	EER	9.8

Common Area Heating & Cooling

Common area conditioning systems serve interior corridors and stairways. Summaries are provided for common entry buildings only (since garden style buildings, by definition, have no enclosed common areas).

Table 97. Washington Common Area Heating

Fuel	Common Area Heating System	Sites (n)	Percent
---	None	1	10%
Electricity	Electric resistance	7	70%
Electricity	Split system HP	1	10%
Gas	Gas Furnace	1	10%

Table 98. Washington Common Area Cooling

Fuel	Common Area Cooling System	Sites (n)	Percent
---	None	7	70%
Electricity	Split system HP	3	30%

Interpretations:

- Corridors and stairwells were commonly heated with electric resistance equipment.
- Common area cooling was infrequently encountered, but when present (in 2 buildings), was provided by split system HPs with average efficiencies of 11.4 EER and 16.6 SEER.

Additional Data Items

The following tables and figures serve to describe the sample of surveyed buildings. Roughly three-quarters of the buildings were sampled from climate zone 4C, with the remaining buildings sampled in climate zone 5B (Table 99).

Table 99. Washington Climate Zone Sampling

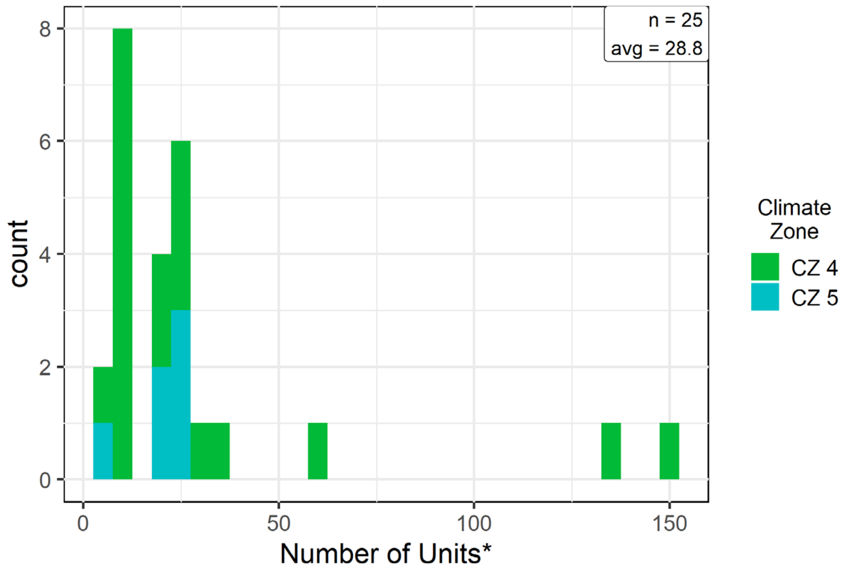
Climate Zone	n	Percent
4C	19	76%
5B	6	24%

These were primarily garden style buildings (living unit entry doors are to outside vs an enclosed corridor). And most (76%) of the sampled buildings had three residential floors, rather than two.

Table 100. Washington Building Type Sampling

Surveyed Building Type	n	Percent
common entry	10	40%
garden style	15	60%

The majority of sampled buildings had fewer than 50 dwelling units (Figure 63, Table 101), and 50,000 or less square feet of conditioned residential square footage (Figure 64, Table 102).

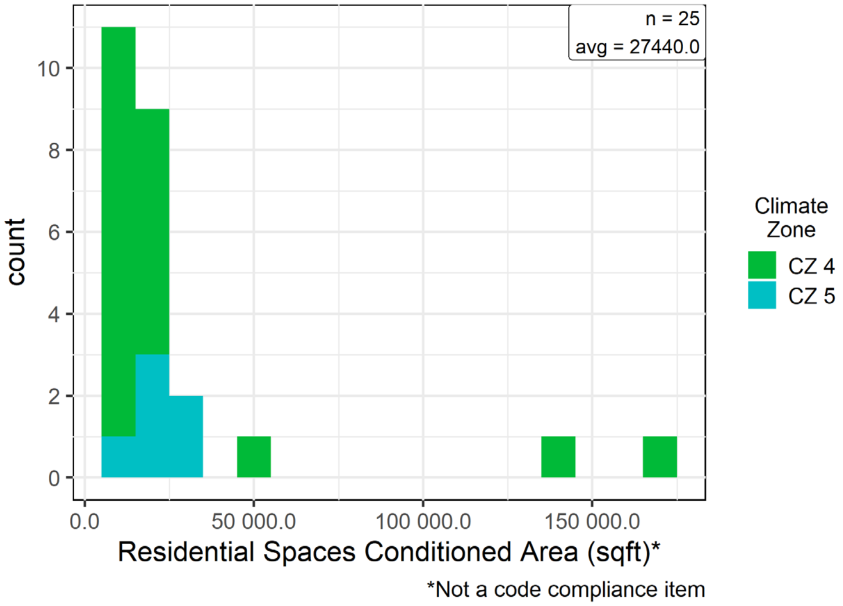


*Not a code compliance item

Figure 63. Washington Number of Units

Table 101. Washington Number of Units

Climate Zone	CZ4	CZ5	Statewide
Number	19	6	25
Range	6 to 148	6 to 24	6 to 148
Average	31.8	19.3	28.8



*Not a code compliance item

Figure 64. Washington Residential Spaces Conditioned Area

Table 102. Washington Residential Spaces Conditioned Area (sqft)

Climate Zone	CZ4	CZ5	Statewide
Number	19	6	25
Range	6,000 to 171,000	6,000 to 29,000	6,000 to 171,000
Average	29,580	20,670	27,440

Average unit sizes by number of bedrooms are presented in Table 103:

Table 103. Washington Average Unit Area (sqft)

Bedrooms	Average Unit Area (sqft)
Studio	451
1	664
2	947
3	1,192

The majority of surveyed buildings followed the prescriptive code, while approximately a quarter of the buildings followed a performance (simulation) or UA tradeoff pathway.

Table 104. Washington Path to Energy Code Compliance

Compliance Path	n	Percent
Performance	1	4%
Prescriptive	17	68%
UA tradeoff	5	20%
Unknown	2	8%

Most surveyed buildings had not received any energy efficiency certification (Table 105). However, it was unknown whether 20% of the buildings had or were pursuing efficiency certifications. In these cases, this information was unavailable on the plans and on-site contacts were unable to clarify this topic. Several buildings had energy efficiency certifications; these were either Built Green or Evergreen Sustainable Development Standards. These are local (county Master Builders Association) or state green building performance standards for affordable housing projects, respectively. In some cases, certifications may have above-code requirements for specific components; however, even in instances where energy efficiency programs do not have above-code thresholds, pursuit of a certification indicates some prioritization of energy efficiency in the building design.

Table 105. Washington Energy Efficiency Certification

Energy Efficiency Certification	n	Percent
Yes	5	20%
No	15	60%
Unknown	5	20%

APPENDIX B – EQUIVALENT COP CALCULATIONS

Equivalent COP calculation for water source heat pump

As the water-source heat pump has multiple equipment affects to the COP, the equivalent COP of the entire system was calculated based on the actual system of one arbitrary site and the federal equipment COP requirement.

Table 106. Systems of MN-531001

Number of dwelling units	48
Boiler	Natural gas: Lochinvar KnightXL KBN400 * 3 Efficiency: 80% (based on federal requirement) Gross output: 376 MHB
Fluid cooler	Chandler FNHD12F418 Unit kW: 23.1 Cooling capacity: 1,056,371 Btu/h = 88 tons
Indoor Heat Pump Unit	Daikin WVFC1012 Cooling capacity: 12,000 Btu/h Cooling COP: 3.22 (based on federal requirement) Heating Capacity: 14,000 Btu/h Heating COP: 3.40 (based on federal requirement) Water Flow: 3.0 GPM Air flow: 400 cfm

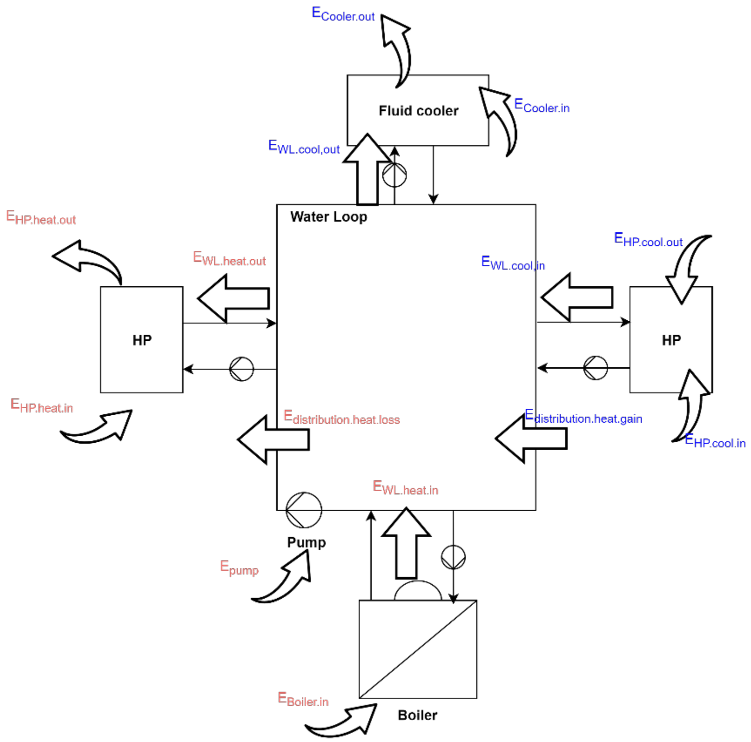


Figure 65. Schematic diagram of Water Loop Heat Pump

Heating COP calculation

- $COP_{HP.heat}$=3.4
- $E_{HP.heat.out} = 14{,}000\ \text{Btu/h} \times 48 = 4{,}102\ \text{W} \times 48 = 196{,}896\ \text{W}$
- $E_{HP.heat.in} = \frac{E_{HP.heat.out}}{COP_{HP.heat}} = \frac{4{,}102\ \text{W}}{3.4} = 1206.5\ \text{W} \times 48 = 57{,}912\ \text{W}$
- $E_{WL.heat.out} = E_{HP.heat.out} - E_{HP.heat.in} = 138{,}984\ \text{W}$
- $E_{ditribution.heat.loss} = 20\ \text{W/unit} \times 48\ \text{units} = 960\ \text{W}$
- $E_{WL.heat.in} = E_{WL.heat.out} + E_{ditribution.heat.loss}$
- $Eff_{Boiler} = 0.80 = \frac{E_{WL.heat.in}}{E_{Boiler,in}} = \frac{139{,}947\ \text{W}}{E_{Boiler,in}}$
- $E_{Boiler,in} = 174{,}933\ \text{W}$
- $E_{pump} = 4.44\ \text{HP} = 3.32\text{kW}$[39] (Only for main pump, other miscelleous pump ingnored)
- If the boiler is gas boiler,
  - $COP_{sys.heat} = \frac{E_{HP.heat.out}}{E_{HP.heat.in}+E_{Boiler,in}+E_{pump}} = \frac{196{,}896\ \text{W}}{57{,}912\text{W}+174{,}933\ \text{W}+3{,}320\text{W}} = 0.83$
- If the boiler is electric boiler
  - $COP_{sys.heat} = \frac{E_{HP.heat.out}}{E_{HP.heat.in}+E_{Boiler,in}+E_{pumps}} = \frac{196{,}896\ \text{W}}{57{,}912\text{W}+139{,}947\ \text{W}+3{,}320\text{W}} = 0.98$

---

[39] Assumed pressure: 77 ft of water, Flow rate: 144 gpm, Pump efficiency: 70%, Drive Motor Efficiency: 90%

Cooling COP calculation

- $\mathrm{COP_{HP.cool}} = 3.22$
- $\mathrm{E_{HP.cool.out}} = 12{,}000\ \mathrm{Btu/h} \times 48 = 3{,}517\ \mathrm{W} \times 48 = 168{,}816\ \mathrm{W}$
- $\mathrm{E_{HP.cool.in}} = \frac{\mathrm{E_{HP.cool.out}}}{\mathrm{COP_{HP.cool}}} = \frac{3{,}517\ \mathrm{W}\times 48}{3.22} = 52{,}427.3\ \mathrm{W}$
- $\mathrm{E_{distribution.heat.gain}} = 20\ \mathrm{W/unit}\ \times 48\ \mathrm{units} = 960\ \mathrm{W}$
- $\mathrm{E_{WL.cool.out}} = \mathrm{E_{HP.cool.out}} + \mathrm{E_{HP.cool.in}} + \mathrm{E_{distribution.heat.gain}} = 222{,}203\ \mathrm{W}$
- $\mathrm{E_{Cooler.in}} = 23.1\mathrm{kW}\ (\text{from cutsheet})$
- $\mathrm{E_{pump}} = 3.32\ \mathrm{kW}$
- $\mathrm{COP_{sys.cool}} = \frac{\mathrm{E_{HP.cool.out}}}{\mathrm{E_{HP.cool.in}} + \mathrm{E_{Cooler,in}} + \mathrm{E_{pumps}}} = \frac{168{,}816\ \mathrm{W}}{52{,}427.3\ \mathrm{W} + 23{,}100\ \mathrm{W} + 3{,}320\ \mathrm{W}} = 2.14$

APPENDIX C – MODELING WORKFLOW

The diagram below describes two sides of the Energy Use Analysis workflow. It describes the formation of inputs - how surveyed data collection was transformed into EnergyPlus inputs.

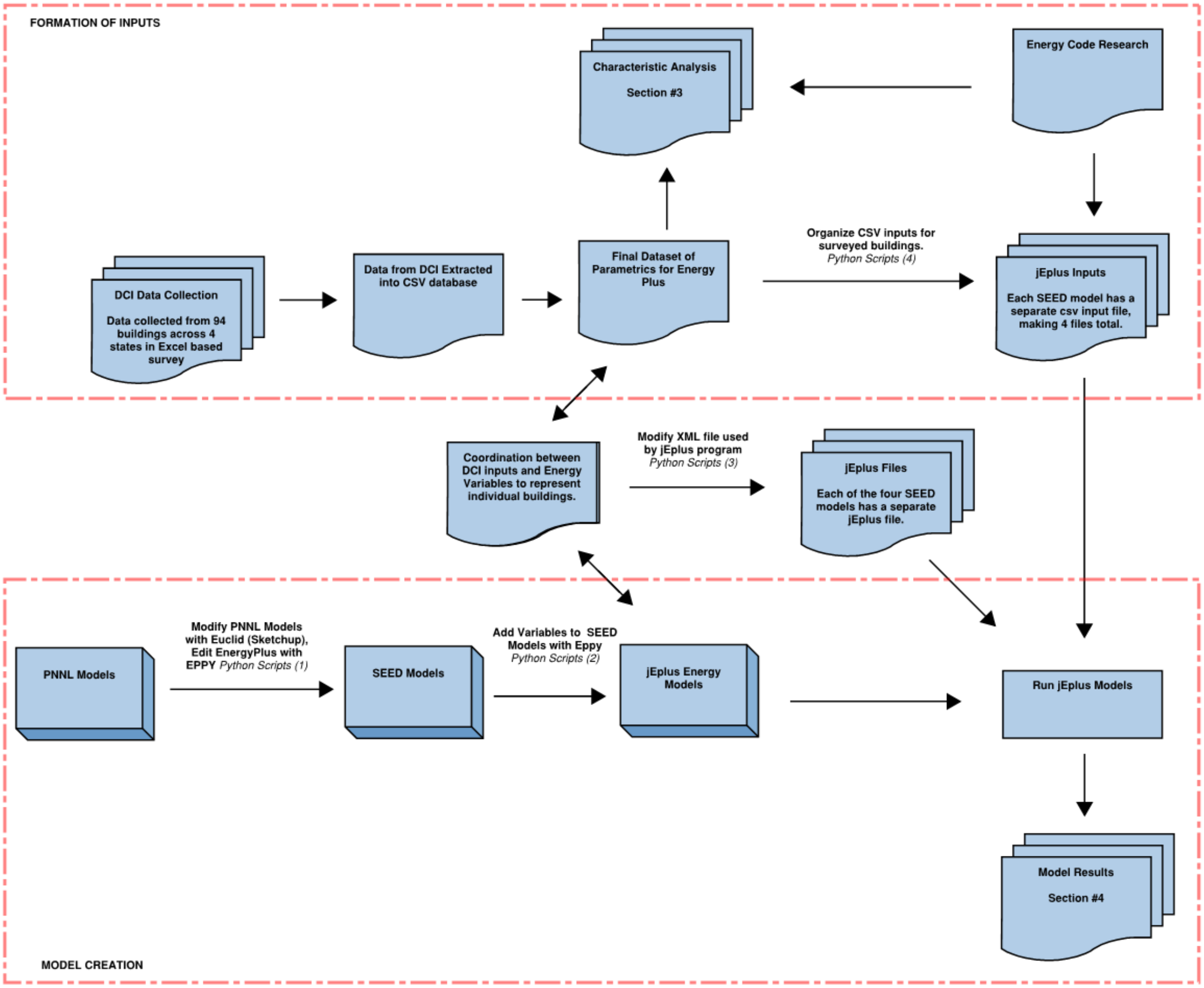


Figure 66. EnergyPlus Modeling Workflow Diagram

After the cross-walk between DCI and EnergyPlus was established, three sets of Python scripts were used to replace values in seed models with variables (*Python Scripts (2)*), create a table of CSV values from DCI data (*Python Scripts (4)*), and create jEplus files for each seed model (*Python Scripts (3)*). See Figure 66 for diagrammatic representation of how each script was used in Energy Use Analysis Workflow.

Python Scripts (2) referenced a cross-walk table and used Eppy to replace EnergyPlus inputs with variables referenced by jEplus. *Python Scripts (4)* took DCI outputs, and converted them to EnergyPlus inputs. In most cases DCI outputs are in English units and EnergyPlus inputs are in metric units.

Additionally, some logic and assumptions, discussed in more detail below, were made when converting from DCI outputs to EnergyPlus inputs. Four CSV files were created, one for each seed model, to run parametric analysis in jEplus. *Python Script (3)* created the jEplus XML reference file. jEplus reads an XML file which specifies variables. This XML file was automatically generated from the DCI to EnergyPlus cross-talk using Python to save time and ensure variable consistency. A full list of modified EnergyPlus Variables, seed models which reference those variables, and DCI inputs used to create inputs for those variables is included in Appendix D – DCI to EnergyPlus.

APPENDIX D – DCI TO ENERGYPLUS

In many cases, such as static pressure, the EnergyPlus inputs were calculated or established from more than one DCI variable. The following paragraph described how DCI inputs for constructions, mechanical systems – including heating, cooling, and ventilating, hot water systems, and lighting are combined and fed into EnergyPlus through jEplus.

The thermal envelope of the seed models was altered to match the thermal envelope of buildings surveyed. This included modifying roof, exterior wall, slab, below grade wall, window u-value, and window SHGC. For roof, exterior wall, below grade wall, and window u-value only the u-value was modified to match the u-values from surveyed data. For all constructions except windows the u-value was modified by altering insulation properties. To modify insulation properties correctly, thermal conductivity of all other materials in the construction was accounted for, so the final construction u-value matches the building survey. Window u-value and SHGC were less complicated because they could be modified directly through the EnergyPlus Simple Glazing object.

Unitary air-to-air heat pumps were used in all seed models. COPs and performance curves were modified to represent other mechanical systems. For heating systems electric resistance, gas furnace, hydronic baseboard with gas boiler, packaged terminal heat pump, split systems heat pump, water source heat pump with electric boiler, and water source heat pump with gas boiler were all represented. For cooling systems packaged terminal heat pump, split system heat pump, split systems AC, packaged terminal AC, and water source heat pump with evaporative coolers were represented. Details on COP and performance curve calculations can be found in Appendix B – Equivalent COP Calculations. For systems with refrigeration cycles for heating, a set of performance curves were used to represent changes in equipment performance and capacity under different part load and temperature conditions.

Ventilation static pressure considers the system type, whether it is a central system or distributed, and if there is an energy recovery ventilator (ERV). Central systems with a centralized air handling system, have more ductwork to travel through, with more elbows and taps creating additional static pressure loss. 1” of static pressure is added for central systems. ERVs are an additional heat exchanger in the airstream that recovers heat from exhaust air and adds it to supply air. ERVs can be enthalpy wheels, plate and frame heat exchangers, or run-around loops. ERVs are typically an energy saving device because they reduce heating requirements. However, they do add a small static pressure. For this study 0.25” of static pressure was added for ERVs.

Hot water energy was modeled using an efficiency and heat loss coefficient. All seed models used the mixed electric hot water tank EnergyPlus object, but inputs were altered to represent other system types. Efficiency was taken directly from the DCI or, if no value was given in the DCI, it was estimated based on the equipment type.

All building surveyed, except for one, had either natural gas or electric boiler heating for potable hot water. Typical efficiencies for natural gas boilers are around 0.8, although condensing systems can be as high as 0.95. Efficiencies for electric boilers are typically around 0.9.

The heat loss coefficient is a measure of how quickly energy from the hot water system is lost to the space through tank, pipe, and insulation [W/°K]. In smaller multifamily buildings, a hot water heater with in-unit tank is typically installed in each apartment. This tank is typically insulated well, and pipe run outs to fixtures requiring hot water are short. As a result, in-unit tanks have a relatively low heat loss to the space. In larger apartment buildings it becomes more economical to install a central water heating plant and run pipe out to the individual apartments. In order to ensure, apartments receive hot water on demand, and a loop around the apartment is constantly circulated so it contains water at the appropriate temperature. Extra-piping and water recirculation in central systems contributes significantly to energy use. A central system typically adds 30% to the energy use of a hot water system.

Lighting power densities (LPDs) are taken from the DCI, or, if no value is given, the code minimum for the corresponding jurisdiction. LPDs for units, corridors, basements, exterior corridors, exterior parking, and interior parking are all included. Interior parking is the basement area if included. If no interior parking is included in a building with a basement, the basement is typically a storage area. Code values for LPDs are given in all areas except units. Code requires a percentage of fixtures to be high efficiency bulbs in residential units. The code is written in a way to allow building tenants to have multiple lighting options, some ceiling mounted, and some plugged into the wall. Unit lighting is the largest electricity use in the lighting category. Most buildings surveyed were found to have relatively low LPDs in units. See Section 3 Characteristics Summaries for more details on LPD distributions.

Table 107. EnergyPlus, DCI Survey Cross Walk

EnergyPlus Variable	Common Basement	Common Slab	Garden Basement	Garden Slab	DCI Input
Building Name	X	X	X	X	sitex, runinput
Unit heating efficiency (COP)	X	X	X	X	inunit_heat, HVACcentral_YN
Unit heating efficiency curves1	X	X	X	X	inunit_heat
Unit heating efficiency curves2	X	X	X	X	inunit_heat
Unit heating efficiency curves3	X	X	X	X	inunit_heat
Unit heating efficiency curves4	X	X	X	X	inunit_heat
Unit heating efficiency curves5	X	X	X	X	inunit_heat
Unit heating efficiency curves6	X	X	X	X	inunit_heat
Unit cooling efficiency (COP)	X	X	X	X	inunit_cool, HVACcentral_YN
Unit cooling efficiency curves1	X	X	X	X	inunit_cool
Unit cooling efficiency curves2	X	X	X	X	inunit_cool

EnergyPlus Variable	Common Basement	Common Slab	Garden Basement	Garden Slab	DCI Input
Unit cooling efficiency curves3	X	X	X	X	inunit_cool
Unit cooling efficiency curves4	X	X	X	X	inunit_cool
Unit cooling efficiency curves5	X	X	X	X	inunit_cool
Unit DHW Loss Coefficient - ON	X	X	X	X	centraldhweff_avg, inunitdhweff_avg
Unit DHW Loss Coefficient - OFF	X	X	X	X	centraldhweff_avg, inunitdhweff_avg
Unit DHW Thermal Efficiency	X	X	X	X	centraldhweff_avg, inunitdhweff_avg
Unit LPD [W/sf]	X	X	X	X	LPD_unit
Unit Ventilation Flowrate [m3/s]	X	X	X	X	Ventcentral_YN, Vent_inuniterv_YN, Vent_inunit_erveff
Unit Ventilation SP [Pa]	X	X	X	X	Ventcentral_YN, Vent_inuniterv_YN
Unit HVAC Fan SP [Pa]	X	X	X	X	Ventcentral_YN, Vent_inuniterv_YN
Exterior Wall Insulation Conductivity [W/m*K]	X	X	X	X	wtmn_GenlWallU
Ceiling Insulation Conductivity [W/m*K]	X	X	X	X	wtmn_CeilingU
Slab Insulation Conductivity [W/m*K]	X	X	X	X	Fnd_wtmn_u, Fnd_wtmn_f
Windows Ufactor [W/m2*K]	X	X	X	X	wtmn_WindowU
Windows SHGC	X	X	X	X	wtmn_WindowSHGC
Lighting Stairwell [W]	X	X	X	X	LPD_IntStairwell
Internal Parking Lights [W]	X	X	X	X	LPD_IntPk_common, FndType
External Parking Lights [W]	X	X	X	X	LPD_ExtPk
Unit heating setpoint temp [C]	X	X	X	X	
Unit cooling setpoint temp [C]	X	X	X	X	
Corridor heating efficiency (COP)	X	X			common_heat, Central_Sys
Corridor heating efficiency curves1	X	X			common_heat

EnergyPlus Variable	Common Basement	Common Slab	Garden Basement	Garden Slab	DCI Input
Corridor heating efficiency curves2	X	X			common_heat
Corridor heating efficiency curves3	X	X			common_heat
Corridor heating efficiency curves4	X	X			common_heat
Corridor heating efficiency curves5	X	X			common_heat
Corridor heating efficiency curves6	X	X			common_heat
Corridor cooling efficiency (COP)	X	X			common_cool, HVACcentral_YN, Central_Sys
Corridor cooling efficiency curves1	X	X			common_cool
Corridor cooling efficiency curves2	X	X			common_cool
Corridor cooling efficiency curves3	X	X			common_cool
Corridor cooling efficiency curves4	X	X			common_cool
Corridor cooling efficiency curves5	X	X			common_cool
Corridor LPD (W/sf)	X	X			LPD_IntCorridor
Corridor Ventilation Flowrate [m3/s]	X	X			Ventcentral_YN, Vent_corridorerv_YN, Vent_corridor_erveff
Corridor Ventilation SP [Pa]	X	X			Ventcentral_YN, Vent_corridorerv_YN
Corridor HVAC Fan SP [Pa]	X	X			Ventcentral_YN, Vent_corridorerv_YN
Corridor heating setpoint temp [C]	X	X			
Corridor cooling setpoint temp [C]	X	X			
Bsmt heating efficiency (COP)	X		X		Heat_bsmt_type, Central_Sys
Bsmt Heating efficiency curves1	X		X		Heat_bsmt_type
Bsmt Heating efficiency curves2	X		X		Heat_bsmt_type

EnergyPlus Variable	Common Basement	Common Slab	Garden Basement	Garden Slab	DCI Input
Bsmt Heating efficiency curves3	X		X		Heat_bsmt_type
Bsmt Heating efficiency curves4	X		X		Heat_bsmt_type
Bsmt Heating efficiency curves5	X		X		Heat_bsmt_type
Bsmt Heating efficiency curves6	X		X		Heat_bsmt_type
Bsmt cooling efficiency (COP)	X		X		
Bsmt cooling efficiency curves1	X		X		
Bsmt cooling efficiency curves2	X		X		
Bsmt cooling efficiency curves3	X		X		
Bsmt cooling efficiency curves4	X		X		
Bsmt cooling efficiency curves5	X		X		
Bsmt Ventilation Flowrate [m3/s]	X		X		Vent_bsmt_YN, Vent_bsmterv_YN, Vent_bsmt_erveff, LPD_IntPk_common
Bsmt Ventilation SP [Pa]	X		X		Vent_bsmterv_YN
Bsmt HVAC Fan SP [Pa]	X		X		Vent_bsmterv_YN
Bsmt Wall Insulation Conductivity [W/m*K]	X		X		BsmtWallU
Floor Insulation Conductivity [W/m*K]	X		X		BsmtFloorU
Bsmt heating setpoint temp [C]	X		X		Heat_bsmt_YN
Bsmt cooling setpoint temp [C]	X		X		Heat_bsmt_YN
Exterior corridor Lights [W]			X	X	none

APPENDIX E – PERFORMANCE MAPS

Performance maps for each building component studied in each climate zone are shown below. These were created by taking an average code compliance building and running a parametric analysis of only the component in question. Results were then plotted, with the y-axis as EUI, and the x-axis as values of the building component in question. Building quantities are shown only for sampled climate zones or components present in surveyed buildings.

