February 22, 2021

REPORT #E21-011

2015 Washington State Energy Code Energy Savings Analysis—Commercial Provisions

Prepared For NEEA:
Shilpa Surana, Code and Standards Engineer

Prepared by:
Mike Kennedy

Mike D. Kennedy, Inc.
PO Box 1936
Port Townsend WA 98368

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

Table of Contents

List of Tables

Glossary of Acronyms

4C	Climate zone 4C (western Washington)
5B	Climate zone 5B (eastern Washington)
6B	Climate zone 6B (northeastern Washington)
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
CFA	Conditioned floor area
DCV	Demand control ventilation
DOAS	Dedicated outdoor air system
HVAC	Heating, Ventilation and Air Conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
LPD	Lighting power density (W/ft^2)
NC	New construction
NEEA	Northwest Energy Efficiency Alliance
NPCC	Northwest Power and Conservation Council
OCCE	Oregon Code Compliance Evaluation Study
RBSA	Residential Building Stock Assessment
SHGC	Solar heat gain coefficient of fenestration
SHGCA	Solar heat gain coefficient times fenestration area
TMY3	Typical Meteorological Year 3
UA	Building heat loss expressed as U-value times area
VAV	Variable air volume
WA12	WSEC 2012
WA15	WSEC 2015
WSEC	Washington State Energy Code
WSEC 2012	Washington State Energy Code 2012
WSEC 2015	Washington State Energy Code 2015

Glossary of Units

aMW	Average megawatt
Btu	British thermal unit
Btuh	British thermal unit per hour
ft^2	square feet
kBtu	British thermal unit (1000s)
kBtuh	British thermal unit (1000s) per hour
kWh	kilowatt-hour
MMBtu	British thermal unit (1000000s)
mWh	megawatt-hour
W	Watt

Executive Summary

The 2015 Washington State Energy Code (WSEC 2015) was developed by the Washington State Building Code Council and adopted statewide for commercial construction permitted as of July 1, 2016. It replaces the previous 2012 Washington Commercial Energy Code (WSEC 2012). The commercial provisions section of the code impacts all types of commercial buildings and multifamily buildings over three stories tall. The WSEC 2015 code represents a major change in requirements for lighting power allowances, reductions in fan power energy consumption and requiring some building types to have dedicated outdoor air system (DOAS)-based HVAC and increased additional efficiency option requirements.

The Northwest Energy Efficiency Alliance (NEEA) has played a pivotal role in states to deliver more effective and efficient energy codes. The main objective of this report is to quantify the energy savings resulting from adoption of the commercial provisions of the 2015 Washington Energy Code (WSEC 2015) in new buildings and additions.

Methodology

The study was developed in two phases. The first phase involved identifying all code changes that resulted in possible energy changes and making a qualitative assessment of whether the measure warranted quantitative evaluation. All major code changes were selected for quantification except for metering and commissioning changes that impact building operations. Only changes in the code prescriptive path were evaluated. Many smaller code changes were not selected for evaluation due to limited evaluation resources and diminishing returns of evaluating changes that impact very narrow slices of new construction.

The second phase involved development of savings estimates for the selected changes. The building energy modeling software EnergyPlus (DOE 2018) was utilized and supplemented with engineering calculations. A suite of 16 prototype buildings, derived from the Bonneville Power Administration (BPA) new vintage existing building models (Navigant Consulting 2016) and modified for code evaluation, were utilized. The BPA models share many characteristics with the national reference models but have been modified to capture region-specific construction practices. Specific model inputs representing code values were developed based in some cases on impacts estimated from those same regional building data sets, and in other cases on Pacific Northwest National Laboratory (PNNL) modeling inputs for ASHRAE Standard 90.1 savings determinations (Thornton et al. 2011, PNNL 2014a, PNNL 2014b, and PNNL 2017).

The estimated savings include current practice adjustments to improve its representation of actual energy savings. The adjustments account for areas of code for which current practice is always better than code, as well as new provisions for which substantial portions of the commercial sector are already implementing the provision.

Total state estimates combine the unit area savings estimate with the new construction/addition floor area forecasts from the Northwest Power and Conservation Council (NPCC) Seventh Power Plan.[1] The prototype models directly represent 83% of Washington commercial sector floor area. Where absolute savings are presented, it is assumed that the average of the modeled sectors can be used to represent those sectors not modeled.

Results

The WSEC 2015 represents a major change in requirements. In total, 66 changes impacting new construction were noted in the new code, of which 49 were determined to likely impact energy use, 41 decreasing energy use and eight increasing it. A total of 19 changes were evaluated to quantify the energy savings. These include a 21% decrease in lighting power allowances, requiring some building types to have DOAS-based HVAC, and an additional efficiency requirement that requires buildings to comply with two options from nine possible. The unevaluated measures included many niche provisions (e.g., lowering leakage allowed in high pressure ducts) as well as some larger measures such as refrigeration provisions that the models are not configured to handle.

Energy Savings Estimates

Table 1 presents the estimated energy savings for the NPCC forecast building types after adjustment for current practice on a floor area normalized basis and forecast sector savings. The forecast sector savings combine the floor area normalized savings with forecast annual new floor area in the state. The evaluation found significant electric savings and a small amount of gas savings. The savings are steady across building types.

Table 2 presents adjusted current practice savings by major code provision. Electric savings are dominated by provisions reducing lighting and plug-load equipment energy use. These same provisions result in increased heating energy use, much of which is provided by gas. The net difference of all the provisions is a small change in gas use, with gas savings resulting from new envelope and HVAC provisions in the code largely offset by this increased gas use in the lighting and equipment provisions. Gas savings comprise all fuels including natural gas, propane, and oil consumption.

Table 3 presents the percent change in several metrics as a result of implementation of the WSEC 2015. Adoption of the WSEC 2015 energy code represents a substantial advance in new building energy efficiency. The analysis shows that WSEC 2015 will achieve energy savings of 11.7% for site energy and 10.8% for source energy, respectively, compared to the WSEC 2012 edition. This code engenders substantial electric savings (10.0%) and fossil fuel savings (16.5%). The code provision changes that generate the bulk of energy savings are DOAS system requirements, interior lighting power, and C406 extra efficiency options.

[1] Supporting data files from: Seventh Northwest Electric Power and Conservation Plan, Northwest Power and Conservation Council

Due to the current practice adjustments, these estimates are not comparable to savings numbers from national energy code determinations (Thornton et al. 2011, PNNL, 2014a, PNNL 2017).

Table 1. Estimated Annual Energy Savings by Building Type – Current Practice

	Normalized Savings				Forecast Sector Savings	
Building Type	**Site Energy kBtu/ft²**	**Source Energy kBtu/ft²**	**Electric kWh/ft²**	**Gas therm/ft²**	**Electric aMW**	**Gas MMBtu**
Assembly	5.13	8.38	0.99	0.017	0.08	1,214
Hospital	7.77	12.95	1.58	0.024	0.20	2,626
K-12 School	5.87	9.53	1.12	0.021	0.05	825
Lodging	10.71	15.97	1.60	0.052	0.08	2,376
Multifamily	2.43	4.16	0.53	0.006	0.19	1,970
Office – Large	3.70	6.36	0.81	0.009	0.38	3,819
Office – Medium	3.95	7.47	1.07	0.003	0.32	759
Office – Small	4.49	8.41	1.20	0.004	0.09	270
Other	5.13	8.38	0.99	0.017	0.29	4,397
Other Health	8.46	14.44	1.82	0.022	0.25	2,700
Restaurant	20.38	23.26	0.88	0.174	0.03	4,429
Retail – Big Box/Anchor	7.13	10.28	0.96	0.038	0.07	2,408
Retail – Small/High End	13.23	20.56	2.23	0.056	0.19	4,294
University	4.70	8.10	1.04	0.012	0.05	468
Warehouse	3.01	4.06	0.32	0.019	0.05	2,749
Total	**6.11**	**9.99**	**0.99**	**0.017**	**2.31**	**35,305**

Table 2. Annual Energy Savings by Code Provision - Current Practice

Code Item	Normalized Savings Electric kWh/ft^2	Normalized Savings Gas therms/ft^2	Forecast Sector Savings Electric aMW	Forecast Sector Savings Gas MMBtu
Envelope Changes	-0.048	-0.0006	-0.11	-1,244
Minimum Skylight Area	0.009	-0.0001	0.02	-249
Interior Lighting Power	0.463	-0.0026	1.09	-5,289
Interior Lighting Controls	0.012	0.0000	0.03	0
Exterior Lighting Controls	0.025	-0.0002	0.06	-383
Receptacles	0.148	-0.0007	0.35	-1,447
Aggregate Cooling Efficiency Changes	0.015	0.0000	0.04	-3
Air Flow Control - Fan Speed	0.074	-0.0006	0.17	-1,188
DCV Threshold Reduction	0.000	0.0001	0.00	127
DCV Kitchen Hood	0.009	0.0015	0.02	2,986
C403.6 DOAS	0.147	0.0092	0.34	18,819
Heat Pump Heating Efficiency	0.001	0.0000	0.00	0
Heat Pump Required if DX AC & Electric Heat	0.001	0.0000	0.00	0
VAV Optimization	0.002	-0.0002	0.01	-333
High Input Rated Hot Water	0.000	0.0005	0.00	1,123
Service Hot Water Circulation Demand Control	0.014	0.0018	0.03	3,699
C406 Addition Efficiency Aggregate	0.180	0.0122	0.42	24,929
Commissioning	-0.068	-0.0030	-0.16	-6,243
Total	**0.986**	**0.017**	**2.31**	**35,305**

Table 3. Percent Savings in Metrics as a Result of Implementation of WSEC 2015

	Energy Use				Carbon[1]		Energy Cost
	Electric	Gas	Site Btu	Source Btu	NPCC	WSEC	WSEC
Washington	10.0%	16.5%	11.7%	10.8%	10.8%	11.3%	10.7%

1 – NPCC carbon estimate utilizes the Northwest Power and Conservation Council estimate of marginal carbon in 2030 for electricity. The WSEC carbon estimate utilizes the carbon assumption for electricity negotiated for use in the WSEC building performance path.

The savings estimates associated with this work come with some limitations and uncertainty. Only the primary code provisions are evaluated. Many other code provisions are not quantified, mostly due to expected small overall savings, occasionally to uncertainty about current practice and application, and a few cases in which the models are not suited to evaluate the provision. In addition, the forecast sector savings are limited to new construction and additions and do not include major renovations and alterations to existing buildings. These factors combined mean that significant additional savings occur but are not quantified. As such, this work forms a conservative estimate of improvement in energy efficiency as a result of the code and market changes.

Estimates attributing savings to specific fuels have additional uncertainty due to the limited data on current and future HVAC system and fuel type choices and uncertainty associated with future additional efficiency option selections. Differences between assumed system and fuel type in the current prototype models and future installed system and fuel types will directly impact electric and gas savings from envelope provisions and, due to HVAC interaction, the savings associated with interior lighting and receptacles. This is a special concern when the code change is encouraging system change. Future work could be considered to address these limitations and enhance the analysis to access code adoption impacts.

1. Introduction and Purpose of Report

This work evaluates energy savings from the 2015 Washington State Energy Code (WSEC 2015) in commercial and in multifamily buildings that are four or more stories tall. The effective date of most of the new provisions was July 1, 2016, with one mechanical provision becoming effective July 1, 2017.

This work estimates electric and gas savings from the 2015 WSEC by comparing to the 2012 WSEC baseline with current practice adjustments. Energy codes follow practice, extending best practices and in some cases standard practices to all buildings. The current practice savings are adjusted for actual building conditions in an attempt to better capture the actual impacts of the codes and market forces by fuel type.

Savings are projected to the new building floor area forecast by the Northwest Power Planning Council for completion starting in 2018, one year after the code effective date. Savings are not quantified for changes to existing buildings. While doing so might involve large additional savings, it would also involve significant interactions with utility programs and issues related to enforcement and code applicability.

The savings estimates associated with this work come with some limitations and uncertainty. Only the primary code provisions are evaluated. Many other code provisions are not quantified, mostly due to expected small overall savings, occasionally to uncertainty about current practice and application, and a few cases in which the models are not suited to evaluate the provision. Adding this to remodeling activity means that significant additional savings occur but are not quantified. As such, this work forms a conservative estimate of improvement in energy efficiency as a result of the code and market changes.

Previous Northwest Energy Efficiency Alliance (NEEA) reports evaluated energy savings associated with regional non-residential code changes made between 1996 and 2015 (Kennedy, 2005-2016).[2] This work relies heavily upon the methods used in this earlier work and upon work by Pacific Northwest National Laboratory (PNNL) (Thornton et al. 2011, PNNL 2014a, PNNL 2014b, PNNL 2017).

[2] Residential code energy savings for the same period were estimated by the Northwest Power and Conservation Council.

2. Methodology and Data Sources

The analysis method used in this report provides the incremental energy savings for moving from the previous code to the recently adopted code. The method has been used by the Northwest Energy Efficiency Alliance (NEEA) and the Northwest Power and Conservation Council (NPCC) for more than 20 years to estimate regional energy savings potential from improvements to new and existing buildings. The savings are meant to be a conservative estimate of actual energy savings rather than a measure of code stringency.

The process utilizes a hybrid simulation and engineering calculation approach with baseline characteristics derived from regional building characteristic data as follows:

- Estimate the maximum heat loss rate (UA/ft^2), and cooling efficiency performance requirements for the base code (e.g., WSEC 2012) and the newly adopted code (e.g., WSEC 2015). This is primarily done by applying the code to each building in a sample of recently-constructed buildings to utilize real building traits to weight the occurrence of space, construction, and equipment types. The current evaluation utilized primary data sets that included 350 commercial buildings (NEEA 2004 NC discussed in Section 2.1) and 23 mid- and high-rise residential buildings (RBSA 2014).
- Estimate of lighting power density (LPD) for each building type by applying code allowances to each space type assumed by ASHRAE/IES space type.
- Determine the current practice condition. For LPD, UA/ft^2, and other traits that apply to every building, it is a deration for the fact that buildings have always been better than code since the first evaluation. The starting LPD is better than code minimum, the percent change in code value is applied to that LPD, so the final LPD is better than code and the change is slightly reduced. For certain discrete provisions such as the minimum skylight provision, the fraction of floor area that already has skylights is determined from available data and removed from the savings pool.
- Estimate energy savings for the code-to-code changes and the current practice changes in representative prototype buildings by climate zone using EnergyPlus 8.9 building energy simulation software and, where needed, engineering calculations.
- Measures with broad applicability and generally positive savings were modeled both individually and as a package. Individual savings were then adjusted uniformly so the sum of individual savings matched the package. Additional measures were simulated incrementally from the final package.
- Measures not modeled were determined using engineering calculations typically based on model predictions of end-use consumption. This evaluation has no example of this step.
- Engineering calculations are used to determine savings for measures not modeled. Typically, the calculation is some adjustment of the model-predicted end-use consumption. For example, savings from service hot water circulation system controls are taken to reduce the model predicted hot water energy use by an assumed percentage, which is based upon evaluation studies.

- Engineering calculations adjust savings for other heating fuel types and, where warranted, for applicability and current saturation.
- The savings results were normalized per unit floor area and were combined with the expected new construction/addition floor area forecast from the Northwest Power and Conservation Council (NPCC) Seventh Power Plan[3] to provide a weighted savings for each building prototype and a weighted result for all commercial buildings.

2.1. Primary Data Sources

Primary sources of building data used in this project are listed in this section. These data were used to establish typical building traits such as HVAC system type and heating fuel, building envelope proportions and construction types, and many other traits. Three of the data sources were regional studies and contain data for buildings in Idaho, Montana, Oregon, and Washington. In general, these studies do not contain adequate sample within each state to characterize individual building types. For these data sets the regional averages were used to represent Washington on the presumption that issues related to variation between states were less significant than the gains in statistical significance when looking at individual building types.

2.1.1. NEEA Baseline Characteristics of the 2002-2004 Non-Residential Sector (NEEA 2004 NC)

The primary characteristics data used in this work are derived from data collected as part of the NEEA Baseline Characteristics of the 2002-2004 Non-Residential Sector (NEEA 2004 NC) study (Baylon and Kennedy, 2008).[4] The data set include data on 350 buildings constructed between 2002 and 2004 in Washington, Oregon, Idaho, and Montana. These data were used to determine space and water heating fuel saturations, HVAC system and equipment types and associated minimum code performance, and building envelope characteristics and geometry. This data set is referred to as the NEEA 2004 NC data.

2.1.2. Commercial Building Stock Assessment (CBSA) 2014

The 2014 Commercial Building Stock Assessment (Navigant Consulting 2014) data are used as auxiliary characteristics data, filling in where the NEEA 2004 NC data are missing or incomplete. The new cohort in the 2014 CBSA is slightly newer than the NEEA 2004 NC data (2004–2012 vs. 2003–2005 completion years); however, it has a few shortcomings that negate some of this value. It spans three code cycles, which makes interpreting the data difficult, and is based primarily on site visits. The NEEA 2004 NC data made heavy use of plans and building O&M manuals in addition to site visits. Because extracting data from the NEEA 2004 NC data was easier, it was chosen as the primary data set and CBSA 2014 as the secondary data set.

---

[3] Supporting data file 7P Forecasts D2.xlsx from: Seventh Northwest Electric Power and Conservation Plan, Northwest Power and Conservation Council, 2016. Currently can be found under Conservation Supply Curve Workbooks, crosscutting at: https://www.nwcouncil.org/reports/technical-information-and-data

[4] http://www.nwalliance.org/resources/reportdetail.asp?RID=134

2.1.3. NEEA Residential Building Stock Assessment (RBSA 2011) Characteristics

The primary characteristics data used for the mid- and high-rise multifamily buildings work are derived from data collected as part of the NEEA Residential Building Stock Assessment (RBSA), which surveyed existing multifamily building characteristics (Baylon et al., 2013). A total of 79 mid-rise and high-rise multifamily buildings were surveyed, of which 23 were built between 2001 and 2012. Table 4 presents a summary of the sampled buildings. The RBSA sample was not segmented to isolate new mid-rise and high-rise buildings and the resulting sample has a large uncertainty when looking at these building types in isolation. Most notable is that while the overall multifamily sample is a regional sample, most all of the mid-rise and high-rise occur in Seattle.

Despite concerns about the small number of new mid-rise and high-rise buildings in the sample, these data were used to determine building and unit code maximum lighting power densities (LPD), and building envelope characteristics, geometry, and code minimum performance. The data were also considered in selecting the HVAC system and fuel type and the service hot water heating fuel types. The study buildings were built to the standards current during the construction year. The forms of the buildings (e.g., the distribution of lighting space types) built in the 2001–2012 period were considered typical of new buildings. For each code, the codes were applied to each of the buildings to determine code allowances and the average values used as inputs in the simulation models.

