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2019 Oregon New Commercial Construction Code Evaluation Study

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Glossary of Terms & Acronyms

AC	air conditioning
AFUE	annual fuel utilization efficiency
ASHP	air source heat pump
CBSA	Commercial Building Stock Assessment
CFL	compact fluorescent light
DCI	data collection instrument
DHW	domestic hot water
DOAS	dedicated outdoor air system
EER	energy efficiency ratio
ETO	Energy Trust of Oregon
ETO NB	Energy Trust of Oregon New Buildings program
EUI	energy use intensity (kBtu/ft^2-yr)
GPM	gallons per minute
HAL	halogen
HVAC	heating, ventilation, and air conditioning
HID-MH	high-intensity discharge metal halide
HP	heat pump
HSPF	heating seasonal performance factor
HVAC	heating, ventilation and air conditioning
ID	identifier
INC	incandescent
IT	information technology
kBTU/hr	thousand British thermal units/hour
LED	light emitting diode
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
MEP	mechanical, electrical, and plumbing
OEESC	Oregon Energy Efficiency Specialty Code
NEEA	Northwest Energy Efficiency Alliance
PRTU	packaged rooftop unit
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
UA	heat loss (Btu/hr ^oF)
U_o	UA divided by total building area (6 sides)
RBSA	Residential Building Stock Assessment
RPM	revolutions per minute
SEER	seasonal energy efficiency ratio
VAV	variable air volume
VFD	variable frequency drive
VRF	variable refrigerant flow
W/ft2	watts/square foot
WSHP	water source heat pump

Executive Summary

This report details current work in Oregon to evaluate compliance with the most recent cycles of the Oregon Energy Efficiency Specialty Code (OEESC) 2010 and 2014 versions, specific to commercial buildings. This statewide research study, based on a representative sample, set out to determine how well the commercial energy code was being implemented and to determine whether the code was resulting in lower energy consumption in the Oregon new commercial construction market. Other important goals were to provide direction to the Northwest Energy Efficiency Alliance (NEEA) and key stakeholders on future commercial code and program development.

The work was carried out on four major building types (Schools, Retail, Multifamily, and Office). Ecotope used a Dodge dataset of new construction starts to create the sample frame. The sample was designed to select buildings within different floor area categories within each type. Table ES1 shows the final study group consisted of 46 buildings, representing 28 percent of the overall floor area of potential building stock that could be surveyed (about 20.4 million ft^2). Also, of note is that about 70% of the total square footage studied participated in Energy Trust of Oregon's New Buildings (ETO NB) program, which offers incentives for a variety of energy efficiency measures.

Table ES1. Overall Square Footage of Building Stock Surveyed

	Sample Frame (# of Buildings)	Buildings Surveyed	Sample Frame (Total Floor Area ft^2)	Floor Area Surveyed (ft^2)***
Schools	39	14	2,217,477	1,322,876
Multifamily	66	13	10,782,500	2,664,274
Office	48	7	5,934,543	1,225,944
Retail	69	12*	1,439,110	431,891
Total	**222**	**46**	**20,373,630**	**5,644,985**

This study combines detailed architectural and mechanical/electrical/ plumbing (MEP) plan review with site surveys of the main energy use systems in each sampled building: mechanical (HVAC) systems, service and domestic hot water, envelope, and lighting (Storm, 2016).

To achieve the project goals, Ecotope divided work in to three areas: building characteristics, compliance, and energy use.

- **Building Characteristics** are summarized in terms of the major systems that influence building energy performance: mechanical (HVAC) systems, service and domestic hot water, envelope, and lighting. The characteristics are presented in ways to aid in these important uses: show state of the stock and design trends, identify where future code and program opportunities exist, and provide inputs to building simulations to accurately define modeling efforts.
- **Code Compliance** is assessed by building system category against either the 2010 or 2014 edition of the OEESC. The primary categories of mechanical (HVAC), service hot water, envelope, and lighting (interior and exterior) are further divided into 14 total subcategories such as overall heat loss rate and interior lighting power density (LPD).

Compliance was assessed in two main ways: at the individual building level with an aggregate binary logic approach. In the aggregate binary logic approach, if any of the main parts of the code including envelope, mechanical, lighting, and service hot water had non-complying elements, the entire building did not comply. In the subcategory approach, each building component subcategory in each building was assessed independently.

The aggregate binary logic approach effectively treats the building as a unit of study answering the question: How many buildings comply with code? The second view, an overall look at all the subcategories, effectively examines the building market in its entirety as the unit of study. It answers the question: What parts of code are being followed and what parts are not? The latter approach is particularly geared toward providing insight to determine if a certain building system should draw attention for code development, enforcement, training, or efficiency program work.

All compliance was assessed on a prescriptive basis, regardless of whether buildings were permitted via a trade-off or performance path. This approach provides a clearer picture of the compliance of major components. It also compensates for the fact that the actual simulations and documentations, for a target performance approach, were rarely available for review and no real compliance beyond the individual components could be assessed.

- **Energy Use** was analyzed to evaluate whole-building performance. This approach has been used on previous commercial building evaluations in the Northwest (and elsewhere) to afford "bottom line" evaluation of building performance. The weather normalized Energy Use Intensity (EUI) is the primary figure of merit for commercial buildings and has been commonly used to compare different sets of buildings (and building types) for over 20 years.

Findings Highlights

The main body of the report presents highlighted findings which are further summarized here. Additional material, tables, and graphs are provided in the report appendices. A full dataset of collected data also accompanies the report.

Characteristics

- HVAC systems, especially in offices and schools, are moving away from traditional centralized systems such as variable air volume (VAV) toward modern zonal systems such as variable refrigerant flow (VRF). The percentage of floor area conditioned by VAV in this study was much smaller than in previous regional commercial building stock assessments. This is a very significant shift, in terms of design approach and EUI. Future commercial building codes might be well-served by including new language to continue to encourage more zonal systems and to ensure optimum VRF system design and installation. Regional planning efforts to address demand reduction should take note of the shift in HVAC system specification and installation.
- Nearly *all* natural-gas water heaters use condensing gas heat exchangers, meaning combustion efficiency is > 90%. In contrast, almost none of the natural gas heating equipment uses condensing technology, representing a programmatic opportunity.
- The newest commercial buildings have moved to LEDs in a big way; overall lighting power density (LPD) is now heading toward 0.5 W/ft^2 in non-retail spaces and is around 0.80 W/ft^2

for retail (vs the code allowance of just over 1 W/ft^2). Retail LPD has fallen by almost a factor of 5 in 20 years in the Pacific Northwest. Codes have had great influence on declining LPD, but increasing product offerings and much lower costs, all largely attributable to the advent of LEDs, are accelerating change. These factors may drive LPDs even lower independent of code. This finding suggests an "easy win" for code improvements in future years is to continue to target LPD.

- The average building heat loss rate has decreased dramatically compared to studied buildings built in 2002-2004 reflecting the continued march of increasing envelope performance requirements (Baylon 2008). Notably, more than half of all windows in Multifamily buildings now have U-Values below 0.3 Btu/hr/F. Low-e coatings also now appear nearly universally present in windows. Nevertheless, there remain opportunities for further envelope improvements by, for example, insulating slabs and masonry walls.

Code Compliance

- Overall, the study showed high code compliance levels across the building types and systems. A closer assessment shows that, when then non-compliance was found, it was with "near misses" and relatively few "large misses." Causation is difficult to prove but it would appear that designers and builders are paying attention to the code. There would likely not be such a high compliance rate across all subcategories otherwise.
- Assessing buildings with the aggregate binary logic approach, we found that Schools showed the highest compliance rate while Multifamily showed the lowest. Interior lighting was the highest complying building system; otherwise, compliance was relatively evenly distributed across building types and systems.
- Using the overall subcategory view (items such as HVAC efficiency, building heat loss rate, lighting power density, etc.) we found that 90% of all the subcategory items complied. Hot water loop pump controls showed the lowest compliance rate at 63%, economizers for cooling systems were next lowest at 83%, while the rest were close to 90% or above. Again, Schools exhibited the highest compliance rates but otherwise the other building types had generally equal subcategory compliance.
- Mechanical system efficiency complied in well over 90% of the cases but, somewhat curiously, given the widespread product availability, economizer provisions were met only 83% of the time.
- Hot water circulation pump controls were the least adhered to piece of the code likely due to concerns that hot water would not be available to the occupants when they wanted it. This issue should be studied further to consider if future code versions should remove or greatly modify this provision, especially around building type. In any event, increasing the pipe insulation requirement and adding a variable frequency drive (VFD) requirement for the pump would achieve energy savings.

- With some exceptions, thermal envelopes met code requirements. [1] Uninsulated masonry walls exemplified the non-compliance cases. In Multifamily and Office buildings, the window/wall ratio often exceeded the prescribed allowance, but this was almost always traded-off against better thermal performance elsewhere so that total UA still met code.
- There were several large, non-complying lighting systems in Retail buildings but in most other cases, systems complied or nearly missed. Overall, the average LPD across all building types is much lower than the code allowance.

Energy Use

- Energy Use Intensity (EUI, expressed as kBtu/ft^2 of conditioned area) was evaluated for 35 buildings in this study and found to be trending downward across all building types. It is at least 30% lower than buildings built in the 2002-2004 or 2003-2014 periods (Baylon, 2008 and Navigant, 2014). Interestingly, this finding still holds when examining participation in the Energy Trust New Buildings program. In this building cohort participation led to neither lower nor higher energy use compared to non-participation.
- Energy use was, unsurprisingly, not found to correlate with code compliance. Some of the highest performing buildings (lowest EUIs) failed some aspects of code compliance while others met all aspects of the code and had higher than average EUIs.
- Both high and low energy use, as demonstrated in several case studies, is still driven by design and operation choices. Those choices, operating without an EUI target, allow for both high and low energy use. Future code could consider recommending equipment types and design specifications that are proven to dramatically lower mechanical EUI.

[1] This conclusion is based primarily on architectural plan review, given the field review could typically only confirm glazing and attic insulation details.

1. Overview

The Oregon New Commercial Construction Code Evaluation Study was conducted by Ecotope, Inc. for the Northwest Energy Efficiency Alliance (NEEA) to assess the degree to which code was present in new buildings, and to observe the energy performance of newly occupied buildings. This report is comprised of four major sections: an overview containing background and basic method exposition, building characteristics, compliance, and energy use. The main body of the report presents highlighted findings. Additional material, tables, and graphs are provided in the appendices.

1.1. Goals

This statewide research study set out to determine how the 2010 and 2014 versions of the Oregon Energy Efficiency Specialty Code (OEESC) were being implemented and to determine whether the code was resulting in lower energy consumption in the Oregon new commercial construction market. The study had the following goals:

- Assess the degree to which code is present in new buildings.
- Summarize construction practices in the new commercial building sector.
- Observe the energy performance of the newly occupied buildings.
- Identify major compliance gaps in code implementation.
- Provide direction to NEEA and stakeholders on future commercial code and program development.

1.2. Background

The Northwest Energy Efficiency Alliance contracted Ecotope, Inc. to conduct a small Pilot Study to develop and test a methodology for commercial energy code evaluation (Storm, 2016). The insights from the Pilot Study were then applied to this larger-scale study.

Energy codes have been identified as a key strategy for meeting a number of energy planning and policy goals, including integrated resource plans as well as aggressive regional, state, and municipal carbon reduction goals. These goals increasingly depend on dramatic energy reductions in new buildings. Energy codes have typically focused on measures designed to deliver relatively small incremental energy savings over time. Over the next decades, energy codes will need a major overhaul to encourage building designers and engineers to significantly decrease building energy requirements. Code evaluations and compliance assessments must be geared to support this transformation.

To meet policy goals and avoid lost opportunities for deep energy savings in new buildings, energy codes must be more stringent, buildings must comply with these codes, and the codes must deliver the increased efficiency that policies are counting on. Realizing these outcomes requires an effective research strategy that can track code progress and guide future code development and enforcement. The Pilot Study created a reliable and repeatable methodology for measuring code compliance and evaluating improvements in energy performance over time. This methodology was used for the 2019 Oregon New Commercial Construction Code Evaluation Study.

1.3. Sample Design

The sample was designed to provide insights into the key building types of Office, Retail, School, and Multifamily. Other types in the commercial sector in Oregon were not sampled. Therefore, this is not a sector-wide survey but instead one that focuses on significant building types within the sector. The sample targeted new construction and significant alterations or additions permitted under the 2010 and 2014 versions of the Oregon Energy Efficiency Specialty Code (OEESC). The sample frame, a Dodge dataset, included "building starts" from the second quarter of 2013 through the second quarter of 2016. The data were cleaned to remove entries that did not reflect actual new building construction. Various screens were implemented:

- Construction values less than $250,000 were used to remove projects that were likely not significant buildings (e.g., remodels or small free-standing auxiliary buildings).
- Entries that did not reflect new buildings were removed. "Non-building" projects (e.g., stream restoration, dam spillways, etc.) were also removed.
- Unconditioned buildings (e.g., parking garages) and some residential buildings, including all low-rise multifamily buildings and all single-family projects, were removed.

The design was to reach a 90/10 confidence/precision on building floor area. Floor area was chosen as the variable of merit because it correlates well with other building features we would like to understand including energy use and lighting power. The original sample plan called for a target of 64 buildings using a three-strata design to be efficient with the number of sites surveyed.[2] However mid-stream changes, in response to recruiting challenges, led to a more efficient design. This revised design varied the number of strata across building types, based on floor area, and resulted in a final sample of 46 buildings, targeting similar levels of confidence and precision.

1.4. Data Collection

The largest portion of the study centered on the field data collection effort. Two tools were employed by the team. Recruiting staff tracked the outreach, responses, and recruiting of sites in a web-based tool called Zoho. Field staff captured the data for each surveyed site in an Excel-based data collection instrument (DCI) that was built for this purpose.

1.4.1. Recruitment

A multi-pronged approach was used to recruit buildings from the sample frame. The recruiting lists were developed in conjunction with outreach to jurisdictions. Potential sites were sent introductory letters and follow-up emails. Once contact was established with a site, a phone

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[2] The strata were delineated on building size so that we could essentially survey fewer smaller buildings while still being assured of surveying enough larger buildings. Each building within a type and strata was assigned a weight so that average characteristics values could be accurately calculated. See section 2.1.1.

screening script was used so that a standard set of questions was asked to determine eligibility of the building including construction start date, building type and main use, estimated building square footage, whether building was new or an addition and/or remodel, and date building would be at least 85% occupied. All information regarding recruitment was logged in the Zoho tool, so that different recruiters could see the notes and communication history with each site. The tracked responses were: agreed, declined, screened out, no response. A maximum of 10 attempted calls per site was made before a site was categorized as having no response.

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.

1.4.2. Plan Reviews

Field staff collected and reviewed the architectural as well as MEP plans prior to site visits. They entered details from the plans into the DCI ahead of the on-site assessment, which had the advantage of saving time on-site and flagging any potential building features that needed closer 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. Because on-site time is typically limited by site personnel obligations, the most critical element of the process is the plan review. The project's as-built plans represent the most deliberate and complete record of the building's intended physical presence and, by extension, have the greatest bearing on both code compliance and actual system performance. The details in the DCI were later verified in the field.

1.4.3. On-site Assessments

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 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. Signed billing release forms were collected on site when possible or obtained through subsequent contact with the site.

1.4.4. Quality Control

Quality control was built into the field work, which was overseen by two 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. Once the field manager accepted each DCI as complete, thank you letters and, where applicable, incentive payments, were sent to the sites.

1.5. Sites Surveyed

Figure 1 shows the location of sample frame buildings, and the 46 sampled buildings. As to be expected, there was a higher concentration of sites in the urban areas, particularly the Portland metro area and along the I-5 corridor, and a much lower concentration of sites in eastern, central, and southern Oregon.

Targets were reached in many of the strata and the sample was exhausted (either direct declines to participate or no response to repeated inquiries) in those strata that fell short of the targets. In School and Multifamily building types, recruiting successfully exceeded the targets. In the Office and Retail types, not enough buildings were able to be recruited to fill all strata.

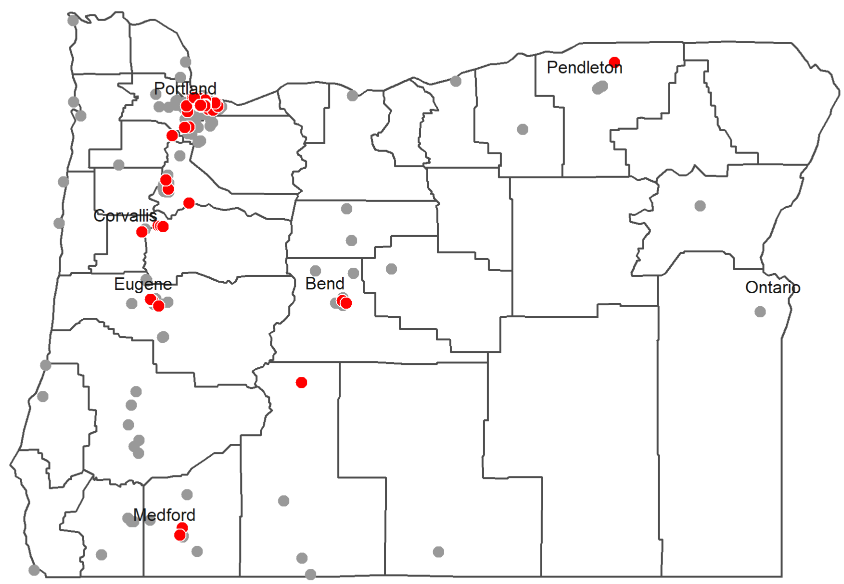


Figure 1. Location of Sample Frame and Sampled Buildings across Oregon

Basic information for the sampled buildings, including Site ID (unique identifier), city, primary and secondary type, floor area, construction category, and code year, is provided in Appendix B.

Table 1 places the total number of buildings surveyed in the context of the sample frame. Overall, the table shows that a substantial fraction of the overall sample frame was surveyed: 21% of all available buildings, comprising 28% (about 5.6 million ft^2) of the possible floor area.

Table 1. Overall Square Footage of Building Stock Surveyed

	Sample Frame (# of Buildings)	Buildings Surveyed	Survey of a Building Addition**	Sample Frame (Total Floor Area ft^2)	Floor Area Surveyed (ft^2)***
Multifamily	66	13	0	10,782,500	2,664,274
Office	48	7	1	5,934,543	1,225,944
Retail	69	12*	1	1,439,110	431,891
Schools	39	14	7	2,217,477	1,322,876
Total	**222**	**46**	**9**	**20,373,630**	**5,644,985**

* includes 4 restaurants
** a subset of buildings surveyed
***includes surveys of building additions

In analyzing the collected data, Ecotope encountered three main challenges in achieving the desired floor area observation precision at the 90% confidence level. First, the variation in the building floor area ultimately observed for the sampled buildings was larger than estimated at the time of the sample design. Second, some buildings that had been assigned a size stratum at the time of the sample design were found, when surveyed, to have a floor area belonging to other strata. That is, the values provided in the Dodge dataset for building area were not always accurate. This led to under-representation in some strata and over-representation in others while, all the while, effectively increasing the observed variation in the sampled buildings. Third, buildings could not always be recruited to fill the strata resulting in a lack of observed data points in a given size range.

Table 2 shows the sample recruiting outcome and provides the average floor area of the sampled buildings, the standard deviation, the coefficient of variation, the confidence interval at 90%, and the precision achieved at the 90% confidence level. The table shows that 10% precision on floor area observations was not achieved. Interestingly, however, it was reached (or nearly so) for several other important metrics like lighting power density (LPD) and overall building envelope heat loss (Uo). Those characteristics exhibited smaller variance than floor area. Overall, despite the challenges in achieving the sample design goals, given that the buildings surveyed comprised 28% of the total floor area, a substantial amount about the underlying population has been observed in this study.

Table 2. Average Floor Area (ft^2) of Sampled Buildings

Building Type	n	Floor Area (ft^2)	Standard Deviation (ft^2)	Coefficient of Variation (Cv)	90% Confidence Interval (ft^2)	Precision at 90% Confidence
Multifamily	13	147,345	110,174	0.75	± 50,261	±34%
Office	7	84,735	84,543	1.00	± 52,560	±62%
Retail	12	29,685	29,737	1.00	± 14,120	±48%
School	14	94,491	71,951	0.76	± 31,630	±33%

1.6. Analysis

1.6.1. Characteristics Assessment

Analysis was conducted on major systems that influence building energy performance including HVAC, lighting, envelope, and service/domestic hot water. Data summaries were assembled using a weighting procedure that reflects the sampling probability for each building within the various strata. Many summaries were constructed and weighted using building-level information. In cases where the characteristics were summarized for specific technologies (e.g., fixture types or HVAC types), summaries and weighting were based on subspaces within the buildings. For example, the average percent floor area served by a given heating fuel or equipment.

The data summaries include information taken from drawings and specifications, on-site data, and post-site visit follow-up with designers, builders, and buildings staff for additional details as needed. Data were assembled into a dataset for future reference of building characteristics as determined by this snapshot of commercial construction. Note that this report contains only a fraction of all the data that was collected. Additional data is available in the project dataset.

1.6.2. Compliance Assessment

Compliance was assessed by code category: mechanical (HVAC), service hot water, envelope, and lighting (interior and exterior). These primary categories were then divided into 14 total subcategories such as overall heat loss rate and interior LPD. Compliance was then assessed with aggregate binary logic at an individual building level and with an overall subcategory view. An additional set of calculations and comparisons was made to allow for more lenient compliance. This was done in order to see how many more of the ‘near miss’ sites would comply and also facilitated a closer look at these cases. Jump ahead to section 3.1 for further explanation.

1.6.3. Energy Performance Assessment

Energy use was assessed through billing analysis after the buildings were occupied for at least 12 months. Electric and gas bills were collected for nearly every site. Nine buildings with additions were excluded from analysis, since there was no way to assign the metered energy use to the additions that were surveyed. Two other buildings were also excluded: a school in rural Oregon that used propane, and a retail site that did not supply gas bills. Analysis was conducted by calculating annual, normalized energy use for electricity and gas. Heating, cooling, and baseload were disaggregated from total bills based on temperature-energy regression. This was conducted on all billing streams (electric and gas).

1.7. Database

Data were recorded in the electronic data collection instrument (DCI) organized to assist surveyors in collecting building characteristics information. The structure of the DCI also ensured that information could be extracted on each building’s characteristics and collated to examine all surveyed buildings. The final dataset contains full surveyed data on all 46 buildings in relational tables linked through identifier codes (mostly site IDs but also HVAC systems, lights and fixtures, units, envelope components, etc.). These tables were then used to summarize building characteristics and calculate weighted averages using sampling probabilities for each surveyed building.

1.8. Study Limitations

The primary study limitation has to do with the relatively small sample size of 46 buildings in relation to the large variation in the underlying population. As discussed in section 1.5, and shown in Table 2, not enough buildings were sampled to achieve a 10% precision estimate of floor area at the 90% confidence level. Other characteristics such as LPD and Uo, however, exhibit lower variation and achieved greater precision. When working with the study data, for any given characteristic, users should assess whether the precision of the estimate is acceptable for their needs. In some cases, 10% precision at 95% confidence (95/10) may be needed but in others, 80/20 may be more than enough. To assist users in assessing the results, the tables in Appendix B provide the 90% confidence interval for each point estimate.

Further, although the sample size appears small, it should be reiterated that 21% of the buildings in the sample frame were observed comprising 28% of the floor area. This is a substantial fraction of the total and should be weighed in the analyst’s mind as comparatively far more useful than none or 10% of the buildings. Moreover, combining the data observed here with additional observations, previous studies, and engineering judgement provides a useful framework for determining how much to lean on the data. If the analyst can build a coherent story across that framework, more confidence can be placed in the conclusions.

A feature of the sample, because it is also a feature of the building population, is the high rate of participation in Energy Trust of Oregon's New Buildings program. Energy Trust estimates that over half of all new buildings participate in the program (conversation with Energy Trust staff, May 2019). Similarly, more than half of the buildings surveyed were also participants. The program encourages a variety of improvements in building practices designed to lead to lower energy use. This may manifest in lower overall energy use across the population. While this study was not specifically designed to compare non-participant and participant buildings, further implications are discussed throughout the report beginning in section 2.2.1.

An additional limitation emerged in the Retail category, where four restaurant use-types were unintentionally incorporated into the study. These buildings had restaurants as part of a strip-mall type establishment or were not identified as restaurants until after the building was surveyed due to indeterminant plans. Analysis of the characteristics revealed no meaningful difference between the Retail and restaurant buildings, so they are summarized together throughout the report until the energy use section. Restaurant energy use is known to be high on an area-normalized basis and these four are no different.

Another limitation relating to energy use shows up in Schools, where seven of the 14 buildings were significant additions. These additions provided valuable information on characteristics and compliance but they did not include a new, separate utility meter for that addition so those could not be included in the energy analysis.

A last, fundamental limitation with the study method is the inability to visually verify all aspects of a building's characteristics. For example, it was not possible to observe the wall insulation in completed buildings. Instead, the study relied on the architectural drawings and assumed, if insulation was called for, it was installed. A direct, visual verification would require multiple visits to a site during construction. Given typical construction schedules, this would have greatly increased this project's timeline (by several years) and budget. Related, the study did not conduct air leakage tests of the buildings nor inspect all component assemblies to see if they complied with prescriptive air leakage requirements. Again, the testing would have greatly increased the project budget and it is extremely difficult to conduct a leakage test in a large, occupied commercial building.

Despite the limitations, the study provides useful insight into the new commercial sector in Oregon. Taken as a whole, and not as individual building types, it is possible to draw more conclusions. By applying engineering judgment and knowledge of previous building surveys—in particular, the 2002-2004 New Commercial Baseline (Baylon and Kennedy, 2008), the 2013 Residential Building Stock Assessment (RBSA) (Ecotope, 2014), and the 2014 Commercial

Building Stock Assessment (CBSA) (Navigant Consulting, 2014)—it is possible to increase confidence in the results and generalize the findings.[3]

[3] Although it was a residential study, the 2013 RBSA included detailed surveys of mid- and high-rise multifamily buildings, which were not surveyed in either the 2002-2004 New Commercial Baseline or the 2014 CBSA

2. Building and System Characteristics

This section presents and discusses the main elements of each building that contribute to its energy usage: the thermal envelope, the mechanical systems, the lighting fixtures/lamps/controls, and the service hot water. Each of these elements is described both in summary terms and in the context of the energy code. The characteristics are presented in ways to aid in these important uses: show state of the stock and design trends; show where future code and program opportunities could be; and provide inputs to building simulations to accurately define modeling efforts. This section highlights findings and the accompanying Appendix A includes more tables and graphs, which notably include error estimates, for detailed reference.

This section also revisits how survey sites were selected and how this selection process bears on the weighting scheme used to determine overall statistics for many of the study's independent variables. Use of case weights has been a standard feature of previous regional evaluations of commercial building stock; it is essential to using data obtained from a sample frame designed to efficiently represent a sub-sector of the commercial building stock, and, by extension, commercial buildings as a whole (when all sub-sectors are surveyed).

Highlighted findings from the characteristics review are:

- With some exceptions, thermal envelopes are meeting the new code including higher performance windows and thermally broken steel-framed assemblies. This conclusion is based primarily on architectural plan review, given the field review could typically only confirm glazing and attic insulation details.
- HVAC systems, especially in offices, are moving away from traditional systems such as variable air volume (VAV) toward more granular, efficient systems such as VRF. The percentage of floor area conditioned by VAV in this study was much smaller than in previous regional commercial building stock assessments. This is a significant shift, in terms of design approach and impact on EUI.
- The newest commercial buildings have started to move to LEDs in a big way; overall lighting power density (LPD) is now heading toward 0.5 W/ft^2 in non-retail spaces (with several buildings in this study already below that point) and is around 0.80 W/ft^2 for retail (vs the code allowance of just over 1 W/ft^2). Retail LPD has fallen by almost a factor of 5 in 20 years in the Pacific Northwest.

2.1. Methods Used to Provide Characteristics Summaries

Characteristics of recruited buildings were determined via architectural plan review with field verification of the main energy using systems in each sampled building: HVAC systems, envelope, lighting, and service and domestic hot water. When available, conversations with knowledgeable on-site staff were also useful during field verification. Collected information was then verified by the field manager who reviewed each DCI. Data from each of the individual DCIs were then collated into a dataset consisting of relational tables which included information from all applicable buildings. These were then further combined to summarize the characteristics of interest for this study.

2.1.1. Sample Weighting

As discussed above, this effort targeted a sample of newly constructed commercial buildings from four building use types. To increase sampling efficiencies, samples were distributed across building size strata. (See Appendices E and F.) The sample was then subject to sample weighting to ensure an unbiased estimate was produced from the data gathered at the individual buildings. By design, for each building type, a set of weights was calculated from the inverse of the sampling probability in each stratum. For example, if there were 30 buildings in Stratum 1, and three of them were sampled, the sampling probability was 10% and the case weight was 10 for each case. If in the same sample, Stratum 3 included 40 buildings with a sample of six, the sampling probability was 15% and each case had a weight of 6.7. For purposes of developing a population summary from these two strata, each building in Stratum 1 represented 10 buildings and each building in Stratum 3 represented 6.7 buildings. The analysis then used these weights to calculate means and probabilities of any surveyed characteristic. Because this study targeted four building use types from approximately a dozen total commercial building use types, the results presented here are to be considered representative only of the surveyed building types in Oregon, rather than the commercial sector as a whole.

2.1.2. Classification Schema

Classification schema were used to provide summaries at a scale relevant to building or system operation as well as to allow comparisons to past commercial building stock and compliance assessments. Because many of the building details were recorded in greater detail during data collection than required for analysis, most characteristics were further organized into higher-level categories to facilitate characteristic summarization. For example, compact fluorescent type lamps may have been recorded as compact fluorescent twist or pin base lamps based on plan review or on-site findings. However, for the purposes of characterizing the percentage of interior watts by building type, simply knowing which were compact fluorescent assemblies--versus the predominant tubular types (T8s and T5s) or other non-fluorescent lighting technologies--was sufficient. Descriptions of the classification schema used in this report are presented in each of the relevant sections.

2.2. Characteristics Highlights

This section focuses on the physical characteristics of the site inventory, beginning with a basic summary of conditioned floor area by building type, code year and specialty programs/ certifications, and then proceeding into envelope, HVAC, lighting, and hot water.

2.2.1. Basic

Buildings surveyed in this study fell under two OEESC code cycles, 2010 and 2014. Roughly two-thirds of surveyed buildings were under the 2010 code. Table 3 shows the distribution of surveyed building area by code year and building type. The combination of study timing, and practicality of having a large enough sample frame to draw from, necessitated spanning two code cycles. In this particular case, these cycles had relatively minor differences between them, easing the inclusion of both. Refer to section 3.1.1 for a comparison.

Table 3. Surveyed by Code Year and Building Type (% Floor Area)

Code Year	Multifamily	Office	Retail	School
2010	84.9	54.0	66.7	48.5
2014	15.1	46.0	33.3	51.5

Beyond meeting OEESC requirements, approximately 25% of surveyed buildings were certified under Leadership in Energy and Environmental Design (LEED) programs. Certification through above-code programs indicates these buildings may have been designed and constructed at standards above those required by OEESC. The degree to which they are above-code depends on the path taken through LEED's points-based system. Simple LEED certification does not guarantee a better than code building or actual energy use. Table 4 shows the percent of surveyed floor area certified at LEED levels by building type. All building types, except Retail, had over 30% of surveyed area qualified through at least some level of LEED certification.

Table 4. Certification Through Above Code Programs (% Floor Area)

Above Code Programs	Multifamily	Office	Retail	School
LEED Platinum	11.7	22.3	0.0	0.0
LEED Gold	21.3	13.1	0.0	28.0
LEED Silver	0.0	14.1	0.0	0.0
LEED Basic	0.0	0.0	0.0	7.2
Other	0.0	0.0	0.0	7.3
No	59.3	50.6	100.0	33.8
Unknown	7.6	0.0	0.0	23.7

New construction and major renovation projects in Oregon, such as those surveyed in this study, may also participate in Energy Trust of Oregon's New Buildings program. The New Buildings program is designed to provide incentives and guidance for customers of Oregon's investor-owned utilities to pursue energy efficient designs, construction, and commissioning with the goal of achieving less energy use than comparable "code-only" buildings. Table 5 shows the buildings from this study and breaks them into those that are included in the New Buildings program, and those that are not included. Six study buildings were outside of ETO's service area, and therefore ineligible to participate.

Table 5. Participation in the Energy Trust of Oregon's New Buildings Program (# of Buildings)

Energy Trust New Buildings Program	Multifamily	Office	Retail	School
Participating Buildings	13	4	6	9
Non-Participating Buildings	0	2	5	1
Ineligible Buildings	0	1	1	4

Energy Trust of Oregon estimates that the New Buildings program is active in over half of all commercial buildings (Energy Trust of Oregon, 2019). In this study, New Buildings participants account for 70% of the sample. Given the overlap, participation in the New Buildings program is explored within the context of many of the building characteristics, code compliance, and energy performance summaries in this report. Buildings outside of Energy Trust's service area are included in the "non-participant" category for the remainder of the report as only the construction location differentiates them from other non-participants. Table 6 shows the distribution of New Buildings program participants by percent of floor area.

Table 6. Participation in the Energy Trust of Oregon's New Buildings Program (% Floor Area)

Energy Trust New Buildings Program	Multifamily	Office	Retail	School
Participating Buildings	100.0	67.5	50.6	51.2
Non-Participating Buildings	0.0	32.5	49.4	48.8

2.2.2. Mechanical (HVAC)

In combination with the thermal envelope of the building, the heating, cooling, and ventilation systems are the most important determinants of space conditioning energy usage. For this study, the "V" part of HVAC refers to either central or small zone ventilation systems and also includes specialty systems such as kitchen range hoods and garage exhaust.

At the highest level, we summarize the percentage of building square footage served by the two utility-supplied fuels (Figure 2). Note that the 'heat pump' category refers to electric heat pumps; it is separated from the 'electric' category since the latter indicates electric resistance heat rather than heat provided by the refrigeration cycle. (One school is served by propane, so this is also noted in the graphic.) Not surprisingly, electric zonal and heat pump heat dominates in Multifamily buildings. Given challenges in venting gas heat in living units; the small percentage of multifamily floor area heated by gas refers to common areas such as corridors and amenity spaces.

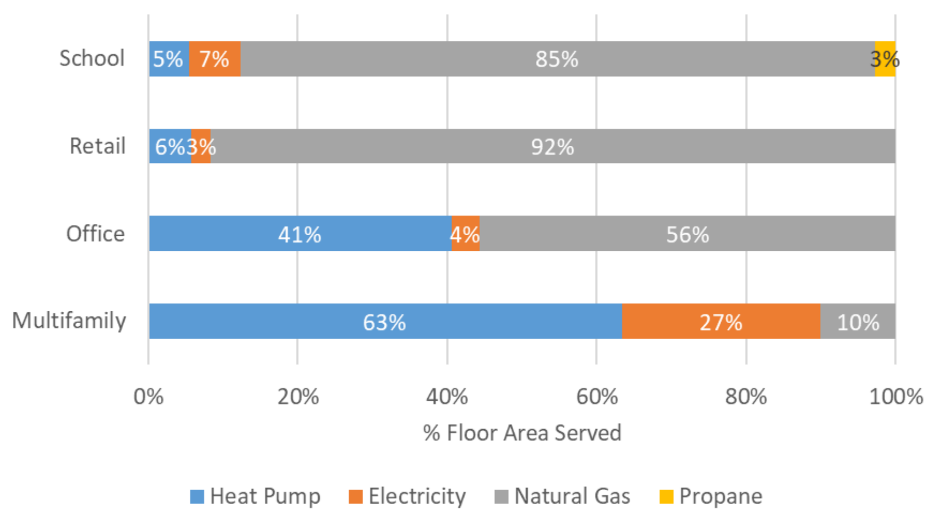


Figure 2. Heating Fuel Classification and Percentage of Floor Area Served

Looking back at past regional studies, the percentage of floor area heated by natural gas has stayed relatively constant at 72% for the 2004 Commercial Building Stock Assessment (CBSA) (KEMA-Xnergy Inc, 2004) and 68% for the 2009 CBSA (Cadmus, 2009). The percentage was not reported directly for the 2014 CBSA (Navigant Consulting, 2014). The percentage of floor area heated by heat pumps (both air and water-source) was 8.7% in the 2004 CBSA, 10% in the 2009 CBSA, and 15% in the 2014 CBSA. As depicted in Figure 2, the trend toward more heat pumps in Multifamily and Office occupancies appears to build on the regional increase over the years.

Figure 3 shows the distribution of heating equipment for study buildings as a percentage of overall building square footage. There are many systems represented in the graphic, so it is helpful to review system descriptions in advance of studying the figure. Also note that the following section in the report goes into more detail on the types of distribution systems that are associated with the primary heating plant types. Herewith are descriptions of the most commonly found systems in the study.

- **Inverter-driven heat pump**: The heart of this system is a compressor (or compressors) powered by a direct-current motor. The DC motor means the system has a wide modulation range and this typically increases operating efficiency by at least 50 percent compared to traditional, fixed-RPM equipment. 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). This type of system is also built with a cooling-only option (most commonly found in computer server rooms).
- **PRTU** (packaged rooftop unit): This is the prevailing type of system found in retail and includes both evaporator and condenser coils (and fans) in one enclosure. The heating plant is attached to ducts that then distribute conditioned air in the space. Heating fuel is most commonly natural gas, but systems can also be heat pumps or use electric resistance heat (rare).
- **PTHP/PTAC** (packaged terminal heat pump and packaged terminal air conditioner): These are smaller versions of PRTUs and are unducted; units are typically installed in wall cut-outs and are relatively common in multifamily living units.
- **Boiler**: This is typically a larger-capacity (over 500,000 Btu/hr) system that serves fan coils; most systems in this study were condensing boilers. (These are almost all hot water boilers; a small fraction used steam.)
- **Wall heater/unit heater**: Relatively simple systems that include electric baseboards, wall heaters (that have small distribution fans), or gas-fired unit heaters.
- **Furnace**: A residential-type system which may also employ direct expansion (DX) cooling via a 'split' system (outdoor condensing unit connected to furnace section by refrigerant lines). Conditioned air is delivered into the space by ducts.
- **WSHP** (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.
- **ASHP** (air source heat pump): Same as WSHP but the heat source/sink is the air surrounding the outdoor unit.

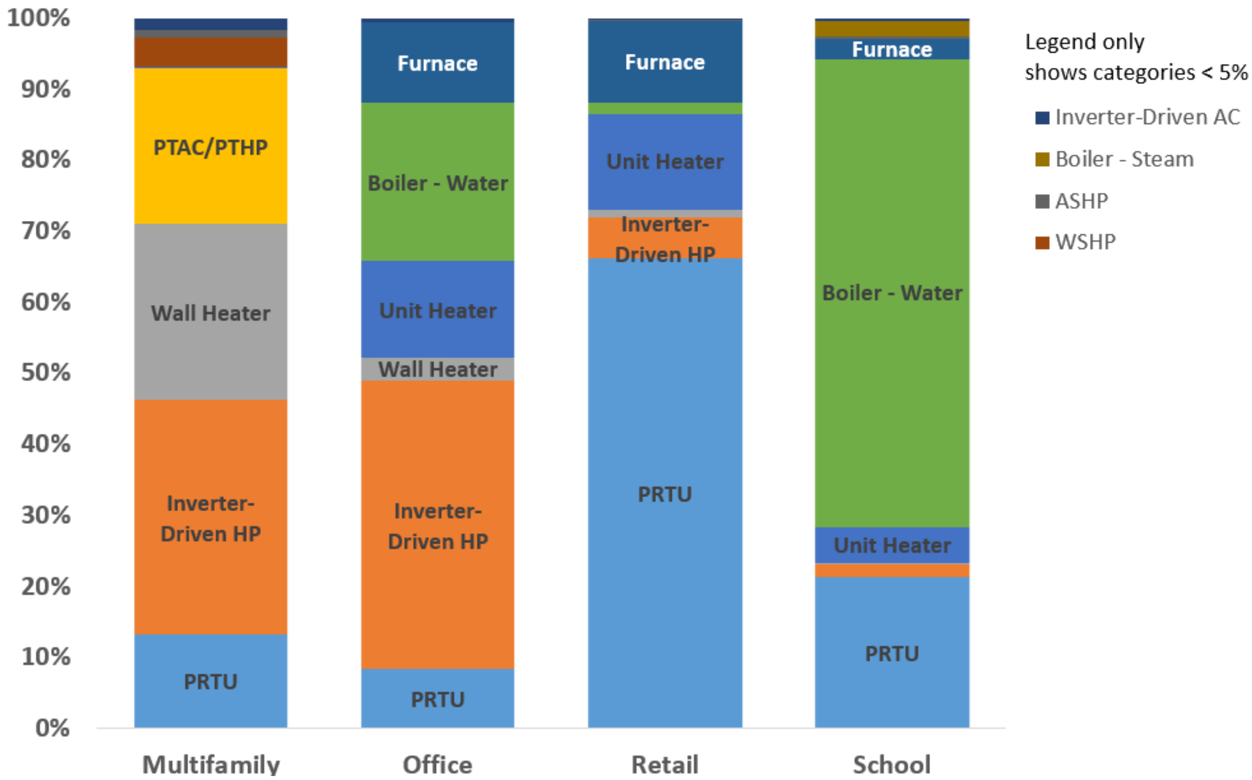


Figure 3. Heating Systems by Building Type (% of floor area)

Not surprising is the continued dominance of PRTUs in Retail; this is the system type that makes the most sense in this sector due to its convenient location, relatively simple distribution system, and relatively low first cost.

Perhaps more intriguing is the large fraction of the Office and Multifamily sectors that are now heated by inverter-driven compressor heat pumps. For Offices, this includes VRF systems where a larger capacity outdoor unit serves multiple indoor units; indoor and outdoor units are connected just by refrigerant lines.

For Multifamily, the most common inverter-driver compressor system is the ductless (split system) heat pump. Also note the yellow bar in Multifamily: this represents packaged terminal heat pumps and AC units. These systems, especially heat pumps, are increasingly common in new low and high-rise multifamily buildings. They do not have the same nominal efficiency as inverter-driven systems, which can deliver heating and cooling with much more modulation than traditional packaged air source heat pumps, but they do offer heating at an efficiency greater than electric resistance. Depending on living unit size, only one of these systems might be installed in the main living area (along with electric resistance heat in bedrooms and bathrooms).

The ‘PRTU’ category includes packaged units that use both natural gas and compressors to provide heat. None of the gas packaged units in the study were condensing, so this remains an opportunity for improved efficiency.

As mentioned above, many of the buildings in this study participated in Energy Trust of Oregon’s New Building program, which offers incentives for a wide range of energy conservation measures. Figure 4 (analogous to Figure 3) shows predominant heating systems by participant and non-participant; the scale on the left is percentage of building type square footage. Within the Multifamily group, fully a third of the conditioned square footage is served by inverter-driven heat pumps (typically one to one systems), and the Energy Trust of Oregon's incentives are likely a factor. Within the Office sector, almost 70% of the conditioned floor area is served by inverter-driven heat pumps (typically VRF systems); a review of program records showed the majority of the Office buildings received "market solutions offering" incentives, and we surmise these incentives often applied to VRF. It is notable that none of the non-New Buildings sites used VRF. Also notable is the number of condensing boilers in both Office and School buildings; most of the buildings with new condensing boilers received NB boiler incentives.

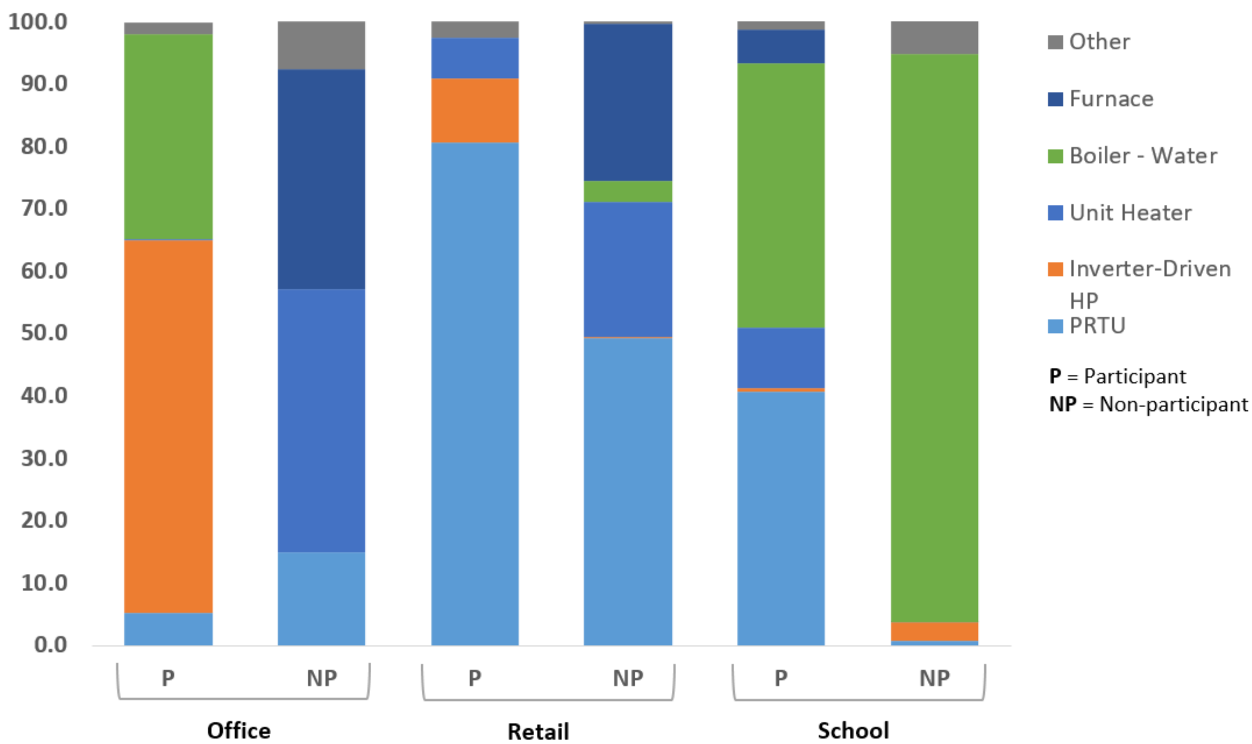


Figure 4. Heating System by Building Type and ETO New Buildings Status (% of floor area)[4]

2.2.2.1. Heating and Cooling Distribution

The following tables show the frequency of heating (Table 7) and cooling (Table 8) distribution systems in the study. Most important to note is the high percentage of variable refrigerant flow (VRF) systems in the office sector; this type of system allows part of a building to be either in heating or cooling mode, ideally transferring heat/cool from one zone to the next, and, as thermal envelopes improve, this means heating and cooling EUIs drop. These systems typically pair at least 10 indoor heads or fan coils with a single outdoor unit. The relatively large 'other' category

[4] All of the Multifamily sites participated in the New Buildings program so this sector is not shown in the graph. For "Other" category definition, refer to Appendix B Table B11.

in offices is due to one larger office that had about 200,000 ft^2 of space served by chilled beams. As noted above and depicted in Figure 4, many of the Offices in the study participated in the Energy Trust's New Buildings program, although the incentive lists are not specific enough to prove that all the VRF systems installed in those buildings received program incentives.

Schools in the study used a combination of two- and four-pipe systems (with heat typically delivered by condensing boiler loops) and single-zone ducted systems (packaged rooftops); larger schools also used chillers (including large capacity air-to-water heat pumps) to provide cooling (although the five schools that had usable utility data showed little mechanical cooling).

Also notable is the very low percentage of variable air volume (VAV) systems. In previous CBSA evaluations (2004 and 2009), especially for building types such as schools and larger offices, VAV systems predominated, as these systems had become common practice for their flexibility and familiarity to design engineers. A small percentage of schools and office buildings used variations of VAV. However, these systems have been recognized by many (for example, Heller, 2014) as remarkably wasteful, since they routinely allow simultaneous heating and cooling and they also use excessive electricity to provide ventilation.

Multifamily buildings were perhaps the most balanced, in terms of the distribution of heating/cooling systems. Electric resistance zonal heating is the most common, not surprisingly, but there is also a large chunk of VRF and single-zone ducted (mostly amenity areas). One Multifamily building used a multi-split ductless heat pump system, with a total of 4 indoor heads served by one outdoor unit. Retail, as expected, was predominantly heated and cooled by single-zone ducted systems (aka packaged rooftops).

Table 7. % of Floor Area Served by Heating Distribution System Type (By Building Type)

Heat Distribution Type	Multifamily	Office	Retail	School
Electric resistance zonal	47.5	16.9	14.7	5.4
Single zone ducted (spit or packaged)	14.6	19.9	76.9	43.8
VRF	30.2	40.7	0.0	1.2
Two/Four Pipe Systems	0.0	3.4	0.0	27.7
Hydronic (boiler)	0.0	19.0	1.5	5.6
Minisplit (single head DHP)	2.4	0.1	5.7	0.4
Multisplit (residential type)	1.1	0.0	0.0	0.0
Multi Zone VAV	0.0	0.0	0.0	6.0
Multi Zone w/reheat	0.0	0.0	1.1	0.6
VAV w/reheat	0.0	0.0	0.0	9.2
Water-source heat pump loop	4.3	0.0	0.0	0.0

Table 8. Cooling Distribution Systems by % of Floor Area Served

Cooling Distribution Types	Multifamily	Office	Retail	School
Zonal (PTAC or window unit)	29.1	0.0	0.0	0.0
Single zone ducted (spit or packaged)	19.1	24.0	86.9	59
VRF	39.4	50.0	0.0	1.6
Two/Four Pipe Systems	0.0	4.2	0.0	30.0
Minisplit (single head DHP)	5.3	0.8	7.5	1.1
Multisplit (residential type)	1.4	0.0	0.0	0.0
Multi Zone VAV	0.0	0.0	1.4	8.4
Water-source heat pump loop	5.6	0.0	0.0	0.0
Other	0.0	21.0	4.1	0.0

In the Pacific Northwest, codes and practice have shifted in the last five to ten years toward inclusion of a dedicated outdoor air system (DOAS) to provide outside air to meet the ventilation code. The 2015 Washington Commercial Energy Code included this system as a prescriptive option as of January 1, 2017. The 2014 Oregon Code, however, did not reference this system. These systems run independently of the central heating/cooling plant and employ much smaller circulation fans rather than using the large, central air handler which also supplies heating and cooling. The code cycles in this study did not require or offer DOAS as an option; still, several buildings incorporated it, most notably Offices and Schools, as shown in Table 9. Also, in each of these cases, some of the sites incorporated heat recovery into the system to reduce the energy needed to condition outside air to suitable delivery temperatures.