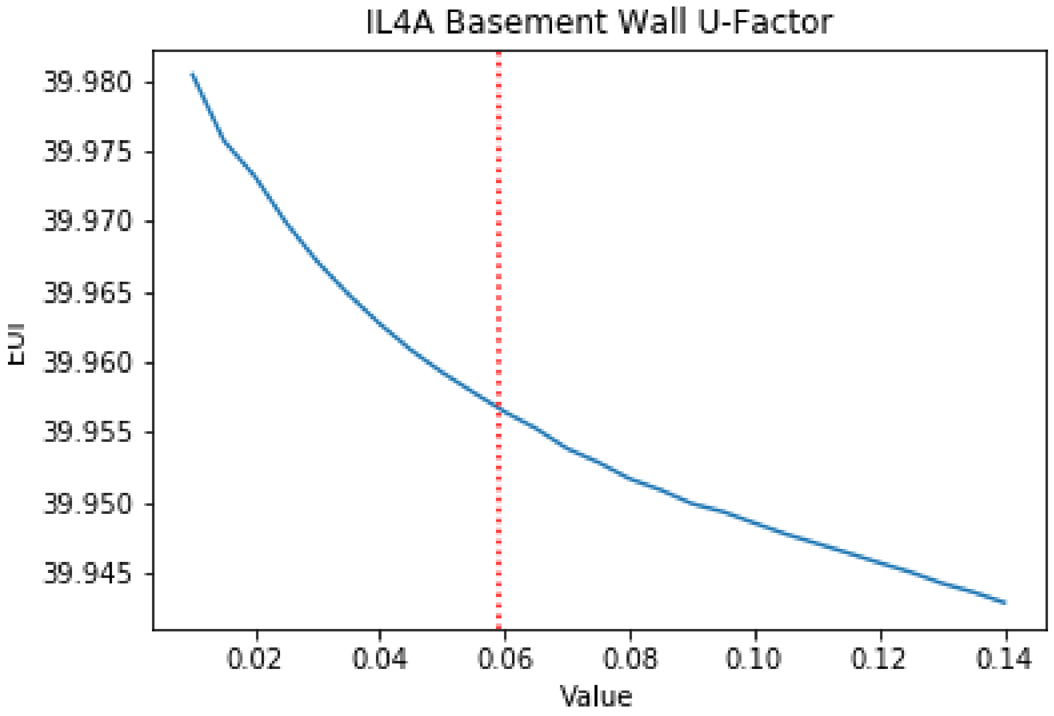


Figure 67. Illinois 4A Basement Wall U-Factor

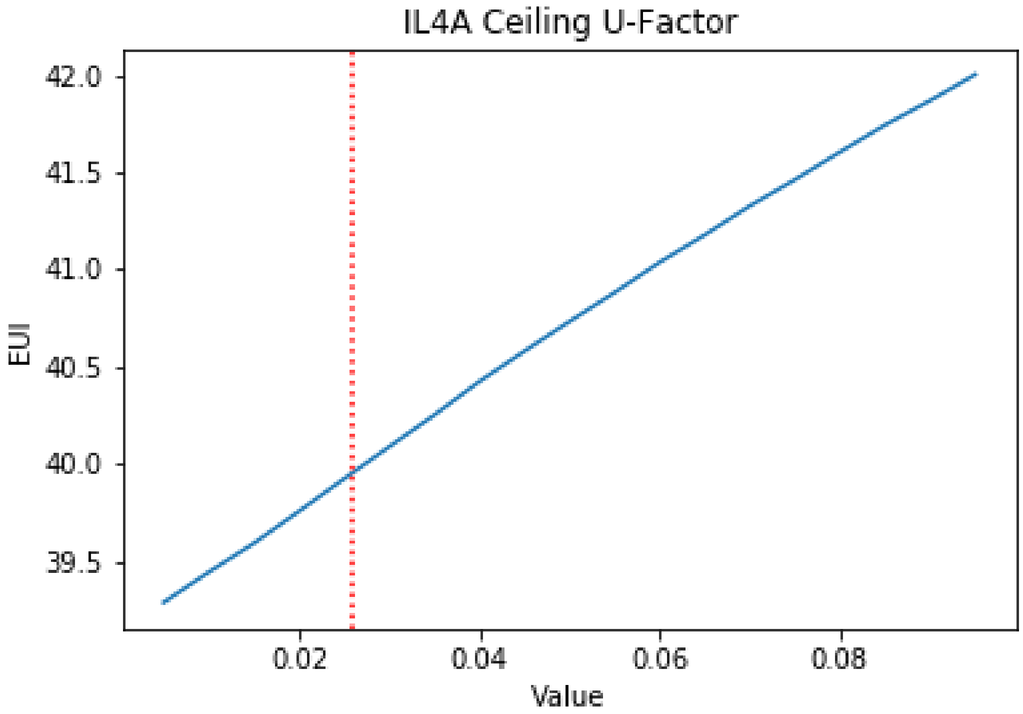


Figure 68. Illinois 4A Ceiling U-Factor

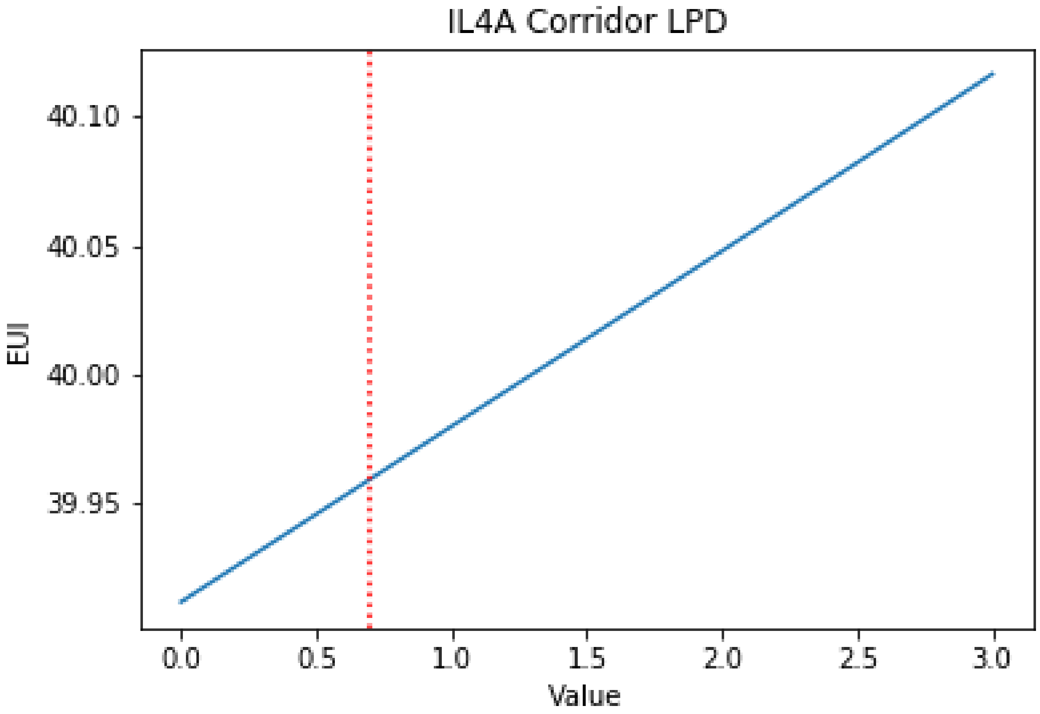


Figure 69. Illinois 4A Corridor LPD

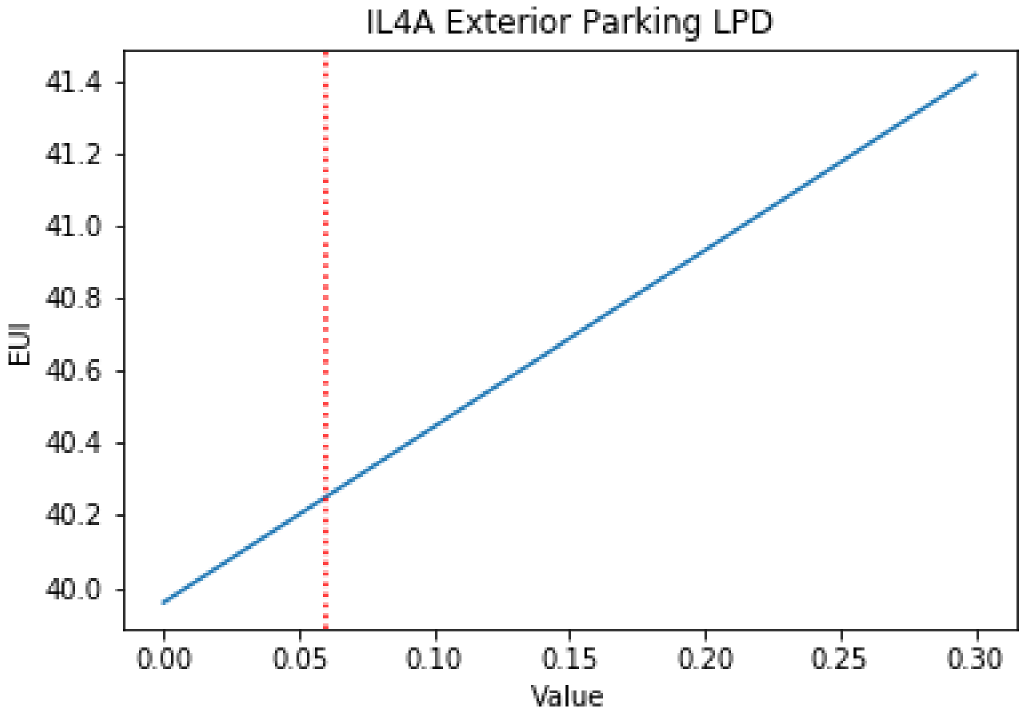


Figure 70. Illinois 4A Exterior Parking LPD

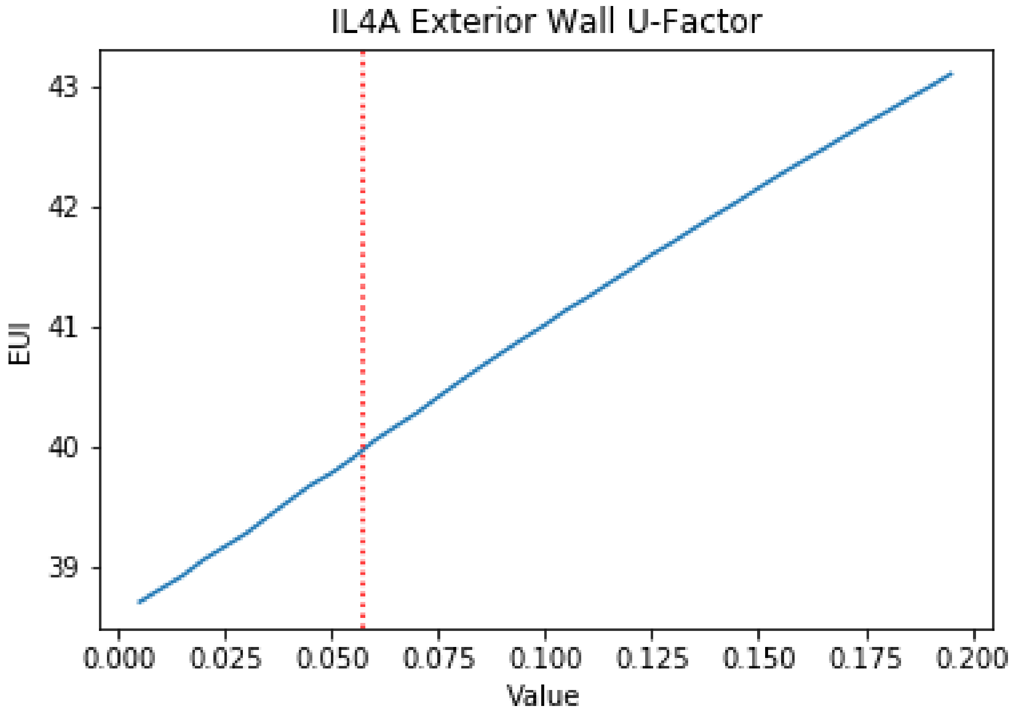


Figure 71. Illinois 4A Exterior Wall U-Factor

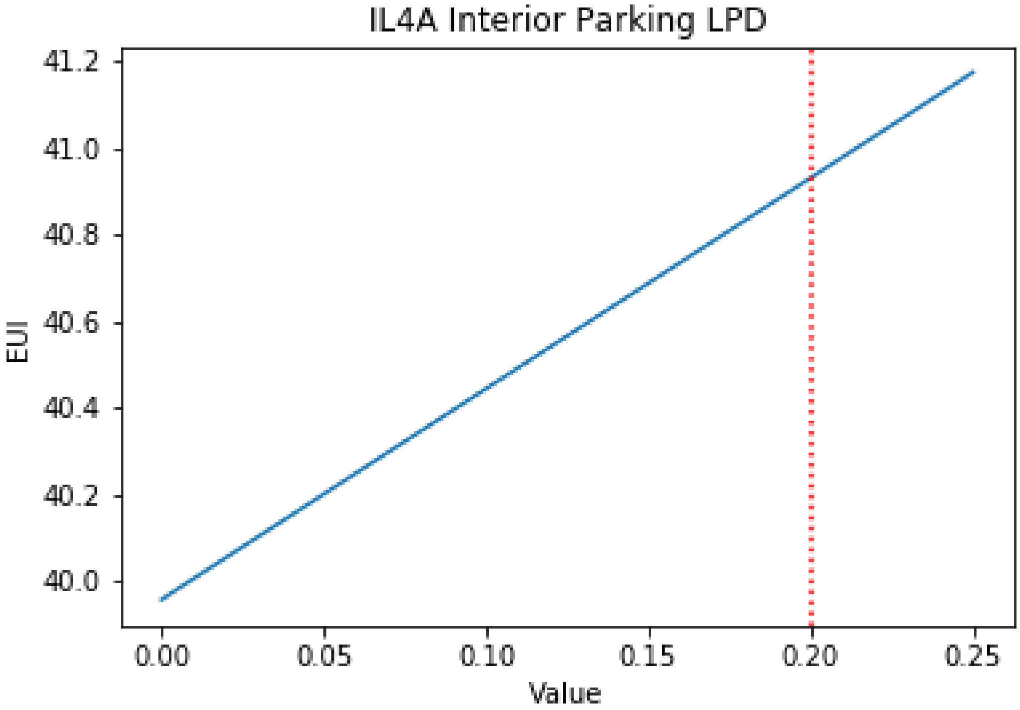


Figure 72. Illinois 4A Interior Parking LPD

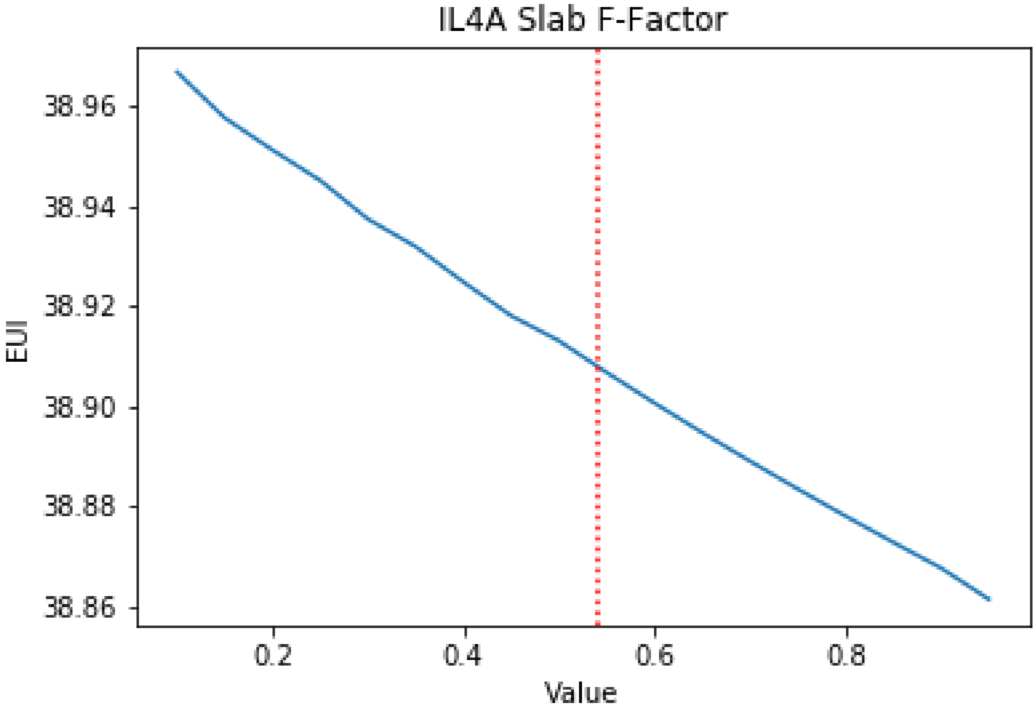


Figure 73. Illinois 4A Slab F-Factor

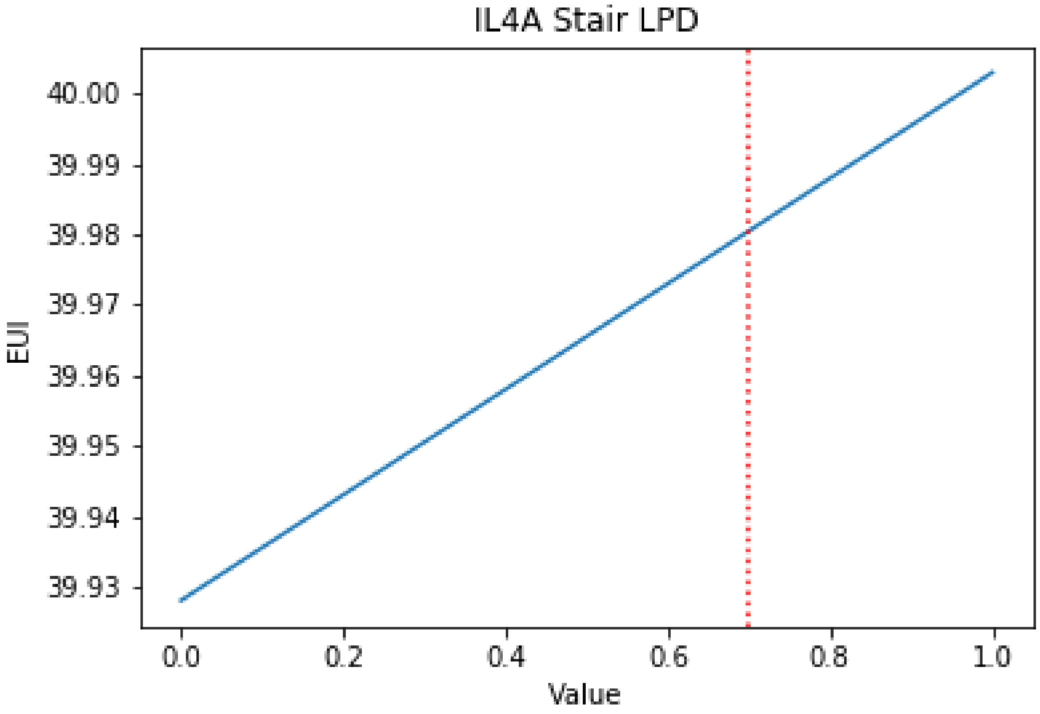


Figure 74. Illinois 4A Stair LPD

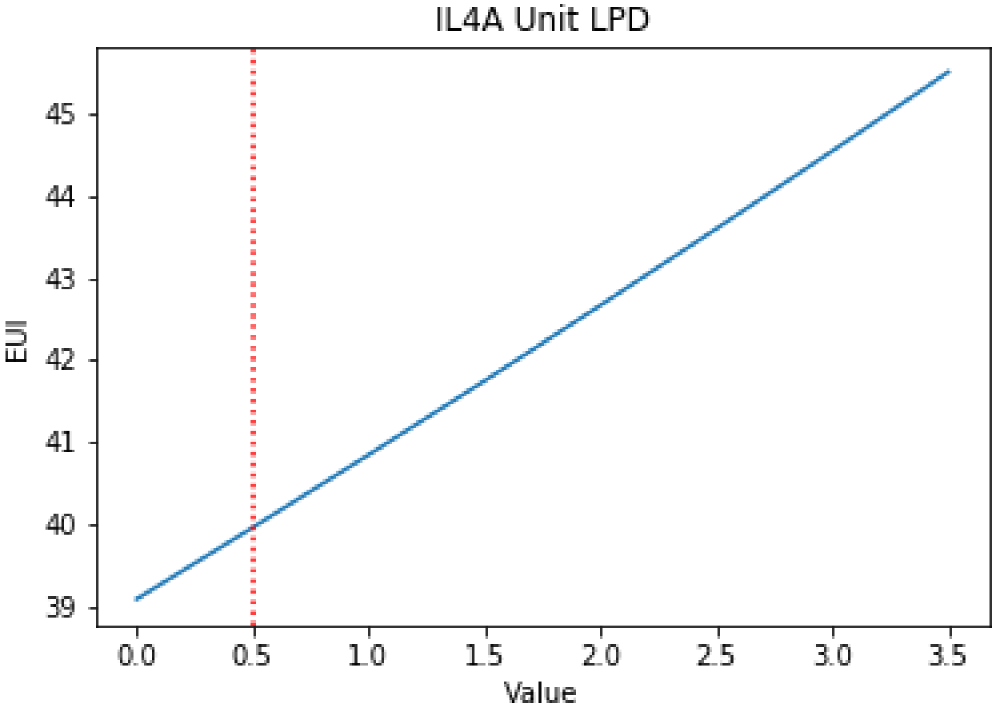


Figure 75. Illinois 4A Unit LPD

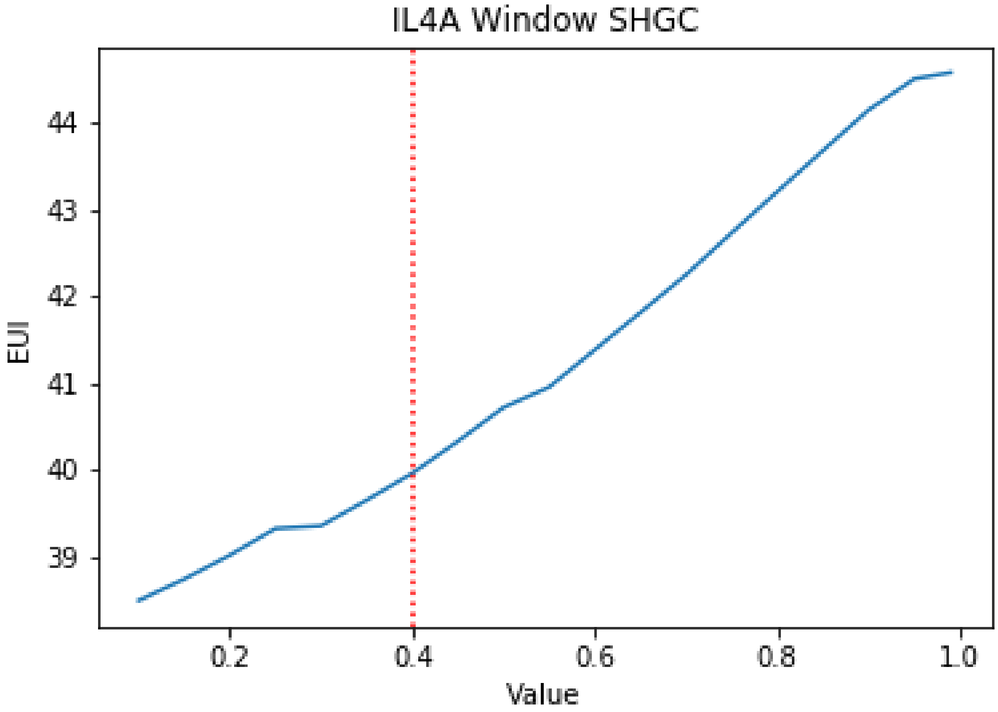


Figure 76. Illinois 4A Window SHGC

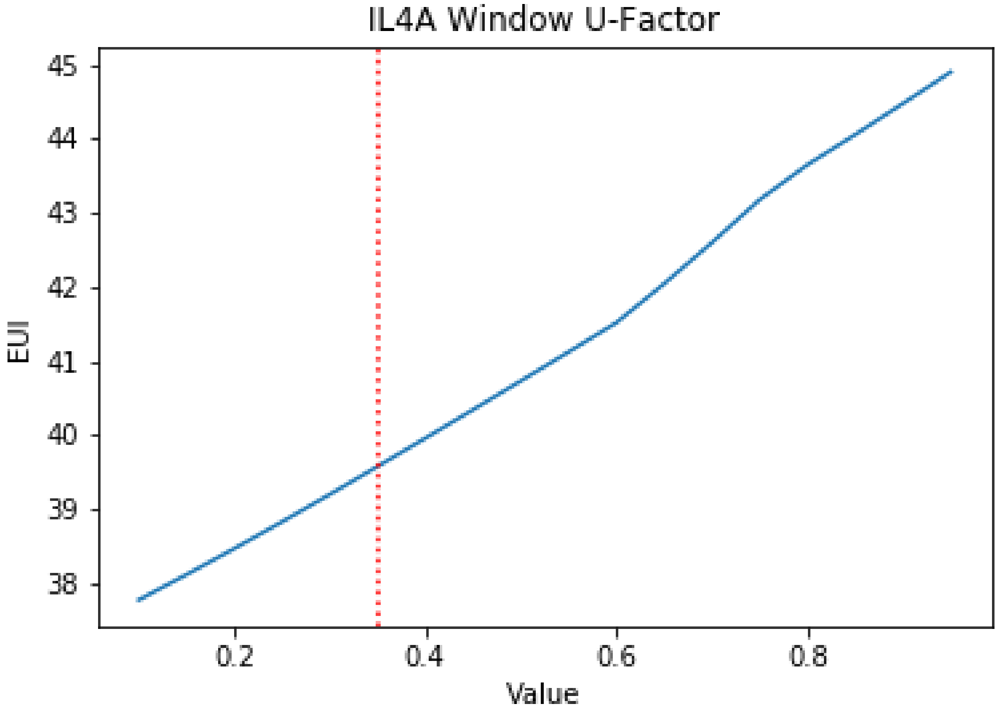


Figure 77. Illinois 4A Window U-Factor

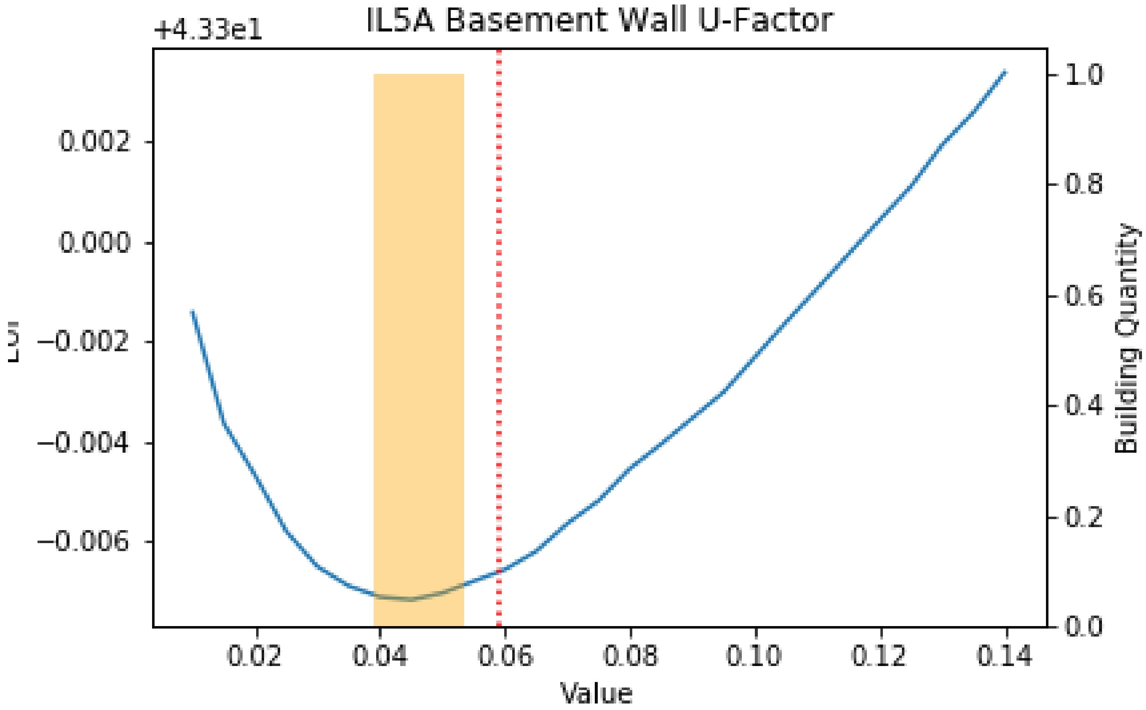


Figure 78. Illinois 5A Basement Wall U-Factor

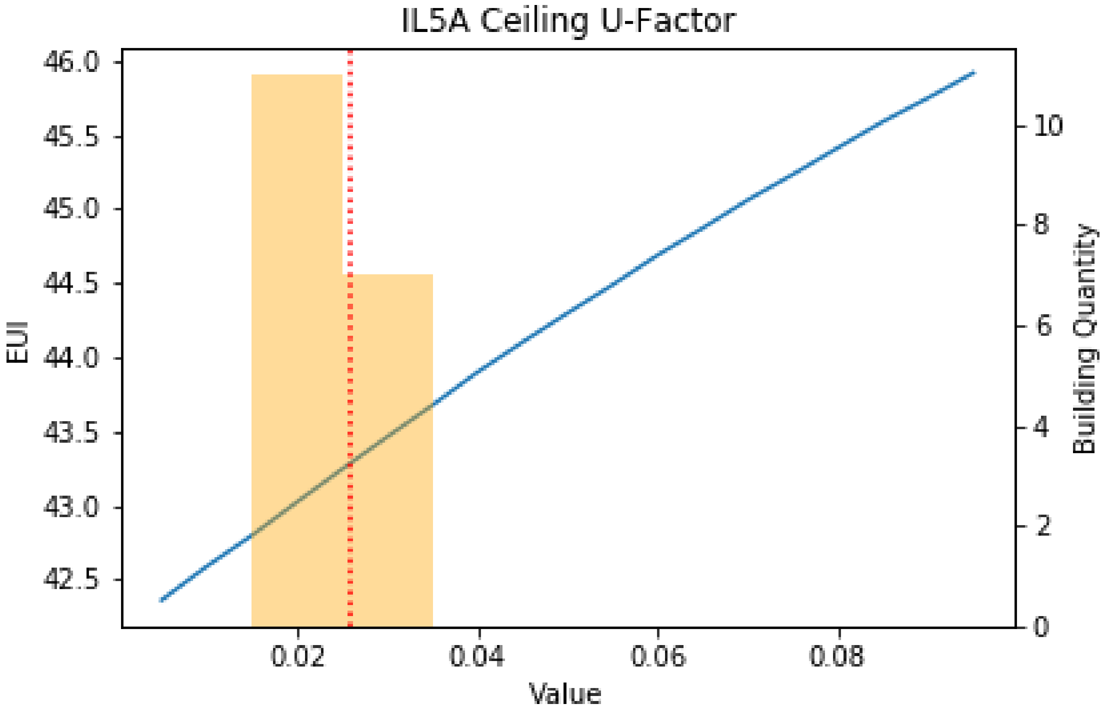


Figure 79. Illinois 5A Ceiling U-Factor

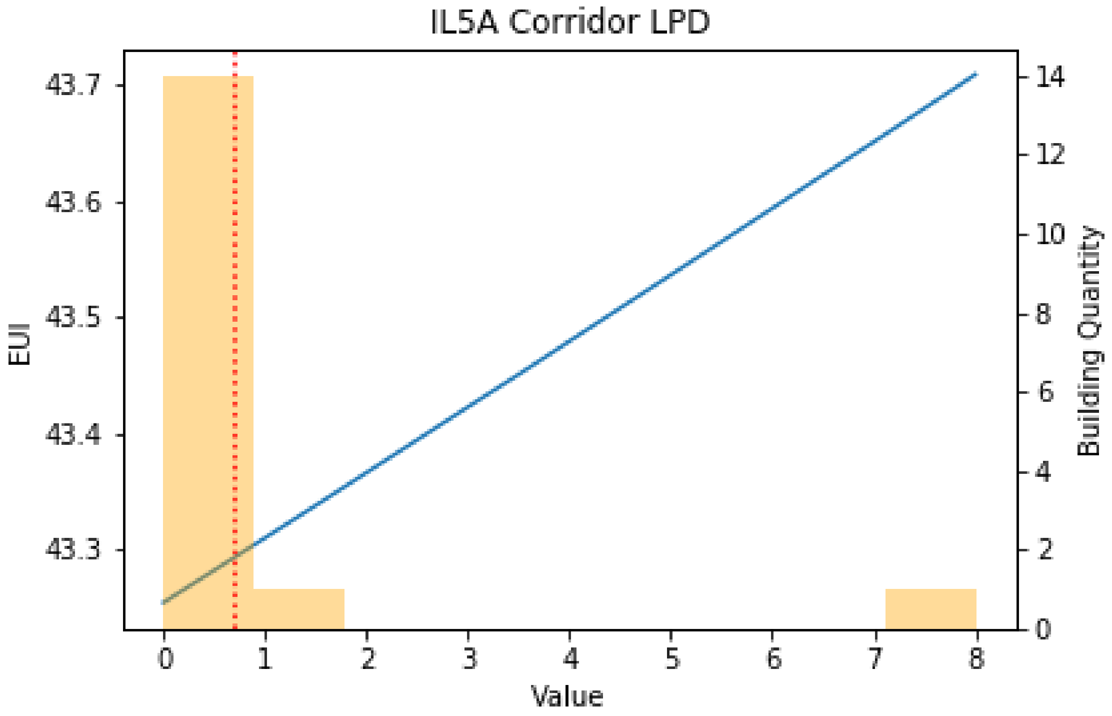


Figure 80. Illinois 5A Corridor LPD

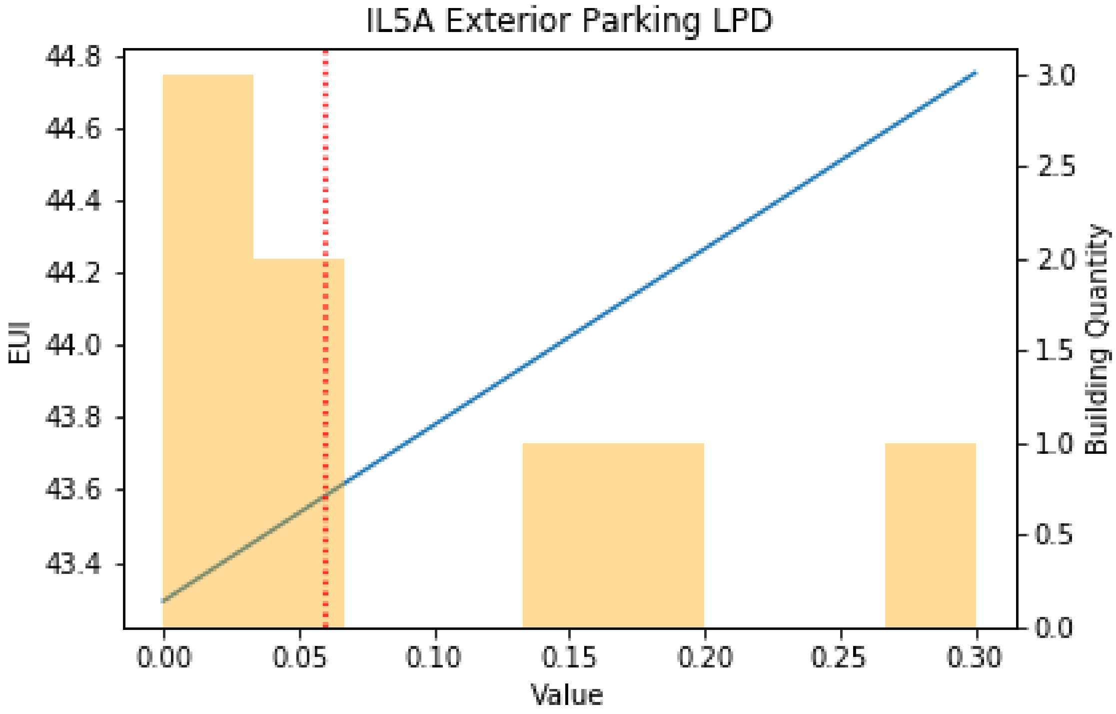


Figure 81. Illinois 5A Exterior Parking LPD

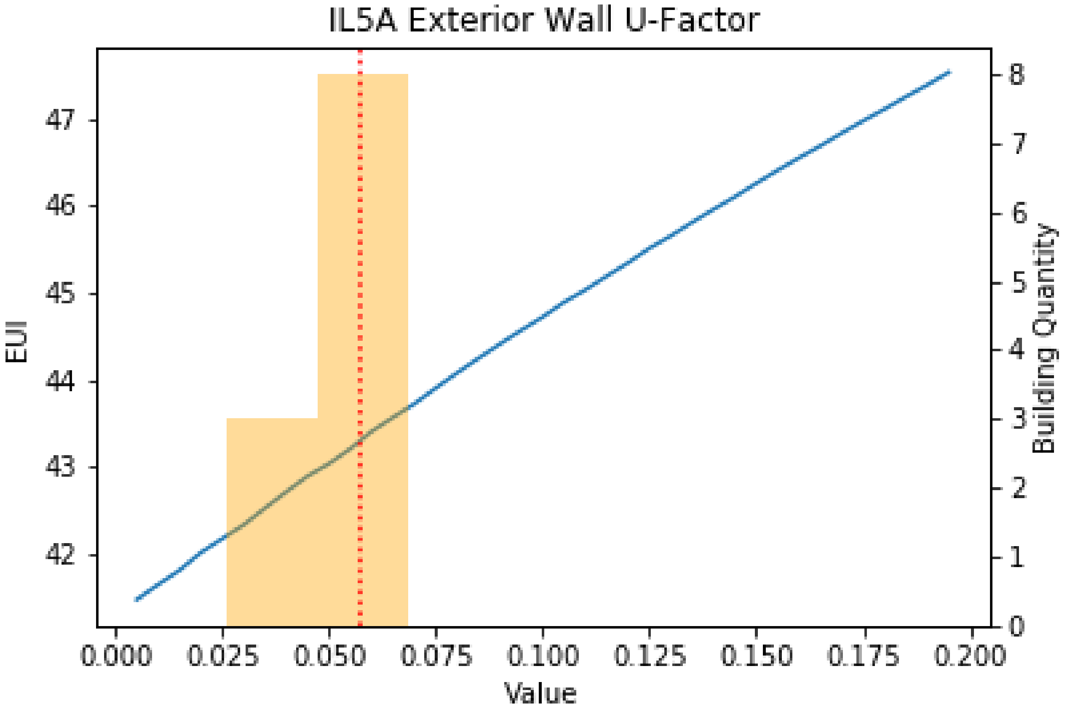


Figure 82. Illinois 5A Exterior Wall U-Factor

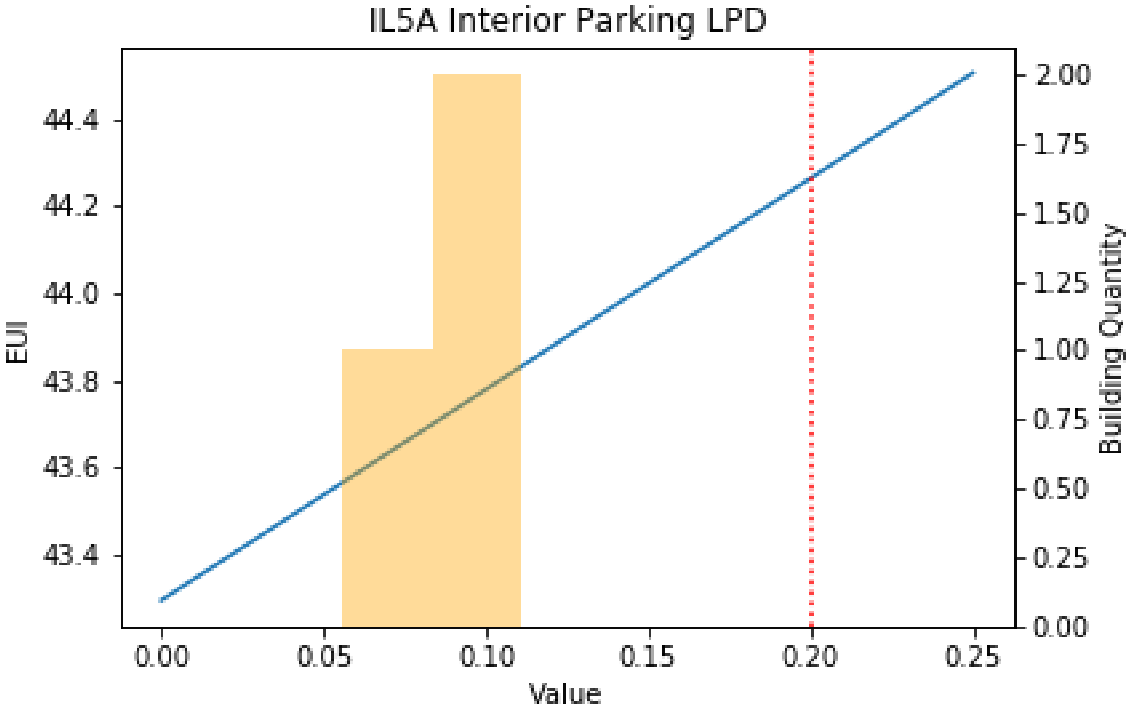


Figure 83. Illinois 5A Interior Parking LPD

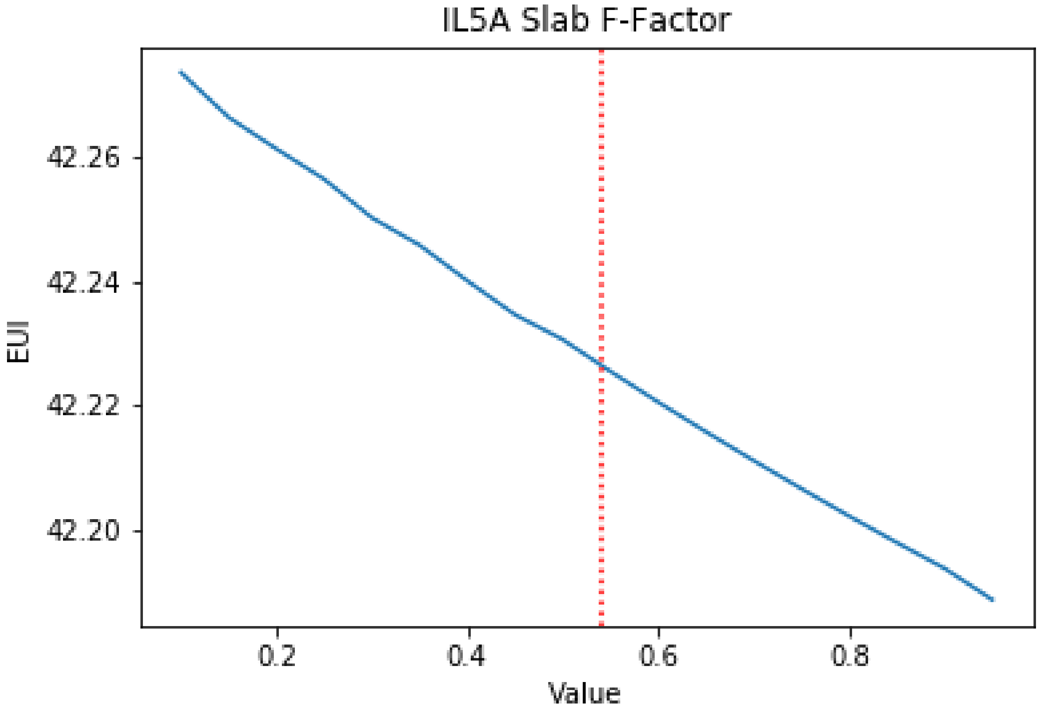


Figure 84. Illinois 5A Slab F-Factor

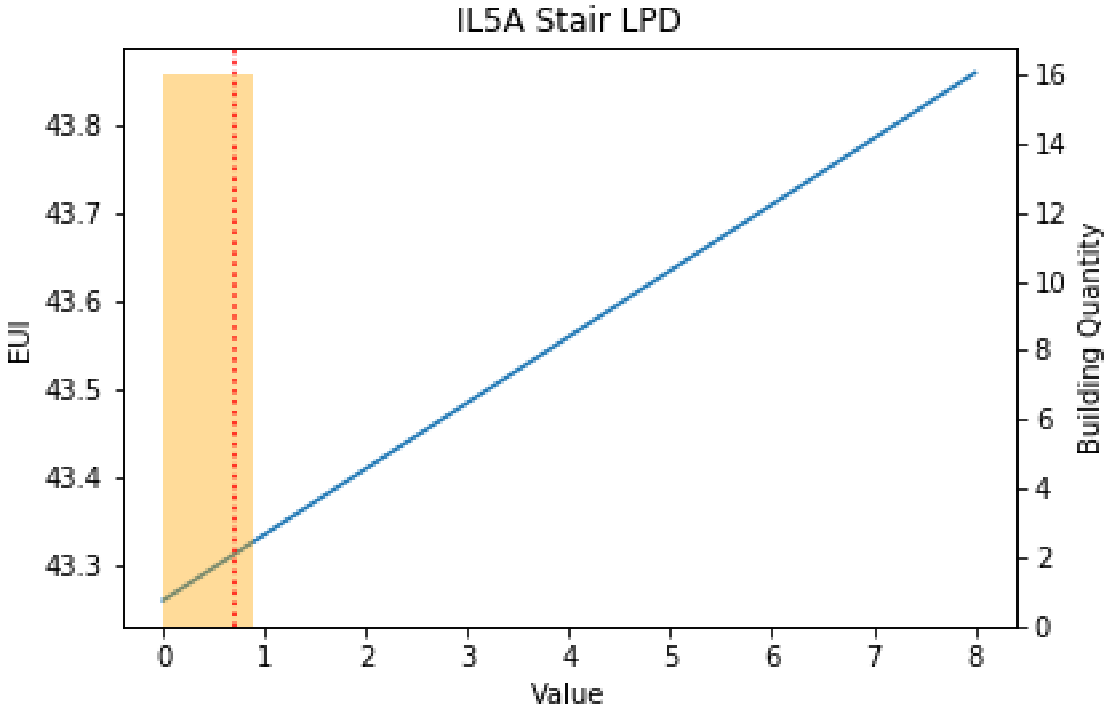


Figure 85. Illinois 5A Stair LPD

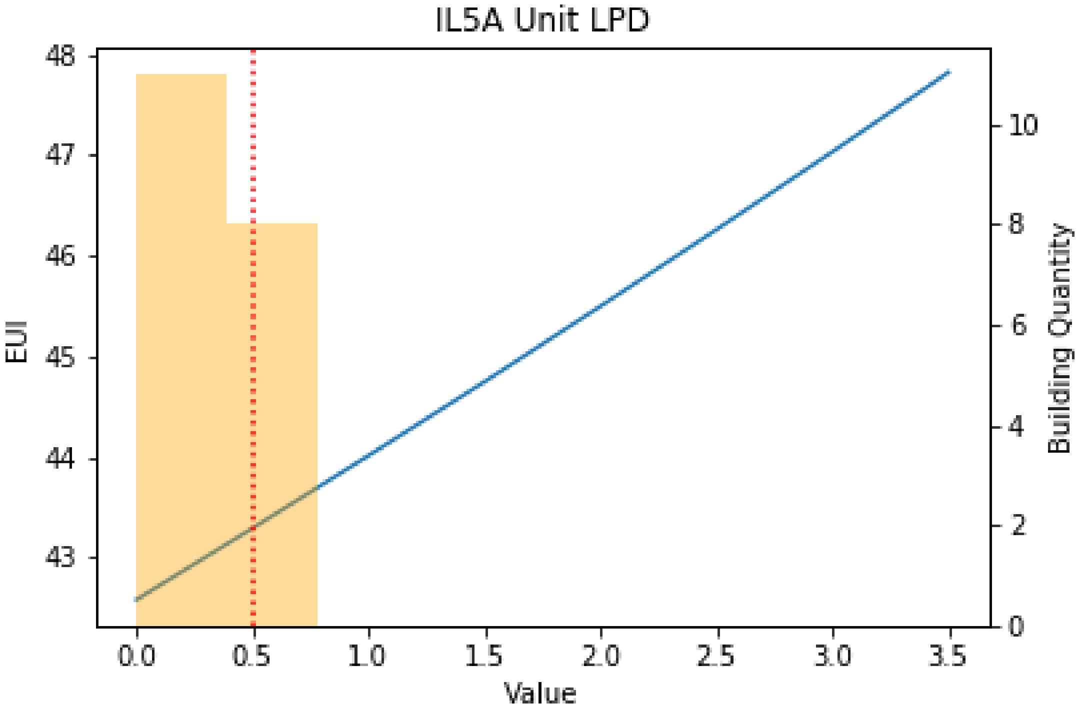


Figure 86. Illinois 5A Unit LPD

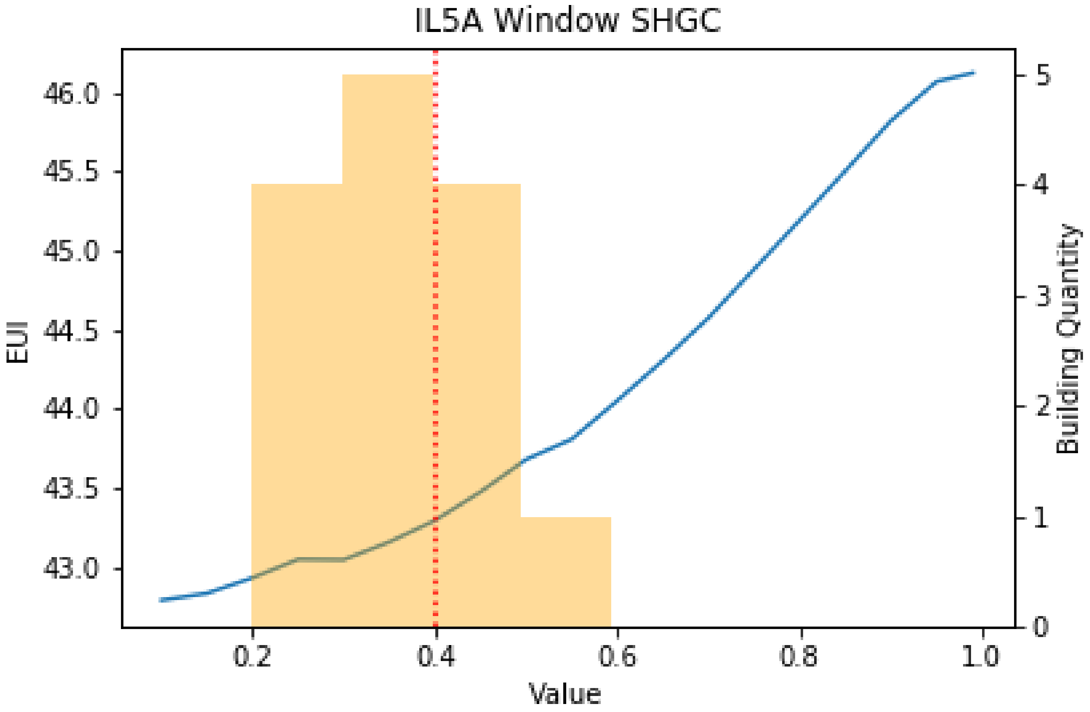


Figure 87. Illinois 5A Window SHGC

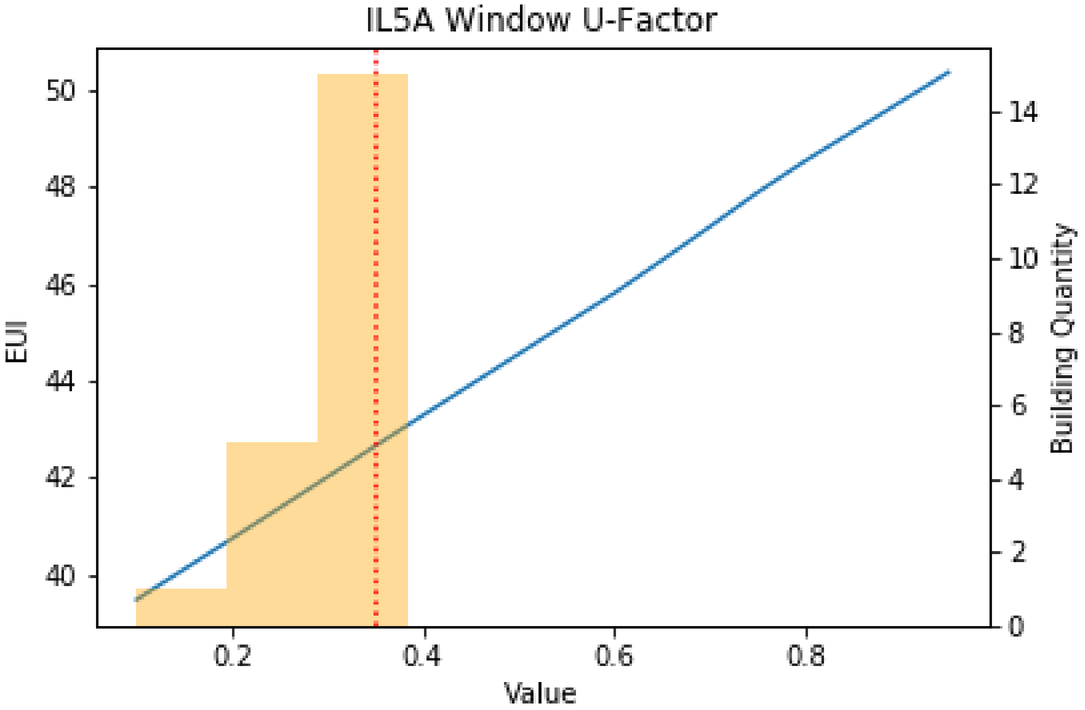


Figure 88. Illinois 5A Window U-Factor

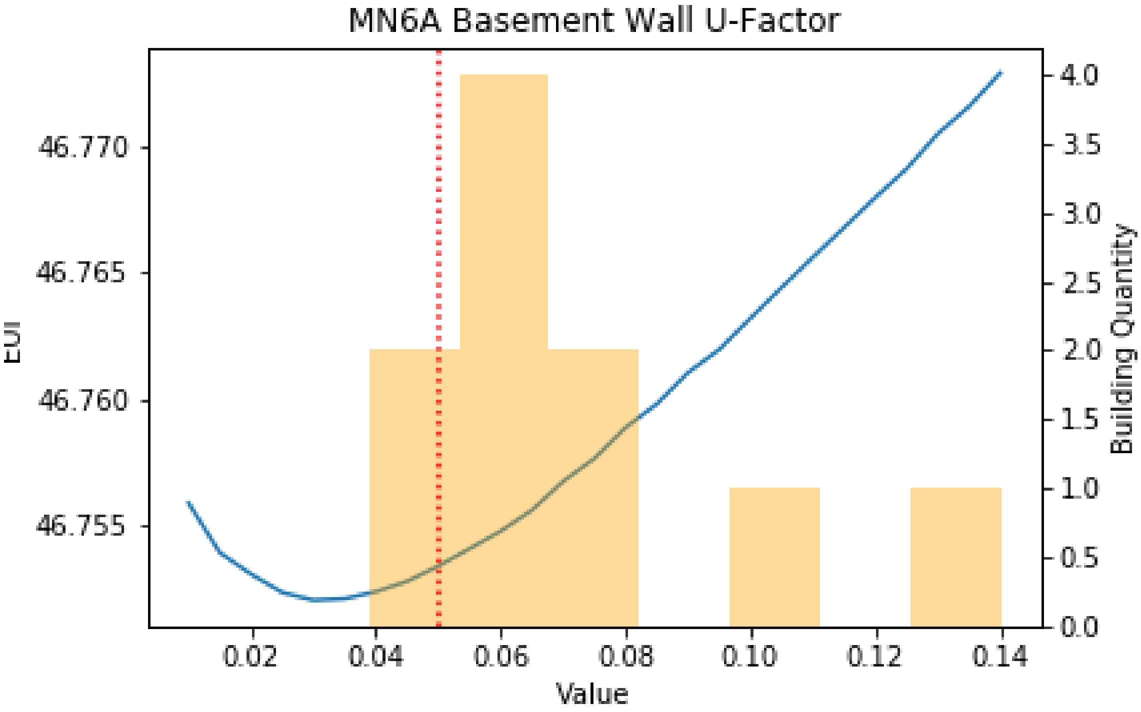


Figure 89. Minnesota 6A Basement Wall U-Factor

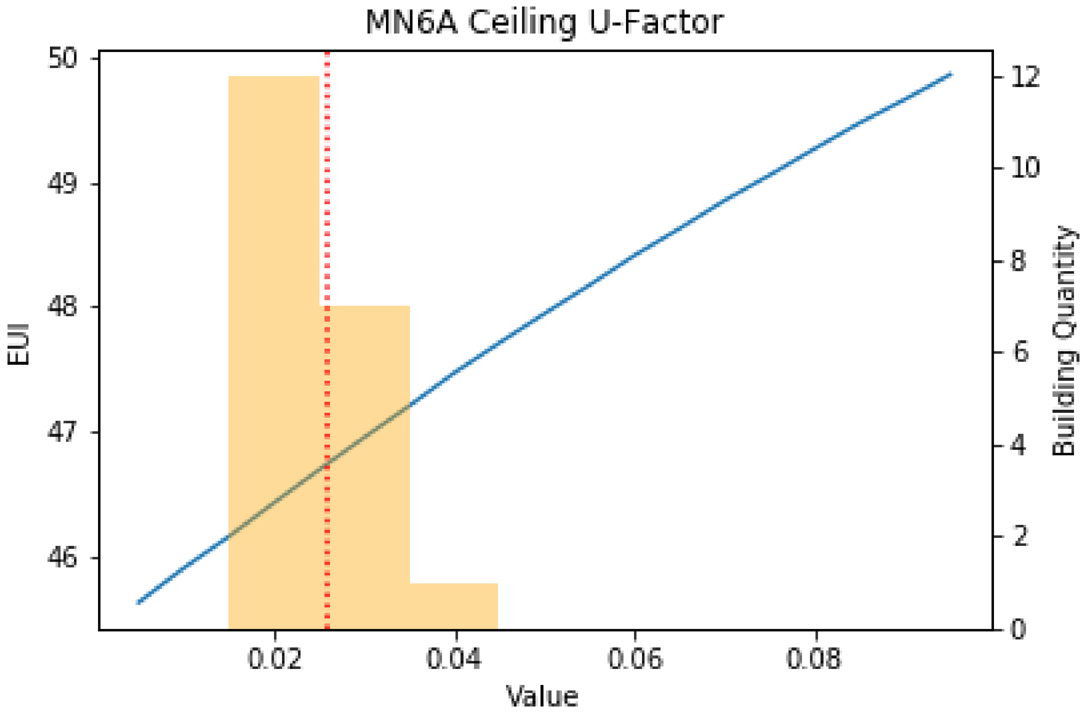


Figure 90. Minnesota Ceiling U-Factor

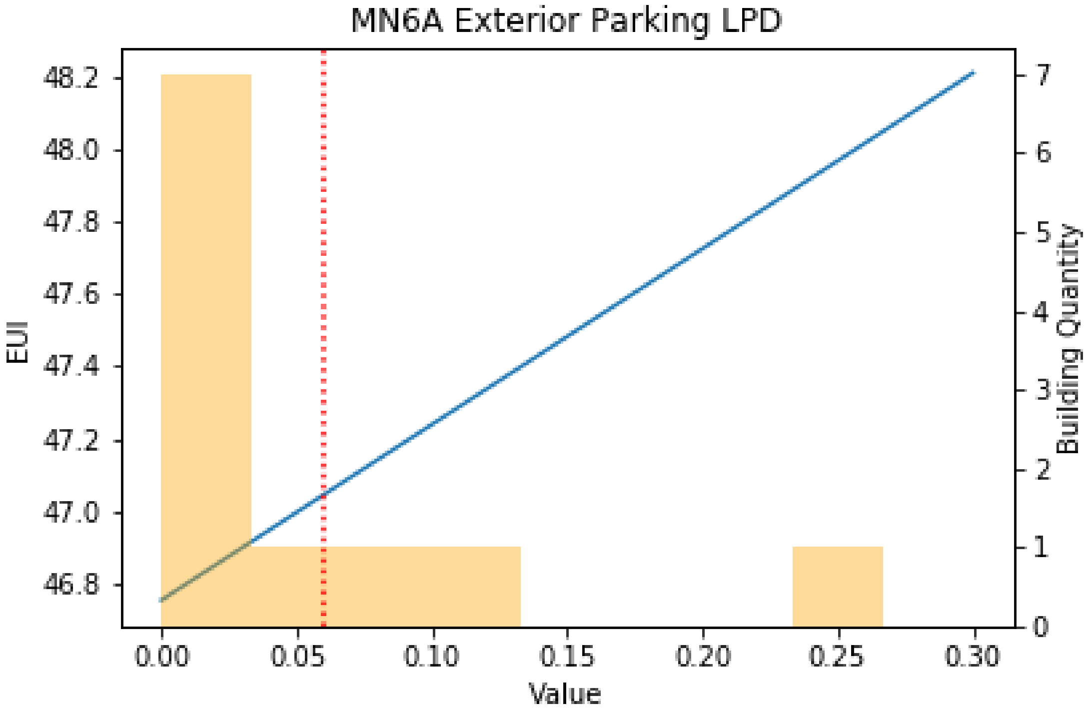


Figure 91. Minnesota 6A Exterior Parking LPD

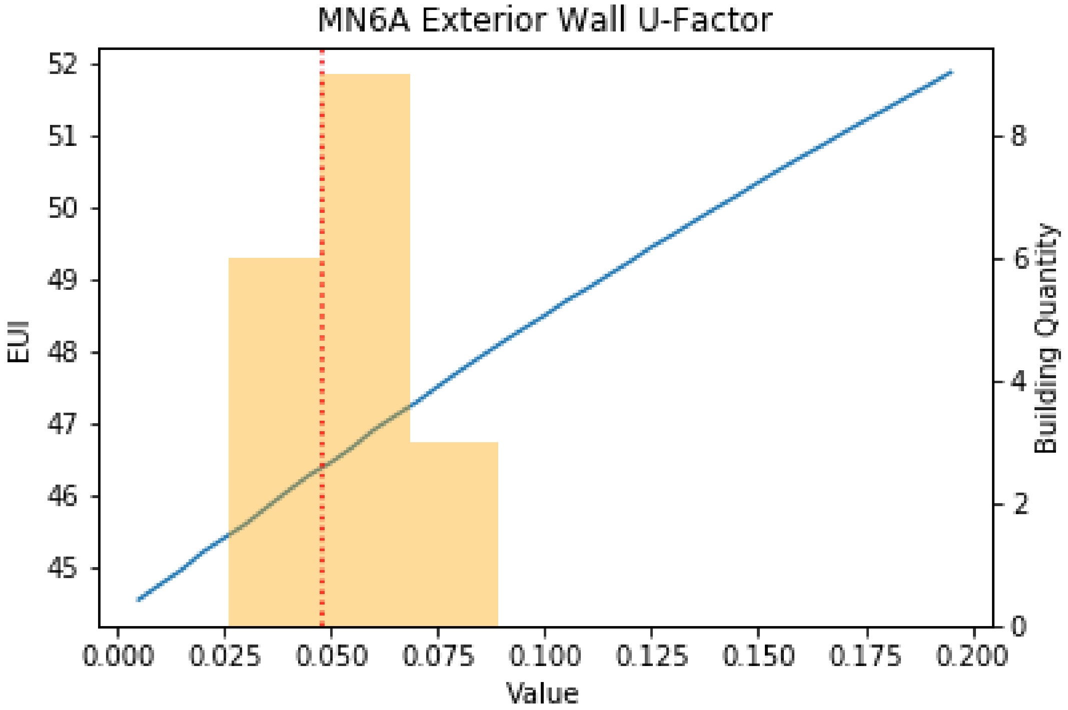


Figure 92. Minnesota 6A Exterior Wall U-Factor

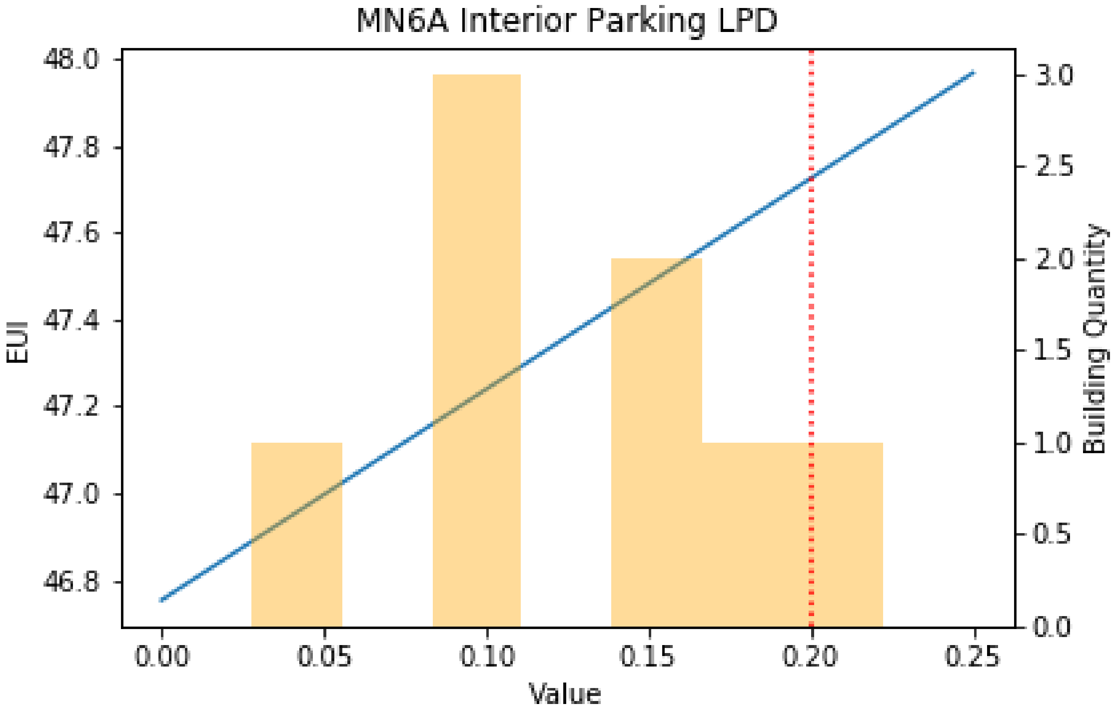


Figure 93. Minnesota 6A Interior Parking LPD

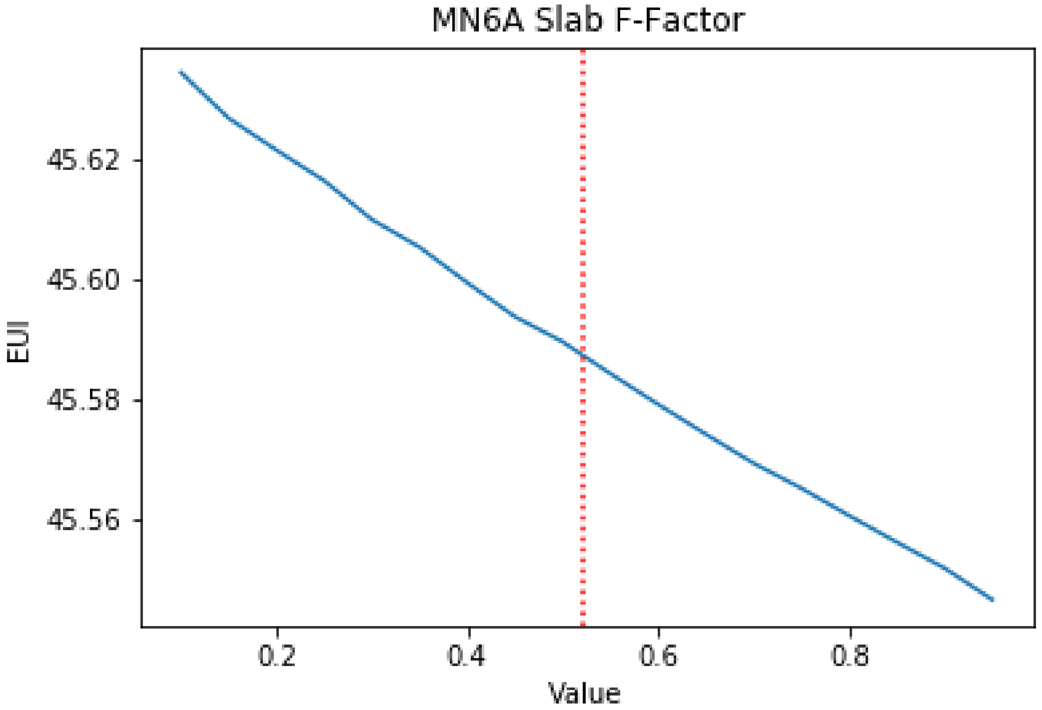


Figure 94. Minnesota 6A Slab F-Factor

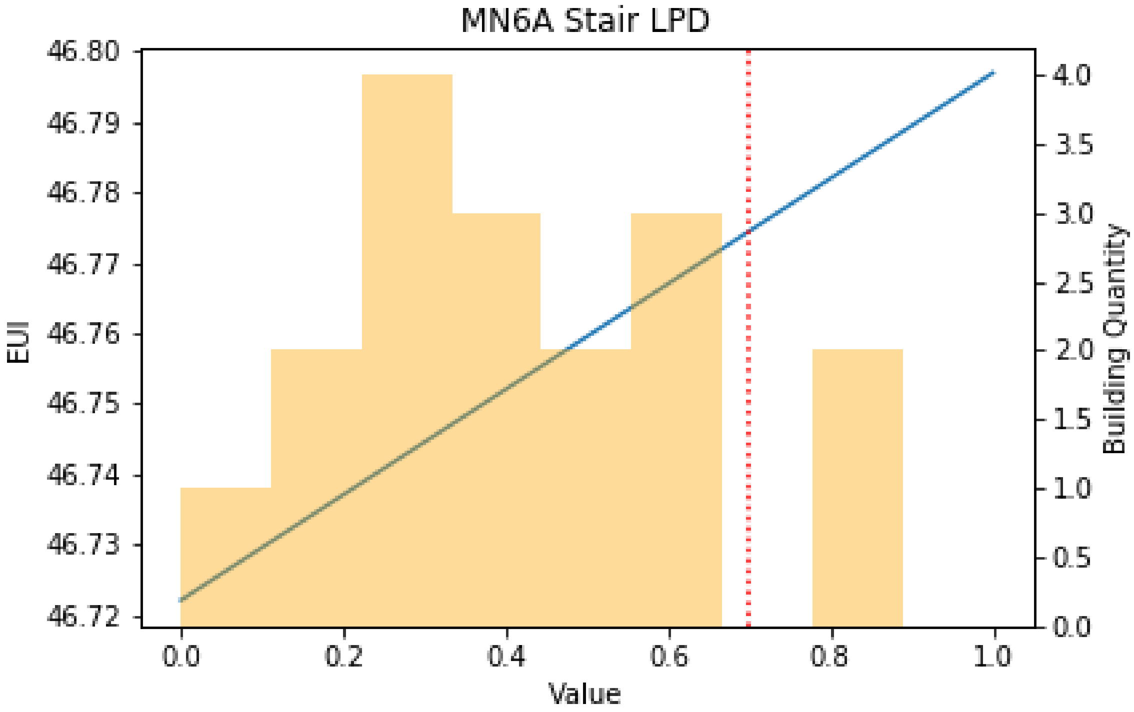


Figure 95. Minnesota 6A Stair LPD

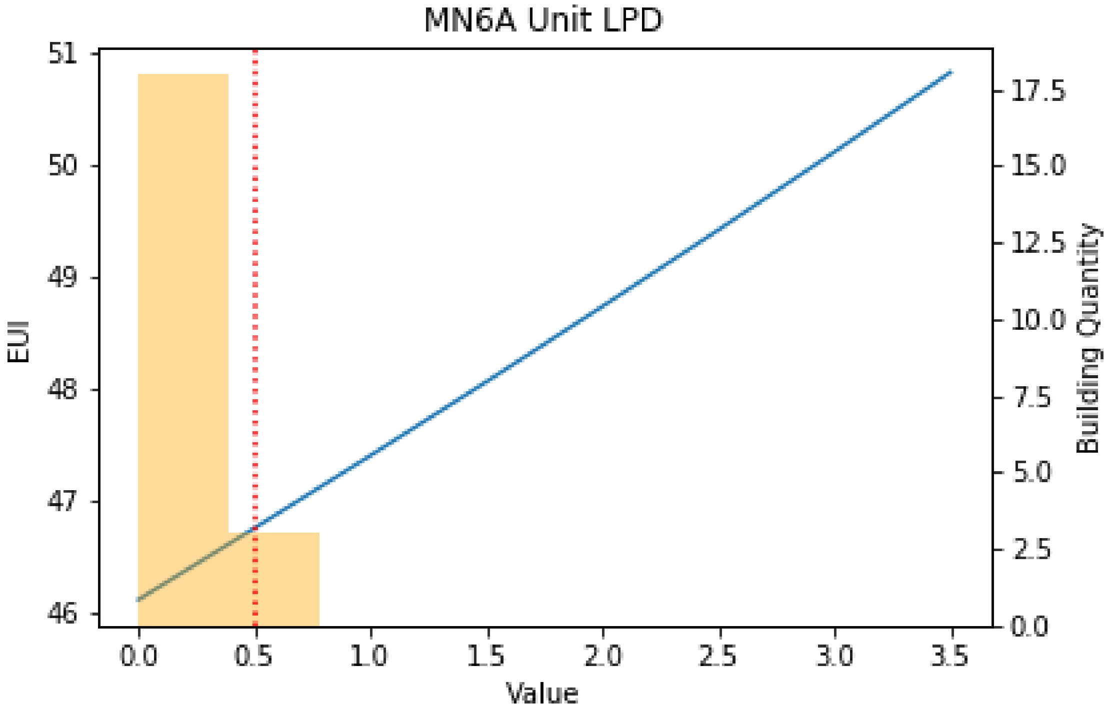


Figure 96. Minnesota 6A Unit LPD

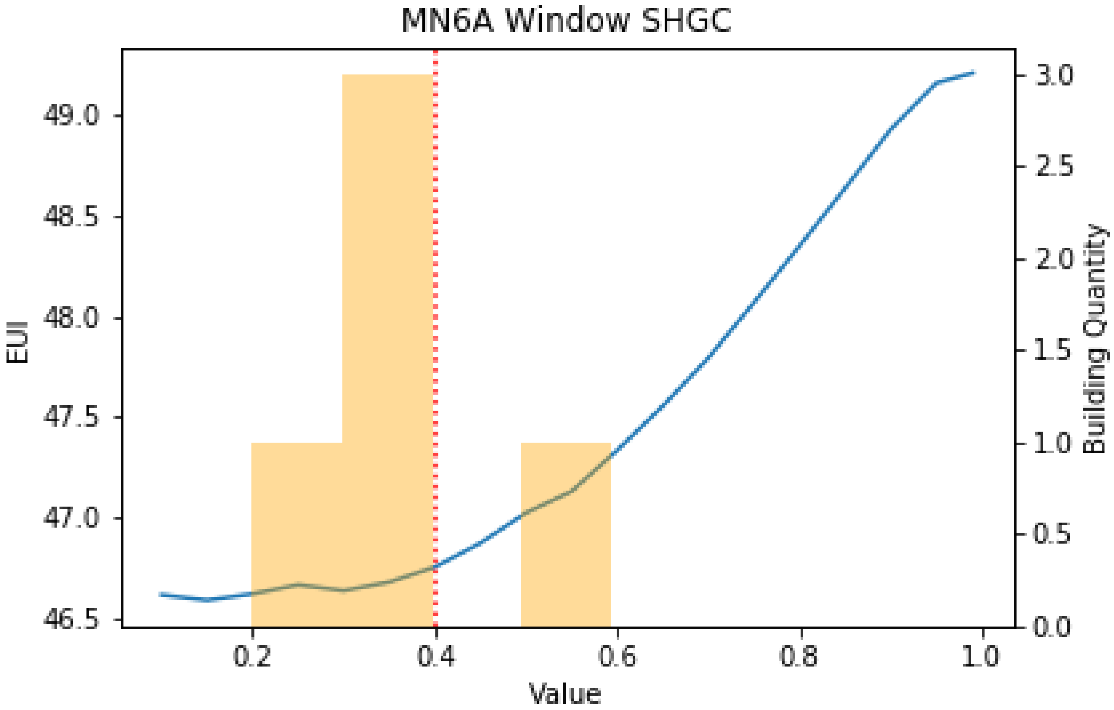


Figure 97. Minnesota Window SHGC

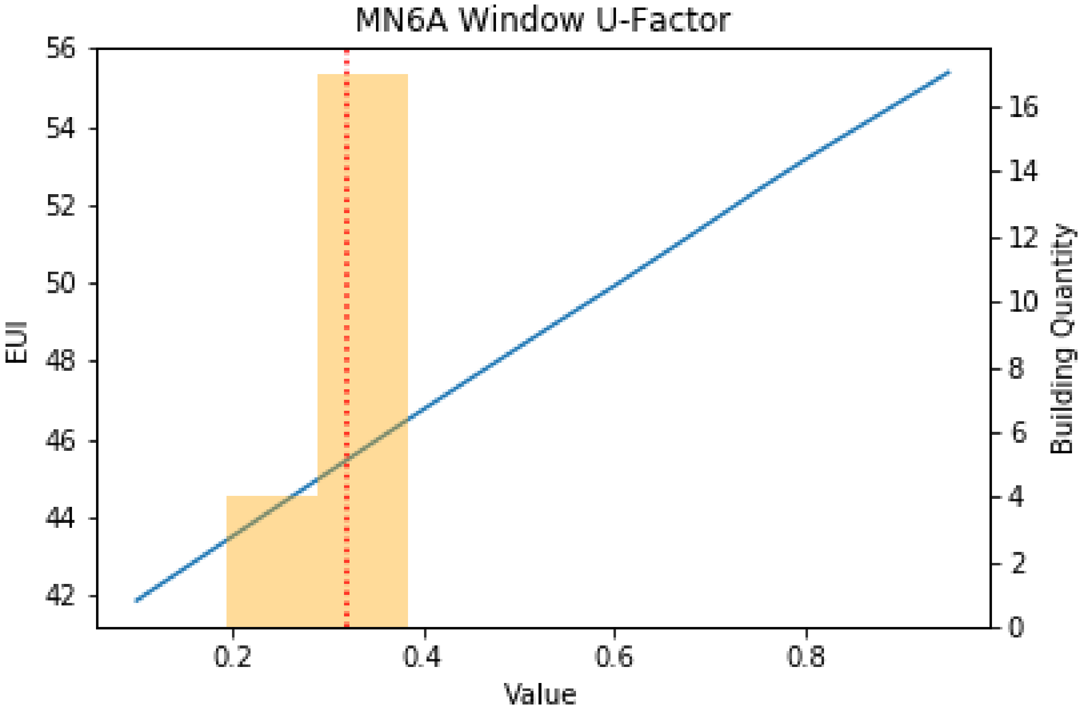


Figure 98. Minnesota 6A Window U-Factor

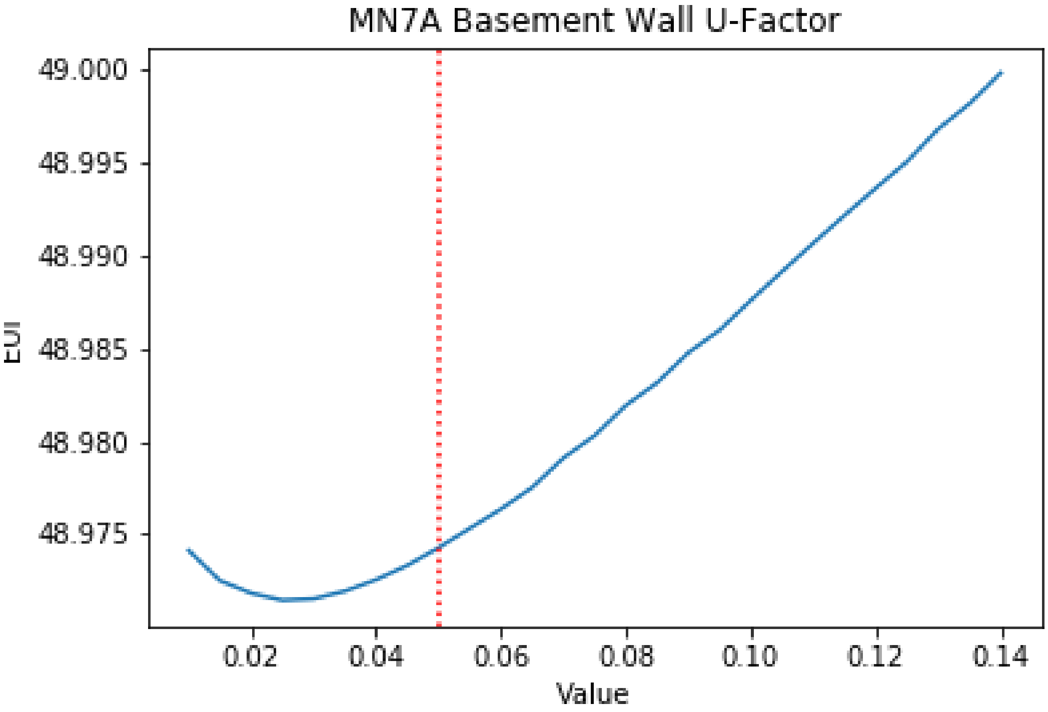


Figure 99. Minnesota 7A Basement Wall U-Factor

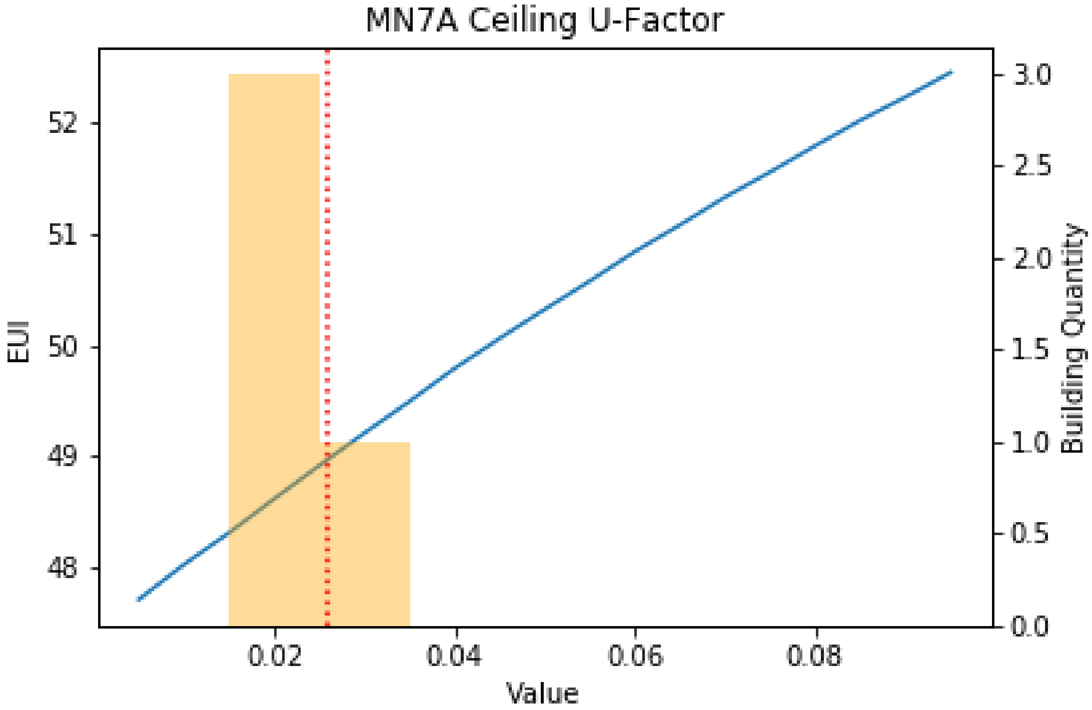


Figure 100. Minnesota 7A Ceiling U-Factor

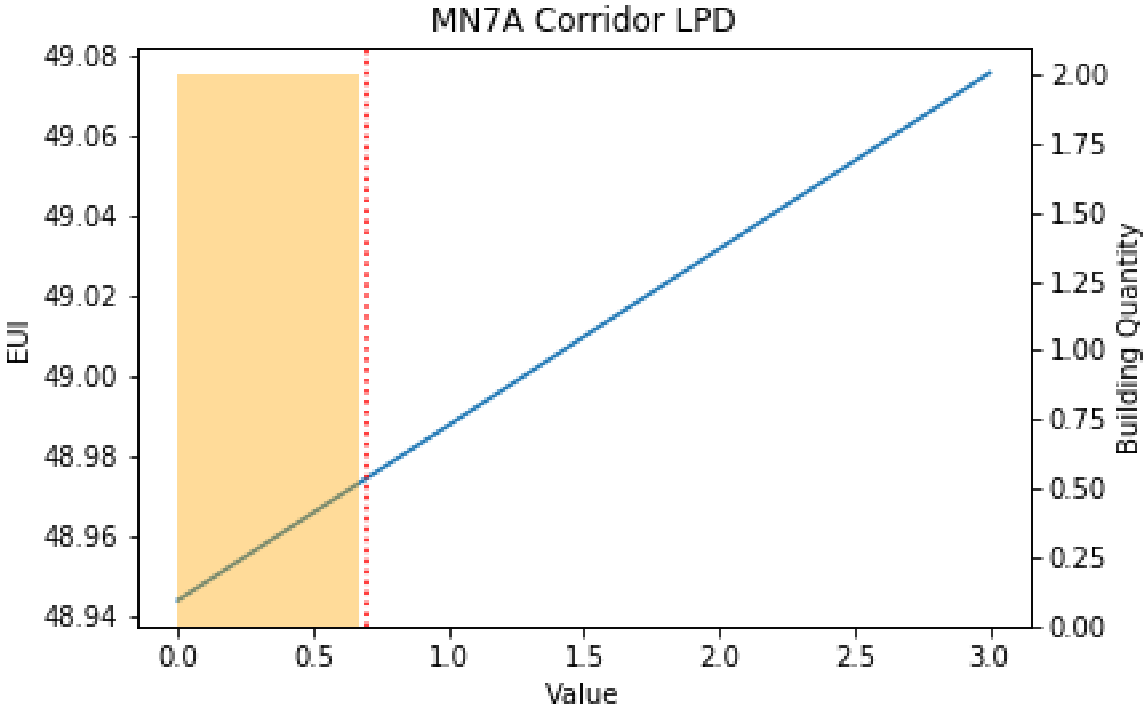


Figure 101. Minnesota 7A Corridor LPD

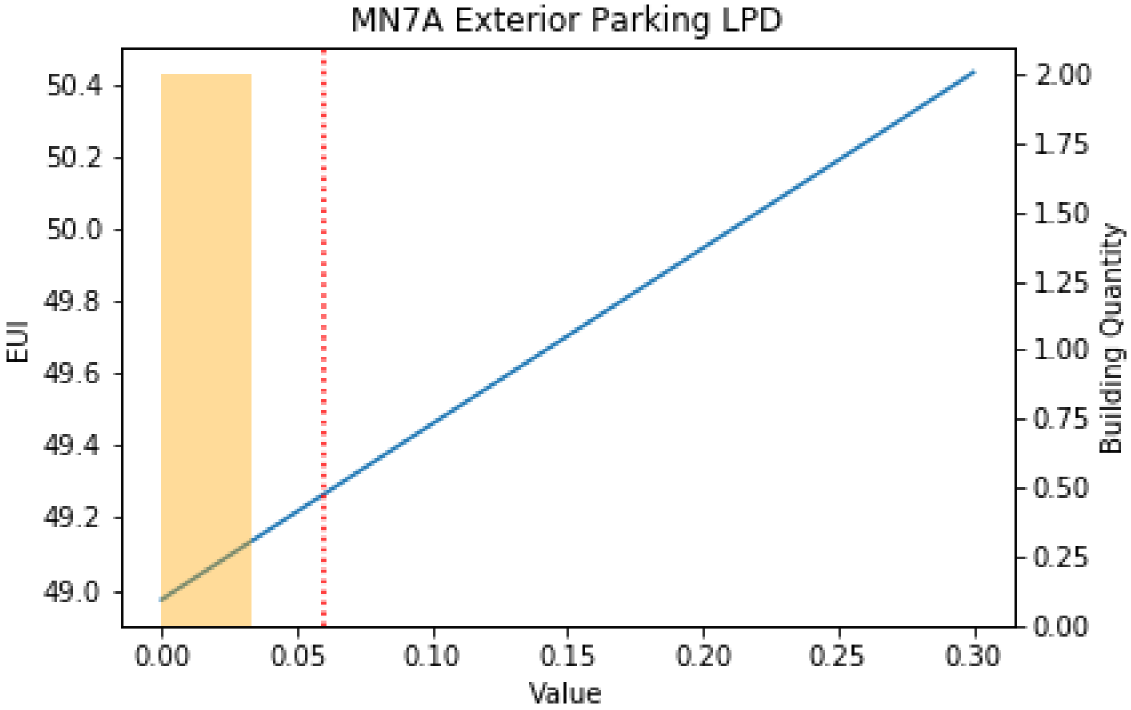


Figure 102. Minnesota 7A Exterior Parking LPD

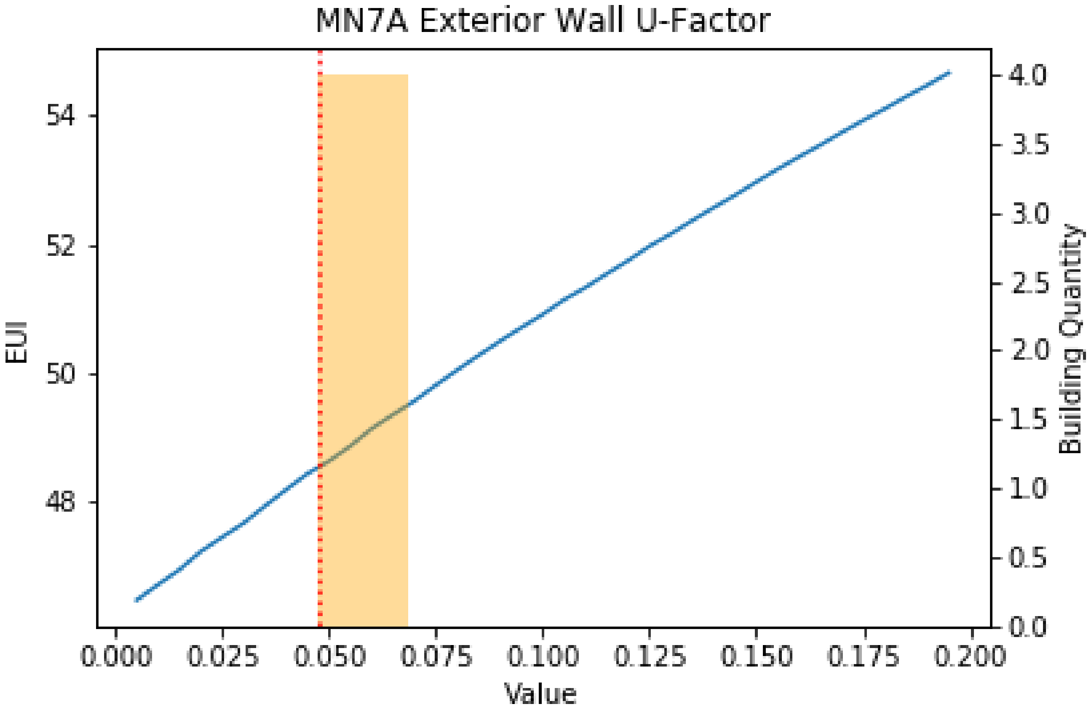


Figure 103. Minnesota 7A Exterior Wall U-Factor

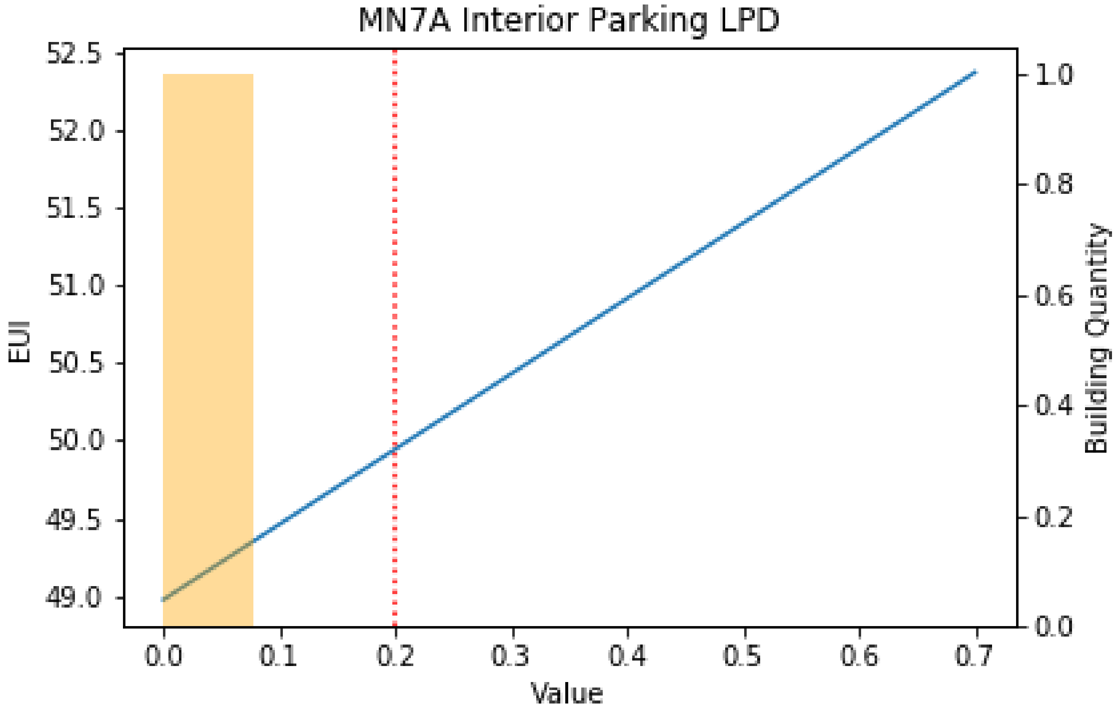


Figure 104. Minnesota 7A Interior Parking LPD

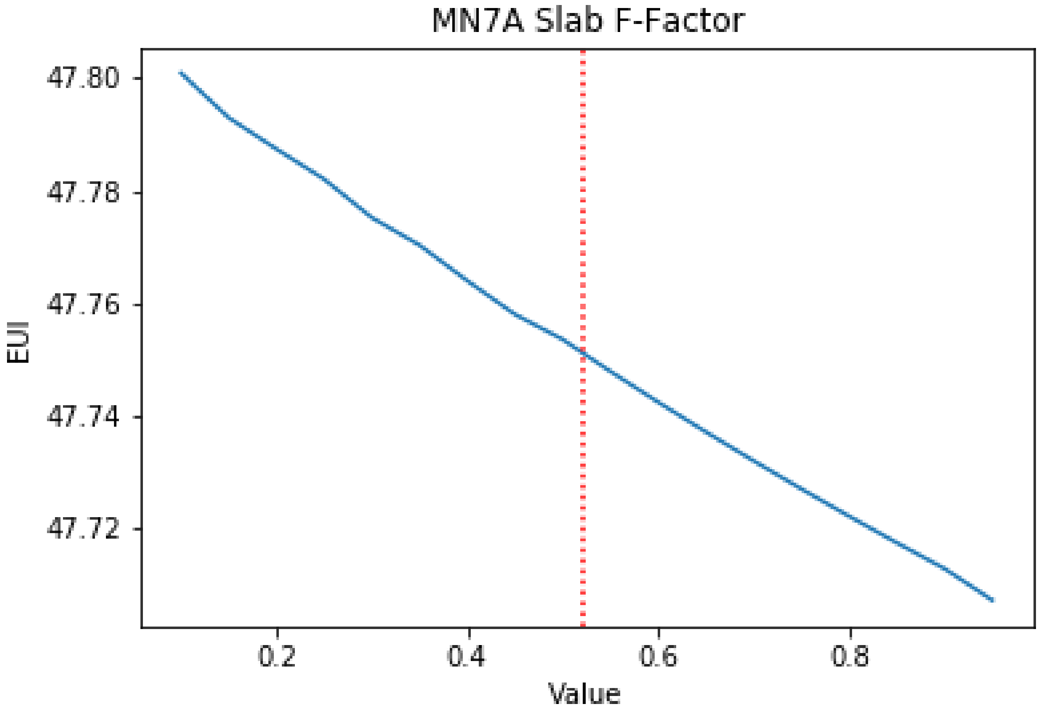


Figure 105. Minnesota 7A Slab F-Factor

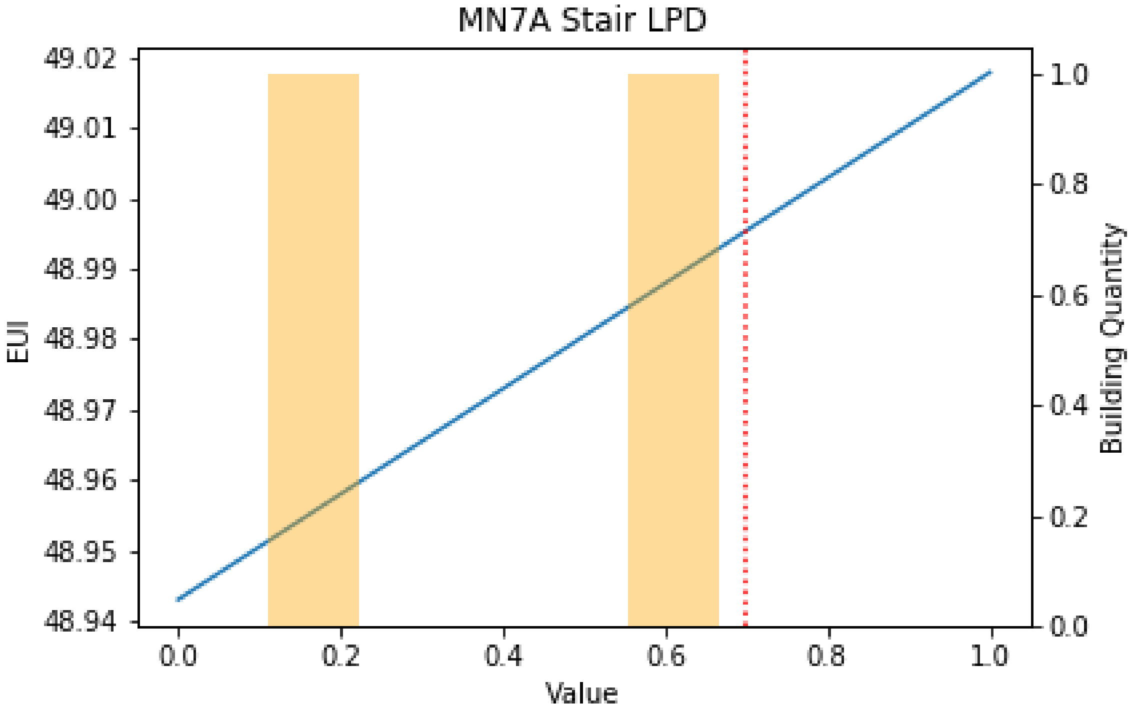


Figure 106. Minnesota 7A Stair LPD

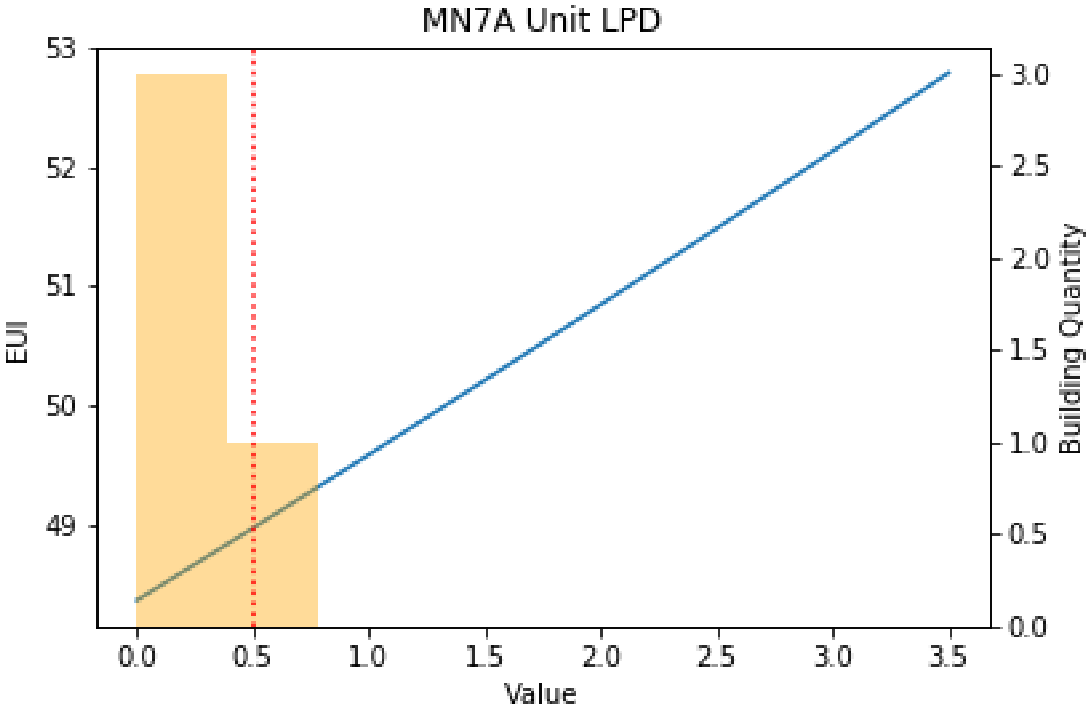


Figure 107. Minnesota 7A Unit LPD

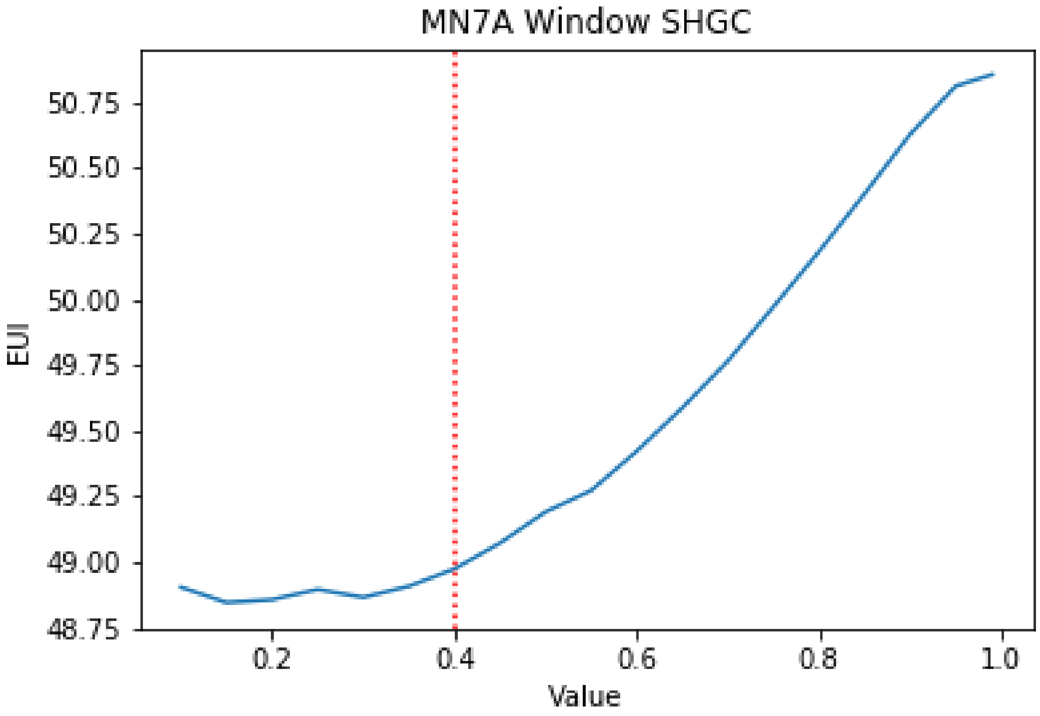


Figure 108. Minnesota 7A Window SHGC

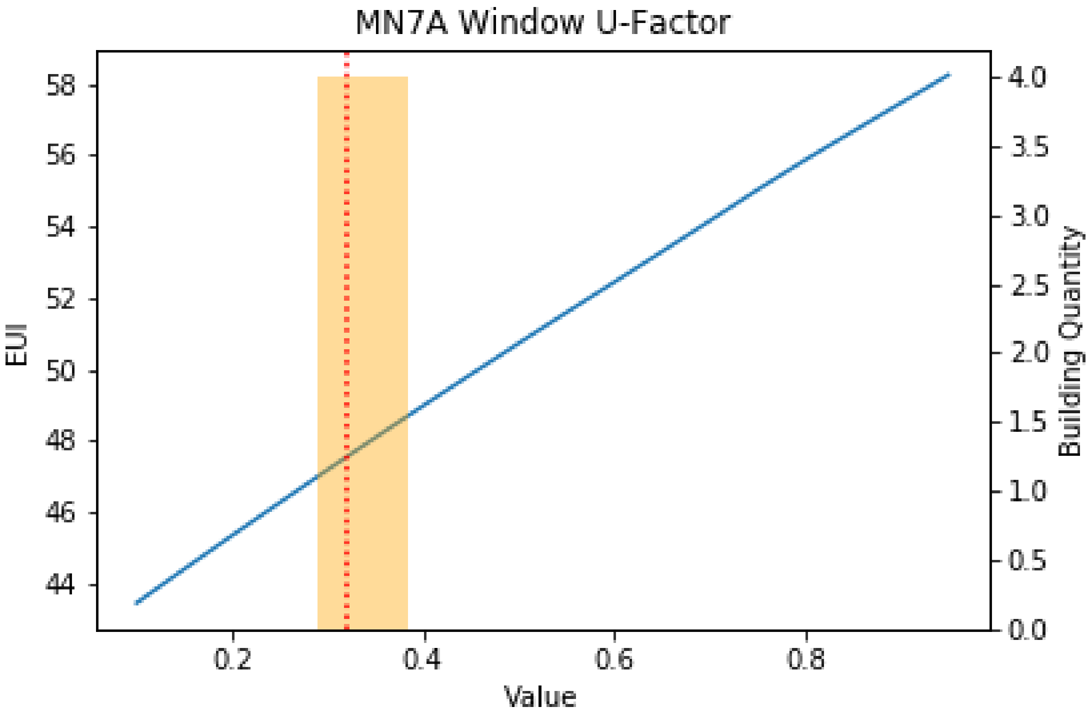


Figure 109. Minnesota 7A Window U-Factor

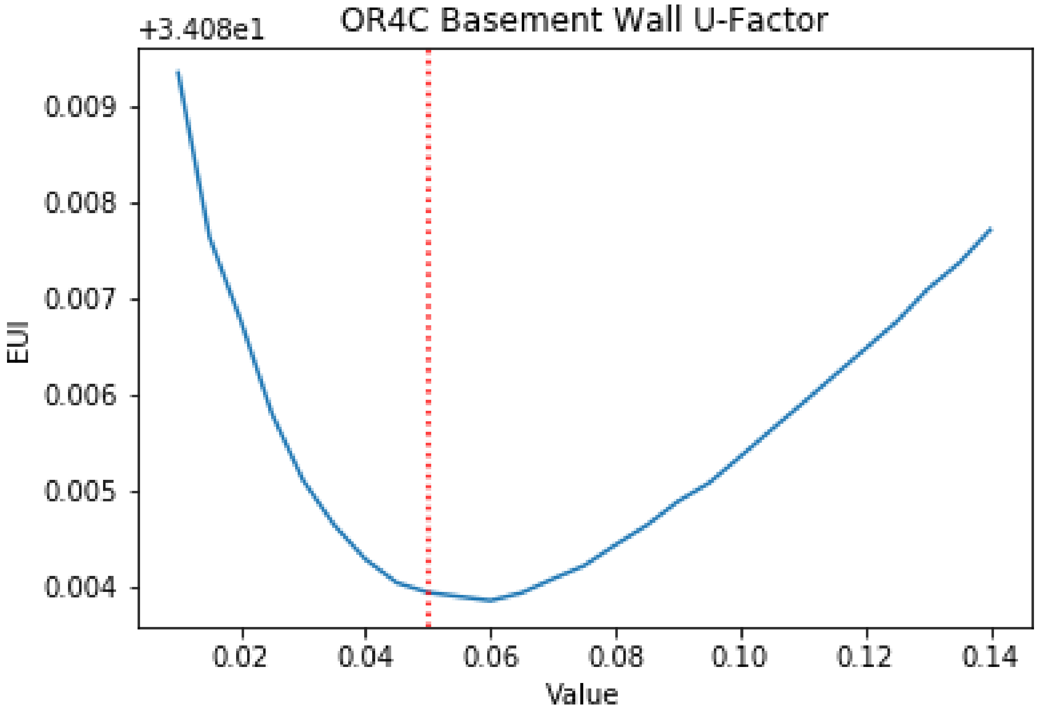


Figure 110. Oregon 4C Basement Wall U-Factor

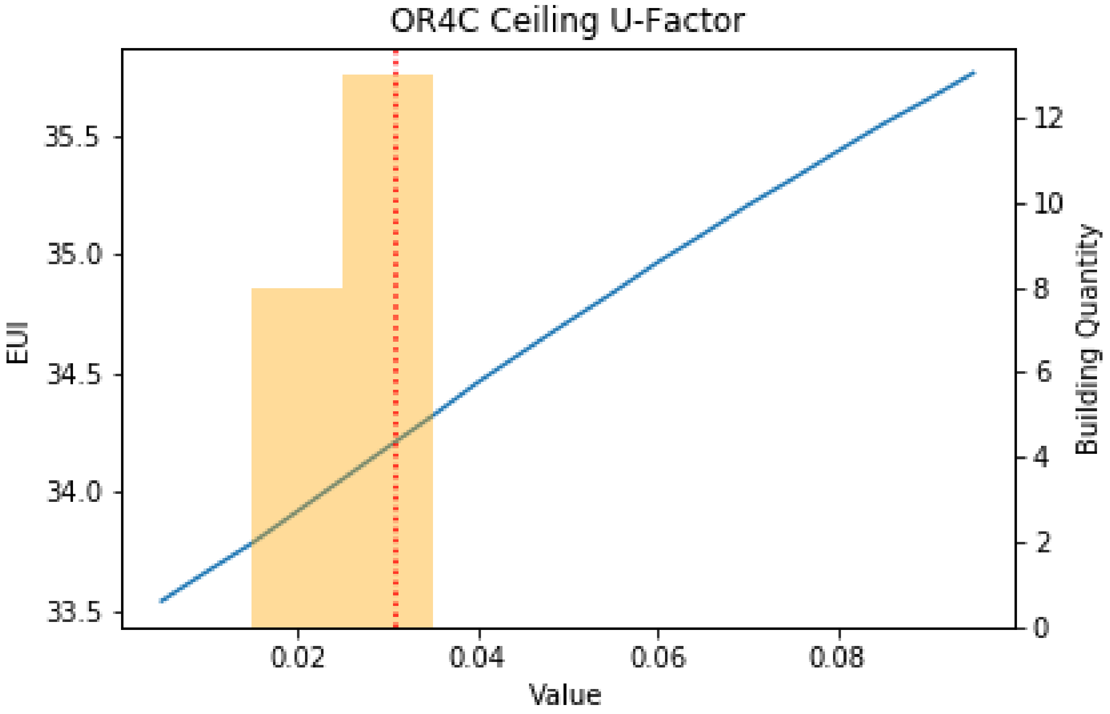


Figure 111. Oregon 4C Ceiling U-Factor

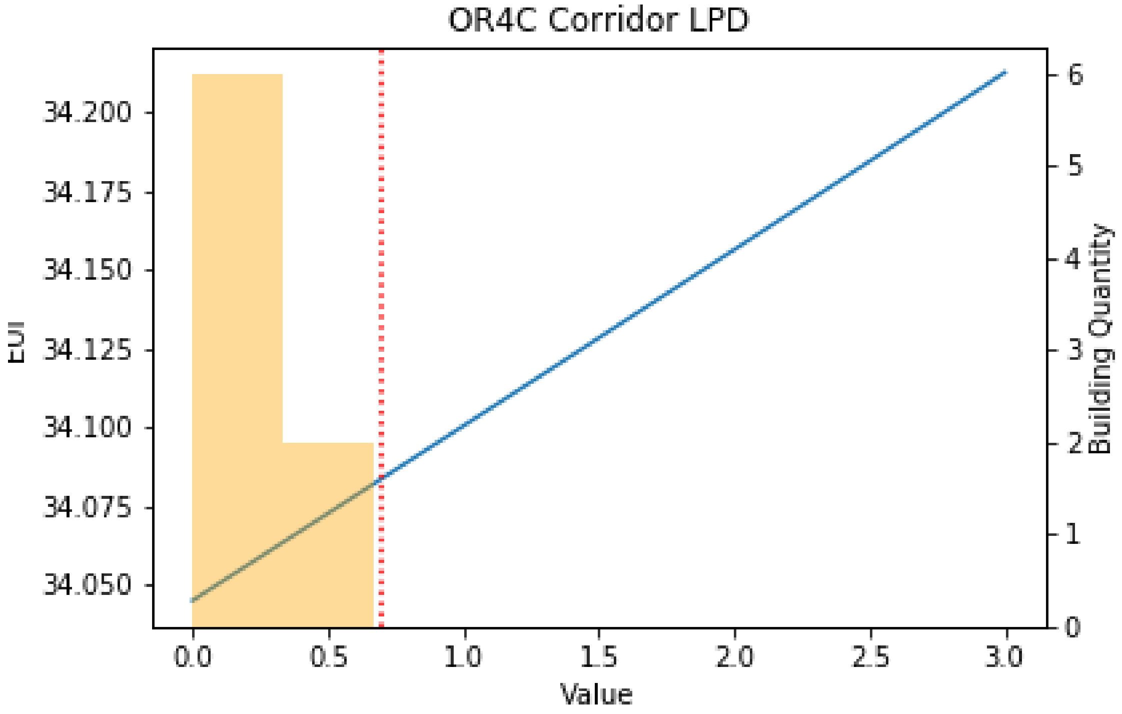


Figure 112. Oregon 4C Corridor LPD

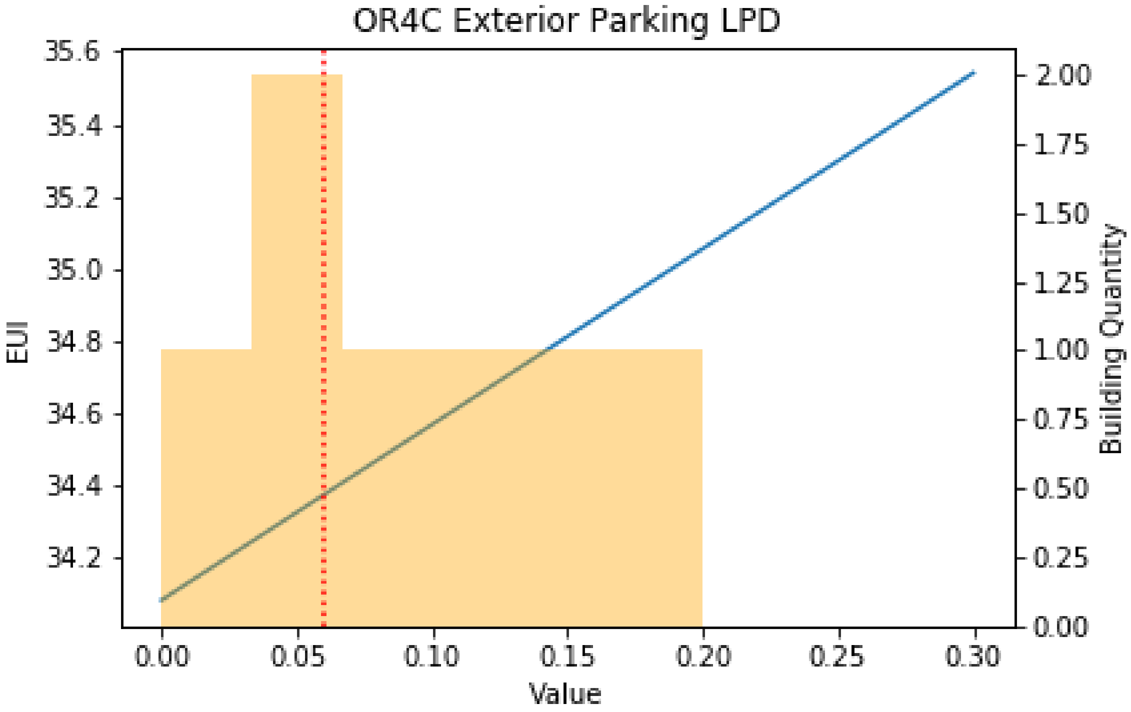


Figure 113. Oregon 4C Exterior Parking LPD

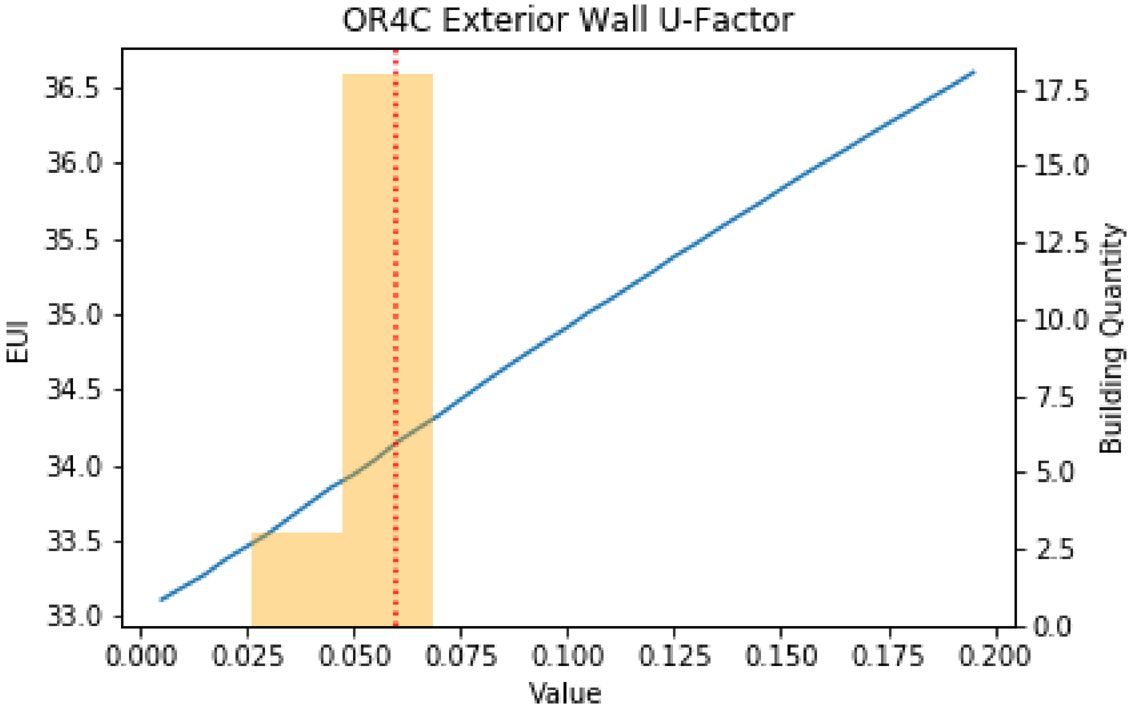


Figure 114. Oregon 4C Exterior Wall U-Factor

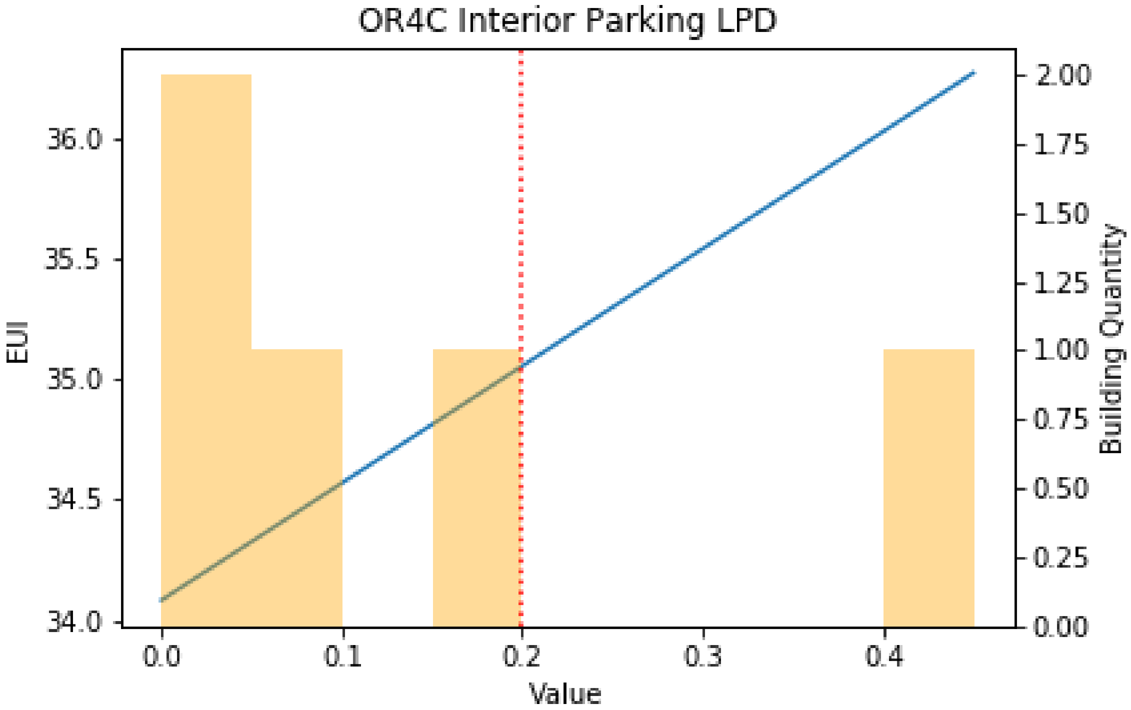


Figure 115. Oregon 4C Interior Parking LPD

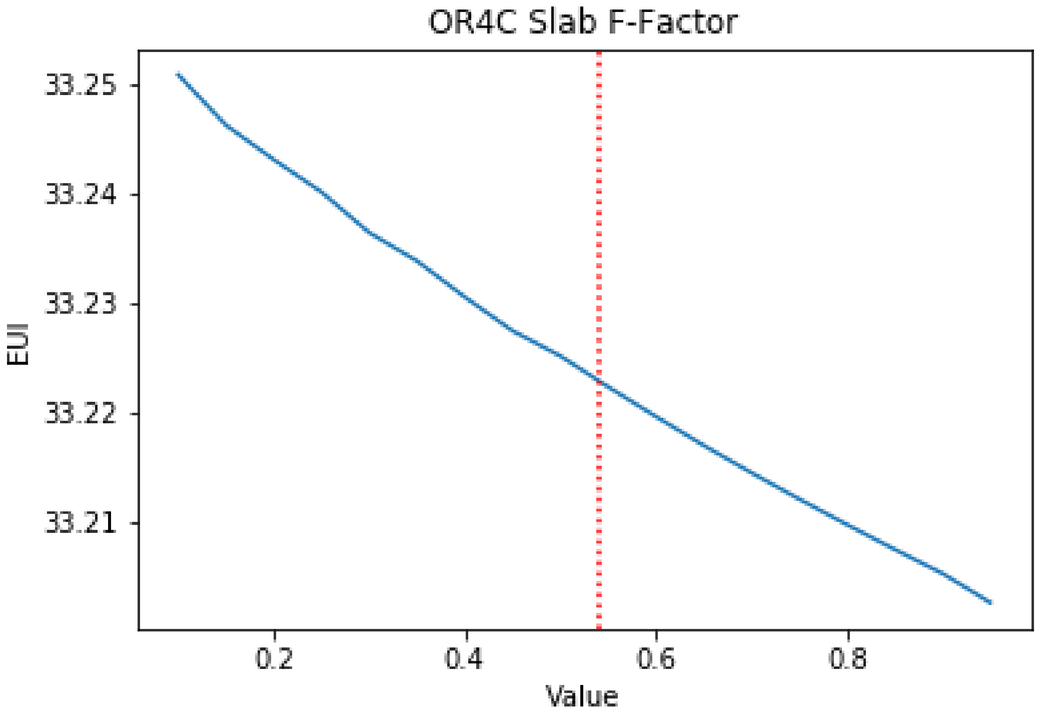


Figure 116. Oregon 4C Slab F-Factor

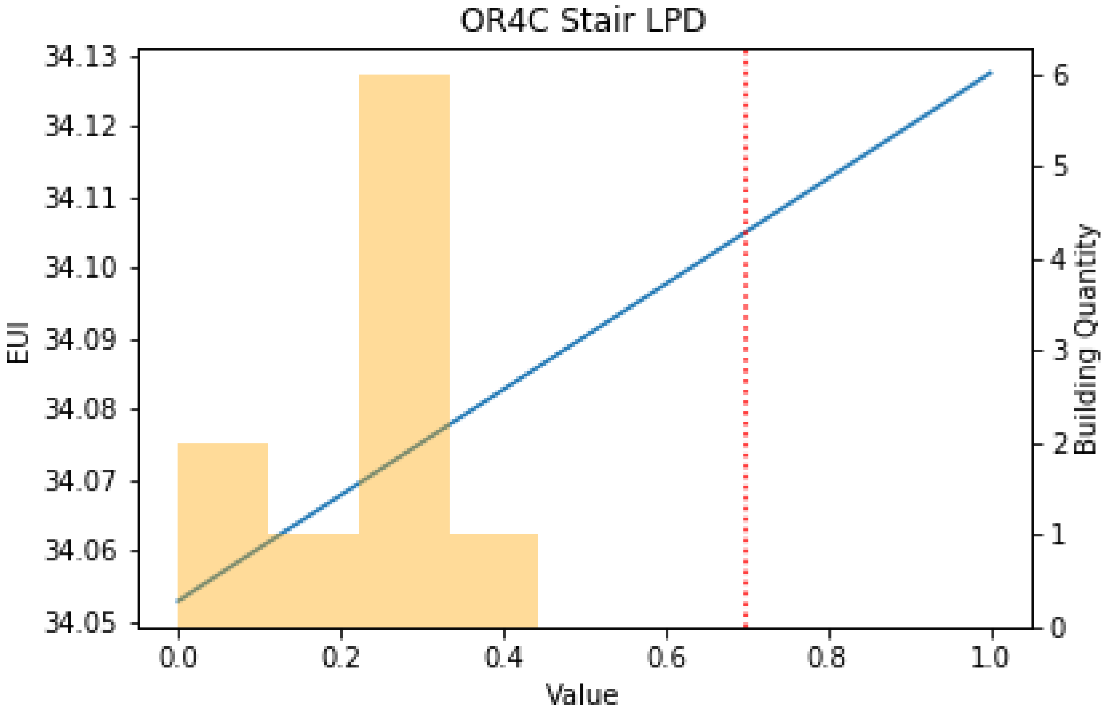


Figure 117. Oregon 4C Stair LPD

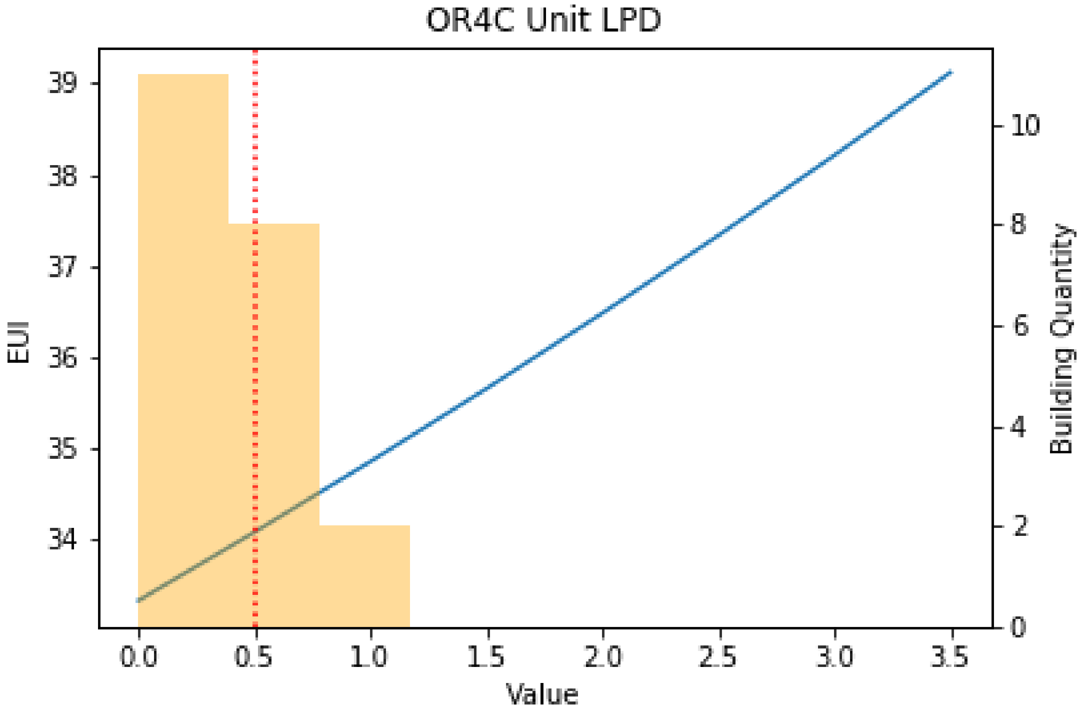


Figure 118. Oregon 4C Unit LPD

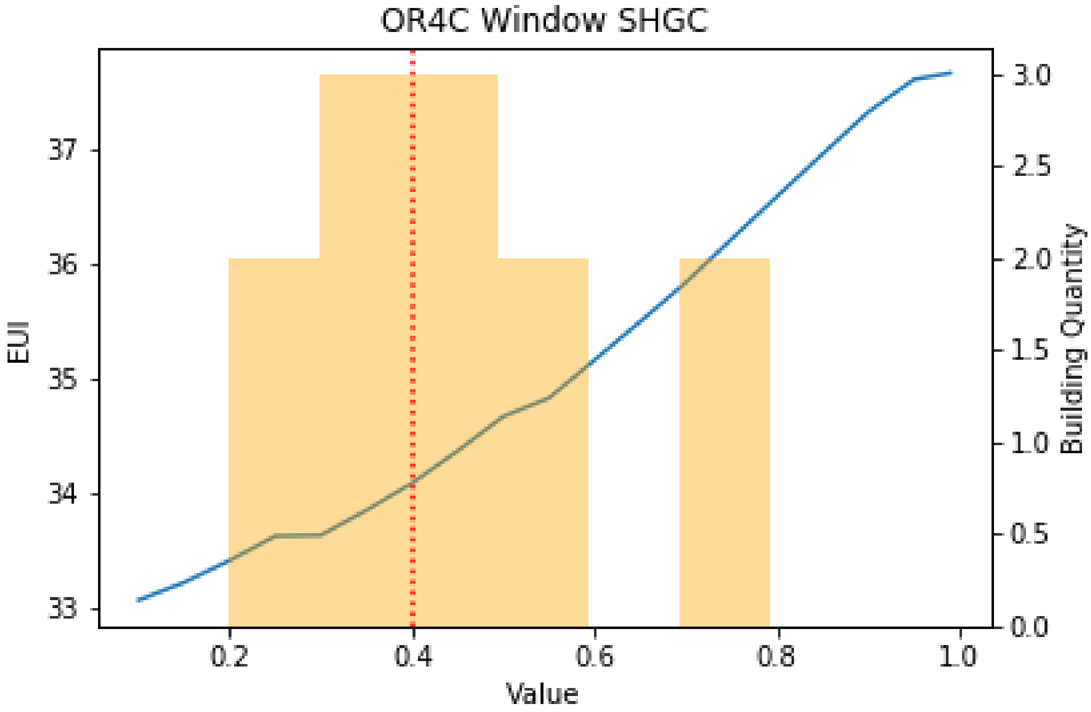


Figure 119. Oregon 4C Window SHGC

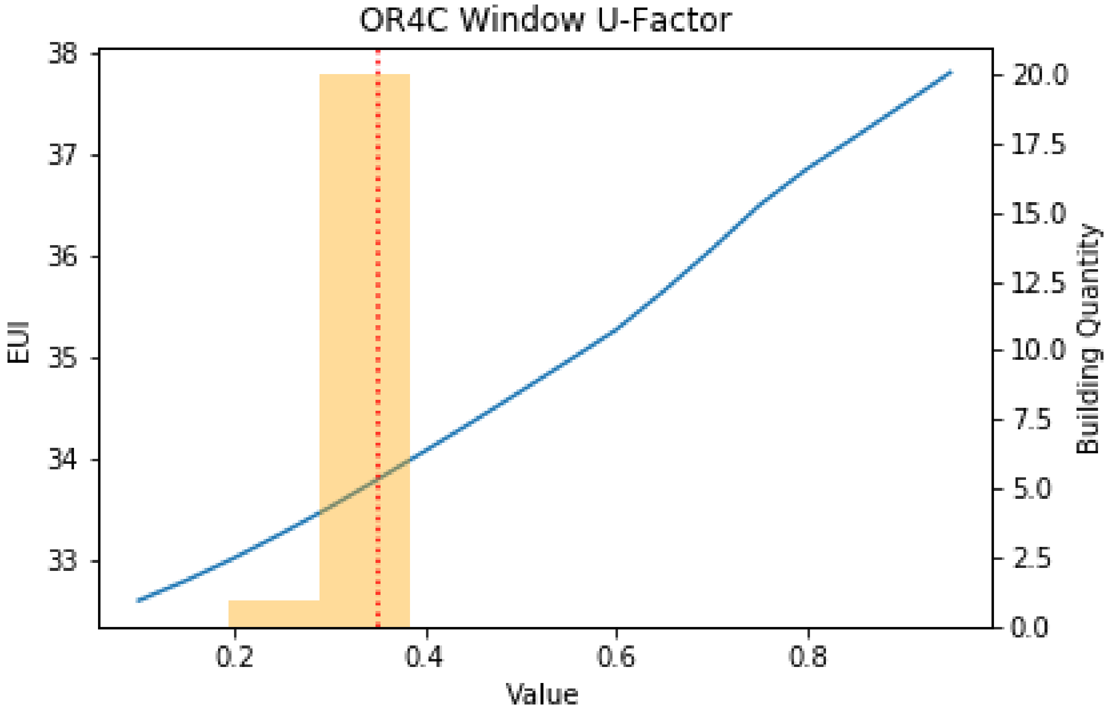


Figure 120. Oregon 4C Window U-Factor

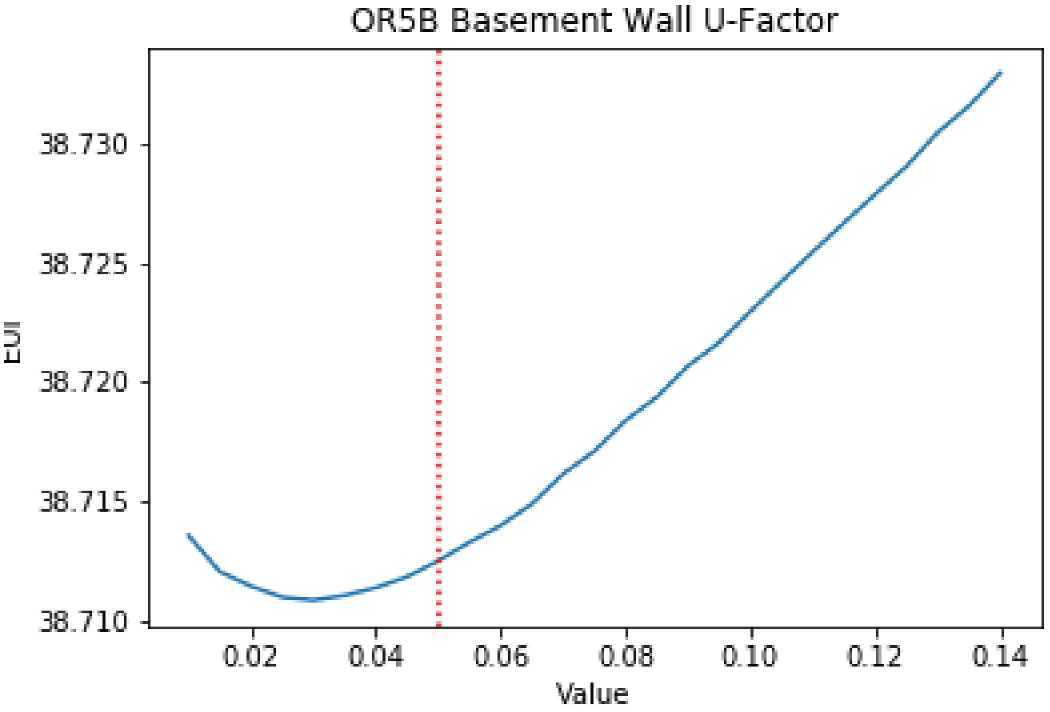


Figure 121. Oregon 5B Basement Wall U-Factor

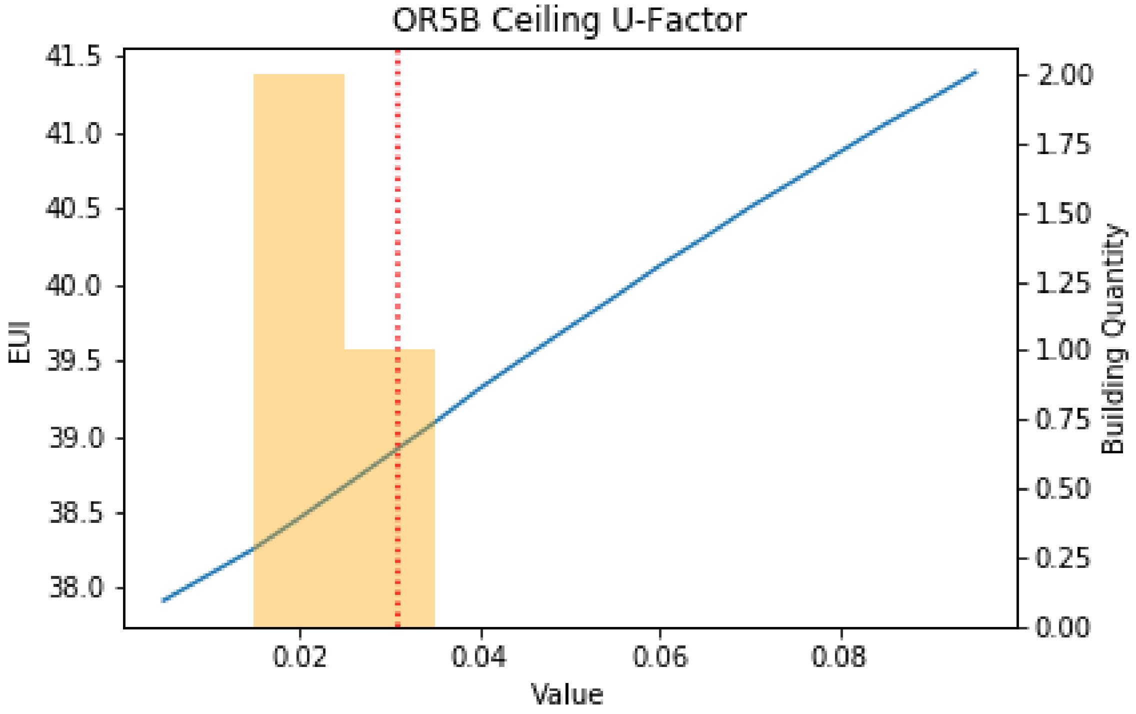


Figure 122. Oregon 5B Ceiling U-Factor

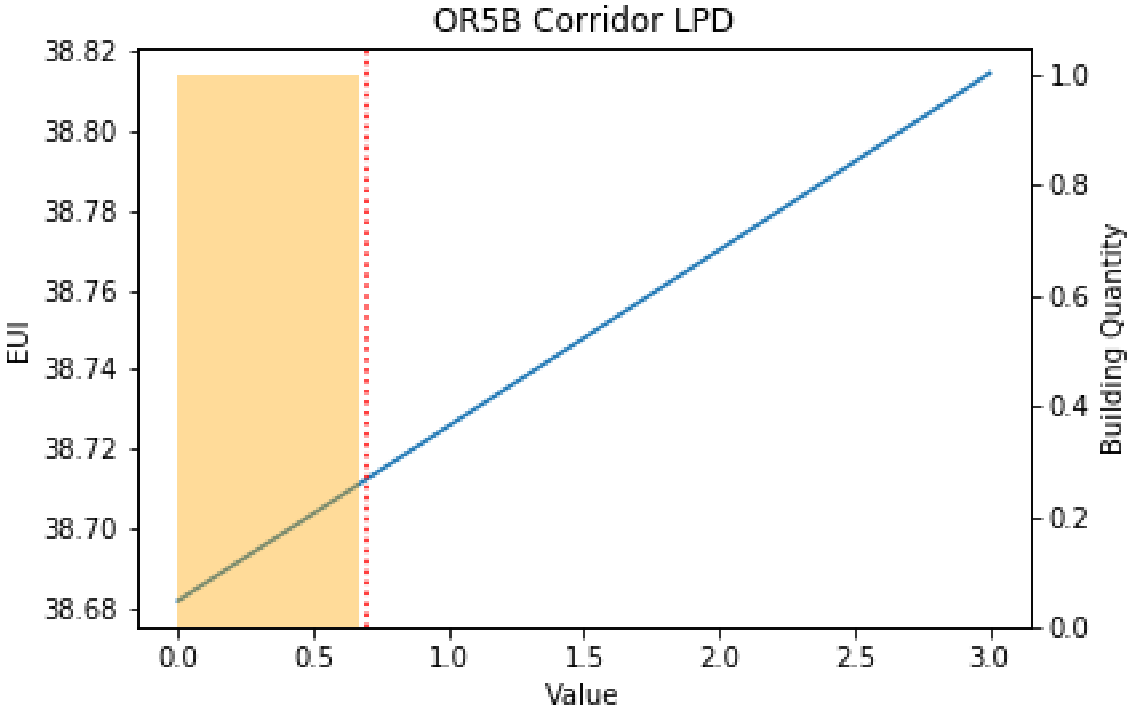


Figure 123. Oregon 5B Corridor LPD

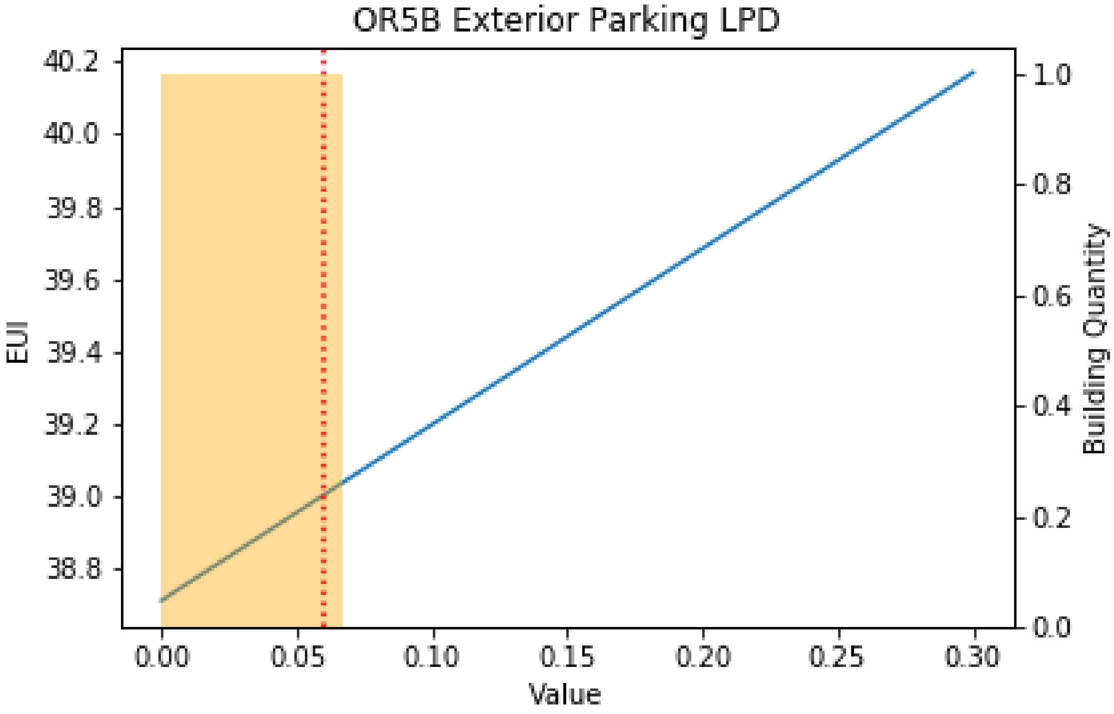


Figure 124. Oregon 5B Exterior Parking LPD

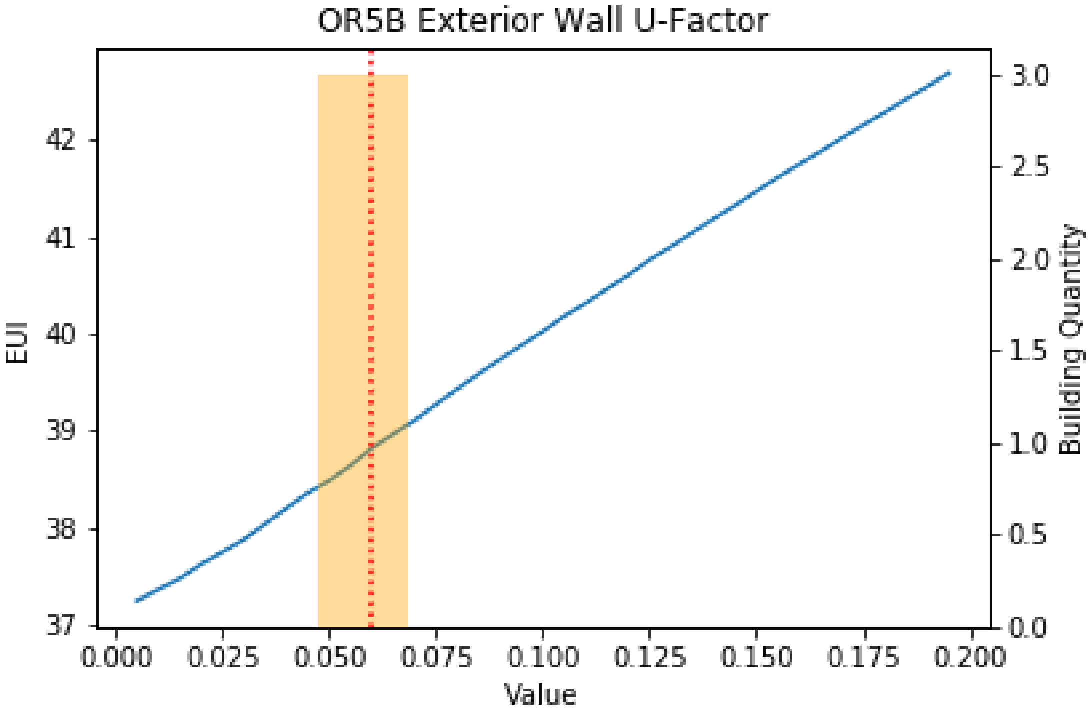


Figure 125. Oregon 5B Exterior Wall U-Factor

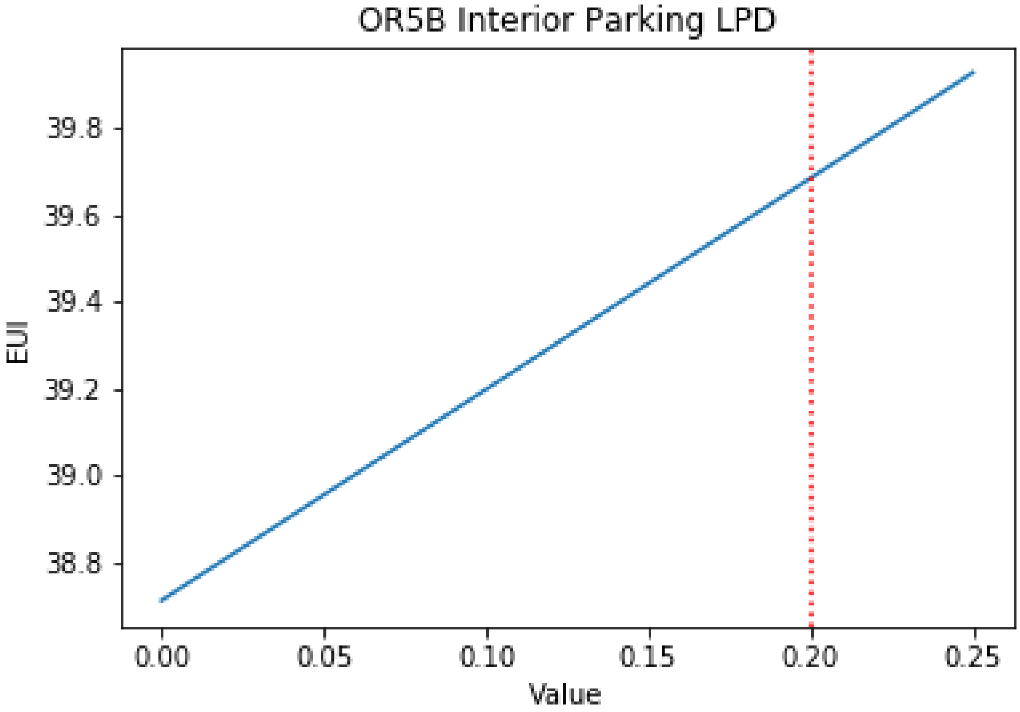


Figure 126. Oregon 5B Interior Parking LPD

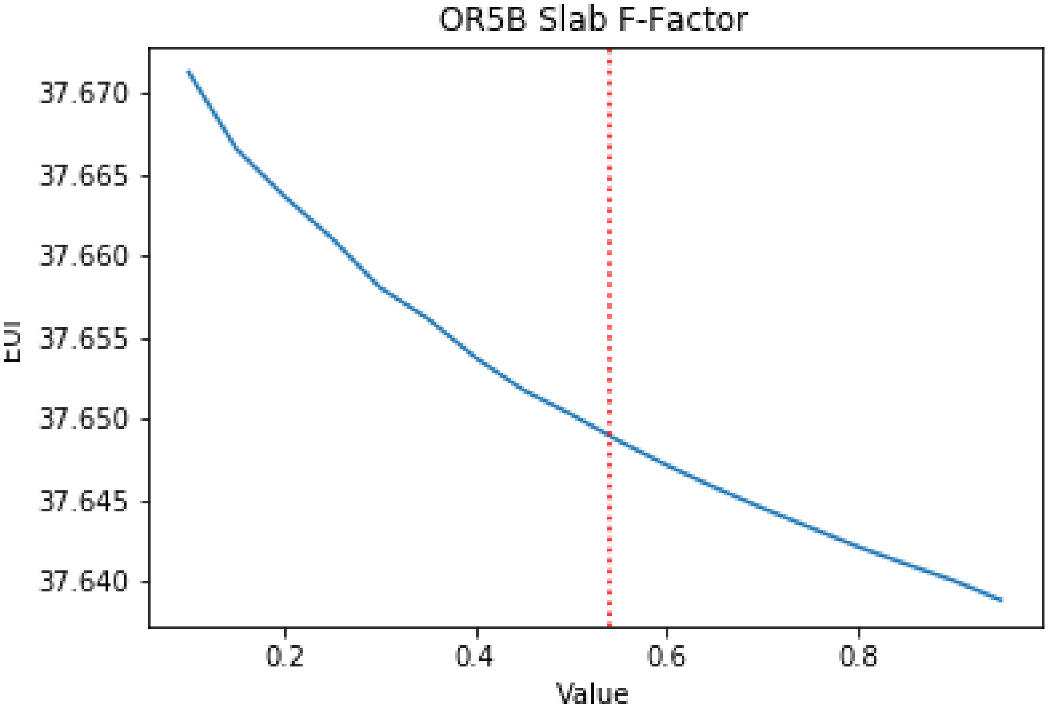


Figure 127. Oregon 5B Slab F-Factor

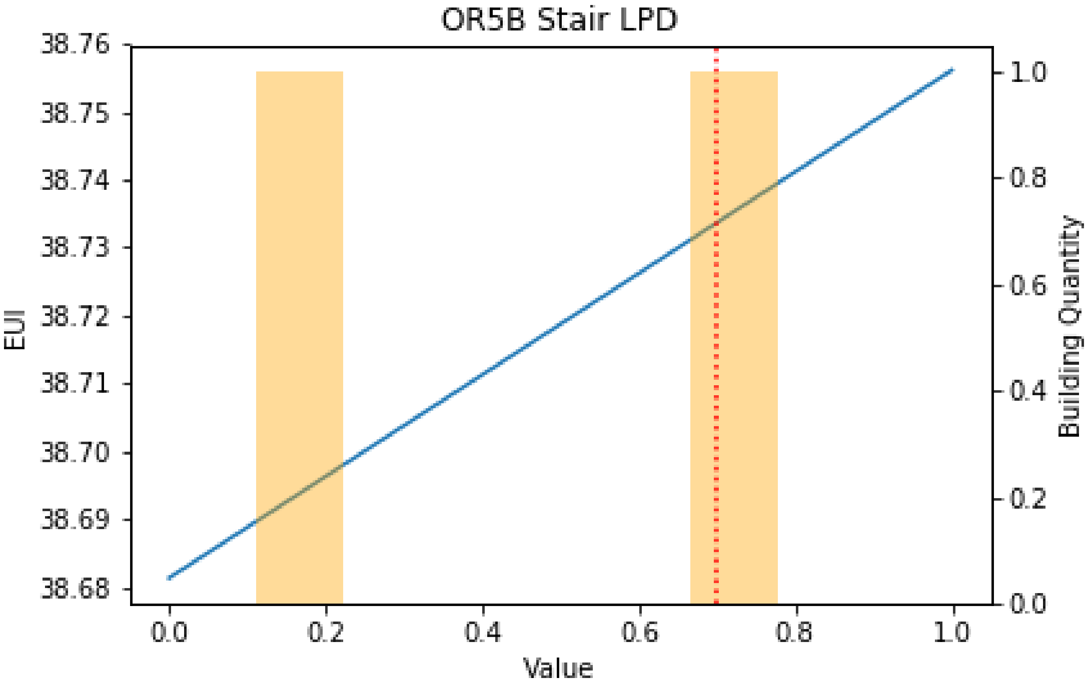


Figure 128. Oregon 5B Stair LPD

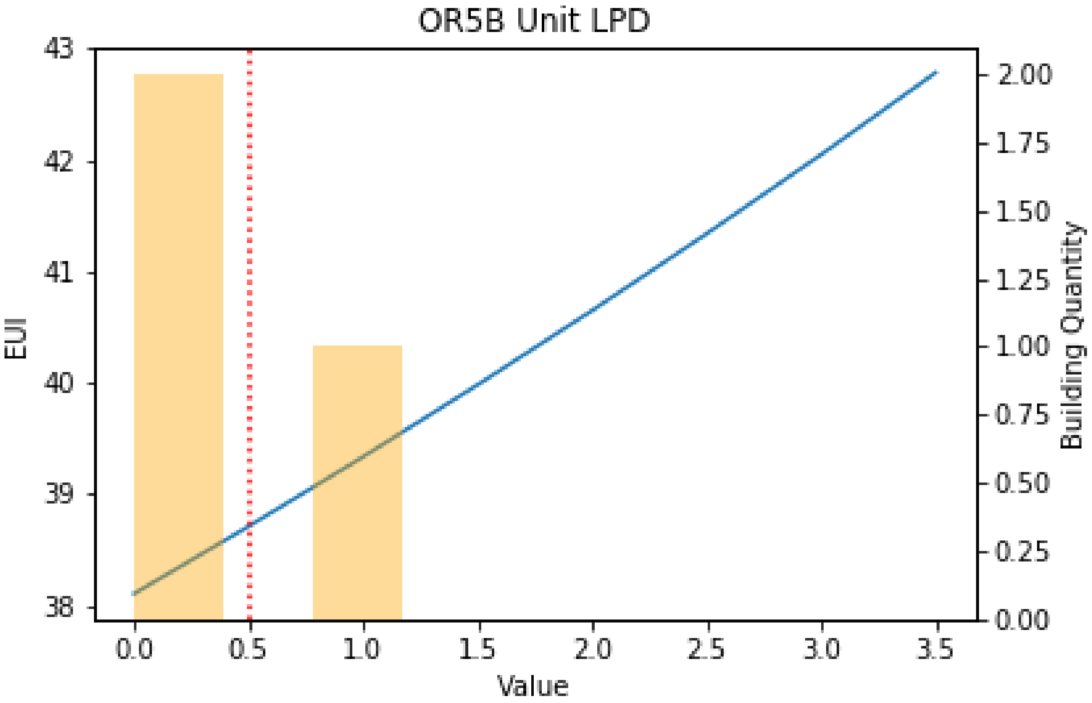


Figure 129. Oregon 5B Unit LPD

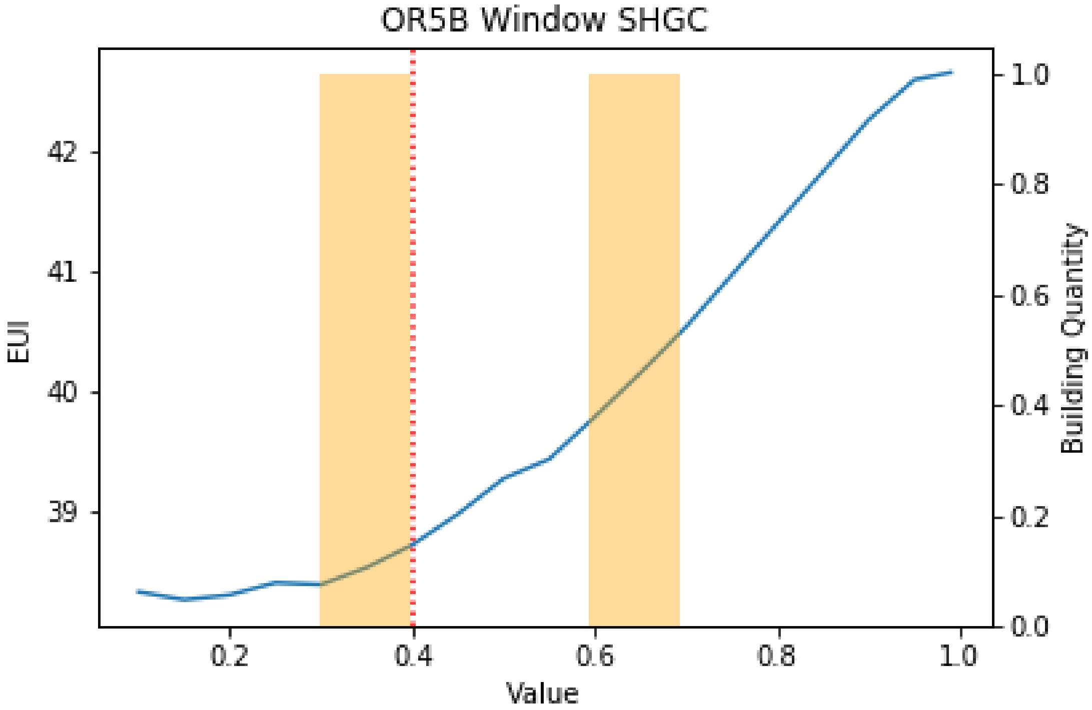


Figure 130. Oregon 5B Window SHGC

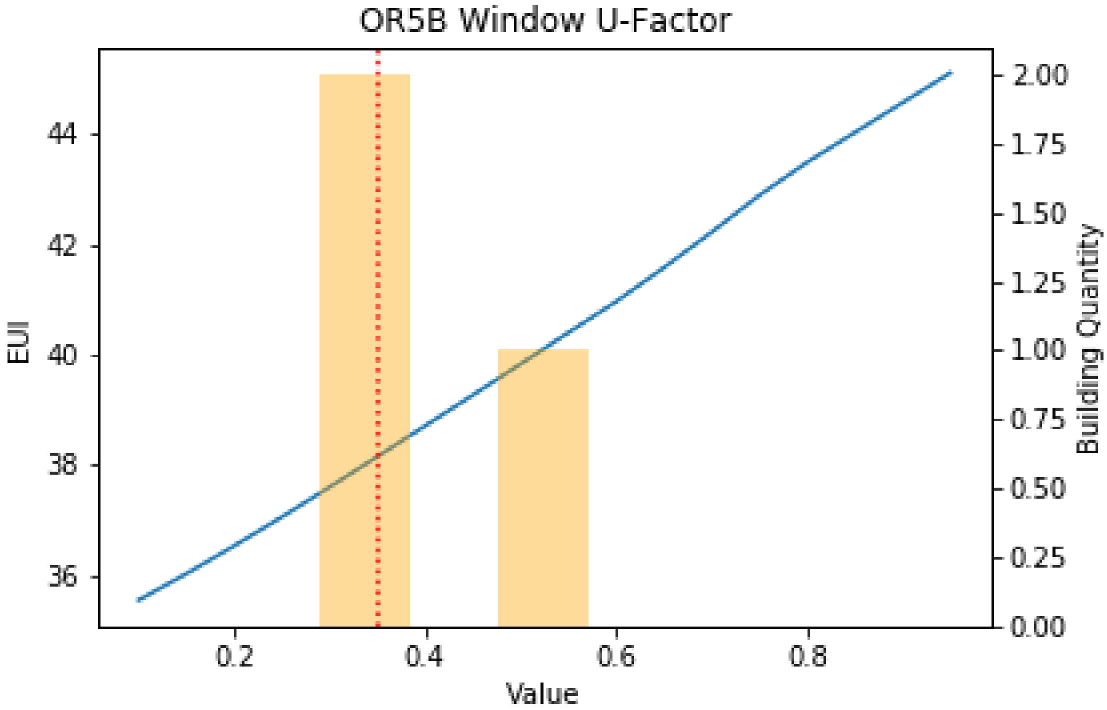


Figure 131. Oregon 5B Window U-Factor

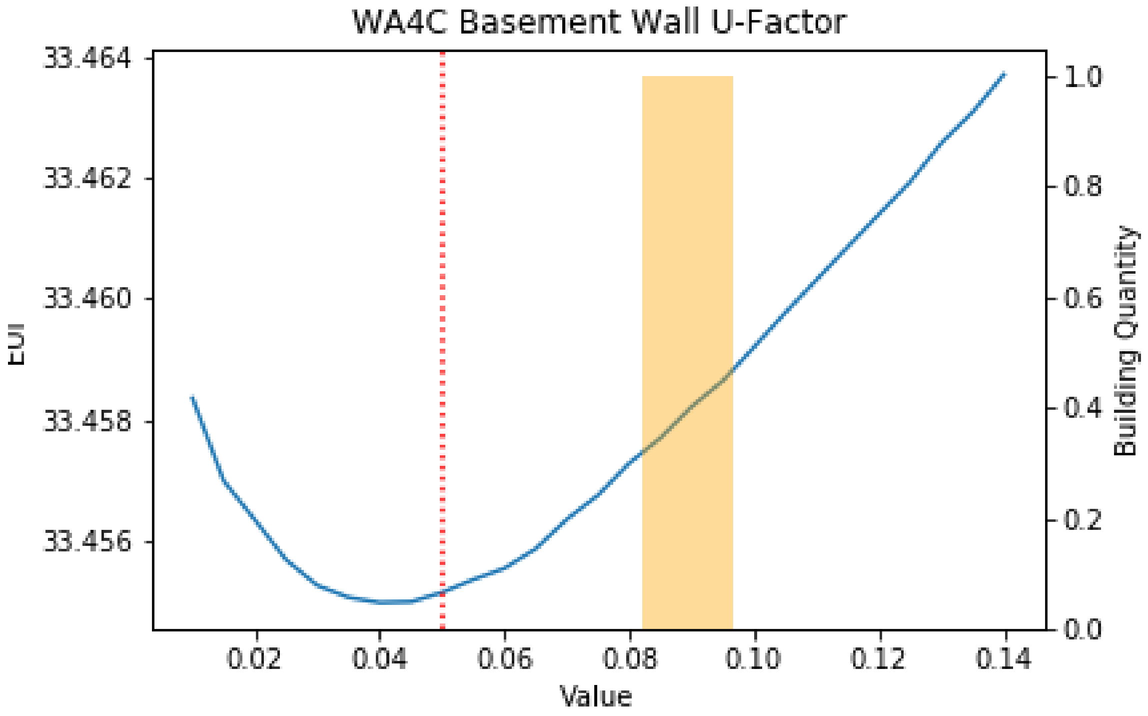


Figure 132. Washington 4C Basement Wall U-Factor

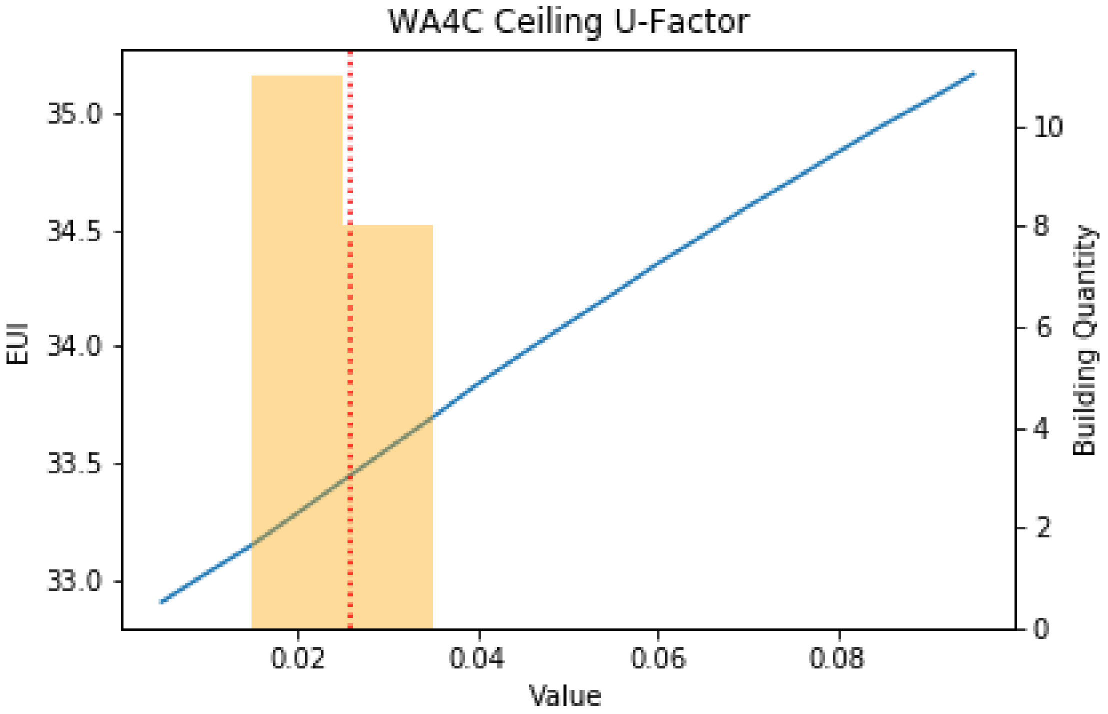


Figure 133. Washington 4C Ceiling U-Factor

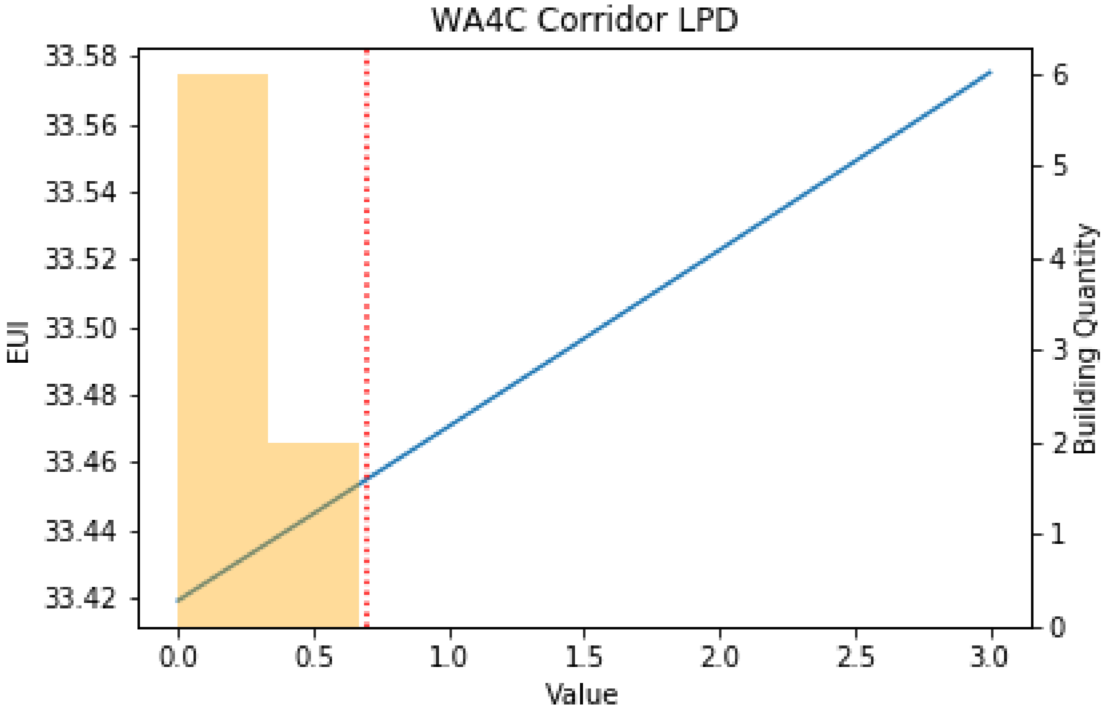


Figure 134. Washington 4C Corridor LPD

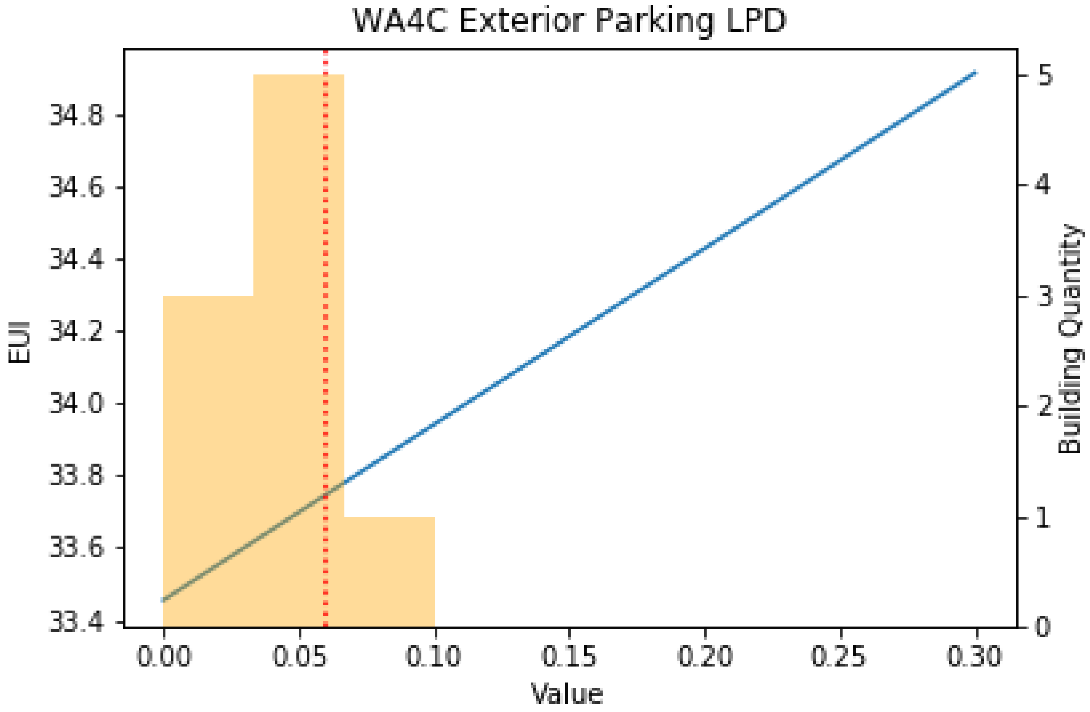


Figure 135. Washington 4C Exterior Parking LPD

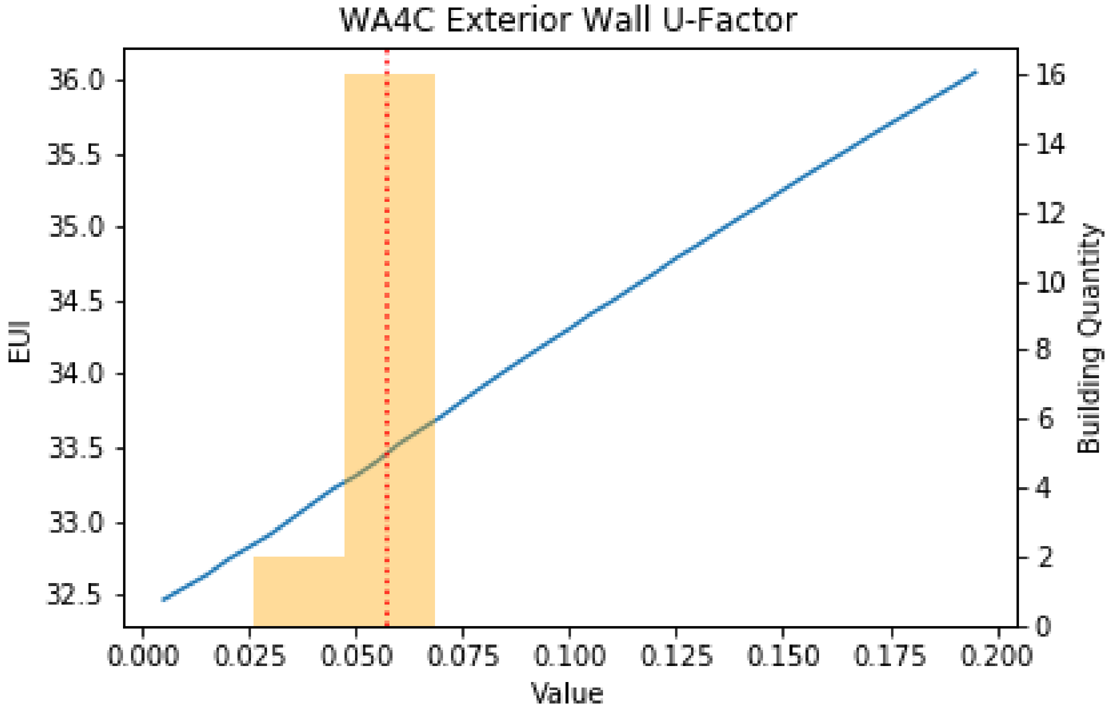


Figure 136. Washington 4C Exterior Wall U-Factor

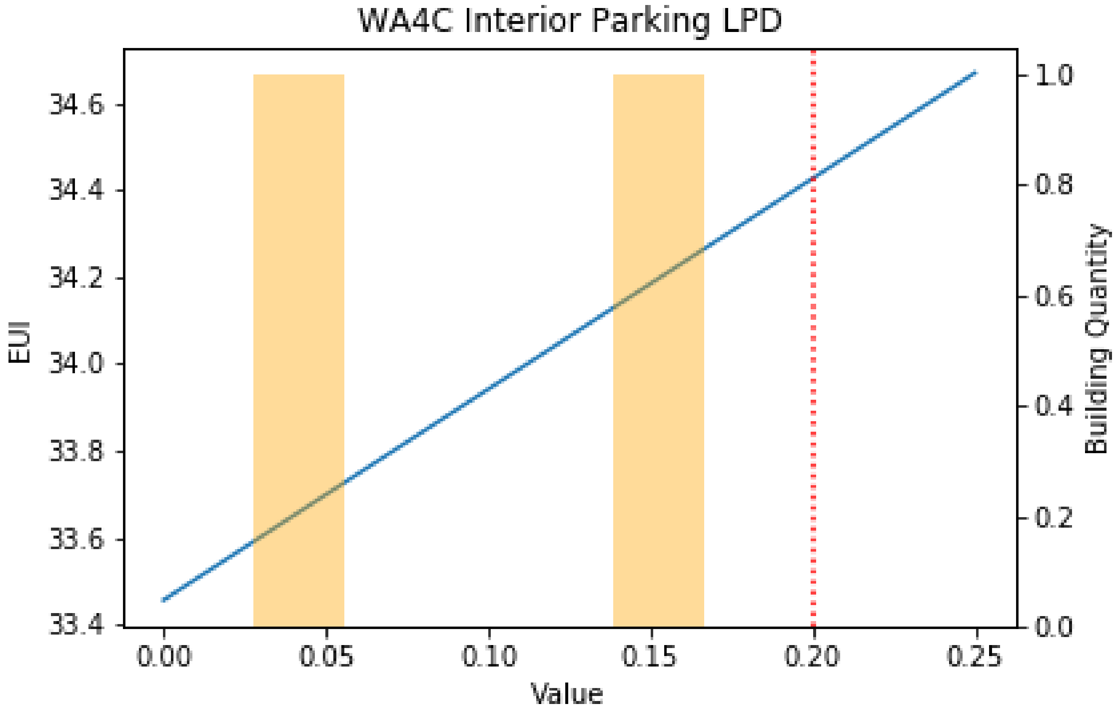


Figure 137. Washington 4C Interior Parking LPD

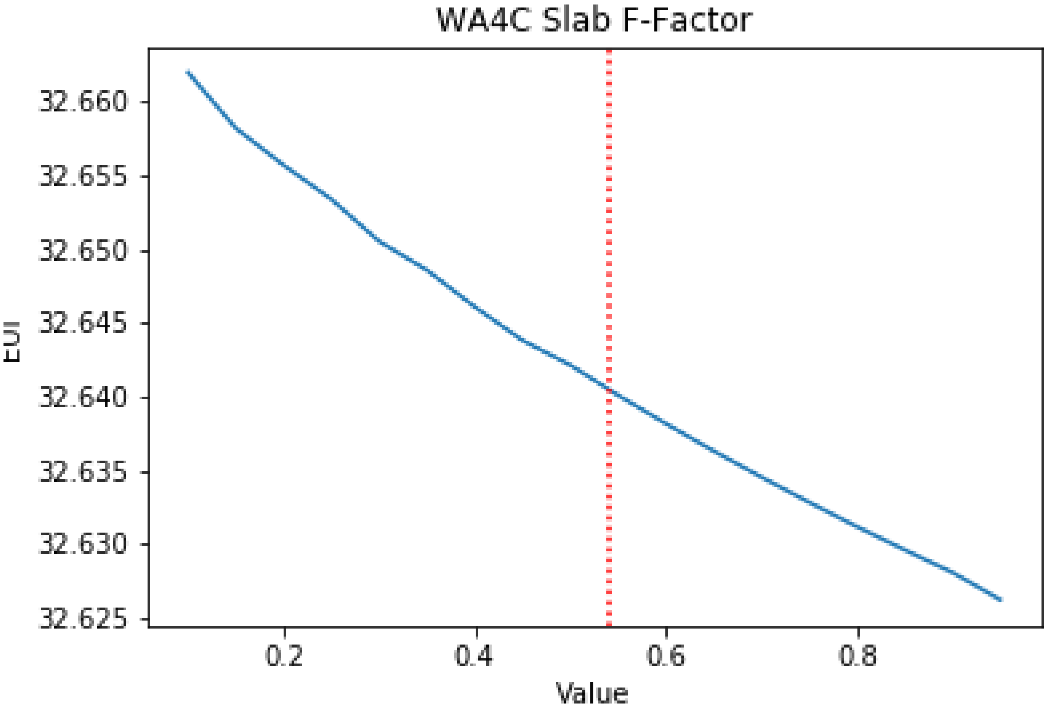


Figure 138. Washington 4C Slab F-Factor

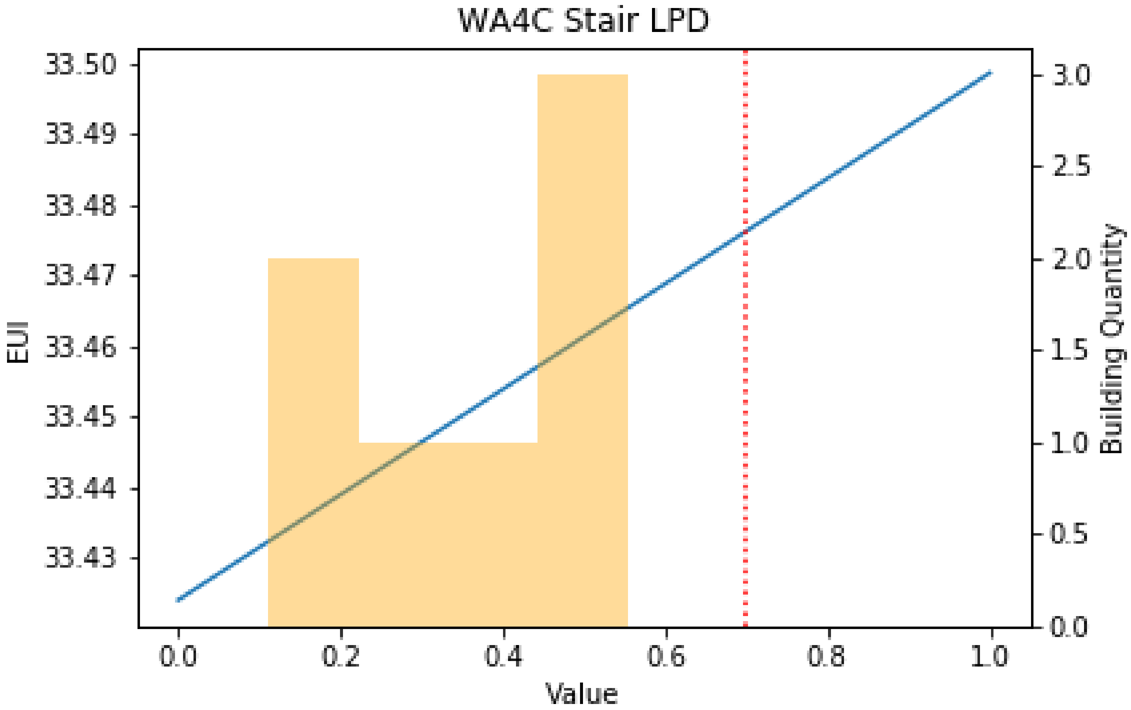


Figure 139. Washington 4C Stair LPD

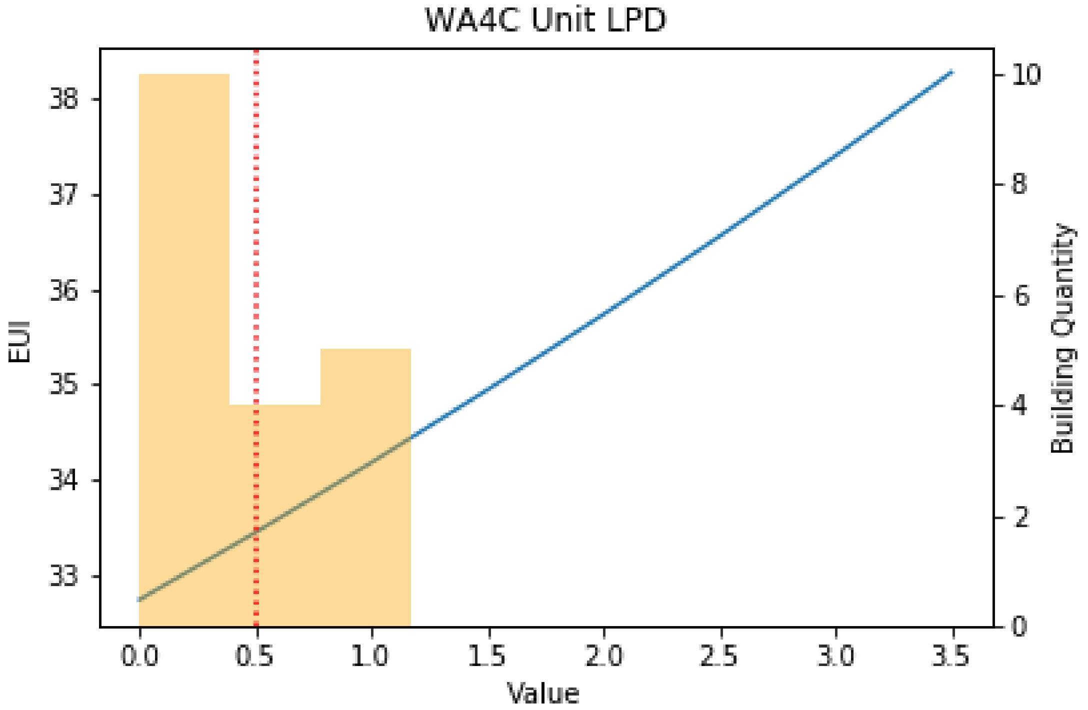


Figure 140. Washington 4C Unit LPD

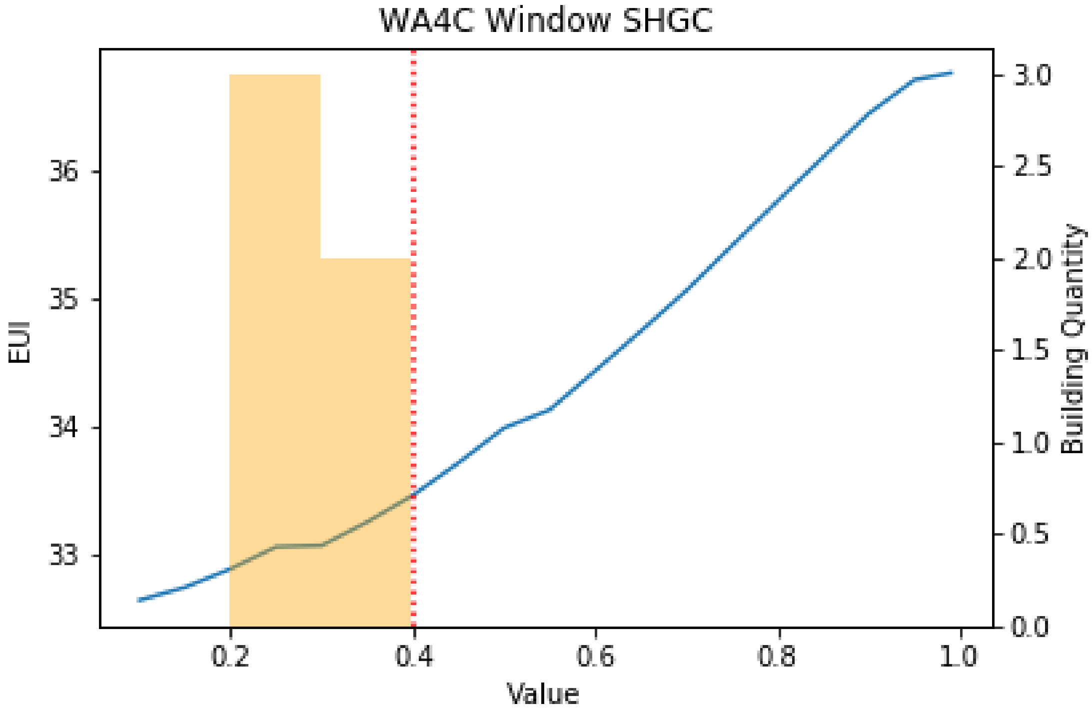


Figure 141. Washington 4C Window SHGC

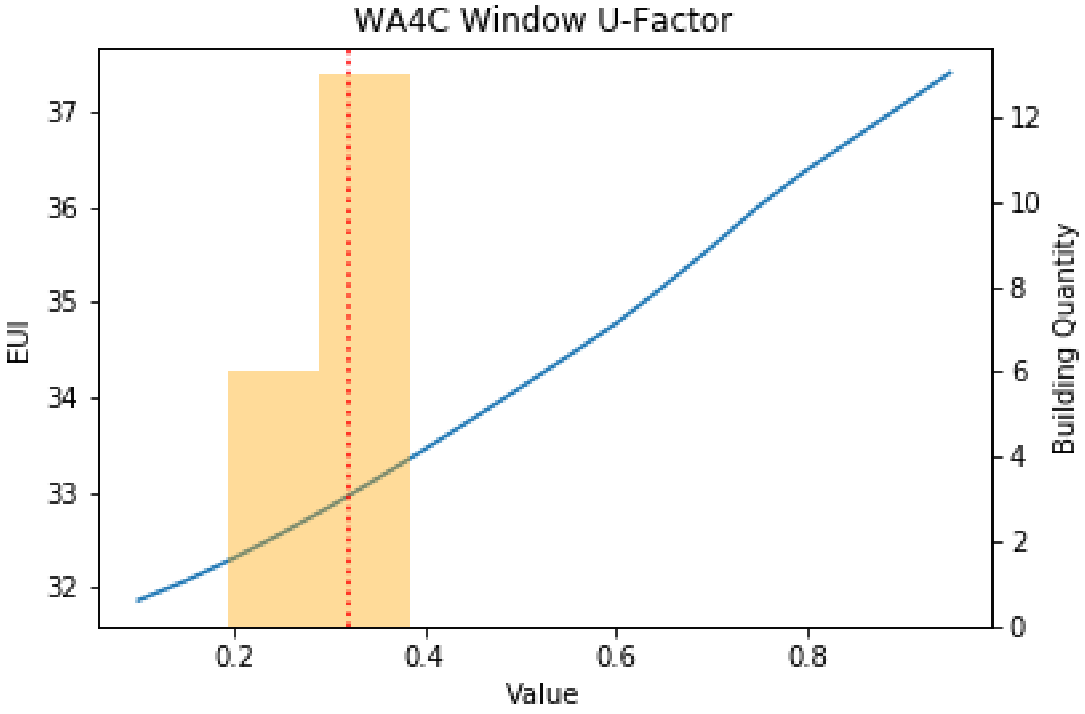