Table 4. RBSA Multifamily Building Sample

	2001-2007	2008-2012	Total
Audited Buildings (count)			
High-rise	5	5	10
Mid-rise	7	6	13
Total	12	11	23
Sector Building Distribution (%)			
High-rise	5.49	21.34	26.82
Mid-rise	6.95	56.22	73.18
Total	2.44	77.56	100.0
Sector Floor Area Distribution (%)			
High-rise	0.68	41.21	51.89
Mid-rise	6.48	31.64	48.11
Total	7.15	72.85	100.0

Mid-rise and high-rise multifamily buildings are characterized by RBSA as being comprised of unit areas, common areas, and commercial non-residential floor area. The commercial non-residential floor area found in residential buildings is typically retail and other commercial occupancies located on the first floor of the building. The current evaluation is limited to the residential dwelling unit areas and the common areas serving the dwelling unit areas. Commercial floor area found in RBSA, and code energy savings associated with it, are covered by the NPCC commercial floor area forecast and the energy code savings determined in previous evaluations of commercial buildings; they are therefore not addressed here. This data set is referred to as RBSA 2014.

2.1.4. NPCC Seventh Plan and Floor Area Forecast

The Northwest Power and Conservation Council (NPCC) Seventh Power Plan developed a regional state-by-state floor area forecast for a range of building types. The Council's forecast provides square footage estimates for each year through 2035. The medium growth scenario data are used in all floor area estimates in this evaluation.

2.1.5. Bonneville Power Administration (BPA) Future Codes Analysis

Building population distribution among climate zones within the state uses work conducted by Bonneville Power Administration (BPA) (Kennedy 2012) to map the distribution of new commercial buildings to these zones based on Dodge construction data from 2002–2008. The available data set did not include mid-rise and high-rise residential buildings and climate zone distribution was not available. The NPCC forecast assumes 18% of multifamily units are in mid-rise and high-rise buildings. A weighted average of the weights used for all other building types was used for multifamily buildings, which may overweight the proportion of mid-rise and high-rise multifamily buildings assigned to the 5B climate zone (described in the following section).

2.2. WSEC 2015 Code Changes

The base code for this evaluation is the WSEC 2012 code and the final code is the WSEC 2015. The WSEC 2015 went into effect July 1, 2016 with one major provision having a delayed implementation date of July 1, 2017.

Table 5 presents the significant measures evaluated and Table 6 indicates the key prescriptive provisions not evaluated. A more in-depth listing of code differences can be found in Appendix B. The major changes include an average 21% drop in lighting power allowance, a new requirement for extra efficiency measures across all building types, and a requirement to adopt dedicated outdoor air system (DOAS) ventilation systems in office, education, and retail spaces.

This evaluation compares changes in the code prescriptive paths only. No attempt is made to compare performance paths.

Table 5. Evaluated Prescriptive Code Changes

WSEC 2015 Section	Code Provisions
C403.1.3 C403.1.4	Envelope maximum conductance
C402.4.1.1	Relaxed daylight zone criteria for increased WWR
Table C402.4	SHGC increase
C402.4.2	Minimum skylight area
C403.2.3	Equipment efficiency EER changes
C403.2.11.5	Air flow control – two-speed fans
C403.2.3	Air and water source heat pump efficiency
C403.2.3.3	Package electric heating required to be heat pump
C403.2.6.2	DCV threshold reduction
C403.4.4.3	Variable air volume (VAV) optimization
C403.2.7.1	Kitchen DCV hood
C404.2.1	High input hot water
C404.7, C404.8	Service hot water demand circulation control
C405.4.2	Interior lighting power
C405.4.2	Parking garage lighting power
C405.2	Lighting control changes
C405.2.5	Egress light control language
C405.10	OS receptacle controls
C406	Additional efficiency packages
C408.3	Changes to commissioning threshold

Notes: WWR = window-wall ratio; SHGC = solar heat gain coefficient of fenestration; EER = energy efficiency ratio; DCV = demand control ventilation; OS = occupancy sensor

Table 6. Key Mandatory Provisions Not Evaluated

WSEC 2015 Section	Code Provisions	Reason
C403.5.1	Energy recovery for systems operating 8000+ hours	Hospital prototype not set up to handle provision.
C405.8	New electric motor efficiency tables	Captured in VAV terminals but not elsewhere due to time and resources.

Climate zones 4C, 5B, and 6B are present in Washington but the state has adopted one set of envelope requirements for the whole state. Only one minor mechanical provision, related to water source pump loop design, varies by climate zone in the state. This evaluation uses three different climates which represent the overlap between the pre-2012 WSEC zones and the current climate zones. The zones provide good representation of the western marine areas (Seattle), the southeastern low-lying areas (Pasco), and the colder northeastern areas (Spokane). The small portion of the state that is in International Energy Conservation Code (IECC) climate zone 6B accounts for ~1% of commercial floor area and is assigned to the Spokane climate.

2.2.1. Federal Appliance and Equipment Standards

Previous NEEA energy code savings evaluations made no attempt to separate energy savings due to energy codes from those due to federally covered appliance and equipment energy efficiency standards (hereafter referred to as DOE standards). Savings for items in the energy code were counted as savings even if they also occurred as part of a standard. At the same time, savings from items that were in standards but not in the energy code were not included. HVAC equipment efficiency has been the primary area of overlap with standards since state energy codes are not allowed to preempt the national standards.

Starting in 2015, NEEA has worked to influence DOE standards in addition to regional codes and will be evaluating savings for these new DOE standards separately from codes. DOE standards regulate efficiency in most classes of HVAC and hot water heating equipment as well as electric motor efficiency, lighting, and refrigeration equipment. This overlap can be direct in that energy codes regulated the efficiency in the same way as DOE standards (i.e., HVAC equipment rated efficiency). It can also be indirect with codes regulating one aspect and standards another (i.e., lighting efficacy vs. lighting power density and unitary DX IEER vs. two-speed fan).

The WSEC 2015 code provisions that overlap DOE standards mostly predate NEEA influence, and this evaluation therefore has continued the approach of claiming savings for codes and standards where there is overlap. The only exceptions are the new commercial refrigeration code provisions, which due to resource constraints were not evaluated.

2.3. Savings Estimation

Energy savings from code provisions are estimated using building energy simulation supplemented with engineering calculations. Savings estimates are made on a unit area basis for each building type/state combination. Total state and regional savings estimates combine the unit area savings estimate with the new construction/addition floor area forecasts from the Northwest Power and Conservation Council (NPCC) Seventh Power Plan.[5]

Simulations of the prototype buildings were used to determine savings from incremental changes in the primary performance variables (e.g., LPD, equipment efficiency, and envelope component efficiency) and also for several secondary code changes. Individual simulations were completed for each change and a package of all measures was also modeled. The results from the individual runs were post-processed to achieve final savings estimates for each measure that summed to the package savings. The end use energy consumption of the final package was used in all engineering estimates.

This section provides a generalized discussion of the savings calculations. Details on the evaluated measures and individual savings calculations can be found in Appendix A.

[5] Supporting data files from Seventh Northwest Electric Power and Conservation Plan, Northwest Power and Conservation Council, available at https://www.nwcouncil.org/reports/seventh-power-plan.

2.3.1. Prototype Buildings and Simulations

Simulations were conducted using EnergyPlus V8.9, a building energy simulation program developed by the US DOE. The prototype building descriptions are derived from the BPA new vintage existing building models (Navigant Consulting 2016). The BPA models are based on the DOE reference buildings with several modifications to make them more applicable to NW buildings. The BPA descriptions are implemented in the Params framework developed by Big Ladder Software.[6] This framework assembles building descriptions dynamically from templates based on predefined parameters.

This evaluation included a major effort to upgrade the BPA templates and inputs to better represent new construction, allow dynamic changes to windows and skylight fractions, and to streamline several aspects of the HVAC specification. This work is partially summarized in Appendix C of this report.

This evaluation was conducted under the notable constraint that the prototypes utilize HVAC systems typical 10–15 years ago, prior to substantial changes in the marketplace. Regional data sources are generally lacking for the recent time period. While variable refrigerant flow (VRF) and chilled beam systems were not present during the NEEA 2004 NC study, they are clearly present now; anecdotally, interest in water source heat pumps seems to be growing.

Table 7 lists the modeled prototype buildings and the selected HVAC system types.

The prototype base characteristics for LPD, window-to-wall ratio, envelope heat loss, and equipment efficiency for each prototype were updated for the evaluated codes. The prototype LPD and heat loss rate are scaled so that the modeled building traits are the same as the average found by the code change increment process described in the next section.

The code provisions are modeled individually or, in the case of the envelope insulation and WWR, as a group. This allows the attribution of savings to individual provisions and also allows applicability and current practice adjustments. The major generally-applicable measures (e.g., lighting, envelope, motor control) are modeled first individually and then as a group. The group run is used to adjust the individual runs for interactive effects. Subsequent measures are modeled incrementally.

---

[6] https://bigladdersoftware.com/projects/params/

Table 7. Prototype Descriptions

Building Type	Baseline System/Fuel*
Mid-rise residential	ASHRAE Standard 90.1 savings determination-derived model with electric resistance heat and no cooling in the dwelling units and single-zone packaged AC/furnace in the common area
High-rise residential	Same geometry as the mid-rise model but with 8 floors rather than 10 floors. Dwelling unit HVAC is packaged AC/ electric resistance and common areas have single zone packaged AC/furnace.
Office – large	VAV with series fan powered terminals on perimeter and pinch boxes in the core with electric resistance reheat.
Office – medium	Packaged single-zone AC/gas furnace
Office – small	Packaged single-zone AC/gas furnace
Retail – large	Packaged single-zone AC/gas furnace
Retail – small	Packaged single-zone AC/gas furnace
Grocery	Packaged single-zone AC/gas furnace
School – secondary	Single zone air handlers with hydronic heating and cooling
School – primary	VAV with pinch boxes and electric hydronic reheat in classrooms. Single-zone air handlers with hydronic heating and cooling for common areas.
Warehouse	Packaged single-zone AC, gas furnace in office. Gas fired unit heaters in storage.
Hospital	CAV and VAV with pinch terminals. Gas boiler, hot water reheats.
Restaurant – sit-down	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.
Restaurant – fast food	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.
Lodging – Hotel	Common areas: single zone air handlers; rooms: four pipe fan coils
Lodging – Motel	Common areas: packaged single-zone AC, gas furnace; rooms: PTAC

* This is the modeled fuel type. Conversion of results to other heating fuel types is done as part of the engineering calculations to capture first order effects of other fuels.

TMY3 weather files were used in this work as shown in Table 8. Zone 5b has been divided into two zones along the boundary of the old Washington Zones 1 and 2. This was required for the evaluation of the WSEC 2012 code and has been maintained as two segments to increase the accuracy of predictions. Spokane has traditionally been used for Washington Zone 2, which included the colder half of eastern Washington. The team decided to use that and then to use Pasco, WA to represent the warmer half of eastern Washington. National analysis tends to use Boise, ID (HDD 5395, CDD 756) or more recently Denver, CO to represent zone 5B, which would clearly over-predict cooling energy and possibly under-predict heating.

Table 8. Weather Data – TMY 3

Climate Zone	Weather Station	Heating Degree Days	Cooling Degree Days
WSEC Zone 4C	Seattle, WA	4640	129
WSEC Zone 5B1	Pasco, WA	4920	711
WSEC Zone 5B2	Spokane, WA	6715	341

2.3.2. Determining Model Inputs

This study relied heavily on characteristics from the actual NW building stock to determine WSEC 2012 and WSEC 2015 inputs.

The code envelope heat loss, window area, and cooling efficiency for each code were estimated by applying the codes to the construction types and areas, and equipment types found in each building of the NEEA 2004 NC commercial building and RBSA new mid-rise and high-rise data sets. The resulting estimated building characteristics (e.g., envelope heat loss, cooling efficiency) are averaged by building type for each code.

The code interior lighting power allowance for each prototype was calculated as the weighted average of the code space-by-space allowances using weights taken from the ASHRAE/IES building area allowance calculations.

The resulting values represent the code maximum allowed and are adjusted for current practice. The prototype characteristics are then scaled so the model average matches the average current practice characteristic. Using the average for many buildings implicitly weights the various lighting area types, envelope component types, and equipment sizes so that the efficiency increase (or decrease) represents the sector response rather than that found for just the few situations represented in the models.

For other code provisions, exterior lighting power lighting, lighting and equipment control measure increments, inputs were derived utilizing inputs from the ASHRAE Standard 90.1 savings determinations (Thornton et al. 2011, PNNL2014a, PNNL 2014b, PNNL 2017). No current practice adjustments were made to inputs or outputs for these provisions.

Provision-by-provision details are presented in Appendix A.

2.3.3. Current Practice Adjustments

The code-to-code increment produces an estimate of the upper bound of possible savings. Every field study of Northwest buildings in which building and code data are collected has found that average new building characteristics exceed the average code requirements. For example, in the NEEA 2004 NC data, the average office building LPD is 1.03 W/ft^2, 18% lower than the 1.257 W/ft^2 average code-allowed LPD for those buildings at the time of construction. Using the arithmetic code-to-code change takes credit for saving the lighting power between the base code maximum power and actual installed power.

To account for this and ensure estimates are conservative, current practice adjustments are made to reduce savings where current practice typically exceeds code in the base code (WSEC 2012). For maximum LPD and envelope thermal performance, this adjustment is made to the model input values. A percent reduction is applied to both the base code (WSEC 2012) and new code (WSEC 2015) input assumptions. The primary impact is that the difference between the base and new code inputs modeled is reduced as are the resulting savings.

In previous NEEA commercial code savings studies, the adjustment was based upon the average LPD and code allowances at time of construction for the buildings in the NEEA 2004 NC data. Due to some concern about the reliability of the NEEA 2004 NC code allowance and a desire to move away from the NEEA 2004 NC data it was decided to use fixed percentages across all building types. A 5% adjustment was applied to code envelope UA/ft^2 and 10% adjustment was applied to code LPD. These values are conservative estimates based on the 2004 NEEA NC Data. The 10% lighting adjustment is smaller than the 15% average adjustment based upon the 2004 NEEA NC data. The envelope value is fairly close to the average for envelope found in the 2004 NEEA NC data.

A more complete discussion of the current practice adjustment of LPD can be found in the 2011 NEEA Energy Code Evaluation (Kennedy, 2011, Appendix E) along with the implied after-code LPD for the NEEA New Construction Survey buildings for each scenario and code.

For other provisions requiring a specific technology in specific situations field data was used to assess adoption of the technology prior to code and where specific adoption was occurring the saturation is adjusted so savings were not claimed for this prior adoption. The change in the minimum skylight provision threshold is a case in point. Skylights with top daylight harvest controls predate the code requirements by a decade or more in many building types. The current practice estimate was based on the assumption that code requirement to have skylights in spaces between 2,500 and 10,000 square feet do not save energy for the fraction of floor area found in these spaces that had skylights in the NEEA 2004 NC data.

2.3.4. Savings Calculation Spreadsheets

All savings calculations are processed through spreadsheets that combine simulation results, engineering calculations, end use fuel saturations, current practice adjustments, and new construction floor area estimates to produce energy savings estimates. Within each climate workbook are worksheets for each provision, or in some cases for a group of provisions.

The calculation worksheets calculate electric, gas, and heat pump space heating and water heating from the modeled system consumption using simplified conversion factors and heating fuel saturation factors determined from the NEEA 2004 NC and RBSA data. This method provides better estimates of changes in electric vs. gas without the need to model each fuel type.

The dedicated outdoor air system requirement in 2015 WSEC directly impacts HVAC design, requiring designers to do something new and pushing buildings to adopt zonal systems with DOAS. Beyond simply impacting the magnitude of the savings, the choice can impact the fuel type used for space heating. Possible shifts include single zone gas furnaces and gas and electric variable air volume (VAV) systems to VRF and other zonal systems. Fuel switching has not been assumed in this evaluation and may be evaluated in future work if market data supports this trend.

The simulation results for each measure are normalized by floor area or sometimes by other factors. Normalized savings are estimated for the two non-modeled fuels. These results are then combined with an applicability factor reducing savings based on the estimated applicability of the code language to the given building type, heating fuel, system type, or other factor. A current saturation factor further reduces savings for measures with extensive saturation prior to code adoption (e.g., minimum skylight in retail). Total saturation is the assumed end result. All applicable buildings that lack a particular required technology are assumed to have installed it. The applicability and saturation factors are determined from field data and study results where possible. The current practice estimates are rolled up into an overall current practice savings estimate by building type.

The NPCC forecast building type categories differ somewhat from the prototype building types. A map was developed to weight the prototype simulation results into the forecast building types. Both normalized and total savings are reported based upon the forecast building types.

To arrive at sector savings, the prototype normalized energy use and savings estimates for each worksheet are combined with the applicable floor area for the given region and building type. The WSEC 2015 went into effect on July 1, 2016 with the DOAS provisions delayed until July 1, 2017. The team assumed that buildings built to the new code started entering service and accruing savings in 2018. The average NPCC forecast annual floor area for 2018–2027 is used to weight energy savings estimates between building types. Weighting the three modeled climate zones is done using an analysis of the distribution of new construction based on data developed by BPA for the years 2002–2008 (Kennedy 2012).

2.3.5. Prescriptive Additional Efficiency Package Options

The WSEC 2015 code introduces a requirement that buildings meet the provisions of one or two “additional efficiency” measures and provides eight options from which to choose. This is one of the three major changes this cycle. Little basis exists for knowing which options will be chosen, and even the number of options required is uncertain due to code language that leads to tenants’ improvement areas needing a single option, while building area and buildings developed under a single permit need two.

The study team developed a choice model that estimates the number of options required and the assumed likelihood of adoption weighted by each building type. The savings for seven of the “increased building efficiency” options have been estimated and combined with the choice model to create a savings estimate.

The savings for this measure can come from different energy sources depending on the option selected. And some HVAC systems have paths to credits not available to others, which indirectly drive system and fuel choice. This introduces significant uncertainty into the predictions of electric and gas savings, but less so for total energy use.

2.3.6. Engineering Method

Measures such as service hot water circulation loop controls were evaluated using a simplified engineering approach. This approach was chosen when modeling was difficult within the confines of the current modeling framework and prototypes, or when modeling an "average" case was difficult, or sometimes where the modeled parameter was a fixed percent of use savings rate derived from evaluations or other sources.

Engineering calculations are implemented in the calculation spreadsheets. Generally, savings are calculated as a fraction of total energy use or on the energy used for a specific end use, as determined from the prototype simulations. If applicable, engineering calculations utilize HVAC interaction factors developed from the simulations to account for HVAC energy changes as a result of changes in internal heat gains. To minimize double counting, end use consumption and interaction factors were taken from simulations that included the code LPD, UA, and HVAC performance improvements rather than the base case models.

As with the simulation results, the savings are modified to account for heating fuel saturations and the applicability of the code language to a given building or system type. The applicable population is adjusted to exclude current saturation of the technology.

2.3.7. Overall Sector Energy Use and Percent Savings

While the primary purpose of this work is to estimate electric and gas savings, a secondary goal is to characterize overall energy savings and the percentage change in energy use. Overall WSEC 2015 savings are presented for several metrics: Site Btu, source Btu, carbon dioxide, and energy cost. Key assumptions are shown in Table 9.

To calculate percent savings, the individual provision savings are summed and the total savings divided by the estimated WSEC 2012 energy use. The savings include current practice adjustments; the resulting percent savings are therefore not directly comparable to similar metrics in work by PNNL.