Table 9. Dedicated Outdoor Air Systems (DOAS) by % of Floor Area Served

Dedicated Outdoor Air System Types	Multifamily	Office	Retail	School
DOAS no Heat Recovery	1.5	8.2	0.0	14.2
DOAS w/ Heat Recovery	0.8	17.9	0.1	14.0
No DOAS	97.8	73.8	99.9	71.8

Commercial energy codes have, for some time, required programmable comfort controls (thermostats or the like) for the bulk of usable space in most occupancies. This study evaluated the presence of required thermostats or zone sensors (to inform central control systems) and also collected information on schedules. This is shown in Table 10. "Smart" thermostats, of the kind recently popularized in single-family houses, were not found in any quantity. In large part, for many of the building types, this has to do with the fact that they are already set up with central thermostat controllers and an energy management system. No additional analysis has been done on these data**.**

Table 10. Thermostat Types by % of Floor Area Served

Thermostat Type	Multifamily	Office	Retail	School
Slave (EMS Sensor)	0.5	90.6	27.4	95.8
Programmable	68.4	7.3	40.3	1.4
Manual	27.2	2.2	32.2	2.7
Not Applicable	3.3	0.0	0.0	0.0
Unknown	0.6	0.0	0.0	0.0

2.2.3. Service and Domestic Water Heating

Service and domestic water heating can be a large contributor to overall energy use depending on building type within the commercial sector. Multifamily buildings, being residences, will have larger domestic water use while retail spaces are likely to only have limited use in lavatories. Of interest for energy use are the characteristics of fuel type, central vs "in-unit" systems, equipment efficiency, and, if a circulation loop is present, pump controls.

One of the most significant findings is that of natural gas fired water heaters surveyed, all but one used a condensing flue gas heat exchanger. In other words, nearly all the gas capacity had a combustion efficiency greater than 90 percent. On the electric side, there were no heat pump water heaters found, only electric resistance equipment.

As has traditionally been the case, natural gas is the dominant fuel source for service and domestic water heating in these four building categories. Figure 5 shows the distribution of water heating fuels by equipment output capacity. Assessing on output capacity can have the tendency to skew the distribution toward gas equipment because gas output is somewhat cheaper to install than electric. Nevertheless, barring a study which directly measures hot water flow, this is likely the best representation of water heating fuel distribution. In the surveyed buildings, Retail featured more in-unit tanks than the other categories which tends toward electricity and explains the relatively higher prevalence of electric heating in that sector.

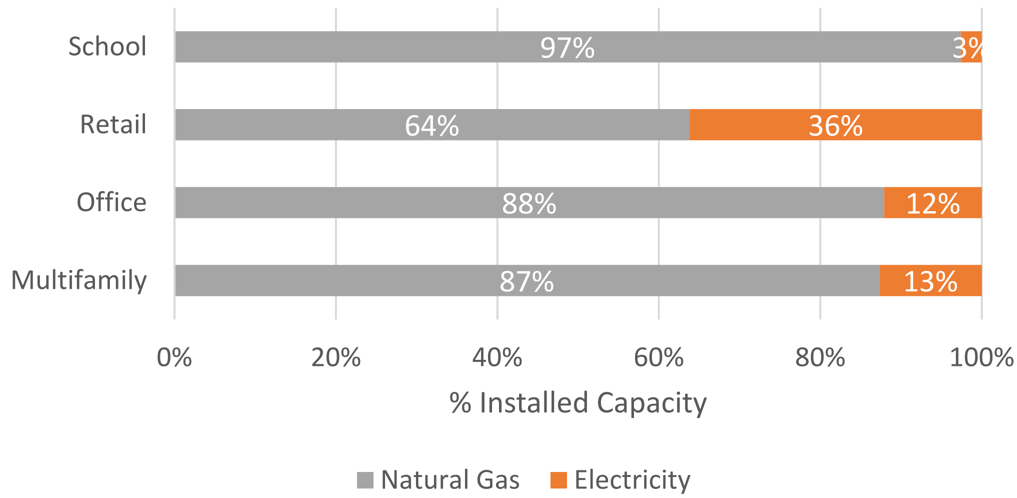


Figure 5. Water Heating Fuel Type by % of Installed Capacity

Table 11 shows the distribution of water heater system type, again, by installed output capacity. A central system is defined as any system where a circulation loop is used. Both gas and electric equipment are in use in central systems but most of the output capacity for these is gas. The equipment types used are both water heaters and boilers with and without additional storage tanks /heat exchangers (there are little efficiency differences between them). In-unit systems are more evenly split across gas and electric fuels.

Table 11. Water Heating System Type by % of Installed Capacity

Central vs In-Unit Distribution	Multifamily	Office	Retail	School
Central	85.8	96.7	6.1	98.4
In-Unit-Tank	14.1	2.7	77.8	1.4
In-Unit-On Demand	0.0	0.0	16.1	0.2
In-Unit-Other/Unknown	0.1	0.0	0.0	0.0
Unknown-Tank	0.0	0.6	0.0	0.0

The distribution of pump control type is shown in Table 12. In this case, the control type is summarized by the number of buildings with that type (as opposed to the equipment output capacity) since control is more a singular property of the building than the equipment. Water heating equipment, not on a circulation loop, does not have pumps and therefore controls do not apply. The pump controls are intended to turn off the circulating loop when hot water is not needed. The intent is to reduce the heat loss through the pipes whereby saving energy. The code requires all circulation loops to have pump controls of some type. Both Office and Retail all have some type of demand or timer control while over 50 percent of Multifamily and Schools have no controls. Section 3.2.3.2 discusses the implications further.

Table 12. Percent of Pump Controls in Buildings with Hot Water Circulation Loops

Pump Controls Type	Multifamily	Office	Retail	School
Demand	8.8	82.0	15.9	10.9
Timer	13.2	12.7	68.2	13.9
Pressure	2.2	0.0	0.0	7.3
None	58.8	0.0	0.0	57.0
Not Applicable	5.5	0.0	0.0	0.0
Unknown	13.7	9.0	15.9	18.2

2.2.4. Envelope

For most of the study buildings, architectural drawing sets were available that described building shell assemblies. Typical assemblies described the construction components of walls, roofs, and floors and generally provided adequate information to approximate U-values. Occasionally, exposed insulation and framing, or removal of electrical receptacle covers allowed for on-site confirmation.

On a very high level, the average heat loss rate of buildings in this study has decreased dramatically (approximately 60%) since the 2002-2004 New Commercial Baseline (Baylon and Kennedy, Ecotope, 2008). The average heat loss (U_o) is total building heat loss (UA) divided by total building surface area. Table 13 shows the regional (WA, OR, ID, and MT) average U_o for the four building types permitted in 2002-2004 compared to the Oregon only buildings permitted in 2012-2016.

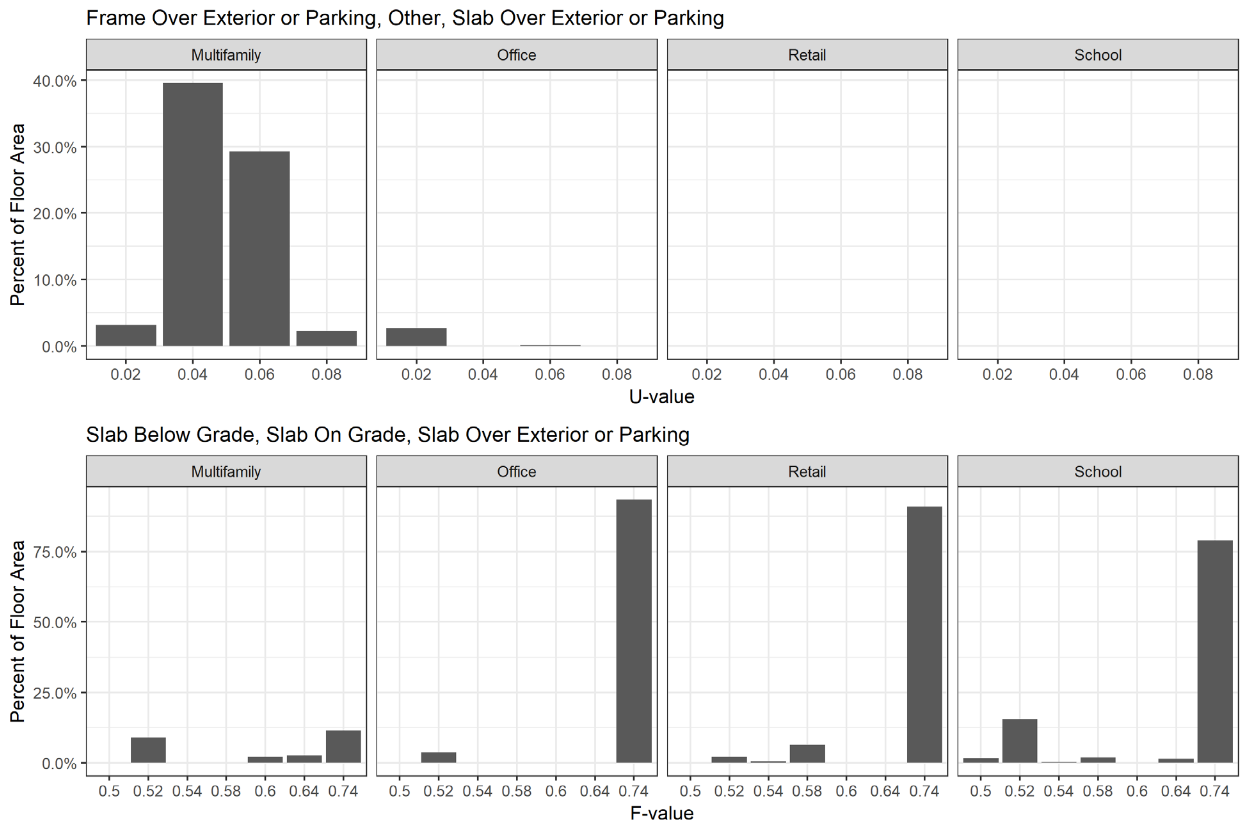
Table 13. Overall Heat Loss--U_o (UA/total building surface area)

	Multifamily	Office	Retail	School
2002-2004 New Commercial Baseline	0.120	0.160	0.210	0.140
This study	0.077	0.060	0.083	0.061

2.2.4.1. Envelope Component U-values

This section addresses the methodology for how building heat loss/gain components were analyzed. Floors and windows are highlighted. See Appendix A for more exposition on walls and ceilings.

Floors were split by U-value (framed or concrete floors over exterior or buffer space) and F-value (slab on grade). Figure 6 shows Multifamily buildings were most likely to have floors over exterior or buffer space. This occurred more often for Multifamily due to interior parking garages under the conditioned envelope, and oddly shaped buildings with exposed floors. Office, Retail and School were largely constructed with completely uninsulated concrete slabs, as shown by the F-values in the 0.74 bin. Schools are the building type with the highest percentage of insulated slabs (about 13% of School floor area). Simply adding perimeter insulation to slab on grade floors would greatly improve the thermal envelope.



Note x- and y-axis scales differ

Figure 6. Floor U-Value by Building Type

2.2.4.2. Windows

Prescriptive code dictates a maximum allowable window-to-wall area of 30 percent. The average window-to-wall area for each building type was below this maximum, as shown in Table 14. The higher glazing percentage for Multifamily and Office correlates to findings from the 2002-2004 New Commercial Baseline (Baylon and Kennedy, Ecotope, 2008). Higher window-to-wall area in these building types relative to others is likely due to market pressures. Developers may assume that more glazing will make spaces more attractive. Overall, glazing percentage appears to have increased in Multifamily, Retail, and Schools while, somewhat curiously, decreased in Offices. As a point of reference, the 2002-2004 New Commercial Baseline (Baylon and Kennedy, Ecotope, 2008), which found an average of 16.4% across all building types in Oregon; however, inclusion of historically minimally glazed buildings such as groceries and warehouses likely skews that average downward compared to individual types in this study

Table 14. Window % of Gross Wall Area

	Multifamily	Office	Retail	School
2002-2004 New Commercial Baseline	24.5	28.9	13.5	13.9
This study	27.1	23.5	22.5	18.6

Building plan window schedules and, where available, code submittals were used to estimate window thermal properties. Often, direct field observations were most helpful to accurately obtain frame material, number of glass panes, and low emissivity (low-e) coating; a low-e meter was used on site to determine presence and type. Table 15 shows the result of the effort to determine U-values ("Class 30" corresponds to a U-Value of 0.30 Btu/hr-ft^2-/^{o}F; lower 'classes' mean more efficient windows). Table 16 shows the distribution of low emissivity ('low-e') coating in the study. Across almost all building types (Retail being the exception), low-e is found in over 90% of glazing.

Table 15. Window U-Factor as % of Total Glazing Area

Window U-Factor Class	Multifamily	Office	Retail	School
< 30	58.7	26.5	0.0	0.0
30-40	16.3	72.4	15.8	27.1
41-50	18.5	0.1	55.8	70.1
51-60	6.5	1.1	5.7	2.3
> 60	0.0	0.0	22.6	0.6

Table 16. Low Emissivity Coating Type as % of Total Glazing Area

Low-e coating	Multifamily	Office	Retail	School
Low-e (e < 0.05)	63.8	69.2	19.5	40.8
Low-e (e = 0.05–0.10)	29.8	30.8	66.2	57.6
None	0.9	0.0	12.9	1.6
Unknown	5.5	0.0	1.4	0.0

2.2.5. Lighting

Interior lighting analysis showed a significant saturation of LED lighting; however, there is still plenty of opportunity to replace T5, T8, and CFL fixtures with lower-wattage LEDs. Here is a condensed description of lighting fixtures and bulbs as a prelude to further discussion of what was found during plan and field review.

- **Light Emitting Diode (LED) Integrated** lamps are so-called because the fixture and lamp are sold as a single unit (versus an LED lamp that can be used in an existing fixture). These could be linear or non-linear configurations.
- **LED Linear** lamps are linear tubes, often used to replace T5 and T8 lamps.
- **LEDs** are non-linear lamps that are not integrated into the fixture. These typically have pin or screw-in base configurations.
- **Linear Fluorescents** are linear tube lamps, typically T5 and T8 configurations.
- **Compact Fluorescent Light (CFL)** are all other fluorescent twist and pin base lamps.

Less common lamp types included filament-type halogen (**HAL**), incandescent (**INC**) bulbs, and high-intensity discharge metal halide (**HID-MH**) lights. Although halogen and incandescent bulbs were not common and mostly observed in interior retail and multifamily applications, HID-MH lights rarely had interior applications, but continue to be an exterior lighting strategy in the surveyed building types.

As shown in Table 17, Office buildings were found to have the highest level of LEDs at 85%, compared to Retail at just over 30%. Note that INC/HID-MH lighting sources are prohibited from use in *exterior* lighting, with some exceptions, although the code does not mention interior applications. In this study, these lamp types represented only a very small percentage of the overall installed Watts.

Table 17. Interior Lamp Types as % of Interior Watts

Lamp Type Interior	Multifamily	Office	Retail	School
LED Integrated	38.9	42.8	11.5	29.6
LED Linear	0.6	40.7	16.1	12.3
LED	0.3	1.5	2.7	0.3
T5	10.0	1.2	6.5	9.6
T8	23.6	13.4	42.4	40.7
CFL	12.6	0.2	4.2	6.0
HAL	1.6	0.0	1.5	0.0
HID-MH	0.0	0.0	2.0	0.0
INC	0.4	0.0	4.9	0.0
Other/Unknown	12.0	0.1	8.2	1.5

Table 18 examines interior lamp type by building type and participation in the Energy Trust New Buildings program.

Table 18. Interior Lamp Types (% Interior Watts) by New Buildings Program Participation

	Multifamily		Office		Retail		School	
NB Program Participation?	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
LED Integrated	38.9	--	54.8	0.9	10.7	12.3	22.6	34.3
LED Linear	0.6	--	40.7	40.8	29.7	0.7	29.8	0.3
LED	0.3	--	0.9	3.8	3.6	1.8	0.8	0.0
T5	10.0	--	0.0	5.5	5.2	8.0	4.8	13.1
T8	23.6	--	3.4	48.2	27.2	59.7	32.8	45.9
CFL	12.6	--	0.0	0.8	3.1	5.5	6.8	5.4
HAL	1.6	--	0.0	0.0	0.9	2.0	0.0	0.0
HID-MH	0.0	--	0.0	0.0	3.7	0.0	0.0	0.0
INC	0.4	--	0.0	0.0	9.2	0.0	0.0	0.0
Other/Unknown	12.0	--	0.1	0.0	6.7	9.9	2.3	1.0

Although many building types show both participants and non-participants installing LED-type lamps, participants do have more LEDs, while linear fluorescents are more commonly installed in market baseline buildings. Not all New Building program participants include lighting in their implemented measures; approximately 30% did not pursue lighting upgrades.

Table 19 breaks down interior lighting power density (LPD) allowance and actual interior and exterior LPD across building types. The actual interior LPD is well below code allowance for all building types. This demonstrates an opportunity to further reduce LPD code allowances to meet current practices. Further, as suggested by Table 17, there is still more opportunity to tighten LPD code allowances because there are still opportunities to install LED lamps. The 2002-2004 Baseline Study showed Office LPD at 1.01 W/ft^2 and Retail LPD at 1.38, both around 40 percent higher than the average today. Expressing exterior lighting power in terms of interior floor area is a somewhat strange approach but it has a distinct advantage of being comparable with interior LPD. The aggregate LPD is then the total lighting power associated with the building normalized by building area.

Table 19. Allowed and Actual LPD Across Building Types

LPD (W/ft^2)	Multifamily	Office	Retail	School
Interior LPD Code Allowance	**0.58**	**0.91**	**1.32**	**1.01**
Interior LPD	0.41	0.62	0.81	0.84
Exterior Parking LPD	0.04	0.21	0.29	0.03
Exterior Non-Parking LPD	0.02	0.03	0.16	0.03
Aggregate LPD	0.45	0.82	1.03	0.86

The following table examines LPD metrics across New Building program participants and non-participants. Schools show lower LPD for participants while, curiously, Office participants have a higher LPD.

Table 20. Allowed and Actual LPD by ETO New Building Program Participation

	Multifamily		Office		Retail		School	
NB Program Participation:	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Interior LPD Code Allowance	**0.58**	**0.58**	**0.91**	**0.91**	**1.32**	**1.32**	**1.01**	**1.01**
Interior LPD	0.41	--	0.73	0.49	0.82	0.80	0.71	1.01
Aggregate LPD	0.45	--	0.81	0.84	1.01	1.04	0.71	1.06

Exterior LPD not included due to sample size limitations

Lighting control strategies were varied. In many cases, a given fixture may have multiple lighting controls. For example, lights in an office may have occupancy sensors, but may also have a manual switch. For the purposes of this report, we assigned control type based on primacy. That is, the “most local” control to the fixture was given precedence. The order of precedence used in selection is in the following control category list.

- **Occupancy** captures both occupancy and vacancy sensors that control light operation based on the presence or absence of occupants. These controls were common in School and Office settings in classrooms, enclosed offices, and other enclosed spaces.
- **Daylight** controls reduce lighting energy requirements by dimming or turning lights off when sensors detect sufficient ambient light from natural or other nearby artificial light sources. This strategy can be combined with occupancy sensors; in which case, fixtures were designated as having **occupancy and daylight** controls.
- **Central** controls include building system or light-panel level control to program light operation based on daily or weekly schedules. Central controls are a common strategy in Retail and Office settings for corridors and common areas, but were also used in some Schools, for corridors, gyms, food preparation or dining areas, and performance spaces.
- **Timer Dials** are similar to manual switches, but they differ in that the occupant selects a duration of occupancy as they turn on the light. At the end of the timer period, the lights switch off whether or not the occupant is still in the room. These were not commonly encountered but did appear in a single Multifamily building as controls for in-unit kitchens as well as building storage areas.
- **Manual Switch** controls are typically wall switches used by occupants to turn a light on or off. These were frequently found in Multifamily and Retail applications but were not entirely absent from other building use types.

- **Hardwired** fixtures do not have a switch of any kind and are always on. Some Multifamily common spaces, corridors, as well as service areas (e.g., electrical rooms, resident storage) had hardwired fixtures, but they were also found in other building use types.
- The **Other** category was reserved for cases that were not categorized above but also include sensing switches that were not attributed to daylight or occupancy sensors, and a few fixtures in a single office building with luminaire level lighting control.

The code pushes Office and School building types towards more controls. Multifamily and Retail are often exempt from several lighting control requirements. Although contiguous, single-tenant retail is exempt from providing local shutoff, and therefore exempt from light reduction controls, retail over 2,000 sf is still required to provide automatic lighting shutoff. As shown in Table 21, this seems to mainly manifest in use of a central controller. For Offices, manual control is nearly non-existent as the primary control. The majority of spaces for Office and School are primarily controlled with occupancy or some other automatic control.

Table 21. Primary Interior Lighting Control as % of Total Interior Watts

Primary Interior Lighting Control	Multifamily	Office	Retail	School
Occupancy	10.6	63.2	13.6	56.2
Daylight	1.2	0.6	0.2	3.2
Occupancy and Daylight	0.1	12.1	0.0	14.1
Manual Switch	73.2	2.2	33.7	12.1
Central	0.1	21.6	49.6	13.8
Hardwired	11.5	0.3	0.1	0.3
Timer Dial	0.4	0.0	0.0	0.0
Other	0.5	0.0	2.8	0.2
Unknown	2.5	0.0	0.0	0.0

3. Code Compliance

3.1. Compliance Assessment Methodology

The compliance assessment evaluated components at the building system level: mechanical (HVAC), hot water (domestic and service), envelope, and lighting (exterior and interior). Each of the categories were further broken down into subcategories such as equipment efficiency and lighting controls. Analysts then manually compared the subcategories to code requirements to record a yes/no for each. Refer to Table 22 for list of categories and associated subcategories.

After the subcategories had been assessed, a broader view of compliance was reached through several ways including (1) an aggregate, binary logic approach and (2) an overall look at all the subcategories. For a building to show code compliance with the binary logic approach, all subcategories within a category must comply and all categories within a building must comply. This effectively treats the building as a unit of study answering the question: How many buildings comply with code? The second view, an overall look at all the subcategories effectively examines the building market as the unit of study. It answers the question: What parts of code are being followed and what parts are not?

An obvious drawback to the binary logic approach is that it can lead to overly simplified conclusions. For example, even if the interior lighting power density at a site complied, if a single control for a lighting zone was missing, the entire lighting system was listed as non-compliant. The omitted lighting control's impact on energy use is very modest, yet the building's interior lighting system would not pass. To ameliorate some of the drawbacks, we assessed compliance both in a "strict" and "lenient" sense. In the lenient cases, we allowed some "near misses" to pass if they were judged to be close enough and have minimal impact on energy use.

Likewise, a drawback of the overall subcategory view is that it treats each point as equivalent when their energy impacts may differ. For instance, non-compliance in the first eight feet of hot water pipe insulation has a far smaller impact than non-compliance in total building envelope UA. Future studies may decide to weight the relative energy importance of each code requirement in an attempt to more evenly assess compliance. That would be the most beneficial when examining compliance at the whole building level. Nevertheless, this overall subcategory view remains useful in providing insight to determine if a particular building system should draw attention for code development, enforcement, training, or efficiency program work.

Last, following recommendations in the Pilot Study, all compliance was assessed on a prescriptive basis, regardless of whether buildings were permitted via the targeted performance path (Storm, 2016). This approach provides a clear picture of both category-level and subcategory-level compliance. It is also an expedient approach because the actual simulations and documentations, for a target performance approach, were rarely available for review and no real compliance beyond the individual components could be assessed.

3.1.1. 2010 and 2014 Codes Compared

All compliance categories were assessed against the 2010 or 2014 Oregon Energy Efficiency Specialty Code's prescriptive requirements - whichever it was determined the building was permitted under. Overall, most aspects of the Oregon Energy Efficiency Specialty Code remained consistent from 2010 to 2014 version. Interior and exterior LPD allowances, lighting control, and envelope remained the same. Modifications to the code, impacting the building systems we evaluated, were only for the following HVAC equipment efficiencies:

- Increased minimum EER cooling efficiencies for PTAC/PTHP
- Changed minimum EER efficiency ratings for AC-water cooled and AC-evaporative cooled units
- Increased heating and cooling efficiencies for air source heat pumps (ASHP), split or packaged with less than 65 kBtu/hr capacity
- The 2010 code does not discuss VRF systems; the 2014 code has a table of minimum efficiency requirements

3.1.2. Compliance Criteria

For each of the areas of compliance (mechanical, service water, lighting, and envelope), the plan review and on-site survey data were compared against the code requirements. The first pass of compliance used a strict interpretation of the code, with margins for imprecision in data collection. Lenient compliance was introduced to further handle subcategory failures that were believed to have low impact on energy usage and yet led to category and overall site failures.

Within each overall category, the following were assessed:

- Mechanical
  - *HVAC Equipment Efficiency* – Do equipment efficiencies, found in documents, on-site, or cutsheets, meet code requirements?
  - *Economizer* – Required for air handling units with nominal cooling capacity greater than 54kBtu/hr.
  - *Fan HP* – Do fans over 1 HP meet code requirements?
- Service and Domestic Hot Water
  - *DHW Equipment Efficiency* – Did equipment efficiencies, found in documents, on-site, or cutsheets, meet code requirements?
  - *Pump Controls* – Did systems with recirculation loops have pump controls?
  - *Pipe Insulation* – Systems with recirculation loop required pipe insulation.
- Interior Lighting
  - *Interior LPD* – Is measured LPD within 10% of code LPD allowance?
  - *Interior Lighting Controls* – If occupancy and/or daylighting are reported, assess if the controls are applied to the correct spaces and as required. If none, check if spaces in building are exempt.
- Exterior Lighting
  - *Exterior LPD* – Is measured LPD within 10% of code LPD allowance?
  - *Exterior Façade LPD* – Is measured LPD within code façade LPD allowance?

  - *Exterior Lighting Controls* – If some type of exterior lighting control is reported, system passes. If reported control was none, manual, or on 24/7, then system fails.

- Thermal Envelope
  - *Total UA* – Is actual UA within 10% of calculated code UA? We used a "Total UA" target approach which allows envelope components to be traded off against one another as long as the total UA is within the code target. The component trade-off approach effectively supersedes window and skylight ratios, so it controlled for overall envelope compliance although both window and skylight ratios were independently assessed.
  - *Window Ratio* – Is measured window-to-wall ratio within 1% code maximum?
  - *Skylight Ratio* – Is measured skylight-to-roof ratio <= code maximum?

Potential compliance responses were as follows:

- Yes – passed prescriptively
- No – failed prescriptively
- Unknown – information could not be observed in field or from plan set documentation
- Not applicable (NA) – subcategory did not apply to that building or system

An unknown response in a subcategory did not preclude a site from complying; effectively it was a pass. If all subcategories were unknown, then the category was also unknown. Compliance rates were assessed based on the amount of known and applicable responses. Not applicable and unknown responses were excluded from the total when calculating rates.

As noted, some categories were allowed a margin to account for imprecision in the field survey. For UA, if a building had a heat loss rate found to be within 10% over the allowance, it was compliant. Similarly, interior and exterior LPD were allowed a 10% margin. Window area was given a 1% margin over code allowance. Other categories, such as skylight area, were held at a strict line due to the high level of accuracy in plans, the low allowance, and negligible number of near misses.

3.1.2.1. Relaxed Criteria

The criteria discussed above were utilized to determine "strict" compliance. It was a strict interpretation of the code, with some margins for imprecision in data collection. Lenient compliance was introduced to further handle subcategory failures that were believed to have low impact on energy usage and yet led to category and overall site failures. The lenient pass option allowed near misses to be counted as compliant. The following subcategories were relaxed as such:

- *Total UA* – Allowed 10% above code
- *Exterior LPD* – Allowed 10% above code
- *Exterior Building Façade Lighting Power* – Allowed 10% above code
- *Interior LPD* – Allowed 10% above code

- *DHW Pump Controls* – Allowed to have none in all cases. (See Section 3.2.3.2 for rationale)

Ecotope considered relaxing the requirements in other areas but we often found that doing so would have no change in the compliance. In other words, the non-compliant features were well beyond a small relaxation of the requirements.

3.2. Compliance Findings

3.2.1. Overall Compliance

3.2.1.1. Overall Binary Logic Compliance

The overall compliance findings are summarized in Figure 7. Each building system contains compliance subcategories, which are discussed in the following subsections. Using the compliance logic discussed previously, where if any subcomponent did not meet the code, then the overall system did not meet the code—and the overall building did not meet the code—can provide a pessimistic view of compliance. It leaves no room for near misses and has other previously discussed drawbacks.

Nevertheless, this type of graph is useful in showing some general trends: Schools showed the highest rate of compliance, with Multifamily showing the lowest; interior lighting was the highest complying building system; otherwise, compliance was relatively evenly distributed across building types and systems. A closer assessment shows there were many near misses on compliance with relatively few "large misses." More context is provided in the following sections.

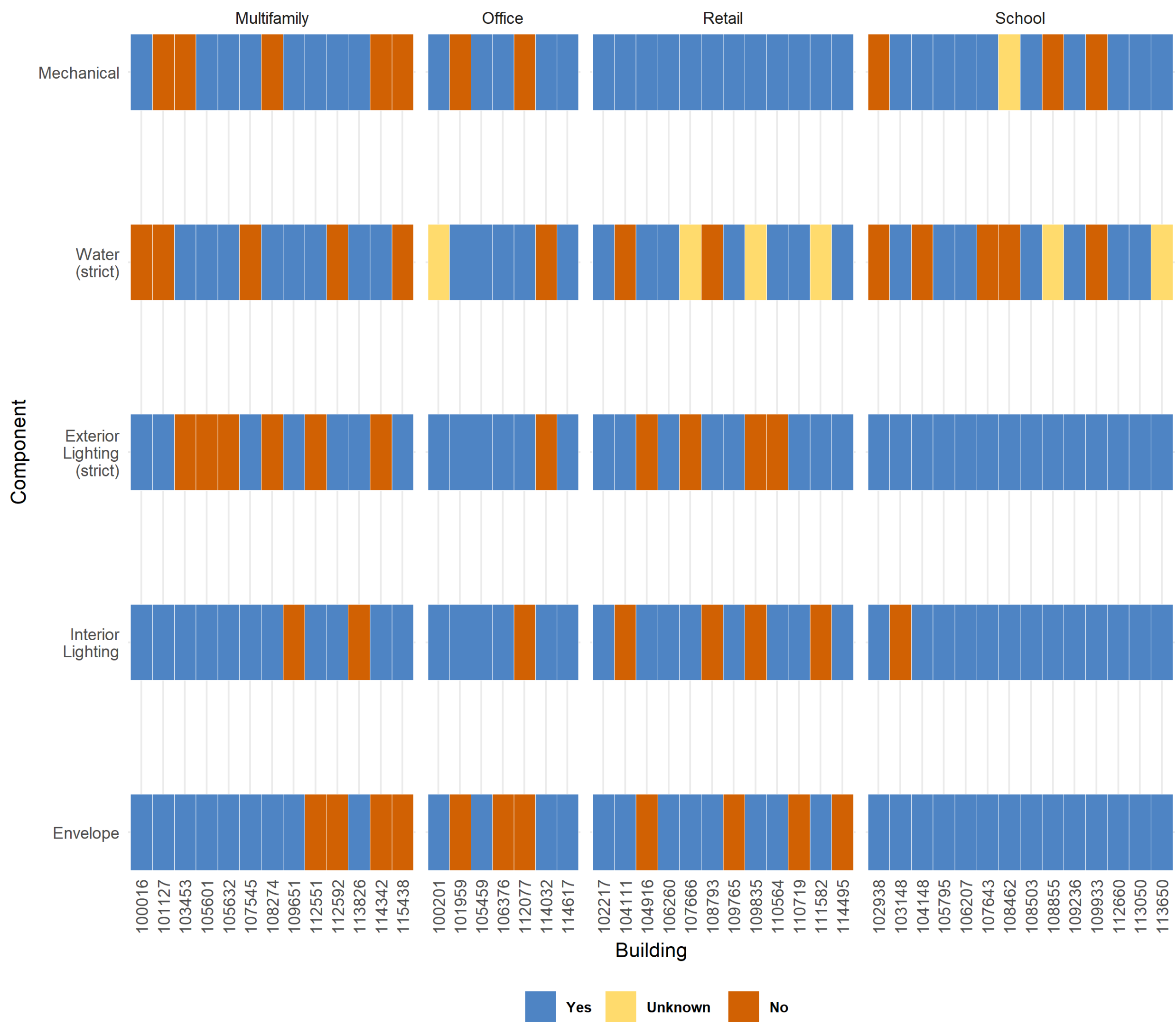


Figure 7. Overall Compliance – Strict – Binary Logic Approach

3.2.1.2. Overall Subcategory Compliance

Another look at summary compliance is the overall subcategory view. In all, analysts considered compliance at 644 individual points (14 subcategories across 46 buildings). We found the strict compliance rate to be 89% across all subcategories. (There were 115 not applicable cases and 30 unknowns.) Table 22 shows the breakdown by subcategory. This approach treats all subsystems with equal importance in a "checklist" fashion. Compared to the binary logic approach applied at the individual building level, it shows that the vast majority of systems across the building market comply with code. Overall, compliance by subcategory generally stays around 90% with the exceptions of pump controls (63%) and economizers (83%). The rate for window/wall ratio at only 83% is likely irrelevant since Total UA compliance is at 91%. (See Thermal Envelope discussion in Section 3.1.2).

Table 22. Overall Compliance View by Building System Subcategory

Category	Subcategory	Yes	No	NA	UNK	Comply Rate (Strict)
Mechanical	Equipment Efficiency	39	5	0	2	89%
	Economizers	29	6	11	0	83%
	Fans	17	0	28	1	100%
Service Water Heating	Equipment Efficiency	35	0	0	11	100%
	Pipe Insulation	28	3	12	3	90%
	Pump Controls	17	10	12	7	63%
Envelope	Total UA	42	4	0	0	91%
	Window / Wall Ratio	38	8	0	0	83%
	Skylight / Ceiling Ratio	12	1	33	0	92%
Interior Lighting	Controls	44	2	0	0	96%
	Lighting Power Density	40	6	0	0	87%
Exterior Lighting	Controls	38	2	2	4	95%
	Exterior Lighting Power	37	6	2	1	86%
	Façade Lighting Power	27	3	15	1	90%
Overall	**--**	**443**	**56**	**115**	**30**	**89%**

The high compliance rate at the subcategory level reveals an additional, important finding: since the vast majority of the code provisions were met, it is highly likely builders, designers, architects, engineers, etc., were paying close attention to the code. Causation cannot be demonstrated this way, but there does seem to be a clear correlation between the code and building design choices. Further, we did not find buildings where all, or most, of the categories did not comply, which might be the case if there were complete ignorance of the code. In current times, given the accepted role of building departments and inspectors, we think active attempts to circumvent the code are unlikely.

3.2.2. Mechanical (HVAC)

The primary criteria for evaluation of mechanical system compliance were the following:

1. Minimum required equipment efficiencies (SEER, HSPF, AFUE, etc.) for all HVAC systems in the building
2. Presence of air-side economizers (where required)
3. Fan efficiency (for larger horsepower systems)

System controls (thermostats, occupied/unoccupied settings, optimal start, etc.) were also evaluated for each system at each building. Overall time constraints on site dictated the study team focus on the more basic aspects of whether thermostatic controls were in place and whether there was the opportunity for the settings to be enabled. It was generally not practical to do a deeper review of control system settings relative to their code requirements. Within those constraints, the study team did not find notable non-compliance, with an exception being unusual operating schedules at some sites.

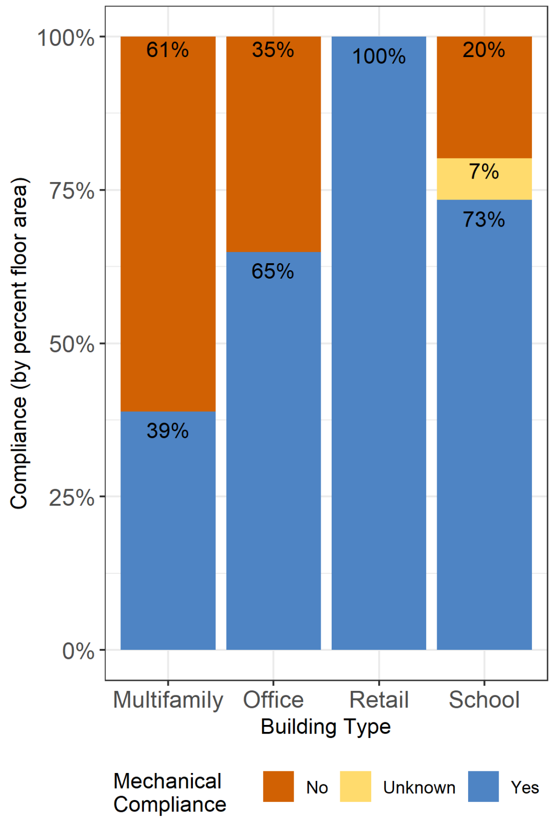


Figure 8. HVAC Compliance – Strict (% Floor Area)

Equipment efficiencies (SEER, AFUE, etc.) were largely compliant and buildings that failed typically did so due to one system. Table 23 breaks down the types of HVAC equipment evaluated and the compliance response. Each column sums to the total number of buildings in the study. For example, under PTAC/PTHP, 9 out of 10 possible buildings complied based on review of all PTAC/PTHP systems at these buildings. Most buildings did not have these systems, so there are many NA cases under this HVAC type. Also, because of limited access at some sites, the nameplate efficiencies could not always be evaluated (with 'furnaces/unit heaters' making up the largest group here).

Economizers were the most commonly failed HVAC component. This was a perplexing miss, as economizers are widely available and are generally incorporated into air-handling units. Nor was there any change in requirements between the 2010 and 2014 energy codes.

There was a high rate of compliance with some of the more commonly found systems, such as AC which was found in 43 of the 46 buildings and only had 1 failure. Air source heat pumps did not meet minimum standards at two School buildings. Other equipment efficiency failures were for a chiller in an Office, and, in Multifamily, an AC and a PTAC/PTHP.

Table 23. Equipment Efficiency Compliance by Building Count

	Furnaces & Unit Heaters	PTAC & PTHP	AC	Air Source Heat Pump	Large Cooling (chiller/cooling tower)	VRF	Boilers
Yes	20	9	34	18	7	1	13
No	0	1	1	2	1	0	0
Unknown	10	0	8	4	0	4	1
NA	16	36	3	22	38	41	32

3.2.3. Service and Domestic Water Heating

The water heating portion of the energy code consists mainly of three areas as it applies to the building types studied: equipment efficiency, pipe insulation, and temperature maintenance control in distribution systems (i.e. recirculation loops).

3.2.3.1. Water Heating Equipment Efficiency and Pipe Insulation

Unsurprisingly, the study found all water heating equipment complied with minimum efficiency requirements. The code requirements are the federal minimums and lower efficiency equipment is not allowed to be sold in the country.

All automatically circulating water loops are required to have pipe insulation (~R-4) whereas non-recirculating systems were required to have pipe insulation installed within 8 ft of the water heater only if no heat trap was installed. Modern water heaters were assumed to have an integrated heat trap and therefore did not require pipe insulation. Since most pipe is routed behind walls, the field teams could only verify the exposed portion of the piping and review the plans. If plans called for insulation and the visible pipe portions had insulation, the building was deemed in compliance. When applicable, 90 percent of the buildings complied with the requirement. All Multifamily and Schools complied, with only one Office and two Retail establishments missing insulation.

3.2.3.2. Temperature Maintenance Controls

The controls for circulation loops and temperature maintenance showed the lowest compliance rate of any subcategory in the study at 63%. The code states the system “shall have demand sensing controls.” Ecotope used a broad definition of controls, allowing any type of control (timer, pressure, temperature, etc.) to count as a pass. In many of the Multifamily and School buildings, no control was found. Circulation loops are less common in Office and Retail buildings and those systems, when found, did have controls.

For the lenient assessment, Ecotope opted to ignore the controls requirement for two reasons. First, since it was the least complying category, it offers a “what if” analysis: what does the overall compliance look like if all the controls complied? Second, based on Ecotope’s direct engineering experience, there is a good reason these controls were not present in certain buildings: turning off the temperature maintenance of a hot water delivery system at inappropriate times can result in inadequate delivery temperature to the point of use. Plumbers and building designers are aware of hot water delivery time constraints because, if temperature maintenance is inadequate, residents complain about not being able to get hot water in any reasonable amount of time.

The reason pumps cannot be turned off is as follows: Plumbing design requires pipes to be sized for peak flow events – when many fixtures on the same distribution pipe are in simultaneous use. That leads to distribution (riser) pipe diameters from one to several inches depending on end uses present. Spread out from tens to hundreds of feet in a building, that creates a significant volume of water in the piping. If the circulation pump is turned off and the water allowed to cool, in excess of the entire pipe volume (nominally 1.5 times) must be cleared before it is possible to provide hot water at the farthest fixtures from the water heater. Even in the best case (where only tens of gallons are contained in the distribution pipe volume), it will still take several minutes for a typical 5-10 gallon per minute (gpm) pump to clear the cold water. In more typical cases, it takes even longer. It is not possible to increase the pump size to, say 20-100 gpm because then the pipe diameter would need to be increased to allow the higher flow rate which in turn requires a bigger pump and larger pipe diameter.

Being able to successfully turn off a circulation pump depends on the hot water use schedule of the building. With highly regimented occupancy schedules, like schools, pumps may be controlled to turn off at night or on weekends with little negative effect on hot water delivery to users. Still, there is a risk that cold showers are provided for slightly off-schedule athletic activities or that people consistently wash hands in cool water in bathrooms because there is never enough flow for warm water to reach the fixture

In contrast to the highly regimented buildings, those with near constant hot water use (or use at least every hour), like the medium and large-scale multifamily buildings studied, there is little opportunity to turn off the pump. Measurements of hot water use from recently built 92-unit and 118-unit buildings in Seattle showed that someone in the building was using hot water nearly around the clock, even at 3 AM (Heller, 2015). There were some nights where no water was used for several hours, but not every night, and knowing the non-use nights *a priori* is likely not possible. Ecotope observed similar behavior in 3, 18-unit buildings (currently unpublished).[5] More study is needed to draw a conclusive finding; however, the data so far allow us to leniently pass a lack of pump controls.

Overall, Figure 9 shows the compliance by hot water subcategory. It displays the strict interpretation of code. If we relax the requirement of pump controls, that entire row comes into compliance and total hot water compliance increases to 93 percent, with only three non-complies in pipe insulation. Figure 10 shows the binary compliance approach assessed in terms of building floor area.

[5] Clearly, in a single occupant building, there is a time when that person is sleeping so the temperature maintenance system can be shut off. As the number of occupants increases to two to ten to twenty and beyond, the use patterns spread out, making it no longer feasible to turn off temperature maintenance. Further, there is little to no energy savings to be had by turning the system off for sub hourly periods because the temperature in the pipes changes little. Note that a better option for reducing pump energy is installing a variable frequency drive. Likewise, increasing the insulation on the distribution system is a better option.

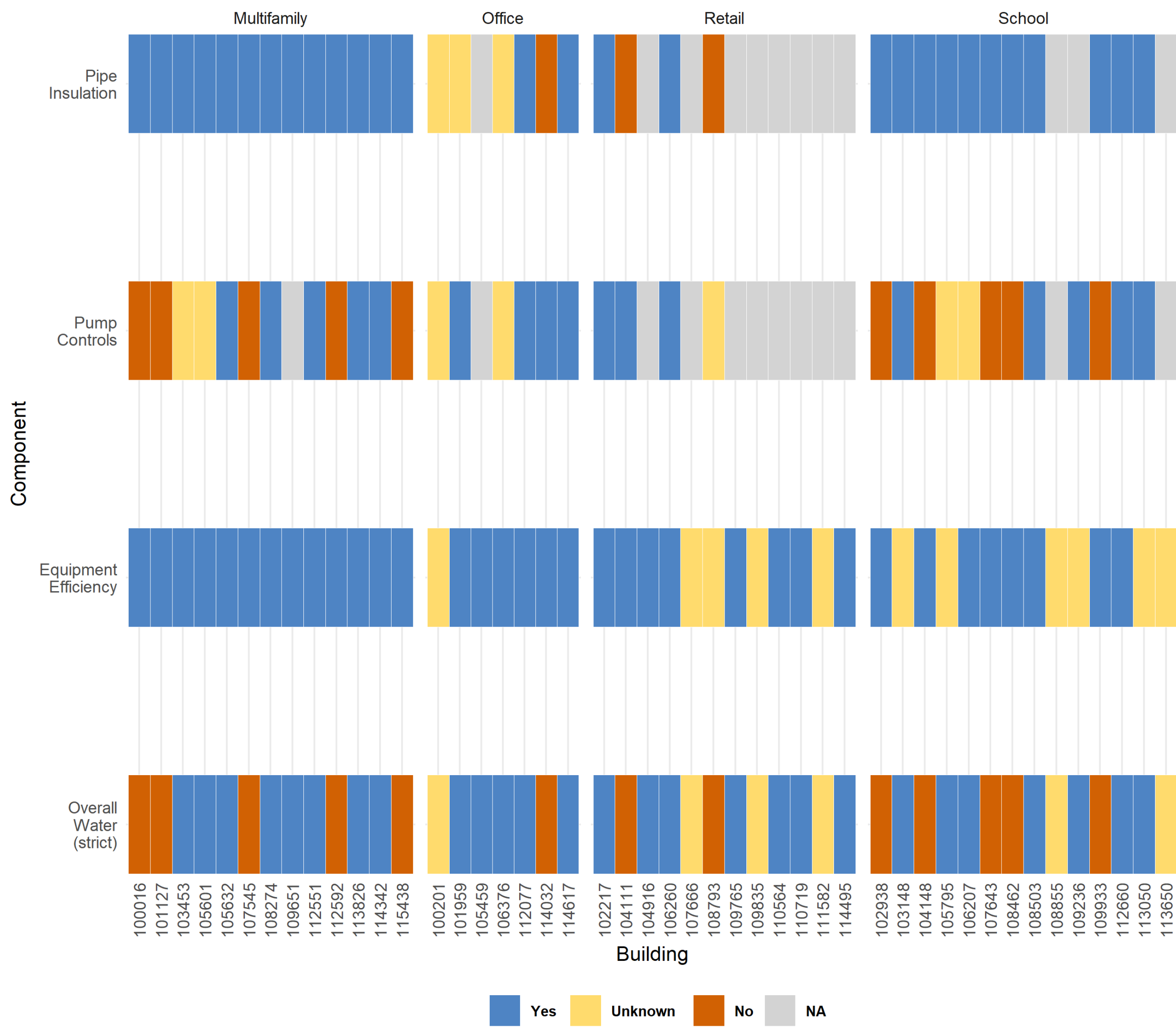


Figure 9. Service/Domestic Water Heating Compliance (strict)

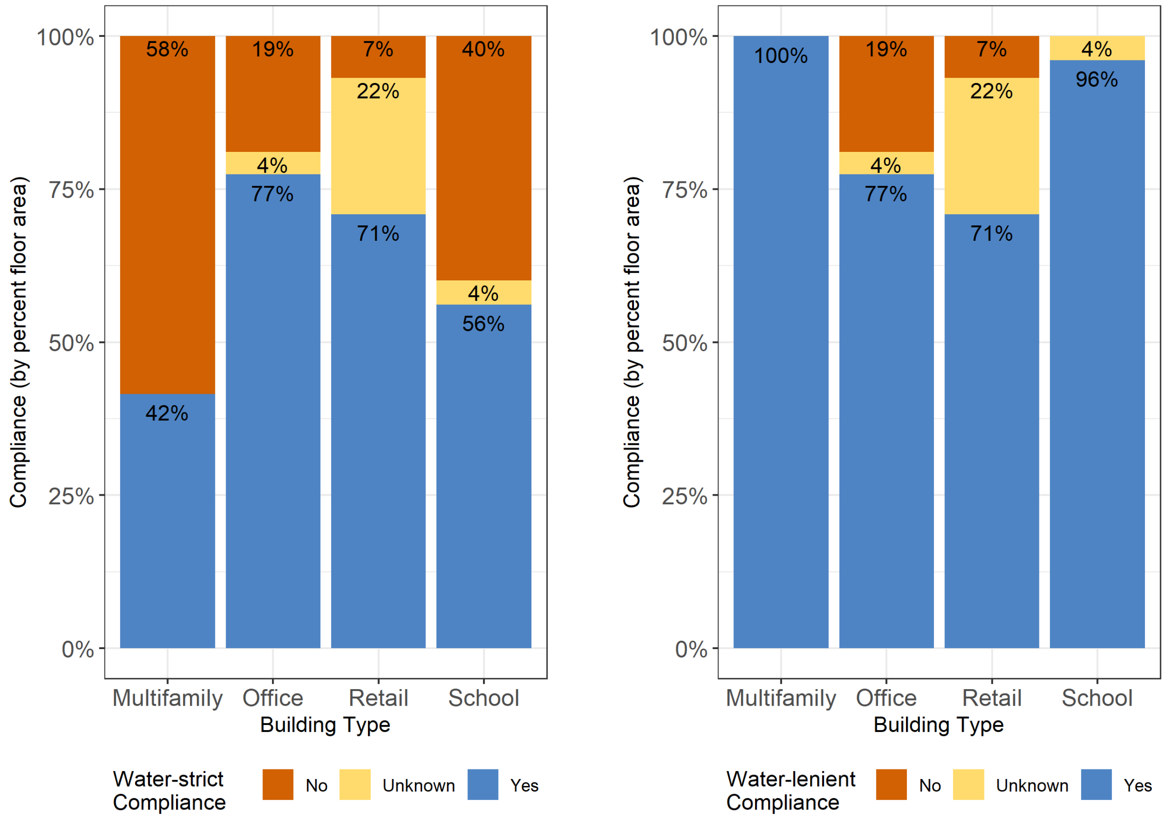


Figure 10. Service/Domestic Water Heating Compliance – Strict and Lenient (% Floor Area)

3.2.4. Lighting

Lighting system compliance was assessed for both interior and exterior lighting systems. In general, surveyed buildings had high compliance rates for both interior and exterior lighting power requirements.

3.2.4.1. Interior Lighting

Surveyed buildings were assessed for interior lighting power density (W/ft^2) and the presence of interior lighting controls (e.g., local shutoffs, occupancy sensors, and light reduction) when required. Figure 11 shows the subcomponent compliance for interior lighting using strict criteria. Lighting controls were almost always present when required, with only two buildings lacking required occupancy sensors, and one of those buildings also lacking required lighting reduction. Additionally, few buildings exceeded the allowable lighting power density by building use type.