Figure 142. Washington 4C Window U-Factor

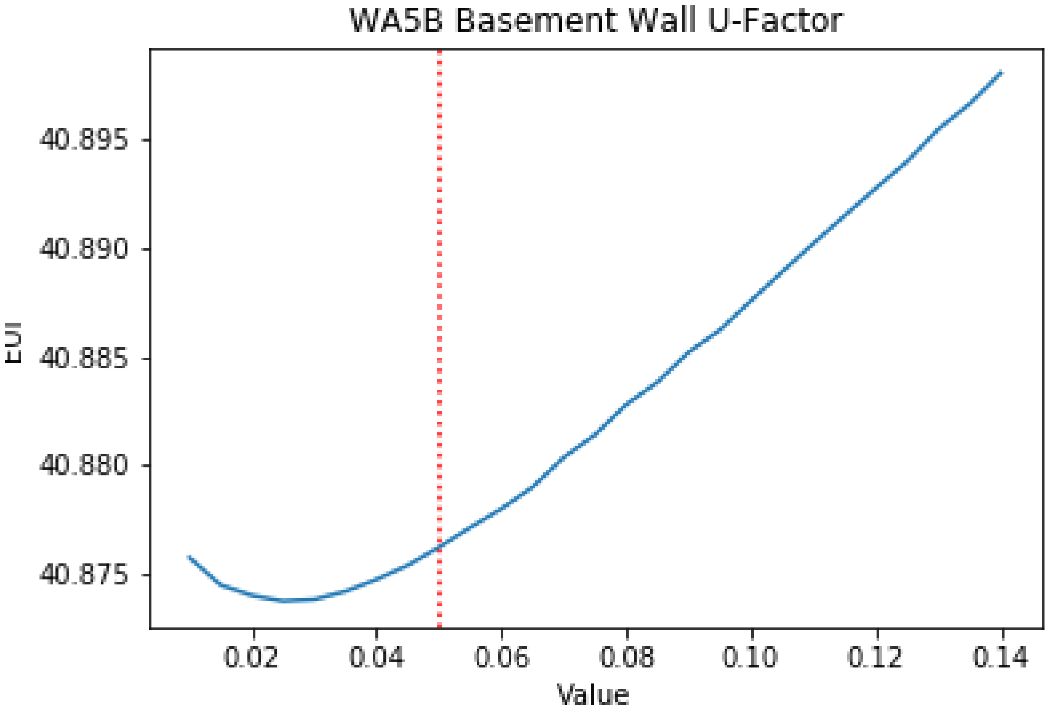


Figure 143. Washington 5B Basement Wall U-Factor

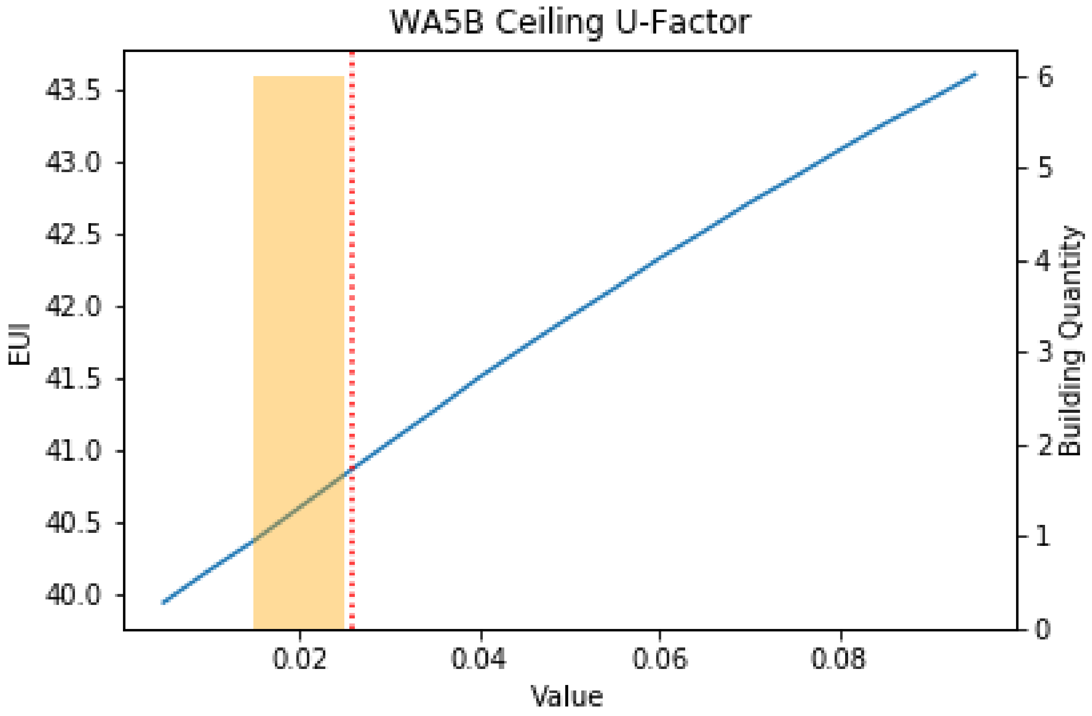


Figure 144. Washington 5B Ceiling U-Factor

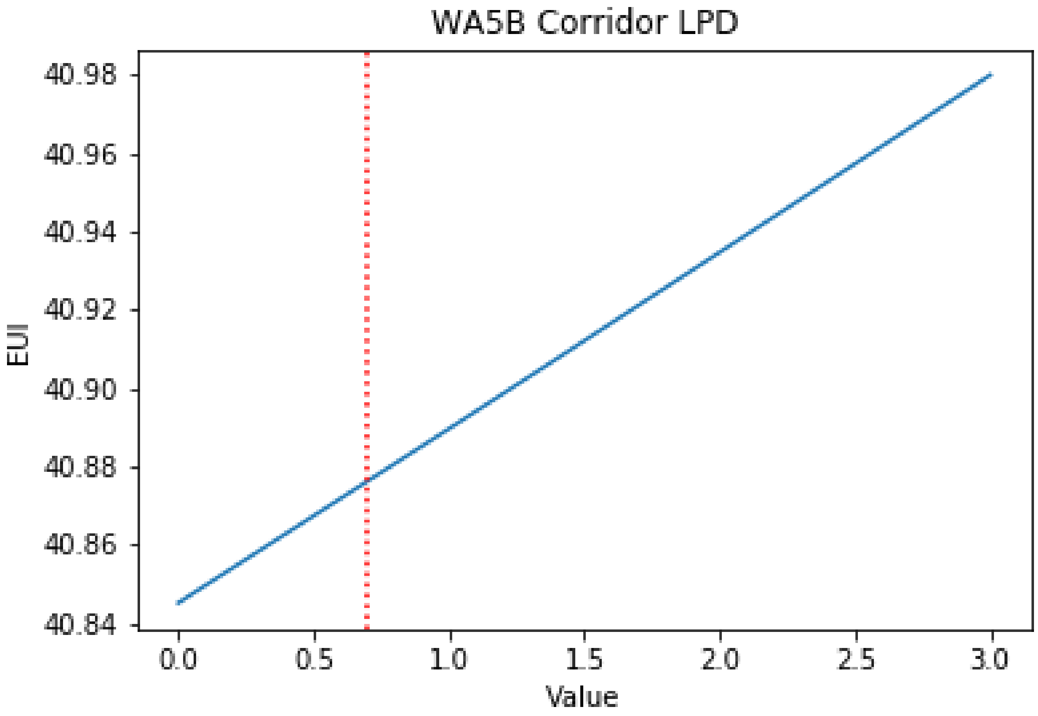


Figure 145. Washington 5B Corridor LPD

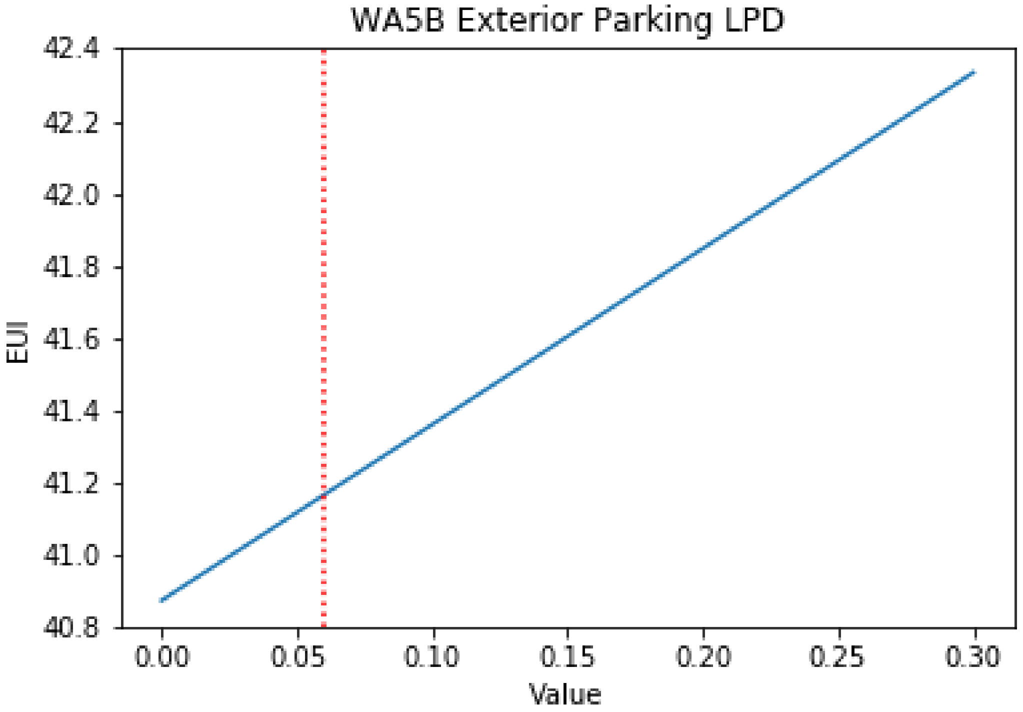


Figure 146. Washington Exterior Parking LPD

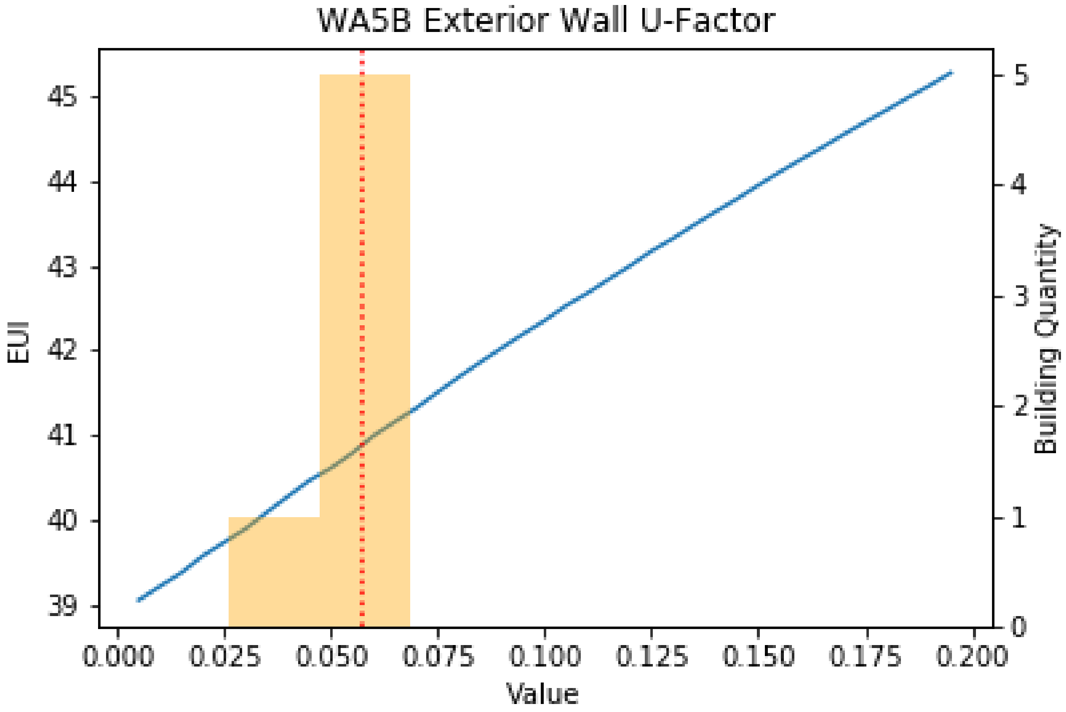


Figure 147. Washington 5B Exterior Wall U-Factor

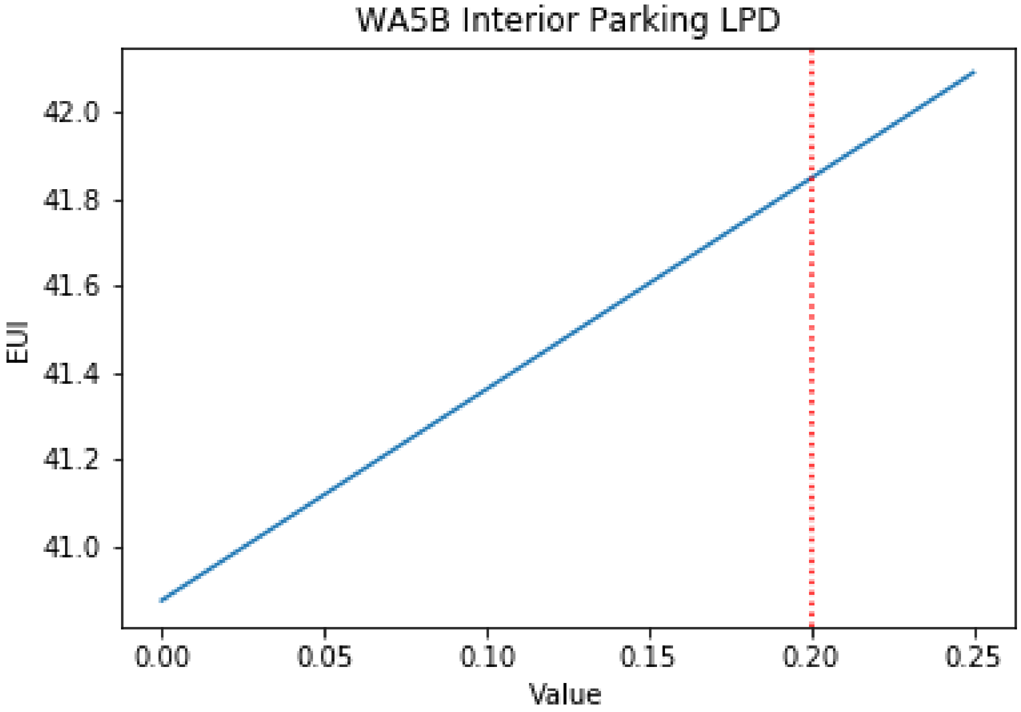


Figure 148. Washington 5B Interior Parking LPD

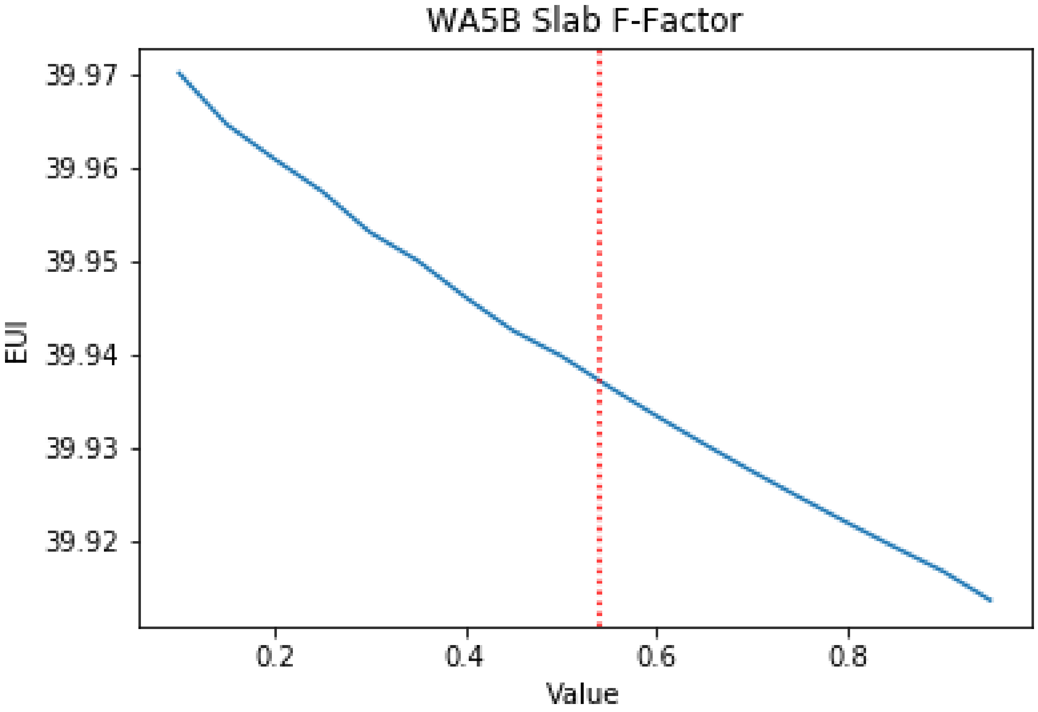


Figure 149. Washington 5B Slab F-Factor

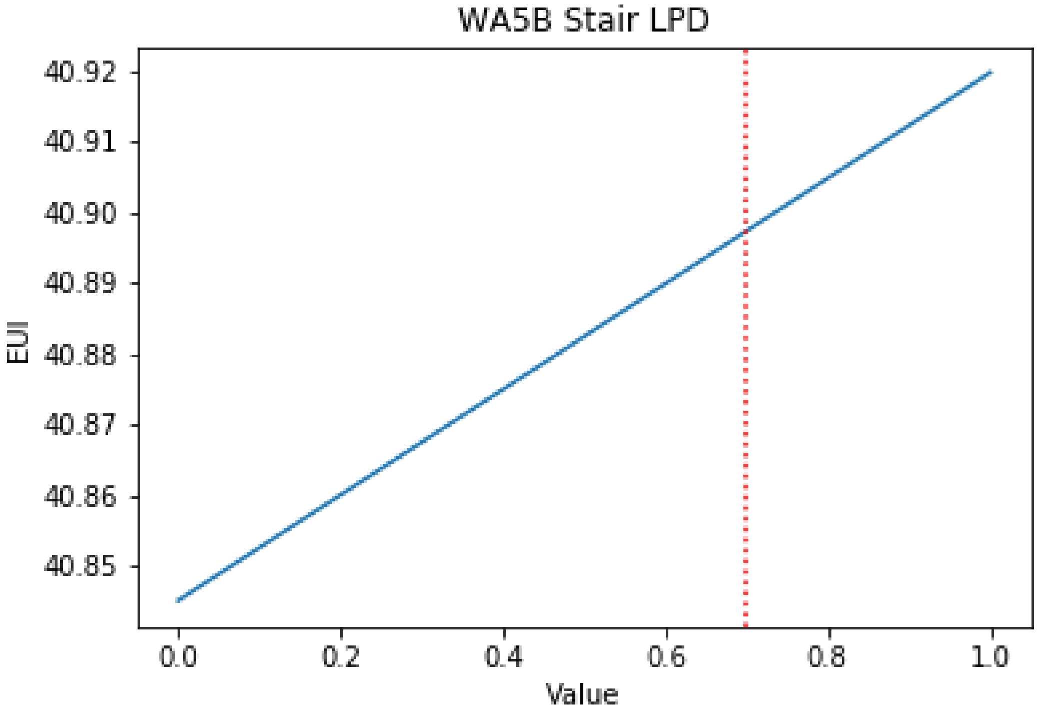


Figure 150. Washington 5B Stair LPD

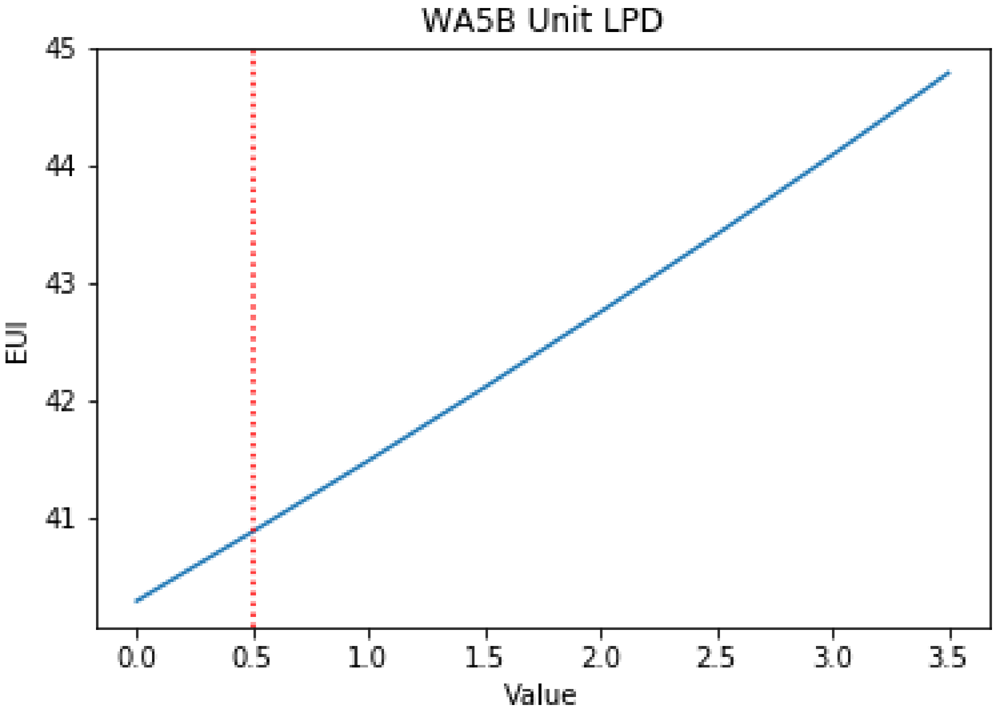


Figure 151. Washington 5B Unit LPD

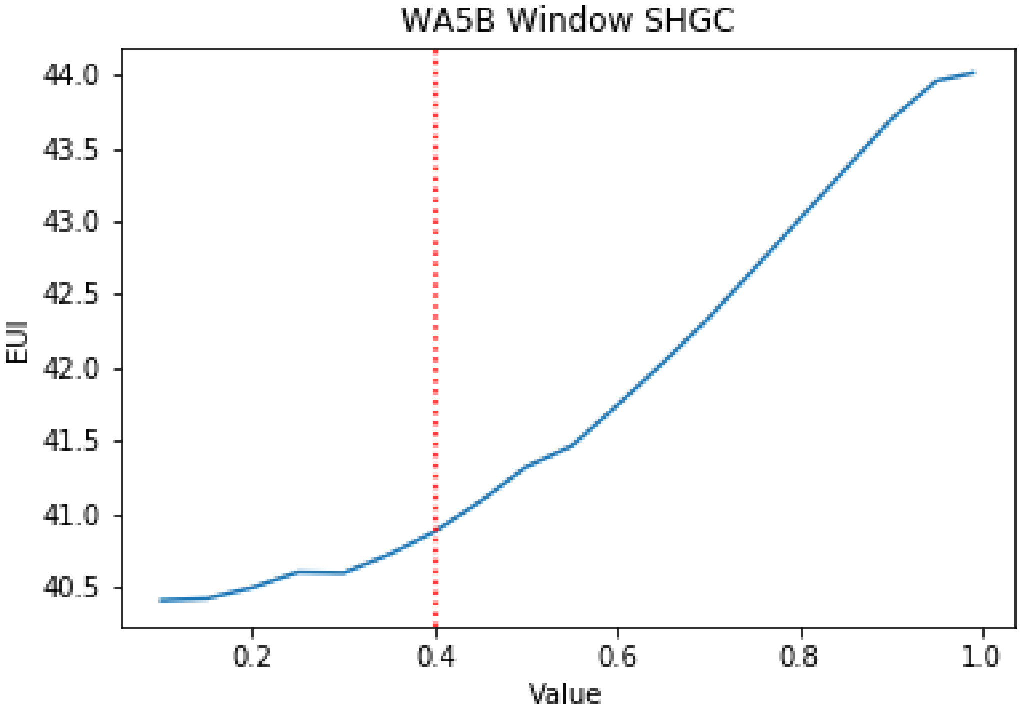


Figure 152. Washington 5B Window SHGC

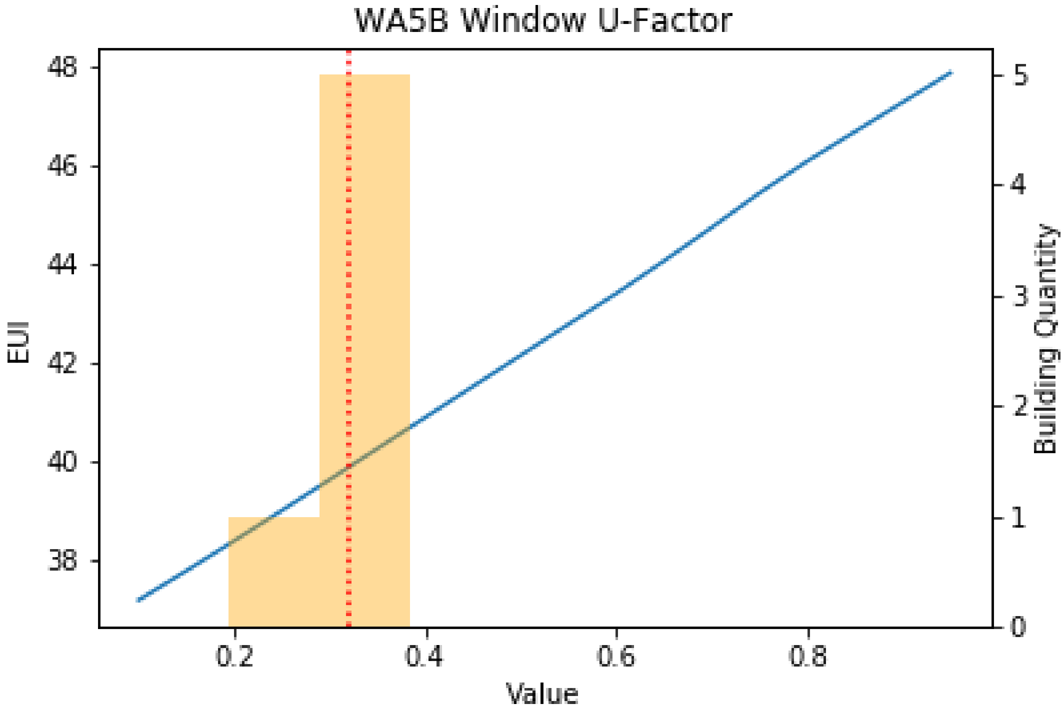


Figure 153. Washington 5B Window U-Factor

APPENDIX F – SAMPLE DESIGN MEMO (2018)

1. Introduction

The following memo describes the sample design for the Low-Rise Multifamily Baseline and Energy Study (Baseline Study) developed by Ecotope for the U.S. Department of Energy (DOE). The Baseline Study is a subset of a series of DOE low-rise multifamily studies, including market research and air tightness testing. The Baseline Study is designed to assess characteristics, compliance, and energy use in newly constructed low-rise multifamily buildings. This memo includes background information, study goals, sampling parameter development, and the sampling approach for the study. The low-rise multifamily Baseline Study builds from the Single-Family Residential Energy Code Field Study,[40] reusing decisions and methodologies where feasible, but also proposing new methods where the single-family methods are not applicable to the multifamily study.

The study aims to create a reliable, affordable, and practical methodology to measure the impact of multifamily energy codes, while also characterizing the new construction low-rise multifamily building stock. The analysis will attempt to identify energy and cost saving opportunities by building system type, which will help inform targeted training for code compliance and enforcement, development of new codes and above-code programs, and development of more accurate energy forecasts.

The multifamily data collection relies on a combination of plan review and a single onsite data collection visit, with identification of the source of each data point. Data will be collected from as-built plans and then data will be verified on-site as much as possible. The data collection tool will indicate whether a data point was verified on site. There are not enough buildings to allow partial data collection at a high number of buildings, so all data points will be collected on whole buildings that have been completed.

The study will collect building characteristics on a sample of new, low-rise multifamily buildings. Characteristics will be assembled into a new construction baseline dataset, including characteristics related to building configuration, occupancy, construction practice, lighting, HVAC, appliances, etc. These characteristics will be summarized directly and be assessed for code compliance related to key code measures. The energy impact of fully complying buildings versus as-built buildings will be assessed to identify the biggest opportunities for energy and cost savings. The results from these study findings will be used to inform the future implementation of standardized studies around the country.

The proposed sample design is a building-based sample of low-rise multifamily buildings (five or more units, one to three total floors). The study will target significance for compliance summaries at 90% or higher (meaning summaries such as percent of buildings complying with nominal insulation levels are expected to be significant if the mean is 90% or higher). Using these criteria, the target number of buildings for each of the four states is 22 buildings using calculations from Scheaffer (1986), though the sample will be increased to 25 buildings per state to get more characteristics and account for data attrition. Since the sampling is based on buildings, not all characteristics of interest will have enough

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[40] More information on all of the studies can be found on the Building Energy Codes Program website: https://www.energycodes.gov/compliance/energy-code-field-studies.

data for significance. Findings from these four states will inform the sample size calculations in future studies.

2. Target Population

The target building type is a new construction, low-rise (one-to-three story), R-2 apartment building (flats) containing five or more living units, designed for occupants who are primarily permanent in nature.[41] These buildings cannot have ground-to-roof walls unless the units are served with common mechanical systems. Mixed occupancy buildings are included in the study, where mixed occupancy is defined as a building containing both residential and non-residential spaces, with more than half of the floor area being dedicated to the residential occupancy type defined above. The primary data collection will be on the residential portion of the building. The non-residential spaces will be identified during the data collection effort, but no detailed data will be collected for the non-residential spaces.

Buildings excluded from the study include single-family detached, single-family attached (duplexes, triplexes, fourplexes, townhouses, and row-houses), R-1, R-3, and R-4 building types, as well as R-2 building types not specified in the previous paragraph; these R-2 exclusions include dormitories, residential hotels and motels, monasteries, nursing homes, assisted living facilities, and other classifications not typically defined as multifamily dwellings. Also, buildings four stories above grade or higher are not included in this study, even if the residential portion is three or less of those stories. Buildings four stories and greater are excluded because they fall into the commercial building code. The exclusions related to other residential uses, such as dormitories, hotels, etc., are due to the study focus on energy use in permanent dwellings.