This process does not account for non-modeled energy use, in particular, energy use resulting from poor operation and scheduling, items that would lead to commissioning and metering savings. In general, the models assume correct controls operation. The estimate of percent current practice savings is therefore likely to be optimistic compared with real-world consumption.

Table 9. Carbon and Cost Factors

Quantity	Assumption	Source
Source Btu – electrical	6.69 kBtu / kWh	Combined cycle turbine – estimated
Source Btu – gas	1.0 kBtu/kBtu	None
Carbon – Gas	117 lbs/MMBtu	Environmental Protection Agency (EPA)
Carbon – Electricity NPCC	0.97 lbs/kWh	NPCC 7th Plan 2031 Marginal Carbon
Carbon – Electricity WSEC	0.55 lbs/kWh	WSEC Energy Code Technical Advisor Group
Energy Cost – Gas	0.818 $/therm	Washington Commerce Department
Energy Cost – Electricity	0.0856 $/kWh	Washington Commerce Department

3. Results

Table 10 presents the average annual current-practice energy savings for all the evaluated code changes in the WSEC 2015 code. The current practice results reflect adjustments for current practice and are used by NEEA in setting actual code energy savings. Floor area normalized savings acquired each year are 0.986 kWh/ft^2 of electricity and 00.017therm/ft^2 of gas. Forecast statewide annual electricity savings combining the normalized savings with forecast annual floor area additions in the state are 2.31 average megawatts and 35,305 MMBtu of gas and other combustion fuels. Table 11 presents the current practice savings as a percent of building energy use using various metrics. Savings are based upon current practice; a code-to-code measure would likely be 10% higher.

Table 10. Annual Energy Savings by Building Type (Current Practice)

	Normalized Savings				Forecast Sector Savings	
Building Type	Site Energy kBtu/ft^2	Source Energy kBtu/ft^2	Electric kWh/ft^2	Gas therm/ft^2	Electric aMW	Gas MMBtu
Assembly	5.13	8.38	0.99	0.017	0.08	1,214
Hospital	7.77	12.95	1.58	0.024	0.20	2,626
K-12 School	5.87	9.53	1.12	0.021	0.05	825
Lodging	10.71	15.97	1.60	0.052	0.08	2,376
Multifamily	2.43	4.16	0.53	0.006	0.19	1,970
Office – Large	3.70	6.36	0.81	0.009	0.38	3,819
Office – Medium	3.95	7.47	1.07	0.003	0.32	759
Office – Small	4.49	8.41	1.20	0.004	0.09	270
Other	5.13	8.38	0.99	0.017	0.29	4,397
Other Health	8.46	14.44	1.82	0.022	0.25	2,700
Restaurant	20.38	23.26	0.88	0.174	0.03	4,429
Retail – Big Box/Anchor	7.13	10.28	0.96	0.038	0.07	2,408
Retail – Small/High End	13.23	20.56	2.23	0.056	0.19	4,294
University	4.70	8.10	1.04	0.012	0.05	468
Warehouse	3.01	4.06	0.32	0.019	0.05	2,749
Total	**6.11**	**9.99**	**0.99**	**0.017**	**2.31**	**35,305**

Table 11. Current Practice Savings as a Percent of Building Energy Use – WSEC 2015

	Energy Use				Carbon		Energy Cost
	Electric	Gas	Site Btu	Source Btu	NPCC	WSEC	WSEC
Washington	10.0%	16.5%	11.7%	10.8%	11.3%	9.2%	10.7%

Table 12 presents the detailed breakout of the average annual savings by state and code provision. Electric savings are dominated by lighting power allowance changes, the C406 options, receptacle controls, and DOAS. Regional gas savings are dominated by the extra efficiency options and DOAS, and are sensitive to assumptions in the C406 choice model. If several buildings choose lighting versus HVAC and hot water efficiency, gas savings could be a factor of 2 lower.

Table 12. Annual Energy Savings by Measure – WSEC 2015

	Normalized Savings		Forecast Sector Savings	
	Electric	Gas	Electric	Gas
Code Item	**kWh/ft^2**	**$therms/ft^2$**	**aMW**	**MMBtu**
Envelope Changes	-0.048	-0.0006	-0.11	-1,244
Minimum Skylight Area	0.009	-0.0001	0.02	-249
Interior Lighting Power	0.463	-0.0026	1.09	-5,289
Interior Lighting Controls	0.012	0.0000	0.03	0
Exterior Lighting Controls	0.025	-0.0002	0.06	-383
Receptacles	0.148	-0.0007	0.35	-1,447
Aggregate Cooling Efficiency Changes	0.015	0.0000	0.04	-3
Air Flow Control - Fan Speed	0.074	-0.0006	0.17	-1,188
DCV Threshold Reduction	0.000	0.0001	0.00	127
DCV Kitchen Hood	0.009	0.0015	0.02	2,986
C403.6 DOAS	0.147	0.0092	0.34	18,819
Heat Pump Heating Efficiency	0.001	0.0000	0.00	0
Heat Pump Required if DX AC & Electric Heat	0.001	0.0000	0.00	0
VAV Optimization	0.002	-0.0002	0.01	-333
High Input Rated Hot Water	0.000	0.0005	0.00	1,123
Service Hot Water Circulation Demand Control	0.014	0.0018	0.03	3,699
C406 Addition Efficiency Aggregate	0.180	0.0122	0.42	24,929
Commissioning	-0.068	-0.0030	-0.16	-6,243
Total	**0.986**	**0.017**	**2.31**	**35,305**

4. Conclusions

Adoption of the WSEC 2015 energy code represents a substantial advance in new building energy efficiency. The current practice savings represent an 11.7% reduction in site Btu, with a 10.0% reduction in electric use and a 16.5% reduction in fossil fuel use. The code provision changes that generate the bulk of energy savings are dedicated outdoor air system (DOAS) system requirements, interior lighting power, and C406 extra efficiency options.

This evaluation has added uncertainty in the individual gas and electric savings beyond previous code savings evaluations. A significant change in HVAC system / fuel type has occurred with the arrival of a whole new generation of building HVAC systems with VRF, chilled beam, and other zonal systems that utilize separate dedicated ventilation systems. The saturation of these new systems is not yet well-known, and that creates uncertainty in the saturation of baseline heating fuels and the electric and gas savings.

In addition, the WSEC 2015 introduces new provisions with the potential to shift savings between electric- and gas-using systems and also to change the heat system type and fuel depending upon the choices made in response to the provisions. In the future, the actual system choices on which designers settle will be well-established, and results here could be reformulated with significantly greater detail.

References

Acker, B., C. Duarte, and K. Wymelenberg. 2012. *Office Space Plug Load Profiles and Energy Saving Interventions.* ACEEE Summer Study. ACEEE, Washington D.C. Retrieved from: https://www.aceee.org/files/proceedings/2012/data/papers/0193-000277.pdf

ADM Associates. 2002. *Lighting Controls Effectiveness Assessment Final Report on Bi-level Lighting Study*. ADM Associates, Sacramento, CA. Retrieved from: http://www.calmac.org/publications/3005.pdf

Baylon, D., P. Storm, B. Hannas, K. Geraghty, and V. Mugford. 2013. *Residential Building Stock Assessment: Multifamily Characteristics and Energy Use*. Northwest Energy Efficiency Alliance, Portland, OR. Retrieved from: https://neea.org/img/documents/residential-building-stock-assessment-multi-family-characteristics-and-energy-use.pdf

Baylon, D. and M. Kennedy. 2008. *Baseline Characteristics of the 2002-2004 Non-Residential Sector: Idaho, Montana, Oregon, and Washington*. Northwest Energy Efficiency Alliance, Portland, OR. Retrieved from: https://neea.org/img/uploads/BaselineCharacteristicsofthe20022004NonresidentialSectorIdahoMontanaOregonandWashington.pdf

Building Codes Divisions, Oregon Department of Consumer and Business Services. 2017. *Comparison of 2014 Oregon Energy Efficiency Specialty Code Performance to ASHRAE 90.1-2013 Technical Report*. Retrieved from: https://www.oregon.gov/bcd/codes-stand/Documents/energy-14oeesc-ashrae90.1-2013-technical-report.pdf

California Utilities Statewide Codes and Standards Team. 2011. *Multifamily Central DHW and Solar Water Heating.* Retrieved from: *http://h-m-g.com/T24/Res_Topics/2011.05.13MeetingDocuments/MF_DHW_Solar_Water_Heating_ZhangWei_051311_final.pdf*

Dentz, J., Ansanelli, E., Henderson, H., Varshney, K. June 2016. *Control Strategies to Reduce the Energy Consumption of Central Domestic Hot Water Systems*, Advanced Residential Integrated Energy Solutions under contract with US DOE, New York, NY. Retrieved from: https://www1.eere.energy.gov/buildings/publications/pdfs/building_america/control-strategies-to-reduce-energy-consumption-of-central-domestic-hot-water-systems.pdf

DOE. 2018. *EnergyPlus Energy Simulation Software, V8.9*. U.S. Department of Energy, Washington, DC, USA. Retrieved from: https://www.energyplus.net/downloads

Emmerich, Steven J., Andrew K. Persily. 2005. *Airtightness of Commercial Buildings in the United States*. Building and Fire Research Laboratory, National Institute of Standards and Technology Gaithersburg, MD, USA. Retrieved from: https://www.nist.gov/publications/airtightness-commercial-buildings-united-states

Emmerich, Steven J., Timothy P. McDowell, Wagdy Anis. 2005. *Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use*. Building and Fire Research Laboratory, National Institute of Standards and Technology Gaithersburg, MD, USA. Retrieved from: https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860985

Kennedy, Mike. 2018. *Washington 2015 Non-Residential Energy Code - Energy Savings – Draft Report.* Northwest Energy Efficiency Alliance, Portland, OR.

Kennedy, Mike. 2016. *Mid-Rise & High-Rise Residential Energy Savings from Northwest Energy Code Changes 2008-2015.* Northwest Energy Efficiency Alliance, Portland, OR.

Kennedy, Mike. 2014. *Non-Residential Energy Savings from Northwest Energy Code Changes 2011-2014.* Northwest Energy Efficiency Alliance, Portland, OR.

Kennedy, Mike. 2012. *Analysis of Next-Generation Nonresidential Energy Codes in the Northwest*. Bonneville Power Administration, Portland, OR. Retrieved from: https://www.bpa.gov/EE/Utility/research-archive/Documents/NextGenerationEnergyCodesAnalysis.pdf

Kennedy, Mike. 2011. *Non-Residential Energy Savings from Northwest Energy Code Changes 2008-2010.* Northwest Energy Efficiency Alliance, Portland, OR.

Kennedy, M. and D. Baylon. 1992. *Energy Savings of Commercial Energy Code Compliance in Washington and Oregon*. For the Washington State Energy Office, Olympia, WA. Retrieved from: https://ecotope-publications-database.ecotope.com/1992_004_EnergySavingsCommercialEnergyCode.pdf

Kim, H, J. C. Baltazar, and J.S. Haberl. 2013. *Methodology for Calculating Cooling and Heating Energy-Input-Ratio (EIR) From the Rated Seasonal Performance Factor (SEER or HSPF)*. Texas A&M University, College Station, TX. Retrieved from: https://oaktrust.library.tamu.edu/bitstream/handle/1969.1/152118/ESL-TR-13-04-01.pdf?sequence=1

Larson et al. 2019. *2019 Oregon New Commercial Construction Code Evaluation Study.* Northwest Energy Efficiency Alliance, Portland, OR. Retrieved from: https://neea.org/img/documents/2019-Oregon-New-Commercial-Construction-Code-Evaluation-Study.pdf

Mayer et al. 2004. *National Multiple Family Submetering and Allocation Billing Program Study Executive Summary.* Aquacraft & East Bay Municipal Utility District. Retrieved from: https://www.owasa.org/Data/Sites/1/media/customerservice/submeter%20billing%20report%20executive%20summary--conservation.pdf

NEEA. 2020. *2019 Residential Lighting Market Analysis*. Northwest Energy Efficiency Alliance, Portland, OR. Retrieved from: https://neea.org/resources/2019-residential-lighting-market-analysis

Navigant Consulting. 2014. *2014 Commercial Building Stock Assessment: Final Report*. For Northwest Energy Efficiency Alliance, Portland, OR. Retrieved from: https://neea.org/resources/2014-cbsa-final-report

Navigant Consulting. 2016. *Existing Building Simulation Project: Model Documentation. For Bonneville Power Administration. Unpublished.*

Ng, L., Emmerich, S.J., Persily, A. 2014. *An Improved Method of Modeling Infiltration in Commercial Building Energy Models*. NIST. Gaithersburg, MD. Retrieved from: https://www.nist.gov/publications/improved-method-modeling-infiltration-commercial-building-energy-models

PNNL. 2014a. *ANSI/ASHRAE/IES Standard 90.1-2013 Determination of Energy Savings: Quantitative Analysis*. Pacific Northwest National Laboratory, Richland, Washington. Retrieved from: https://www.energycodes.gov/sites/default/files/documents/901-2013_finalCommercialDeterminationQuantitativeAnalysis_TSD.pdf

PNNL. 2014b. *Enhancements to ASHRAE Standard 90.1 Prototype Building Models*. Pacific Northwest National Laboratory, Richland, Washington. Retrieved from: https://www.energycodes.gov/sites/default/files/documents/PrototypeModelEnhancements_2014_0.pdf

PNNL. 2017. *Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016*. U.S. Department of Energy. Retrieved from: https://www.energycodes.gov/sites/default/files/documents/02222018_Standard_90.1-2016_Determination_TSD.pdf

Richman et al. 2018. *National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007.* ACEEE Summer Study. ACEEE, Washington D.C. Retrieved from: https://www.aceee.org/files/proceedings/2008/data/papers/3_250.pdf

Tabor et al. 2016. *Existing Building Simulation Project: Model Documentation.* For Bonneville Power Administration, Portland OR.

Thornton, B. A., Wang, W., Cho, H., Xie, Y., Mendon, V. V., Richman, E. E., Zhang, J., Athalye, R. A., Rosenberg, M. I., and Liu, B.. 2011. *Achieving 30% Goal: Energy and Cost Saving Analysis of ASHRAE/IES Standard 90.1-2010*. Pacific Northwest National Laboratory, Richland, Washington. Retrieved from: https://www.energycodes.gov/sites/default/files/documents/BECP_Energy_Cost_Savings_STD2010_May2011_v00.pdf

US DOE. 2011. *Metering Best Practices, A Guide to Achieving Utility Resource Efficiency, Release 2.0*. https://www.energy.gov/sites/prod/files/2013/10/f3/mbpg.pdf

US DOE. 2015. *Metering Best Practices, A Guide to Achieving Utility Resource Efficiency, Release 3.0*. Retrieved from: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23892.pdf

Appendix A. Measure Evaluation Details

This section presents evaluation details of WSEC 2015 code provisions.

A.1. Envelope

The impact of all envelope measures are evaluated together by applying the codes to the NEEA 2004 NC building data and determining an average UA/ft^2 and SHGC by building type to represent the aggregate envelope changes. The WSEC 2012 and 2015 codes are applied to each of the 350 buildings in the data set based upon audited component types. For buildings where window-wall ratio (WWR) or skylight-roof ratio (SRR) exceeds code limits, adjustments are made to the window and skylight U and SHGC values per section C403.1.5 (except for WSEC 2015 SHGC). The average code thermal conduction and SHGC of each component and code is then determined. These values account for all the code envelope changes. Past evaluations included a data-based current practice adjustment to account for the fact that the average building heat loss rate has been below the code maximum in every NW baseline characteristics study. The current data is dated, and for simplicity the team assumed code-compliant buildings will on average exceed code by 5%. This has an effect of reducing savings from envelope measures 5%.

The table below presents the average code heat loss rate and SHGC for the NEEA 2004 NC buildings. The Heat Loss Rate/Current Practice fields include the 5% shift to capture standard practice. The “WA15/WWR Adj” column contains the code SHGC assuming the SHGC values for high WWR buildings are adjusted lower as the glazing increases above maximum WWR. The “WA15/wo WWR Adj.” contains average SHGC assuming no WWR adjustment is made. The WSEC 2015 made an unintentional rollback in SHGC when the SHGC was not subjected to the trade-off calculations.

In general, the prototypes have less surface area per unit floor area than the NEEA 2004 NC data. This means the prototypes underestimate envelope heat loss relative to the NEEA 2004 NC data. Therefore, the average code values were adjusted for differences between the prototype geometry and the NEEA 2004 NC data, as discussed in Appendix C1. The averaged and adjusted values, capturing all changes of the envelope code, are then modeled.

Table 13. Average Code Heat Loss Rate and SHGC

	Average Heat Loss Rate (ua/ft^2)				Average SHGC		
	Code		Current Practice		WA 12	WA 15	
Building Types	WA12	WA15	WA12 Prop	WA15 Prop.	WA 12	WWR adj.	wo WWR adj.
Apartment, high-rise	0.077	0.076	0.073	0.072	0.378	0.404	0.418
Apartment, mid-rise	0.072	0.072	0.068	0.068	0.4	0.432	0.432
Healthcare—hospital	0.063	0.061	0.060	0.058	0.388	0.422	0.426
Hotel, large	0.088	0.087	0.083	0.083	0.398	0.432	0.432
Hotel, small	0.088	0.087	0.083	0.083	0.398	0.432	0.432
Office, large	0.075	0.077	0.071	0.074	0.325	0.397	0.432
Office, medium	0.075	0.077	0.071	0.074	0.325	0.397	0.432
Office, small	0.114	0.113	0.109	0.108	0.398	0.432	0.432
Residential care	0.066	0.065	0.063	0.062	0.398	0.432	0.432
Restaurant, full-service	0.121	0.120	0.115	0.114	0.4	0.432	0.432
Restaurant, quick service	0.121	0.120	0.115	0.114	0.4	0.432	0.432
Retail, stand-alone	0.118	0.114	0.112	0.108	0.389	0.420	0.432
Retail, strip mall	0.152	0.150	0.144	0.142	0.381	0.419	0.432
Retail, supermarket	0.095	0.090	0.090	0.086	0.4	0.432	0.432
School, primary	0.083	0.080	0.079	0.076	0.400	0.432	0.432
School, secondary	0.083	0.080	0.079	0.076	0.400	0.432	0.432
Warehouse, heated	0.092	0.089	0.088	0.085	0.4	0.432	0.432
Warehouse, semi-heated	0.085	0.083	0.081	0.079	0.4	0.432	0.432
Warehouse, unheated	0.316	0.315	0.300	0.300	0.4	0.432	0.432

A.1.1. Maximum WWR and SRR

The primary envelope code difference between the WSEC 2012 and 2015 is the change to the WWR limit exceptions, which will allow most buildings to have a 40% WWR limit rather than 30%. The daylight zone exception allowing 40% WWR has been substantially eased for buildings of three or more stories. Previously almost no buildings could qualify for this exception, but now 58% of buildings (weighted by floor area) with WWR >30% qualify. There is also a new exception allowing 40% WWR for buildings complying with the new DOAS mechanical provisions. As a result, a minimum of 91% of floor area in high WWR buildings qualifies for the WSEC 2015 40% maximum WWR, compared to virtually none previously.