Under strict criteria, 85% of visited buildings met compliance requirements for interior lighting. Compliance by percent floor area is shown in Figure 12. Lenient compliance used an interior LPD threshold 10% higher than code allowances. Relaxed criteria allowed only the non-compliant Office building to comply, which would bring the Office building type to 100% compliance by area (see Figure 12), but it also demonstrates that non-complying interior LPD's generally exceeded code allowances by more than 10%, which can be seen in

Figure 13.

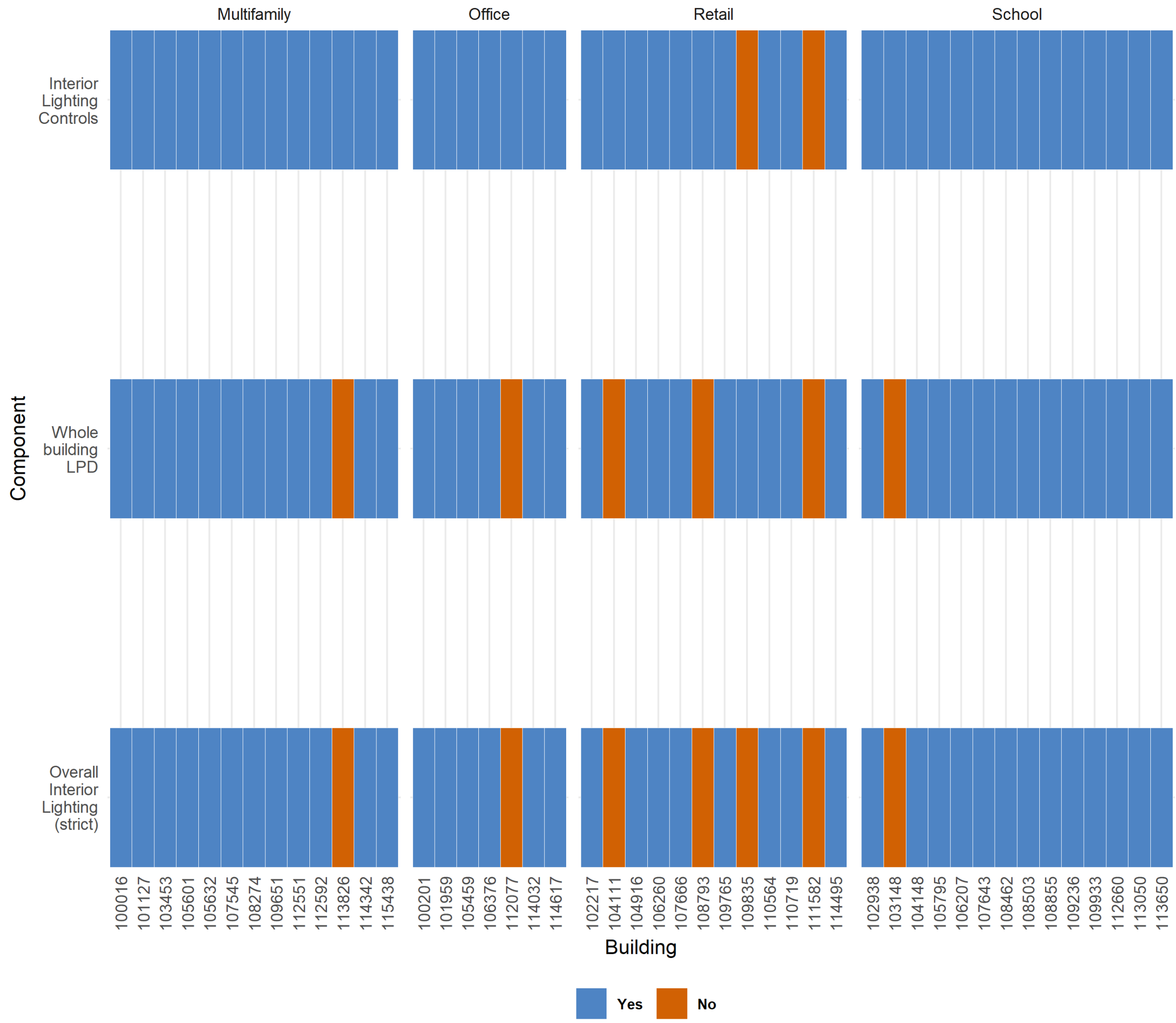
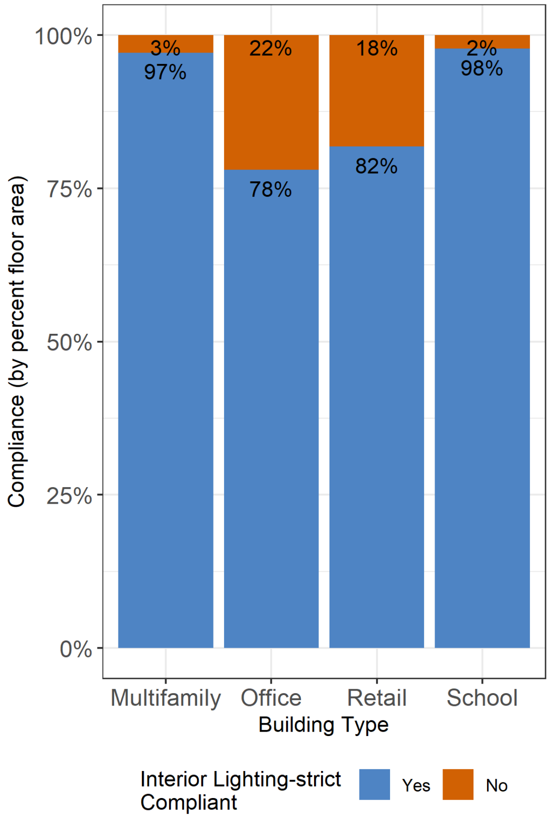


Figure 11. Interior Lighting Compliance – Strict



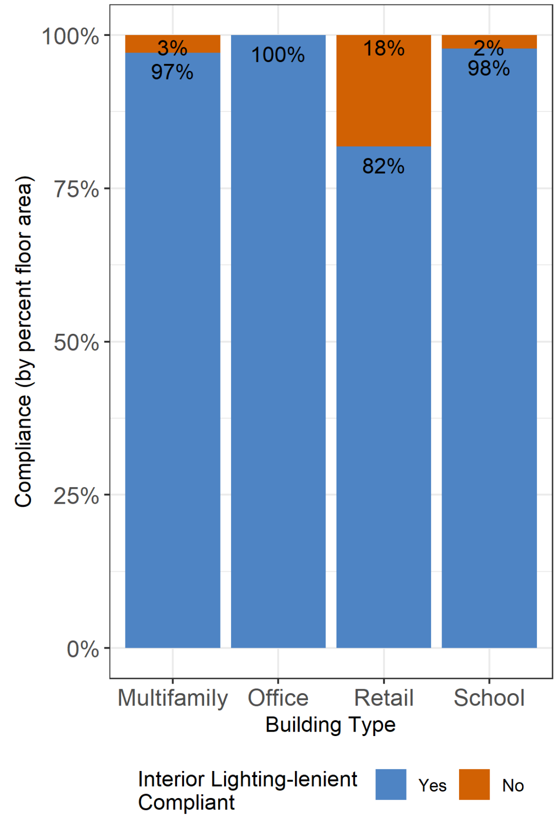


Figure 12. Interior Lighting Compliance – Strict and Lenient (% Floor Area)

The surveyed lighting power density of each building is provided relative to the OEESC allowance for that building use type in

Figure 13. Note that with one multifamily and one school building, the LPD exceed the code allowance by less than 10% and these buildings were deemed to pass (in Figure 11) due to possible measurement imprecision. With few exceptions, most surveyed buildings had interior lighting power densities well below the allowable threshold. For example, although three of 12 Retail buildings did not comply with interior lighting power requirements, and therefore had the lowest rate of compliance for this subcomponent, the Retail buildings that did comply had lighting power densities that were an average of 44% lower than the code allowance. Other buildings that complied with lighting power requirements for their building type were 29-38% less than provided allowances.

Retail buildings with LPDs that greatly exceeded their code allowances were a car dealership, which had twice as many lights installed as indicated on plans, and two agricultural supply stores. Although these supply stores had similarities to chain home improvement stores and 60% T8 fluorescent lighting, they effectively had no LED lighting. Moreover, roughly 30% of the interior wattage used to light the retail space was attributed to high power custom track lighting fixtures with per-lamp wattages approximately double that of a linear T8 – a system that could provide comparable light output at far lower energy input. As a result, their LPDs were almost twice similarly configured home improvement stores like Building 102217. Interestingly, 102217 and one of the agricultural supply stores were both Energy Trust of Oregon New Buildings participants. However, only the home improvement store had lighting measures implemented.

It is worth noting that linear fluorescent fixtures as well as LEDs were commonly installed at many of the compliant buildings. As LED fixtures become the predominant lighting technology used in new construction, even lower lighting power densities will be more easily achievable.

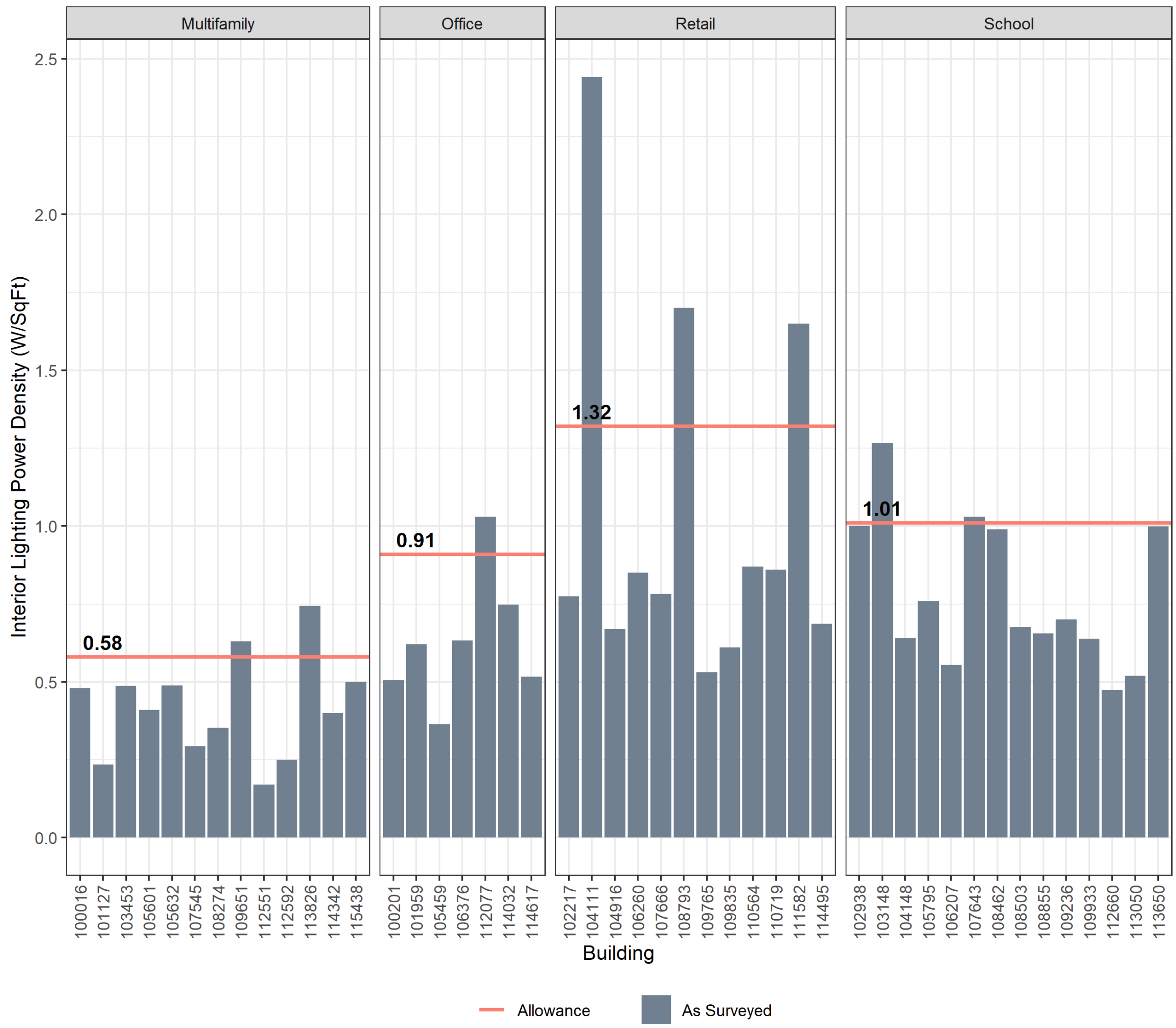


Figure 13. Interior Lighting Power Density

3.2.4.2. Exterior Lighting

OEESC requirements for exterior lighting include a base building allowance plus individual allowances for specific exterior use areas. The absence of incandescent or mercury vapor lighting sources (unless for an accepted area or use) and the presence of exterior lighting controls, where required, were also assessed in compliance screening. Exterior lighting power requirements were evaluated using both strict and lenient protocols. In the latter case, exterior lighting power density thresholds were relaxed.

No buildings had exterior incandescent or mercury vapor lighting sources, and only two building were lacking the appropriate photocell or timer controls. Relaxing the criteria for exterior lighting power density requirements allowed approximately 10% more buildings to be assessed as compliant. Subcomponent and overall exterior lighting compliance, as well as the effect of lenient criteria, can be seen in Figure 14 and Figure 15.

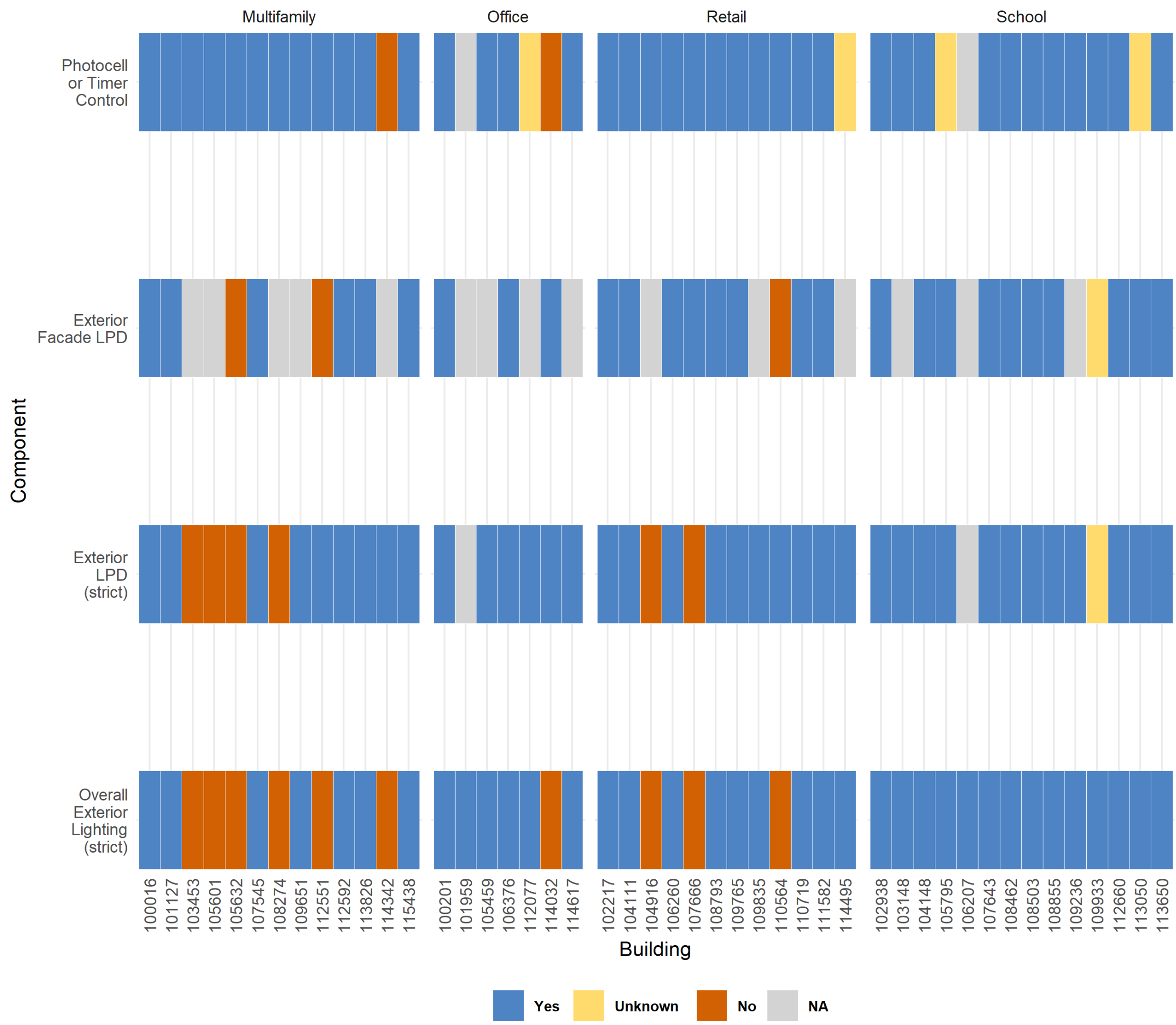
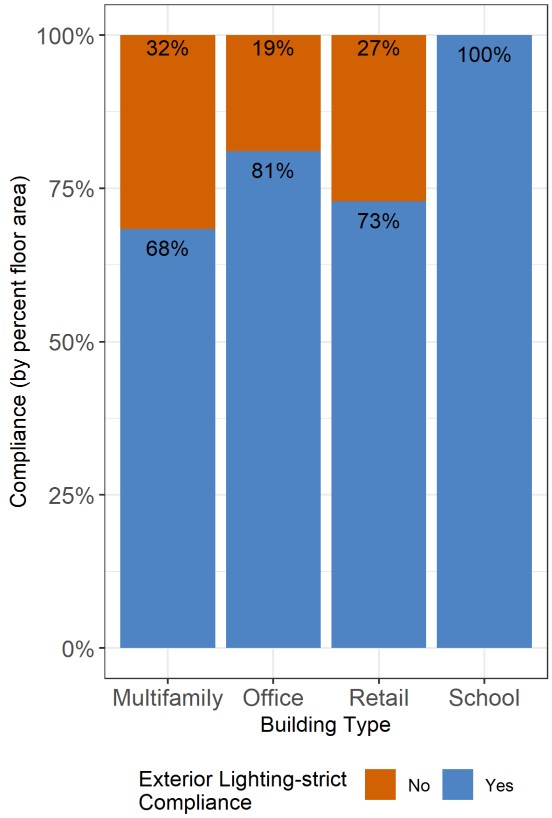


Figure 14. Exterior Lighting Compliance – Strict

The impact of strict versus lenient criteria by percent floor area is shown in Figure 15, with strict criteria on the left and lenient criteria on the right.



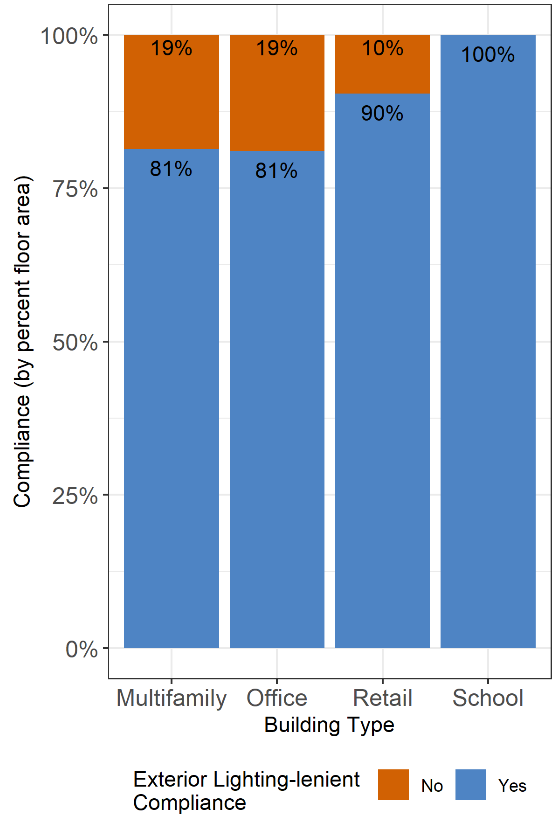


Figure 15. Exterior Lighting Compliance - Strict and Lenient (% Floor Area)

Figure 16 shows compliance with the exterior lighting allowance for the individual surveyed buildings. Exterior lighting was normalized by building area to make the buildings more comparable with one another and with the interior lighting power density summaries. Where the orange allowance line is below the top of the bar, the building exceeded the allowance. Comparing Figure 16 with Figure 14 gives insight into whether the allowance exceedance was sufficient to classify a building as non-compliant using strict compliance protocols. Schools and Offices had no exterior lighting allowance issues, but a handful of Multifamily and Retail buildings did. This was uncommon, and when it did occur, the building generally exceeded their allowance by a narrow margin. Lenient criteria allowed a single additional building from each Multifamily and Retail building types to be assessed as compliant.

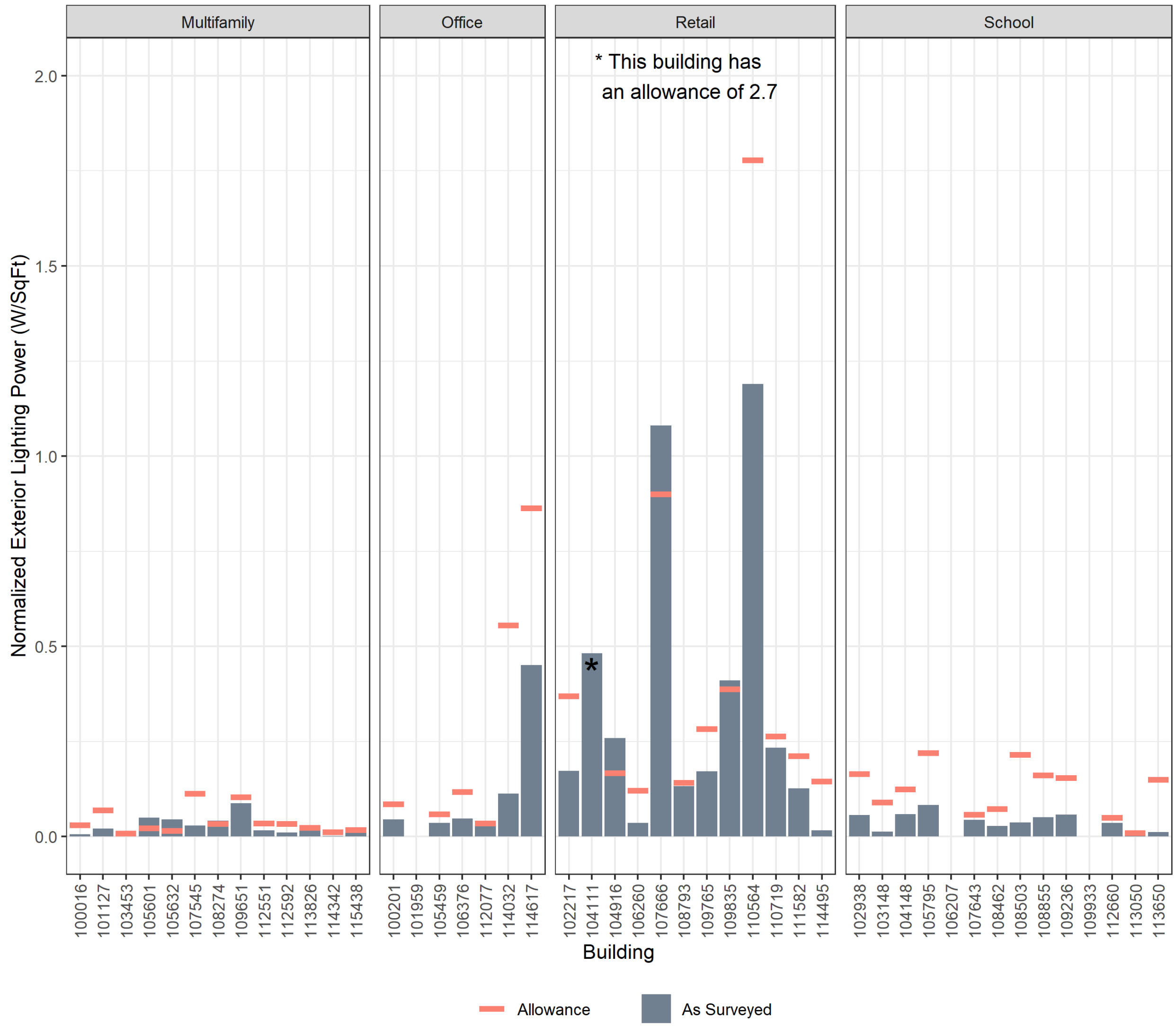


Figure 16. Exterior Lighting Power Normalized by Building Area

Even more so than interior lighting, LEDs were the predominant lighting technology for exterior areas (by exterior wattage). Multifamily buildings, which had the lowest compliance rate (70%) for this subcomponent, had the highest proportion of non-LED exterior wattage. However, even though compliance rates were higher in other building use sectors, targeting sectors with overall higher allowances for lowered thresholds may lead to more energy savings. The two Retail buildings that most exceeded their allowances included a car dealership and a car parts service station.

3.2.5. Envelope

The primary envelope compliance metric for all buildings is total building heat loss rate (UA). The Oregon commercial code also specifies maximum allowed window to wall area and skylight to roof areas. These ratios were calculated, but only the total UA was used to determine shell compliance, since it combines all shell features into one number and easily allows sites to be compared to a building that uses all of the maximum allowed U-values for opaque components and windows, along with actual component areas (that is, a building with a code-target UA).

Fewer than 30 percent of the buildings surveyed had skylights, and only one building exceeded the skylight to roof ratio. The window to wall ratio was more commonly exceeded. Eight buildings exceeded the allowed 30 percent window ratio, with five of those over 40 percent glazed. Office and Multifamily were the most commonly "overglazed" building types. This was likely compensated for in reduced U-values for windows and opaque components since only one of the "overglazed" buildings exceeded the code-allowed UA.

Figure 17 depicts the breakdown of envelope subcategory and overall envelope compliance using the UA comparison method. For the 'strict' compliance method, it is important to note that a 10% margin is used here to account for possible imprecisions in specific U-values assigned to opaque components and windows (and also to allow for some imprecision in measurement of conditioned floor area). Also note that in Figure 17 the envelope compliance is expressed using floor area weights, so larger buildings are depicted as having an overall greater influence on overall envelope compliance. Under the strict compliance method, all School and Office buildings comply; almost 20% of the Retail square footage does not comply.

As in other parts of the analysis, a second, more lenient method of evaluating compliance was employed on the thermal envelope. For lenient envelope compliance, an additional 10% was added to the target UA and the comparisons re-run. Using this method, almost all building square footage complies. The holdouts are buildings with higher glazing percentages and also that include a higher percentage of concrete masonry walls with limited insulation.

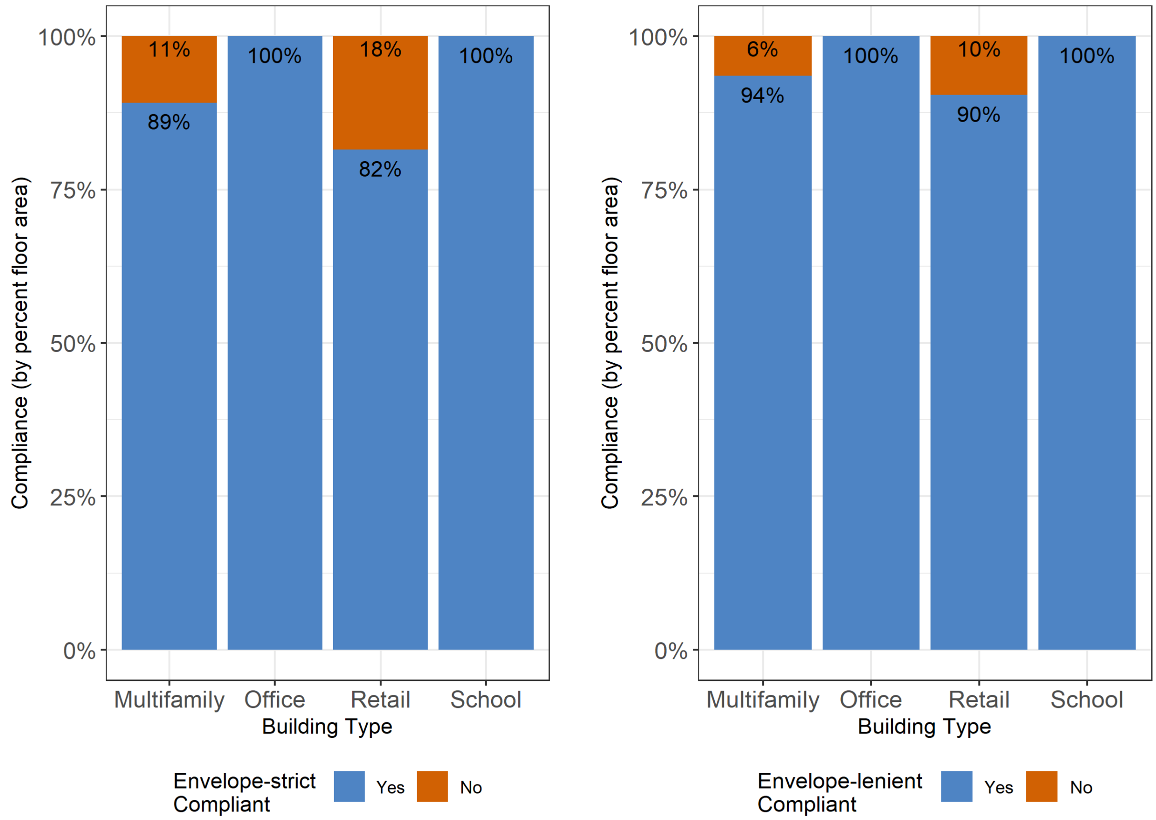


Figure 17. Envelope Compliance – Strict and Lenient (% Floor Area)

To further evaluate the envelope, the overall heat loss (U_o) of the entire building, divided by the entire skin area (walls, ceiling, and floor) was determined. Use of U_o allows easier comparison across all buildings, since the effect of building size is levelized. Total UA was also divided by conditioned floor area for a final comparison.

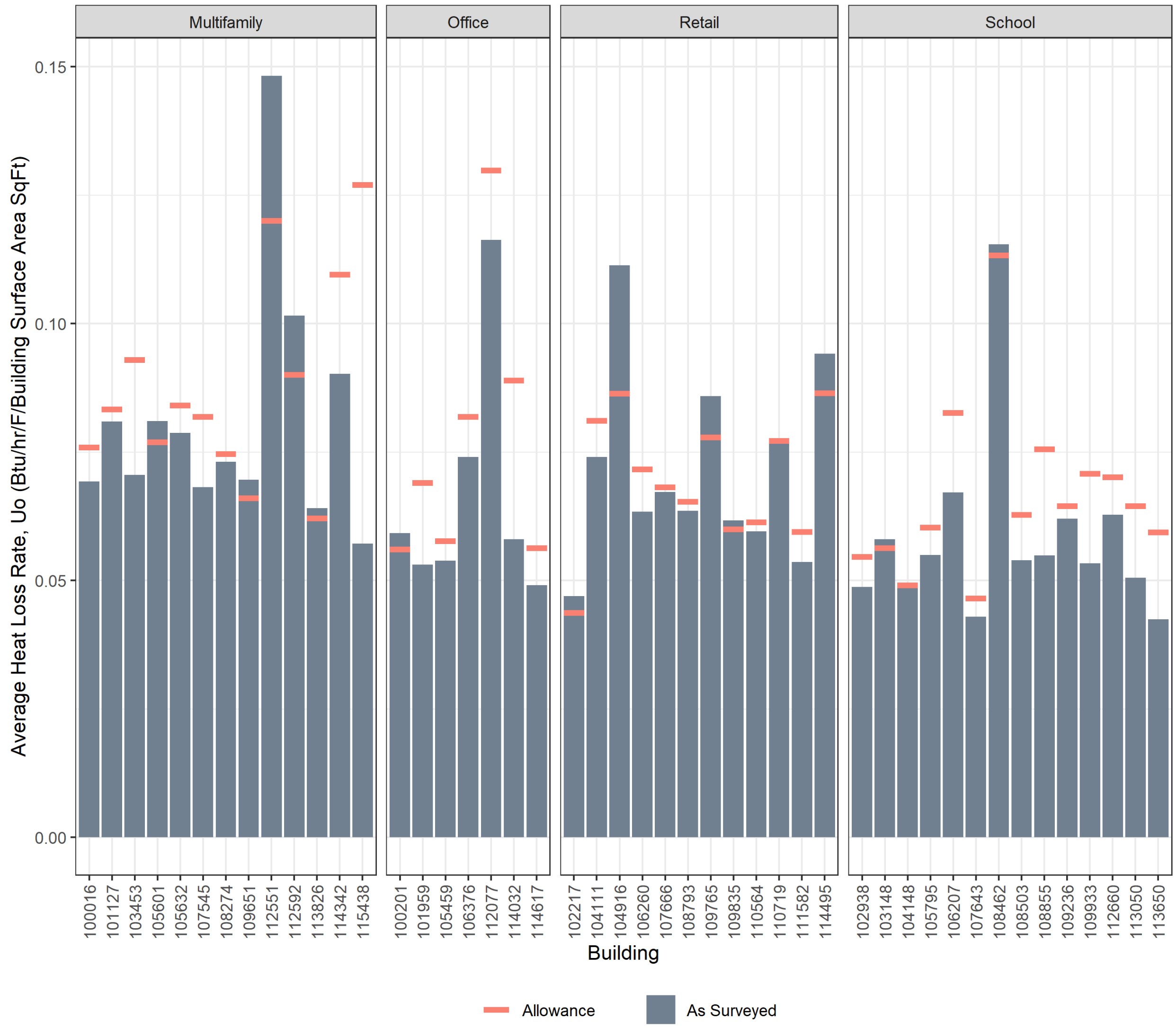


Figure 18. Overall Heat Loss Normalized by Total Building Surface Area (Uo)

From Figure 18, this normalized take on heat loss showed similarity in thermal envelope across building types. Schools and Offices had the lowest average overall heat loss, at approximately 0.060 Btu/hr -ºF-ft^2. Retail had an average U_o of 0.071 Btu/hr-ºF-ft^2 and Multifamily came in highest, with an average of 0.081 Btu/hr-ºF-ft^2.

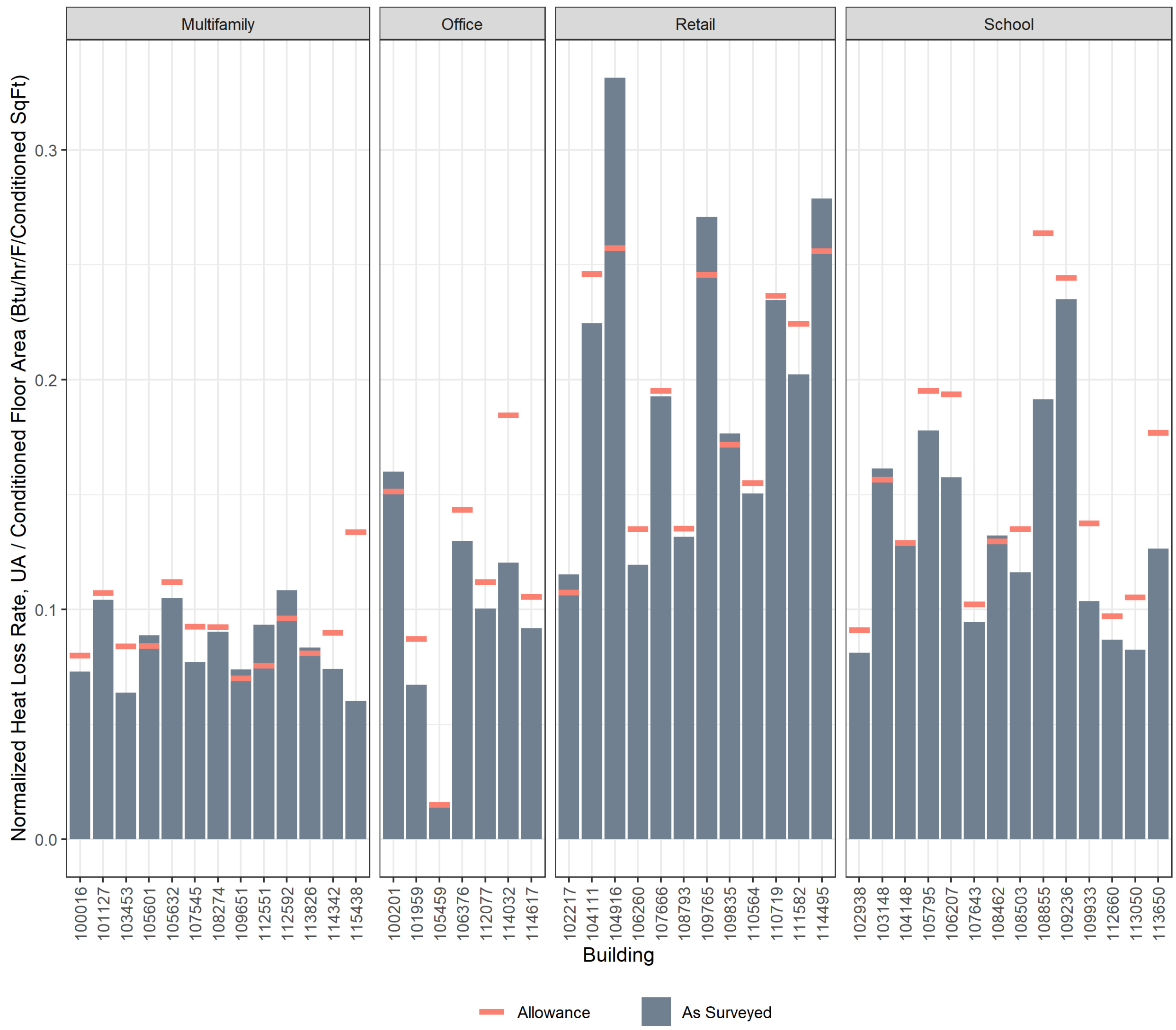


Figure 19. Heat Loss Normalized by Conditioned Floor Area

The final comparison of envelope performance normalizes total heat loss rate by conditioned floor area. This metric varied much more than U_o (Figure 19). This highlights the differences in height to conditioned floor area between building types. Multifamily and Office tended to be multiple stories and thus had significant conditioned floor area. Retail and School often had double-height spaces and were only one or two levels; therefore, Retail and School had more thermal envelope surface area compared to the conditioned floor area.

3.3. Compliance Across Code Years

As described in Section 3.1.1, most aspects of the code remained consistent from 2010 to 2014. Changes between the two code cycles focused on increased efficiencies for HVAC systems, which fell under the mechanical component category for compliance assessment. For the unchanged OEESC requirements, there may be the expectation that increased familiarity with, or knowledge of, the code would lead to stable or even increased rates of compliance in the later code cycle. Whereas compliance with updated sections may have been more challenging to attain, with decreased compliance observed (relative to unchanged sections of the code).

Looking across all components and subcomponents, compliance rates were largely similar across code years or higher for code year 2014 buildings. Mechanical compliance was the exception, with the overall category showing decreased compliance when compared to buildings constructed under the 2010 code. Eighty-one per cent of 2010 buildings were compliant in the mechanical category, whereas only 71% of 2014 buildings reached compliance for that component. This is suggestive that meeting increased mechanical efficiency requirements in 2014 may have been more difficult to achieve. It is worth noting that the requirement for economizer presence was unchanged between the two cycles, and the economizer subcomponent had the lowest compliance of all criteria in 2014 (67% of buildings were compliant).

Although there was a lowered compliance rate for HVAC equipment efficiency in buildings subject to 2014 requirements, this appeared to be due to just a few buildings. Additionally, overall small sample size for the more recent code year precludes conclusive year-to-year comparisons. Exploration of this topic across several code cycles, with increased samples from each code cycle, could provide additional insights into this topic.

4. Energy Performance

One of this study's primary objectives is to evaluate whole-building site energy usage for both electricity and natural gas. The Energy Use Intensity (EUI), kBtu/ft^2-yr is the primary figure of merit for commercial buildings and has been commonly used to compare different sets of buildings (and building types) for over 20 years. A key part of this evaluation was gathering utility bills and performing weather-normalized analysis to estimate the part of the bill that is associated with either cold temperature dependence (heating) or warm temperature dependence (cooling); the residuals remaining were assigned to the building's baseload (lighting, water heating, refrigeration, and miscellaneous electrical loads).

The energy performance assessment uses empirical data to explore relationships between energy use and compliance. It also explores trends in new construction progress and effectiveness of code requirements over time. The last items examined are design practices and characteristics of low- and high-energy using cases.

4.1. Energy Use Analysis Methods

Ecotope collected the electric and gas utility bills for nearly every building. The process began with a signed bill release for the building and documentation of the utility meter numbers during the onsite survey. Ecotope then worked with the relevant utility in Oregon to obtain the bills using a secure data transfer protocol to protect customer identities.

Of the 46 buildings in the study, 11 were excluded from the energy use analysis for the following reasons.

- One School used propane for heating.
- We could not obtain the gas meter information for one Retail building.
- Nine buildings with additions were excluded. These were primarily Schools. While still a significant portion of the new construction area, it was important to survey their characteristics, yet it was not possible to determine the energy use associated strictly with the added building area. Put another way, building additions seldom come with new, separate utility meters serving exclusively the addition.

In addition to the exclusions, we split the energy use data in to one additional building type: food service. As the surveys were being conducted, it became apparent that four of the Retail buildings were exclusively food service or contained a food service business in the building. These were all "strip mall" type buildings with multiple tenants. Sometimes, this was only obvious after the building had been recruited and a site visit had been complete. Not wanting to exclude the building because it had already been selected, we opted to differentiate the food service from the rest of the retail category in the energy use analysis. An examination of the other building characteristics showed that the food service was indistinguishable from other retail in terms of other characteristics (except for the obvious difference of food preparation appliances and larger water heaters). Table 24 lists building counts relevant for energy use analysis.

Table 24. Energy Use Analysis Building Counts by Category

Category	Count
Education	5
Office	13
Multifamily	6
Retail	7
Food Service	4

The energy use analysis proceeded in two-phases. The first was to compile the bills into raw, site energy use for electricity, gas, and site total, on an annualized basis. A further eligibility requirement, aside from those mentioned previously, is a long enough billing record to accurately establish an annual pattern. For an ideal minimum, this would be data in excess of one year. There are several sites we included where the electric bill period spanned ¾ of a year. We were able to include them because the data included the warmest and coolest months. All gas billing data exceeded one year in length. On average, we had 2.3 years of billing history corresponding to 27.5 data points per site.

The second, more involved phase, was to disaggregate the energy use in to heating, cooling, and baseload components and to calculate weather-normalized, annual energy use. Ecotope used a variable base degree day technique to determine the temperature dependent portion of the energy use: both heating and cooling (Hannas, 2015). All analysis was carried out using the RStudio interface for the popular, open-source statistical software R. Regressions of energy use on outdoor temperature were conducted using the "rterm" package developed specifically by Ecotope for billing analysis investigations (Ecotope, 2017). Once the temperature dependence of the energy is known, we then normalize the total energy use to typical climate conditions for a normalized EUI.

A more detailed examination of all the data is available by consulting the project dataset. There, the electricity and gas use are totaled and weather-normalized separately for all buildings. The analysis only disaggregates energy in to the cool and warm temperature-dependent components which we assert is a proxy for heating and cooling respectively. All remaining energy is considered baseload. We stop short of disaggregating this use farther, which contains lighting, water heating, fan energy, etc., because it can only be done by informed guessing. Even with a detailed survey, the guessing is only poorly informed. In some cases, where natural gas is used only for water heating in a building for example, it is possible to separate. Such an analysis is possible using the data in the dataset.

A limitation of the energy analysis is there is no direct metering of the equipment in the buildings and temperature-dependent disaggregation can only go so far. Determining the dependence relies on finding a "bottom" to the heating or cooling energy use which requires a time period with neither in use. This often does not happen in commercial buildings where shoulder seasons may see a week of heating followed by a week of cooling in the same month. Moreover, some of the buildings may be heating and cooling within the same day, sometimes simultaneously. The net effect is the building baseload is often overestimated, and, in the mild cooling requirements of Oregon, cooling is often underestimated. The weather normalization is still reliable, but the disaggregation remains challenged.

4.2. Overall EUI & Trends

The average EUI for each of the five building types is presented under the 2019 Oregon New Commercial Construction Code Evaluation heading of Table 25. The difference between the building categories is expected and aligns with our understanding of commercial buildings. For instance, education, which in this case is K-12 schools, has buildings occupied only ¾ of the year while offices are year-round. Activities within the buildings are similar but the unoccupied period for education suggests it should always have a lower EUI.

Most striking in Table 25 are the comparisons to previous new construction studies which suggest the buildings in this 2010-2014 code cycle use less energy than any previous cohort. Comparisons across studies are challenging because geographic areas sometimes differ as do the exact classification of buildings within a type. For instance, the reference values for the 2002-2004 New Commercial Baseline (Baylon, 2008) and the 2014 Commercial Building Stock Assessment (CBSA) (Navigant Consulting, 2014) include all buildings across the Pacific Northwest, not just those in Oregon. Likewise, the 2013 Residential Building Stock Assessment (RBSA) (Ecotope, 2014) multifamily comparison value is for all building sizes (low-, mid-, and high-rise) while the 2019 Oregon New Commercial Construction Code Evaluation value is just for mid- and high-rise. Despite some of these challenges, the comparison nevertheless suggests a downward trend in energy use. Certainly, for each category in this study's 2019 dataset, there are a limited number of buildings; however, every category shows less energy use. Essentially, the average of all 35 buildings shows energy use decreasing.

Table 25. Energy Use Intensity (Site kBtu/ft^2-yr) – By Building Type, Across Studies

	Multifamily	Office	Retail	School	Food Service
2019 Oregon New Commercial Construction Code Evaluation	32.0	55.6	73.8	34.4	230
2002-2004 New Commercial Baseline	--	71.7	95.5	61.4	--
2014 CBSA (2004-2013 Buildings)	--	78.3	75.5	64.2	362
2013 RBSA (all sizes)	46.7	--	--	--	--

As mentioned previously, a significant fraction of the buildings in this study participated in ETO's New Buildings program. The program is designed to lower energy use in new buildings so we might expect broad participation to lower the energy use observed in this study. Of the 35 buildings where we have EUIs, 25 were in the New Buildings Program. Table 26 shows the simple average EUI of buildings in and out of the program by building type. All multifamily buildings participated, so no comparison is available there. In all other categories, participation was split about in half. Given the small dataset it is not possible to determine program influence on EUI.

Table 26. Energy Use Intensity – By Building Type and ETO New Buildings Participation

	Multifamily		Office		Retail		School		Food Service	
ETO New Buildings Program Participant	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
EUI (kBtu/ft^2-yr)	33.2	--	66.6	38.5	94.6	53.0	35.2	39.7	295	188
Count	13	0	4	2	4	3	2	3	2	2

Last, asserting causation is tricky, yet the data show a correlation between increasing energy code stringency and reduced energy use. The data from Table 25 span multiple code cycles starting in the early 2000s and ending in the mid-2010s with the current study. Combined with the high code compliance rate, these energy use data are indicative of the code having a cumulative, downward effect on energy use. That is, it may not be possible to determine the trend in a single, or even several, code cycles but, over many cycles, the data suggest a correlation between increasing code stringency and decreasing energy use. The report authors recommend against drawing a single line between two data points and projecting a precise downward trend. Instead, we recommend continued tracking of the new construction energy use over time to build a more robust dataset.

4.3. EUI and Compliance

A potentially intriguing investigation, maybe even the most critical investigation, of this project is to examine whole-building energy usage to see if there is a relationship between that usage and compliance with the main categories of the commercial energy code. Perhaps the expression of this relationship is reversed, but the idea should be clear: compliance with the code should result in lower EUIs, especially as the codes become more stringent.

Figure 20 shows, in one scan, all EUIs that could be determined. Schools and Multifamily are the best performers, with Offices and Retail quite similar to one another, on average. Not at all a surprise is the Restaurant group (actually mixed food service and retail in same building). The superscripts above the bars indicate the parts of the code that were not complied with. For each building sub-group, most of the sites have at least one category where they do not comply.

If one stopped there, an important point would be missed: even with non-compliance, many sites have EUIs well under 50 (or even 30). In the context of new commercial buildings, this indicates the site is performing better than average. Does this mean that code compliance is unimportant? Not necessarily, especially if there is no firm EUI target established by building type.[6] It might instead mean that merely looking at code compliance will not indicate how much energy a site uses. The use type of the space itself will tend to indicate what EUI one can expect, especially in extreme cases such as restaurants.

Visual inspection of Figure 20 reveals that there is no strong relationship between non-compliance categories and energy use. For example, envelope non-compliance does not correlate with higher or lower use. Again, much of the reason for this goes back to the fact there is not a target EUI for a particular building type and that there is a large degree of flexibility within the mechanical code to select systems which, although they comply, produce a range of energy use in practice.

[6] Portland and Seattle require larger buildings to report energy usage and conditioned square footage, but no EUI requirements have been established; Washington State's law passed in May 2019 includes mandatory EUI compliance by 2026.

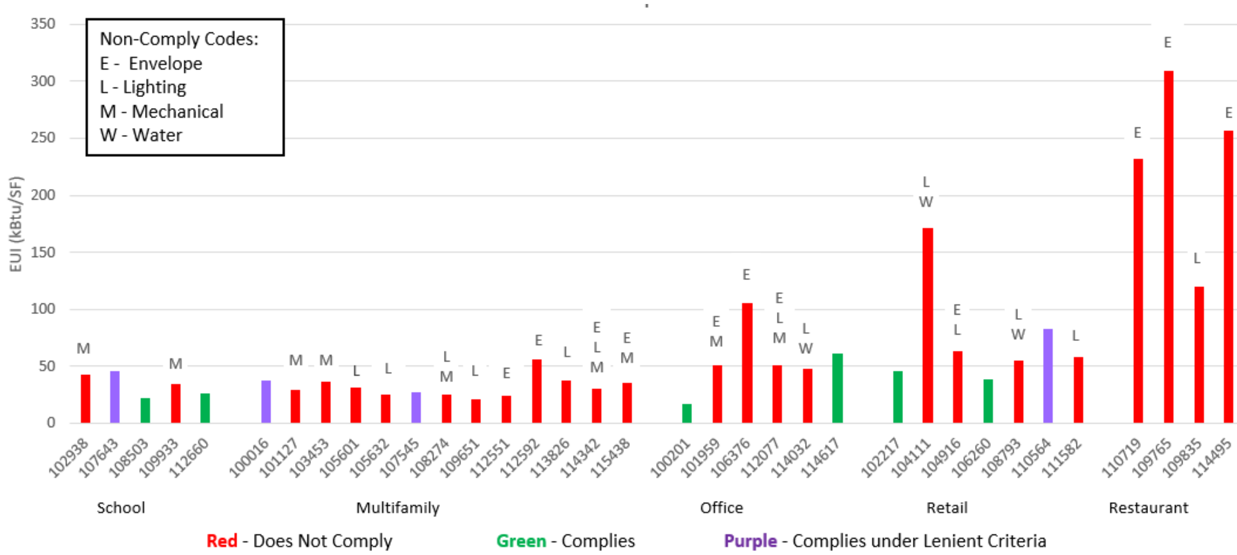


Figure 20. EUIs for Sites Surveyed

4.4. EUI by Building Type

This section discusses whole building energy uses normalized by site floor area (EUI), which is the main figure of merit for this study. Despite overall differences in building construction type, HVAC system, lighting, and other baseload, if the whole usage can be compared on an equal footing (EUI), one can see quite quickly how one building, or a group of buildings, performs in comparison to other buildings, both within the study and within a larger context such as all commercial buildings. Note that only a subset of all EUI data is discussed (for space reasons), but complete EUI graphics by building type and end use are found in Appendix D.