The primary sampling unit in this Baseline Study is a building. The secondary sampling unit is the living unit within the building. For characteristics, a fixed number of units will be drawn from each building. These units will be used to characterize items such as permanently installed unit lighting, unit appliances, etc. These primary and secondary sampling units were selected due to critical differences between the single-family and low-rise multifamily populations. The single-family study (BECP 2015) is a measure-based sample, where buildings are recruited until each individual measure is observed the targeted number of times (63 times). Homes for the single-family study were observed at any stage of construction, so each home only had a limited number of items that could be observed, which meant the number of homes visited is much more than the target number of observations per measure. Unlike the single-family sample, the target population of low-rise multifamily buildings is small even in states where it appears viable to complete this study. Therefore, there will not be enough sites to sample 63 observations of each key item (which could require 2–4 times the number of buildings that can be recruited from the small sample frames). In addition, if observations of key code compliance items are used as the sampling unit, building characteristics cannot be generalized to the target population of buildings (meaning, the study will not deliver a reliable baseline dataset).

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[41] The Illinois amendment to the adopted IECC explicitly includes buildings up to 4 stories above grade in the residential code for municipalities have a population of 1,000,000 or more. This is clearly an amendment written for the City of Chicago. In that locality, we will include buildings up to 4 stories in our target population.

Like the single-family study, this low-rise multifamily study does not focus on a particular energy code, but rather collects data in the context of the code to which each building is built. Given the recruitment in 2018 of a three-year window of new construction buildings, most buildings in the pilot study will likely be built under the 2012 or 2015 residential codes, but some may have been permitted under the 2009 code or under the commercial code or under a local jurisdiction modified code.

Since energy codes are typically adopted at the state level, the pilot study is focused on defining the target population and sampling at the state level, and recommendations for future studies are based on state-level studies. For the pilot, independent studies will be conducted concurrently on four states: Illinois, Minnesota, Oregon, and Washington.

The source of the target population is the 2014–2016 Dodge data provided by the Pacific Northwest National Laboratory (PNNL).[42] Since PNNL is the source of the data and DOE has contracted PNNL to be a resource for these studies, it allows for any state in the future to use the same methods in this study to generate the target population for their own state. The three-year population of buildings mirrors the length of time of the single-family energy code field study target population.

Each record in the Dodge dataset represents a project and may include multiple buildings per record. The Dodge query provided to PNNL does not include the number of buildings field, but other Dodge exports used by the Ecotope team in the past do have this field, so we can use these older datasets to gauge how many low-rise multifamily buildings are typically found in these projects. The state sample calculation will use these mean values found in Table 108 to estimate the population of buildings by state in the PNNL Dodge data extract.

Table 108. Summary of Number of Buildings per Record (Using Dodge Data from Other Projects)

Dataset	Mean	Min	1Q	Median	3Q	Max	n
Minnesota (2015)	1.8	1	1	1	1	18	63
Oregon (2011–2016)	4.2	1	1	1	5	39	114
Washington (2011–2016)	2.6	1	1	1	2	19	272

For purposes of extrapolating the number of buildings and setting sample targets, the target population is defined to be the total number of low-rise multifamily new construction projects from the Dodge dataset built over a three-year period for each state.

Other data sources considered for the target population were from the Census, including the American Community Survey (ACS), the American Housing Survey (AHS), and the Building Permits Survey (BPS). The BPS is the data source for the single-family studies, but both the BPS and the ACS are of limited use for low-rise multifamily summaries because of the lack of designation between low-rise buildings (1–3 stories) and buildings with four or more stories; in these surveys the multifamily buildings with five or more units are summarized together and not split out by building height. The BPS will be used later in the memo as a check on the Dodge data conclusions and to inform the distribution of buildings. The AHS

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[42] Dodge Pipeline data, a product of Dodge Data & Analytics (www.construction.com)

allows for summaries specifically of low-rise multifamily buildings (1–3 stories with 5 or more units), but the AHS is only a survey of metro areas and cannot be summarized by state (only metro areas or nationally). The AHS metro data also often spans state lines, such as including Vancouver, WA, in the Portland AHS dataset, which is not consistent with the approach of the Baseline Study to be state-focused. The AHS will be used later in this memo to provide insight on the ratio of low-rise multifamily buildings to all multifamily buildings. The EIA Residential Energy Consumption Survey (RECS) provides low-rise multifamily estimates as well, but cannot be summarized by state, and when looking at new construction low-rise multifamily, RECS is limited by the total number of responses so only summaries at the region or national level provide any insights for building characteristics for this small subset of the sample.