The six buildings that don't qualify for the daylight zone allowance, and that are of types not required to have DOAS, have WWR between 0.30 and 0.336. Most are hospital or civic buildings that could install DOAS, even though it is not required. Because system types and saturations have changed since the 2002-2004 buildings in the NEEA 2004 NC data, little basis exists to make assumptions about baseline saturation of DOAS with zonal systems such as VRF and chilled beam. Therefore, these six buildings are assumed to not have DOAS and to have a 30% maximum WWR.

Code maximum skylight fenestration area (SRR) was inadvertently reduced from 5% to 3% during code production. A code interpretation a year later returned it to 5%, and a code value of 5% is assumed here. Under both WSEC 2012 and WSEC 2015, buildings with more than 5% skylight will be assumed to maintain the high SRR and to improve U and SHGC to compensate.

A.1.2. Window SHGC

The new code introduces separate less-restrictive SHGC requirements for north vertical fenestration. This is appropriate if applied to north glazing. However, the code allows the higher north glass value to be averaged with other orientations, which results in the WSEC 2015 average SHGC requirement being 0.4324 rather than 0.4 (assuming equal orientation).

A second code change is that the SHGC is no longer constrained by the maximum WWR and SRR. In the WSEC 2012, buildings with fenestration in excess of the code limits had to reduce the fenestration SHGC so the product of the proposed fenestration SHGC and area was less than the product of the code SHGC and allowed area. In the WSEC 2015 this was eliminated, and fenestration in buildings with excess fenestration must simply have SHGC below the standard code maximum. The one exception is that high WWR buildings that chose the high-performance fenestration alternative must comply with a lower SHGC of 0.35; however, this path is mostly not required due to the DOAS and daylight zone alternatives.

The team used the NEEA 2004 NC data to determine the average code SHGC for both codes, and the resulting average SHGC is modeled. The SHGC values in the “WA15/wo WWR Adj.” were used.

A.1.3. Minimum Skylight

The WSEC 2015 lowers the room size requiring skylights from 10,000ft^2 to 2,500ft^2. Skylights and daylight zones were modeled and savings applied to the applicable floor area determined from the NEEA 2004 NC data.

A.1.4. Envelope Insulation

The WSEC 2015 made several small changes to the envelope insulation requirements. The roof deck insulation requirements increased with conductance going from U-0.034 to U-0.027.

The U-factor table introduces two new components, “joist or single rafter” and “mass transfer deck.” The WSEC 2015 joist or single rafter category allows U-0.27 where WSEC 2012 would have considered this as “Attic and Other,” with a U-0.021, so that code is weakened. While the mass transfer deck component nominally weakens the code, the argument made during adoption is that this area was being ignored and that having a line item would lead to better buildings. This constitutes a small amount of area on certain building types/situations. This new component is not represented in the NEEA 2004 NC audit data so is not evaluated.

New mass wall criteria have been introduced based upon the heat capacitance of the wall. While the team assumed that this difference does not make a change, it did not conduct a detailed review of marginal mass walls.

A.2. Mechanical

The mechanical chapter of the code was substantially revised from WSEC 2012 to WSEC 2015. This included incremental changes such as increased equipment efficiency and more controls, to structural changes such as requiring DOAS in certain building types. One significant issue is the data used to determine the baseline systems. The NEEA 2004 NC buildings were built during 2002-2004; HVAC systems have changed substantially since then, which complicates determination of the prevalence of one or another baseline system type. With the lack of alternative data, baseline system types are based upon the NEEA 2004 NC data are used in this evaluation for commercial buildings, and the more recent RBSA Multifamily data are used for residential. The DOAS requirement with heating and cooling fans off during ventilation combined with the need to comply with the options path will result in system changes in some fraction of floor area. Rather than guess at this change from an uncertain base this evaluation mostly assumes system and fuel type do not change.

A.2.1. C403.2.3 HVAC Equipment Performance Requirements

The primary changes in equipment efficiency from WSEC 2012 to WSEC 2015 are:

- Increased SEER in < 65,000 Btu air conditioners
- Increased IEER requirements in > 65,000 Btu air-cooled air conditioners and heat pumps
- Increased HSPF in < 65,000 Btu heat pumps
- Increased water source heat pump cooling and heating performance
- Increased IEER requirement in air-cooled VRF units over 65,000 Btuh
- Introduced IEER requirement in water-cooled VRF units
- Increased boiler efficiency in small boilers (< 300 kBtu)
- Increased compressor driven chiller performance.

For air-cooled air conditioners and heat pumps under 65,000 Btuh, the requirements improved for seasonal energy efficiency ratio (SEER) from 13 to 14 and for heating season performance factor from 7.7 to 8.0 and 8.2. For air- and water-cooled air conditioners and heat pumps over 65,000 Btuh, the energy efficiency ratio (EER) is not changed but the integrated energy efficiency ratio (IEER) improves by 5%–10%. IEER is a weighted average of the performance at four different operation points and reflects average performance much better than EER. Water source heating and cooling efficiency increased very slightly. Chiller efficiency improved across the board.

The WSEC 2012 included IEER requirements for DX equipment for the first time. That analysis assumed that the new code part load performance requirements represented standard practice and were not a change. The WSEC 2015 IEER for larger DX equipment increases ~10% and forced some consideration of how to model changes in IEER. IEER is dependent on compressor efficiency at various part load conditions and upon fan speed during low cooling and ventilation. Having a two-speed supply air fan increases IEER by 5%–10% but has a different savings than changing the compressor efficiency to achieve the same change in IEER. The difficulty occurs because code also regulates fan speed. In fact, IEER values are only required by equipment in size categories required by code to have two-speed fans with low flows and power draws during ventilation and low cooling. Since code peak efficiency did not change for this equipment and available data seemed to verify that units with two-speed fans would meet the WSEC 2015 IEER requirements, the team decided to not model compressor efficiency changes for this equipment and to assume that the two-speed fan modeling captures this cooling increment. Future IEER changes will primarily reflect changes in compressor efficiency, and some sort of evaluation technique will be needed, either scaling part load efficiency to reflect the percentage change in IEER or separate representative part load curves.

To simplify the modeling of savings from cooling efficiency changes for small AC, water source heat pumps (WSHP), and chillers, the team calculated an average cooling efficiency for each building type. The saturation of each type of equipment in the 2005 NEEA 2004 NC building data was used to determine the average code compressor efficiency for each code, and the average delta efficiency across all cooling equipment types within each building type. This average base efficiency and delta cooling efficiency were applied to the equipment used in each prototype.

A significant issue in the analysis of equipment efficiency is that it relies on a distribution of equipment types based upon the 2005 NEEA 2004 NC building data. As such, there are no VRF units, and other system type shifts such as chilled beam had not yet happened. Even if excellent system distribution data were available from buildings built last year, it is not clear how appropriate it would be for estimating equipment saturations in the future given changing technology and a code that is forcing 50% of floor area to adopt DOAS ventilation systems, which will lead to HVAC system changes as well.

The impact of the VRF part load efficiency change on equipment choice (likely not large) will not be captured.

The heating changes in this cycle are limited to air and water source DX heat pumps and small boilers. Small air-cooled heat pumps < 65,000 Btuh improved significantly and WSHP performance improved slightly. The savings are calculated using a simplified engineering calculation based upon percentage improvement in rated efficiency and modeled heating load. Gas heating equipment efficiency improvements were limited to the smaller < 300,000 Btuh boilers, which make up only 1.8% of the commercial sector boiler capacity based upon the NEEA 2004 NC. The 2.5% change in boiler efficiency weighted across all boiler types results in an overall change in boiler efficiency of 0.045%. The team has decided to disregard these savings.

The heating impact of air source heat pumps is modeled assuming a 50/50 split between packaged and split system heat pumps. The modeled heating COP is developed from HSPF correlations developed by Kim (Kim et al. 2013). The heating impact of water source heat pump efficiency increases was calculated using an engineering calculation based upon the change in rated efficiency and the model predicted heating energy use.

Table 14. Average Code Heat Pump Efficiency

Category	Code	HSPF	Heating COP to model
Split/Packaged Heat Pump	WA12	7.700	3.738
Packaged Heat Pump	WA15	8.000	3.813
Split Heat Pump	WA15	8.200	3.860
50% Packaged / 50% Split	WA15	8.099	3.836

A.2.2. C403.2.3.3 Packaged Electric Heating and Cooling Equipment

The new code reduces the heat capacity threshold above which packaged AC/electric heat units must be a HP from 20,000 Btu/hr to 6,000 Btu/hr. This primarily impacts packaged terminal air conditioners (PTAC) units, which are common in lodging and residential care. The saturation of PTAC/PTHP units in NEEA 2004 NC is 29% of lodging, with 33% of that being HP. Residential care had PTAC/PTHP saturation of 35%, all of which was HP. The savings for going from electric resistance to heat pump will be modeled in the small hotel prototype and results adjusted for the proper floor area fraction.

Table 15. Packaged Terminal AC/HP Saturation Assumptions

Building Type	Saturation of PTAC/HP	Fraction of PTAC/HP Already HP
Education	0%	100%
Grocery	0%	0%
Other	0%	100%
Residential Care	35%	100%
Residential/Lodging	29%	33%
Warehouse	0%	0%

A.2.3. C403.2.4.5 Snow- and Ice-Melt System Controls (2009 IECC)

Code change specifies control configuration where previously it specified control capability and did not require configuration. Though basically unchanged, this measure has not previously been evaluated. No information is available on saturation or current control baseline. Code language is likely not significantly different than standard practice. PNNL did not evaluate this measure and for now it will not be evaluated.

A.2.4. Section C403.2.4.6 Freeze Protection System Controls (2015 IECC)

This is a new section that specifies controls for freeze protection systems. No information is available on saturation or current control baseline. PNNL did not evaluate this measure and for now it will not be evaluated.

A.2.5. C403.2.6.2 Demand Control Ventilation

The new code drops the threshold for DCV from > 25 to ≥ 25/1000, which brings DCV to classrooms for ages 1–8 and school computer labs. The WSEC 2012 exempts systems with > 1000 cfm of design outdoor air and spaces with < 1200 cfm of supply air. As a result, classrooms for ages 9 and up served by multiple zone systems would be required to have DCV if the classroom supply air is greater than 1200 cfm (not many). Classrooms served by single zone systems would never need DCV since a single classroom will never have 1000 cfm of design outdoor air. The WSEC 2015 lowered the system outdoor air to 750 cfm, which is not low enough to cause the typical classroom with a single zone air handler to need DCV. As a result, very few classrooms will be required to have DCV. Only those served by multi-zone equipment, and spaces > 1200 cfm of supply air, must have DCV control.

Other changes to the DCV landscape occur indirectly. DCV is exempt from multiple zone systems lacking zone level DDC. The WSEC 2015 requires zone level DDC in multi-zone HVAC systems if the air handler fan is over 10 hp, so most multi-zone systems will have zone level DDC and will not qualify for this exemption. This could extend DCV to more conference rooms. Another external factor is that the new DOAS provision requires energy recovery, the presence of which is an exemption to the DCV provisions. The DOAS requirement does exempt heat recovery in spaces required to have DCV; however, to handle delivery temperatures, heat recovery will likely take priority so it will be assumed designers give a priority to energy recovery anywhere 100% OA systems are required.

The actual energy savings from these changes is extremely difficult to assess. The WSEC starting in 2009 requires classrooms, conference rooms and gymnasiums to have occupancy sensor control of the OA damper or fan, or to have DCV. The evaluation of the WSEC 2009 assumed outdoor air and fan energy were reduced by this requirement. This limits the savings from any new DCV control in classrooms. In multi-zone systems, VAV dampers lead to fan energy savings; single-zone fan systems were likely controlled directly such that the OS requirement had significant fan energy savings. With DOAS now required in classroom areas, the potential for fan energy reduction from this control is now unclear. Dampers will decrease air flow, but fans are not required to be variable speed so there is no clear mechanism to maintain the energy savings counted in previous codes.

Yet another consideration is that the new DOAS provisions exempt zones served by DOAS from needing economizers. The code DCV requirements are limited to systems with air economizers, OR with automatic modulating outdoor air dampers, OR with design OA flow of > 3000 cfm. Ventilation systems serving classroom areas smaller than approximately 10,000ft^2 will be below the 3,000 cfm OA threshold and will no longer be required to have DCV.

In this work, DCV savings are evaluated in the school libraries, which are considered media centers with an occupancy rate of 25 people/1,000 ft^2. The baseline school assumes DCV in all classrooms as a way of complying with the OS control requirement.

A.2.6. Section C403.2.11.5 Fan Air Flow Control

The code now requires two-speed flow with low-speed operation. This low-speed operation is to be used in ventilation and low cooling modes in all unitary systems > 5 tons, and in all chilled water terminals >= 0.25 hp. System flow is reduced to ≤ 66% of peak flow with power to ≤ 40%. Previous code required this only for unitary systems > 9.5 tons, and required all systems serving large rooms with > 10,000 cfm supply air (~10,000 ft^2) to have fan turndown to 66% or to have designated ventilation units with cycling heat/cool fans on at least 50% of units.

This is an important expansion of this requirement, although it impacts only a modest portion of the overall sector equipment. Also important: the savings from this requirement and the new DOAS requirement are targeting the same fan power. Since this measure is mandatory and is an incremental change in the triggering threshold of an existing requirement, savings will be calculated for this measure first and DOAS will be credited with the remaining fan energy savings.

The WSEC 2012 and 2015 requirements were applied to the NEEA 2004 NC data to determine the fraction of equipment required to have two-speed fan operation under each code. Fan air flow control is modeled in small office, retail, school, and warehouse. Savings are calculated for going from single-speed fan to two-speed fan and then multiplying savings by the applicability.

To properly account for fan power for the other measures, the team modeled a two-speed fan with a modified turndown. A test found that modeling the two-speed fan with the average fan power and flow turndown from the mix of single- and two-speed equipment resulted in almost the same savings as modeling single-speed and two-speed fans separately and applying the applicability factor. Average turndown was calculated both before and after the WSEC 2015 provisions, and the fan is modeled at the average conditions to ensure fan power is not improperly accounted for when evaluating other measures.

A major caveat to the savings estimate is the clear evidence that many single zone HVAC units do not have the fan running continuously. CBSA 2014 found some 75% of units cycling. While the CBSA 2014 number is somewhat suspect, other sources also find a significant fraction of fans cycling. By code, the fans should be operating to deliver code minimum ventilation, so a code-to-code analysis would assume the fan operates continuously, while a standard practice-to-code will have to account for fans cycling. Modeling for baseline systems in this evaluation assumes continuous fan operation except for the core retail zone, which is assumed to cycle as needed to meet conditioning requirements.

Table 16. Two-Speed Fan Requirements

Building Type	Percent of Floor Area w/ Single Zone	Two Speed Fan Required (percent of SZ)	
		WSEC 2012	WSEC 2015
Grocery	88.4	55.7	49.7
Hospital	7.5	20.5	77.7
Office – Large	20.3	19.3	34.6
Office – Medium	65.5	19.3	34.6
Office – Small	97.3	22.1	42.0
Residential Care	98.8	3.5	4.3
Residential/Lodging[1]	83.5	4.2	12.8
Restaurant / Bar	100.0	42.5	63.6
Retail – Large	83.5	39.1	42.3
Retail – Small	95.4	6.0	38.7
School - Primary[2]	69.0	18.2	42.3
School - Secondary[2]	76.3	18.2	42.3
Warehouse	45.7	5.4	7.5

1 – All equipment requiring two speeds is assumed to be located in the large hotel fraction and is adjusted accordingly.
2 – School OEESC 2014 two-speed requirements are assumed to apply to the large common area systems only. OCEC 2019 changes are applied to the classroom wings of the school.

A.2.7. Section C403.3 Economizers

The economizer section of WSEC 2015 now has a significant new exception, and two other exceptions have been altered to greatly increase their applicability. The new exception is for buildings with C403.6-compliant DOAS ventilation and HVAC systems. The two existing exception changes are the VRF exception, for which the building size limit has been removed, and the chilled beam water economizer exception, for which the capacity limit has been removed. To a large degree, these latter two changes are inconsequential because most buildings with VRF or chilled beam systems will also comply with the new DOAS path. The DOAS exception will allow VRF, chilled beam systems, and possibly water source heat pumps to exclude air and water economizers without added efficiency required by the previous exceptions for these system types. The changes here will be evaluated as part of the system type evaluation grid for the DOAS provision (e.g., VRF, chilled beam, fan coils). DOAS-compliant systems will not have economizers.

A.2.8. Section C403.4.1.2 Multiple-Zone System Reset Controls

This section adds requirements to detect, raise an alarm, and provide an easy work-around for zones that excessively drive reset logic. This excellent new requirement for multiple-zone systems will ensure buildings operate closer to the performance assumed by building energy simulation models, which generally assume loads and capacity are well-balanced. No information is available on the number of buildings that lack this ability and that also have critical zones that are problematic. While the logic to identify and ignore problem zones is fairly common, this requirement will be a change for some. Due to the difficulty of characterizing this item and the uncertainty about current saturation, this code provision is not evaluated.

A.2.9. Section C403.4.4.3 Multiple-Zone VAV System Ventilation Optimization Control (IECC 2015)

The International Mechanical Code (IMC) requires multi-zone air systems to size air handler outdoor air intake and terminal minimum flow rates so that every zone gets adequate outdoor air. As a design calculation, this procedure often leads to very high outdoor air flow rates. A new energy code provision requires non-fan-powered VAV systems to automatically adjust outdoor air flows continuously for changes in the system ventilation efficiency. This generally reduces outdoor air flow significantly from the peak design flows.

The saturation of VAV systems with fan-less VAV terminals, well-established in the NEEA 2004 NC data, is presented in Table 17. While VAV has a significant saturation, roughly two-thirds of the systems utilize some sort of fan-powered terminal.

Table 17. VAV Optimization Applicability

Building Type	Overall	Fraction Std.	VAV
Health – Outpatient	0.045	0.116	0.386
Hospital	0.211	0.435	0.485
Lodging – Hotel	0.00	0.000	0.009
Lodging – Motel	0.000	0.000	0.009
Office – Large	0.029	0.038	0.775
Office – Medium	0.037	0.109	0.337
Retail – Large	0.006	0.297	0.019
Retail – Small	0.001	1.000	0.001
School – Primary	0.234	0.802	0.292
School - Secondary	0.060	0.335	0.178
Warehouse	0.004	0.922	0.004

Further, some VAV systems may be installed without outdoor area conforming to the multiple zone recirculating system procedure in the code, which would negate energy savings from the dynamic adjustment. Also, the implementation of this provision in current new construction appears to be extensive. Two designers each reported they were doing some version of this in both fan-less and fan-powered VAV systems. They indicated it was difficult and were sure many were not doing it. Without better data on current practice, all buildings are assumed to be doing proper outdoor air sizing with the multiple zone procedure. A current practice adjustment of 25% is deemed necessary to adjust savings for projects that have been doing this.

EnergyPlus has the ability to model this sizing and control with some limitations. This measure is modeled in both schools and the large office prototypes. The normalized savings were applied to the fraction of floor area with standard terminal VAV systems.

A.2.10. Table C403.5.1 Exhaust Air Energy Recovery (Not evaluated)

The thresholds for exhaust air energy recovery are changed with a table added for systems operating 8,000 hours or more. This new table expands heat recovery requirements for 8,000+ hour systems with lower outdoor air fractions and lower total outdoor air flow.