The first group to examine is schools, as seen below in Figure 21 and Figure 22. The study looked at more than ten Schools but the majority of the buildings were either additions or remodels and so it was not practical to express EUI for just the new/remodeled areas. Still, there were five sites where a whole building approach was practical, and the average EUI of just under 35 kBtu/ft^2-yr is very impressive. One School building (discussed in more detail below) had an EUI of about 22 and no apparent mechanical cooling (except for fan energy for economizers); this is particularly notable since many new School buildings are now being designed for year-round operation (that is, including summer months). For this group, only one School building (site 102938) shows mechanical cooling usage, which is indeed very modest.

Most schools in the study participated in ETO's New Buildings Program, and most sites received incentives for a wide range of measures. Lighting was the most common incentivized measure (including custom lighting system design/controls) and sites also received incentives for items such as condensing boilers, chillers, efficient cooking equipment, service hot water heating, and faucet aerators. In Figure 21, the two schools on the right of the graph (EUIs lower than the group average) participated in the ETO NB program and the two on the left did not. (Note sites 102938 and 107643 are not served by ETO member utilities.) Still, the lowest EUI school was not a New Buildings Program participant.

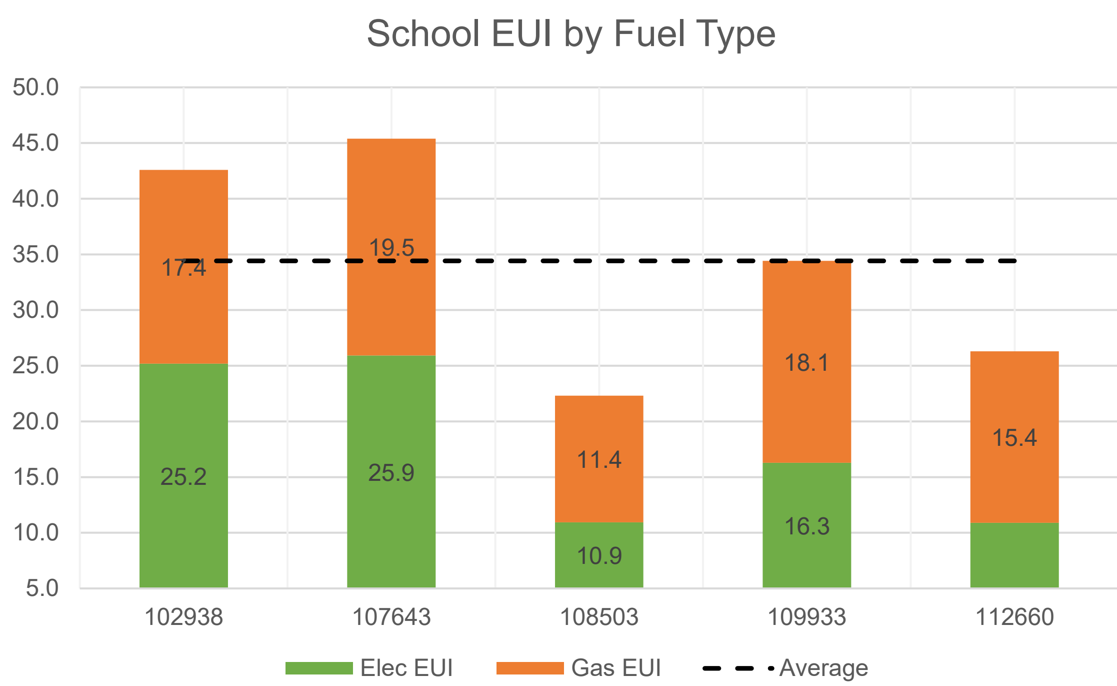


Figure 21. School EUI by Fuel Type

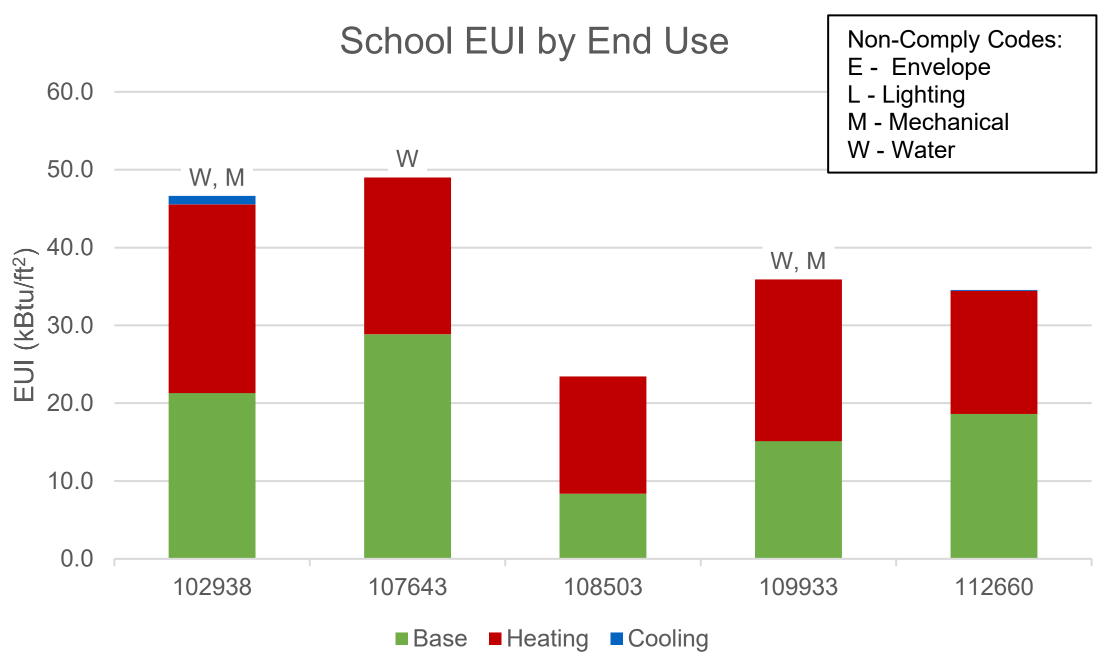


Figure 22. School EUI by End Use

Following this line of inquiry, offices also show some interesting features (Figure 23). The average office EUI, excepting the highest EUI site, is about 50, meaning a 35% reduction from the 2014 CBSA for offices constructed between 2003 and 2014. Also, the amount of the total electricity billing attributed to mechanical cooling (exclusive of economizer operation) is very low. The Office buildings in the study did not use much traditional VAV; they instead mostly relied more on zonal VRF systems and condensing boilers serving zonal fan coil units. The high outlier in this group, Site 106376, also relied mostly on zonal fan coils and a VRF heat pump; its heating usage is not outrageous. However, the base load, due to a lot of IT load (call center), is a major contributor to the EUI. We suspect that part of what has been assigned to base load is actually mechanical cooling; this illustrates the limitation of using billing analysis to disaggregate loads.

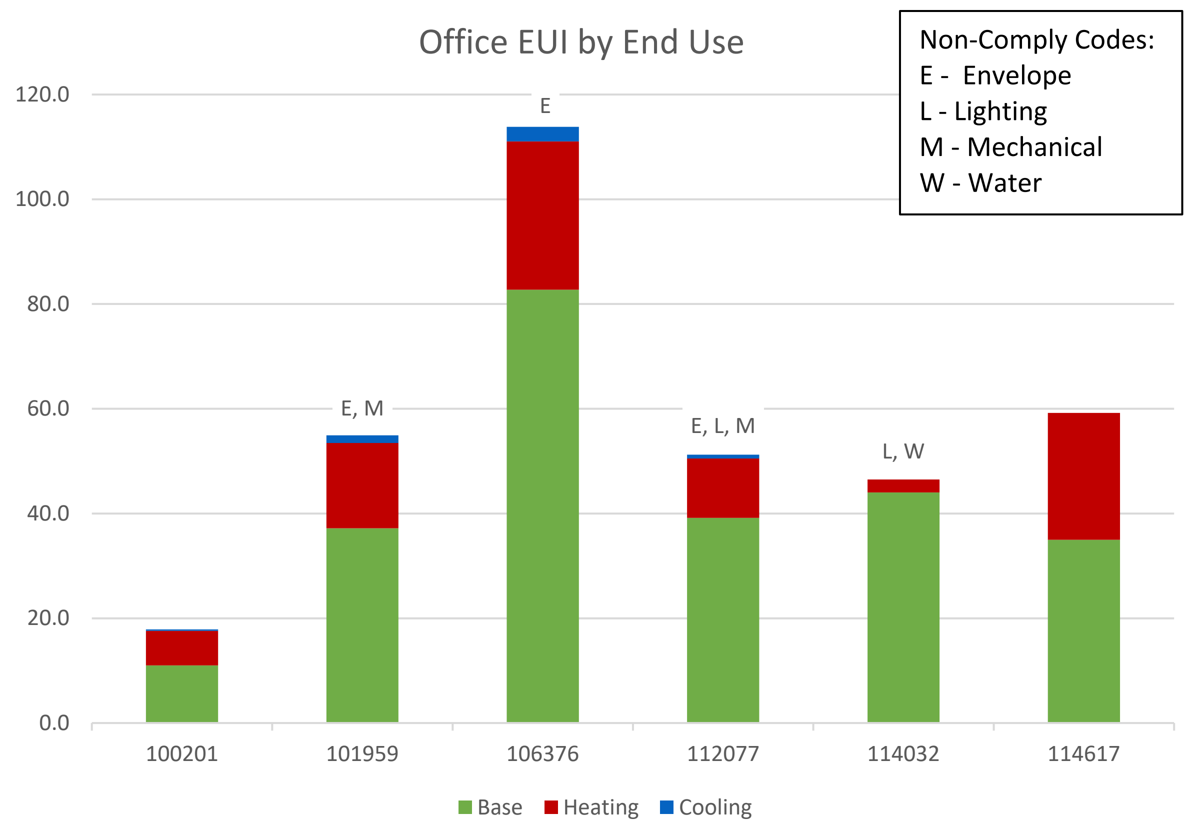


Figure 23. Office EUI by End Use

4.5. Case Studies

Two buildings will be discussed in some detail in this section, one a School building with an impressively low EUI and the other a Retail building with a much larger EUI. In each case, the design and installation details are significant in overall building energy performance.

4.5.1. Low EUI School Example

The first building, site 108503, is a 105,000ft^2 middle school located in the Willamette Valley. Overall EUI is 22.3 kBtu/ft^2-yr, with usage split about evenly between natural gas and electricity. The site complied with all aspects of the code. The main mechanical system relies on condensing gas boilers and a chiller; aggressive use of outside air (economizing) for cooling resulted in no apparent mechanical cooling (other than the electricity needed to the fan coil fans to supply the outside air). The site did not participate in the ETO NB program (but it also was not a customer of the utilities that are under the ETO umbrella.)

A key element of HVAC scheduling and control was to pre-cool the building with outside air during times of year when daytime temperatures and solar/internal gains might be sufficient to trigger a large cooling demand. Also notable is that the data rooms at this site are even effectively cooled by outside air. Figure 24 shows the care taken with the terminations in the data rooms: outside air is directed aggressively onto the server racks.

Figure 24. Data Room Cooled by Outside Air

The lighting system at this site is LEDs throughout with some use of daylighting zones (but otherwise the prevailing control is occupancy/vacancy sensors); the interior LPD was calculated as 0.68 W/ft^2, well below the 1.01 W/ft^2 allowance and about 15% below the average for all schools in the study. The site does have a cafeteria with range hoods, cooking equipment, and refrigeration. There is a modest amount of solar PV installed, and also a solar pre-heat system for domestic hot water. The school district's accounting, from the net meter, estimates the PV production reduced the EUI by about 0.5 kBtu/ft^2-yr over the first year of operation.

This school district has employed a full-time energy engineer for over 20 years and the mechanical engineers for the site have extensive experience with innovative design. There is a fully operational DDC system on site with easy remote access and trending capability. All of the above are important components in achieving the low energy use.

4.5.2. High EUI Retail Example

In contrast to the School building described in the previous section is site 104111, a new car dealership. The site passed the envelope and mechanical sections of the code. Its EUI, however, is almost 172, which is more than twice the average for all Retail buildings. About 40 % of the EUI comes from natural gas; the site does have a snow melt system and unit heaters for some of the parking garage. This building was a participant in the ETO NB program, receiving incentives for lighting, service hot water, and HVAC (multiple measures).

The site's internal LPD is more than twice that allowed by the code, and another contribution to the high baseload is an extensive inventory of auto servicing equipment. One lighting example is a room containing both LED downlights and 2'x4' T8 troffers. Another example, shown in Figure 25, is three times as many track spotlights (75W each) installed as the plans called for. It isn't known how many (if any) of the lighting fixtures were added to the site after initial installation.

Figure 25. High LPD with Excessive Amount of Track Spotlights

5. Conclusions

This report described results of a thorough review of the Oregon Energy Efficiency Specialty Code (2010 and 2014 editions) for a statewide sample of 46 commercial buildings. The study looked at four commercial building types: Office, Multifamily, School, and Retail.

The work relied on a combination of building plan review and field verification and was completed primarily in 2018. Evaluation of compliance relied on looking at major building systems (mechanical, service hot water, thermal envelope, and lighting) and expressed compliance in both pass/fail terms and by overall surveyed square footage. Compliance was evaluated both in 'strict' terms (that is, 'by the book') and more 'lenient' terms, where a small, low energy impact additional allowance was given to see how many more sites would comply.

A key part of the work was to look at utility billing records to assess the area-normalized energy usage (Energy Use Intensity, or EUI) of each building. This is the primary figure of merit that can be compared amongst any group of commercial buildings.

5.1. Notable Characteristics and Findings

- The average building heat loss rate has decreased dramatically compared to buildings studied built in 2002-2004 reflecting the continued march of increasing envelope performance requirements (Baylon 2008). Notably, more than half of all windows in Multifamily buildings now have U-Values below 0.3 Btu/hr ºF. Low-e coatings also now appear nearly universally present in commercial windows. Nevertheless, there remain opportunities for further envelope improvements by, for example, requiring slab insulation in all commercial buildings (which is part of the 2015 IECC) and tightening requirements for insulation of masonry wall systems.
- HVAC systems, especially in offices and schools, are moving away from traditional centralized systems such as VAV toward more zonal systems such as VRF. The percentage of floor area conditioned by VAV in this study was much smaller than in previous regional commercial building stock assessments. This is a very significant shift, in terms of design approach and EUI. A significant number of buildings used Energy Trust incentives to offset the cost of VRF systems. Future commercial building codes might be well-served by including new language to continue to encourage more zonal systems and to ensure optimum VRF system design and installation. Regional planning efforts to address demand reduction should take note of the shift in HVAC system specification and installation.
- Nearly *all* natural-gas boilers in the study used condensing gas heat exchangers, meaning combustion efficiency is > 90%. In contrast, almost none of the lower capacity natural gas heating equipment used condensing technology, representing a programmatic opportunity.
- The newest commercial buildings have moved to LEDs in a big way; overall lighting power density (LPD) is now heading toward 0.5 W/ft^2 in non-retail spaces and is around 0.80 W/ft^2 for retail (vs the code allowance of just over 1 W/ft^2). Retail LPD has fallen by almost a factor of 5 in 20 years in the Pacific Northwest. Codes have had great influence on declining LPD, but increasing product offerings and much lower costs, all largely attributable to the advent of LEDs, are accelerating change. These factors may drive LPDs even lower

independent of code. This finding suggests an "easy win" for code improvements in future years is to continue to target LPD.

5.2. Code Compliance

- Using the aggregate binary logic approach to assess how many buildings fully comply with code, we found that Schools showed the highest rate while Multifamily showed the lowest. Interior lighting was the highest complying building system; otherwise, compliance was relatively evenly distributed across building types and systems. A closer assessment shows there were many near misses on compliance with relatively few "large misses."
- Using the overall subcategory view to assess what parts of code are being followed and what parts are not, we found that 89% of all the subcategory items complied. Hot water loop pump controls showed the lowest compliance rate at 63%, economizers for cooling systems were next lowest at 83%, while the rest were close to 90% or above. Again, Schools exhibited the highest compliance rates but otherwise the other building types had generally equal subcategory compliance.
- Causation is difficult to prove but it would appear that designers and builders are paying attention to the code. There would likely otherwise not be such a high compliance rate across all compliance subcategories.
- Hot water circulation pump controls were the least adhered to piece of the code likely due to concerns that hot water would not be available to the occupants when they wanted it. This issue should be studied further to consider if future code versions should remove or greatly modifying this provision, especially around building type. In any event, increasing the pipe insulation requirement and adding a VFD requirement for the pump would achieve energy savings.
- With some exceptions, thermal envelopes met code requirements. Uninsulated or partly insulated masonry walls exemplified the non-compliance cases. In Multifamily and Office buildings, the window/wall ratio often exceeded the prescribed allowance, but this was almost always traded-off against better thermal performance elsewhere so that total UA still met code.
- There were several, large, non-complying lighting systems in Retail buildings but in most other cases, systems complied or nearly missed. Overall, the average LPD across all building types is much lower than the code allowance.

5.3. Energy Use

- Energy Use Intensity (EUI, expressed as kBtu/ft^2-yr) was evaluated for 35 buildings in this study and found to be trending downward across all building types. It is at least 30% lower than buildings built in the 2002-2004 or 2003-2014 periods (Baylon, 2008 and Navigant, 2014). Interestingly, this finding still holds when examining participation in the Energy Trust New Buildings program. From this building cohort, it is not possible to determine whether participation improved energy performance compared to non-participation.

- Energy use was, unsurprisingly, not found to correlate with code compliance. Some of the highest performing buildings (lowest EUIs) failed some aspects of code compliance while others met all aspects of the code and had higher than average EUIs.
- Both high and low energy use, as demonstrated in several case studies, is still driven by design and operation choices. Those choices, operating without on EUI target, allow for both high and low energy use. Future code could consider recommending equipment types and design specifications that are proven to dramatically lower mechanical EUI.

Appendix A: References

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Appendix B: Commercial New Construction Baseline Summary

The following sections include all characteristic summaries tables and figures from the full report, as well as additional summaries. Tables are of weighted averages (unless indicated otherwise) and include 90% confidence interval error bounds.

Building Level Data

Table B1. Overall Square Footage of Building Stock Surveyed

	Population Frame (# of Buildings)	Buildings Surveyed	Survey of a Building Addition**	Population Frame (Total Floor Area ft^2)	Floor Area Surveyed (ft^2)***
Schools	39	14	7	2,217,477	1,322,876
Multifamily	66	13	0	10,782,500	2,664,274
Office	48	7	1	5,934,543	1,225,944
Retail	69	12*	1	1,439,110	431,891
Total	**222**	**46**	**9**	**20,373,630**	**5,644,985**

* includes 4 restaurants
** a subset of buildings surveyed
*** includes surveys of building additions

Table B2. Basic Information for Surveyed Buildings

Building ID	City	Primary Type/Strata	Detailed Use Type	Surveyed Floor Area (ft^2)	Construction Category	Code Year
105601	Portland	Multifamily 1	Multifamily (4-6 stories)	29,447	New	2010
107545	Portland	Multifamily 1	Multifamily (4-6 stories)	45,093	New	2014
101127	Portland	Multifamily 1	Multifamily (4-6 stories)	49,878	New	2014
105632	Portland	Multifamily 2	Multifamily (4-6 stories)	81,921	New	2010
108274	Beaverton	Multifamily 2	Multifamily (4-6 stories)	82,229	New	2014
109651	Portland	Multifamily 2	Multifamily (4-6 stories)	106,140	New	2010
112592	Portland	Multifamily 3	Multifamily (4-6 stories)	110,887	New	2010
100016	Portland	Multifamily 3	Multifamily (4-6 stories)	129,775	New	2010
103453	Portland	Multifamily 3	Multifamily (4-6 stories)	160,149	New	2010
115438	Portland	Multifamily 4	Multifamily (7+ stories)	287,597	New	2010
113826	Portland	Multifamily 5	Multifamily (4-6 stories)	181,200	New	2010
114342	Portland	Multifamily 5	Multifamily (7+ stories)	295,534	New	2010
112551	Portland	Multifamily 5	Multifamily (7+ stories)	392,066	New	2010
114617	Crescent	Office 1	Office- Admin, Professional, Government, Financial	15,762	New	2014
114032	Medford	Office 1	Office- Admin, Professional, Government, Financial	21,054	New	2014
101959	Portland	Office 2	Office- Admin, Professional, Government, Financial	63,555	New	2014
106376	Salem	Office 2	Office- Admin, Professional, Government, Financial	64,957	New	2010
105459	Albany	Office 2	Warehouse, Distribution	71,731	Addition	2010
100201	Tualatin	Office 4	Other Office	43,059	New	2010
112077	Portland	Office 4	Office- Admin, Professional, Government, Financial	264,983	New	2010
109765	Portland	Retail 1	Strip Shopping Center	7,160	New	2014
114495	Portland	Retail 1	Strip Shopping Center	7,454	New	2010
109835	Newberg	Retail 2	Strip Shopping Center	9,800	New	2014
104916	Albany	Retail 2	Vehicle Repair	14,114	New	2010
106260	Portland	Retail 2	Auto/Boat Dealer/Showrm	18,240	New	2010
104111	Bend	Retail 3	Auto/Boat Dealer/Showrm	10,954	New	2010
108793	Bend	Retail 3	Home Improvement	33,141	New	2010
110564	Medford	Retail 3	Auto/Boat Dealer/Showrm	33,814	New	2010
111582	Corvallis	Retail 3	Home Improvement	36,989	New	2010
110719	Sherwood	Retail 4	Strip Shopping Center	10,771	New	2010
107666	Salem	Retail 5	Auto/Boat Dealer/Showrm	61,595	Addition	2010
102217	Albany	Retail 5	Home Improvement	108,792	New	2014
113650	Helix	School 1	High School	12,082	Addition	2010
108462	Eugene	School 1	High School	30,720	New	2010
104148	Portland	School 1	Elementary School	21,711	Addition	2010
109236	Portland	School 1	Elementary School	4,477	Addition	2010
108855	Portland	School 1	Elementary School	5,072	New	2014
103148	Portland	School 1	Elementary School	9,373	Addition	2014
107643	Eugene	School 2	Elementary School	53,762	New	2010
105795	Stayton	School 2	Elementary School	7,762	Addition	2010
102938	Eugene	School 2	Elementary School	55,301	New	2010
108503	Eugene	School 2	Middle School	105,630	New	2014
109933	Portland	School 3	Middle School	141,495	New	2010
112660	Portland	School 3	Other K-12 School	149,766	New	2014
113050	Portland	School 3	High School	237,036	Addition	2014
106207	Portland	School 3	High School	119,157	Addition	2014

Table B3. Surveyed by Code Year and Building Type by % Floor Area

Code Year	Multifamily	Office	Retail	School
2010	84.9 ± 12.1	54.0 ± 21.0	66.7 ± 28.9	48.5 ± 19.2
2014	15.1 ± 12.1	46.0 ± 21.0	33.3 ± 28.9	51.5 ± 19.2

Table B4. Reported Commissioning by Building Type by % Floor Area

Building Commissioning	Multifamily	Office	Retail	School
Yes	55.5 ± 10.7	49.4 ± 34.7	2.1 ± 3.0	68.8 ± 18.2
No	9.9 ± 11.7	14.7 ± 20.5	24.9 ± 24.2	20.0 ± 16.2
Unknown	34.6 ± 9.9	35.8 ± 34.7	73 ± 24.5	11.2 ± 7.0

Table B5. Certification through Above Code Programs by % Floor Area

Above Code Programs	Multifamily	Office	Retail	School
LEED Platinum	11.7 ± 10.0	22.3 ± 17.3	0.0 ± 0.0	0.0 ± 0.0
LEED Gold	21.3 ± 13.5	13.1 ± 18.7	0.0 ± 0.0	28.0 ± 21.8
LEED Silver	0.0 ± 0.0	14.1 ± 23.7	0.0 ± 0.0	0.0 ± 0.0
LEED Basic	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	7.2 ± 9.8
Other	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	7.3 ± 1.6
No	59.3 ± 13	50.6 ± 34.7	100.0 ± 0.0	33.8 ± 18.1
Unknown	7.6 ± 7.1	0.0 ± 0.0	0.0 ± 0.0	23.7 ± 5.1

Table B6. Participation in Energy Trust of Oregon's New Buildings Program

Energy Trust New Buildings Program	Multifamily	Office	Retail	School
Participating Buildings	13	4	6	9
Non-Participating Buildings	0	2	5	1
Ineligible Buildings	0	1	1	4

Table B7. Participation in Energy Trust of Oregon's New Buildings Program by % Floor Area

Energy Trust New Buildings Program	Multifamily	Office	Retail	School
Participating Buildings	100 ± 0.0	67.5 ± 33.2	50.6 ± 21.0	51.2 ± 13.9
Non-Participating Buildings	0.0 ± 0.0	32.5 ± 33.2	49.4 ± 21.0	48.8 ± 13.9

Table B8. Air Test and Balance Reports Available During Audits by % Floor Area

Reports Available	Multifamily	Office	Retail	School
Yes	5.3 ± 8.2	36.4 ± 29.2	0.0 ± 0.0	8.7 ± 3.5
No	37.4 ± 13.5	46.7 ± 33.7	76.0 ± 23.6	67.6 ± 8.4
Unknown	57.3 ± 14.0	17.0 ± 20.0	24.0 ± 23.6	23.7 ± 5.1

HVAC Data

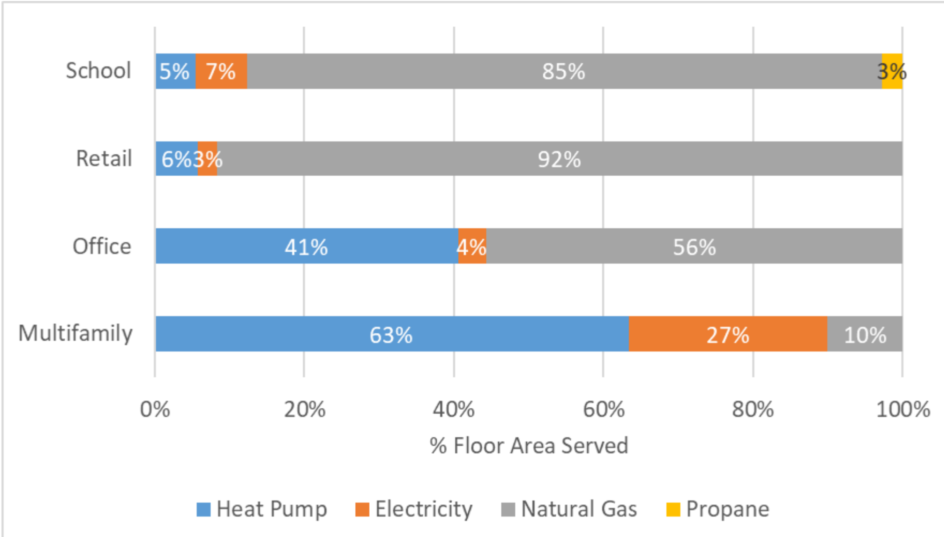


Figure B1. Heating Fuel Classification and Percentage of Floor Area Served

Table B9. Heating Fuel by Building Type by % Floor Area Served

Heating Fuel	Multifamily	Office	Retail	School
Heat Pump	63.4 ± 8.3	40.6 ± 30.3	5.8 ± 11.0	5.4 ± 2.7
Electricity	26.5 ± 9.0	3.7 ± 3.0	2.5 ± 3.0	6.9 ± 1.5
Natural Gas	10.1 ± 1.6	55.7 ± 29.5	91.7 ± 13.7	84.9 ± 4.8
Propane	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 4.0

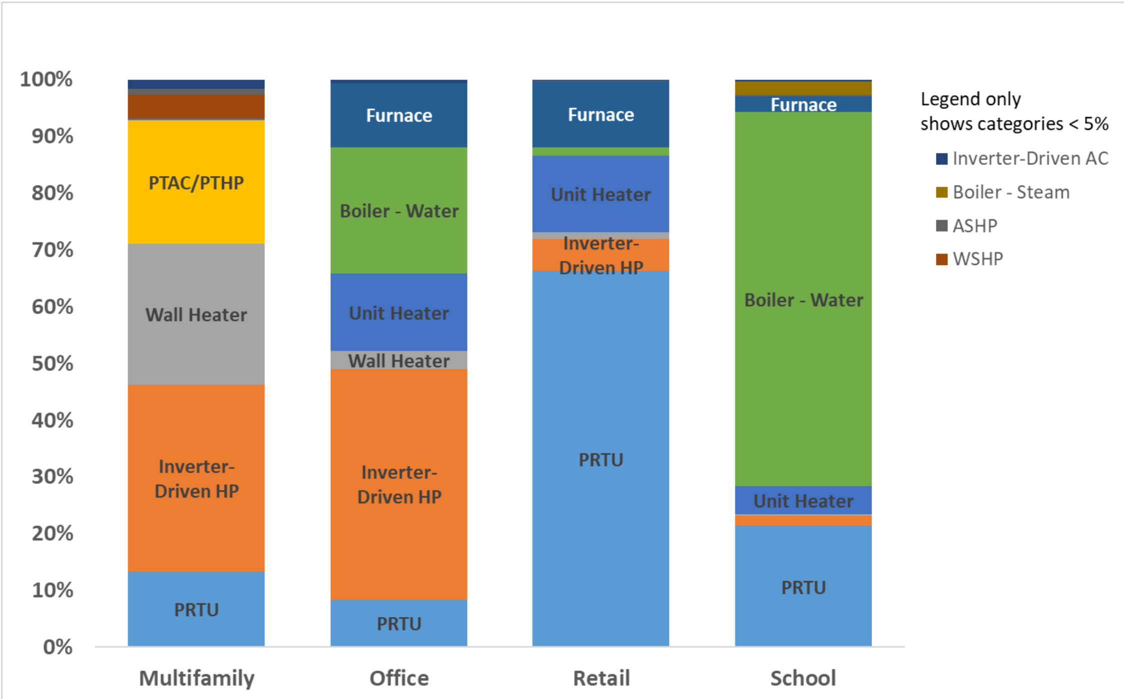


Figure B2. Heating Systems by Building Type

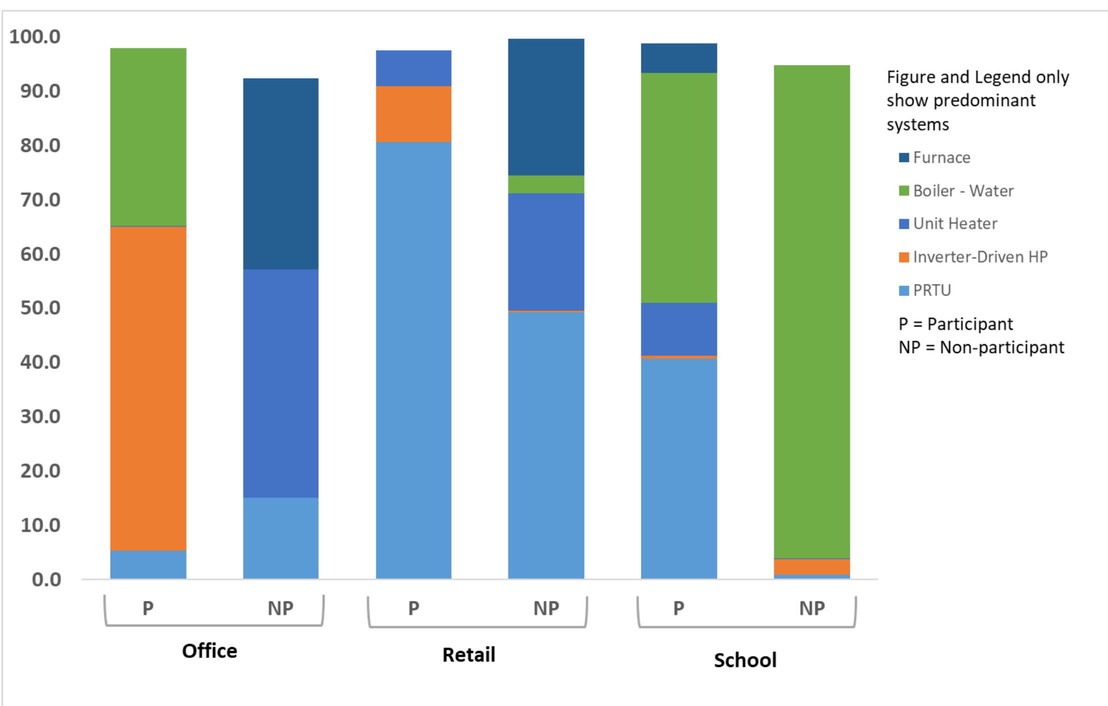


Figure B3. Heating Systems (Energy Trust New Buildings Program Participation Included)

Table B10. Heating Equipment by Building Type by % Floor Area Served

Heating Equipment	Multifamily	Office	Retail	School
PRTU	13.3 ± 1.7	8.4 ± 5.3	66.2 ± 25.8	21.4 ± 6.6
Inverter-Driven HP	33.0 ± 3.0	40.6 ± 30.3	5.7 ± 11	1.7 ± 1.7
Wall Heater	24.7 ± 9.3	3.2 ± 2.5	1.2 ± 2.4	0.3 ± 0.3
PTAC/PTHP	21.9 ± 9.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Unit Heater	0.2 ± 0.3	13.6 ± 14.6	13.5 ± 12.3	5.0 ± 1.1
Boiler - Water	0.0 ± 0.0	22.3 ± 18.5	1.5 ± 2.6	65.9 ± 10.0
Furnace	0.0 ± 0.0	11.3 ± 14.3	11.6 ± 19.2	2.8 ± 4.0
WSHP	4.2 ± 3.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
ASHP	1.0 ± 1.1	0 .0± 0.0	0.1 ± 0.1	0.3 ± 0.4
Boiler - Steam	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.2 ± 3.2
Inverter-Driven AC	1.7 ± 2.6	0.5 ± 0.5	0.2 ± 0.2	0.4 ± 0.1

Table B11. Heating Equipment (% Floor Area Served) by New Buildings Program Participation

	Multifamily		Office		Retail		School	
Program Participation:	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
PRTU	13.3 ± 1.7	--	5.3 ± 10.7	15.0 ± --	80.6 ±32.1	49.3 ±51.4	40.7 ± 6.8	0.8 ± 0.8
Inverter-Driven HP	33.0 ± 3.0	--	59.7 ± 16.4	0.0 ± --	10.4 ±23.9	0.2 ± 0.1	0.6 ± 0.5	2.9 ± 3.4
Wall Heater	24.7 ± 9.3	--	1.7 ± 0.8	6.4 ± --	2.2 ± 5.1	0.0 ± 0.0	0.6 ± 0.7	0 ± 0
PTAC/PTHP	21.9 ± 9.2	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Unit Heater	0.2 ± 0.3	--	0.2 ± 0.1	42.1 ± --	6.5 ± 8.4	21.7 ±28.6	9.7 ± 1.6	0.1 ± 0.1
Boiler - Water	0.0 ± 0.0	--	32.8 ± 15.4	0.0 ± --	0.0 ± 0.0	3.3 ± 10.2	42.4 ±11.5	91.0 ± 6.9
Furnace	0.0 ± 0.0	--	0.0 ± 0.0	35.3 ± --	0.0 ± 0.0	25.2 ±70.6	5.4 ± 9.1	0.0 ± 0.0
WSHP	4.2 ± 3.6	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
ASHP	1.0 ± 1.1	--	0.0 ± 0.0	0.0 ± --	0.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.8
Boiler - Steam	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	4.6 ± 6.8
Inverter-Driven AC	1.7 ± 2.6	--	0.2 ± 0.1	1.2 ± --	0.1 ± 0.1	0.3 ± 0.3	0.7 ± 0.1	0.1 ± 0.1

Table B12. Heating Distribution by Building Type by % Floor Area Served

Heating Distribution	Multifamily	Office	Retail	School
Electric resistance zonal	47.5 ± 5.0	16.9 ± 15.1	14.7 ± 13.1	5.4 ± 1.3
Single zone ducted (spit or packaged)	14.6 ± 2.4	19.9 ± 16.9	76.9 ± 21.7	43.8 ± 18.1
VRF	30.2 ± 2.7	40.7 ± 30.4	0.0 ± 0.0	1.2 ± 1.7
Two/Four Pipe Systems	0.0 ± 0.0	3.4 ± 2.8	0.0 ± 0.0	27.7 ± 22.5
Hydronic (boiler)	0.0 ± 0.0	19 ± 15.8	1.5 ± 2.6	5.6 ± 2.5
Minisplit (single head DHP)	2.4 ± 0.7	0.1 ± 0.1	5.7 ± 11.0	0.4 ± 0.3
Multisplit (residential type)	1.1 ± 1.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Multi Zone VAV	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	6.0 ± 7.4
Multi Zone w/reheat	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 1.6	0.6 ± 0.1
VAV w/reheat	0.0 ± 0.0	0.0 ± 0.0	0 ± 0.0	9.2 ± 2.0
Water-source heat pump loop	4.3 ± 3.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Table B13. Heating Distribution (% Floor Area Served) by New Buildings Program Participation

	Multifamily		Office		Retail		School	
Program Participation:	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
Electric resistance zonal	47.5 ± 5.0	--	1.9 ± 0.9	49.1 ± --	8.8 ± 10.8	21.7 ± 28.7	10.3 ± 2.0	0.1 ± 0.1
Single zone ducted (spit or packaged)	14.6 ± 2.4	--	5.3 ± 10.8	50.9 ± --	78.7 ± 32.7	74.7 ± 38.9	47.1 ± 7.7	40.3 ± 35.9
VRF	30.2 ± 2.7	--	59.7 ± 16.4	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.6 ± 3.4
Two/Four Pipe Systems	0.0 ± 0.0	--	5.0 ± 2.4	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	10.7 ± 7.6	45.6 ± 40.6
Hydronic (boiler)	0.0 ± 0.0	--	27.9 ± 13.1	0.0 ± --	0.0 ± 0.0	3.3 ± 10.2	10.9 ± 4.1	0 ± 0
Minisplit (single head DHP)	2.4 ± 0.7	--	0.1 ± 0.1	0.0 ± --	10.4 ± 23.9	0.2 ± 0.1	0.6 ± 0.5	0.3 ± 0.3
Multisplit (residential type)	1.1 ± 1.8	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Multi Zone VAV	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.2	11.1 ± 14.6
Multi Zone w/reheat	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	2.1 ± 3.3	0.0 ± 0.0	1.2 ± 0.2	0.0 ± 0.0
VAV w/reheat	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	17.9 ± 3	0.0 ± 0.0
Water-source heat pump loop	4.3 ± 3.7	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Table B14. Electric Resistance Heating Equipment by Building Type by % Floor Area Served

Electric Resistance Heating Equipment	Multifamily	Office	Retail	School
Zonal	52.8 ± 17.0	100.0 ± 0.0	90.3 ± 20.7	5.4 ± 7.5
Unit Heater	0.4 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	88.2 ± 7.0
PTAC	46.8 ± 16.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
PRTU	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	6.4 ± 0.4
Reheat	0.0 ± 0.0	0.0 ± 0.0	9.7 ± 20.7	0.0 ± 0.0

Table B15. Cooling Equipment by Building Type by % Floor Area Served

Cooling Equipment	Multifamily	Office	Retail	School
PTAC/PTHP	29.1 ± 9.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Chiller	0.0 ± 0.0	25.2 ± 20.2	0.0 ± 0.0	61.4 ± 12.4
DX-Air	19.1 ± 3.8	24.0 ± 25.0	88.4 ± 14.6	35.0 ± 11.0
DX-Water	5.6 ± 4.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Inverter-Driven HP	44.0 ± 6.0	50.1 ± 30.0	7.2 ± 13.2	2.1 ± 2.0
Inverter-Driven AC	2.2 ± 3.4	0.7 ± 0.7	0.2 ± 0.2	0.5 ± 0.1
Evaporative	0.0 ± 0.0	0.0 ± 0.0	4.1 ± 5.6	1.0 ± 1.6

Table B16. Cooling Distribution by Building Type by % Floor Area

Cooling Distribution	Multifamily	Office	Retail	School
Zonal (PTAC or window unit)	29.1 ± 9.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Single zone ducted (spit or packaged)	19.1 ± 3.8	24.0 ± 25.0	86.9 ± 14.7	59.0 ± 25.9
VRF	39.4 ± 5.3	50.0 ± 30.1	0.0 ± 0.0	1.6 ± 2.1
Two/Four Pipe Systems	0.0 ± 0.0	4.2 ± 3.4	0.0 ± 0.0	30.0 ± 27.5
Minisplit (single head DHP)	5.3 ± 3.2	0.8 ± 0.7	7.5 ± 13.3	1.1 ± 0.4
Multisplit (residential type)	1.4 ± 2.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Multi Zone VAV	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 2.1	8.4 ± 9.2
Water-source heat pump loop	5.6 ± 4.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Other	0.0 ± 0.0	21.0 ± 16.8	4.1 ± 5.6	0.0 ± 0.0

Table B17. Cooling Distribution (% Floor Area Served) by New Buildings Program Participation

	Multifamily		Office		Retail		School	
Program Participation:	**TRUE**	**FALSE**	**TRUE**	**FALSE**	**TRUE**	**FALSE**	**TRUE**	**FALSE**
Zonal (PTAC or window unit)	29.1 ± 9.6	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Single zone ducted (spit or packaged)	19.1 ± 3.8	--	5.1 ± 11.3	97.7 ± --	77.3 ± 28.4	99.3 ± 0.2	82.6 ±3.2	42.2 ± 38.2
VRF	39.4 ± 5.3	--	62.9 ± 16.1	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 3.6
Two/Four Pipe Systems	0.0 ± 0.0	--	5.3 ± 2.6	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	11.7 ±4.2	43 ± 42.9
Minisplit (single head DHP)	5.3 ± 3.2	--	0.4 ± 0.2	2.3 ± --	12.8 ± 26.2	0.7 ± 0.2	1.9 ± 0.9	0.4 ± 0.3
Multisplit (residential type)	1.4 ± 2.3	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Multi Zone VAV	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	2.5 ± 4	0.0 ± 0.0	3.8 ± 0.5	11.7 ± 15.5
Water-source heat pump loop	5.6 ± 4.8	--	0.0 ± 0.0	0.0 ± --	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Other	0.0 ± 0.0	--	26.4 ± 13.0	0.0 ± --	7.4 ± 10.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Table B18. Dedicated Outdoor Air Systems by % Floor Area Served

Dedicated Outdoor Air System (DOAS) Types	Multifamily	Office	Retail	School
DOAS no Heat Recovery	1.5 ± 1.5	8.2 ± 11.6	0.0 ± 0.0	14.2 ± 14.2
DOAS w/ Heat Recovery	0.8 ± 1.1	17.9 ± 20.1	0.1 ± 0.1	14.0 ± 4.5
No DOAS	97.8 ± 1.4	73.8 ± 21.1	99.9 ± 0.1	71.8 ± 10.0

Table B19. Distribution of Boiler Efficiency (unweighted)

Output Capacity	Thermal efficiency	CI	N	Percent Total Capacity
< 500	0.90	0.08	3	2.21
500-1500	0.90	0.05	8	16.87
1500-2500	0.94	0.02	17	59.96
> 2500	0.93	--	4	20.96

Table B20. Distribution of Chiller Efficiency (unweighted)

Cooling source	Compressor Type	Capacity	Efficiency Metric (EER or kw per Ton)	CI	N	Percent Total Capacity
Air	Scroll	< 150 Tons	10.30	1.49	8	60.05
Water	Centrifugal	>= 150 Tons	0.513	0.03	2	39.95

Table B21. Thermostat Types by % Floor Area Served

Thermostat Type	Multifamily	Office	Retail	School
Slave (EMS Sensor)	0.5 ± 0.5	90.6 ± 9.6	27.4 ± 21.8	95.8 ± 1.7
Programmable	68.4 ± 8.4	7.3 ± 9.2	40.3 ± 16.1	1.4 ± 1.2
Manual	27.2 ± 9.8	2.2 ± 1.5	32.2 ± 15.8	2.7 ± 1.0
Not Applicable	3.3 ± 5.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Unknown	0.6 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Table B22. Presence of Heat Recovery by % Floor Area Served

Presence of Heat Recovery	Multifamily	Office	Retail	School
Yes	20.5 ± 18.1	70.3 ± 26.9	0.0 ± 0.0	33.0 ± 1.6
No	77.2 ± 19.2	29.7 ± 26.9	100.0 ± 0	56.0 ± 2.9
Unknown	2.3 ± 4.4	0.0 ± 0.0	0.0 ± 0.0	11.0 ± 2.8

Table B23. Packaged Heating Equipment Efficiency by % Installed Capacity

Packaged Heating Equipment Efficiency	% Capacity	Mean Efficiency	Units	Efficiency N
DAC/HP	60.5 ± 37.6	9.39	HSPF	75
VRF	28.7 ± 26.9	3.48	COP	11
PTAC/HP	7.7 ± 8.9	3.07	COP	712
ASAC/HP	0.9 ± 1.1	3.27	COP	8
WSHP	2.1 ± 2.7			
Other	0.1 ± 0.2	2.20	COP	2

Table B24. Packaged Cooling Equipment Efficiency by % Installed Capacity

Packaged Cooling Equipment Efficiency	% Capacity	Mean Efficiency	Units	Efficiency N
VRF	61.5 ± 10.0	18.25	IEER	11
PTAC/HP	17.2 ± 8.5	10.57	EER	820
DAC/HP	13.2 ± 6.9	16.76	SEER	220
ASAC/HP	3.3 ± 1.9	13.90	SEER	10
WSHP	4.6 ± 4.3			
Other	0.3 ± 0.3	9.70	EER	3

Table B25. Packaged Gas Equipment Efficiency by % Installed Capacity

Packaged Gas Equipment Efficiency	Multifamily	Office	Retail	School
0.78	0.0 ± 0.0	1.2 ± 1.1	0.0 ± 0.0	0.0 ± 0.0
0.8-0.82	63.6 ± 8.8	63.3 ± 45.4	82.6 ± 17.5	94.0 ± 0.0
0.95-0.98	0.0 ± 0.0	1.6 ± 2.7	0.0 ± 0.0	0.0 ± 0.0
Unknown	36.4 ± 8.8	33.9 ± 46.1	17.4 ± 17.5	6.0 ± 0.0

Service and Domestic Hot Water Data

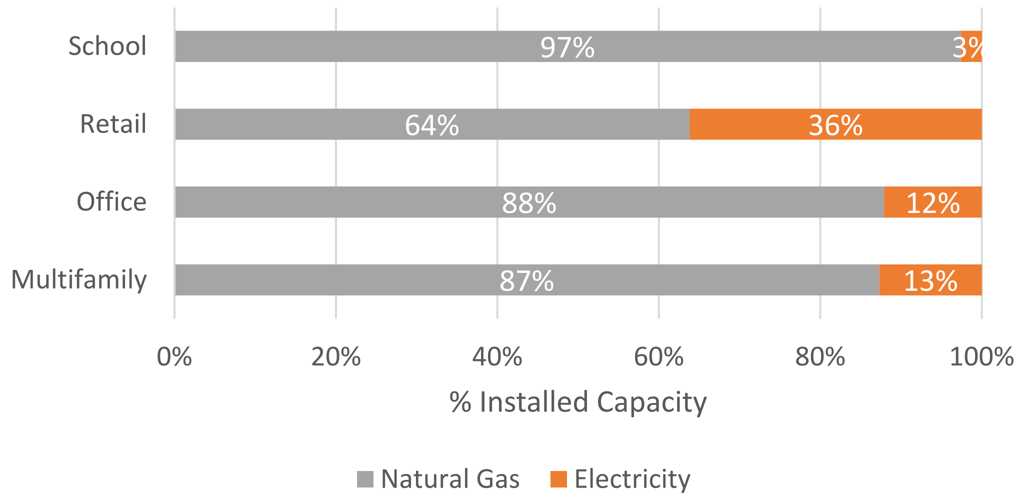


Figure B4. Water Heating Fuel Type by % Installed Capacity

Table B26. Water Heating Fuel Type by % Installed Capacity

Water Heating Fuel	Multifamily	Office	Retail	School
Natural Gas	87.3 ± 17.0	87.9 ± 18.3	63.8 ± 45.3	97.4 ± 1.4
Electricity	12.7 ± 17.0	12.1 ± 18.3	36.2 ± 45.3	2.6 ± 1.4

Table B27. Water Heating System Type by % Installed Capacity

Central vs In-Unit Distribution	Multifamily	Office	Retail	School
Central	85.8 ± 19.3	96.7 ± 5.0	6.1 ± 5.5	98.4 ± 1.3
In-Unit-Tank	14.1 ± 19.2	2.7 ± 4.7	77.8 ± 17.5	1.4 ± 1.1
In-Unit-On Demand	0.0 ± 0.0	0.0 ± 0.0	16.1 ± 19.5	0.2 ± 0.3
In-Unit-Other/Unknown	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Unknown-Tank	0.0 ± 0.0	0.6 ± 0.6	0.0 ± 0.0	0.0 ± 0.0

Table B28. Pump Controls by % Buildings with Hot Water Circulation Loops

Pump Controls	Multifamily	Office	Retail	School
Demand	8.8 ± 14.0	82 ± 12.7	15.9 ± 30.6	10.9 ± 14.9
Timer	13.2 ± 13.9	12.7 ± 14.5	68.2 ± 26.6	13.9 ± 18.4
Pressure	2.2 ± 2.0	0.0 ± 0.0	0.0 ± 0.0	7.3 ± 1.9
None	58.8 ± 26.7	0.0 ± 0.0	0.0 ± 0.0	57.0 ± 24.6
Not Applicable	5.5 ± 8.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Unknown	13.7 ± 23.8	9.0 ± 14.8	15.9 ± 30.6	18.2 ± 15.4