Using the Dodge data from PNNL, the target population can be seen in Table 109 in the first two data columns. The last two columns of this table show the estimated number of buildings using the conversions calculated in Table 108. In the first data column are the counts used for generating the sample size.

Table 109. Three-Year Target Population Estimates by State

State	3-Year Population from Dodge (projects)	Estimated Number of Projects per Year	3-Year Building Estimate	Estimated Number of Buildings per Year
Illinois	102	34	184	61
Minnesota	163	54	293	98
Oregon	103	34	433	144
Washington	178	59	463	154

For comparison, Figure 154 shows a summary of the Building Permits Data of the average number of multifamily buildings built per year by state over the same period as the Dodge data; these include buildings of any number of stories (low, mid, and high rise all combined) that have five or more units. Comparing the information from Table 109 and Figure 154, roughly 25% of the multifamily buildings being built in Illinois and Washington are low-rise multifamily while roughly 60% of buildings in Oregon and Minnesota are low-rise multifamily.

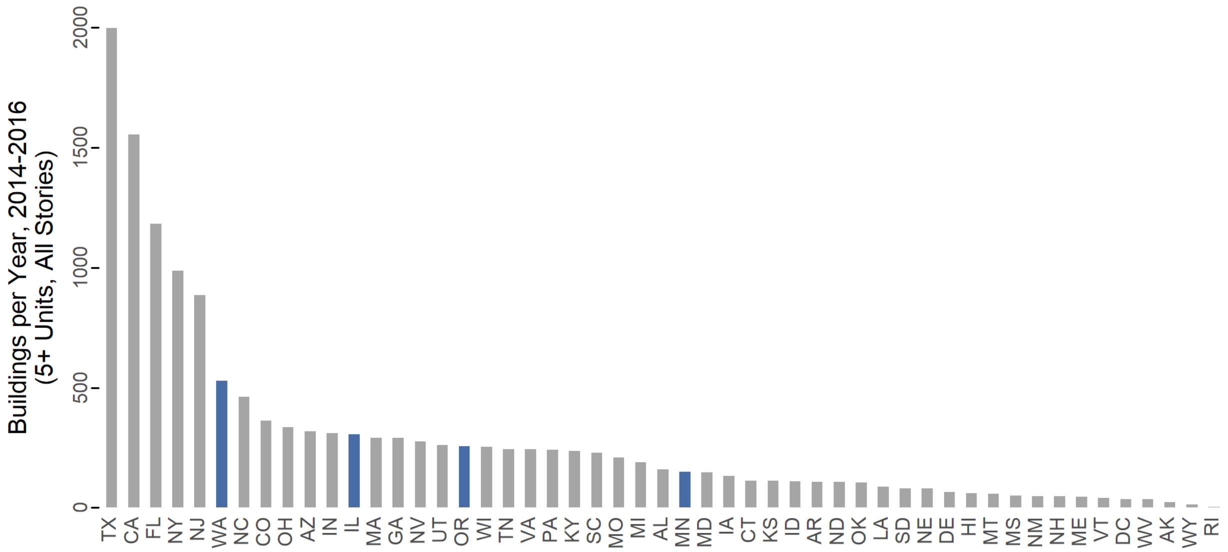

Figure 154. Multifamily Buildings Built Per Year by State (5+ Units, All Stories)

Figure 155 below shows the geographic distribution of low-rise multifamily buildings in the Dodge dataset. As expected, Illinois is heavily concentrated around Chicago, Minnesota is concentrated around Minneapolis, Oregon around Portland, and Washington around Seattle. Other than the Chicago area and a small cluster around Peoria, Illinois appears to only be sparsely populated with low-rise multifamily new construction. Minnesota has a heavy concentration along I-94, along with areas like Rochester to the south and Duluth to the north. In Oregon and Washington, the I-5 corridor on the west side of these states accounts for almost all the low-rise multifamily new construction; other areas include the greater Spokane area, the Tri-Cities of Washington, and the Bend, OR, area.

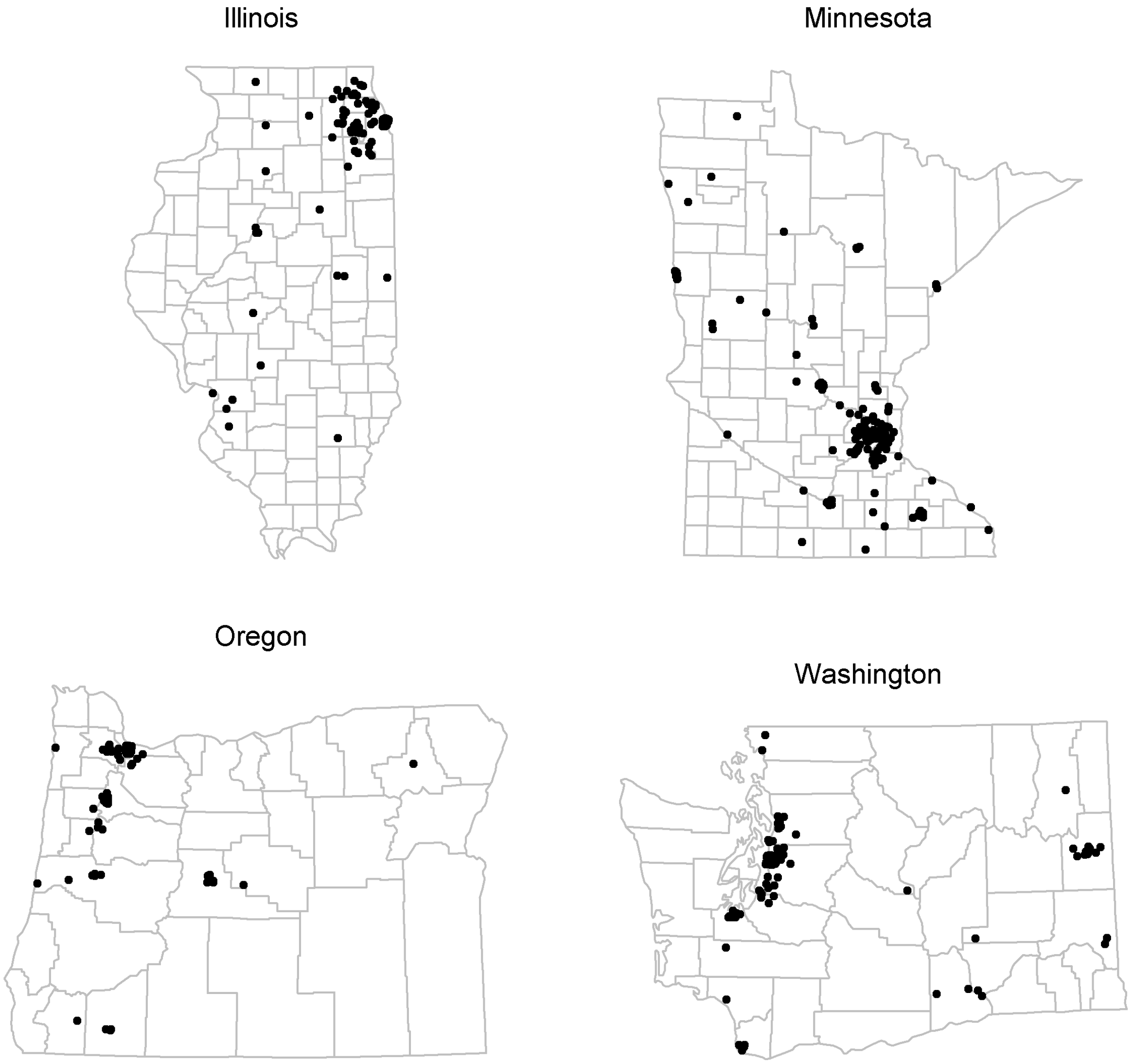

Figure 155. Distribution of Low-Rise Multifamily Buildings in 2016 Dodge Construction Dataset

3. Sample Frame

The sample frame differs from the target population in that the sample frame is the list of sites from which the study sample is drawn, whereas the target population is the total count of the population of interest. If we had a dataset with complete coverage of the population and included identifying information (such as address and contact phone numbers), then the target population is the number of records in the dataset and the dataset itself is the sample frame from which the random sample can be drawn.

For the Baseline Study, there are two proposed options for creating the sample frame. The first option is to use the Dodge data to identify jurisdictions from which the sample frame would be developed and the second option as a backup is to use the Dodge data for the sample frame itself (it is already being used for the target population).

The first option involves identifying jurisdictions from around the state that have low-rise multifamily new construction buildings and then contacting the jurisdictions to obtain contact information for these buildings. The second option involves requesting an expanded version of the Dodge data, which would include expanded information and contact information for the buildings to aide in screening the data and recruiting. Note, this second option requires funding to cover the cost of obtaining the additional data from Dodge. For this Baseline Study we will implement the first option as outlined above and discussed in more detail below.

3.1 Sampling Method

Sampling will be conducted using probability sample and will use a randomized assignment to set the recruiting priorities. This recruiting list, based on randomized assignment, will have more than the number of sites in the sample target to ensure that the representativeness of the characteristics will be preserved even with recruitment rates well below 100%.

Sampling will be based on a simple random sample by state with no stratification. Stratification based on common entry versus garden style apartments may be advisable in some states in future studies if one style is not dominant over the other style and if the key characteristics of interest vary based on the style of building. Low building populations make stratification difficult, so this stratification based on entry style likely will not be an option for most states.

While the sampling is based on a simple random sample within the state, the logistics of recruiting with small building populations means there are numerous jurisdictions in the sample frame that construct less than one new building per year. Recruiting from these jurisdictions can consume study resources without the expectation of even finding a building that meets the screening criteria. This study will utilize a similar screening criteria to the single-family study including in the sample frame only jurisdictions meeting both of the following: (1) the jurisdictions comprise an aggregated 90% of the state total population and (2) jurisdictions having at least three buildings built over the three-year period. For the single-family study this number was 20, but that cutoff is too high for the low-rise multifamily population. More information about the methods of generating the list of jurisdictions and target numbers can be found in section 0 below.

The statistical criteria for this pilot study is a 90/10 design, meaning we want 90% confidence of being within ±10% of the mean for the variables of interest. The sample sizes are calculated with a finite population correction (Cochran 1977).

4. Sample Size

4.1 Building Sample

The sample size for the study is based on the target population size, the statistical criteria, and *a priori* assumptions about the mean and variance of key variables of interest. Looking at sampling decisions in the context of many variables of interest, the mean and variance for each variable of interest are combined to create the coefficient of variation (CV), which is a unitless relative measure of variation of a parameter (CV is standard deviation divided by mean, or σ/μ). Higher CVs will require a larger sample to establish significance within the statistical criteria. Using CVs allows direct comparison of key variables, and the selection of a target CV will show which variables are expected to have significance in the final analysis.