For systems operating 8,000 hours/yr or more, the flow thresholds are considerably reduced so that heat recovery is required in a wide array of systems. In Zone 4C, systems with 5,000 cfm with 40-50% OA and systems with 1,500 cfm with 70-80% OA and 100% OA systems over 120 cfm are required to have heat recovery. Because the change is limited to systems that operate 8,000 hours or more a year, its impact is limited to a few building types: Hospital, and possibly lodging and police/fire. In hospital, most systems operate 8,000+ hours, but many high-OA systems have flows and outdoor air fractions such that they are currently required to have heat recovery. However, smaller systems that previously were not required will now have to have energy recovery. In lodging, central ventilation systems would trigger the threshold if they were configured to run 24/7 but, in many cases, they utilize side wall exhaust, so would be excluded.

The hospital model is set up with four very large systems and is poorly suited to evaluate this measure. With more resources, the model could be reconfigured to break up the large constant air volume (CAV) systems serving the medical areas into smaller systems more typical of hospitals. The PNNL models offer a good template for this. The hotel model included substantial uncertainty about the prevalence of central air supply ventilation vs. side wall or bathroom exhaust systems. This measure has not been evaluated in this study. Future model changes will target improving the hospital prototype so that savings might be included in future evaluations.

A.2.11. Dedicated Outdoor Air System (DOAS)

DOAS ventilation with heat recovery and separate heating and cooling systems without fans, or with fans that cycle, are required in office, retail, education (classroom) areas and in libraries and fire stations as of July 1, 2017. An alternate compliance route exists for high-performance VAV systems. Starting on July 1, 2016, HVAC systems with C403.6-compliant DOAS ventilation systems do not need economizers on cooling equipment, and buildings that have C403.6-compliant DOAS systems throughout will be allowed to increase maximum WWR from 30% to 40%. The high-performance VAV alternate does not qualify for these.

Electric and gas savings strongly depend upon the baseline system type and the complying system type. The baseline system types are not well-characterized. Regional data on baseline system saturation largely predates VRF. The NEEA 2004 NC data, which have very detailed HVAC information, include no VRF or chilled beam data as the data set largely predates these system types. The complying system type is even hazier. Which systems will be installed and whether they will be the same fuel type is pure speculation at this point, informed only by anecdote. This code change may very well drive adoption of VRF in spaces previously dominated by gas heat. The extreme case would yield little electric savings, possibly even an increase in use, and massive gas savings; VAV could largely go away and with it the electric reheat resulting in large electric savings; or high-performance VAV is adopted with the central chilled water option and all the electric reheat remains. Each of the scenarios represents a large block change in the real electric savings from this code provision.

Conversations with a few designers indicated that at least a few former VAV designers are choosing to move to alternate systems generally based upon water-cooled VRF and water source heat pumps. This remains anecdotal, however, as each designer knows only their clients and niche building type. Since the predicted future system selection has such a large impact on savings, the anticipated choice largely determines the answer and should be based upon better information. Energy savings for this transition to new system types, partly as a result of the energy code, will only be known in a few years. To isolate the impact of the energy code, one would need good information on 2015–2017 buildings to establish some sort of base case.

Given the lack of data, this evaluation has chosen to evaluate minimal changes to system type and fuel. VAV systems are assumed to migrate to high-performance VAV with the same fuels. Single-zone systems are assumed to stay with single-zone air systems of the same fuel type but with cycling fans and added DOAS ventilation. Electric resistance, combustion, and heat pump fuel saturations are assumed to remain as they were.

DOAS ventilation was modeled for the main system in each of the office, retail, and school prototypes. In a few cases the team also modeled an alternate base system with separate savings predictions for a different DOAS or high-efficiency VAV case. Increased glazing area allowance associated with DOAS in the building types that required it were modeled in aggregate with the envelope provisions.

The DOAS fan energy savings are largely dictated by the baseline heating and cooling system sizing assumptions. Right-sized cooling systems or continuous non-solar cooling loads limit fan energy savings and can even lead to increased energy use. System sizing was done in EnergyPlus with 25% and 15% oversize factors for heating and cooling, respectively. DOAS pressure drops, fan and fan motor efficiency were developed using basic engineering calculations for the office, retail and school prototypes. DOAS controls were assumed to deliver un-tempered air to the zone and not to have bypass; however, DOAS pressure drops assumed the presence of a heating coil. The model used did not allow tempering, otherwise tempered air would have been modeled.

The DOAS tab of the calculation spreadsheet builds up a model to mix and match the DOAS and high-efficiency VAV simulation results to the building type and to the baseline system and heating fuel type cases.

Current practice saturation factors are deemed, but the team did not attempt to capture the negative savings associated with the baseline DOAS systems. For buildings of all types that were already choosing DOAS-based systems such as VRF, chilled beam, and water source heat pumps, the new code requirements are neutral or a step backwards from the previous code. Projects can now have more glass and avoid water side economizers, and in some cases avoid previously-required extra efficiency that was mandated as part of economizer exceptions for water source heat pumps and VRF. The hope and likelihood is that this reduction in efficiency will be offset by DOAS savings in buildings where the system previously was not installed; however, for the baseline saturation of DOAS-compliant systems (e.g., VRF, chilled beam, zonal systems in lodging and Group-R occupancies, and water source heat pumps (WSHP)), the higher WWR constitutes a weakening of the envelope code.

A complicating factor to this discussion of increased glazing allowance as an incentive is that many of these building types will also qualify for the new daylight zone exception that also allows 40% WWR for an extremely low threshold of daylighting. As a result, the increased glazing levels may not be a negative in the cases required to have DOAS, and do not serve as a carrot in those that are not.

A.2.12. Section C403.7 High Efficiency Variable Air Volume (VAV) Systems (New)

This code section is required only for projects utilizing C403.6 exception 2. It includes a detailed list of system configuration, equipment, and control sequences required for high efficiency VAV systems. Key elements are advanced control with zone level and central DDC, terminal minimum flow optimization for all systems including those with fan-powered terminals, variable speed fan-powered boxes, outdoor and supply air flow stations, with hydronic cooling with 25% more efficient chiller or hydronic reheat with condensing boiler, heat pump boiler, or heat recovery chiller-generated hot water, and 10% lower fan power. Some items are vague, such as requiring controls to implement strategies per ASHRAE Guideline GPC-36, which is currently not completed.

While this high-performance VAV path allows buildings to use VAV systems without installing DOAS, it does not qualify for increased glazing and projects must use the high-performance glazing or daylight zone exceptions to achieve a 40% WWR. In buildings three or more stories tall, the revised daylight zone exception with requires 25% of “net” floor area to be daylit will be available to most projects, so VAV may not be disadvantaged.

The team has completed modeling for the path in the medium and large office prototypes with both the chilled water and heated water variants. The modeling approach captured the following changes:

- Outdoor air optimization on changing ventilation efficiency
- Variable speed fan-powered boxes approximated as a 40% reduction in terminal fan power
- 10% lower fan power
- High efficiency hot water heating for the hot water reheat cases
- High efficiency chilled water cooling for the electric reheat cases

A.3. C404 Service Water Heating (All IECC 2015)

All service water heating savings estimates are made using engineering calculations that utilize the model-predicted service water heating EUI and also, where applicable, a model-predicted HVAC interaction factor to correct for changed heating and cooling loads that would result from changes in hot water system heat loss.

A.3.1. C404.2.1 High Input-Rated Service Water Heating Systems

This new provision requires service water heating systems in buildings with > 1,000,000 Btuh of total gas water heating capacity, excluding water heaters with capacity < 100,000 Btuh, to have an average thermal efficiency of 90%. The main threshold will be triggered in hospitals and most lodging buildings. However, an exception exists for buildings in which 25% of the service water heating is provided by site-solar or site-recovered energy, and C403.5.4 requires condenser heat recovery to hot water in facilities based upon criteria that most hospitals trigger.

Savings are estimated using engineering calculations assuming a savings of 12.5% from raising water heating efficiency from 80% to 90%. The team determined the saturation of systems meeting the capacity threshold from the NEEA 2004 NC data. Unfortunately, that data set has largely incomplete water heater efficiency data. The team assumed 20% of existing water heat in these facilities is heated with condensing hot water units. Fifty percent of hospital floor area was assumed to have heat recovery and thus qualified for the exception.

A.3.2. C404.7 Heated-Water Circulating and Temperature Maintenance Systems

WSEC 2015 adds a new requirement for automatic pump systems to stop/start on demand. Heat trace control language is a bit less clear. Trace needs to be controlled by a thermostat and time clock, and while there is a requirement about automatically turning off when there is no hot water demand, a time clock could be construed to comply with this. The WSEC 2012 required time switches or other controls to turn the circulation system off during periods of non-use.

Evaluation studies of automatic controls have yielded a wide range of results. Dentz et al. (2016) conducted a literature review and found demand control savings from 5% to 44%. Savings from timers ranged from -1% to 14%. Savings result from less circulation pump operation, reduced conduction from piping, and reduced usage temperatures, and are sensitive to the size of the loop, water temperatures, and usage patterns. Savings expressed as a fraction of overall usage are also sensitive to the overall usage since pump savings and piping conduction loss are not generally correlated with overall usage.

Unfortunately, considerably less data are available on time switch savings. The one study that presents savings of demand control compared with a time clock (2013 CBUEC CASE Report Multifamily Central DHW and Solar Water Heating) has limited measured data. It reports savings of 16%, and 18% for demand control over time clock in two buildings. In a third building, savings are reported as 22%, but for that site the timer control led to negative savings over continuous operation so that the demand control savings are only 11% over continuous operation. The small sample and high variability of the data resulted in these data not being used as the basis for savings estimates for the WSEC 2015 evaluation.

The prototype models have water consumption largely based upon the ASHRAE Standard 90.1 savings determination models with equipment and distribution systems from the DOE reference models, which have not been updated. Savings are calculated using an engineering model based upon the overall prototype water heating usage. Given the wide range of results, the study team has chosen to assume timer controls save 6% of DHW energy over continuous operation, and demand control savings of 10% over timer control. Fifty percent of the resulting savings are assumed to be conduction savings, to which HVAC interaction factors have been applied. Pump run times have been estimated by building type and savings calculated assuming pump power of 0.25 horsepower per 50,000 ft^2.

Frequency of recirculating systems is taken from the NEEA RBSA Multifamily and NEEA 2004 NC data sets. Because the presence of recirculating systems is highly correlated with hot water heating fuel type, the team has developed the saturation rate separately for each fuel type. There is anecdotal evidence that recirculation systems are becoming more popular, and the saturation assumed here is possibly low.

A.4. C405 Electrical Power and Lighting Systems

A.4.1. Lighting Controls

WSEC 2015 includes several changes to lighting control requirements. All involve subtle or unintentional changes that may or may not result in changed behavior.

- Lounges have been added to the list of spaces requiring OS controls. Some lounges would have been included previously under employee lunch and break rooms, but some additional spaces are covered. Not evaluated.
- Manual controls are required, but no longer required in every room. No change is assumed.
- Daylighting control requirements more clearly delineate requirement for step dimming to have an off step. Continuous dimming minimum power turndown is reduced from 20% power to 15% power and it now must have the ability to switch lights off.
- Warehouse OS control requirements changed from requiring 100% shutoff of the lighting to only requiring a 50% turndown with no provision for night shutoff. PNNL assumed the 50% OS control reduced occupied hour lighting use by 10%. The WSEC 2012 100% OS control requirement was estimated to save 22.5% during the

evaluation of that code. For WSEC 2015, the occupied hour schedule fractions were assumed to increase by 12.5% from the WSEC 2012 assumptions. This effectively reduces the total claimed savings for warehouse OS control over scheduled control to 10%.

- Lighting types covered in the special application controls section (e.g., accent lighting) are now required to also have automatic off controls unless the fixtures qualify for exceptions in the automatic control sections. The old language should have been interpreted in this same way, and was by all other codes, but a Washington State Building Code Council (SBCC) interpretation said these lights only needed the additional controls, so automatic off was not required for accent lighting. This interpretation was not included in the previous evaluation, so automatic off was assumed to extend to accent lighting. Therefore, no savings are estimated from this change.
- Hotel/motel sleeping units are no longer required to have a master switch at the door. Now all lighting must be OS or captive key controlled and there is no longer a 50-unit threshold. Assume savings for this change are evaluated. Previous evaluations did not estimate savings for OS/card key control of lighting, so this analysis will include a “retroactive” estimate. See the baseline lighting discussion in Appendix C for the applicable factors used in this estimate.
- The amount of egress lighting allowed on at night is lowered from 0.05W/ft^2 to 0.02 W/ft^2. In a prior code cycle, egress lighting was assumed to be all off based upon language in the 2009 WSEC. This likely reflects the impact of the 0.02 W/ft^2, so no additional savings are accumulated in this work; however, base lighting levels try to capture this reduced nighttime lighting.

A.4.2. Daylighting

Daylighting savings were previously determined based upon engineering calculations. With the new models, daylighting is handled explicitly; daylighting inputs had to be incorporated into all of the models for the WSEC 2012 and WSEC 2015. Due to the similarities of the WSEC requirements with ASHRAE Standard 90.1, the team borrowed extensively from the ASHRAE Standard 90.1 savings determinations to develop inputs. Minimum skylight area and side and top daylighting controls required by WSEC 2012 are modeled as part of the baseline condition.

The WSEC 2015 makes a small change to continuous dimming, reducing the minimum required turndown from 20% power to 15% power and adds the requirement to switch off. This is written in language that clearly is ignored. As written, neither GE (3% light, 23% power) nor Sylvania (5% light, 26% power) offers T8 ballasts meeting this threshold, and all but one unit fails the WSEC 2012 20% value, yet these T8 ballasts are commonly installed. Conversations with lighting designers indicate that this provision has been either ignored or assumed to be the light output in the past.

LED lighting is purported to have much lower minimum power use at minimum light; however, power at dimmed conditions is never published, making compliance difficult to determine. A 2015 National Electrical Manufacturers Association (NEMA) presentation indicates that at 20% light, LED luminaire efficacy is equal to rated efficacy. Between 21% and 100% light, LED luminaires have higher efficacy than full power, and below 20% light the efficacy falls below full power conditions to about 10% power at 5% light, which easily meets code. For the evaluation minimum conditions of continuous dimming under the WSEC 2015 will be assumed to go from 20% power at 5% light to 15% power at 5% light with the ability to switch off.

The required illuminance is set to 550 lux in retail space, 500 lux in classroom, 375 in office, 300 in assembly areas and fine warehouse storage, and 200 in bulk warehouse storage.

Table 18. Top Daylighting

Building Type	Control Type[1]		Illuminance[2] (lux)	Spaces required to have skylights[3]	
	WSEC 2012	WSEC 2015		WSEC 2012	WSEC 2015
School, primary	Step	Step	500	None	Gym, library, cafeteria
School, secondary	Step	Step	500	None[4]	None[4]
Retail, stand-alone	Step	Step	550	Core sales	Core sales, back
Retail, strip-mall	None	Step	550	None	Large stores
Retail, grocery, sales	Continuous	Continuous to Off	550	Sales	Sales
Retail, grocery, storage	Step	Step	300	None	Storage where LPD ≥ 0.5W/ft^2
Warehouse –storage	Step	Step	300 fine storage / 200 bulk storage	Bulk and fine storage where LPD ≥ 0.5W/ft^2	Bulk and fine storage where LPD ≥ 0.5W/ft^2

1 – Daylight controls are assumed to switch to off per C405.2.4.1 item 5 though the placement is confusing as the main control description in in C405.2.4.2. Continuous dimming is assumed to dim to 15% power and then off. Step dimming is assumed to have two steps (66%, 33%) followed by off.
2 - Control illuminance set points are derived from the ASHRAE Standard 90.1 savings determinations.
3 – Assuming space LPD < 0.5 and ceiling height > 15 feet. Sites can exclude side daylight zones from the zone before applying the size threshold so that spaces larger than the threshold will have potential top daylight zones below the threshold.
4 – WSEC exempts multistory buildings even if the space is single story, and most secondary schools are two stories or more.

Code only requires 50% of the space to be in a daylight zone. The team addressed this through adjustments to the modeled savings in the spreadsheets.

Because the skylight requirements have many exceptions, the savings calculation is a hybrid. Applicability is determined from the NEEA 2004 NC data. Savings per square foot are determined by simulation and combined with the applicability. Between the single-story building, greater than 15 feet ceiling height, and greater than 0.5 W/ft^2 LPD, few additional spaces are required to have skylights by the reduction of the room size from 10,000 ft^2 to 2,500 ft^2. The LPD threshold in particular is interesting given that warehouses are generally moving below the threshold as more efficient lighting is adopted. In this code cycle, many fewer warehouses are considered to have skylights and daylighting.

Table 19. Side Daylighting[3]

Building Type	Control Type[1]		Fraction of lighting controlled[4]		Spaces required to have skylights
	WSEC 2012	WSEC 2015	Primary zone	Secondary zone	
Hospital	Continuous	Continuous to Off	0.56	0.21	Lobby, various offices
Hotel, small					Lounge, front office, meeting room
Hotel, large					Lobby
Office, small	Continuous	Continuous to Off	0.24	0.03	All
Office, medium	Continuous	Continuous to Off	0.38	0.14	All
Office, large	Continuous	Continuous to Off	0.39	0.14	All
Restaurant, fast food	Continuous	Continuous to Off	0.25	0.25	Dining
School, primary	Continuous	Continuous to Off	0.28	0.28	Cafeteria, classrooms, lobby, office, library
School, secondary	Continuous	Continuous to Off	0.28	0.28	Cafeteria, classrooms, lobby, office, library
Warehouse	Continuous	Continuous to Off	0.29	0.1	Office

1 – Daylight controls are assumed to switch to off per C405.2.4.1 item 5. Continuous dimming is assumed to dim to 20% power/5% light, and continuous to off dims to 15% power/2% light and then off. Step dimming is assumed to have two steps (66%, 33%) followed by off.
2 - Control illuminance set points are derived from the PNNL ASHRAE Standard 90.1 savings determinations.
3 – WSEC exempts Group A-2 (banquet, restaurants, and bars) and Group M (mercantile) occupancies from side daylighting provisions.
4 – Fraction of lighting controlled is largely borrowed from ASHRAE Standard 90.1-2013 savings determinations. Schools are the exception, for which PNNL assumed 76% of corner classroom lighting is in the primary or secondary zones and 56% of lighting in other classrooms. This stems from having high glazing levels and ceiling heights compared to NW field data and assuming corner classrooms have windows on two sides, where most designs do not have extensive windows on the second side.

A.4.3. C405.2.7 Exterior Lighting Power and Control

Exterior lighting power allowances do not change with WSEC 2015, except for parking garages, which code includes in the interior budget. The evaluation models do not include an explicit garage area, so the garage lighting power is added to the exterior lighting power based upon CBSA saturation of garages and the building area lighting power allowance for parking garages.

The WSEC 2012 requires photocell or astronomic time clock control for lighting designated dawn-to-dusk. For lighting not designated dawn-to-dusk, the WSEC 2012 requires photocell and time clock or astronomic time clock control.