Envelope Data

Table B29. Overall Heat Loss--U_o (UA/total building surface area)

	Multifamily	Office	Retail	School
2002-2004 New Commercial Baseline	0.120	0.160	0.210	0.140
This study	0.077 ± 0.005	0.060 ± 0.006	0.083 ± 0.011	0.061 ± 0.009

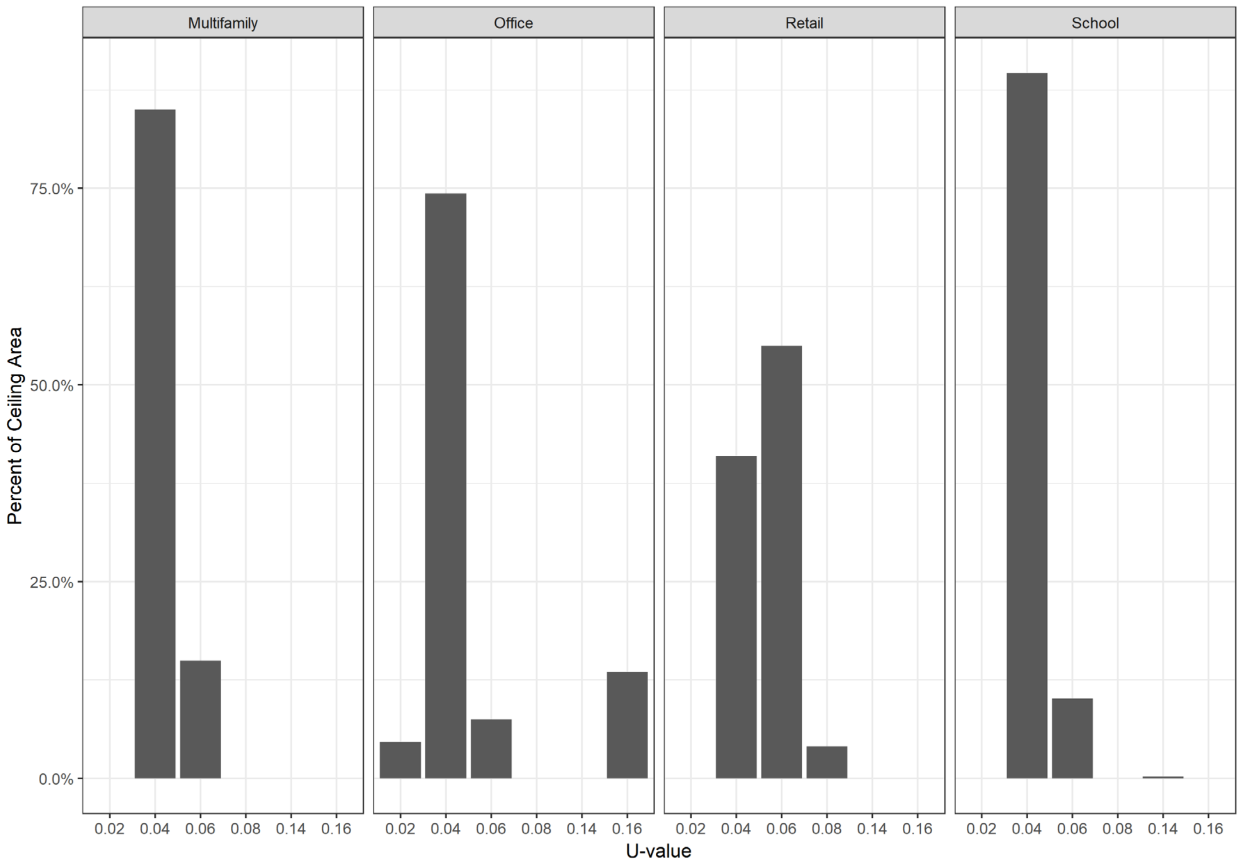
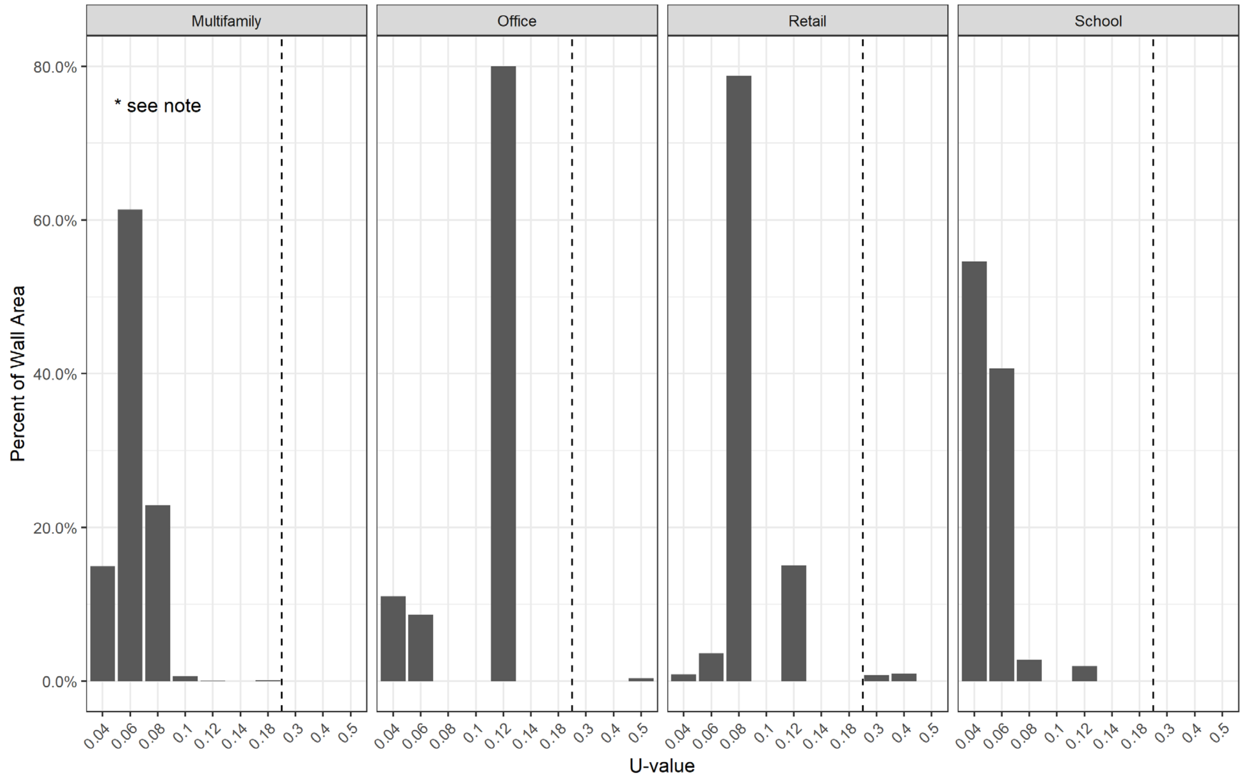


Figure B5. Roof U-value by Building Type (unweighted)

Table B30. Roof Construction by % Gross Roof Area

Ceiling Structure	Multifamily	Office	Retail	School
Roof deck	81.7 ± 15.5	40.1 ± 10.9	68.6 ± 29.4	80.0 ± 15.4
Metal	0.0 ± 0.0	27.9 ± 33.2	19.8 ± 22.5	1.4 ± 0.3
Cavity	10.6 ± 17.0	0.0 ± 0.0	0.0 ± 0.0	18.6 ± 15.3
Attic	0.0 ± 0.0	15.5 ± 22.7	1.5 ± 0.2	0.0 ± 0.0
Other	7.7 ± 12.9	16.5 ± 17.5	10.0 ± 17.7	0.0 ± 0.0

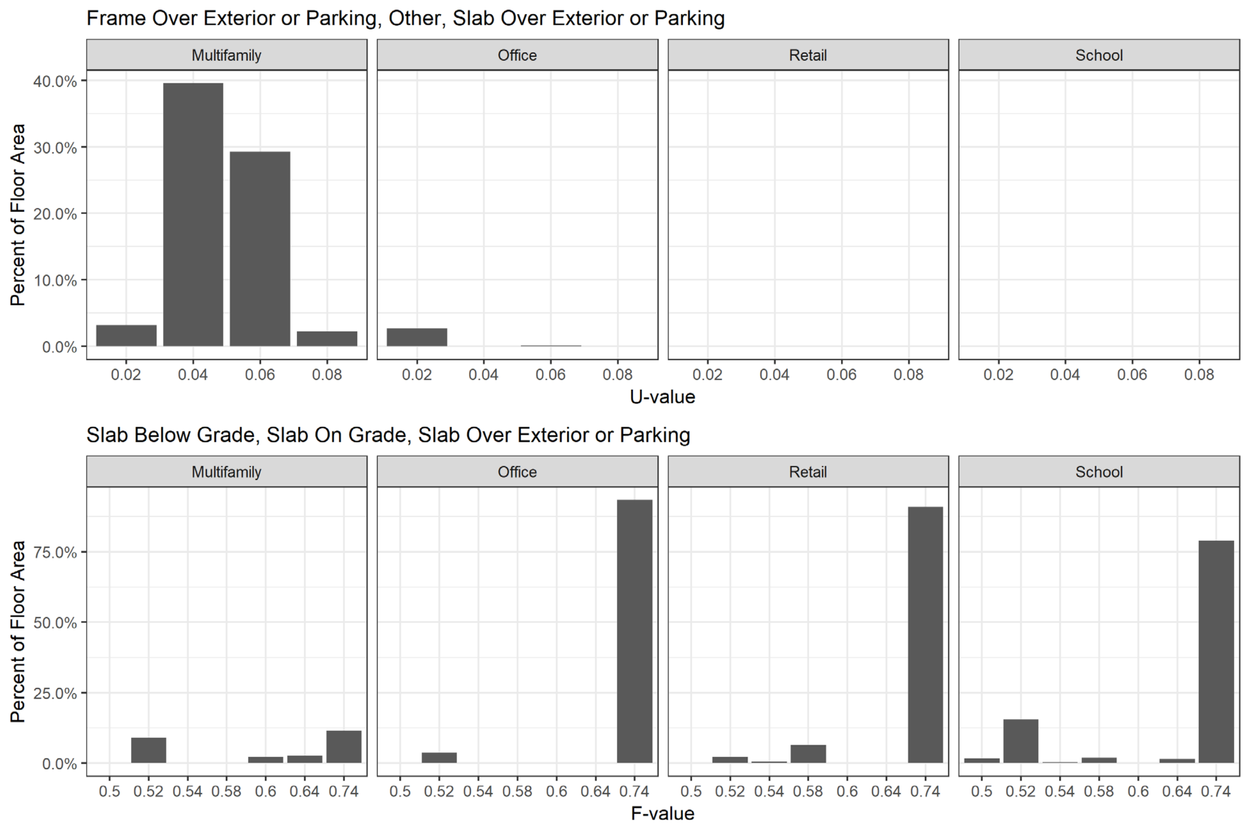


* No Concrete - below grade walls included for any building type
U-values left of dashed line increment by 0.02, right of line increment by 0.1
u = 0.82 (0.04%) removed from Multifamily

Figure B6. Wall U-value by Building Type (unweighted)

Table B31. Wall Structure by Building Type by % Gross Wall Area

Wall Structure	Multifamily	Office	Retail	School
Frame-wood	45.1 ± 5.4	47.6 ± 13.4	19.0 ± 22.0	15.1 ± 7.7
Frame-metal	50.0 ± 4.0	49.4 ± 14.7	41.5 ± 28.8	37.8 ± 21.4
Concrete Block - Filled	0.9 ± 0.8	0.9 ± 1.0	26.1 ± 21.1	13.7 ± 2.8
Concrete Block - Not Filled	0.1 ± 0.1	0.0 ± 0.0	11.5 ± 9.5	5.7 ± 5.0
Other	2.1 ± 1.9	0.0 ± 0.0	1.9 ± 2.6	26.7 ± 15.3
Unknown	0.0 ± 0.0	2.1 ± 2.3	0.0 ± 0.0	0.0 ± 0.0



Note x- and y-axis scales differ

Figure B7. Floor U-value and F-values by Building Type (unweighted)

Table B32. Floor Structure by % Gross Floor Area

Floor Structure	Multifamily	Office	Retail	School
Slab On Grade	54.8 ± 8.6	88.3 ± 15.9	100.0 ± 0.0	98.4 ± 0.3
Slab Over Exterior or Parking	35.1 ± 9.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Slab Below Grade	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.5 ± 0.4
Frame Over Exterior or Parking	6.6 ± 7.2	2.0 ± 3.0	0.0 ± 0.0	0.0 ± 0.0
Other	3.6 ± 3.2	9.8 ± 15.4	0.0 ± 0.0	0.1 ± 0.1

Table B33. Skylight Area by % Gross Roof Area

Multifamily	Office	Retail	School
0.00 ± 0.00	2.20 ± 2.84	0.88 ± 0.94	0.56 ± 0.34

Table B34. Window and Door Area by % Gross Floor Area

Multifamily	Office	Retail	School
0.14 ± 0.01	0.15 ± 0.05	0.19 ± 0.03	0.13 ± 0.02

Table B35. Window Area by % Gross Wall Area

	Multifamily	Office	Retail	School
2002-2004 New Commercial Baseline	24.5	28.9	13.5	13.9
This study	27.11 ± 2.55	23.52 ± 6.02	22.45 ± 5.23	18.57 ± 3.11

Table B36. Window U-Factor by % of Total Glazing Area

Window U-Factor Class*	Multifamily	Office	Retail	School
< 30	58.7 ± 9.1	26.5 ± 36.5	0.0 ± 0.0	0.0 ± 0.0
30-40	16.3 ± 9.3	72.4 ± 36.6	15.8 ± 6.1	27.1 ± 8.8
41-50	18.5 ± 10.3	0.1 ± 0.1	55.8 ± 19.3	70.1 ± 8.3
51-60	6.5 ± 3.9	1.1 ± 1.8	5.7 ± 5.5	2.3 ± 1.7
> 60	0.0 ± 0.0	0.0 ± 0.0	22.6 ± 15.6	0.6 ± 0.8

*U-Factor Class of 30 corresponds to U-Value of 0.30 Btu/hr/F

Table B37. Low Emissivity Coating Type as % of Total Glazing Area

Low-e coating	Multifamily	Office	Retail	School
Low-e (e < 0.05)	63.8 ± 9.2	69.2 ± 17.7	19.5 ± 11.7	40.8 ± 18.2
Low-e (e = 0.05–0.10)	29.8 ± 11.7	30.8 ± 17.7	66.2 ± 14.5	57.6 ± 16.7
None	0.9 ± 0.6	0.0 ± 0.0	12.9 ± 10.6	1.6 ± 1.8
Unknown	5.5 ± 8.4	0.0 ± 0.0	1.4 ± 0.2	0.0 ± 0.0

Lighting Data

Table B38. Interior Lamp Type by % of Interior Watts

Lamp Type (Interior)	Multifamily	Office	Retail	School
LED Integrated	38.9 ± 9.1	42.8 ± 19.7	11.5 ± 6.7	29.6 ± 21.1
LED Linear	0.6 ± 0.5	40.7 ± 17.9	16.1 ± 18.4	12.3 ± 2.7
LED	0.3 ± 0.2	1.5 ± 1.9	2.7 ± 3.4	0.3 ± 0.1
T5	10.0 ± 5.2	1.2 ± 1.4	6.5 ± 5.4	9.6 ± 4.7
T8	23.6 ± 5.7	13.4 ± 11.9	42.4 ± 13.5	40.7 ± 13.9
CFL	12.6 ± 6.6	0.2 ± 0.3	4.2 ± 1.8	6.0 ± 2.7
HAL	1.6 ± 1.4	0.0 ± 0.0	1.5 ± 1.6	0.0 ± 0.0
HID-MH	0.0 ± 0.0	0.0 ± 0.0	2.0 ± 2.8	0.0 ± 0.0
INC	0.4 ± 0.6	0.0 ± 0.0	4.9 ± 8.6	0.0 ± 0.0
Other/Unknown	12.0 ± 8.3	0.1 ± 0.1	8.2 ± 4.9	1.5 ± 0.7

Table B39. Interior Lamp Types (% Interior Watts) by New Buildings Program Participation

	Multifamily		Office		Retail		School	
Program Participation:	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE	TRUE	FALSE
LED Integrated	38.9 ± 9.1	--	54.8 ± 22.0	0.9 ± --	10.7 ± 8.5	12.3 ± 14.7	22.6 ± 3.4	34.3 ± 35
LED Linear	0.6 ± 0.5	--	40.7 ± 16.4	40.8 ± --	29.7 ± 7.8	0.7 ± 1.4	29.8 ± 4.5	0.3 ± 0.5
LED	0.3 ± 0.2	--	0.9 ± 2.0	3.8 ± --	3.6 ± 6.8	1.8 ± 3.3	0.8 ± 0.1	0.0 ± 0.0
T5	10 ± 5.2	--	0.0 ± 0.0	5.5 ± --	5.2 ± 7	8.0 ± 5.3	4.8 ± 0.7	13.1 ± 7.9
T8	23.6 ± 5.7	--	3.4 ± 4.0	48.2 ± --	27.2 ± 11.7	59.7 ± 29.4	32.8 ± 10.4	45.9 ± 23.7
CFL	12.6 ± 6.6	--	0.0 ± 0.0	0.8 ± --	3.1 ± 2.4	5.5 ± 5.2	6.8 ± 3.4	5.4 ± 3.8
HAL	1.6 ± 1.4	--	0.0 ± 0.0	0.0 ± --	0.9 ± 0.4	2.0 ± 6.2	0.0 ± 0.0	0.0 ± 0.0
HID-MH	0.0 ± 0.0	--	0.0 ± 0.0	0.0 ± --	3.7 ± 5.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
INC	0.4 ± 0.6	--	0.0 ± 0	0.0 ± --	9.2 ± 17.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Other/ Unknown	12 ± 8.3	--	0.1 ± 0.3	0.0 ± --	6.7 ± 7.9	9.9 ± 4.5	2.3 ± 0.3	1.0 ± 1.3

Table B40. Exterior Lamp Type by % Exterior Watts

Lamp Type (Exterior)	Multifamily	Office	Retail	School
LED Integrated	28.4 ± 13.6	93.8 ± 7	80.1 ± 15.4	63.0 ± 16.9
LED Linear	1.2 ± 0.8	2.2 ± 1.9	0.0 ± 0.0	0.0 ± 0.0
LED	4.3 ± 3.3	0.0 ± 0.0	3.0 ± 4.3	0.0 ± 0.0
T5	0.6 ± 0.9	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
T8	31.9 ± 19.2	4.0 ± 6.5	3.2 ± 3.1	4.8 ± 5.7
CFL	12.2 ± 10.1	0.0 ± 0.0	4.4 ± 3.3	16.4 ± 7.1
HID-MH	17.0 ± 25.1	0.0 ± 0.0	9.2 ± 12.9	15.8 ± 10.1
Other/Unknown	4.4 ± 5.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0

Table B41. Allowed and Actual LPD Across Building Types

Watts/ft^2	Multifamily	Office	Retail	School
Interior LPD Code Allowance	**0.58**	**0.91**	**1.32**	**1.01**
Interior LPD	0.41 ± 0.05	0.62 ± 0.13	0.81 ± 0.09	0.84 ± 0.09
Exterior Parking LPD	0.04 ± 0.03	0.21 ± 0.28	0.29 ± 0.07	0.03 ± 0.01
Exterior Non-Parking LPD	0.02 ± 0.01	0.03 ± 0.03	0.16 ± 0.08	0.03 ± 0.01
Aggregate LPD	0.45 ± 0.07	0.82 ± 0.07	1.03 ± 0.06	0.86 ± 0.12

Table B42. Allowed and Actual LPD by ETO New Building Program Participation

	Multifamily		Office		Retail		School	
Program Participation:	**TRUE**	**FALSE**	**TRUE**	**FALSE**	**TRUE**	**FALSE**	**TRUE**	**FALSE**
Interior LPD Code Allowance	**0.58**	**0.58**	**0.91**	**0.91**	**1.32**	**1.32**	**1.01**	**1.01**
Interior LPD	0.41 ± 0.05	--	0.73 ± 0.04	0.49 ± --	0.82 ± 0.18	0.80 ± 0.16	0.71 ± 0.10	1.01 ± 0.12
Aggregate LPD	0.45 ± 0.07	--	0.81 ± 0.06	0.84 ± --	1.01 ± 0.14	1.04 ± 0.12	0.71 ± 0.15	1.06 ± 0.12

** Exterior LPD not included due to sample size*

Table B43. Primary Interior Lighting Control (% Interior Watts Controlled by Particular Strategy)

Primary Interior Lighting Control	Multifamily	Office	Retail	School
Occupancy	10.6 ± 1.9	63.2 ± 16.2	13.6 ± 10.5	56.2 ± 5.9
Daylight	1.2 ± 0.2	0.6 ± 0.9	0.2 ± 0.0	3.2 ± 2.8
Occupancy and Daylight	0.1 ± 0.1	12.1 ± 8.7	0.0 ± 0.0	14.1 ± 6.0
Manual Switch	73.2 ± 3.8	2.2 ± 1.1	33.7 ± 11.5	12.1 ± 4.8
Central	0.1 ± 0.1	21.6 ± 10.2	49.6 ± 14.9	13.8 ± 4.9
Hardwired	11.5 ± 4.1	0.3 ± 0.2	0.1 ± 0.0	0.3 ± 0.1
Timer Dial	0.4 ± 0.4	0.0 ± 0.0	0.0 ± 0	0.0 ± 0.0
Other	0.5 ± 0.9	0.0 ± 0.0	2.8 ± 3.9	0.2 ± 0.3
Unknown	2.5 ± 2.9	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0

Appendix C: Energy Code Compliance Summary

Overall Compliance

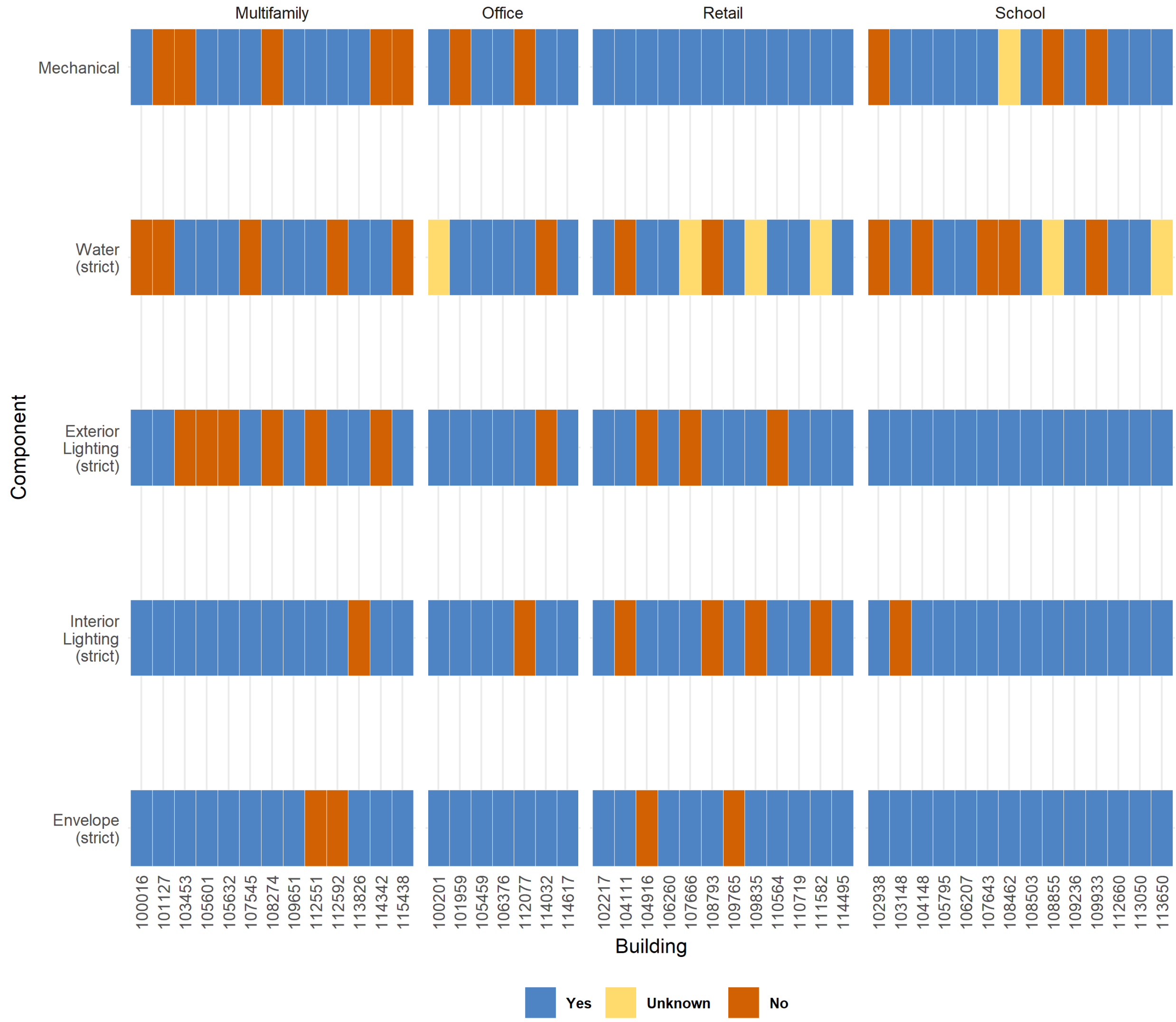


Figure C1. Overall Compliance (strict)

Table C1. Overall Subcategory Compliance View by Building Count

Category	Subcategory	Yes	No	NA	UNK	Comply Rate (Strict)
Mechanical	Equipment Efficiency	39	5	0	2	89%
	Economizers	29	6	11	0	83%
	Fans	17	0	28	1	100%
Service Water Heating	Equipment Efficiency	35	0	0	11	100%
	Pipe Insulation	28	3	12	3	90%
	Pump Controls	17	10	12	7	63%
Envelope	Total UA	42	4	0	0	91%
	Window / Wall Ratio	38	8	0	0	83%
	Skylight / Ceiling Ratio	12	1	33	0	92%
Interior Lighting	Controls	44	2	0	0	96%
	Lighting Power Density	40	6	0	0	87%
Exterior Lighting	Controls	38	2	2	4	95%
	Exterior Lighting Power	37	6	2	1	86%
	Façade Lighting Power	27	3	15	1	90%

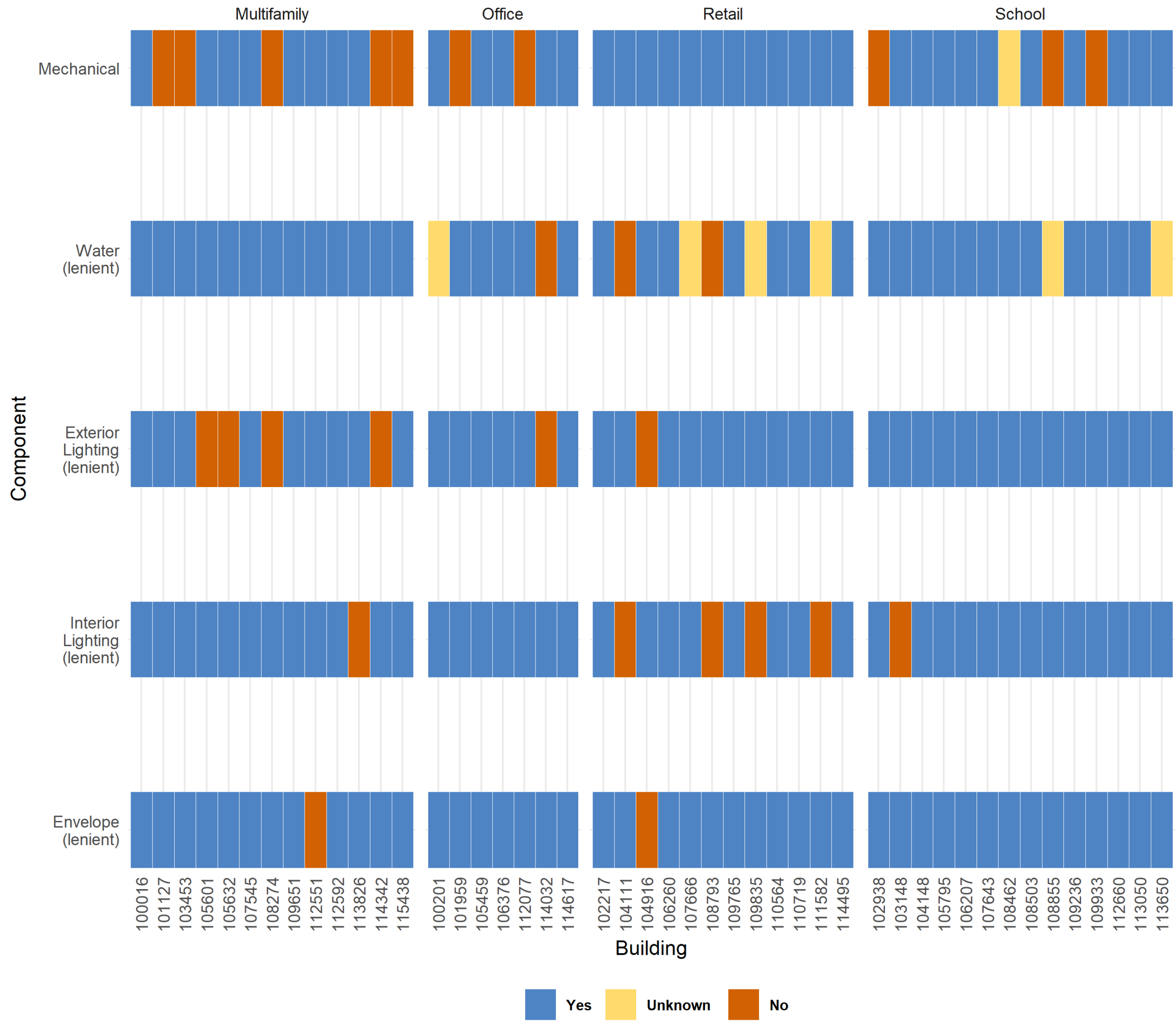


Figure C2. Overall Compliance (lenient)

Envelope Compliance

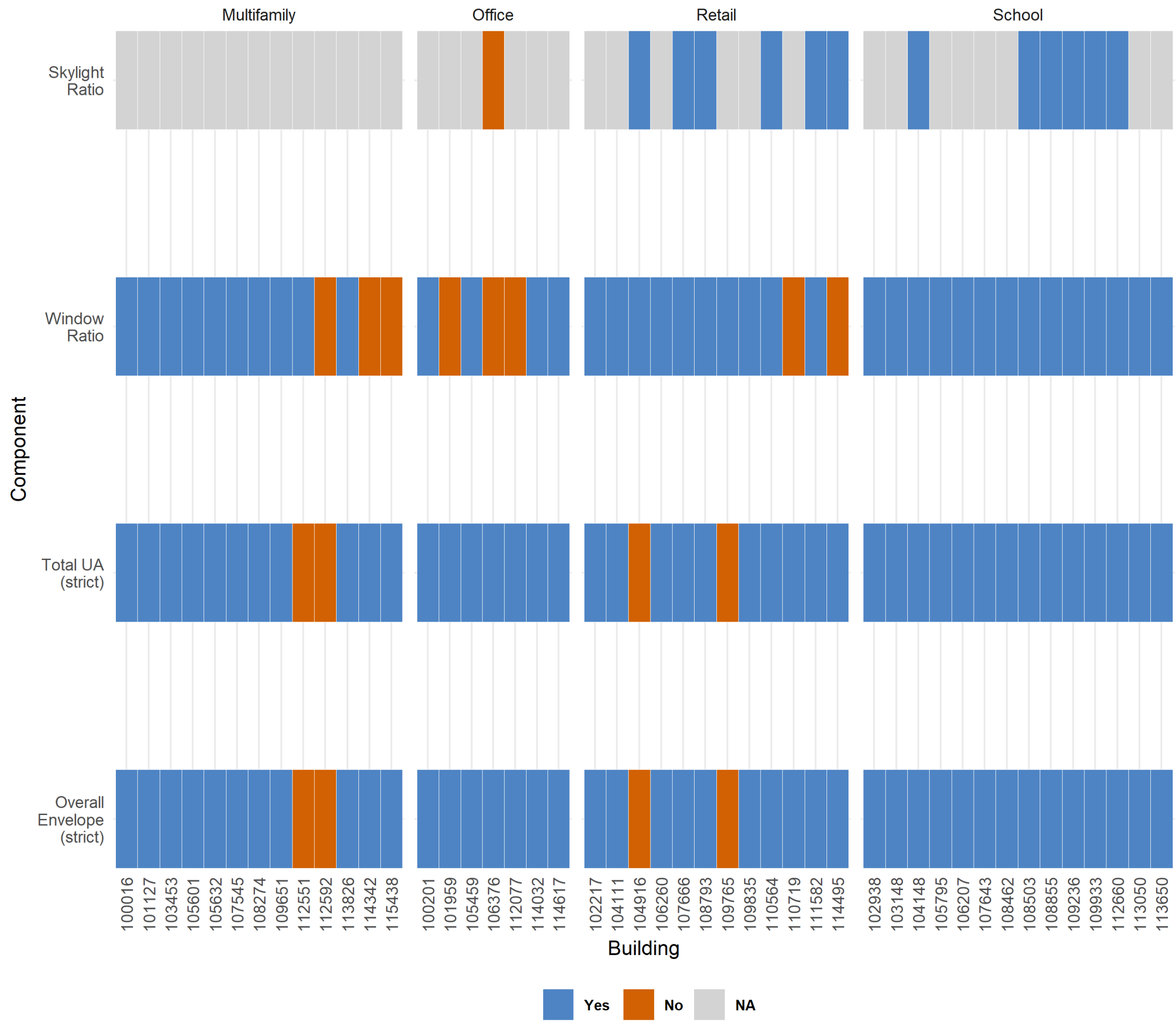


Figure C3. Envelope Compliance (strict)

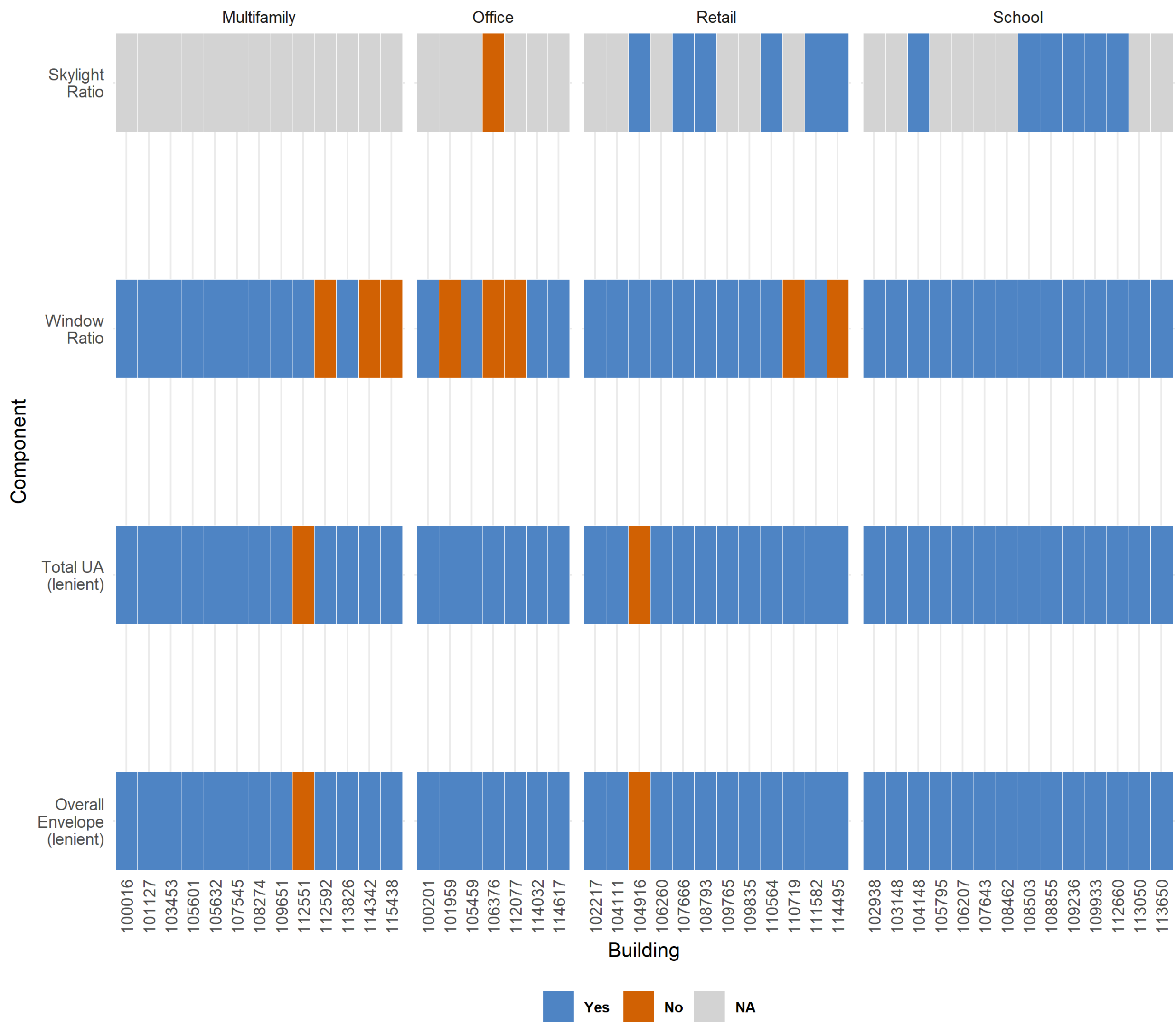


Figure C4. Envelope Compliance (lenient)

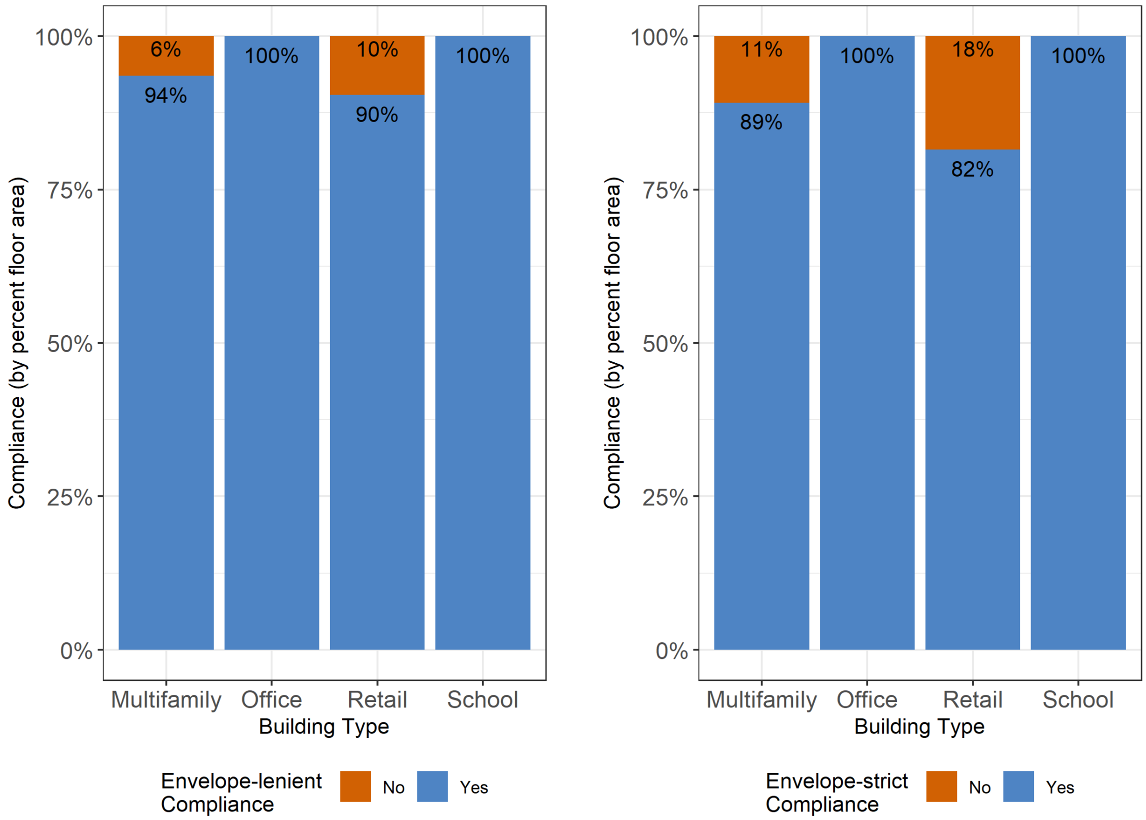


Figure C5. Envelope Compliance – Strict and Lenient (% Floor Area)

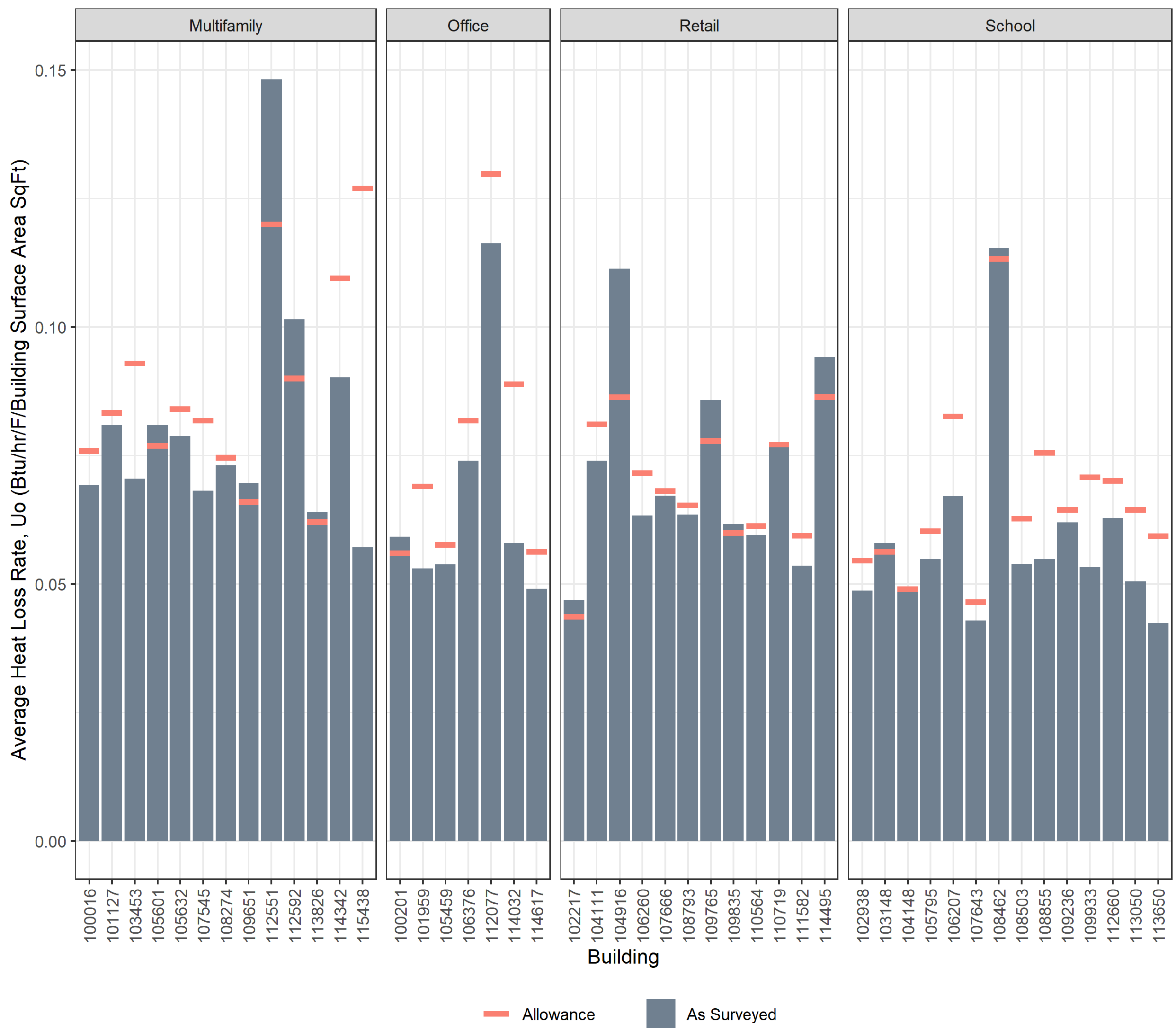


Figure C6. Overall Heat Loss Normalized by Total Building Surface Area (Uo)

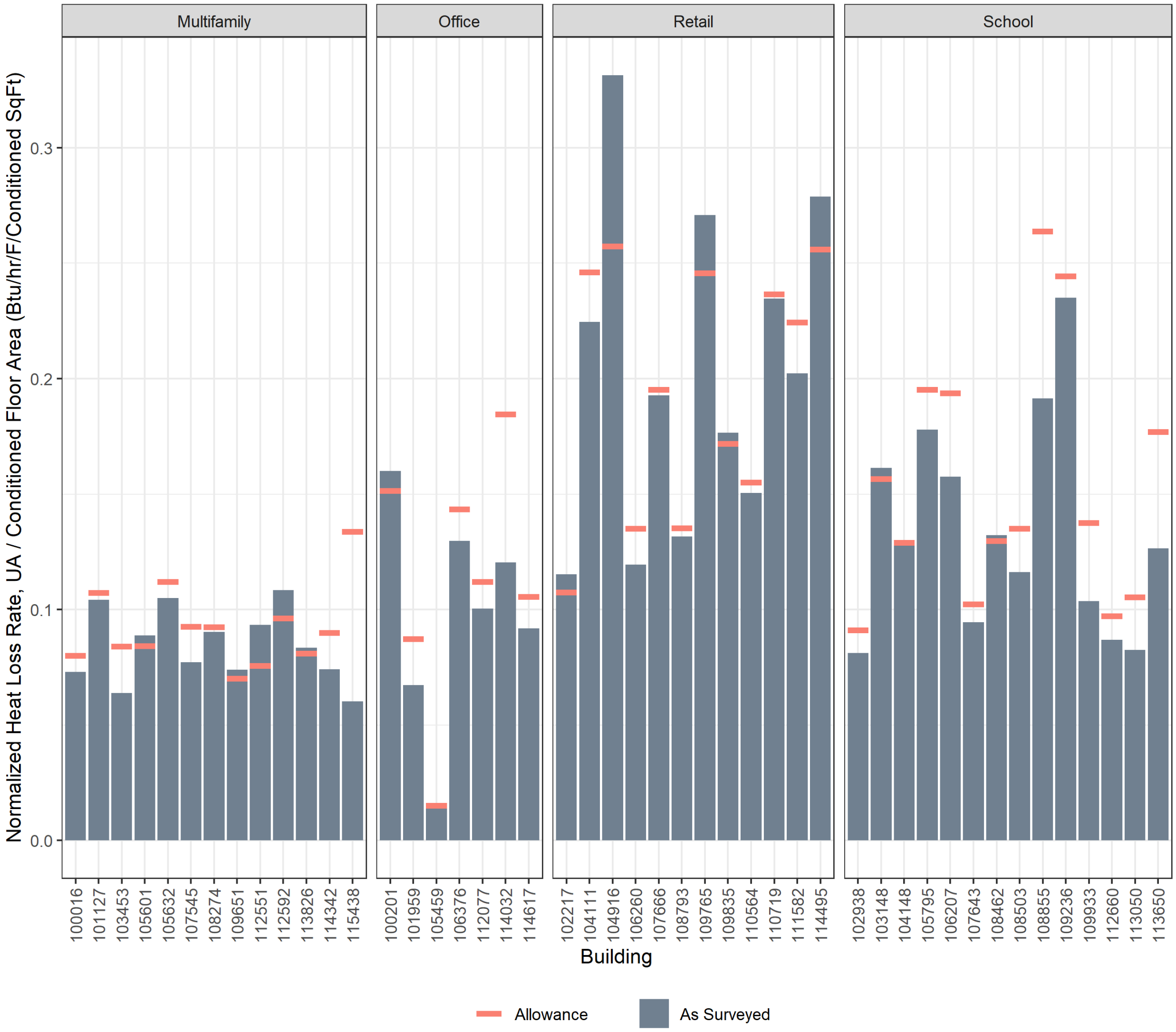


Figure C7. Heat Loss Normalized by Conditioned Floor Area

HVAC Compliance

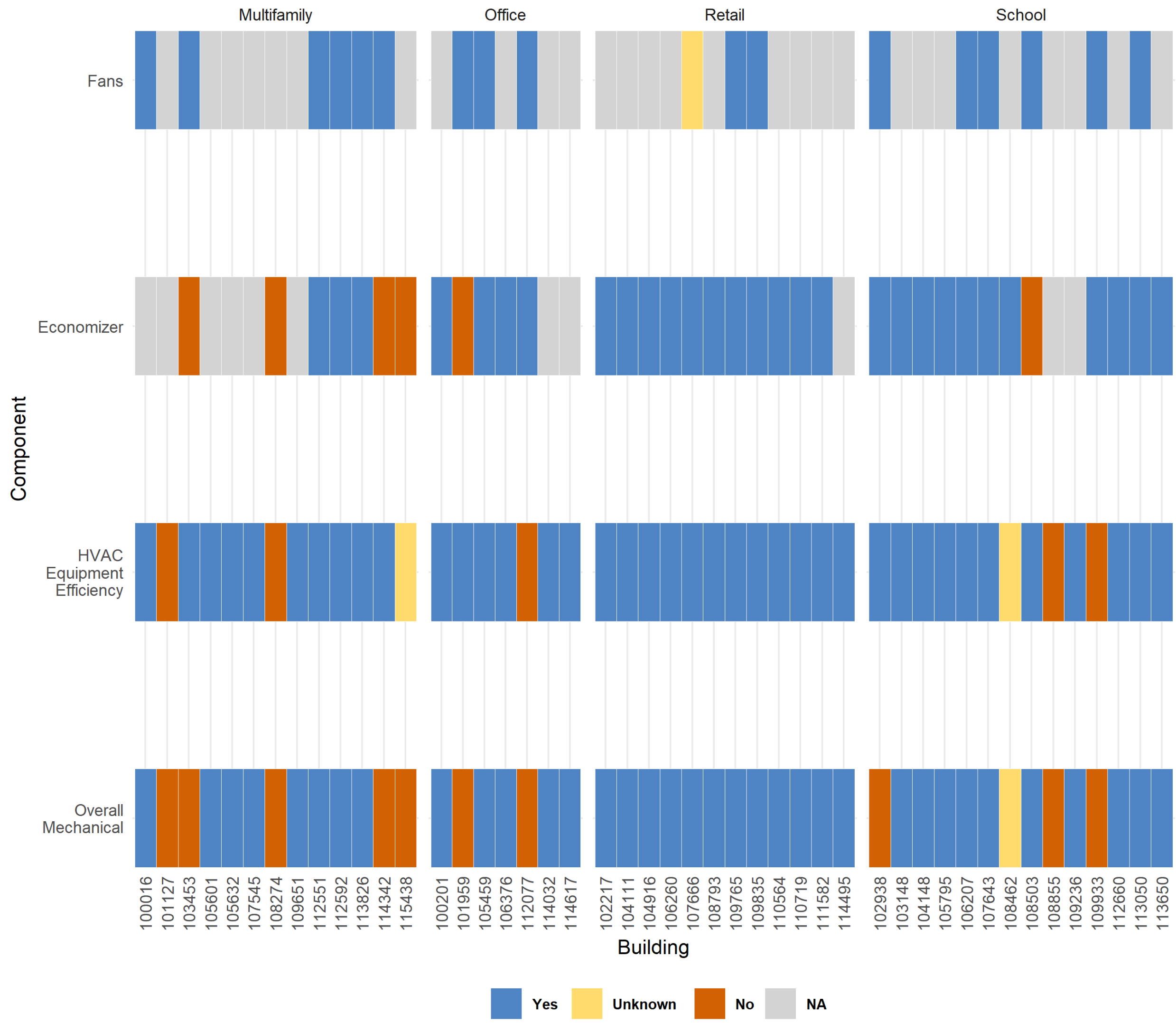


Figure C8. HVAC Compliance (strict)