The key items proposed for the low-rise multifamily field study pilot are provided in Table 110. The code references provided in the far-right column of Table 110 refer to the IECC, unless otherwise specified. Except for duct leakage, all the key characteristics from the single-family study are included in the low-rise multifamily study. These characteristics were selected for the single-family study due to potential energy impact. Duct leakage is not included in the low-rise study since ductwork, if present, is typically located within conditioned spaces in these buildings. The low-rise multifamily data collection protocol also includes several additional items that are directly relevant to low-rise multifamily buildings (see items with an asterisk in Table 110).

Table 110. Key Characteristics for Low-Rise Multifamily Study

Component	Data Collected	Code Reference†
Building		
Exterior wall insulation	R-value	Tables R402.1.2, R402.1.4
Ceiling insulation	R-value	Tables R402.1.2, R402.1.4
Foundation insulation	R-value	Tables R402.1.2, R402.1.4
Window	U-factor	Tables R402.1.2, R402.1.4
Window	SHGC	Tables R402.1.2, R402.1.4
Exterior lighting	Wattage	Section C405.5
Central HVAC*	Efficiency rating	Section C403, (referenced by IECC section R403.8)
Pipe insulation*	R-value	Section C403.2.10
Central DHW*	Efficiency rating	Section C403
Circulating system*	Pump controls	Section C404.6
Envelope tightness	Air changes per hour (ACH)	Section R404.4.1.2
Common Areas		
Lighting	Lighting power density	Section C405.4.2
Corridor ventilation*	Air flow (CFM/ft2)	Table 403.3 (IMC)
Units		
Lighting	Percent high efficacy	Section R404.1
Ventilation	Flow rating	Section M1507 (IRC), (referenced by IECC section R403.6)
Envelope tightness	Air changes per hour (ACH)	Section R404.4.1.2

† - IECC reference. Individual state energy code references vary.
* Additional items added for low-rise multifamily study not included in single-family study

An extensive list of key variables and CVs will not be used to determine sample sizes because the population of interest is buildings and not individual components. There are items that will not be found in all buildings, and the small populations of buildings means there may not be significance in each key compliance item and each variable of interest. For example, if a state has a high proportion of garden-style apartments with unit HVAC and unit DHW systems, then there will likely not be enough information to draw conclusions about compliance with central systems in that state.

The following table shows a summary of CVs from a few characteristics that are found on all buildings. These come from the 2009 RECS data, filtered for low-rise multifamily (1–3 stories, 5 or more units) built between 2000 and 2009. The RECS sample is small with this restriction (179 total units), so only a national summary is shown in the Table 111 below. Some of these variables are continuous variables (displayed as CVs), and some of the variables are binary variables (displayed as percent of population). These sampling parameters can be used for reference when looking at sample size calculations in the next part of this section. As noted above, these values are based on a national sample of new construction low-rise multifamily, so parameters correlated with geography/climate will likely have lower CVs in state-based populations compared to the national summary. In addition, the RECS summary includes ten years of construction compared to the three years of construction in this low-rise multifamily study, so this may reduce the CVs as well. Table 111 also contains summaries from a new construction multifamily study from RLW, which contained 200 multifamily units at 100 buildings built between 2003 and 2006 in the Northwest. The RLW study had a broader definition of multifamily buildings than the current DOE study but results should still be generally informative.

Table 111. Sampling Parameters of a Few Key Variables

Variable	Sampling Parameter
Source: RECS	
DHW in-unit	86.4%
DHW electricity	71.3%
Lighting high-efficacy	1.12 CV
Lighting total lamps turned on at least one hour per day	1.01 CV
Number of major appliances per unit	0.33 CV
Unit floor area	0.58 CV
Units in building	1.55 CV
Unit EUI (kBtu/sqft)	0.88 CV
Has warm air furnace (not including heat pump)	77.1%
Has heat pump	14.9%
Source: RLW	
Hardwired LPD	0.66 CV
Overall LPD	0.67 CV
Number of Fixtures	1.06 CV
Number of Lamps	0.86 CV

Binary variables and continuous variables were both explored for the sample size calculation of this pilot study. All binary variables (i.e., true/false) provide significance even at the worst-case scenario (50/50) for all sample frames with continuous variables with a CV greater than 0.5. This is significant because the national average of variables like average CV for unit floor area, per RECS data, is 0.58, and the national CV for number of units in the building is 1.55. Since these continuous variables have a CV greater than 0.5, if we choose a CV threshold to include these continuous variables then the binary variables would also be expected to have significance. Table 112 shows the sample sizes needed for various continuous CVs by state using the finite population correction, while Table 113 shows the sample sizes needed for binary variables.

Table 112. Continuous Variable Sample Size Calculations (90/10) for Pilot Study by State

Expected CV	IL	MN	OR	WA	Pilot Study Total
0.1	3	3	3	3	12
0.2	10	11	10	11	42
0.3	20	22	20	22	84
0.4	31	35	31	35	132
0.5	41	48	41	50	180
0.6	50	61	51	63	225
0.7	58	74	58	76	266
0.8	65	84	65	88	302
0.9	70	94	71	99	334
1.0	75	102	75	108	360
1.1	78	109	79	116	382
1.2	81	115	82	123	401
1.3	84	121	85	129	419
1.4	86	125	87	134	432
1.5	88	129	89	138	444
Total Population	*102*	*163*	*103*	*178*	*546*

Table 113. Binary Variable Sample Size Calculations (90/10) for Pilot Study by State

Expected Value	IL	MN	OR	WA	Pilot Study Total
95%/5%	12	12	12	12	48
90%/10%	20	22	20	22	84
85%/15%	26	29	26	29	110
80%/20%	31	35	31	35	132
75%/25%	34	39	34	40	147
70%/30%	37	43	37	44	161
65%/35%	39	45	39	46	169
60%/40%	40	47	40	48	175
55%/45%	41	48	41	49	179