The WSEC 2015 requires a photocell and time clock, or an astronomic time clock. It requires façade and landscape lighting to turn off automatically between 12am–6am or between business closing and opening, whichever is shorter. Some buildings open and/or close at times that lead to reduced savings from the 12am to 6am assumption; others are closed many more hours and, although not required to, turn off lighting for all closed hours. Other lights shall have controls to reduce lighting by at least 50% between 12am and 6am, or from one hour after close to one hour prior to open, whichever is less, or they shall have

OS sensors that turn down the lighting 50% after 15 minutes of inactivity. An exception exists for covered vehicle exit and entrance areas, in addition to other egress lighting. In addition, facilities with 24/7 operation (apartments, hospital, hotel and residential care) are assumed to reduce their lighting at night. Parking garage lighting is assumed to be on 24/7.

The WSEC 2012 controls, photocell and time clock for lighting not designated dawn-to-dusk, is more or less the same requirement as the WSEC 2006 and a step beyond the WSEC 2003, which only required photocell. The question is how much lighting to assume was controlled by the time clock in the base code and the nature of its operation. The ASHRAE Standard 90.1 savings determinations assumed no lighting was controlled by the time clock and that all exterior lighting was on all night. Exterior lighting is a very significant energy use, and simply assuming the time clock is not utilized produces a large amount of savings. This analysis assumes that under the WSEC 2012, 20% of the lighting is off from 12am to 6am, and under WSEC 2015, this analysis models the new code operating requirements verbatim.

NEEA 2004 NC data were used to determine the portion of exterior lighting falling under parking, façade and landscaping, and other categories. Parking garage lighting is included by energy codes in the interior lighting power budget. The evaluation models do not include an explicit garage area and the ASHRAE Standard 90.1 savings determination models (Thornton et al. 2011, PNNL 2017) assume all parking is surface parking. Since allowances for parking garages and surface parking generally change together, this may be a reasonable assumption in the Standard 90.1 work. However, with the WSEC 2015, parking garage wattages change but the surface parking does not, and the two areas are subject to different control requirement changes.

For this evaluation, the team created separate garage and surface parking lighting objects. NEEA 2004 NC data were used to determine the amount of parking provided in garages. The ASHRAE Standard 90.1 savings determination parking lot areas were assumed to describe the total facility parking. Parking lot area was estimated as the difference between the ASHRAE Standard 90.1 savings determination parking area and the NEEA 2004 NC garage area.

Exterior lighting power is a crucial assumption for estimating lighting power control changes. Exterior lighting power in the BPA prototypes is derived from CBSA data. The ASHRAE Standard 90.1 savings determination exterior lighting power is based upon engineering calculations. The average ASHRAE Standard 90.1-2004 power is lower on average than the CBSA derived values; however, in schools and retail, the ASHRAE Standard 90.1-2004 assumptions are higher than those found in the field for existing buildings. The team decided to use the CBSA wattages but to reduce them by 25% for new lighting sources and code allowances that are part of WSEC 2012.

Table 20. Baseline Exterior Lighting Power

	PNNL 2010				WSEC 2012			
Building Type	All Night	Off 12-6	30% reduction	24/7	All Night	Off 12-6	30% reduction	24/7 Indoor Parking
Apartment, high-rise	10364	0	0	0	10364	0	0	0
Apartment, mid-rise	2553	0	0	0	2553	0	0	0
Hospital	13088	0	0	0	13744	0	0	0
Hotel, large	14952	0	0	0	13161	0	0	1033
Hotel, small	4188	0	0	0	4656	0	0	365
Office, large	0	12979	43305	0	0	4880	17295	20421
Office, medium	0	623	7476	0	0	571	2944	4709
Office, small	0	41	896	0	0	607	501	0
Residential care	-----	-----	-----	-----	3679	0	0	614
Restaurant, full-service	0	154	2302	0	0	371	496	0
Restaurant, quick service	0	123	1039	0	0	815	1092	0
Retail, stand-alone	0	380	4365	0	0	1307	4637	0
Retail, strip mall	0	335	5112	0	0	2768	7982	74
Retail, supermarket	-----	-----	-----	-----	0	3414	4896	37
School, primary	0	150	3340	0	0	2887	4912	105
School, secondary	0	353	8428	0	0	8233	14006	7
Warehouse	0	91	6123	0	0	3330	656	0

A.4.4. C405.4.2 Interior Lighting Power Allowances

WSEC 2015 lowered interior lighting power allowances. Building area allowances average 24% lower, and the space-by-space allowances average 17% lower when the ceiling height adjustment is considered.

Background

In previous Pacific Northwest energy code evaluations, the NEEA 2004 NC data were used to calculate average code LPD allowances by building area type. In the WSEC 2012 analysis, the first WSEC code with the space-by-space allowances, some space-by-space allowances were used to fill in missing building area types (e.g., laboratory). The building area values were further adjusted where there was reason to believe the space-by-space values were substantially more generous (e.g., warehouse), using ASHRAE Standard 90.1-2013 building area values as the basis for this adjustment. The WSEC 2012 space-by-space values were taken directly from ASHRAE Standard 90.1-2013 and thus reflected ASHRAE Standard 90.1-2013 building area values rather than WSEC building area values.

The team made an adjustment for all code cycles to reflect standard practice. The NEEA 2004 NC data reflected 2002–2004 completions. Code values for each building were developed from the audited building area types. In the audited buildings, the average LPD was found to be 15% below the average of the code allowance. This ratio, developed for each building type, was used to adjust the base code and proposed code cases to reflect actual installed lighting levels. This had the same effect as reducing sector savings by 15%. This factor was developed and applied by building type with a range of 0% for hospital to 25% for small office. In the early code cycles this adjustment was very reasonable, but as

LPD allowances were reduced and T8 lighting technology improved only marginally, the adjustments became overly large. The adjustment implied that the average large office LPD in 2009 was 0.69 W/ft^2, very doable but also unrealistically low for the average LPD. Note that a code-to-code approach would imply an even lower LPD.

The procedure above raises several disconcerting issues, including:

- The NEEC 2005 NC building data used to develop the distribution of space types and the current practice adjustment represents design practices from 15 years ago. In particular, the relationship between code allowance and installed power seems inappropriate, with large office having an implied average LPD of 0.5 W/ft^2 for the WSEC 2015.
- The adjustments made to the original current practice adjustments are clearly inadequate. Without current new construction data, there is no sound basis for establishing the currently-appropriate adjustment.
- Codes now have a space-by-space calculation procedure. In the WSEC 2012 and WSEC 2015, the space-by-space allowances are poorly correlated with the building area allowances. WSEC 2012 space-by-space allowances average 7% higher than the building area values. The incongruity is larger in the WSEC 2015, where space-by-space allowances are 10% or 12.5% higher, depending upon weighting of spaces assumed. Developers likely learn which path is more generous and utilize the higher allowances whenever they bump against allowance limits in their primary compliance approach. Having two methods means the real LPD allowance is higher than either set of allowances in isolation. Similarly, the change in LPD from one code to the next is less than indicated by either set of allowances in isolation when the bias between the paths changes, as it does between the WSEC 2012 and WSEC 2015.
- Finally: The procedure, as currently implemented, is difficult to follow and to execute.

The team explored two alternative space-by-space approaches. First, the prototype zones were assigned space-by-space LPD allowances based upon their space type. In cases where the prototype zone is an aggregate of different space types (e.g., office), the team determined a weighted value using the space type weighting used by PNNL for similar work. This produced base and proposed code LPD allowances for each prototype building.

The second approach was to assume buildings are made up of zones in the same proportions as assumed in calculating ASHRAE Standard 90.1 building area allowances from the constituent space-by-space allowances by the IES/ASHRAE. In ASHRAE Standard 90.1, the building area allowances are determined from the space-by-space allowances using assumed space type weights for each building category. Base and proposed code space-by-space allowances are combined with the IES/ASHRAE weights to calculate whole-building allowances, which are assigned to the prototypes.

Both methods lack a direct way to make ceiling height adjustments per the WSEC 2015. The LPD change as a result of ceiling height derived from the NEEA 2004 NC data was applied to the allowances of both alternate methods. Ceiling height adjustments increase the WSEC 2015 space-by-space allowances, particularly in warehouse (~15%), large retail (3%), and secondary school (2%).

Table 21 shows code allowance values for four calculation methods before any ceiling height or current practice adjustments: building area, building area with adjustments for categories with much higher space-by-space allowances, prototype weighted space-by-space, and IES/ASHRAE weighted space-by-space. The space-by-space allowances are similar to each other and both methods result in higher WSEC 2012 and WSEC 2015 LPD allowances on average than the building area allowance. The space-by-space values are closer to the space allowance adjusted building area values, the method used for the WSEC 2012 evaluation.

Table 22 shows the final code allowance values for the current NEEA 2004 NC 2005 process (building area—space adjusted) and the IES and prototype weighted space-by-space methods. The current practice adjustments for the NEEA 2004 NC 2005 allowances are an extension of the procedure implemented in previous evaluations. For the IES and prototype/PNNL allowances, the team made an across-the-board current practice reduction of 10%. These latter two approaches are substantially simplified from the previous process and yet capture the space-by-space allowances much more effectively. A deemed value current practice adjustment better reflects that lack of current data than a convoluted process applied to 15-year-old data. The IES and prototype/PNNL weighted allowances exhibit pretty good agreement, except in hospital and office, where the prototype/PNNL numbers are customized by the sizes and the IES values are not.

The IES weighted values are used in this evaluation.

Table 21. Interior Lighting Power

Building Type	Building Area Allowance - NEEA 2004 NC 2005 Weighted			Building Area Allowance - NEEA 2004 NC 2005 Weighted - Space Allowance Adjusted			Space-by-Space Allowance - IES Weighting			Space-by-Space Allowance - Prototype/PNNL Weighting		
	WSEC 2012	WSEC 2015	Ratio	WSEC 2012	WSEC 2015	Ratio	WSEC 2012	WSEC 2015	Ratio	WSEC 2012	WSEC 2015	Ratio
Healthcare—hospital	1.17	0.85	0.72	1.18	0.85	0.72	1.17	0.95	0.81	0.93	0.73	0.78
Hotel, large	1.01	0.73	0.72	1.01	0.73	0.72	1.01	0.51	0.51	0.94	0.55	0.58
Hotel, small	1.01	0.73	0.72	1.01	0.73	0.72	1.02	0.46	0.45	0.99	0.46	0.47
Office, large	0.90	0.66	0.74	0.90	0.67	0.74	0.93	0.74	0.80	0.98	0.80	0.81
Office, medium	0.90	0.66	0.74	0.90	0.67	0.74	0.93	0.74	0.80	0.95	0.75	0.80
Office, small	0.89	0.68	0.76	0.89	0.68	0.76	0.93	0.74	0.80	0.88	0.71	0.80
Residential care	0.71	0.53	0.74	0.71	0.53	0.74	0.91	0.61	0.67	0.98	0.66	0.67
Restaurant, full-service	0.90	0.72	0.80	0.90	0.72	0.80	0.90	0.72	0.80	0.92	0.73	0.79
Restaurant, quick service	0.90	0.72	0.80	0.90	0.72	0.80	0.91	0.73	0.80	0.92	0.74	0.80
Retail, stand-alone	1.35	1.05	0.78	1.42	1.10	0.78	1.43	1.09	0.76	1.44	1.08	0.75
Retail, strip mall	1.37	1.09	0.80	1.41	1.12	0.79	1.43	1.09	0.76	1.43	1.07	0.75
Retail, supermarket	1.40	1.09	0.77	1.40	1.14	0.81	1.43	1.09	0.76			
School, primary	0.99	0.70	0.71	0.99	0.71	0.71	1.02	0.82	0.80	1.07	0.86	0.80
School, secondary	0.99	0.70	0.71	0.99	0.71	0.71	1.02	0.82	0.80	0.99	0.79	0.80
Warehouse	0.56	0.44	0.79	0.70	0.53	0.76	0.67	0.53	0.79	0.70	0.56	0.80
Sector Floor Area Weighted Average	**0.84**	**0.63**	**0.76**	**0.90**	**0.68**	**0.75**	**0.90**	**0.71**	**0.79**	**0.89**	**0.70**	**0.78**

Table 22. Interior Lighting Power with Current Practice Adjustment

Building Type	Building Area Allowance - NEEA 2004 NC Weighted Space/Height Allowance, Current Practice Adjusted			Space-by-Space Allowance - IES Weighting Space/Height Allowance, Current Practice Adjusted			Space-by-Space Allowance - Prototype/PNNL Weighting Space/Height Allowance, Current Practice, Adjusted		
	WSEC 2012	WSEC 2015	Ratio	WSEC 2012	WSEC 2015	Ratio	WSEC 2012	WSEC 2015	Ratio
Healthcare—hospital	1.09	0.82	0.75	1.05	0.86	0.81	0.84	0.65	0.78
Hotel, large	1.01	0.77	0.76	0.91	0.46	0.51	0.85	0.49	0.58
Hotel, small	1.01	0.77	0.76	0.92	0.41	0.45	0.89	0.41	0.47
Office, large	0.79	0.61	0.77	0.84	0.67	0.80	0.88	0.72	0.82
Office, medium	0.79	0.61	0.77	0.84	0.67	0.80	0.85	0.69	0.81
Office, small	0.88	0.69	0.78	0.84	0.67	0.80	0.79	0.64	0.80
Residential care	0.74	0.58	0.78	0.82	0.55	0.67	0.88	0.59	0.67
Restaurant, full-service	0.94	0.71	0.76	0.81	0.65	0.80	0.82	0.65	0.79
Restaurant, quick service	0.94	0.71	0.76	0.82	0.66	0.80	0.83	0.66	0.80
Retail, stand-alone	1.31	1.06	0.81	1.29	1.01	0.78	1.29	0.99	0.77
Retail, strip mall	1.17	0.95	0.81	1.29	0.98	0.76	1.29	0.96	0.75
Retail, supermarket	1.43	1.12	0.78	1.29	0.99	0.77	1.29	0.99	0.77
School, primary	0.85	0.64	0.75	0.92	0.75	0.82	0.96	0.78	0.81
School, secondary	0.85	0.64	0.75	0.92	0.75	0.82	0.89	0.72	0.81
Warehouse	0.58	0.54	0.92	0.60	0.54	0.89	0.63	0.56	0.89
Sector Floor Area Weighted Average	**0.79**	**0.65**	**0.83**	**0.81**	**0.66**	**0.83**	**0.81**	**0.67**	**0.83**

Table 23 shows the WSEC 2012 and 2015 building-area allowances compared with building allowances determined from WSEC 2012 and 2015 space-by-space allowances with the ASHRAE/IES weights. The SBS/BA column presents the ratio of the ASHRAE/IES weighted WSEC space-by-space allowance to the WSEC building area allowance. The space-by-space allowances allow 7% more lighting power on average, with individual building types varying from there.

For code compliance, developers of buildings for which the space-by-space allowances are low (hotel/motel) will learn that the building area path is the easiest for compliance. Where space-by-space allowances are higher (parking garage, warehouse), projects will use the space-by-space path anytime they need more light.

Table 23. Comparison of Building Area and Space-by-Space Allowances (IES weighting)

	Building Area		Space by Space Equivalent		SBS / BA[1]	
Building Area Type	**WSEC 2012**	**WSEC 2015**	**WSEC 2012**	**WSEC 2015**	**WSEC 2012**	**WSEC 2015**
Automotive facility	0.82	0.64	0.84	0.67	1.02	1.05
Convention center	1.08	0.81	1.09	0.86	1.01	1.06
Court house	1.05	0.81	1.08	0.87	1.03	1.08
Dining: Bar lounge/leisure	0.99	0.79	1.02	0.76	1.03	0.96
Dining: Cafeteria/fast food	0.9	0.72	0.9	0.72	1.00	1.00
Dining: Family	0.89	0.71	0.91	0.73	1.02	1.03
Dormitory	0.61	0.46	0.62	0.49	1.02	1.07
Exercise center	0.88	0.67	0.91	0.72	1.03	1.07
Fire station	0.71	0.54	0.72	0.54	1.01	1.01
Gymnasium	0.95	0.75	1.01	0.81	1.06	1.08
Health care clinic	0.87	0.70	0.91	0.72	1.05	1.03
Hospital	1.2	0.84	1.17	0.95	0.98	1.13
Hotel	1	0.70	1.01	0.51	1.01	0.73
Library	1.18	0.94	1.26	1.02	1.07	1.08
Manufacturing facility	1.11	0.89	1.12	0.88	1.01	0.99
Motel	0.88	0.70	1.02	0.46	1.16	0.66
Motion picture theater	0.83	0.61	0.84	0.67	1.01	1.10
Multifamily	0.6	0.41	0.68	0.55	1.13	1.35
Museum	1	0.80	1.06	0.84	1.06	1.05
Office	0.9	0.66	0.93	0.74	1.03	1.13
Parking garage	0.2	0.16	0.25	0.2	1.25	1.25
Penitentiary	0.9	0.65	0.98	0.82	1.09	1.27
Performing arts theater	1.25	1.00	1.4	1.12	1.12	1.12
Police station	0.9	0.70	0.97	0.79	1.08	1.14
Post office	0.87	0.70	0.92	0.73	1.06	1.05
Religious building	1.05	0.80	1.09	0.87	1.04	1.09
Retail	1.33	1.01	1.43	1.09	1.08	1.08
School/university	0.99	0.70	1.02	0.82	1.03	1.18
Sports arena	0.78	0.62	0.9	0.71	1.15	1.14
Town hall	0.92	0.71	0.95	0.76	1.03	1.07
Transportation	0.77	0.56	0.81	0.6	1.05	1.07
Warehouse	0.5	0.40	0.67	0.53	1.34	1.33
Workshop	1.2	0.95	1.2	0.96	1.00	1.01
Average	**0.91**	**0.70**	**0.96**	**0.74**	**1.06**	**1.07**

1 – SBS / BA is the ratio of the space-by-space allowance to the building area allowances. Low values range from 0.6 (green) to 1.0 (yellow green) and high values range from 1.01 (yellow) to 1.35 (orange).

Multifamily Interior Lighting Power

Only common area lighting power allowances change between the WSEC 2012 and WSEC 2015. Building area allowance is reduced 32%, but space-by-space allowances, which start out significantly more generous relative to building area allowances, only drop 20% and end up even more generous relative to the building area allowances. The table below presents results for space-by-space allowances weighted by NEEA RBSA space type distribution. The space-by-space results are used with a current practice adjustment.

Table 24. Multifamily Interior Common Area Lighting Power

	Building Area[1]		Space-by-Space Equivalent[1]		SBS / BA[2]	
	WSEC 2012	WSEC 2015	WSEC 2012	WSEC 2015	WSEC 2012	WSEC 2015
High-rise Multifamily	0.6	0.41	0.71	0.57	1.18	1.39
Mid-rise Multifamily	0.6	0.41	0.76	0.61	1.18	1.49

1 – No current practice adjustment has been applied
2 – SBS / BA is the ratio of the space-by-space allowance to the building area allowances. Low values range from 0.6 (green) to 1.0 (yellow green) and high values range from 1.01 (yellow) to 1.49 (orange).