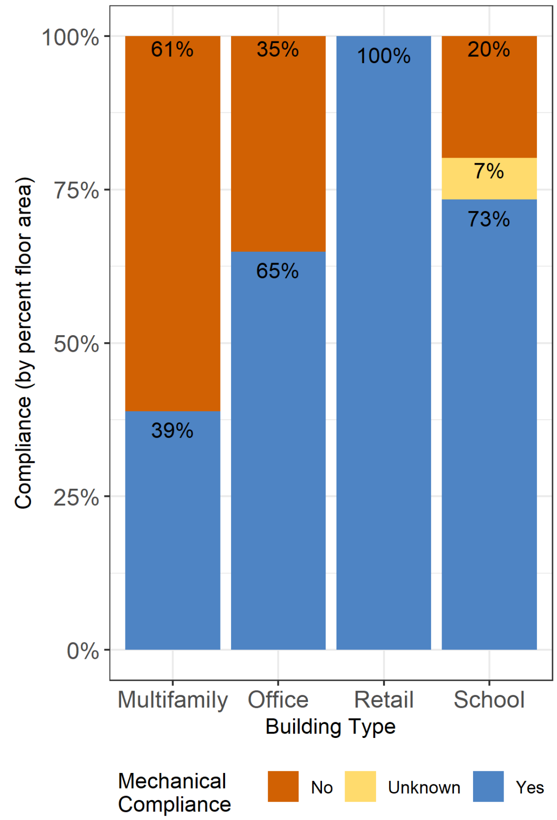


Figure C9. HVAC Compliance – Strict (% Floor Area)

Table C2. Equipment Efficiency Compliance by Building

	Furnaces & Unit Heaters	PTAC & PTHP	AC	Air Source Heat Pump	Large Cooling (chiller/cooling tower)	VRF	Boilers
Yes	20	9	34	18	7	1	13
No	0	1	1	2	1	0	0
Unknown	10	0	8	4	0	4	1
NA	16	36	3	22	38	41	32

Interior Lighting Compliance

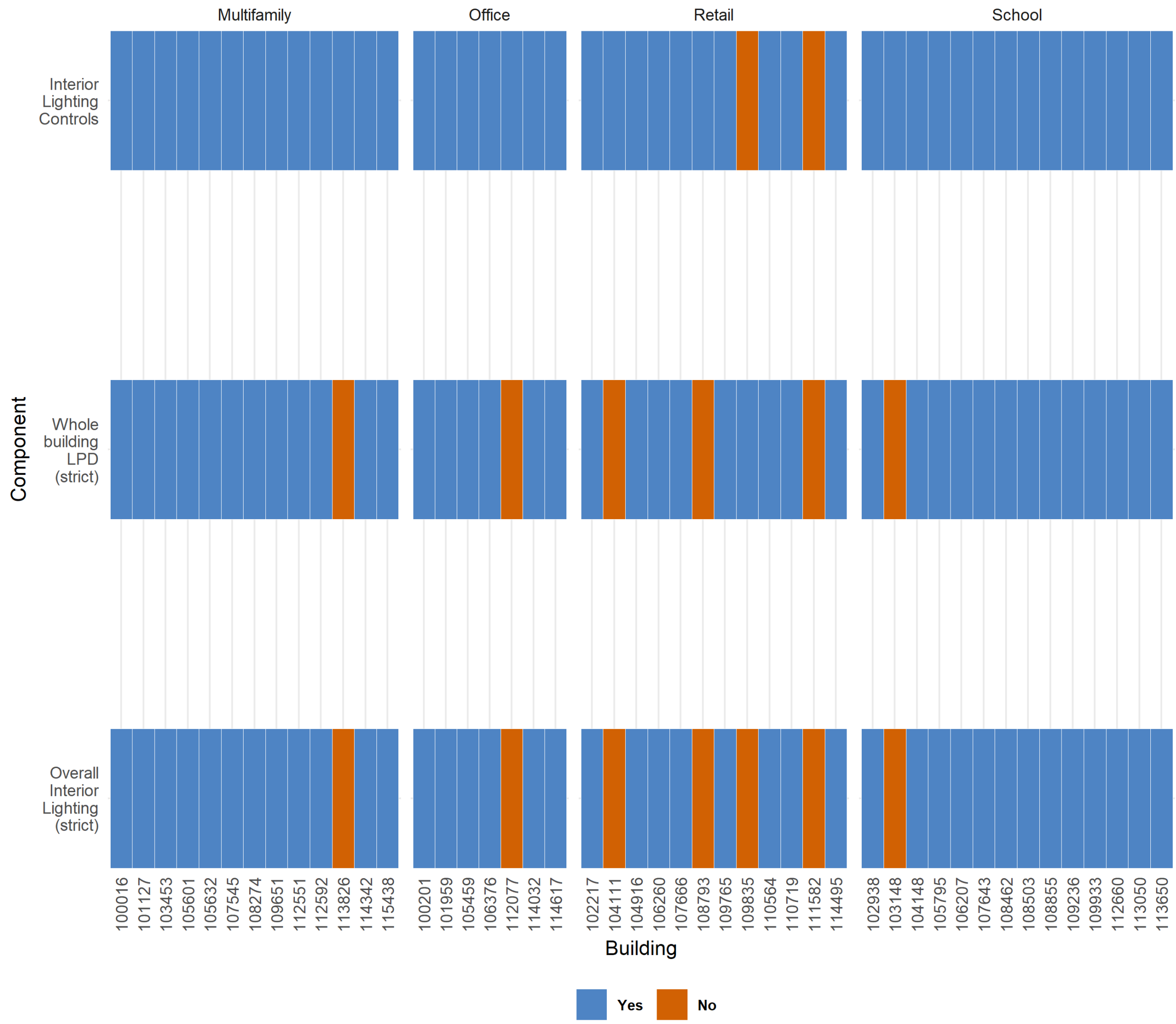


Figure C10. Interior Lighting Compliance (strict)

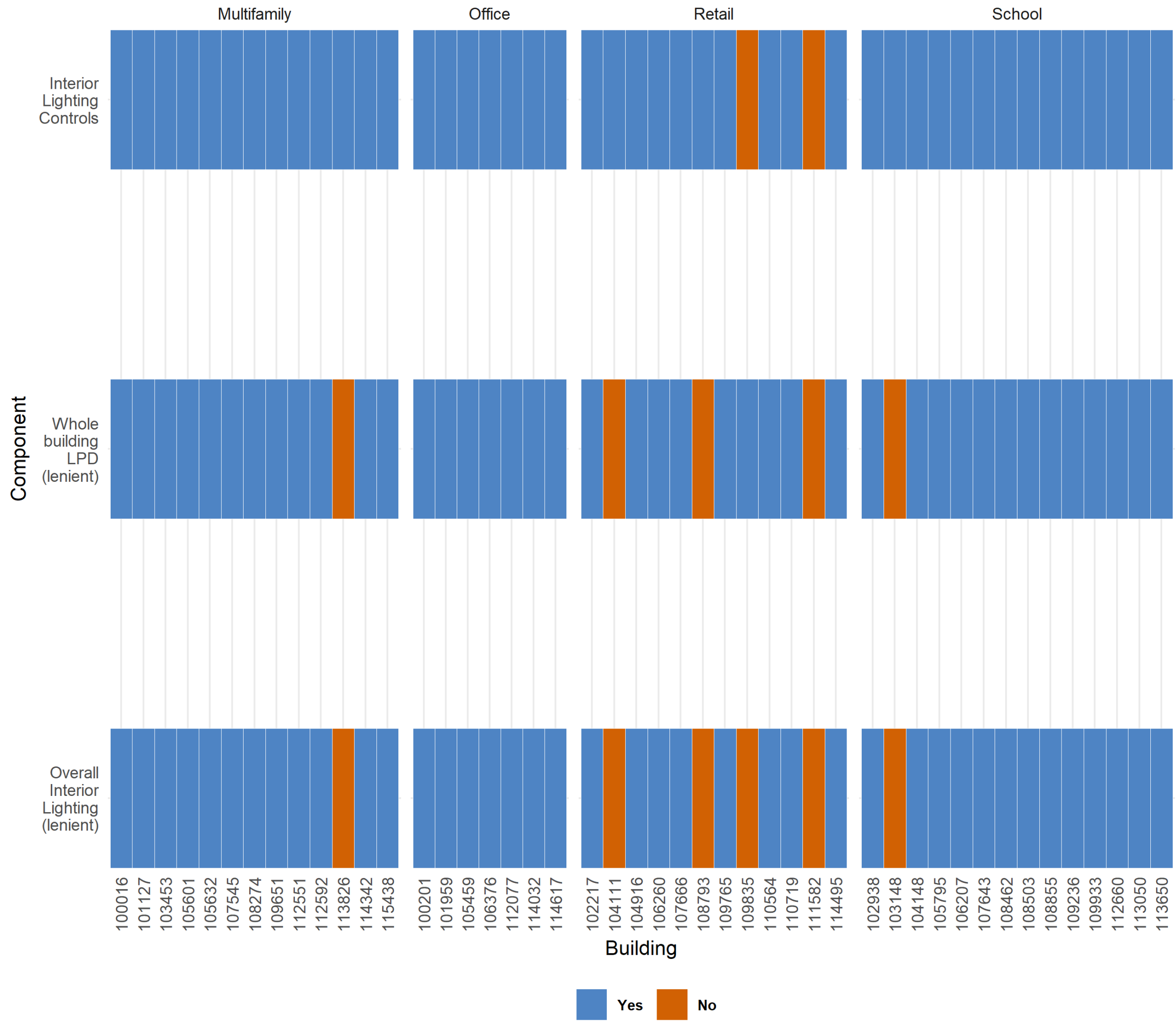


Figure C11. Interior Lighting Compliance (lenient)

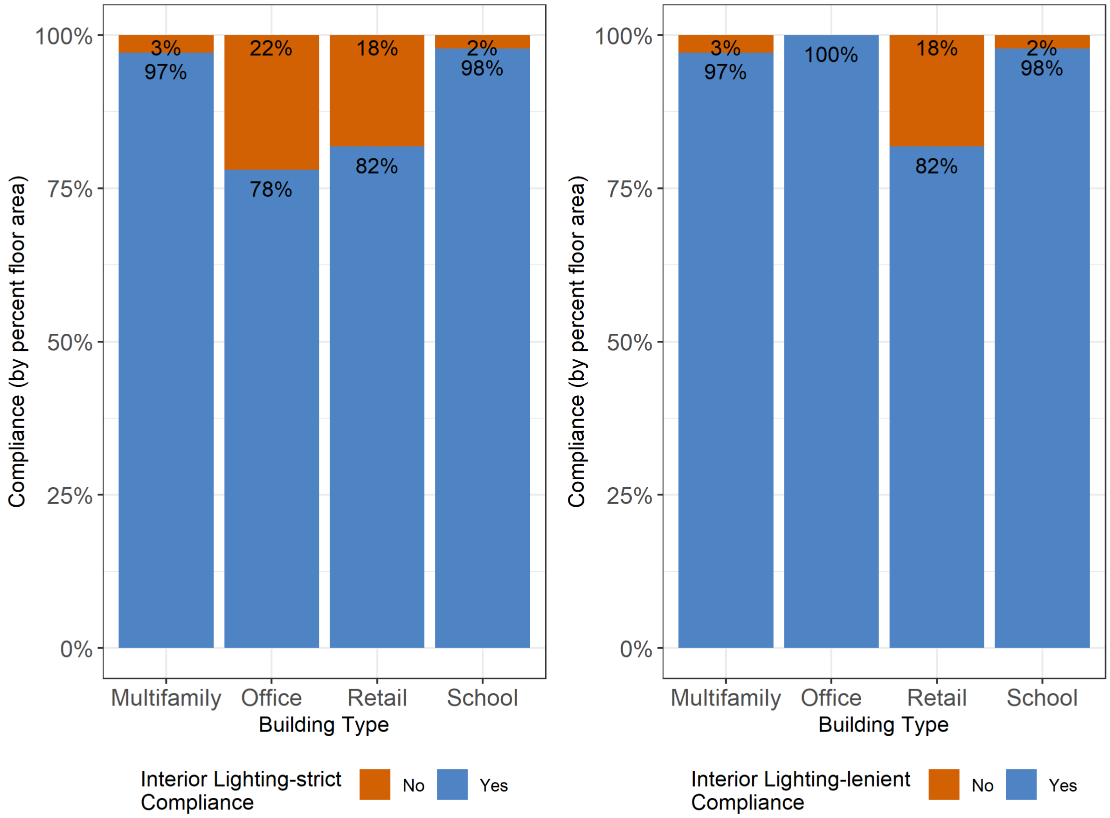


Figure C12. Interior Lighting Compliance – Strict and Lenient (% Floor Area)

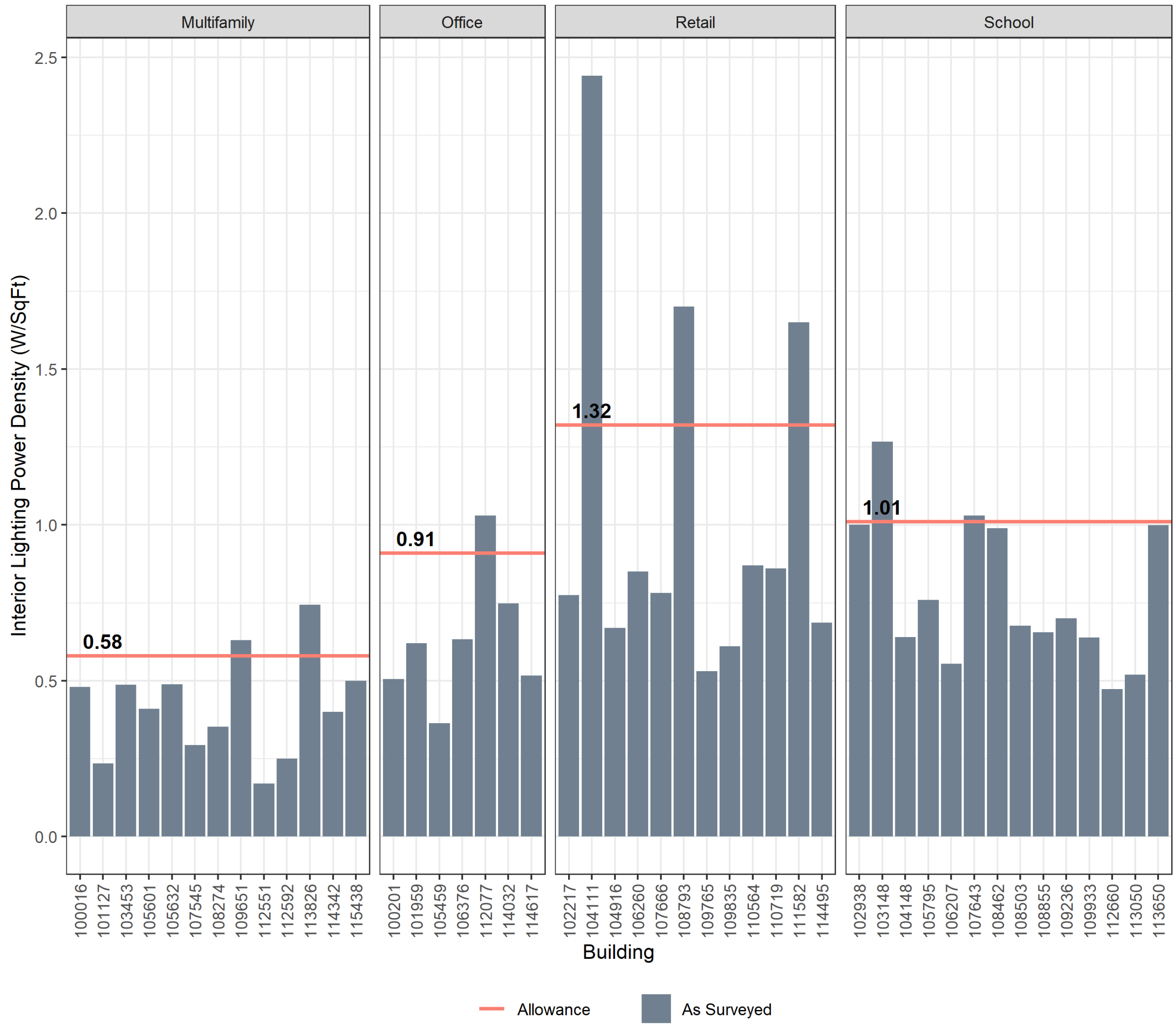


Figure C13. Interior Lighting Power Density

Exterior Lighting Compliance

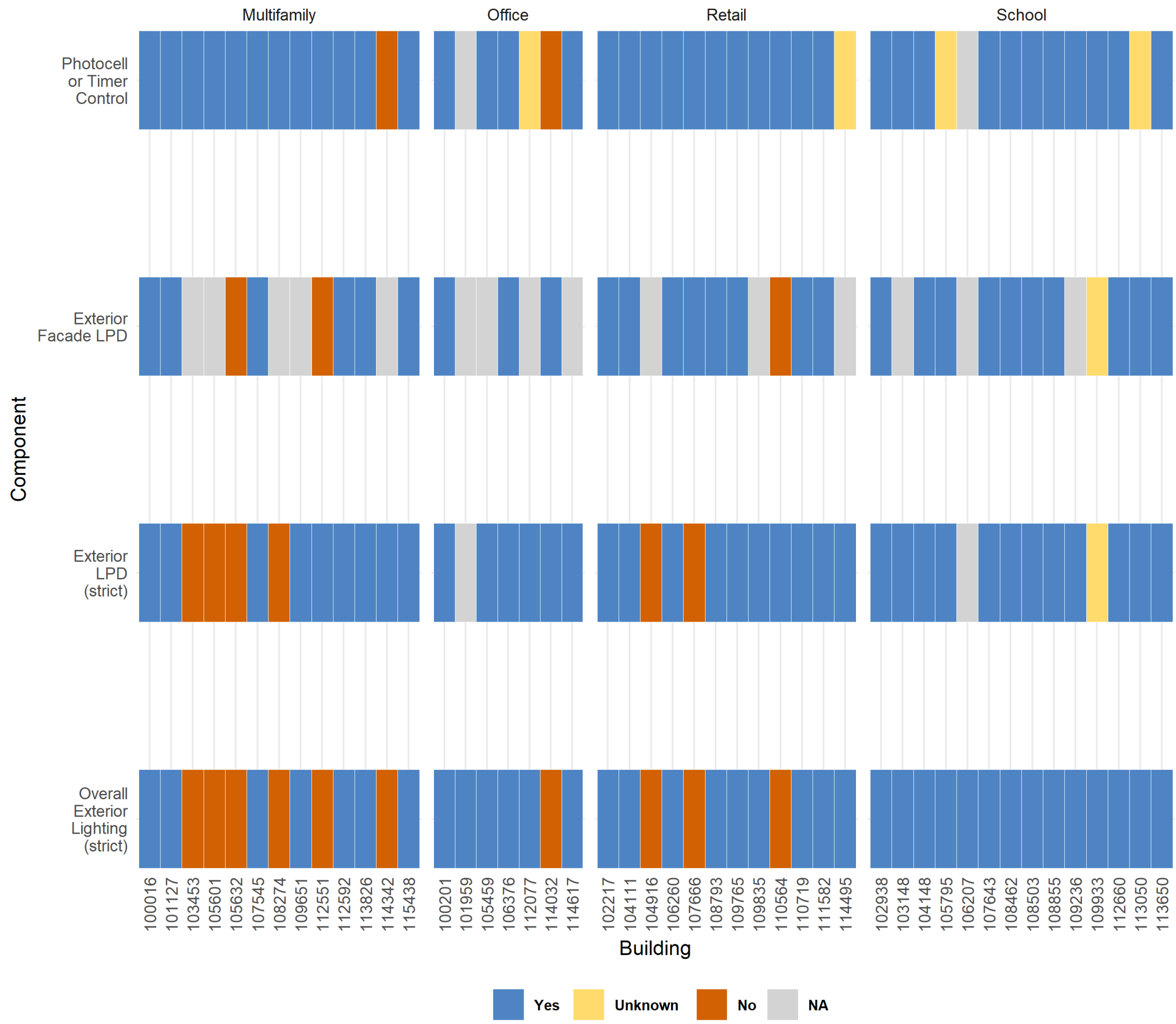


Figure C14. Exterior Lighting Compliance (strict)

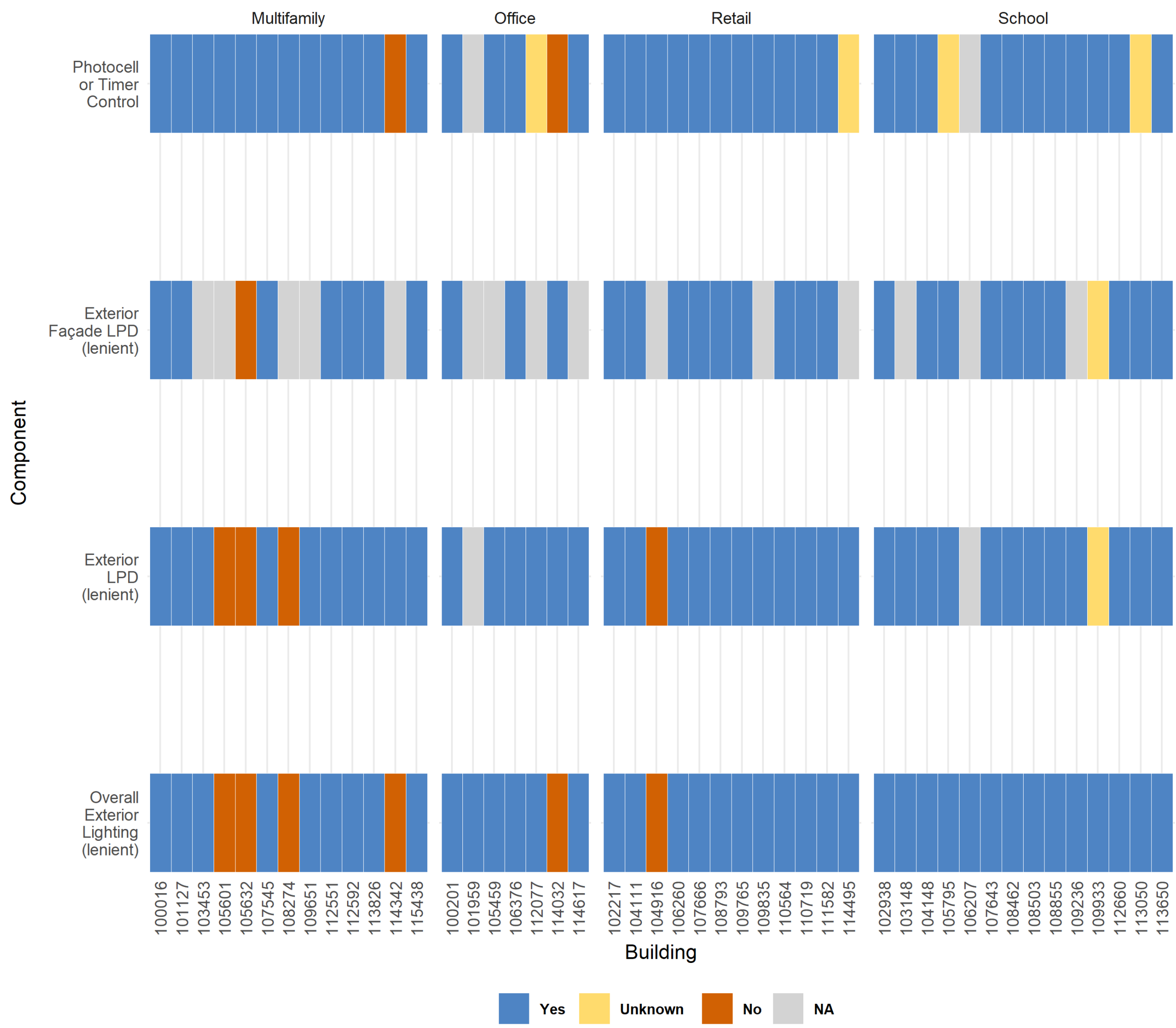


Figure C15. Exterior Lighting Compliance (lenient)

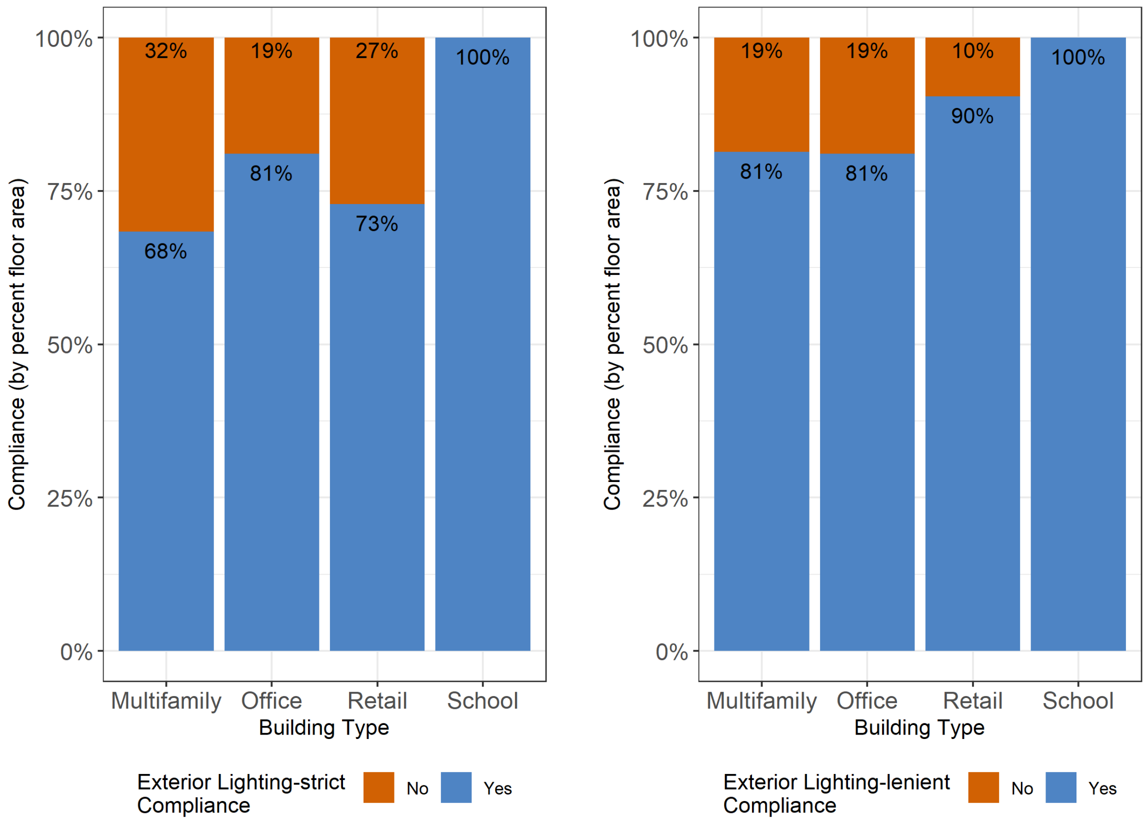


Figure C16. Exterior Lighting Compliance - Strict and Lenient (% Floor Area)

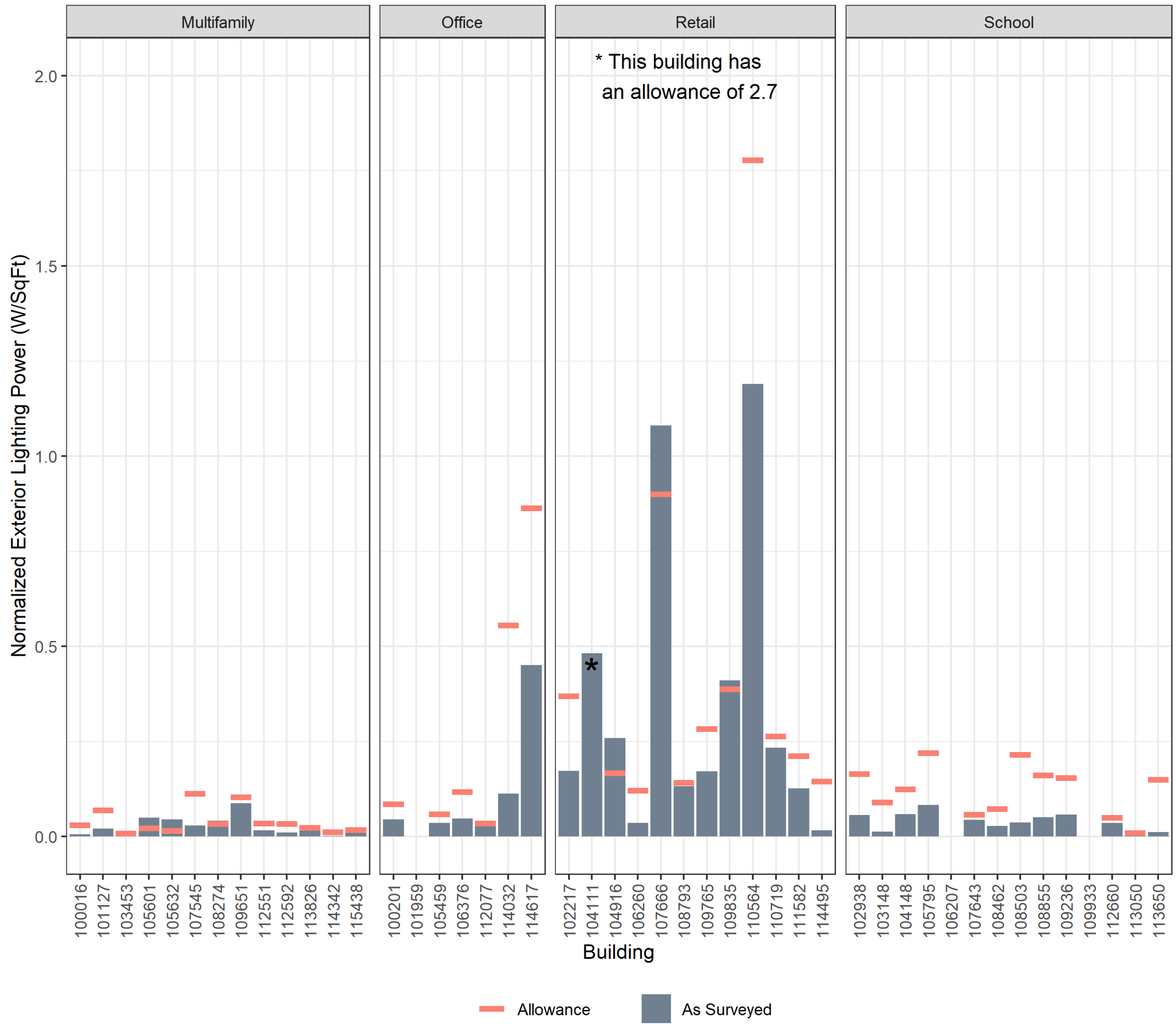


Figure C17. Exterior Lighting Power Normalized by Building Area

Service Water Heating Compliance

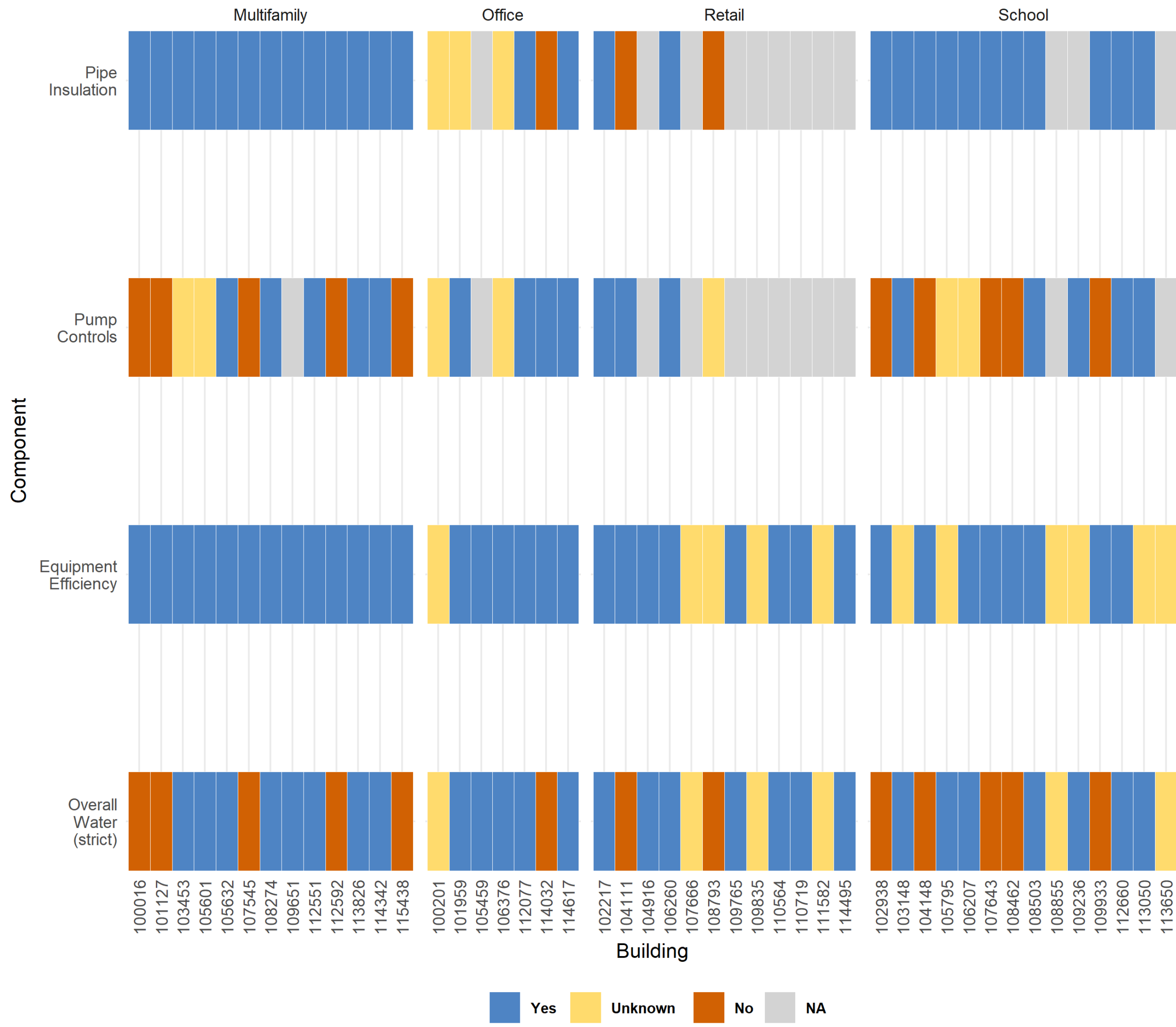


Figure C18. Service Water Heating Compliance (strict)

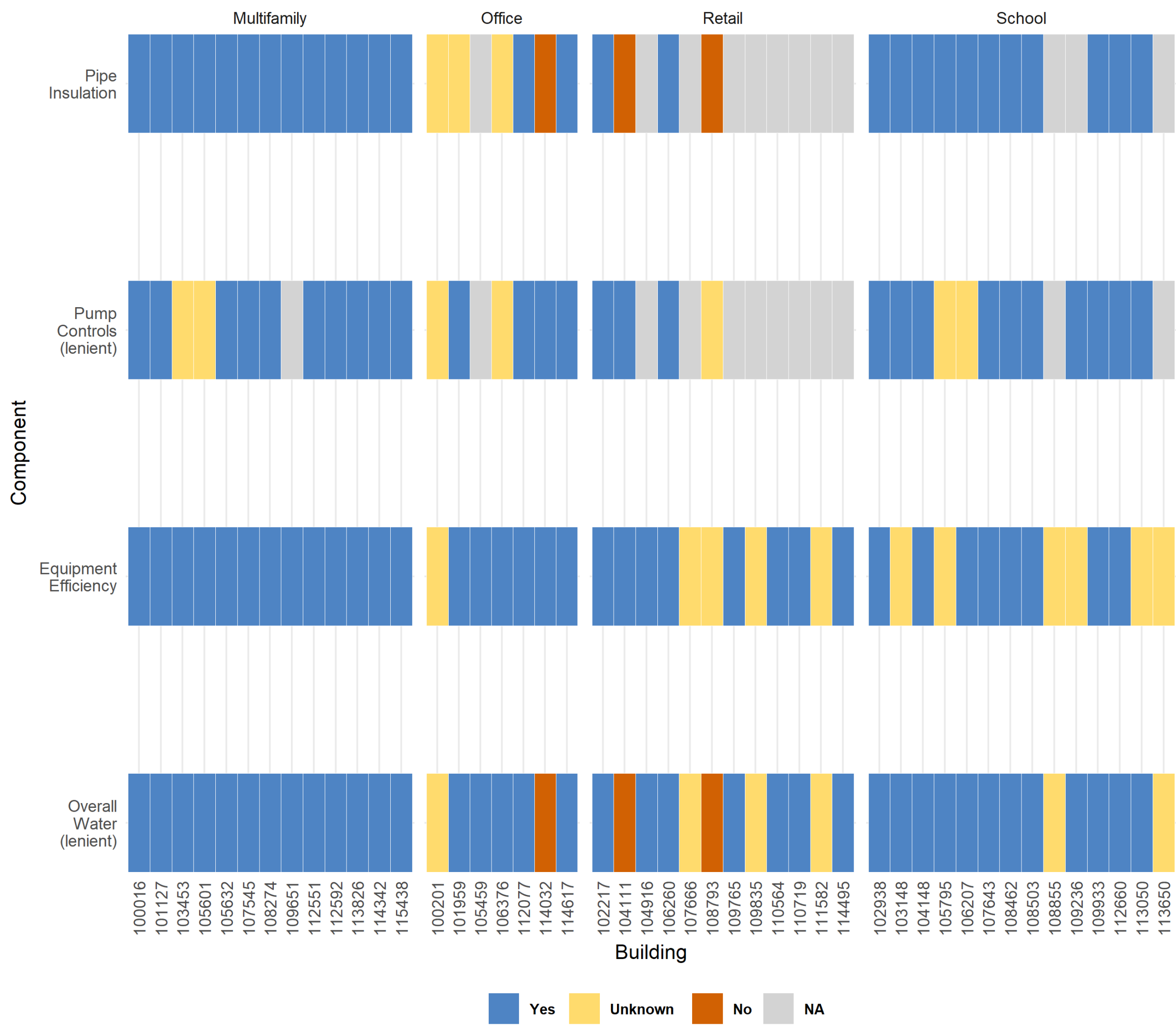


Figure C19. Service Water Heating Compliance (lenient)

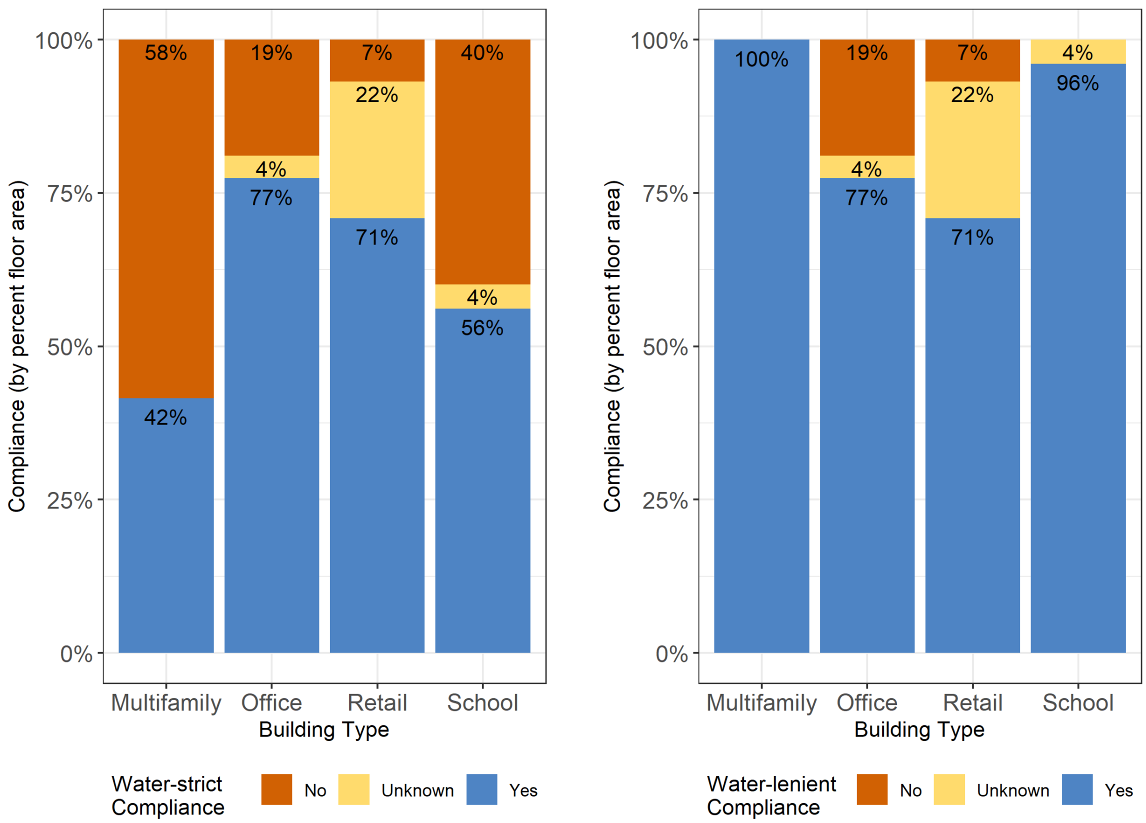
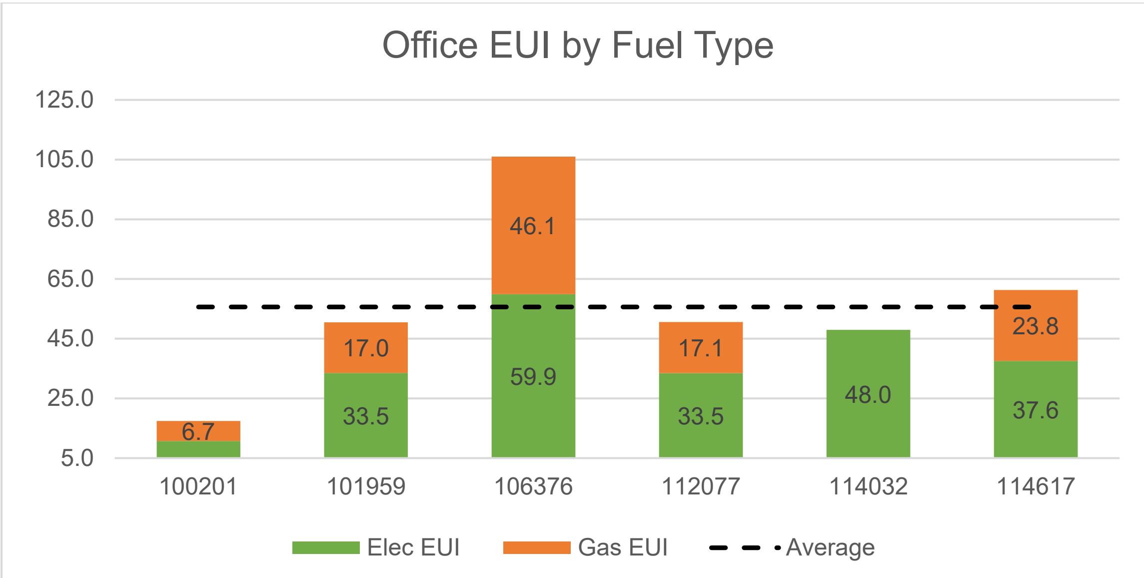
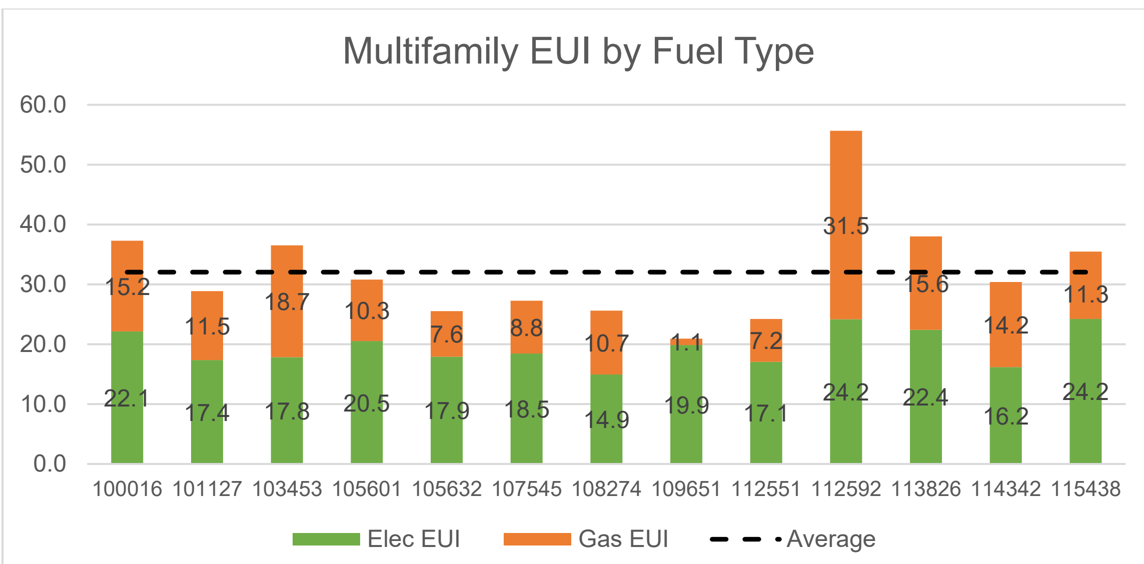


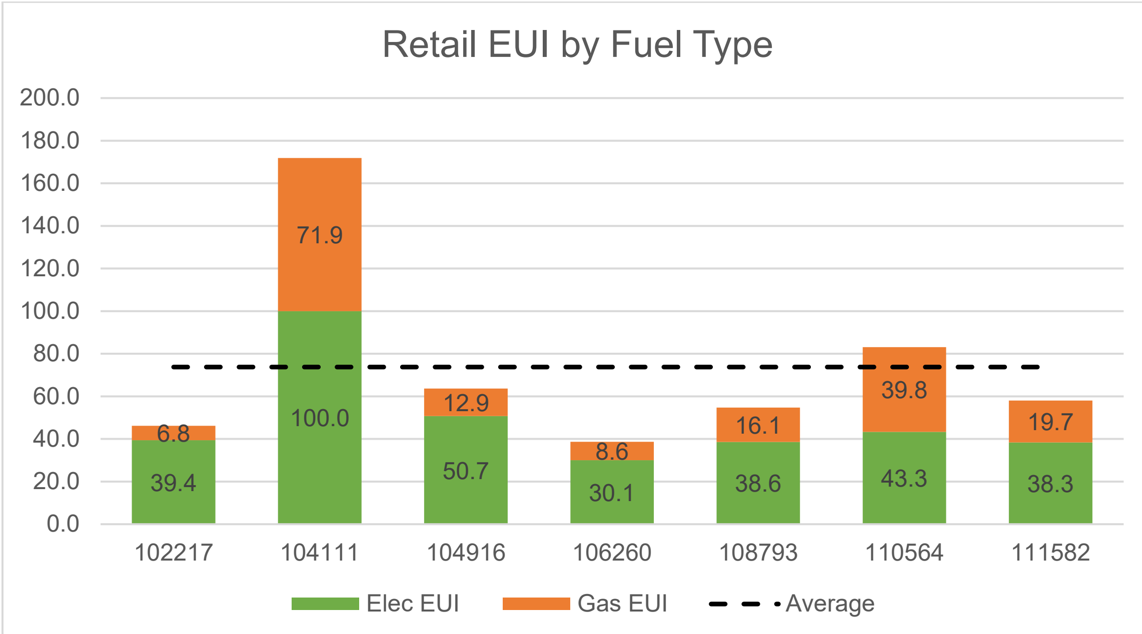
Figure C17. Service Water Heating Compliance - Strict and Lenient (% Floor Area)