50%/50%	41	48	41	50	180
Total Population	*102*	*163*	*103*	*178*	*546*

Total Population	***102***	***163***	***103***	***178***	***546***

4.2 Unit Sample

The secondary sampling unit is dwelling units within the buildings; collecting data on every unit within a building would be uneconomical and the expectation is units within a given building are similar to each other, so the study will sample the dwelling units rather than looking at all of them within a building. This is a two-stage design, with the primary sampling unit being buildings and the secondary sampling units being units. Units will be selected based on a simple random sample within each building. This two-stage design to summarize unit characteristics will have less precision than a simple random sample of a one-stage unit sample with the same number of units, but the two-stage design is likely more precise than a simple random sample within the same overall budget (randomly sampling from all units in a population would mean going into a lot more buildings to get individual unit characteristics).

Within the two-stage design, the number of units sampled per building will be a fixed quantity. This assumes most of the buildings will have about the same number of units, which is an assumption used to minimize the complexity of needing to use a multi-stage unequal sample design; such a design would require on-the-fly calculations of the number of units to sample in each building. The assumption of equal number of units may not be too much of a stretch in some areas given the minimum restriction of five units, the omission of row-houses and townhouses, and the maximum restriction of three stories. Most buildings will have two or three stories and likely have around 15 to 20 units. The guidance for this two-stage sampling with units of equal size is Cochran (1977), and the two-stage design is also discussed in Khawaja (2013). While the assumption of equal number of units is used here in the sample design, the analysis at the end of the study will use the total number of units found per building as a weighting parameter.

The number of units required per building will be built from calculations assuming a simple random sample of all units and then distributing those units equally among the buildings. This calculation does not account for the two-stage design but does provide a straightforward method for calculating the units per building. Given the precision in the two-stage design is likely less than the simple random sample of all units, the result from the simple unit calculation will be rounded up per building, giving a higher total than expected with the calculation alone.

Using the hardwired LPD information from Table 111, the CV is 0.66, and if we use our 90/10 statistical criteria, then the total number of units to sample is 118. There is no finite population correction with this value because the population of units is large. The 118 units will be spread evenly among the buildings, which are 25 buildings per state, so 4.7 units should be sample per building, or 5 units per building after rounding up. This rounding up per building increases the total number of units to 125 instead of the original 118.

5. Sampling Process

The sampling frame development and sampling process (recruiting approach) will attempt to follows closely with the single-family methodology, Each of the building departments that show up in the proportionate sample will be contacted by the field staff and the field staff will develop randomized recruiting lists and then recruit the target number of buildings from the jurisdiction lists. For complexes that include multiple buildings, each building will be included and randomized in the final recruiting lists in order to ensure that each building has an equal probability of selection. In this case, multiple buildings from the same complex may be recruited and surveyed for the study.

In sampling the units of the building, units will be randomly selected by the field technician and cannot be the manager’s unit. Ideally the units will be unoccupied, which will make access and data collection easier and take less time.

The strategy for this pilot study could differ from the recommended study design to be implemented by states following from this study. Budgetary considerations related to a higher analysis budget and primary research into air tightness testing has limited the number of sites to be visited in this pilot study. The current working assumption for the full study implementation is to target a CV of 0.4 and binary of 80% or higher, meaning 30 to 35 buildings per state, though this recommendation will be modified at the conclusion of the Baseline Study. For Baseline Study, a target of significance for binary variables of 90% or greater is the target, meaning the target number of buildings for each of the four states is 22 buildings, which has been rounded up to 25.

6. Final Sample Targets

The final targets can be found in the second column from right of Table 114 through Table 117 below. The statewide sample size is calculated from the Dodge population and then distributed by using the latest three-year window of BPS data. BPS data is adjusted to account for only low-rise multifamily buildings by using results from the American Housing Survey (AHS) data for the main city within each state (Chicago, Minneapolis, Portland, and Seattle for IL, MN, OR, and WA, respectively). The AHS allows for summaries in the primary cities separate from summaries in the suburbs of primary cities, but does not extend to the whole state. Ratios of low-rise multifamily buildings are calculated for the main city, for the suburbs, and then assumed to be almost exclusively (95%) low-rise multifamily in the more rural places. An equation is created from these data to scale the low-rise multifamily ratio by number of buildings in the BPS survey (the jurisdictions with the most buildings have the lowest low-rise multifamily ratio because those are the cities with mid-rise and high-rise buildings as well, whereas rural areas will likely only build low-rise and no mid-rise or high-rise). Chicago’s low-rise multifamily building percent is only around 25% of multifamily buildings whereas the other three cities are between 50% and 60%.