Unit lighting requirements do not change between the WSEC 2012 and WSEC 2015. Both codes require 75% of the lamps in permanently-installed fixtures to be fitted with high efficacy lamps. The 2016 NEEA Multifamily Code savings evaluation estimated units LPD of 0.578 W/ft^2 in response to this requirement, and that value is used in this work without further adjustment. Using the same method, the C406 high efficiency option path results in an apartment LPD of 0.434 W/ft^2.

A.4.5. Controlled Receptacles

The WSEC 2015 requires 50% of receptacles in offices, conference rooms, and classrooms to be controlled on occupancy.

Very little information is available on metered savings from plug load controls. Acker et al. monitored six office spaces and found savings of 0.6 kWh/yr. Relative savings are not presented on an annualized basis but appear to be ~18% during weekdays and greater on weekends. The same study investigated replacing equipment with EnergyStar equipment and found even greater savings. The savings from these two strategies overlap to some degree, and in buildings with EnergyStar equipment, controlled receptacles may save substantially less energy. The methodology of this work raises other concerns (e.g., small non-random sample, existing rather than new buildings) in terms of using it to characterize savings in all new buildings, but it appears to be the only measured data available.

Plug load controls were evaluated for the 2013 California Building Energy Efficiency Standards.[7] Savings in small office were estimated to be 0.49 kWh/ft^2 and in large office to be 0.61 kWh/ft^2. The standards do not report overall plug load consumption or percent savings. Costs were estimated to be \$0.26/ft^2 in small office and \$0.19/ft^2 in large office.

PNNL has also estimated savings from plug load controls by modifying equipment schedules in the zones required to have the control. The modified schedules result in savings of ~8% for small and medium office and an absolute savings of ~0.21 kWh/ft^2. These values are substantially below the savings estimates of the other work, which may or may not be reasonable. Both PNNL and California Energy Commission (CEC) estimates are based upon field-derived equipment counts and energy consumption combined with assumed occupancy and occupant behavior. In its favor, the PNNL evaluation assumes controls only in code-mandated spaces, and codes are generally applied to new buildings, which are likely to contain new efficient equipment. In addition, the BPA prototype baseline equipment power density and schedules are borrowed from the PNNL, making implementation easy.

This code savings evaluation will use the equipment power and schedule assumed for ASHRAE Standard 90.1-2007 in the savings determinations for the base case and the ASHRAE Standard 90.1-2016 assumptions for equipment power and schedule of the new code.

A.5. C406 Additional Efficiency Package Options

C406 is a new code section that requires projects to implement one or two options from eight possible options to achieve additional efficiency. The number of options required varies depending on whether the project is permitted as a shell and core with follow-on initial tenant improvement permits, or is permitted all at once. Initial tenant improvement projects are only required to choose one option, and if the building complies with the Section C406.5, C406.8 or C406.9 options, then the tenant improvement does not need an additional option. So a building that is built and permitted in one phase must have two options, while a building permitted as a shell with tenant permits will have to do two options for the shell and core areas, but one or none for the tenant areas.

Overlap also exists between the requirement that certain building types and areas have DOAS with the DOAS option; the buildings must do DOAS, but it also counts as an option. Savings for the DOAS in this case are included with the DOAS section and the same buildings require one less option here. This will inflate the primary DOAS measure savings and deflate the options savings by the value of one option.

The team developed an option choice model to capture assumptions related to the permitting approach, the saturation of required DOAS, and the types of options selected within each building type. The model is documented in the savings spreadsheets on the

[7] Primary source: https://title24stakeholders.com/wp-content/uploads/2020/01/2013_CASE-Report_Plug-Load-Circuit-Controls.pdf

Option Path Aggregator worksheet. In general, it was assumed office, retail, and to a lesser extent warehouse are developed as shell and core permits with initial tenant improvement permits to follow, which results in a reduced number of required options.

Another complication is the significant interactions among some of the options (e.g., LPD and lighting controls, renewable and hot water (if solar water done), envelope/air leakage and HVAC). The interaction among options is ignored in this analysis. The savings implicitly assume no projects will select the lighting power and the lighting control measure that would substantially diminish savings.

The option frequency resulting from the option choice model is used to weight savings developed for each option path.

A major caveat to this work is the lack of systematic data on any of the assumptions going into the option choice model. The primary assumptions are analyst judgements after talking to a couple of designers and one code official. Significant variation exists in the magnitude and fuel type of savings between the options; several of the options increase one fuel type while decreasing another. As such, the estimates of electric or gas savings from this measure are speculation at best.

A.5.1. Option Specifics

C406.2 More Efficient HVAC. Heating and cooling equipment must exceed minimum requirements by 15%, except up to 10% of capacity can be equipment not listed in the efficiency tables (e.g., electric resistance, gas radiant). In addition, air to water heat pumps and heat recovery chillers can be used, but are not required to have extra efficiency. Each prototype was modeled with 15% better equipment. Savings for gas and heat pump fuel types were developed using fuel type conversion factors. The average savings are calculated by weighting the fuel type savings by NEEA 2004 NC saturation of gas and heat pump. The average savings are used with the option choice model.

Considerable potential exists for fuel switching. Gas rooftop packaged equipment is not available to meet the requirements, so buildings would require other system types. Alternatively heat pumps, packaged or VRF, could be installed and the 15% criteria easily met. This is likely a fairly common choice as it would result in a relatively cheap option. No fuel switching has been assumed or accounted for.

Overlap with high-performance VAV will occur when the plant requirements result in either heating or cooling exceeding the requirements of this section, so they will already be halfway done with this measure. The team made an engineering adjustment to remove the cooling savings from this measure where high-performance VAV is assumed.

C406.3 Reduced Lighting Power. The lighting power allowance is reduced 25%. This measure is modeled using 25% from the WSEC 2015 allowance.

C406.4 Enhanced Digital Lighting Controls. Requires individually addressed fixtures with continuous dimming ability. Savings over the base code lighting control requirements are very uncertain. The main additional feature beyond general code requirements is the continuous dimming capability. Savings estimated with engineering calculations based upon ASHRAE Standard 90.1-2016 lighting control credits for continuous dimming: Open office (30%), enclosed office (5%), and conference rooms and classrooms (10%). The fractions of floor area in classrooms and conference rooms are from NEEA 2004 NC data. The open and enclosed office fractions are taken from the PNNL space type disaggregation for the prototypes. HVAC interaction adjustments are based upon factors calculated from the model results of the main LPD measure.

C406.5 On-Site Renewable Energy. Savings are determined with an engineering calculation using the code-required annual energy production as the savings. Double-counting renewables is a concern, as having site renewables allows one to avoid several other requirements. Nowhere in the code does it indicate that renewables installed here can't be used to qualify for exceptions for renewables that eliminate other standard requirements, so that no real savings accrue. One could also install a solar hot water system in a high-water-use building and qualify for C406.7 with the same renewable capacity. Due to the complexity of the potential interactions and the relatively small number of projects that are likely to fall into the niches where this is possible, no double-counting has been accounted for. If future evidence indicates that this is common, then corrections can be made.

C406.6 Dedicated Outdoor Air System. This option is automatic in buildings required to have DOAS that do not choose to follow the high-efficiency VAV alternative. The overlap is accounted for in the option choice model where the required number of options is reduced for buildings required to have DOAS. This effectively transfers the savings for these cases from the C406 accounting to the DOAS provision. Savings for the DOAS option here are only for buildings not required to install DOAS.

This option is modeled in required building types and also in lodging and high-rise residential models where the systems might have an easy path to DOAS and have a desire to install more glass. Savings are averaged to extend savings to other building types assumed to opt for this option in the choice model.

C406.7 Reduced Energy Use in Service Water Heating. This section requires 60% of the hot water energy use to be met with one of three options: Heat pump water heater, heat recovery, solar hot water. It is limited to high-water-use building types (e.g., restaurants, hotels, multifamily, hospital).

This option introduces several issues. Heat pumps probably represent fuel switching in this class of high water users as the saturation of gas heat is historically very high. Waste heat recovery overlaps refrigeration heat recovery requirements, so medium and large grocery buildings qualify automatically for this option. Use of solar water heating systems is unlikely, but if done, the same capacity could be used to qualify for both this option and C406.5.

Another issue is the higher requirement for hot water generated if the building is subject to condenser heat recovery per C403.5.4. Unfortunately, the structure of C403.5.4 means that buildings with heat recovery or solar providing 60% of hot water qualify for an exception. They therefore are not subject to the C403.5.4 requirements and can avoid the 100% requirement here. Only facilities that implement C402.5.3 but fall short of 60%, or that use condenser heat recovery for space heat, will be required to have 100%; however, they have the option to try to increase the recovery efficiency to 60% and then claim the exception and do nothing more here.

The team developed a choice model for this option, which is implemented in the spreadsheet. All the double-counting is ignored, but the heat recovery that automatically qualifies is accounted for.

C406.8 Enhanced Envelope Performance. This option requires a 15% improvement in overall building heat loss rate, which was modeled in all prototypes.

C406.9 Reduced Air Infiltration. This option requires a 37.5% reduction in infiltration, from 0.4 cfm/ft^2 to 0.25 cfm/ft^2. The reduction was modeled in all prototypes.

A.6. C408 Commissioning

The new code changes the thresholds triggering commissioning and also changes details of the commissioning to be performed. The mechanical threshold changes increase the number of projects for which commissioning is required, while the lighting provisions decrease. Previous WSEC evaluations have claimed savings for commissioning, and the calculations here are an adjustment to those previously-claimed savings.

The changes to the threshold triggers are significant but are also hard to interpret. Mechanical systems commissioning thresholds are lowered to < 240,000 Btu/h cooling capacity and < 300,000 Btu/h heating capacity from 480,000 Btu/h and 600,000 Btu/h, respectively. At the same time, the presence of economizers no longer triggers commissioning. So while the cooling threshold is lowered, for buildings that have economizers with capacities less than the threshold, commissioning is no longer required. One can question whether the WSEC 2012 was interpreted to require commissioning where there was an economizer; however, the previous commissioning evaluation assumed it did.

The lighting thresholds are raised so that less commissioning is required. Previously, commissioning was required if lighting power was over 20 kW OR if more than 10 kW of lighting was controlled by either occupancy sensors or automatic daylight controls. The new code requires commissioning if lighting power is over 20 kW AND more than 10 kW of lighting is controlled by either occupancy sensors or automatic daylight controls. A small 15,000 ft^2 office might have OS control of all lighting, which would have triggered commissioning based upon kW under OS control, but in the WSEC the 20 kW overall capacity means buildings will have to exceed ~30,000 ft^2 before commissioning is required. Additionally, a very large project will not need functional testing of any controls if the combined lighting power controlled by OS or daylight control is under 10 kW. This likely removes lighting commissioning from all multifamily buildings. This threshold change was likely meant to be a clarification rather than a significant change; however, that is not what the language does, and it opens up a loophole.

Changes to the commissioning details and specification include:

- Requires commissioning agent to be a certified commissioning agent or the design professional of record, rather allowing any registered design professional or "approved agent" to conduct the commissioning
- New and improved listed of required checks
- Controls in the new code must now be configured to deliver required strategies rather than simply being capable of delivering them. Commissioning is likely where some of these details will get discovered, and more implemented control logic will mean more areas for savings from commissioning. However, analysis of commissioning in previous codes assumed that control strategies were implemented.

The details of the savings claimed to date are discussed in Kennedy (2014) Appendix A. The assumed savings from third-party commissioning are 22.4% of HVAC gas use, 15.7% of HVAC electric use, and 3.1% of interior lighting electric use, which are based upon evaluations of largely owner-chosen third-party commissioning. Code-driven commissioning was assumed to save 25% of the above numbers.

The changes to the commissioning details, agent, and test specifications likely result in better commissioning, but are assumed to not change savings that result from commissioning. The determination of savings from commissioning, particularly code-driven non-third-party commissioning, is speculative at best. Further refinement to differentiate between two somewhat different code specifications would prove too fine a point.

The team estimated reduced savings from the change to trigger thresholds with engineering calculations using the same factors as previous evaluations, with saturation factors representing the change in floor area required to be commissioned.

Appendix B. Washington State Energy Code 2015 Changes

Table 25 on the following pages provides a list of all changes in the Washington energy code prescriptive provisions between the WSEC 2012 and WSEC 2015 codes. Green indicates increased efficiency with two tones, with very light green indicating items likely to have modest savings and the darker shade indicating larger savings. Peach shading indicates decreased efficiency with the light shade indicating slightly increased energy use and the darker shade indicating items with a larger increase in energy use. These determinations are based on subjective judgement of each item’s impact on a situation and the frequency of the situation within the building stock.

Table 25. Detailed Non-Residential Washington Energy Code Changes from WSEC 2012 to WSEC 2015

Section	Description	Comment	Evaluation Method
C402.1.1 Low energy buildings	Added unstaffed equipment shelters used solely for wireless services to low energy exemption, so exempts from the envelope code	Large reduction in envelope requirements but in building type where envelope is a minor part of load.	Not evaluated
C402.1.2 Equipment buildings	Exempts electronic equipment buildings < 500 ft^2 with >= 7 W/ft^2 of equipment and heating systems <= 5 kW with set point <= 50°F and average roof U of 0.2 from envelope requirements	Likely little impact on overall energy use	Not evaluated
Tables C402.1.3 & C402.1.4 R-values / U-Factors	Increased insulation for roof decks. Added new single rafter roof type that decreases insulation requirement. Add mass transfer deck wall type. Added second alternative continuous wall insulation column for C402.1.3 CI with 0.08% to 0.12% penetrations. These alternative values are thermally equivalent.	Roof deck is clear positive. For single-rafter room, the insulation is decreased. For the new wall type the impact depends upon whether the deck edge was previously ignored or required to comply with mass walls. The new continuous insulation path is designed to be thermally equivalent. There is issue in that U-value table makes no mention of alternate CI values, the tables in Appendix A do not mention it, and 2015 CI definition is not specific about number of fasteners. So people can use the C402.1.4 U-value table with non-compliant CI insulation and avoid the ALT CI values of C402.1.3 footnote e.	Modeled
C402.2.3 Thermal resistance of above-grade walls	Added two additional methods to qualify as a mass wall, both based upon thermal heat capacity.	Might be substantive given generous WSEC provisions related to mass walls and CMU mass walls, but in general does not appear to change the number of walls considered mass walls.	Not evaluated
C402.2.8 Insulation of radiant systems	Insulation required on the back side of radiant systems. Language still unclear. Requirement may or may not be the same. Open to interpretation in both the 2012 and 2015 code.	Unclear what makes a panel "installed in interior or exterior assemblies". It is unclear whether suspended radiant heaters have to comply with the requirement. Unclear whether "radiant heating system panels" in the building thermal envelope include heated slab or any systems that do not come in "panels." The intent was likely to cover any radiant system installed in the thermal envelope, but that is unclear.	Not evaluated

Section	Description	Comment	Evaluation Method
Table C402.4 SHGC projection factor	New code establishes maximum SHGC for each orientation and projection factor rather than having a projection factor adjustment.	Net effect is north glazing is allowed to have higher SHGC in most cases. To the extent this is used on the north, then the energy impact is neutral, but this can also be used in the target SHGC calculation and the increased SHGC spread out to increase SHGC on all surfaces. Assuming equal distribution of glazing, the average SHGC is 0.4325.	Modeled as part of envelope changes
C402.4.1 Maximum area (fenestration)	Intent of this change was simplification, but the skylight limit was inadvertently changed from 5% to 3%.	This has subsequently been changed back to 5% as a result of a code interpretation.	Not evaluated
C402.4.1.1 Increased vertical fenestration area with daylight responsive controls	Criteria for increased fenestration path allowing 40% WWR for buildings 3+ stories tall revised to 25% of net floor area in daylight zones. Previously this was 50% of conditioned floor area.	Many buildings will qualify for this and avoid having to install better glass, and many will then use trade-offs for even higher levels. Need to determine fraction of floor area qualifying in office, hotel, and high rise residential. Combine that with the NEEA 2004 NC data to determine the number of projects using 40% rather than 30% as the base.	Modeled as part of envelope changes
C402.4.1.4 Increased vertical fenestration area with high-performance mechanical system	New increased fenestration path allows 40% WWR if DOAS installed.	Between this and C402.4.1.1, many buildings will qualify for 10% more glass. Office, lodging, high rise residential, and library will all take advantage of this to some extent.	Modeled as part of envelope changes
C402.4.2 Minimum skylight fenestration area	Reduced room size threshold for requiring skylights and daylight controls in single story building rooms from 10,000 ft^2 to 2,500 ft^2. Still limited to single-story buildings.	Definitely increases school common areas required to have skylights. Impact in strip malls will depend upon ceiling height, which in shell and core is not usually known.	Model
C402.5.3 Rooms containing fuel-burning appliances	Requires rooms with open combustion air ducts to be sealed and insulated	Small number of situations	Not evaluated
C403.2.3 HVAC equipment performance requirements	Updated efficiency values and moved computer room efficiency table. Set up separate values for split and packaged AC in the < 65 kBtu size	Significant IEER shift in over 5-ton packaged equipment was not evaluated. Code also requires two-speed fans in this equipment, which improves IEER significantly and generally leads to equipment complying with the new IEER.	Model
C403.2.3.3 Packaged electric heating and cooling equipment	Reduces heat capacity to 6,000 Btu threshold above which packaged AC/electric heat units must have a HP	Will force packaged terminal air conditioners with electric resistance heat to be heat pumps in most cases.	Model
C403.2.4 HVAC system controls	Now requires HVAC controls to be configured to implement all required control functions, not just to be capable of them.	Evaluations to date have generally assumed that controls are configured to deliver code control strategy.	Not evaluated

Section	Description	Comment	Evaluation Method
C403.2.4.1 Thermostatic controls	Adds requirement that neighboring zones cannot simultaneously heat and cool. Current interpretation: Where an interior zone is open to a perimeter zone with permanent openings that are larger than 10% of the floor area of either zone, cooling in the interior zone is permitted to operate at times when the perimeter zone is in heating and the interior zone temperature is at least 5°F (2.8°C) higher than the perimeter zone temperature.	Extremely complex section for any building with open floor plans. Impacts will be limited to open areas with multiple control zones. Open offices are the most obvious. Fairly common for box retail to interlock unit operation, though this might be good to verify. Grocery retail likely has at least two control blocks. Assembly buildings are probably the next most applicable. Not sure this will change much, particularly in terms of how the building is actually run, since people fiddle with set points all the time. Not sure how one would evaluate this – baseline condition would be a complete guess.	Not evaluated
C403.4.4 Zone isolation	Requires zones over 25,000 ft^2 to have isolation dampers from the rest of the system if they are expected to be occupied non-simultaneously.	This IECC code language is an edited version of the language in ASHRAE Standard 90.1 and has been edited in such a way as to greatly dilute its impact. There are no zones that are 25,000 ft^2. Current interpretation is systems serving areas over 25,000 ft^2 must comply with this, which is better but still not equivalent to the ASHRAE Standard 90.1 language, which requires isolation zones anywhere non-simultaneous occupancy is expected and allows similar areas to be grouped into a single isolation zone up to 25,000 ft^2.	Not evaluated
C403.2.4.5 Snow- and ice-melt system controls	Specifies control configuration, where previously it was capability		Not evaluated
C403.2.4.6 Freeze protection system controls	Specifies controls for freeze protection systems		Not evaluated
C403.2.4.7 Economizer fault detection and diagnostics (FDD)	Specifies requirements for automatic fault detection in unitary AC units 5 tons and larger	Evaluation to date assumes economizers work, so savings already included	Not evaluated
C403.2.4.12.1 DDC applications	Requires zone-level DDC for buildings with > 780 kBtuh cooling, or for AHU with fan bhp > 10 hp, or chilled or hot water systems with capacity > 300 kBtu. Must be capable of implementing all required control strategies and of monitoring zone and system demand from fan and pump pressure and heating and cooling and transferring that information to distribution and plant system controllers, and must be capable of collecting and presenting trending of all data.	Previous language required DDC in buildings with > 780 kBtu cooling, but not zone-level, and was typically not interpreted as requiring zone-level DDC.	Not evaluated