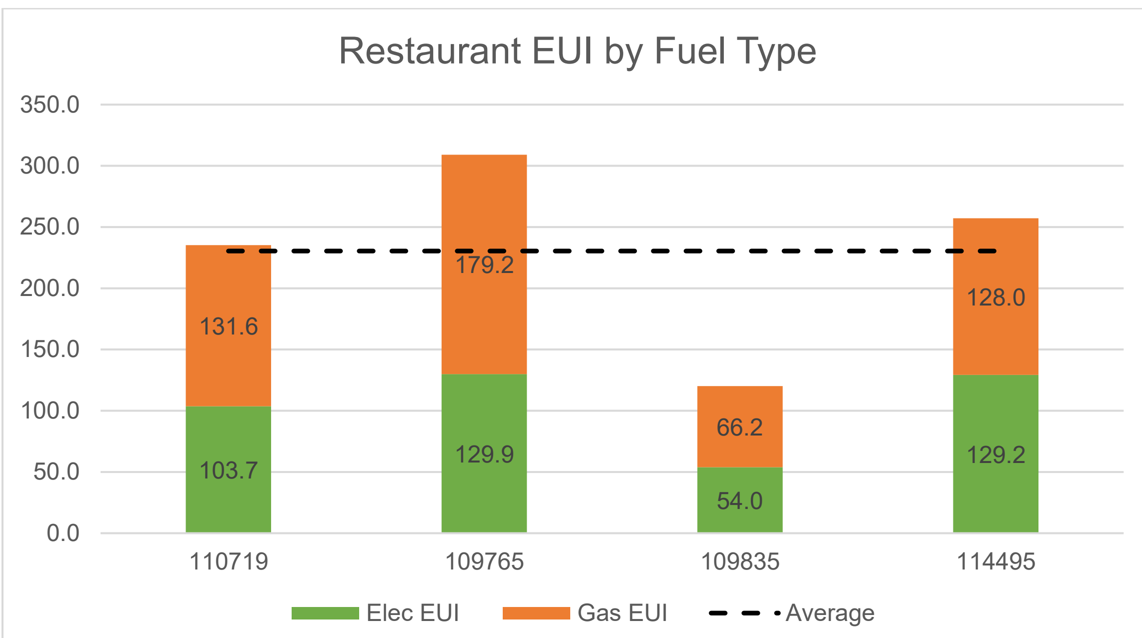
Appendix D: Energy Performance Summary

EUI by Fuel Type

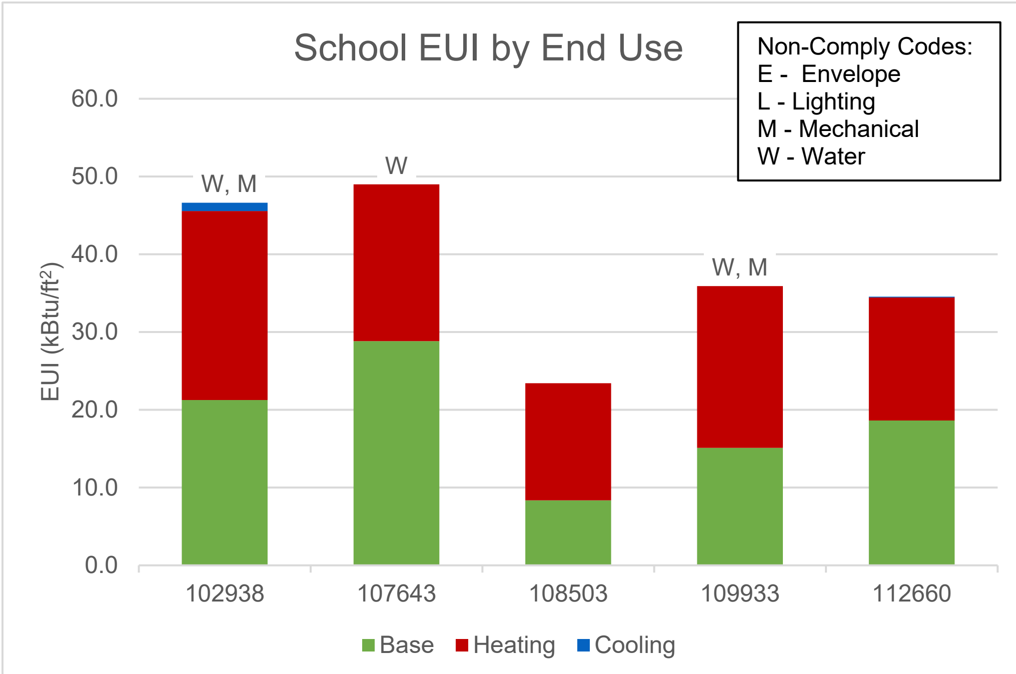


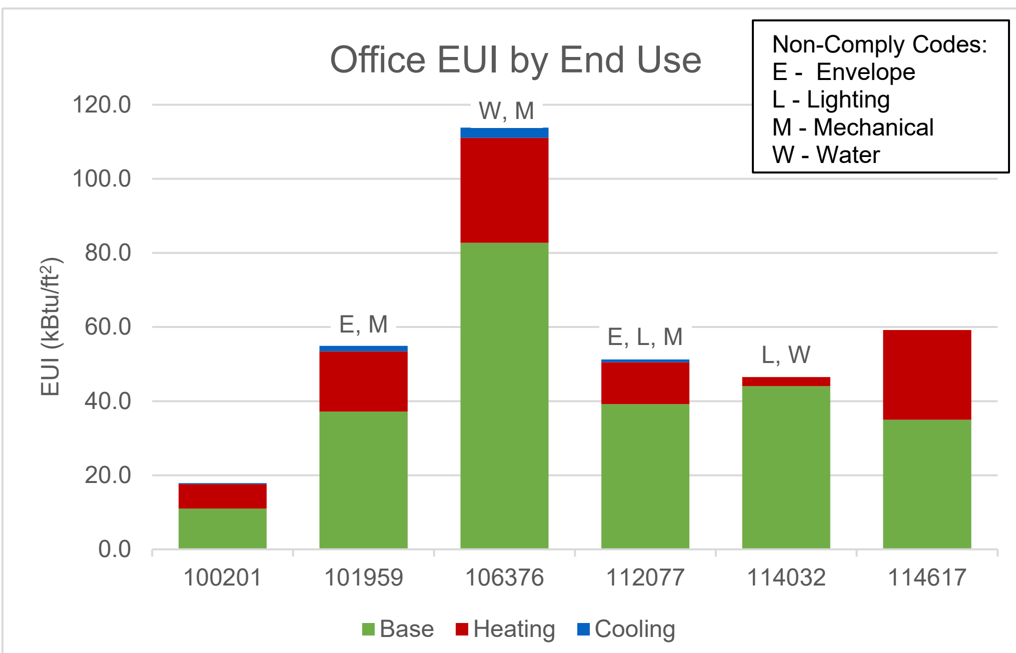


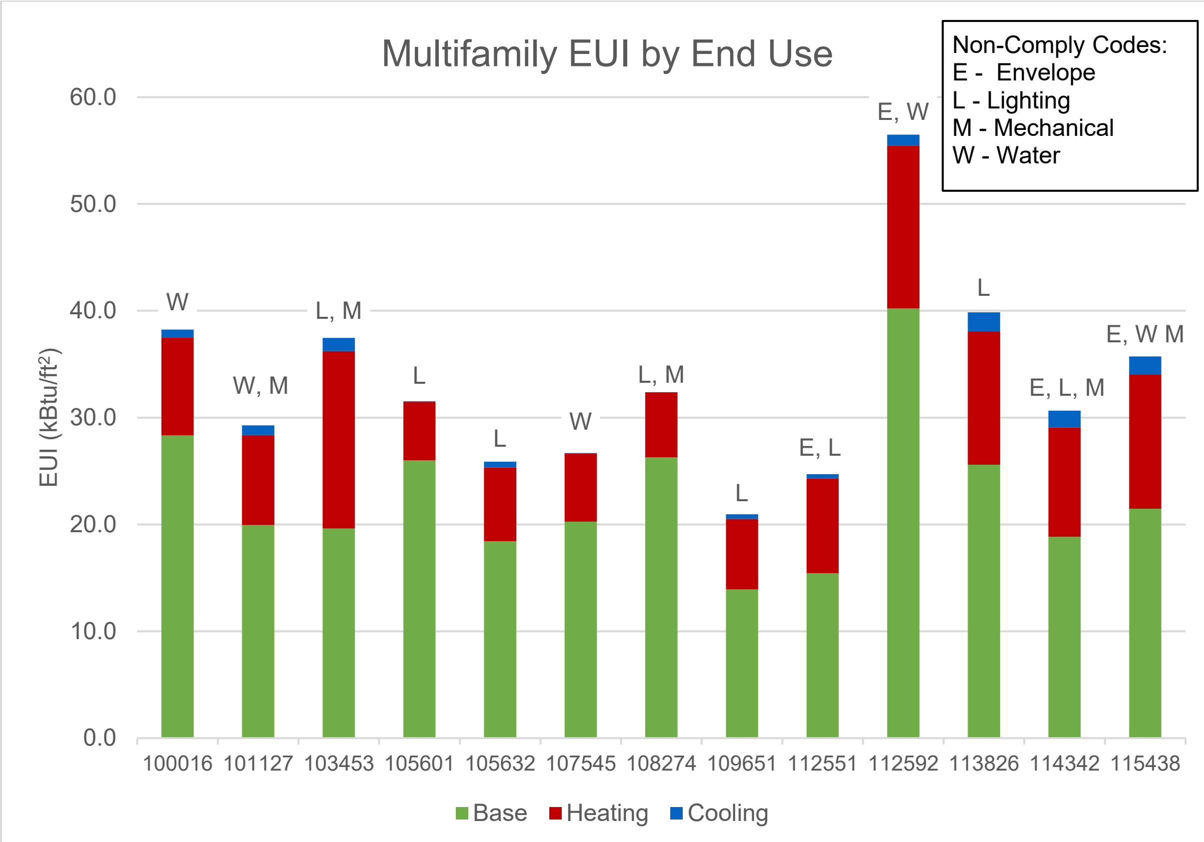

Retail EUI by Fuel Type
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
39.4
6.8
100.0
71.9
50.7
12.9
30.1
8.6
38.6
16.1
43.3
39.8
38.3
19.7
102217
104111
104916
106260
108793
110564
111582
Elec EUI
Gas EUI
Average

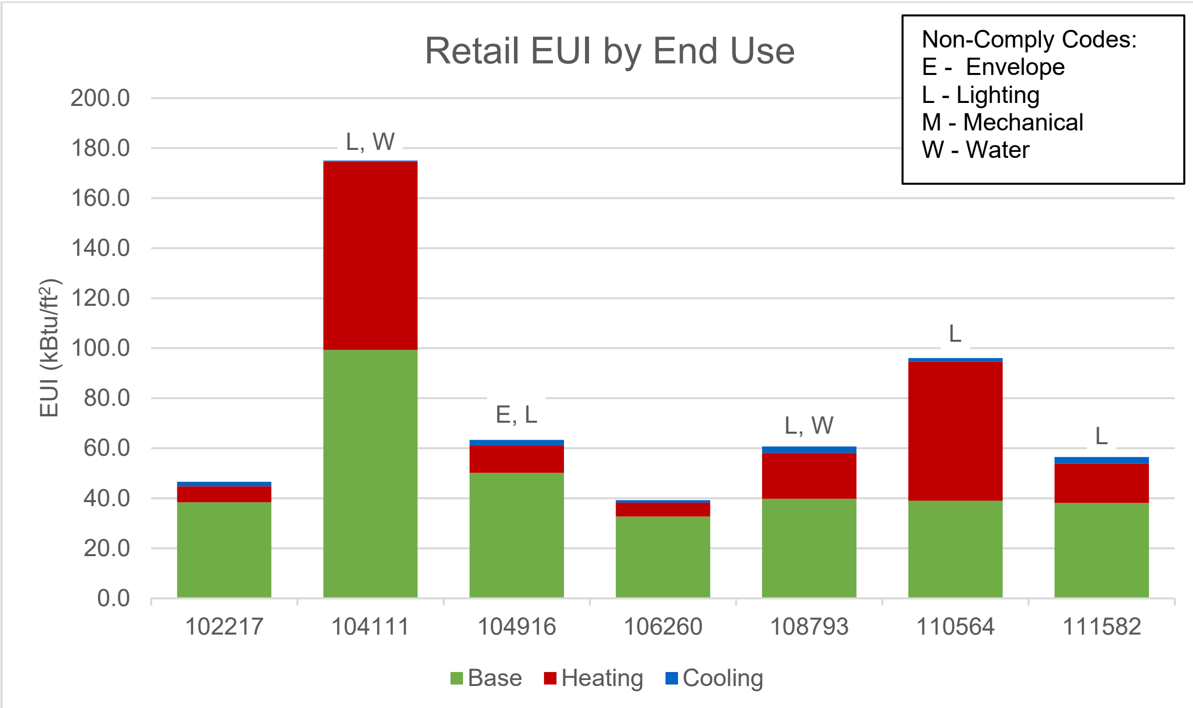

Restaurant EUI by Fuel Type
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
103.7
131.6
129.9
179.2
54.0
66.2
129.2
128.0
110719
109765
109835
114495
Elec EUI
Gas EUI
Average

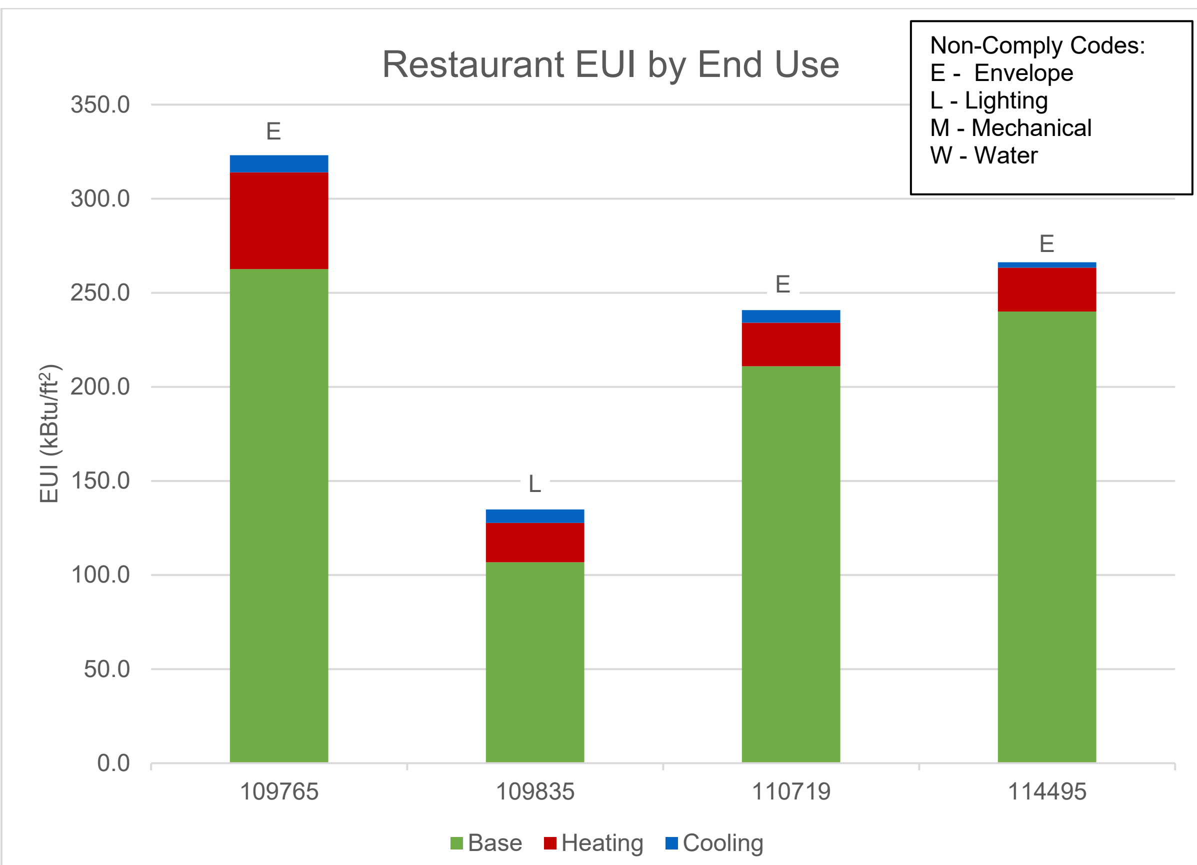
Disaggregated EUIs






Multifamily EUI by End Use
Non-Comply Codes:
E - Envelope
L - Lighting
M - Mechanical
W - Water
EUI (kBtu/ft²)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
W
W, M
L, M
L
L
W
L, M
L
E, L
E, W
L
E, L, M
E, W M
100016 101127 103453 105601 105632 107545 108274 109651 112551 112592 113826 114342 115438
Base
Heating
Cooling


Retail EUI by End Use
Non-Comply Codes:
E - Envelope
L - Lighting
M - Mechanical
W - Water
EUI (kBtu/ft²)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
L, W
E, L
L, W
L
L
102217
104111
104916
106260
108793
110564
111582
Base
Heating
Cooling


Restaurant EUI by End Use
Non-Comply Codes:
E - Envelope
L - Lighting
M - Mechanical
W - Water
EUI (kBtu/ft²)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
E
L
E
E
109765
109835
110719
114495
Base
Heating
Cooling

Appendix E: Sample Design Memo

The following is a memo regarding sample design for Oregon Commercial Code Evaluation Study.

Introduction

The purpose of this memo is to describe the goals, key considerations, and critical decision points for the Oregon Commercial Code Evaluation (OCCE) sample design. The sample design presented in the memo reflect input from the OCCE Working Group provide over several working group sessions. Ecotope will develop the final sample design based on additional stakeholder input and final decisions by NEEA.

Background

It is the goal of all sampling to provide a representative assessment of a particular population. This goal is always linked to some key characteristic such as building area or building energy use. The key assumption is that the population varies in this characteristic and that the sample size would be determined by the size of this variation. If there was no variation in this key characteristic, then theoretically a single sample point would be sufficient.

A second important principle is that the sample be directly linked to the population from which it is drawn. This principle assumes that, for a sample to be representative and useful, the link between the sample points and the population should be well understood (even if it is complex) so that the user can know how to expand the sample to understand the population from which it was drawn. This process almost always involves a "sampling weight" that links the sample points to the population. There can be a complex relationship between the sampling weights and the final summaries but underneath the mathematical complexity the weights can be boiled down to a single concept: the probability of that particular point being drawn from the population becomes the weight attached to that particular case.[7] Complex sample designs can still use this principle even though the sampling probability is different for different groups (Cochran 1977).

The most common sample design for the commercial sector uses size stratification. This is because the large variation in building size suggests a very large sample fraction to characterize this population if only a simple random sample is used. For purposes of an evaluation of energy codes and energy performance the assumption is that the size of the building is predictive of the energy use of the building. For this purpose, the size of the building is a surrogate for actual variation in energy use. To execute this principle the population of buildings is divided into several groups (strata) that are arranged to include all buildings in a particular size range. The effect of this division is to reduce the variation among the individual strata since the buildings in each stratum are of similar size. The idea is that this reduces the sample size needed to represent the commercial building population.

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[7] A discussion of this problem focused specifically on building energy and energy savings can be found in Khawaja, et al, 2013, *The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures, Chapter 11: Sample Design Cross-Cutting Protocols*.

The addition of new criteria for sampling such as building type would complicate this process. In effect the building type would "crosscut" the strata in complex ways depending on the distribution of those individual buildings. Moreover, the size of the new commercial sector is small in any particular year. The effect of dividing the population into building types and size strata is to have substantial issues with the sample as the population in any one cell is reduced considerably. Thus, it is desirable to be careful to focus any further divisions by building type on those buildings that might benefit from a sample, and this would generally be limited to only a few of the most common commercial building types.

The Oregon Commercial Building Sample

While establishing levels of compliance and energy performance with the Oregon energy code is a primary driver for the sample design, the sample will also characterize design practices used in the new construction commercial building stock. The overall goal of the sample design is to characterize this sector based on attributes relevant to stakeholders without compromising the representative sample of the new commercial buildings. The sample design process provided the OCCE working group with an opportunity to help shape the focus of the study by exploring the impacts of various scenarios and assessing tradeoffs.

The OCCE sample designs discussed in this memo were developed to address the following principles:

- Code compliance should address both building type and size. This goal is intended to ensure that non-compliance in smaller buildings does not mask the success of the code in larger buildings. Conversely, if small buildings are generally compliant this should not mask compliance issues with larger (or more energy intensive) buildings.
- To be representative across the diverse commercial sector each building should have a well-defined probability of selection and the basis of stratification by size should be optimized to allow the largest diversity of construction to be represented in each part of the stratification design.
- Frequently there are specific issues that are important to individual utilities and jurisdictions. The sample design should be designed to accommodate oversamples insofar as possible. Oversamples may include specific building types where additional precision in characteristics is required or specific geographic areas where more precision is needed. The design of these oversamples may compete with the fundamental goals of the code compliance and building performance. The sample design should balance these competing goals.

Sample Frame

The sample frame is the list of sampling units in the population targeted by a study. In the case of the OCCE, the sample frame is the list of new commercial buildings that we will designate as the total population from which to draw the sample of buildings for the onsite surveys. The total number and distribution of building types in the Oregon new commercial construction help inform the sample design. This section describes the approach to assembling the sample frame.

Ecotope used a Dodge dataset[8] of new construction starts. The sample frame includes “building starts” from the second quarter of 2013 through the second quarter of 2016. While this sample could be adjusted based on the timing of the field work, a three-year window was selected to ensure an adequate diversity in the building population and an adequate number of buildings in each building type category.

The Dodge database includes construction start date[9], building location (state, county, and city), building type, estimated building square footage and valuation, name and phone numbers of building architect, owner, and/or general contractor. In addition, some description of the type of work and details about the project were usually present.

The data was then cleaned to remove various entries that did not reflect actual new building construction. Various screens were implemented:

- Construction values less than $250,000 were used to remove projects that were likely not significant buildings (e.g., remodels or small free-standing auxiliary buildings).
- Entries that did not reflect new buildings, or entries that represented building additions, or substantial renovations were removed. “Non-building” projects (e.g., stream restoration, dam spillways, etc.) were removed in this step.
- Unconditioned buildings (e.g., parking garages) and some residential buildings, including all low-rise multifamily buildings and all single-family (detached or townhouse) projects were removed.
- Finally, the buildings that were included as remodel, additions, and alterations in the Dodge data base were reviewed to ensure that no misclassifications of new buildings were included in those categories. That review resulted in about a 10% increase in the total number of new buildings in the sample frame.

Once the data were cleaned a sampling variable was constructed to develop the stratification boundaries. The variable is an estimate of the building area based on actual entries in the database. For the cases where no building area was given, area was predicted from the reported valuation and from the remaining entries that reported both area and valuation. This process generated a stratification variable, “Predicted Area,” which was then combined with the cases where area was reported so that a complete set of area entries was constructed.

For the base sample design, the building size estimate was used to develop the sample stratification. The sample was then developed using the Dalenius-Hodges procedure (with a

[8] The Dodge database is a service of McGraw Hill Publishing and is based on interviews with building professionals and general contractors throughout the country. The data is further supplemented by reviewing building permits in each local jurisdiction so that projects not identified in the interviews can be entered into the database when a building permit is issued.

[9] Permit issue date is often reported as a start date.

Neyman allocation) as discussed in Cochran, 1977. This procedure attempts to equalize the square root of predicted area ("density function") across the strata. The algorithm develops the best stratification design based on the cumulative distribution of building sizes. In this case the process was constrained to deliver a three strata design.

The optimization process selects the strata boundaries by optimizing the sample based on the distribution of building sizes in the population in the particular sampling window[10]. This affords a more optimum sample and allows the large differences in the commercial construction to be reflected in the sample. The sample is limited to the particular construction characteristics in the window that was selected.

"Base" Sample Design

The Dodge sample frame was used to develop a stratified random sample across all building types based on building area. This base sample design is show in Table 1. The base sample design is shown without building type breakouts in order to demonstrate the starting point using the new Dodge sample frame. The base sample design aligns with the approach used in previous regional commercial new construction baseline studies. This approach works well when there is a fairly even distribution of building types in a given state. However, supplemental sample designs should be considered when the building type distribution is more uneven or when stakeholders are interested in specific geographic areas or building types. This memo includes an option to supplement the base sample design with individual samples for the most common building types, including multifamily, offices, retail, and schools.

Table 1. Base Sample Design Stratified by Three Size Bins

Stratum	Sample	Population	Max Size (SF)
1	16	371	45,000
2	16	121	185,000
3	19	32	1,000,000
All	51	530	

The total sample size would be 51 buildings. The following table is based on a random sample in each stratum. The distribution of buildings from this sample is compared to the distribution of buildings in the Dodge sample frame. The final sample in this approach would target the overall sample size and building size distribution but the individual building samples would not be targeted. The sample would reflect a random sample of commercial buildings overall.

[10] It is unlikely that any particular sampling window would represent the overall existing commercial building population. It is reasonable to assume however that the sample constructed in this way would represent the particular fraction of buildings in the sampling window.

Table 2. Sample Frame and Disposition for Base Sample Design

Building Type	Population (Dodge)		Base Sample	
	N	Fraction	N	Fraction
Assembly	50	0.09	4	0.08
College	13	0.02	1	0.02
Schools	42	0.08	5	0.10
Grocery	23	0.04	2	0.04
Hospitals	11	0.02	0	0.00
Institution	35	0.06	1	0.02
Lodging	24	0.05	0	0.00
Multifamily	59	0.12	18	0.35
Office	54	0.10	2	0.04
Other	8	0.02	0	0.00
Other Health	56	0.11	4	0.08
Restaurant	18	0.04	1	0.02
Retail	73	0.14	3	0.06
Servers	5	0.01	1	0.02
Warehouse	59	0.11	9	0.18
Total	530		51	

This formulation includes larger multifamily buildings covered in the commercial energy code in both the Oregon energy code and the IECC. This is in contrast to the previous baseline, compliance studies, and the CBSA where they were not included. The advantage of including the multifamily buildings is they are the largest single building type category in the sample frame and they dominate the buildings in both the two largest strata. This building type is generally a "mixed use" which includes small retail, restaurants, etc. (especially in more urban settings) on the ground floor. Finally, this sample best represents the new construction in the commercial sector. For a general assessment of this sector and particularly code compliance this sample would deliver the results within the confidence interval specified. The disadvantage of their inclusion is that they would dominate the larger strata at the expense of the other building types. In most cases a separate oversample would be required if any other individual building type is needed.

Revised Sample Design

Based on the considerations discussed above and input from the OCCE Working Group, an alternative sample design was developed to ensure adequate coverage of the Oregon commercial building sector and to address the important multifamily sector separately. The multifamily buildings were removed from the sample frame and sampled separately using the same stratification design as the overall sample. The result was an efficient and representative sample of multifamily buildings (see Table 3).

Table 3. Multifamily and Mixed-Use Buildings Sample at 90/10

Stratum	Sample	Population	Max Size (SF)
1	6	31	84,000
2	6	16	206,000
3	6	12	414,000
All	18	59	

Once the multifamily population was removed a new final base sample was drawn (see Table 4). The two samples in Tables 3 and 4 represent the final sample agreed to by the working group. A total of 67 buildings are included in these two samples combined.

Table 4. Final Base Sample (Multifamily removed)

Building Type	Population		Sample	
	N	Fraction	N	Fraction
Assembly	50	0.11	1	0.02
College	13	0.03	0	0.00
Schools	42	0.09	6	0.12
Grocery	23	0.05	6	0.12
Hospitals	11	0.02	0	0.00
Institution	35	0.07	1	0.02
Lodging	24	0.05	2	0.04
Office	54	0.11	4	0.08
Other	8	0.02	0	0.00
Other Health	56	0.12	8	0.16
Restaurant	18	0.04	1	0.02
Retail	73	0.15	2	0.04
Servers	5	0.01	3	0.06
Warehouse	59	0.13	15	0.31
Total	471		49	

Optional Supplements

If additional resources are available, the working group recommended the addition of three more individual building types sampled separately at 90/10. These building types represent the major buildings in the sample frame and several of the major targets of new commercial building programs in Oregon, including offices, retail, and schools. The three priority building types are summarized in the three tables below. Each of the building types represented in these tables has the same stratified sample optimization as the larger population in the final base sample but is focused only on one building type at a time. Offices and retail buildings would each add 18 sites to the total sample size. Adding schools would increase the sample by 13 buildings.

Table5. Office Sample at 90/10

Stratum	Sample	Population	Max Size (SF)
1	6	38	17,600
2	7	11	68,000
3	5	5	310,000
All	18	54	

Table 6. Retail Sample at 90/10

Stratum	Sample	Population	Max Size (SF)
1	6	49	17,300
2	5	16	46,500
3	7	8	125,600
All	18	73	

Table 7. K-12 Schools Sample at 90/10

Stratum	Sample	Population	Max Size (SF)
1	5	27	29,000
2	3	10	85,000
3	5	5	473,000
All	13	42	

Appendix F: Final Sample Disposition

The following is a memo regarding the final sample disposition for Oregon Commercial Code Evaluation Study.

Sample Frame

Ecotope used a Dodge dataset[11] of new construction starts. The sample frame includes "building starts" from the second quarter of 2013 through the second quarter of 2016. The data were cleaned to remove various entries that did not reflect actual new building construction. Various screens were implemented:

- Construction values less than $250,000 were used to remove projects that were likely not significant buildings (e.g., remodels or small free-standing auxiliary buildings).
- Entries that did not reflect new buildings, or entries that represented building additions or substantial renovations, were removed. "Non-building" projects (e.g., stream restoration, dam spillways, etc.) were removed in this step.
- Unconditioned buildings (e.g., parking garages) and some residential buildings, including all low-rise multifamily buildings and all single-family (detached or townhouse) projects, were removed.
- Finally, the buildings that were included as remodel, additions, and alterations in the Dodge data base were reviewed to ensure that no misclassifications of new buildings were included in those categories. That review resulted in about a 10% increase in the total number of new buildings in the sample frame.

In all, the final sample frame consisted of 222 buildings. Each of the four building types were divided into strata based on floor area. This is shown in Table F1.

[11] The Dodge database is a service of McGraw Hill Publishing and is based on interviews with building professionals and general contractors throughout the country. The data is further supplemented by reviewing building permits in each local jurisdiction so that projects not identified in the interviews can be entered into the database when a building permit is issued.

Table F1. Building Types by Strata based on Floor Area

Building Type by Strata	Maximum size (ft^2)
Education 1	45,000
Education 2	101,300
Education 3	506,545
Multifamily 1	73,700
Multifamily 2	143,800
Multifamily 3	228,300
Multifamily 4	354,000
Multifamily 5	1,100,000
Office 1	36,000
Office 2	131,000
Office 3	366,400
Office 4	1,000,000
Retail 1	8,700
Retail 2	22,000
Retail 3	39,000
Retail 4	62,000
Retail 5	125,600

Recruiting

The initial target was to recruit 64 buildings from the sample frame of 222. However, recruiting proved very challenging and the final recruited number was 46. Re-stratification in the middle of the recruiting and data collection effort enabled the study to take advantage of additional sampling efficiencies. The new goal was to maintain a predicted 90/10 confidence/ precision on building floor area for 3 of the building types (education, multifamily, retail) with office floor area slightly lower at 80/20. We completed targets in many of the strata and exhausted the sample (either direct declines to be surveyed or no response to repeated inquiries to participate) in those strata that fell short of the targets.

Sites Surveyed by Strata

The original sample plan called for a three strata design but mid-stream project changes, in response to recruiting challenges, led to a more efficient design which varied the number of strata across building types. Ultimately, Educational buildings were split across 3 strata, Office across 4 strata, Multifamily and Retail across 5 strata.

Table F2 shows the final sample disposition: the distribution of the sample frame, the target, and the number successfully surveyed by strata. In two building types, recruiting was successful to meet and exceed the targets. In the Office and Retail types, not enough buildings were able to be recruited to fill all the targets.

Table F2. Sites Surveyed by Strata

Building Type	Sample Frame Population	Target	Recruited	Difference between Target and Recruited	Recruited divided by Sample Frame	Recruited divided by Target
Education 1	23	5	6	1	26%	120%
Education 2	12	4	4	0	33%	100%
Education 3	4	4	4	0	100%	100%
Education Total	**39**	**13**	**14**	**1**	**36%**	**108%**
Multifamily 1	25	2	3	1	12%	150%
Multifamily 2	16	2	3	1	19%	150%
Multifamily 3	10	1	3	2	30%	300%
Multifamily 4	11	2	1	-1	9%	50%
Multifamily 5	4	4	3	-1	75%	75%
Multifamily Total	**66**	**11**	**13**	**2**	**20%**	**118%**
Office 1	32	3	2	-1	6%	67%
Office 2	11	3	3	0	27%	100%
Office 3	2	1	0	-1	0%	0%
Office 4	3	3	2	-1	67%	67%
Office Total	**48**	**10**	**7**	**-3**	**15%**	**70%**
Retail 1	28	2	2	0	7%	100%
Retail 2	23	4	3	-1	13%	75%
Retail 3	9	2	4	2	44%	200%
Retail 4	5	2	1	-1	20%	50%
Retail 5	4	3	2	-1	50%	67%
Retail Total	**69**	**13**	**12**	**-1**	**17%**	**92%**
GRAND TOTAL	**222**	**47**	**46**	**-1**	**21%**	**98%**

Appendix G: Data Collection Instrument (DCI)

a. General

The DCI is an Excel workbook loaded onto a Surface tablet. The first sheets in the workbook contain overview data (site location, ID, etc.) and later sheets require transfer of data from plans and then verification from the field visit. The 2010 and 2014 Oregon Energy Efficiency Specialty Code and Oregon Energy Structural Code (Commercial) are located on the shared part of Ecotope's server for reference:

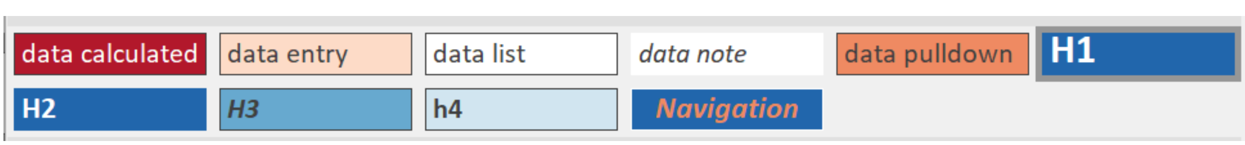
b. Order of Operations

The following is the order of operations for entering data into the DCI. Where noted, the order is important because of the cause-and-effect of some of the entries. For instance, when you define a space #2 in the 'ID relationships' sheet, that #2 gets added to a pull-down list in relevant later sheets. There is a way to turn off some of these requirements, but at a cost of removing some critical QC steps, so the default should always be to have these relationships turned on.

1) General Info can be entered at any time
2) ID Relationships and Spaces must be defined before the rest of workbook is filled out (populating these sheets will pre-populate pull-down menus later in the workbook)
3) Envelope, Mechanical, and Lighting as grouped sheets can then be entered in any order (see next three items for in-group specifics)
4) Within Envelope, enter component sheets prior to 'UA' sheet (since much of 'UA' sheet is calculated from inputs giving in the component sheets)
5) Within Mechanical, enter 'HVAC Systems' first before equipment/control sheets
6) Within Lighting, enter 'Fixtures' before 'Lighting' sheet.

c. Color Codes Within the DCI

The main color code to note here are the red fields are calculated and so require precursor inputs; calculated fields are locked and cannot be modified. The "data pulldown" fields are ubiquitous and should include most common responses. The "data note" format is used for notes regarding the DCI itself, such as a note on the equipment page refering to "Equip tag" explaining what this refers to. In many fields, there is an option of entering "NA" (for Not Applicable) or "UNK" (for Unknown). The two do differ, so if you are heading this direction, make sure you enter the proper response – Not Applicable is for an item that <u>does not apply</u> given the context, and Unknown is for an item that <u>does apply</u> but the value cannot be gathered. We want to minimize the use of Unk as much as possible. The "Navigation" buttons allow you to move forward a sheet, backword a sheet, or to the 'Table of Contents' of the DCI workbook.



d. Note Fields

Notes are very important in the DCI; they are necessary to explain ambiguous entries or to reference photos. "Data Quality Notes" fields should be used to write notes about estimates, non-verification reasons, etc. Other Notes fields should be used to keep track of anything else about an entry that would be useful to know about later (by the Site Manager, Data Manager, or anyone else looking at the data in the future).

e. General Info Sheet

This sheet collects general building information such as site contact info, overall square footage, etc. Some of this information is gathered during the recruiting call and is saved to the recruitment version of the DCI, but much of it must be filled in during plan review.

f. Assigning Zone IDs

This is a key part of how we summarize characteristics across different space typologies for the analysis. With the zoning schedule, we can summarize across systems, like which HVAC systems and lighting loads are on a particular meter.

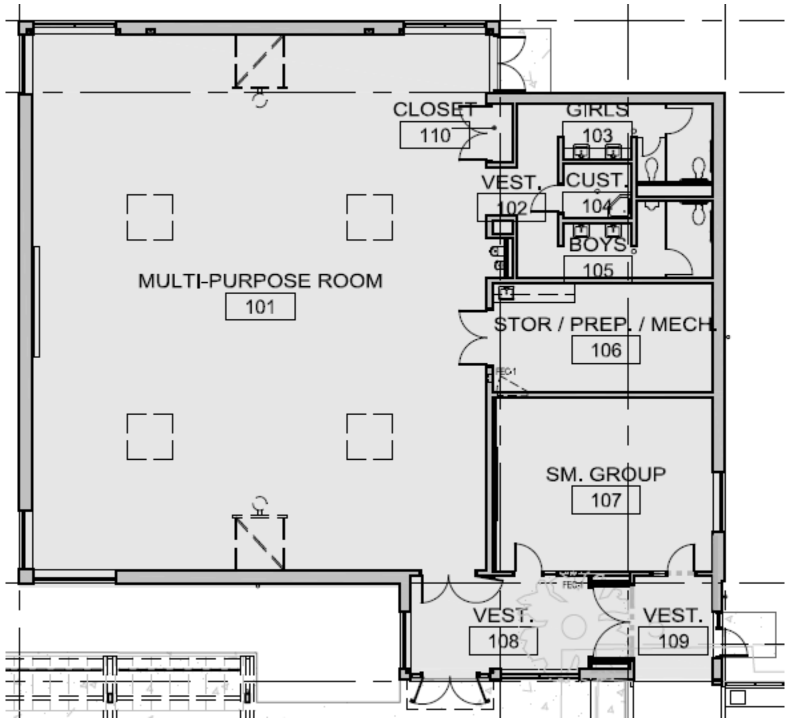
g. ID Relationships Sheet

As you go through the plans, create three basic versions of the plans in a sketch on note paper. The first is where you map the HVAC zones and assign each zone to a sequential number (1, 2, 3, …). Next, map the lighting zones with sequential numbers. And then map the zones based on the energy meters with sequential numbers. Overlay these three maps to create a single zoning map, where each unique subspace of the overlay is a space ID labeled sequentially. These IDs will carry along through other parts of the DCI. The following is an excerpt from the 'ID Relationships' sheet in the DCI where you will record the resulting ID relationships. More detailed assignment criteria are discussed in the Mechanical and Lighting sections that follow.

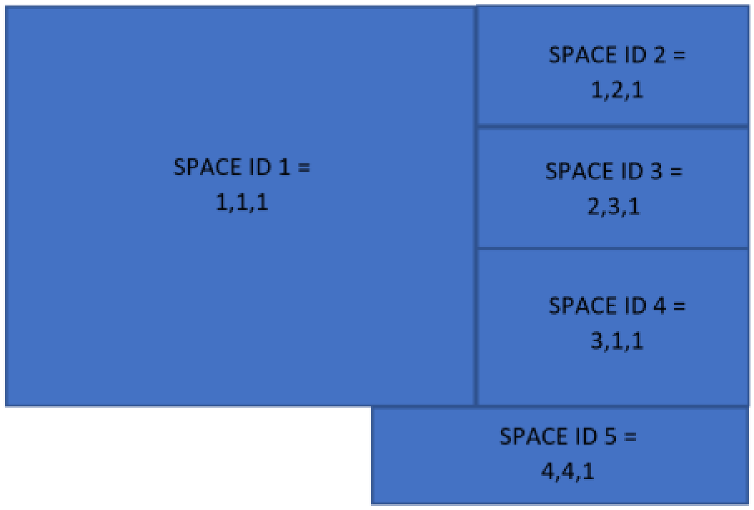
BUILDING CHARACTERISTICS – Spatial Relationships				
Describe relationships between different spatial concepts				
Space ID	HVAC Zone ID	Lighting Zone ID	Meter Zone ID	Description

Here is an example of a 5500sf addition for a school and the space IDs determined for the project:

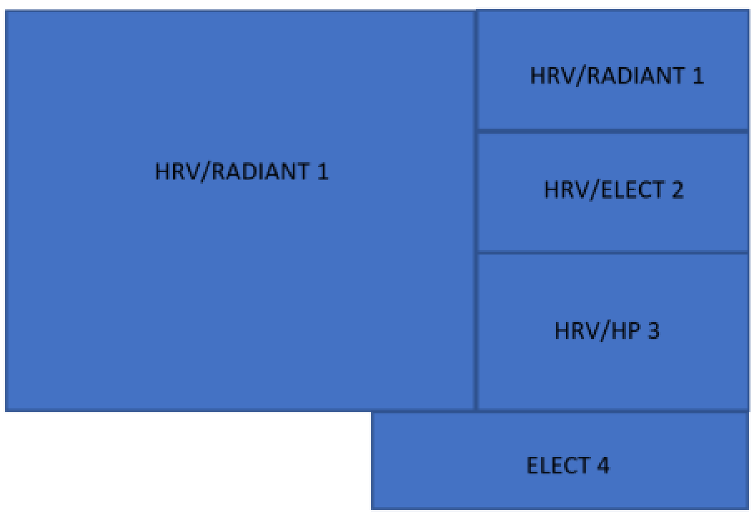
Floor plan of 5500sf school addition



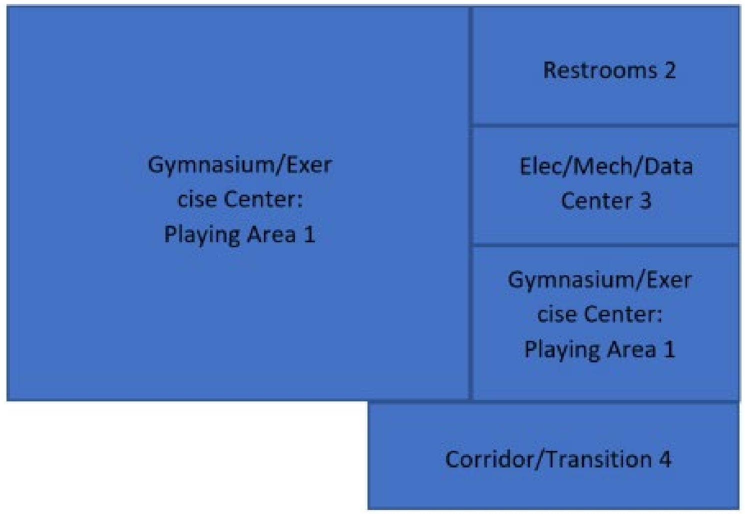
Space IDs (Final result after mapping HVAC IDs, Lighting IDs, and Meter IDs and overlaying them)



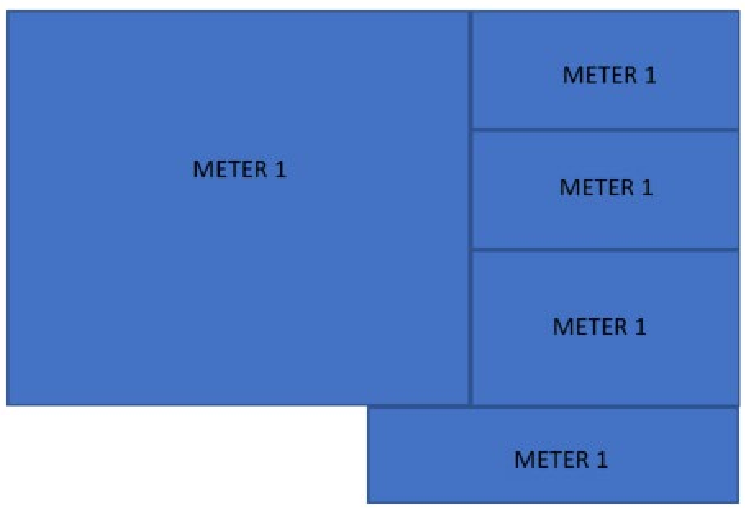
HVAC IDs



Lighting IDs



Meter IDs



h. Lighting Sheet & Lighting Zone IDs

The key guidance here is to divide up the building into different functional spaces: offices, classrooms, retail, etc. This is the way to do it versus using control systems; there can be multiple control systems within one space type. Lighting should be zoned to at least be able to summarize LPD by space types, but similar space types should be lumped together. For the OCCE project, refer to Table 505.5.2(b) in the Oregon Energy Efficiency Specialty Code.

i. Spaces Sheet & Space IDs

Once the 'ID Relationships' sheet is complete, the 'Spaces' sheet in the DCI can be filled out. This allows the surveyor to provide more detail on what part of the building is represented by each of the Space IDs, along with additional characteristics and explanatory information. The overall intent of this process is to make sure all parts of the building are described accurately. The "Total Measurement" and "Conditioned Space Measurement" rely on the "Measurement Units" column, which will be in square feet (sqft) most of the time. Some of the exterior types are not in sqft, though, so you'll need to pay attention to the units for exterior spaces, which is a calculated cell. Example: if the units are sqft, then the total measurement is total sqft, and the conditioned space measurement is the conditioned space sqft.

BUILDING CHARACTERISTICS – Space Summary PREV HOME NEXT

Building Space Utilization Identification

Space ID	Description	Space Type	Space Conditioning	Number of Occupants	Number of Computers	Total Measurement	Conditioned Space Measurement	Measurement Units	Interior/Exterior	Use (Hours/week)	Year This Use Began	Notes	Field Verified	Data Quality Notes

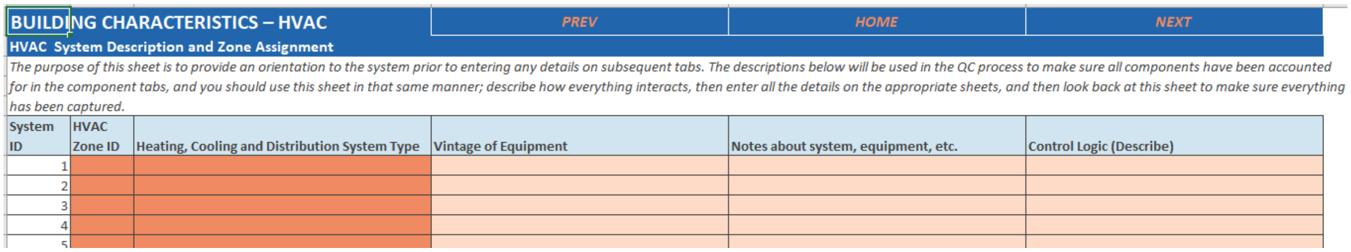
Semi-heated spaces (with installed heating capacity of less than 10 Btu/hr per square foot for climate 4 and less than 15 Btu/hr per square foot for climate 5; CZ4 is west of the Cascades, and CZ5 is east of the Cascades) are addressed in the "Administrative" chapter of the Oregon Energy Efficiency Specialty Code. These spaces are allowed reduced wall insulation and employ a heating system controlled by a thermostat with a fixed set point (45F) for freeze protection. All the other provisions on the envelope code and lighting code and relevant parts of the mechanical code apply to these spaces. These semi-heated spaces should be defined as unique Space IDs.

Exterior spaces (including parking garages) should also be defined as separate Space IDs and lighting characterized within those spaces. Look at Table 505.6.2 (2) in the Oregon Energy Efficiency Specialty Code. (The table is unchanged from the 2010 version). Exterior spaces should use the second column of the following table for exterior space type definitions, and all areas of a particular type can be grouped together into a single space ID entry.

j. HVAC Systems Sheet

Describe HVAC systems as they occur in the building. In many cases, the building will have only one primary HVAC system. In some cases, there may be some sort of supplemental heater or cooler in a zone that is otherwise conditioned by a larger system. In that case the supplemental system should be assigned to the larger zone even if the controls or operation are different. A screen shot of the 'HVAC Systems' sheet follows. This is the "topmost" sheet in the DCI for mechanical systems and allows the tech to describe the HVAC Systems, which HVAC Zone they are in, and provide a brief description of unique system types and system controls. The 'System Control' sheet will allow much more detailed entry of control information, and the sheets that follow 'System Control' are where specifics on individual HVAC system types (air handling units, heat pumps, boilers, chillers, etc.) can be entered. The main purpose of the 'HVAC

Systems' sheet is to have a central place to describe all the systems and all the controls to make sure there aren't any missing.



BUILDING CHARACTERISTICS – HVAC | PREV | HOME | NEXT

HVAC System Description and Zone Assignment

The purpose of this sheet is to provide an orientation to the system prior to entering any details on subsequent tabs. The descriptions below will be used in the QC process to make sure all components have been accounted for in the component tabs, and you should use this sheet in that same manner; describe how everything interacts, then enter all the details on the appropriate sheets, and then look back at this sheet to make sure everything has been captured.

System ID	HVAC Zone ID	Heating, Cooling and Distribution System Type	Vintage of Equipment	Notes about system, equipment, etc.	Control Logic (Describe)
1					
2					
3					
4					
5					

k. Detailed HVAC Sheets

The detailed HVAC sheets (such as 'HPs & ACs', 'Chillers', 'Terminal Units') are where detailed information on HVAC components are recorded (mostly from information on the plans, although some additional research might be needed to find nominal efficiency ratings, etc. It may not always be obvious which sheet will receive this information. Generally, we want to make sure the primary energy-using part of the system is characterized (such as the main air handler) and secondary parts (such as the terminal units) are also characterized. The following table provides guidance on where to record the detailed HVAC information.

As an example, a VAV system, which contains a central rooftop air handler and terminal distribution units with electric reheat, would have entries in both the 'AHUs' (Air Handling Unit) and 'Terminal Units' sheets. The former sheet would receive information on the main fan (CFM, horsepower rating, etc.) and the latter would receive information on reheat fuel, control type, etc.