Table 114. Final Targets for Illinois

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1		Target Count	Target Saturation
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation		
Chicago	Cook	IL	34	36%	405	44%	484	48%	7	28%
Morris	Grundy	IL	0	0%	62	7%	61	6%	2	8%
Champaign	Champaign	IL	1	1%	68	7%	41	4%	2	8%
East St Louis	St. Clair	IL	0	0%	45	5%	29	3%	1	4%
Naperville	Will	IL	2	2%	14	2%	29	3%	1	4%
St Charles	Kane	IL	3	3%	0	0%	25	2%	1	4%
Springfield	Sangamon	IL	0	0%	13	1%	24	2%	1	4%
Schaumburg	Cook	IL	0	0%	21	2%	22	2%	1	4%
Normal	Mclean	IL	0	0%	12	1%	17	2%	1	4%
North Aurora	Kane	IL	0	0%	20	2%	16	2%	1	4%
Lake Forest	Lake	IL	0	0%	3	0%	15	1%	1	4%
Collinsville	Madison	IL	1	1%	12	1%	14	1%	1	4%
Wheeling	Cook	IL	2	2%	15	2%	13	1%	1	4%
Channahon	Will	IL	1	1%	4	0%	13	1%	1	4%
Itasca	Dupage	IL	0	0%	0	0%	12	1%	1	4%
Highland Park	Lake	IL	0	0%	0	0%	11	1%	1	4%
Gilberts	Kane	IL	0	0%	10	1%	10	1%	1	4%

Table 115. Final Targets for Minnesota

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1		Target Count	Target Saturation
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation		
Minneapolis	Hennepin	MN	7	4%	51	11%	63	14%	3	12%
Rochester	Olmsted	MN	16	10%	49	11%	53	12%	3	12%
Mankato	Blue Earth	MN	22	13%	40	9%	35	8%	2	8%
Bemidji	Beltrami	MN	3	2%	23	5%	31	7%	2	8%
Moorhead	Clay	MN	11	7%	29	6%	25	6%	2	8%
Edina	Hennepin	MN	1	1%	17	4%	24	5%	2	8%
St Paul	Ramsey	MN	7	4%	23	5%	22	5%	2	8%
Applevalley	Dakota	MN	4	2%	16	4%	19	4%	1	4%
Grand Rapids	Itasca	MN	3	2%	14	3%	19	4%	1	4%
Lakeville	Dakota	MN	3	2%	12	3%	17	4%	1	4%
Fergus Falls	Otter Tail	MN	4	2%	6	1%	11	2%	1	4%
Minnetonka	Hennepin	MN	1	1%	5	1%	9	2%	1	4%
Chaska	Carver	MN	2	1%	9	2%	8	2%	1	4%
Hopkins	Hennepin	MN	0	0%	0	0%	8	2%	1	4%
Orr	St. Louis	MN	0	0%	9	2%	6	1%	1	4%
Blaine	Anoka	MN	2	1%	6	1%	6	1%	1	4%

Table 116. Final Targets for Oregon

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1		Target Count	Target Saturation
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation		
Portland	Multnomah	OR	114	54%	226	29%	281	36%	7	27%
Salem	Marion	OR	51	24%	54	7%	99	13%	3	12%
Hillsboro	Washington	OR	7	3%	49	6%	55	7%	2	8%
Clackamas County Unincorporated Area	Clackamas	OR	0	0%	71	9%	50	6%	2	8%
Washington County Unincorporated Area	Washington	OR	0	0%	62	8%	45	6%	2	8%
Bend	Deschutes	OR	8	4%	38	5%	39	5%	1	4%
Eugene	Lane	OR	6	3%	60	8%	25	3%	1	4%
Beaverton	Washington	OR	2	1%	21	3%	23	3%	1	4%
Tigard	Washington	OR	1	0%	18	2%	21	3%	1	4%
Medford	Jackson	OR	2	1%	32	4%	16	2%	1	4%
Forest Grove	Washington	OR	2	1%	5	1%	13	2%	1	4%
Happy Valley	Clackamas	OR	0	0%	10	1%	12	2%	1	4%
Lake Oswego	Clackamas	OR	0	0%	2	0%	12	2%	1	4%
Oregon	Clackamas	OR	1	0%	0	0%	11	1%	1	4%
Fairview	Multnomah	OR	0	0%	0	0%	11	1%	1	4%

Table 117. Final Targets for Washington

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1		Target Count	Target Saturation
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation		
Seattle	King	WA	106	56%	369	23%	434	25%	5	20%
Vancouver	Clark	WA	5	3%	97	6%	97	6%	2	8%
Pierce County Unincorporated Area	Pierce	WA	0	0%	51	3%	96	6%	2	8%
Snohomish County Unincorporated Area	Snohomish	WA	0	0%	81	5%	73	4%	1	4%
Spokane	Spokane	WA	14	7%	55	3%	63	4%	1	4%
Spokane County Unincorporated Area	Spokane	WA	0	0%	59	4%	53	3%	1	4%
Spokane Valley	Spokane	WA	2	1%	31	2%	53	3%	1	4%
Bellingham	Whatcom	WA	1	1%	56	4%	52	3%	1	4%
Tacoma	Pierce	WA	5	3%	51	3%	43	2%	1	4%
Clark County Unincorporated Area	Clark	WA	0	0%	45	3%	42	2%	1	4%
Bothell	King	WA	2	1%	32	2%	33	2%	1	4%
Lacey	Thurston	WA	3	2%	26	2%	33	2%	1	4%
Pullman	Whitman	WA	2	1%	32	2%	32	2%	1	4%
Bellevue	King	WA	8	4%	26	2%	29	2%	1	4%
Edgewood	Pierce	WA	0	0%	25	2%	28	2%	1	4%
Moses Lake	Grant	WA	0	0%	23	1%	27	2%	1	4%
Everett	Snohomish	WA	5	3%	20	1%	26	2%	1	4%
Battleground	Clark	WA	0	0%	24	2%	25	1%	1	4%
Liberty Lake	Spokane	WA	0	0%	14	1%	25	1%	1	4%

7. References

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8. Sample Targets

The following are population counts by place name for each of the four states. Place names are from the Building Permits Survey from the U.S. Census and are used in this study and in the single-family study as jurisdiction names for recruiting purposes. There are three datasets summarized in the tables below: Dodge 2014–2016, BPS 2014–2016, and BPS 2015q2–2018q1. Within each of the datasets are two columns, count and saturation, which is simply the percent of count within the state and gives the ability to compare prevalence of multifamily buildings across the three datasets.

The Dodge dataset is a summary of low-rise multifamily buildings and is the primary data source for the sample calculations. The BPS 2014–2016 dataset includes a count of all multifamily buildings (including mid-rise and high-rise) and is provided as a reality check on the Dodge dataset from the same timeframe. The BPS 2015q2–2018q1 dataset is a summary of the BPS data for the recruiting period of the project (second quarter 2015 to first quarter 2018) and is provided as a check to see if there have been any major shifts in building construction trends within a jurisdiction after the Dodge data timeframe.

Table 118. Illinois population counts

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1	
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation
Chicago	Cook	IL	34	36%	405	44%	484	48%
Joliet	Will	IL	4	4%	4	0%	4	0%
Glenview	Cook	IL	4	4%	3	0%	1	0%
Peoria	Peoria	IL	4	4%	0	0%	0	0%
St Charles	Kane	IL	3	3%	0	0%	25	2%
Naperville	Will	IL	2	2%	14	2%	29	3%
Wheeling	Cook	IL	2	2%	15	2%	13	1%
Park Ridge	Cook	IL	2	2%	2	0%	5	0%
Champaign	Champaign	IL	1	1%	68	7%	41	4%
Collinsville	Madison	IL	1	1%	12	1%	14	1%
Channahon	Will	IL	1	1%	4	0%	13	1%
Deer Park	Lake	IL	1	1%	9	1%	9	1%
Morton Grove	Cook	IL	1	1%	5	1%	5	0%
Huntley	Mchenry	IL	1	1%	4	0%	5	0%
Grayslake	Lake	IL	1	1%	0	0%	5	0%
Sugar Grove	Kane	IL	1	1%	4	0%	3	0%
Rolling Meadows	Cook	IL	1	1%	2	0%	3	0%
Lombard	Dupage	IL	1	1%	1	0%	3	0%
Orland Park	Cook	IL	1	1%	4	0%	2	0%
Elgin	Cook	IL	1	1%	3	0%	2	0%
Lake Zurich	Lake	IL	1	1%	0	0%	2	0%
Algonquin	Mchenry	IL	1	1%	1	0%	1	0%
Libertyville	Lake	IL	1	1%	1	0%	1	0%
Edwardsville	Madison	IL	1	1%	6	1%	0	0%
Crystal Lake	Mchenry	IL	1	1%	5	1%	0	0%
Streamwood	Cook	IL	1	1%	1	0%	0	0%
Westmont	Dupage	IL	1	1%	1	0%	0	0%
Belleville	St Clair	IL	1	1%	0	0%	0	0%
Bolingbrook	Will	IL	1	1%	0	0%	0	0%
Burr Ridge	Cook	IL	1	1%	0	0%	0	0%
Cary	Mchenry	IL	1	1%	0	0%	0	0%
Danville	Vermilion	IL	1	1%	0	0%	0	0%
Dixon	Lee	IL	1	1%	0	0%	0	0%
Downers Grove	Dupage	IL	1	1%	0	0%	0	0%
Frankfort	Will	IL	1	1%	0	0%	0	0%
Freeport	Stephenson	IL	1	1%	0	0%	0	0%
Geneva	Kane	IL	1	1%	0	0%	0	0%
Hines	Cook	IL	1	1%	0	0%	0	0%
Long Grove	Lake	IL	1	1%	0	0%	0	0%
Mahomet	Champaign	IL	1	1%	0	0%	0	0%
Mokena	Will	IL	1	1%	0	0%	0	0%
Mundelein	Lake	IL	1	1%	0	0%	0	0%
North Riverside	Cook	IL	1	1%	0	0%	0	0%
Palos Park	Cook	IL	1	1%	0	0%	0	0%
Pontiac	Livingston	IL	1	1%	0	0%	0	0%
Wheaton	Dupage	IL	1	1%	0	0%	0	0%
Woodridge	Will	IL	1	1%	0	0%	0	0%
Morris	Grundy	IL	0	0%	62	7%	61	6%
East St Louis	St. Clair	IL	0	0%	45	5%	29	3%
Springfield	Sangamon	IL	0	0%	13	1%	24	2%
Schaumburg	Cook	IL	0	0%	21	2%	22	2%
Normal	Mclean	IL	0	0%	12	1%	17	2%

North Aurora	Kane	IL	0	0%	20	2%	16	2%
Lake Forest	Lake	IL	0	0%	3	0%	15	1%
Itasca	Dupage	IL	0	0%	0	0%	12	1%
Highland Park	Lake	IL	0	0%	0	0%	11	1%
Gilberts	Kane	IL	0	0%	10	1%	10	1%
Oak Park	Cook	IL	0	0%	9	1%	10	1%
Des Plaines	Cook	IL	0	0%	1	0%	8	1%
Mchenry	Mchenry	IL	0	0%	6	1%	7	1%
Volo	Lake	IL	0	0%	16	2%	6	1%
Woodridge	Dupage	IL	0	0%	6	1%	6	1%
Lebanon	St. Clair	IL	0	0%	12	1%	5	0%
Palatine	Cook	IL	0	0%	7	1%	5	0%
Northlake	Cook	IL	0	0%	3	0%	5	0%
Evanston	Cook	IL	0	0%	9	1%	4	0%
Greenville	Bond	IL	0	0%	5	1%	4	0%
Tinley Park	Cook	IL	0	0%	0	0%	4	0%
Bloomington	Mclean	IL	0	0%	19	2%	3	0%
Maryville	Madison	IL	0	0%	7	1%	3	0%
Oswego	Kendall	IL	0	0%	3	0%	3	0%
Columbia	Monroe	IL	0	0%	0	0%	3	0%
Yorkville	Kendall	IL	0	0%	0	0%	3	0%
Vernon Hills	Lake	IL	0	0%	6	1%	2	0%
Highland	Madison	IL	0	0%	2	0%	2	0%
Loves Park	Winnebago	IL	0	0%	2	0%	2	0%
Peotone	Will	IL	0	0%	2	0%	2	0%
Will County Unincorporated Area	Will	IL	0	0%	2	0%	2	0%
Elmhurst	Cook	IL	0	0%	1	0%	2	0%
Waterloo	Monroe	IL	0	0%	1	0%	2	0%
Wilmette	Cook	IL	0	0%	1	0%	2	0%
Arlington Heights	Cook	IL	0	0%	0	0%	2	0%
Batavia	Kane	IL	0	0%	0	0%	2	0%
Fox Lake	Lake	IL	0	0%	0	0%	2	0%
Lincolnshire	Lake	IL	0	0%	0	0%	2	0%
East Dundee	Cook	IL	0	0%	2	0%	1	0%
Aurora	Kane	IL	0	0%	1	0%	1	0%
Bensenville	Dupage	IL	0	0%	1	0%	1	0%
Charleston	Coles	IL	0	0%	1	0%	1	0%
Clarendon Hills	Dupage	IL	0	0%	1	0%	1	0%
Elmwood Park	Cook	IL	0	0%	1	0%	1	0%
Freeburg	St. Clair	IL	0	0%	1	0%	1	0%
Hampshire	Kane	IL	0	0%	1	0%	1	0%
Lemont	Cook	IL	0	0%	0	0%	1	0%
Manhattan	Will	IL	0	0%	0	0%	1	0%
Mount Vernon	Jefferson	IL	0	0%	0	0%	1	0%
Palos Heights	Cook	IL	0	0%	0	0%	1	0%
Peoria Heights	Peoria	IL	0	0%	0	0%	1	0%
Quincy	Adams	IL	0	0%	0	0%	1	0%
Romeoville	Will	IL	0	0%	0	0%	1	0%
West Dundee	Kane	IL	0	0%	0	0%	1	0%
Worth	Cook	IL	0	0%	0	0%	1	0%
Lake In The Hills	Mchenry	IL	0	0%	7	1%	0	0%
Mascoutah	St. Clair	IL	0	0%	4	0%	0	0%
Homewood	Cook	IL	0	0%	3	0%	0	0%
Urbana	Champaign	IL	0	0%	3	0%	0	0%
Bellwood	Cook	IL	0	0%	1	0%	0	0%
Countryside	Cook	IL	0	0%	1	0%	0	0%
Deerfield	Lake	IL	0	0%	1	0%	0	0%

Godfrey	Madison	IL	0	0%	1	0%	0	0%
Granite	Madison	IL	0	0%	1	0%	0	0%
Hinsdale	Cook	IL	0	0%	1	0%	0	0%
Jerseyville	Jersey	IL	0	0%	1	0%	0	0%
Lockport	Will	IL	0	0%	1	0%	0	0%
Mount Prospect	Cook	IL	0	0%	1	0%	0	0%
St Jacob	Madison	IL	0	0%	1	0%	0	0%
Thornton	Cook	IL	0	0%	1	0%	0	0%

Table 119. Minnesota population counts

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1	
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation
Mankato	Blue Earth	MN	22	13%	40	9%	35	8%
Rochester	Olmsted	MN	16	10%	49	11%	53	12%
Moorhead	Clay	MN	11	7%	29	6%	25	6%
Maplegrove	Hennepin	MN	8	5%	3	1%	3	1%
Minneapolis	Hennepin	MN	7	4%	51	11%	63	14%
St Paul	Ramsey	MN	7	4%	23	5%	22	5%
St Cloud	Stearns	MN	6	4%	14	3%	0	0%
Applevalley	Dakota	MN	4	2%	16	4%	19	4%
Fergus Falls	Otter Tail	MN	4	2%	6	1%	11	2%
Bemidji	Beltrami	MN	3	2%	23	5%	31	7%
Grand Rapids	Itasca	MN	3	2%	14	3%	19	4%
Lakeville	Dakota	MN	3	2%	12	3%	17	4%
St Louis Park	Hennepin	MN	3	2%	12	3%	5	1%
Rosemount	Dakota	MN	3	2%	3	1%	3	1%
Shakopee	Scott	MN	3	2%	2	0%	3	1%
Duluth	St Louis	MN	3	2%	0	0%	0	0%
Sauk Rapids	Benton	MN	3	2%	0	0%	0	0%
Chaska	Carver	MN	2	1%	9	2%	8	2%
Blaine	Anoka	MN	2	1%	6	1%	6	1%
Eagan	Dakota	MN	2	1%	3	1%	3	1%
Forest Lake	Washington	MN	2	1%	3	1%	3	1%
Shoreview	Ramsey	MN	2	1%	0	0%	3	1%
Roseville	Ramsey	MN	2	1%	2	0%	2	0%
Golden Valley	Hennepin	MN	2	1%	1	0%	2	0%
Cambridge	Isanti	MN	2	1%	2	0%	1	0%
Baxter	Crow Wing	MN	2	1%	5	1%	0	0%
Inver Grove Heights	Dakota	MN	2	1%	1	0%	0	0%
Wayzata	Hennepin	MN	2	1%	1	0%	0	0%
Edina	Hennepin	MN	1	1%	17	4%	24	5%
Minnetonka	Hennepin	MN	1	1%	5	1%	9	2%
Champlin	Hennepin	MN	1	1%	3	1%	5	1%
Maplewood	Ramsey	MN	1	1%	3	1%	3	1%
Plymouth	Hennepin	MN	1	1%	1	0%	3	1%
Savage	Scott	MN	1	1%	20	4%	2	0%
Thief River Falls	Pennington	MN	1	1%	2	0%	2	0%
Mahtomedi	Washington	MN	1	1%	1	0%	2	0%
Carver	Carver	MN	1	1%	1	0%	1	0%
Farmington	Dakota	MN	1	1%	1	0%	1	0%
Shorewood	Hennepin	MN	1	1%	1	0%	1	0%
St Michael	Wright	MN	1	1%	1	0%	1	0%
Vadnais Heights	Ramsey	MN	1	1%	1	0%	1	0%
Ramsey	Anoka	MN	1	1%	2	0%	0	0%

Faribault	Rice	MN	1	1%	1	0%	0	0%
Albany	Stearns	MN	1	1%	0	0%	0	0%
Albert Lea	Freeborn	MN	1	1%	0	0%	0	0%
Andover	Anoka	MN	1	1%	0	0%	0	0%
Arden Hills	Ramsey	MN	1	1%	0	0%	0	0%
Blooming Prairie	Steele	MN	1	1%	0	0%	0	0%
Burnsville	Dakota	MN	1	1%	0	0%	0	0%
Byron	Olmsted	MN	1	1%	0	0%	0	0%
Dayton	Hennepin	MN	1	1%	0	0%	0	0%
Fairmont	Martin	MN	1	1%	0	0%	0	0%
Hastings	Dakota	MN	1	1%	0	0%	0	0%
Lake Elmo	Washington	MN	1	1%	0	0%	0	0%
Medina	Hennepin	MN	1	1%	0	0%	0	0%
Monticello	Wright	MN	1	1%	0	0%	0	0%
New Brighton	Ramsey	MN	1	1%	0	0%	0	0%
New Ulm	Brown	MN	1	1%	0	0%	0	0%
Norwood Young America	Carver	MN	1	1%	0	0%	0	0%
Owatonna	Steele	MN	1	1%	0	0%	0	0%
Perham	Otter Tail	MN	1	1%	0	0%	0	0%
Winona	Winona	MN	1	1%	0	0%	0	0%
Hopkins	Hennepin	MN	0	0%	0	0%	8	2%
Orr	St. Louis	MN	0	0%	9	2%	6	1%
Woodbury	Washington	MN	0	0%	4	1%	6	1%
New Hope	Hennepin	MN	0	0%	6	1%	4	1%
Mounds View	Ramsey	MN	0	0%	2	0%	4	1%
Newport	Washington	MN	0	0%	0	0%	4	1%
Big Lake	Sherburne	MN	0	0%	2	0%	3	1%
Columbia Heights	Anoka	MN	0	0%	1	0%	3	1%
Cottage Grove	Washington	MN	0	0%	1	0%	3	1%
Fridley	Anoka	MN	0	0%	1	0%	2	0%
Hutchinson	Mcleod	MN	0	0%	0	0%	2	0%
Oak Park Heights	Washington	MN	0	0%	2	0%	1	0%
White Bear Lake	Ramsey	MN	0	0%	2	0%	1	0%
Barnesville	Clay	MN	0	0%	1	0%	1	0%
Eitzen	Houston	MN	0	0%	1	0%	1	0%
Mound	Hennepin	MN	0	0%	1	0%	1	0%
Prior Lake	Scott	MN	0	0%	1	0%	1	0%
Taylors Falls	Chisago	MN	0	0%	1	0%	1	0%
Eden Prairie	Hennepin	MN	0	0%	0	0%	1	0%
New Prague	Scott	MN	0	0%	0	0%	1	0%
Pelican Rapids	Otter Tail	MN	0	0%	0	0%	1	0%
Stillwater	Washington	MN	0	0%	0	0%	1	0%
Waconia	Carver	MN	0	0%	0	0%	1	0%
Duluth	St. Louis	MN	0	0%	7	2%	0	0%
Chanhassen	Carver	MN	0	0%	3	1%	0	0%
North St Paul	Ramsey	MN	0	0%	3	1%	0	0%
Osseo	Hennepin	MN	0	0%	2	0%	0	0%
St Peter	Nicollet	MN	0	0%	2	0%	0	0%
Alexandria	Douglas	MN	0	0%	1	0%	0	0%
Crystal	Hennepin	MN	0	0%	1	0%	0	0%
Glenwood	Pope	MN	0	0%	1	0%	0	0%
Lake	Wabasha	MN	0	0%	1	0%	0	0%
North Mankato	Nicollet	MN	0	0%	1	0%	0	0%
Robbinsdale	Hennepin	MN	0	0%	1	0%	0	0%

Table 120. Oregon population counts

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1	
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation
Portland	Multnomah	OR	114	54%	226	29%	281	36%
Salem	Marion	OR	51	24%	54	7%	99	13%
Albany	Linn	OR	9	4%	12	2%	4	1%
Bend	Deschutes	OR	8	4%	38	5%	39	5%
Hillsboro	Washington	OR	7	3%	49	6%	55	7%
Eugene	Lane	OR	6	3%	60	8%	25	3%
Beaverton	Washington	OR	2	1%	21	3%	23	3%
Medford	Jackson	OR	2	1%	32	4%	16	2%
Forest Grove	Washington	OR	2	1%	5	1%	13	2%
Tigard	Washington	OR	1	0%	18	2%	21	3%
Oregon	Clackamas	OR	1	0%	0	0%	11	1%
Gresham	Multnomah	OR	1	0%	4	1%	8	1%
Springfield	Lane	OR	1	0%	3	0%	5	1%
Corvallis	Benton	OR	1	0%	40	5%	4	1%
Florence	Lane	OR	1	0%	0	0%	0	0%
Garibaldi	Tillamook	OR	1	0%	0	0%	0	0%
Grants Pass	Josephine	OR	1	0%	0	0%	0	0%
Happy Valley	Multnomah	OR	1	0%	0	0%	0	0%
Island	Union	OR	1	0%	0	0%	0	0%
Keizer	Marion	OR	1	0%	0	0%	0	0%
Clackamas County Unincorporated Area	Clackamas	OR	0	0%	71	9%	50	6%
Washington County Unincorporated Area	Washington	OR	0	0%	62	8%	45	6%
Happy Valley	Clackamas	OR	0	0%	10	1%	12	2%
Lake Oswego	Clackamas	OR	0	0%	2	0%	12	2%
Fairview	Multnomah	OR	0	0%	0	0%	11	1%
Lebanon	Linn	OR	0	0%	15	2%	8	1%
Mcminnville	Yamhill	OR	0	0%	12	2%	8	1%
Tualatin	Washington	OR	0	0%	8	1%	8	1%
King	Washington	OR	0	0%	5	1%	7	1%
Jackson County Unincorporated Area	Jackson	OR	0	0%	6	1%	6	1%
Central Point	Jackson	OR	0	0%	1	0%	6	1%
Sherwood	Washington	OR	0	0%	3	0%	3	0%
Scappoose	Columbia	OR	0	0%	0	0%	3	0%
Troutdale	Multnomah	OR	0	0%	1	0%	2	0%
Redmond	Deschutes	OR	0	0%	3	0%	1	0%
Sandy	Clackamas	OR	0	0%	1	0%	1	0%
Cornelius	Washington	OR	0	0%	0	0%	1	0%
Tillamook County Unincorporated Area	Tillamook	OR	0	0%	0	0%	1	0%
Union County Unincorporated Area	Union	OR	0	0%	5	1%	0	0%
La Grande	Union	OR	0	0%	2	0%	0	0%

Table 121. Washington population counts

Place Name	Primary County	State	Dodge 2014–2016		BPS 2014–2016		BPS 2015q2–2018q1	
			Building Count	Saturation	Building Count	Saturation	Building Count	Saturation
Seattle	King	WA	106	56%	369	23%	434	25%
Spokane	Spokane	WA	14	7%	55	3%	63	4%
Bellevue	King	WA	8	4%	26	2%	29	2%
Vancouver	Clark	WA	5	3%	97	6%	97	6%
Tacoma	Pierce	WA	5	3%	51	3%	43	2%
Everett	Snohomish	WA	5	3%	20	1%	26	2%
Lacey	Thurston	WA	3	2%	26	2%	33	2%
Marysville	Snohomish	WA	3	2%	22	1%	24	1%
Lynnwood	Snohomish	WA	3	2%	13	1%	7	0%
Olympia	Thurston	WA	3	2%	5	0%	6	0%
Spokane Valley	Spokane	WA	2	1%	31	2%	53	3%
Bothell	King	WA	2	1%	32	2%	33	2%
Pullman	Whitman	WA	2	1%	32	2%	32	2%
Richland	Benton	WA	2	1%	27	2%	24	1%
Kent	King	WA	2	1%	20	1%	23	1%
Kirkland	King	WA	2	1%	22	1%	20	1%
Redmond	King	WA	2	1%	16	1%	19	1%
Federal Way	King	WA	2	1%	34	2%	18	1%
Kennewick	Benton	WA	2	1%	10	1%	16	1%
Puyallup	Pierce	WA	2	1%	0	0%	4	0%
Airway Heights	Spokane	WA	2	1%	0	0%	2	0%
Bellingham	Whatcom	WA	1	1%	56	4%	52	3%
Tumwater	Thurston	WA	1	1%	11	1%	22	1%
Issaquah	King	WA	1	1%	20	1%	20	1%
Woodinville	King	WA	1	1%	15	1%	17	1%
Lynden	Whatcom	WA	1	1%	4	0%	12	1%
Burien	King	WA	1	1%	6	0%	6	0%
Centralia	Lewis	WA	1	1%	1	0%	2	0%
Prosser	Benton	WA	1	1%	1	0%	1	0%
Chewelah	Stevens	WA	1	1%	0	0%	0	0%
Longview	Cowlitz	WA	1	1%	0	0%	0	0%
Monroe	Snohomish	WA	1	1%	0	0%	0	0%
Mountlake Terrace	Snohomish	WA	1	1%	0	0%	0	0%
Pierce County Unincorporated Area	Pierce	WA	0	0%	51	3%	96	6%
Snohomish County Unincorporated Area	Snohomish	WA	0	0%	81	5%	73	4%
Spokane County Unincorporated Area	Spokane	WA	0	0%	59	4%	53	3%
Clark County Unincorporated Area	Clark	WA	0	0%	45	3%	42	2%
Edgewood	Pierce	WA	0	0%	25	2%	28	2%
Moses Lake	Grant	WA	0	0%	23	1%	27	2%
Battleground	Clark	WA	0	0%	24	2%	25	1%
Liberty Lake	Spokane	WA	0	0%	14	1%	25	1%
Cheney	Spokane	WA	0	0%	15	1%	16	1%
Covington	King	WA	0	0%	11	1%	15	1%
Des Moines	King	WA	0	0%	1	0%	14	1%
Sumner	Pierce	WA	0	0%	10	1%	12	1%
Thurston County Unincorporated Area	Thurston	WA	0	0%	9	1%	11	1%
Ferndale	Whatcom	WA	0	0%	2	0%	11	1%
Shoreline	King	WA	0	0%	2	0%	11	1%
Bremerton	Kitsap	WA	0	0%	10	1%	10	1%

Ellensburg	Kittitas	WA	0	0%	2	0%	9	1%
Renton	King	WA	0	0%	16	1%	8	0%
Mercer Island	King	WA	0	0%	10	1%	8	0%
East Wenatchee	Douglas	WA	0	0%	9	1%	8	0%
King County Unincorporated Area	King	WA	0	0%	4	0%	8	0%
Newcastle	King	WA	0	0%	6	0%	7	0%
Wenatchee	Chelan	WA	0	0%	4	0%	6	0%
Kenmore	King	WA	0	0%	5	0%	5	0%
Lakewood	Pierce	WA	0	0%	1	0%	5	0%
Mill Creek	Snohomish	WA	0	0%	24	2%	4	0%
Bainbridge Island	Kitsap	WA	0	0%	4	0%	4	0%
Yelm	Thurston	WA	0	0%	4	0%	4	0%
Edmonds	Snohomish	WA	0	0%	2	0%	4	0%
Seatac	King	WA	0	0%	17	1%	3	0%
Stanwood	Snohomish	WA	0	0%	3	0%	3	0%
Walla Walla	Walla Walla	WA	0	0%	3	0%	3	0%
Deer Park	Spokane	WA	0	0%	0	0%	3	0%
Kitsap County Unincorporated Area	Kitsap	WA	0	0%	0	0%	3	0%
Lake Forest Park	King	WA	0	0%	2	0%	2	0%
West Richland	Benton	WA	0	0%	2	0%	2	0%
Granite Falls	Snohomish	WA	0	0%	1	0%	2	0%
Skykomish	King	WA	0	0%	1	0%	2	0%
Maplevalley	King	WA	0	0%	0	0%	2	0%
Port Orchard	Kitsap	WA	0	0%	0	0%	2	0%
Bonney Lake	Pierce	WA	0	0%	10	1%	1	0%
Omak	Okanogan	WA	0	0%	2	0%	1	0%
Sammamish	King	WA	0	0%	1	0%	1	0%
Stevens County Unincorporated Area	Stevens	WA	0	0%	1	0%	1	0%
Auburn	King	WA	0	0%	0	0%	1	0%
Oak Harbor	Island	WA	0	0%	0	0%	1	0%
Snohomish	Snohomish	WA	0	0%	0	0%	1	0%
Fife	Pierce	WA	0	0%	17	1%	0	0%
Gig Harbor	Pierce	WA	0	0%	15	1%	0	0%
Milton	Pierce	WA	0	0%	10	1%	0	0%
Pasco	Franklin	WA	0	0%	4	0%	0	0%
University Place	Pierce	WA	0	0%	2	0%	0	0%
Bridgeport	Douglas	WA	0	0%	1	0%	0	0%
Yakima	Yakima	WA	0	0%	1	0%	0	0%

APPENDIX G – MARKET RESEARCH

Interview Guide

INTRODUCTION

Slipstream, a non-profit research organization, is working in partnership with the U.S. Department of Energy on a study of construction practices in low-rise multifamily buildings.

We were given your name by our partner organization in this study [Ecotope / Center for Energy and Environment] as someone who has insights on the nature of the low-rise multifamily construction market in [State] and the building code that governs it. Do you have a few moments to answer some questions?

QUESTIONS

1. First, can you give me a brief overview of the market for low-rise (3 stories or less above grade) multifamily buildings in your [jurisdiction / geographic area]? I'm interested in things like:

- Types of buildings
  - Common entry
  - Outside entry
- Size – number of units, number of stories
- Prevalence of mixed-use construction (i.e., retail on the ground floor, apartments above)

2. How robust is the market? Number of low-rise multifamily buildings or units going up in a year in your jurisdiction or area. [Make sure the geographic area attached to the number is clear.].

3. How would you characterize the developers in this market?

- Are they primarily:
  - Market rate builders
  - Non-profit affordable housing developers
  - Small residential builders crossing over to the small multifamily market
  - Commercial building developers that do some multifamily
- Or are they a mix of the above?
  - If they're a mix, about what percentage of the market does each group represent?

My next questions concern the code for low-rise multifamily buildings.

4. Do low-rise multifamily buildings follow the residential energy code, the commercial energy code or a combination?

- If a combination, please explain…
    - Mixed use development (ground floor retail; upper floors residential = mixed) commercial/residential?

5. Is air leakage testing required?

- If it is, is the blower door testing generally done one unit at a time, or for whole building?
- AND Is a specific standard protocol used (e.g. per ASTM, HERS, EnergyStar, etc.)?

6. What sorts of energy code compliance issues do you see most?

7. Are there any energy code compliance issues unique to the low-rise multifamily market in your [jurisdiction / geographic area]?

8. What resources are available for developers/builders to help them comply with the energy code?

- Training programs
- Online resources

8B. Are there any specific energy code topics and/or specific groups of industry players where additional resources would be helpful, such as for designers or specific subcontractors?

Thank you for your time. We appreciate your help.

Online/Phone Survey Instrument

INTRODUCTION

Q1 Slipstream, a research firm working with the Department of Energy, needs your help in understanding the design and construction market for low-rise multifamily housing. Low-rise multifamily buildings are no higher than three stories. These buildings can be rental properties or condominiums.

Please complete this short survey and we'll send you a $20 check once we've received your responses.

COMPANY INFORMATION

Q2 Which of the following best describes the company you work for. Select only one.

- ○ **Building Developer** (buy land, finance real estate deals, build or have builders build projects, orchestrate the process of building development from the beginning to end.)
- ○ **Architecture/Engineering Firm** (design and engineering services that may include construction management of building projects.)
- ○ **General Contractor** (provides material, labor, equipment, and services necessary for the construction of a building project.)
- ○ **HVAC Contractor**
- ○ **Electrical Contractor**
- ○ Other: please describe ____

Q3 What is your role in the company?

____

____

____

____

____

Q4 How many people currently work for your company?

- ○ Fewer than 10
- ○ 10 - 50
- ○ 51 - 100
- ○ More than 100
- ○ Don't know

Q5 What is your company's gross annual revenue?

- Less than half a million dollars
- More than $.5 but less than $1 million
- More than $1 million but less than $5 million
- More than $5 million but less than $10 million
- $10 million or more
- Don't know

Q6 Where does your company work?

- Throughout Illinois
- Throughout Minnesota
- Throughout Oregon
- Throughout Washington
- Throughout the Midwest
- Throughout the Pacific Northwest
- Throughout the country
- Other (for example, Chicago metro area): please describe
  ____

DEVELOPERS, A/E, AND GENERAL CONTRACTORS

Display This Question: Which of the following best describes the company you work for (select only one):

- *Building Developer (buy land, finance real estate deals, build or have builders build projects, orchestrate the process of building development from the beginning to end)*
- *Architecture/Engineering Firm (design and engineering services that may include construction management of building projects)*
- *General Contractor (provides material, labor, equipment, and services necessary for the construction of a building project)*

Q7 Approximately what percent of your business comes from each of the following building project types?

Building Project Type	**Percent of Business**
Single-family homes	
Multifamily buildings with 2 to 4 units (e.g., duplexes)	
Multifamily apartment buildings (rental property) that are no higher than 3 stories	
Condominium buildings that are no higher than 3 stories	
Multifamily buildings that are 4 stories or higher	
Mixed-use buildings	
Commercial buildings	

Q8 Approximately what percent of your low-rise (no higher than 3 stories) apartment and condominium projects are in the following categories.

Apartment or Condominium Project Category	**Percent of Business**
Common-entry apartment buildings (rental property)	
Garden-entry apartment buildings (rental property) that are no higher than three stories	
Common-entry condominiums	
Garden-entry condominiums	

Q9 Approximately how many low-rise multifamily building projects does your company begin annually?

- ○ Fewer than 10
- ○ 10 - 50
- ○ 51 - 100
- ○ More than 100
- ○ Don't know

Q10 Which construction delivery method do you use most often for your low-rise multifamily building projects?

- ○ Design-Build
- ○ Design-Build-Bid
- ○ Construction Manager at Risk
- ○ Integrated Project Delivery
- ○ Spec-Build
- ○ Other: please describe ____

Q11 Who is most often responsible for specifying the following key components and systems on your low-rise multifamily building projects?

	Specifier					
	Developer	Architect	General Contractor	Engineer	HVAC Contractor	Electrical Contractor
Insulation levels	○	○	○	○	○	○
Lighting	○	○	○	○	○	○
Windows	○	○	○	○	○	○
HVAC	○	○	○	○	○	○

CODE QUESTIONS

Q12 Now we have some questions pertaining to the building code.

Q13 How do you learn about **residential building code** requirements and methods for complying with those requirements? Do you...

- ○ Attend training sessions on the residential building code
- ○ Use online resources for information on the residential building code
- ○ Work with local code official to understand the residential building code
- ○ Other: please describe ____

Display This Question:
Approximately what percent of your business comes from each of the following project building types?

- *Commercial buildings*

Q14 How do you learn about **commercial building code** requirements and methods for complying with those requirements? Do you...

- ○ Attend training sessions on the commercial building code
- ○ Use online resources for information on the commercial building code
- ○ Work with local code official to understand the commercial building code
- ○ Other: please describe ____

Q15 Do you have any comments to share about the resources available to you for understanding and complying with the **residential building code**?

____

____

____

____

____

Q16 How would you describe your knowledge of the **residential building code** requirements? Do you...

- ○ Know the code requirements inside out
- ○ Know only the code requirements that apply to your work
- ○ Rely on your contractors (or subcontractors) to know the code requirements
- ○ Other: please describe ____

Q17 Are there requirements of the r**esidential building code** that are difficult to comply with?

- ○ Yes
- ○ No
- ○ Don't know

If you answered "NO", skip to Q19.
If you answered, "DON'T KNOW", skip to Q19.

Q18 What requirements are difficult to comply with?

____

____

____

____

____

Q19 Which of the following describes how strictly the **residential building energy code** is enforced in the jurisdictions you work in. Select all that apply.

○ The residential building energy code is strictly enforced in all the jurisdictions we work in
○ Enforcement of the residential building energy code varies by jurisdiction
○ Enforcement of the residential building energy code varies by individual requirements (some requirements receive less scrutiny)
○ There are commonly understood methods for meeting the residential building energy code short of full compliance
○ Other: please describe ____

Q20 When applying for building permits for low-rise multifamily buildings, do you receive feedback and/or correction notices pertaining to the **energy code** requirements?

○ Yes
○ No
○ Don't know

Q21 Is technical support available in the jurisdictions you work in for improving the design and construction of low-rise multifamily buildings?

○ Yes
○ No
○ Don't know

If you answered “NO”, skip to Q23.
If you answered, “DON’T KNOW”, skip to Q23.

Q22 Who offers this service?

○ Utility energy efficiency new construction programs
○ Home building associations
○ Non-profit energy efficiency advocacy organizations

- ○ Engineering firms
- ○ Other: please describe ____

Q23 Are there market dynamics, in addition to the code enforcement process, that influence the energy efficiency of low-rise multifamily buildings in the jurisdictions you work in? Check all that apply.

- ○ More stringent municipal codes
- ○ New construction programs offered by utilities or statewide energy efficiency organizations
- ○ Local stretch codes
- ○ Energy efficiency ratings (Energy Star, LEED, Green Globes, etc.)
- ○ Energy benchmarking ordinances
- ○ Other: please describe ____

Q24 What do you think are the key issues in understanding and complying with the r**esidential building energy code** as it pertains to low-rise multifamily buildings?

____

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TRAINING QUESTIONS

Q25 Our last questions are about your interest in training on the **residential building energy code**.

Q26 Are you interested in taking residential building energy code training?

- ○ Yes
- ○ No
- ○ Don't know

If you answered "NO", skip to end.
If you answered, "DON'T KNOW", skip to end.

Q27 What training format do you prefer?

- ○ On-demand webinars
- ○ Half-day classroom training

- ○ Full-day classroom training
- ○ Other: please describe ____

Q28 What topics would you like to learn about?

____

____

____

____

____

END

Q29 Thank you for completing our survey. Please provide your contact information so we can send you your $20 check for completing our survey.

- ○ Name ____
- ○ Address ____
- ○ Address 2 ____
- ○ City ____
- ○ State ____
- ○ Postal code ____