HVAC System	Sheet for info (1)	Sheet for info (2)	Additional Info
Chilled Water Cooling	'Chillers'	'Terminal Units'. Fan Coils are the most commonly used option. Chilled beams are also found in the Fan Coil section.	We also might use 'Cooling Tower' sheet in this case
Chilled Beams	'Chillers'	'Terminal Units'	
Constant Volume Air Handling Unit (AHU)	'AHUs'		
Constant Volume AHU with Zone Heating Coils	'AHUs'	'Terminal Units'	
DOAS (all flavors)	'Fans'		Make clear if/how heat recovery is done (heat wheel, etc.) in 'HVAC Systems' sheet, and also note on that same sheet how any additional air tempering is done

Electric Resistance (ER) wall, baseboard, or other, plus also Gas Wall Heater	'Terminal Units'		Gas wall heaters likely to be rare in this study; note they are different from ceiling-hung unit heaters
Evaporative Cooler	'HPs & ACs'		
Fan Coils	'Terminal Units'		
Furnace (all types)	'AHUs'		
Garage Fans	'Fans'		
Inverter Driven Split System HP or AC	'HPs & ACs'		Inverter-driven AC units less common but we may see them in small offices, elevator rooms, etc.
Packaged VAV	'AHUs'	'Terminal Units'	
Packaged Rooftop Unit, PRTU-Gas (burned directly)	'AHUs'		Note larger rooftops hit AHUs and split systems go into 'HPs and ACs' sheet. Smaller packaged systems (such as PTACs and PTHPs) go into 'HPs & ACs' sheet
PRTU-Gas (hot water coils)	'Boiler'	'AHUs'	Make clear that the boiler is providing the BTUs (via water loop) in the 'HVAC Systems' sheet in the DCI
PRTU-HP	'AHUs'		
PTAC	'HPs & ACs'		
PTHP	'HPs & ACs'		
Split System HP	'HPs & ACs'		
Unit Heaters (Electric/Gas)	'Terminal Units'		
VRF Heat Pumps	'HPs & ACs'	'Terminal Units'	
Window AC	'HPs & ACs'		

I. Detailed HVAC Sheets – Additional Notes

Please note the following guidance related to Brake HP and VRF systems:

- **Brake HP.** We really want brake HP vs nominal for motors if only one can be gathered. The DCI asks for Fan Efficiency Grade (FEG), but this is a new metric and we are unsure how often this can be gathered. The code regulates only total fan HP (or BHP) so FEG is of secondary importance.
- **VRF systems.** During the late August 2017 training, there was discussion about this class of equipment, and there was confusion about terminology. “VRF” is a general category that indicates there is a central, inverter-driven compressor and distribution to spaces is typically via ceiling or wall-mounted cassettes usually without ducts. Beyond that, some systems include heat recovery (which means a reversing valve array can enable a site to perform heating and cooling at the same time if there is enough load diversity (one zone needs heating and another needs cooling). The Oregon Energy Efficiency Specialty Code table (503.2.3(10)) for VRF includes both with and without heat recovery. It does distinguish between heat recovery and not. We should assume that both are included and that we should note if there is heat recovery. It may be the best way to do this is to figure it out post-survey by looking back at the model numbers (if you aren’t certain while on site what you have).

m. System Control Sheet

The ‘System Control’ sheet will allow much more detailed entry of control information, and the sheets that follow ‘System Control’ are where specifics on individual HVAC system types (air handling units, heat pumps, boilers, chillers, etc.) can be entered. Mostly we want an inventory of control types that correspond to different systems. It will not be necessary to perform functional tests of controls while on site but ask site personnel if there have been issues with controls.

n. Lighting Sheet

The final “pillar” of the study is lighting. Fixtures and lamps are changing fast in commercial buildings, but keep in mind the sites here were permitted a few years ago, so many will not contain the latest and greatest in lighting technology. Here are the main items to keep in mind when working on lighting:

- **Accurate characterization of lighting control systems.** We only need to know control system types; we do not need to test their functionality in the field. It is acceptable to ask key site occupants if the controls work as intended (with “intended” meant to correspond to the control type); do occupancy sensors work? Do daylighting/dimming controls work? What problems have been observed?
- **Accurate fixture/lamp counts.** Most of the work here comes from plan review, but field verification is needed to make sure overall counts align with plans. A project goal is to calculate LPDs by space type as well as overall, so we need accurate Lighting Space ID floor areas, which are entered on the ‘Spaces’ sheet. Therefore, the lighting spaces should be well defined in the plan review process and the site visit should verify these space assignments are accurate. The Lighting ID and Space ID relationships are defined on the ‘ID Relationships’ sheet.
- **Accurate lamp type and power (from plans, mostly).** This is a very important input, since it will feed in directly to the LPD calculation. In some cases, the Wattage rating will be very

clearly identified on the plans, including as part of an overall LPD calculation. In other cases, the surveyor will have to spend some time in the field verifying lamp types by asking key personnel, checking spare lamp containers, etc. It is expected that there will be a number of variations from plans-to-field in the lighting data, so be sure to pay attention in the field to deviations from the plans.

o. Lighting Sheet – Additional Notes

In a particular lighting space, there will be fixture groups that may have separate controls (such as a separate daylighting zone). For those cases, separate the fixture groups by control groups when entering the information on the 'Lighting' sheet. These separate control groups can be assigned to the same space, so use the space guidance above to keep similar types of spaces lumped together, and just enter the control groups as individual line items within that space. The surveyor should estimate the fixtures associated with each control type. Where the controls overlap there is no real alternative to combining the control groups into a single line item.

p. Wall, Floor, Ceiling Sheets

Building envelope is a primary focus of the work, both in terms of code compliance and also in terms of having the DCI construct a heat loss rate (UA) for each site. The plan review phases should identify unique component and window types; opaque components have unique sheets within the DCI. Enough information on assembly type, including framing material (wood, steel), framing spacing, insulation type/amount, and exterior finish, etc. must be gathered from the plans to allow you to feed the automated look-up feature that assigns a U-Value. What follows here is a screen shot of the 'Wall' sheet of the DCI that shows some of these cells. After entering a wall type, confirm that a U-Value was generated – if not, then there is an error in the data entry that needs to be addressed.

BUILDING CHARACTERISTICS – Envelope Characteristics			
Walls			
Wall Characteristics			
Wall ID	1	2	
Wall Type	Metal Frame Wall		
Describe Insulation*	4 inches of rigid outboard of C-channel; rain screen exterior. Most thermal bridges dealt with.		
** Description will be used to QC values below. Example description: "R21 cavity + R5 continuous"*			
Enter only one of the following subsections for each column			
2x4 Wood Frame Wall			
Insulation Cavity R-Value			
Sheathing Thickness			
U-Value			
2x6 Wood Frame Wall			
Insulation Cavity R-Value			
Sheathing Thickness			
U-Value			
Metal Frame Wall			
Insulation Cavity R-Value	R0–R3		
Sheathing Thickness	R15 and greater		
U-Value	0.060		

For further clarification, specific comments are added here for different envelope components:

Field	Question	Answer
'Floor' Sheet: Slab Insulation Position	What if we have different amounts of slab insulation at edge and in middle? Does look up table only consider one level of insulation throughout?	We're not going for this level of detail in the lookup tables. Pick the closest value.
'Wall' Sheet: Masonry Wall Type	What does "CI" mean here?	"continuous insulation".
'Ceiling' Sheet: Attic Insulation	What is the difference between "attic" and "cavity" insulation" categories	Values are similar enough that it doesn't matter which one you choose, so choose one.

		[Attic typically refers to a ceiling with insulation that has open buffer space above (think typical residential construction). Cavity refers to a cathedralized assembly, where the ceiling and roof are in alignment with insulation between, which may have a small ventilated area.]

q. Fenestration Sheet

A similar process should be used for windows, with the most important inputs being frame type, number of panes, frame factor, and low-e type. If the U-Value for different window types is available from the plans, enter it in the DCI. If the U-Value is not available, enter the frame type, number of panes, and low-e type. Once these items are entered, along with a best estimate of the frame factor (see table below), the DCI will calculate a U-Value.

The following screenshot shows two possible ways U-Value will be captured; the left side (Window ID 1) includes frame type, number of panes, and low-e. The DCI then looks up a U-Value and SHGC based on these inputs. The right side (Window ID 2), shows a case where the U-Value and SHGC are listed on the plans, so they can be entered directly.

Use the "U-Value from Plans" for U-Values found on site as well, which may be possible for some window types from reading the NFRC sticker on the window (same for SHGC from plans). For this second case, the window characteristics still need to be entered for QC purposes, but if the values match reasonably well, the U-Value and SHGC from plans will be used in the analysis.[i]

BUILDING CHARACTERISTICS – Envelope Characteristics		
Windows		
Window Characteristics		
Window ID	1	2
Window U-Value from Plans		0.40
Window SHGC from Plans		0.35
Window Frame Type	Non-metal	Non-metal
Window Number of Glass Panes	2	2
Window Low-e	Low-e (ε = 0.05–0.10)	Low-e (ε = 0.05–0.10)
Window Frame Factor (%)	30%	30%
Window U-Value (frame)	0.40	0.40
Window U-Value (center of glass)	0.44	0.44
Window Shade Coefficient	0.45	0.45
Window U-Value	0.43	0.43
Window SHGC	0.32	0.32
Window Notes		
Window Field Verified		
Window Data Quality Notes		

When in the field, the surveyor will confirm whether low-e is present and also the type of low-e; two categories of soft-coat low-e are called out in the DCI (with category 1 referring to emissivity between 0.05 and 0.1 and category 2 referring to emissivity lower than 0.05). The Glass-Chek Pro GC3000 low-e meter provides detailed information on low-e location and type. The Appendix has detailed instructions on low-e type determination.

For the "Frame Factor" field, enter your best estimate of the percentage of the window rough opening area that is opaque frame. Generally, this ranges from about 5–15% for most commercial windows.

Window Framing Fraction Table

Window Type	Frame Fraction	Notes
Curtainwall	0%	
Storefront	10%	
Common Commercial	20%	Punched openings and operator with slim metal frame
Residential	30%	Any frame type

Doors use a similar methodology, but the data collector enters the Opaque Factor as a percentage. If the door is completely opaque (no windows), then enter 100%. If the fenestration is a glass door, enter as 10% for typical glass doors with frames (like a residential sliding glass door). Enter 0% if the glass door is frameless. Estimate the percent opaque to the nearest 10%, so opaque factor will be one of 100%, 90%, 80%, 70%, 60%, 50%, etc.

Fenestration Sheet: Storefront/curtainwall assemblies

Storefront/curtainwall assemblies came up at our training but isn't a terribly crucial distinction. The NFRC rating procedure covers both and surveyors can assign the same U-Values to both based on the characteristics observed. In most cases the only problem will be the current trend away from curtain walls in high rise buildings (especially multifamily). The surveyors would know in advance (Google Streetview) if they were going to a building where this is an issue.

r. Multifamily Units ('MF Units') Sheet

As stated in the Sampling Guidance section, verify information in all the common areas and three of the living units. Selection of living units is left up to the data collector, but the units must be occupied and cannot be the manager's apartment. Ideally, we'd like an unbiased random sample, but work with the site contact to recruit three units that represent typical occupants of the building.

We're sampling three units in the building, and the information from each unit is a column on the 'MF Units' sheet. For each unit, we're collecting:

- General information (floor area, number of occupants, etc.)
- Appliance info (make, model, ENERGY STAR certifications, efficiency values, picture filenames and notes, and general notes about the unit)
- Detailed lighting information, including both fixed and occupant-provided lighting

Outside the 'MF Units' sheet, there may be a few items from the rest of the DCI that need to be verified within the units, including spot checking the windows and possibly the wall construction details, as well as unit HVAC and unit DHW, to make sure they align with the plans. *When entering the information from the plans, make a note in your survey plan of items that can only be verified from within the units so you can make sure to check those items when in the field.*

For the appliances, there is a lot of repetition in the inputs across the appliance types. Here's the general guidance:

- Has *appliance* – yes/no of whether the appliance is present in the unit
- Make/model – record the make and model number of the appliance, and take a picture for verification. Make sure you're recording the model number and not the serial number.
- Is ENERGY STAR certified – look for an ENERGY STAR logo on the appliance. If it is present, select yes. If not, look up the model number when you get back to the office to verify whether it is certified.
- *Appliance* fuel – select the appropriate fuel type.

The lighting table is almost identical to the whole building 'Lighting' sheet, so follow the same instructions as the 'Lighting' sheet. If there are new fixtures in the units, enter these in the general building Fixture schedule, which will make it available in the 'MF Unit' lighting table pull-down menus – you'll need to do this for the occupant-provided fixtures, but the building fixtures will likely already be populated during the plan review. For occupant-provided lighting, record all lighting that is plugged in during your visit (table lamps, stand lamps, task lamps, etc.).

s. QC Report Sheet

The purpose of the 'QC Report' sheet is to consolidate and check information from throughout the worksheet for easier visual review and to provide cross calculations to test the accuracy of data entry. Examples of useful features include area cross-calculations, LPD calculations, and a completeness check. Field Staff should use the sheet prior to submitting the DCI. Site Managers will use the sheet to assist with performing the QC review. The most time will be spent filling in notes for missing fields. Field Staff may prefer to review and complete the 'QC Report' sheet all at once prior to submitting to the Site Manager, or during the data entry process.

QC Checks

There are various cross-sheet calculations performed in the QC checks section. These ensure we have consistent information across the workbook and haven't forgotten any information.

- Is the floor area consistent? There are a number of ways we've entered areas in the workbook, and these QC checks are a roll-up of that information to see if the areas are roughly equivalent. At the beginning of the DCI we enter in the total floor areas (gross and conditioned). Then in the spaces we enter all the individual space floor areas (gross and conditioned), which are added up in this QC check and should be roughly equal to the total floor area (within rounding errors). We can also check the number of stories times the foundation area, which will roughly equal the total floor area if we have a simple building (same area on every floor, which would be likely in a typical boxy office building, for instance). The three Ratios at the end of this check are comparisons of these areas – we expect them to roughly be equal to 1.0 (if our assumptions hold).
- Is the foundation area related to the ceiling area? Typically, the ceiling area is the same size as the footprint of the building, so this is just a check of those two areas to see if the Ratio is roughly equal to 1.0.

- Is the window-to-wall ratio reasonable? In residential situations, particularly in smaller residential buildings, we'll likely be around 15%. If there are a lot of curtain walls or similar, we may approach 40%. Use the calculated ratio and your experience viewing the building to see if the calculation roughly matches your perception of the building.
- Gas checks. These are a summary of all the places in the DCI that could have natural gas usage. If we know it's an all-electric building, then check to make sure no gas items are entered. If we know the building has gas, then make sure a gas meter is entered and look through the end uses to make sure all the gas elements you know about have been entered.

Lighting

These are zone-by-zone LPD calculations, as well as an overall LPD calculation. Since we used the lighting zones to lump together similar spaces, the LPDs should be able to be compared directly to the code requirements. However, in this QC check, you're simply looking through to make sure everything looks reasonable. Most spaces should have LPDs between 0.5 and 1.0, with some space types allowing more or less than that. We're just making sure we don't see a 15 or something like that, which would indicate a data entry error. [Note: in future DCI updates, the code requirements may be added as automatic lookups to this sheet to make the comparisons easier. This wouldn't require any more data inputs, just a connection to a lookup table.]

HVAC Sheets Reviewed

At the top of each individual HVAC sheet is a Complete/Not Complete pull-down menu. By the end of entering information into the DCI, all HVAC sheets should be "Complete" even if there is no information entered on a sheet. This is to ensure the data sheet is intentionally left blank and not just forgotten. Use the HVAC Sheets Reviewed section of the 'QC Report' sheet to ensure all HVAC sheets have been marked Complete.

Completeness Check & Completeness Report

Throughout the workbook there are a lot of dynamic rules indicating whether certain fields are required or not. The Completeness Check table lists the number of fields that are required but are missing. Data collectors should use the notes field in the Completeness Check table to let any reviewer know why something may be missing (and make more detailed notes on the sheet itself). The Completeness Check table also has additional columns to note how many items have or have not been field verified, or whether any of those field verified items have been left blank and need to be filled out. For items that are missing, press *Ctrl-Alt-F5* to refresh the Completeness Report below, which will list all of the questions that have missing items. You can then go back to the individual sheets to look at those questions and make updates/notes.

Appendix H: Sampled Design, Evolution, and Outcome

At the project's conclusion, Ecotope was able to comprehensively assess the sample design, recruiting challenges, and ultimate outcome. Discussed in segments elsewhere in the report, this appendix provides a compact overview.

The project field phase began with the goal of recruiting 64 buildings across 4 building types. The sample design called for 3 strata, delineated on floor area, within each of the building types to achieve 90/10 confidence/precision on building floor area. All of the buildings were placed in strata based on the floor area data provided for the building in the Dodge dataset. Put simply, dividing the sample frame based on floor area is a way to increase sample efficiency. It is done to ensure both small and large buildings are more equally sampled with a smaller number of survey points than a simple random sample. Dividing into more strata effectively allows one to achieve higher confidence/precision levels for a smaller number of sample points.

There were only 222 buildings in the sample frame so the recruiting success rate needed to be 29% for the project. In some building types, such as offices, it needed to be 33%. Approximately half-way through recruiting, it became apparent the success rate was going to be too low to get 64 buildings. Despite the best attempts of the recruiting team, using multiple contact methods and numerous attempts, the success rate remained stubbornly low.

In response to the low recruiting success rate, Ecotope redesigned the sample by dividing into more strata for each building type. This lowered the number of buildings needed to achieve the same confidence/precision levels as before to 46 (apart from offices which was lowered to an 80/20 target). While the increased strata design lowered the required building count and provided a pathway for reaching the confidence/precision targets, it also introduced added risk.

After recruiting was complete (i.e. the sample frame was exhausted), we identified three items that compromised the ability of the sample design to reach the desired targets:

1. The observed variation in floor area was larger than reported in the source material used to design the sample (the Dodge dataset).
2. In specific instances, the building floor area was not what the Dodge dataset reported. For example, two multifamily buildings with floor areas 110,000 and 130,000 square feet had entries in the Dodge dataset that placed them in the 143,800-228,300 square foot stratum. That effectively increases the variation observed in our sample.
3. Quotas were not achieved in some strata. Therefore, buildings went missing in critical locations.

The increased strata design was therefore riskier than the original design because it was more susceptible to problems created by items 2 and 3. Essentially, with fewer buildings overall, each misplaced building (item 2) or missed building (item 3) carried a larger impact in the redesign.

Overall, while the revised sample design could have worked, uncertainties in the underlying sample frame data and persistent recruiting challenges caused it to also miss the target levels. Report sections 1.5 and 1.8 present the outcome in numerical terms.

Appendix I: HVAC Output Capacity vs Building Load

ECOTOPE

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To: Steve Phoutrides, Senior Project Manager, Northwest Energy Efficiency Alliance
From: Scott Spielman, Research Engineer, Ecotope Inc.
Ben Larson, Director of Research and Technology, Ecotope Inc.
Date: August 28, 2019
Re: Oregon New Commercial Construction Code Evaluation Study Building Heating and Cooling Loads Compared to HVAC Equipment Capacity

This memo serves to describe the methodology used to estimate heating and cooling loads in buildings surveyed as part of the Oregon New Commercial Construction Code Evaluation Study and to compare those estimates with surveyed HVAC equipment capacity. This work was performed by Ecotope Inc. under contract with the Northwest Energy Efficiency Alliance (NEEA) to assess attention given to heating and cooling load calculations by design engineers, when sizing HVAC equipment.

Context

The Oregon New Commercial Construction Code Evaluation Study was conducted by Ecotope, Inc. for NEEA to assess the degree to which code was present in new buildings, and to observe the energy performance of newly occupied buildings. The study surveyed 46 commercial buildings and was designed to provide insights into four key building types: Office, Retail, School, and Multifamily.

The objective of this memo is to compare equipment capacities surveyed in the Oregon New Commercial Construction Code Evaluation Study with estimated heating and cooling loads. The provided information will inform NEEA on the degree to which HVAC systems are oversized, undersized, or appropriately sized by engineers. Buying more heating and cooling output capacity than needed can be expensive and be a barrier to installing more efficient equipment. Efficient equipment is often priced higher than standard equipment and higher per unit of output. Therefore, properly sizing equipment may mean the difference between a cost-prohibitive and cost-effective selection.

Furthermore, energy efficiency measures, such as improved thermal envelope and reduced lighting power density, reduce heating and cooling loads. As energy codes improve and more buildings strive to achieve green building certifications these efforts should be reflected in a reduced size and cost in the HVAC equipment.

When load calculations are done properly and used to size equipment, money is saved due to the reduction in purchased HVAC capacity. These savings offset some, or all, of the incremental cost associated with the lighting or envelope improvements.[12] Additionally, off-cycle parasitic power from oversized HVAC equipment can significantly increase energy usage.[13]

The methodology for estimating heating and cooling loads and equipment capacities are described in the subsequent section. Due to the number of buildings, limited information, and time constraints, the load calculations and equipment capacity totals are only estimates. The estimates use surveyed data, rules of thumb, and simplified calculation techniques to provide approximations. The engineers who designed the HVAC systems surveyed had access to architectural drawings and the ability to perform detailed load calculations with modern software. Nevertheless, the estimates provide a uniform way of assessing many buildings at once which reveals general trends in the buildings studied.

Heating and Cooling Load Estimate Methodology

Heating and cooling load calculations were performed based envelope load, outdoor air load, and internal load (cooling only). Outdoor air requirements for heating and cooling are based on ASHRAE 62.1 minimum outdoor air flow rates for surveyed space types. Surveyed equipment airflow was not used for outdoor air flow because the survey captures total airflow and not only outdoor airflow. It was decided that recalculating outdoor airflow, from building square footage, would be a more robust calculation method. After the total loads were calculated, heating loads were converted to sf/kBtu (square feet per thousand British thermal units), and cooling loads were converted to sf/ton for comparison across buildings with different areas. Both sf/kBtu and sf/ton are commonly used values to quickly assess the loads. Lower values indicate greater heating or cooling needs.

Heating Loads

Heating design temperatures are based on American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Handbook of Fundamentals 99.6% Heating Dry-Bulb temperatures. Heating loads were calculated in two parts: envelope conduction and outdoor air load. Heating envelope load was calculated using surveyed overall heat loss (UA) values at heating design temperatures. Heating outdoor air loads were calculated based on the minimum outdoor air requirements estimate.

Cooling Loads

Cooling design temperatures are based on ASHRAE Fundamentals 0.4% Cooling Dry-Bulb temperatures. Cooling loads were calculated in four parts: envelope conduction, envelope radiation (solar heat gains), internal load, and outdoor air load. Cooling envelope conduction was calculated using surveyed overall UA values at cooling design temperatures. Cooling envelope radiation was calculated based on ASHRAE 1985 Fundamentals Chapter 26 methods using Maximum Solar Heat Gain Factor (SHGF) values from

[12] See “Tunneling through the Cost Barrier”, by Amory Lovins – Chapter 6 in Natural Capitalism

[13] See “Energy Impacts of Oversized Residential Air Conditioners”, NREL 2014

August at 48°N, and a Cooling Load Factor (CLF) for August at 2 PM. The SHGF method was used because it allowed for cooling load calculations of all 46 buildings without inputting complex geometry into a load simulation computer program. SHGF was commonly used before computer programs were common and is an accurate way to access the load requirements of an entire building. 48°N was chosen by rounding up from the site locations to the next available latitude in ASHRAE 1985. Rounding up is a conservative approach because the sun in lower in the sky further North, causing a lower angle of incidence and higher solar load. For most buildings, around 2 PM is the highest cooling load. At 2 PM both the South and East sides of the building have received sun and warmed, the South and West side are receiving sun, and the outdoor air is typically the warmest. Cooling internal loads were calculated based on rules of thumb for each building type. Cooling outdoor air loads were calculated based on estimated minimum outdoor air requirements.

Heating and Cooling Load Calculation Assumptions

- Heating and Cooling Design Temperatures.
- Energy Recovery Ventilators (ERVs) were ignored in load calculations.
    - This assumption acts to increase the calculated loads and, in effect, reduce apparent equipment oversizing.
- Internal load assumptions based on building type.
- Outdoor Air requirements based on space type.
- Solar loads include North, South, East, and West facing windows. Delayed thermal gain, and diffuse radiation from the sky are accounted for in the SHGF calculation. Opaque constructions are considered conductive gains only.
- Peak solar load in August at 2 PM for all buildings.
- All buildings are light construction.
- Accurate UA values, spaces type areas, building areas, and envelope areas in survey.
- 500 Btu/hr per person (typical design value from ASHRAE Fundamentals Handbook 2013).

Table 1. Design Temperatures by City

City	Winter Design DB Temperature [°F]	Summer Design DB Temperature [°F]
Portland	25.0	91.2
Albany	24.8	92.7
Bend	22.8	91.8
Salem	5.2	93.2
Stayton	23.7	92.1
Beaverton	23.7	91.2
Newberg	25.0	91.2
Medford	22.8	99.0
Tualatin	25.0	91.2
Sherwood	25.0	91.2
Corvallis	24.8	92.7
Helix	8.2	96.8
Crescent	5.2	93.2

Table 2. Outdoor Air Assumptions.

Building Type	Space Type	Outdoor Air Requirement [cfm/sf]
Office	Office	0.09
	Reception	0.21
	Lobby	0.11
Multi-Family	Living Spaces	0.11
	Reception	0.16
	Lobbies	0.29
Retail	Sales	0.23
School	Classroom	0.47
	Lab	0.43
	Assembly	0.8
	Gym	0.3

Table 3. Internal load assumptions.

Building Type	Lighting Power Density [W/sf]	Equipment Power Density [W/sf]	Occupant Density [sf/person]
Office	0.9	0.5	150
Multi-Family	0.7	0.2	750
Retail	0.7	0.3	100
School	0.7	0.1	50

*Internal load assumptions are based on rules of thumb and adjusted to account for circulation space.

Equipment Capacities

A summation of all surveyed equipment capacities, excluding cooling towers and fluid coolers, was calculated to determine total building equipment capacities.

Equipment Capacity Calculation Assumptions

- Cooling towers and fluid coolers are sized for condensing water only.
- All equipment used to heat and cool is accurately recorded in surveys.

Results

Due to assumptions described above, as well as unique characteristics of certain sites surveyed, a selection of sites are considered outliers and omitted from the results. Table 4 describes the exceptional and omitted sites and attempts to identify the reason for outliers. For each site, an "X" indicates the value could not be calculated accurately due to the reason listed. Columns without an "X" were still calculated. For each building, four calculations are performed: Cooling Load, Cooling Capacity, Heating Load, and Heating Capacity. Most of the omissions are due to difficulty calculating cooling capacity, which means for cooling the sample size for comparing capacity to load is smaller than for heating. For omissions where we suspected a data issue but were not sure exactly what the cause was, we indicated as "- suspect data".

- **Table 4. Table of exceptional sites and omissions.**

Site ID	Building Type	Cooling Load	Cooling Capacity	Heating Load	Heating Capacity	Suspected Reason for Outlier
100201	Office	X	X	X		Capacity outlier – suspect data
103148	School	X	X	X	X	Low envelope area
103453	Multifamily		X		X	Capacity outlier – suspect data
104148	School		X		X	Capacity outlier – suspect data
105459	Office		X			Envelope vs. floor areas misalignment
105601	Multifamily		X			Capacity outlier – suspect data
105795	School		X			Envelope vs. floor areas misalignment
106376	Office				X	Capacity outlier – suspect data
107666	Retail		X		X	Capacity outlier – suspect data
108274	Multifamily		X			Capacity outlier – suspect data
108462	School	X	X			No cooled floor area
108503	School		X			Capacity outlier – suspect data
108793	Retail	X	X			No cooled floor area
108855	School		X			Capacity outlier – suspect data
109236	School		X			Capacity outlier – suspect data
109651	Multifamily		X			Capacity outlier – suspect data
110564	Retail				X	Capacity outlier – suspect data
112551	Multifamily				X	Capacity outlier – suspect data
113050	School		X			Envelope vs. floor areas misalignment

Due to the number of buildings and limited information, load calculations and equipment capacity totals are estimates. For cooling, because of the number of omitted cooling capacity calculations, there is a smaller building sample. A reference table of all the sites and results is below.

Table 5: Compiled list of sites, cooling and heating load estimates and equipment capacities.

SiteID	Building Type	Cooling Load [sf / ton]	Cooling Capacity [sf / ton]	Heating Load [sf / kBtu]	Heating Capacity [sf / kBtu]
100016	Multifamily	551	862	115	60
100201	Office	X	X	X	14
101127	Multifamily	875	664	89	47
101959	Office	1,134	880	117	24
102217	Retail	681	480	58	41
102938	School	522	358	52	12
103148	School	X	X	X	X
103453	Multifamily	588	X	39	X
104111	Retail	695	965	30	11
104148	School	599	X	31	X
104916	Retail	559	X	48	19
105459	Office	1,334	X	79	42
105601	Multifamily	1,110	X	112	77
105632	Multifamily	889	741	99	42
105795	School	892	X	37	14
106207	School	549	872	34	11
106260	Retail	658	676	82	38
106376	Office	691	218	71	X
107545	Multifamily	1,243	1,326	54	25
107643	School	519	343	51	16
107666	Retail	784	X	45	X
108274	Multifamily	804	X	108	35
108462	School	X	X	47	29
108503	School	395	X	31	27
108793	Retail	901	509	25	21
108855	School	840	X	51	36
109236	School	824	X	30	34
109651	Multifamily	1,279	X	129	45
109765	Retail	405	112	36	10
109835	Retail	577	288	48	19
109933	School	478	605	44	29
110564	Retail	441	968	21	X
110719	Retail	787	824	42	18
111582	Retail	598	394	42	26
112077	Office	654	403	64	30
112551	Multifamily	1,119	905	103	8
112592	Multifamily	697	732	100	46
112660	School	618	430	98	36
113050	School	461	640	42	46
113650	School	607	X	23	14
113826	Multifamily	1,050	508	114	41
114032	Office	649	319	82	13
114342	Multifamily	760	619	54	33
114495	Retail	237	371	15	8
114617	Office	759	446	80	14
115438	Multifamily	763	489	122	34

Heating

In general, all building types have oversized heating capacities. Heating capacities were calculated based on all surveyed heating equipment – including electric resistance, hydronic, and heat pump equipment. Buildings are oversize in heating potentially because many buildings use electric resistance terminal heaters. Electric resistance heaters come in discrete sizes and are relatively inexpensive. When a heater is placed in each room, and slightly oversized due to conservative engineering practice, or simply the need to round up to the next, discrete, available size, the total building heating capacity can snowball until the capacity of all HVAC equipment is much higher than the actual calculated load. However, oversized heating is observed in central systems as well, which suggests that, in general, heating capacity is inexpensive and therefore more often oversized than cooling (as seen next).

Although oversizing is observed across all building types for heating it is most prominent in multifamily and office buildings. In multifamily, terminal units, such as electric resistance heaters, are common. When inexpensive terminal units are used in leu of central systems, each terminal unit is slightly over-sized, which, when summed, creates a significantly oversized system. Further, the electrical contractor typically purchases and installs the heaters. Based on Ecotope's experience, it is not clear that there is always good coordination between the HVAC contractor and the electrical in terms of sizing heaters. Additionally, because multifamily buildings will be occupied at night, and on the coldest days of the year, it is not surprising engineers design conservatively and add extra capacity.

Like multifamily buildings, terminal units are common in office buildings. However, because office buildings are not occupied at night, there should not be as big of a reason to conservatively size terminal heating equipment. Office buildings may be an area were more efficient, right-sized equipment, could have an impact.

In both retail buildings' and schools' central systems, such as air handling units, provide heat in most buildings. The use of a centralized system for heating appears to contribute to less oversized equipment.

Figure 1 is a scatter plot of building area per heating equipment capacity to building area per estimated heating load, both in square foot per ton [sf/kBtu]. It gives an understanding of how the designed equipment capacity relates to a calculated load. Building types are color coded and the size of the dot corresponds to the area of the building. Buildings above the line are estimated to have oversized equipment capacity, and buildings below the line are estimated to have undersized equipment capacity.

It is worth noting that some of the most oversized buildings are residential buildings where terminal electric heaters are more common. For instance, site 109651, an apartment building, has 390 electric wall and baseboard heaters that account for much of its oversized capacity. Site 108274, another multifamily building, is similar with 116 electric wall heaters at 500-1250 watts each.

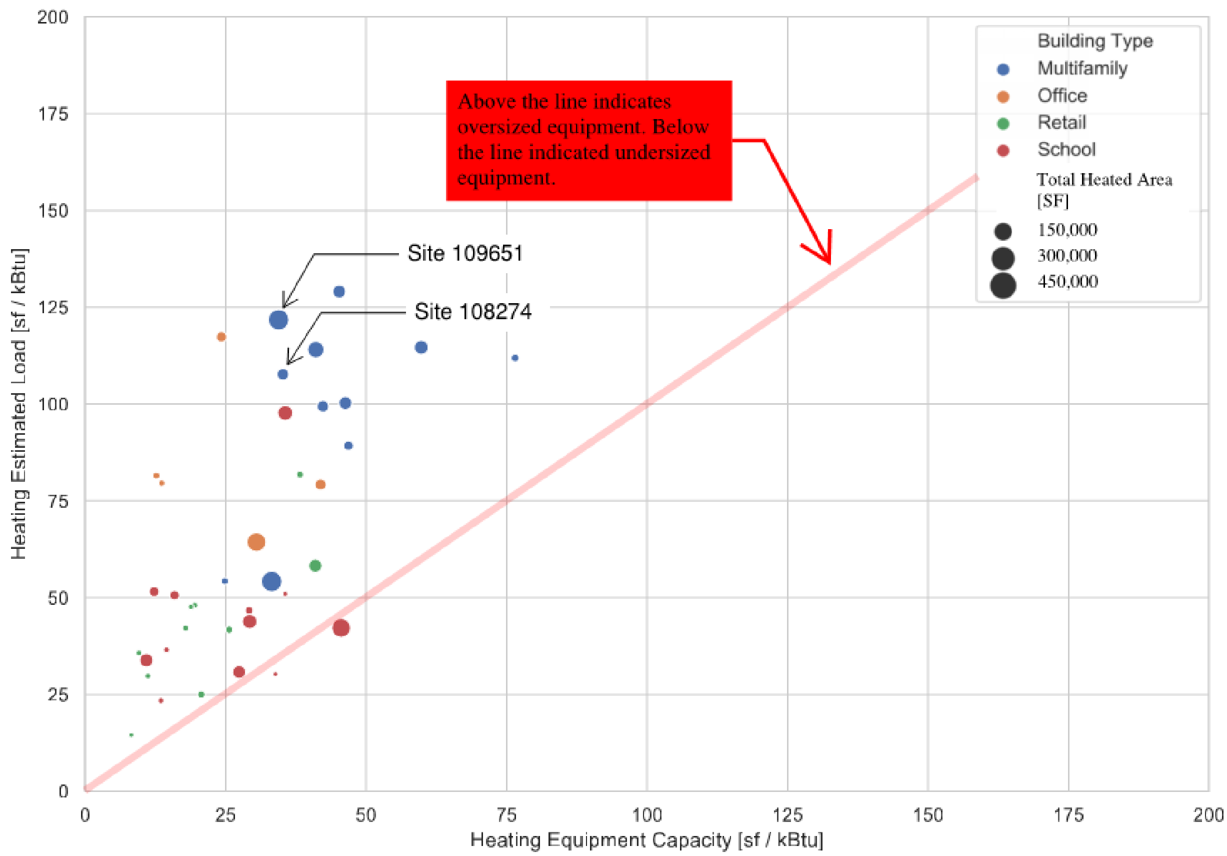

Figure 1: Scatter plot of load vs capacity for heating.

Figure 2 is a box plot showing heating equipment capacity and estimated load both in square foot per ton [sf/kBtu]. In a box plot, the center line is the Median, the box shows the interquartile (for 25th to 75th percentile), and the outer-lines (whiskers) show one and a half times the interquartile. Dots show the outliers. Where heating estimated load is above heating equipment load for a certain building type, that building type was observed to have generally oversized equipment capacity.

On average heating systems are significantly oversized in all building types. Average installed capacity is 2.5 times the average load in multifamily, 4 times the average load in office, 2 times the average load in retail, and 1.5 times the average load in schools. Moreover, our heating loads were calculated with no internal gains or heat recovery. Both are present in the buildings and both act to reduce the heating load further. In effect, the systems are likely even more oversized than stated. If systems were sized closer to actual load significant savings could be achieved in heating system first costs. Right-sizing heating systems can have a cascade effect on infrastructure size and cost. Ductwork, electrical circuits, transformer sizing, gas meters and piping, and mechanical room sizing are all affected by heating system sizing.

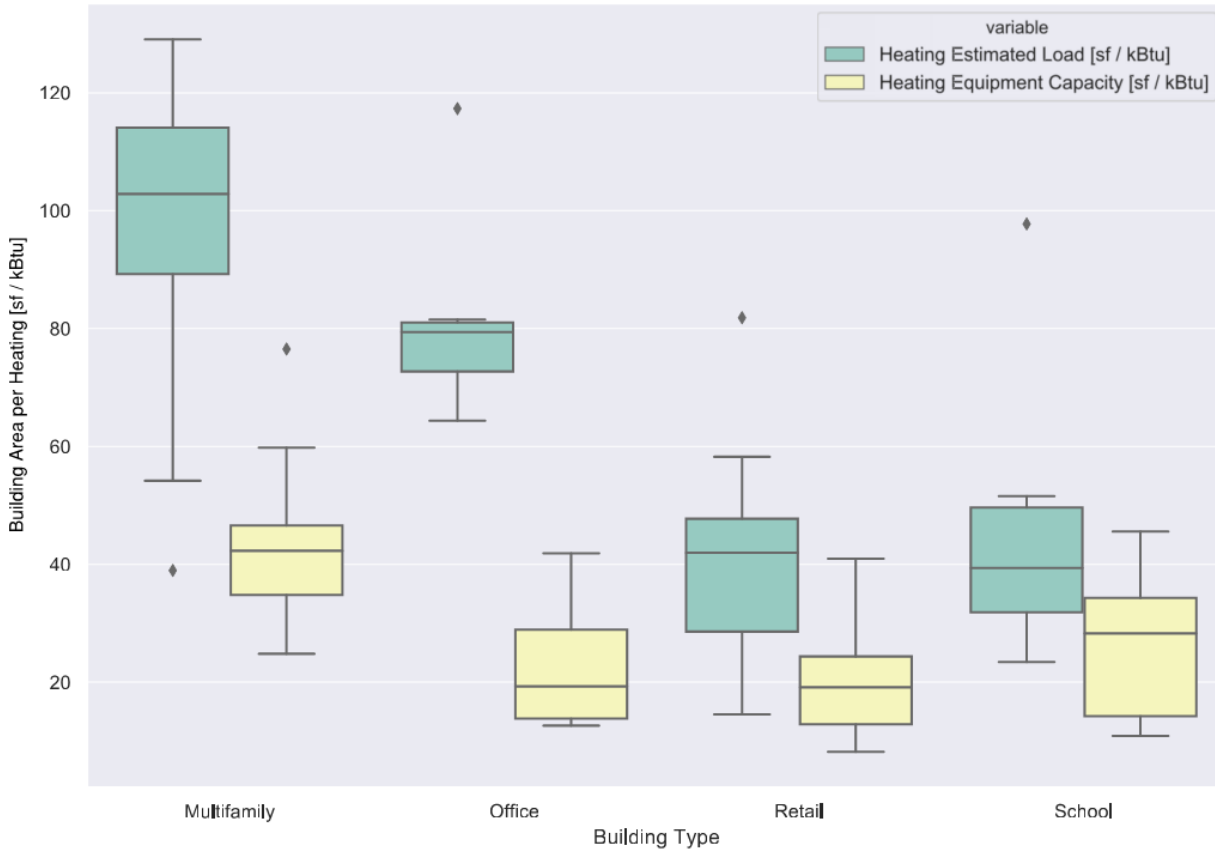

Figure 2: Heating box plots by building type.

Cooling

Cooling capacity and loads are more aligned than heating. Using our calculation methodology cooling does not correlate with oversizing to the same degree that heating does, but certain building types still appear to be generally oversized. Cooling capacity is generally more expensive than heating capacity, and central systems are more common for cooling than for heating. More expensive capacity likely contributes to less oversizing. Additionally, more centralized systems allow for purchase of equipment that more closely matches the overall building thermal load.

For the most part, building types all fell within expected square foot per ton ranges for estimated load and equipment capacity. Only for offices, is building area per equipment capacity [sf/ton] shown as significantly higher than building area per estimated load [sf/ton], which suggests oversized equipment. This could be due to conservative internal load estimates, or conservative outdoor air requirements from engineers when designing offices. Internal loads tend to be rules-of-thumb handed down through generations of engineers. Internal load estimates have not kept pace with advances in lighting, technology, and controls where we have seen trends toward cloud computing instead of in-house servers, laptops, and low-energy flat screens. Additionally, offices may sometimes be designed with lower setpoint temperatures for comfort when wearing a wool suite at a moderate-to-high activity level.

Furthermore, many office spaces are built as core and shell with the final tenant not identified until after the primary building systems have been designed. Therefore, engineers will tend to size with worst-case estimates for what *might* happen in the space such as very high occupancy level with very high plug and server loads as opposed to what is *likely* to happen in the space. For ease of design and perceived lower risk this planning for worst-case conditions tends to be designed into the equipment up front rather than make allowances for adding additional equipment in the future.

Figure 3 is a scatter plot of building area per cooling equipment capacity to building area per estimated cooling load both in square foot per ton [sf/ton]. It gives an understanding of how the designed equipment capacity relates to a calculated load. Building types are color coded and the size of the dot corresponds to the area of the building. Buildings above the line are estimated to have oversized equipment capacity, and buildings below the line are estimated to have undersized equipment capacity.

A couple of larger schools fell below the line. This means that the equipment capacity was theoretically not sized big enough for the estimated load. For site 106207, the apparent under-sizing is potentially due to both design conditions and an ERV. Because schools are not occupied in the summer, design conditions can be relaxed. We conservatively performed all our load calculations for August, even though schools will not be occupied. Additionally, this project includes an ERV to reduce incoming outdoor ventilation air temperature on the warmest days, further reducing the cooling need.

Many multifamily buildings are above the line. This is potentially due to increased use of single zone systems. Single zone systems can be favored in multifamily because they allow the residents to control temperature individually. Site 112551 is a good example of this, where 337 packaged terminal air conditioners account for most of the cooling capacity.

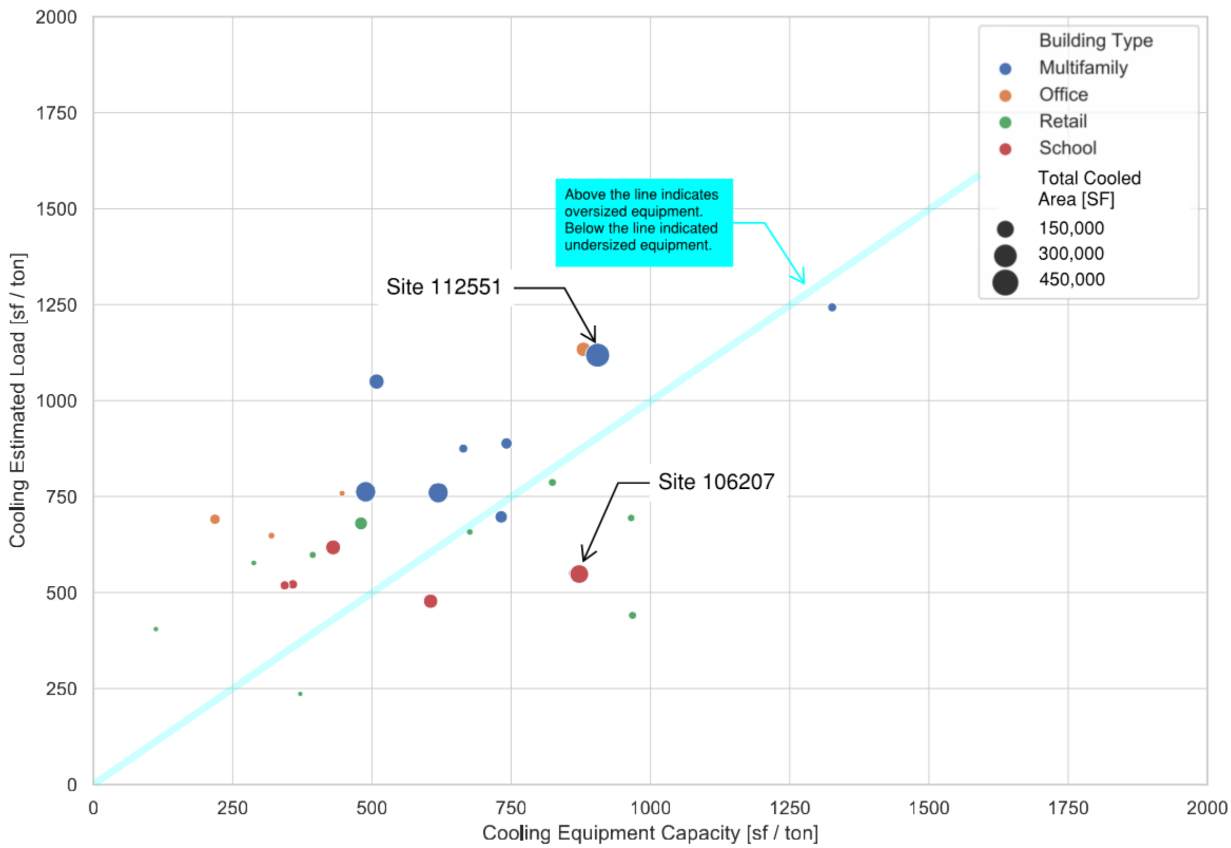

Figure 3: Scatter plot of load vs capacity for cooling.

Figure 4 below is a box plot showing cooling equipment capacity and estimated load both in square foot per ton [sf/ton]. Where cooling estimated load is above cooling equipment load for a certain building type, that building type was observed to have generally oversized equipment capacity.

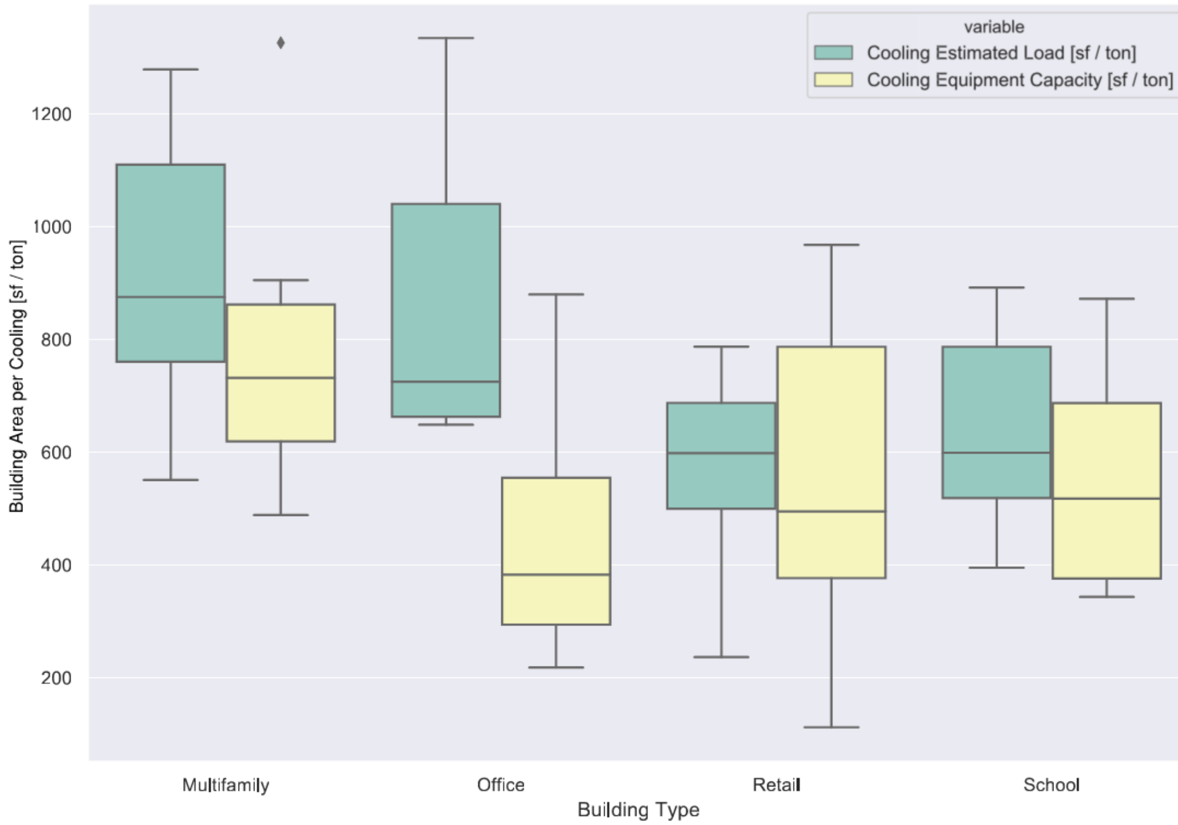

Figure 4: Cooling box plots by building type.

While most building types appear to be sized reasonably close to the conservatively-calculated peak load, average office capacity is about 1.8 times the average office load estimate. The average sizing for office systems is suspiciously close to the Rule-of-Thumb sizing of 400SF/ton that has been used by engineers for 50 years when sizing office cooling systems. This number persists even though lighting loads have been reduced by a factor of 4 over that same time frame and glazing has gone from single pane clear glass to double glazed with low-E coatings.

Although the data shows that schools are slightly over-sized, it could be argued that this indicates significant over-sizing since schools tend to be either unoccupied or very lightly occupied during the summer months.

Conclusion

The data collected in this study indicate that HVAC designers are routinely over-sizing heating and cooling equipment in most building types. On the heating side some amount of over-sizing is likely necessary in buildings which rely on multiple small zonal electric resistance heaters as heaters must be selected at the next largest size required to meet peak load. Some amount of over-sizing is also necessary to recover from setback temperatures during peak heating conditions. On the cooling side, the over-sizing is arguably minor for school, retail, and multifamily buildings.

Over-sizing is typically viewed by the mechanical designer as a safety measure. Designers rarely if ever get into trouble from providing more heating or cooling capacity than is needed. On the other hand, it can be financially disastrous to undersize a system to the point that it can not meet the load and tenants are uncomfortable and complaining. If the designer does not know exactly how the building will be used and exactly what equipment will be in the building, they will tend to make the most conservative assumptions every time and this naturally leads to oversizing.

The mechanical designer tends to focus on the relatively minor capital costs associated with increasing the size of the heating or cooling unit itself. They rarely take into account all of the other downstream costs of oversizing including the need for larger mechanical spaces, heavier structure, larger ducts, larger louvers, deeper soffits, larger electrical circuits, larger gas piping, and larger transformers. Depending on the system type, oversized systems will also lead to more energy use due to higher outside air amounts, more fan energy, higher cycling and parasitic losses, and more part-load penalties. This will also have downstream impact on the utility as it not only must supply more energy for a less efficient oversized system, but higher peak load demands as well.

Overall, the data suggests that designers are using very conservative assumptions for the sizing of HVAC systems and a significant amount of savings could be achieved through right-sizing of equipment. Furthermore, this data suggests that large energy and cost savings may be available from a combination of aggressive energy efficiency measures and integrated design in combination with right-sizing of the mechanical equipment.

One path to avoid oversizing and achieving significant energy benefits is to implement “Whole Building Integrated Design” which includes:

- Energy efficiency measures that reduce heating and cooling loads must be reflected in the sizing of equipment.
- Owners and operators must be involved early in the design to relay to the HVAC designer the actual conditions expected in the building. This will reduce their perceived risk associated with potential undersizing.
- Any potential future unknown loads should be accommodated in the design with additional space allocated for additional equipment rather than increasing the installed capacity in the initial design.
- The impact of the right-sized mechanical equipment must also be reflected in reductions in the designs by the other trades including; structural, electrical, architectural, civil, and plumbing for a truly integrated design.

A whole-building approach to energy efficiency programs and education will therefore be able to achieve more success if it can connect system right-sizing to energy efficiency and achieve reductions throughout the other disciplines.