Section	Description	Comment	Evaluation Method
C403.2.6 Ventilation	Requires ventilation to be no more than 150% of IMC	This was inserted with the idea that spaces are over-ventilated. Data referenced in no way establishes this as fact. The baseline condition is not known. The IMC specifies a minimum occupant density and allows an exception based upon an approved model. But the main language places no limits on the designer assuming a higher density, so a very high occupancy load can be specified without contradicting the IMC. Also speculative spaces such as a strip mall will have to specify what they think the space occupancy will be. Because DOAS is limited in how much ventilation can be delivered, it is likely that the space type with the highest ventilation rate will be chosen to maintain flexibility (e.g., beauty salon or fast food).	Not evaluated
C403.2.6.2 Demand controlled ventilation	Changes DCV threshold to space ≥ 25 people/1,000 ft^2 from > 25 people/1,000 ft^2. Edits exemption 3 from system with < 1,000 cfm OA to those with < 750 cfm OA. Adds DCV exception for correctional cells, daycare sickrooms, science labs, barbers, beauty and nail salons, and bowling alley seating.	Dropping threshold to ≥ 25 people /1000 ft^2 brings DCV to classrooms for ages 1-8, school computer labs, and media centers, but only systems serving multiple or extremely large classrooms will exceed 750 cfm of outdoor air. A big indirect change is the new DOAS language. DOAS heat recovery will trigger an exception to DCV requirements.	Modeled in school media centers
C403.2.7.1 Kitchen exhaust systems	Establishes maximum hood flows, eliminates requirement for compensating hood, and requires 50% transfer air, heat recovery, or demand control. Unclear whether this last requirement applies to all hoods or only those that are in buildings with total hood flow > 2,000 cfm.	Previous language encouraged a design that led to bad hood flow and poor air quality. Impact of the new language is uncertain and could go either way. Baseline flows are uncertain, so effect of new maximums is unknown. Demand vent will save substantial heating and fan energy while lack of compensation will increase heating energy. Since the increased flow and compensation are driven by air quality issues and would be required in any case, possible increased energy use from those changes will be ignored and savings will be counted for DCV hood.	Modeled
C403.2.8.3.3 High-pressure duct systems	Lowered acceptable leakage in high pressure ductwork from CL 6.0 to 4.0	Baseline uncertain. Small impact. Difficult to properly model.	Not evaluated
Table C403.2.11.1 (2) Fan power limitation pressure drop adjustment	For fan power allowance calculations for systems with > 5 hp of fan motors, added fan power allowance deductions for system with no cooling or no heating or with central electric resistance heat.	These reduce the allowable fan power in systems meeting these criteria, but the number of systems with > 5 hp of fans that only have heating or cooling or have electric heating is limited.	Not evaluated
C403.2.11.3 Fan efficiency	For fan systems with > 5 hp of fan motors, requires a minimum fan efficiency grade (FEG) of 67.	Based upon FEG presentation prior to adoption in the national codes, the requirements are meant to establish the metric and do not push changes. Most fans over 5 hp will meet this. FEG is a legacy metric that will be supplanted by FEI in 2021.	Not evaluated

Section	Description	Comment	Evaluation Method
C403.2.11.4 Group R occupancy exhaust fan efficacy	Set minimum efficiency in cfm/W for exhaust fans in Group R occupancies. Exempts systems with HR.	No data on baseline condition. Small overall usage.	Not evaluated
C403.2.11.5 Fan air flow control	Requires two-speed fan with low speed at < 40% power during low cooling and ventilation for all DX system > 5 tons, all CW units >= 0.25 hp, and almost all hydronic terminals. Previous code required this only for DX systems > 9.5 tons and large rooms with > 10,000 cfm supply air (~10,000 ft^2) single zone VAV with variable speed drive and 75% flow turndown, DOAS with cycling heat/cool fans, or designated ventilation units with at least 50% of units cycling with heat/cool.	This and DOAS are going after the same piece of the pie, so savings here will not be so large and a lot of this detail will not make sense for a building with DOAS and cycling HVAC fans on heating and cooling. Really should have had DOAS exception for some systems.	Model
C403.3 Economizers	Major changes—added DOAS exception, VRF exception building size limit removed, chilled beam water economizer capacity limit removed.	DOAS exception will allow VRF, chilled beam systems, and possibly water source heat pumps to exclude economizer without added efficiency required by the WSEC 2012 exceptions for these system types. Moving small qualified equipment to C503 will come as a shock for those that used it in new situations.	Model as part of DOAS change
C403.4.1.2 Multiple-zone system fan control	Adds requirements to detect, raise an alarm, and provide an easy work-around for zones that excessively drive reset logic.	Very good requirement, though impact is unknown. Designers indicate this is already common. Some, particularly in small VAV systems, may be pushed to implement better controls. Models assume smart reset already.	Not evaluated
C403.4.2.5 Boiler turndown	Adds minimum turndown requirements for boiler systems over 1,000,000 Btuh.	May or may not be change from current practice	Not evaluated
C403.4.3 Heat rejection equipment	Expanded list of covered equipment to include dry coolers. Expanded list of exempt-rated equipment to include all tables that could have rated equipment that includes the heat rejection side.	No efficiency requirement for dry coolers though. Only impact will be from new multiple-cell heat rejection language below.	Not evaluated
C403.4.3.1.2 Multiple-cell heat rejection equipment	Requires multiple cell heat rejection equipment with variable speed fan drives to run equipment as parallel as possible.	Only applies to built-up equipment. Big savings for large plants but mostly limited to fairly large situations, though could possibly apply to dry coolers. Could not get EnergyPlus model developed in time.	Not evaluated
C403.4.3.3 Tower flow turndown	Requires multiple open circuit tower cell pump design to run in parallel manner.	Only applies to built-up equipment. Big savings for large plants but mostly limited to fairly large situations. Could not get EnergyPlus model developed in time.	Not evaluated

Section	Description	Comment	Evaluation Method
C403.4.4.3 Multiple - zone VAV system ventilation optimization control	Requires non-fan powered VAV systems to do VAV system optimization based upon system ventilation efficiency	Big change in code stringency for this system type. Key to this measure is whether the baseline system used the multiple zone ventilation rate procedure to size the minimum flow rates to zones. If yes, then this saves substantial energy; if no, then this can increase energy use while improving ventilation. Very little information to inform this baseline issue. This evaluation assumes proper multiple zone sizing is done. The overall impact is limited since VAV systems without fan-powered terminals are less common than systems with fan-powered terminals.	Model
Table C403.5.1 Energy recovery requirement	Adds table for systems that run 8,000 hours or more that greatly expands heat recovery requirements.	Limited to a few building types: Hospitals, lodging, and police/fire. Hospital air flows probably triggered previous thresholds. Ran out of resources to develop this. At future date, review hospital, lodging models.	Not evaluated
C403.6 Dedicated outdoor air systems (DOAS)	Requires DOAS in office, retail, education, libraries, and fire stations with an exception for areas served by C403.7-compliant high-efficiency VAV. Requires 60% sensible heat recovery or DCV (if DCV required). Heating and cooling fans must be off during ventilation-only hours.	Overlap with DCV will reduce savings in schools and some other space types. Significant existing saturation is likely since VRF, water source heat pump, and chilled beam economizer exceptions required heat recovery DOAS. But the existing saturation unknown.	Model
C403.7 High efficiency variable air volume (VAV) systems	Section is only required for projects utilizing C403.6 exception 2. Detailed list of equipment and controls for high-efficiency VAV systems. Several items are vague, such as requiring controls to implement strategies per ASHRAE Guideline GPC-36, which is currently uncompleted.	Only required as alternative to DOAS. No information on whether any buildings utilize this provision. To avoid fuel switching, assume large offices follow this route. Many of the control requirements are impossible to model so increment can only capture some of the requirements.	Model as alternative to DOAS
Table C404.2 Minimum performance of water heating equipment	Changed electric water heater and gas storage water heater efficiency values on a couple of pieces of equipment. Somehow, the main changes in ASHRAE Standard 90.1-2013 were not incorporated.	This does not apply to small electric and gas tanks or to boilers, so very small impact. To capture codes AND standards savings, will need to evaluate ASHRAE Standard 90.1-2013 table.	Not evaluated
C404.2.1 High input-rated service water heating systems	Buildings with > 1,000,000 Btuh of total gas water heating capacity from water heaters > 100,000 Btuh must be condensing.	Main threshold will definitely be triggered in hospital and lodging with central systems. C403.5.4 will also impact hospital and has strong interaction. Options might as well.	Engineering calculation

Section	Description	Comment	Evaluation Method
C404.3 Efficient heated water supply piping	Measure limits stranded water in piping and the resulting stand-by losses. Buildings must comply with C404.3.1 or C404.3.2. C404.3.1 limits pipe length from water source (tank, circulation loop, heat trace system) to fixture. C404.3.2 limits pipe volume for the same piping run.	Painful detail. From trainings it appears this is a large change that will reduce piping losses in all building types. This will increase the surface area of the circulation system which increases losses but decrease the amount of stranded water in piping runs. No time to develop a model of this measure	Not evaluated
C404.6 Pipe insulation	Changed simple 1" insulation requirement for recirculation and heat trace piping to requirement to look at Table C403.2.9, which specifies insulation by temperature and pipe size. For pipes < 1.5 inches with water < 140°F, 1 inch of insulation is required. Larger pipes or pipes with hotter water have increased insulation requirements from 1" to 1.5" or 2".	Likely impacts a few buildings such as hospital, but savings from going from 1 inch to 1.5 inches of insulation are fairly small	Not evaluated
C404.7 Heated-water circulating and temperature maintenance systems.	Requires automatic pump system stop/start on demand. Heat trace control language is a bit less clear. Trace needs to be controlled by thermostat and then there is a blurb about automatically turning off when there is no hot water demand. This seems a bit counter to the design point of heat trace systems, but will probably be interpreted as time clock control.	WSEC 2009 more or less required this, but the merge with IECC allowed manual control. Apply evaluation study-based savings estimates for automatic controls to fraction of buildings with circulation systems.	Engineering calculation
C404.7.3 Controls for hot water storage	Requires controls on pump between a hot water heater and storage tank to cycle with the heater allowing for extra 5 minutes after burner shutoff	This pump is very small, so pump energy savings would be minimal. Standby loss savings would be more significant but still very small. Baseline is completely unknown.	Not evaluated
C404.8 Demand recirculation controls. Previously shut-off controls	Seems to require the same control as C404.7. Has specific detail to require demand recirculation, not just time switch control. Also has blurb limiting water returning to the cold water system to 104°F.	Seems to require the same control as C404.7.	Evaluated with C404.7
C404.11 Energy consumption of pools and permanent spas	Changed permanently installed “in-ground spas” to “spas” so that requirements extend to permanently installed above-ground spas, however the requirements for covers are still limited to pools and in-ground spas.	Number of above-grade spas that would be part of permit is likely fairly limited, so this measure’s impact is limited.	Not evaluated
C405.2 Lighting controls	Expanded exceptions to cover all exits even if not part of the "means of egress" lighting. Also added exception for lights with individual programmable LLLC controls.	Not sure how to assess these changes. Code officials may believe whatever the lighting designer says in terms of egress lights. LLLC control will have increased abilities, but is not required to be configured to deliver code-required control strategies.	Not evaluated

Section	Description	Comment	Evaluation Method
C405.2.1.2 Occupant sensor control function in warehouse	OS control function in warehouse lighting changed to allow reduction if 50% rather than full turnoff.	Reduces warehouse requirement in that lights never have to automatically turn off. May increase real savings if previous OS to off control caused it to be disabled. Assume increased lighting fractions during all hours.	Modeled
C405.2.3 Manual controls	No longer requires each room to have manual control. Only indicates switches shall be accessible so a single switch for several rooms for a portion of the floor would be just fine up to the limit of 4,000 watts (assume 277 v).		Not evaluated
C405.2.4.1.1 Dimming	Changed continuous dimming from 20% to 15% power, and requires continuous dimming in offices, classrooms, labs, and library reading rooms. Requires step-dimming to have two steps between 0 and 100% and no longer specifies minimum for low step. Requires continuous and step systems to step to off, whereas previously this was only required for step systems.	Significant improvement in control requirements with lower power minimum, dim to off, and forcing continuous dimming, which will improve daylighting control savings. Previous step dimming language more clearly indicated that two illumination levels plus off are required. Required continuous dimming will increase acceptance for any situation where the designer was thinking of step dimming.	Modeled
C405.2.4.2 Sidelight daylight zone	Defines side daylight zones with separate primary and secondary. Now exempts spaces for small amounts of windows and exempts spaces with low VT.	Exempting spaces is negative, but the criteria used will only cut out spaces with very small amounts of glazing, which probably did not use the daylight control anyway. Splitting space into primary and secondary likely helps acceptance of the controls and will increase savings in primary zones.	Not evaluated
C405.2.5 Additional lighting controls	Requires these in addition to other controls. Old language should have too, but there was a SBCC interpretation that said special applications only need the special application control and that OS or other automatic off was not required for accent lighting. Hotel/motel control no longer required to have master switch at the door. All lighting must be OS or captive key controlled (no longer has 50-unit threshold), lighting on at night lowered to 0.02 W/ft^2 from $0.05W/ft^2$.	Previous evaluation assumed special application lighting also needed primary controls since this is how the IECC was interpreted. When SBCC indicated main controls were not required for lights covered by this section, previously-assumed savings were eliminated and are now returned. Egress lighting was evaluated in the WSEC 2009 for much more aggressive language. The introduction of the $0.05W/ft^2$ limit with the WSEC 2012 and now the $0.02W/ft^2$ limit are less stringent than the previous evaluated savings case.	Not evaluated
C405.2.7 Exterior lighting control	Adds requirement for lighting to be turned off when business closed and late at night	Real energy savings would depend upon the baseline conditions, whether lights are turned off or down at night. Previous code required photocell and time clock or astronomic time clock, so capabilities have not changed. Modeled as being off 6 hours at night with baseline control assumed to be 20% off all night.	Modeled

Section	Description	Comment	Evaluation Method
C405.4.1 Total connected interior lighting power	Defines how the proposed watts are calculated. Form of equation changes but no substantial change. New exception excludes mirror lighting in dressing rooms and requires exempt plant growth task lighting to have an efficacy > 90 L/W.	Plant growth lighting > 90 lumens/watt is big change. The total floor area where this is applicable and the baseline lighting density are completely unknown. Floor area is likely small, wattage may not be.	Not evaluated
Table C405.4.2(1) Interior lighting power allowances - building area method	New LPD allowances are 20+% lower.	Big change but space-by-space allowances are more generous. Evaluate together with space-by-space method changes.	Model
Table C405.4.2(2) Interior lighting power allowances - space-by-space method	New LPD allowances are 20+% lower. A few new categories (e.g., facilities for the visually impaired) which can increase lighting. And the WSEC 2009 ceiling height adjustment has been resurrected.	Evaluate together with building area method changes. Ceiling height adjustment increases allowed LPD, especially in warehouse.	Model
C405.5.1 Exterior building grounds lighting	Minimum efficacy for 100 W lamps is changed from 60 to 80 lumens per watt.	Mostly not relevant since a 100 W 60 lumens/watt lamp is larger than typical building grounds lighting, which includes walkways and stairways based upon lighting allowance table. If people apply this to parking lots, such as a light pole that is installed in the perimeter planting area but illuminates the parking lot, then it might have a small impact.	Not evaluated
Table C405.5.2(2) Individual lighting power allowances for building exteriors	Building façade lighting category changed to have allowance for the total above-grade wall area. Previously the allowance was limited to the illuminated area of the wall or based upon the linear feet of perimeter of illuminated surfaces.	While the allowance is 25% below the previous value applied to the illuminated area, this is a substantial increase in lighting except in buildings under 15 feet in height. Good thing this is in non-tradable. Clear trend in CBSA is to more exterior light in newer buildings, but whether the code limits are having any impact is not known. In this case it is not tradeable, so the only downside is using allowance from an un-illuminated side to increase the façade lighting on another.	Not evaluated
C405.8 Electric motor efficiency	Motor efficiency requirements of the mechanical chapter and lighting chapter are consolidated and added two new tables for small motors.	Code requirements directly reflect national standards.	Not evaluated
C405.9.1 Elevator cabs	Sets minimum lighting efficacy at 35 lumens/watt and maximum fan power and requires both be turned off after 15 minutes of inactivity.	Good measure, but small savings in a limited number of situations.	Not evaluated
C405.9.2 Escalators and moving walkways	Previously required specific control; now just requires that speed be reduced.	Not sure there is anything to check now except that there be some sort of automatic control.	Not evaluated

Section	Description	Comment	Evaluation Method
C405.10 Controlled receptacles	Adds requirement for 50% of receptacles in offices, conference rooms, classrooms, to be controlled on occupancy.	Substantial uncertainty related to utilization of controlled vs. uncontrolled receptacles.	Engineering + model
C406 Additional efficiency package options	New section that requires two additional efficiency options for new construction	A great deal of uncertainty as there are very few “obvious” easy options. As a result, savings magnitude and even which fuels are saved will be highly uncertain. Choice model developed to determine fraction of floor area following each option, and savings applied accordingly.	Model + engineering
C406.1.1 Additional efficiency package options, tenant spaces	Only requires tenant spaces to have single option. TIs will have lower requirements than buildings not completed as TI.	Initial tenant improvement will only have to comply with a single option 2, 3, 4, 6, or 7. If the building complies with options 5, 8, or 9, the tenant space is deemed to comply with the options path. This worked when requiring one option but with two required, it is a loophole that allows tenant spaces to have a single option. Now a building can comply with 5, 8 or 9 plus, say, LPD in non-tenant areas and the tenant areas will not have to do anything. Need to have good assessment of the floor area done as shell and core.	Evaluate as part of C406
C406.2 More efficient HVAC equipment and fan performance	Requires 90% of total HVAC capacity to be C403-listed equipment and requires 15% better heating and cooling equipment unless heat recovery chiller or air-to-water heat pump. Standalone fans with motors > 1 hp must be FEQ71 and at design conditions within 10% of max total efficiency of the fan or the static efficiency of the fan.	Efficiency change is based upon 15% decrease in modeled heating and cooling energy. Applicability is limited to situations where equipment is capable of improving 15% (not applied to fraction of floor area with gas-fired RTU). Fan power savings are not evaluated.	Engineering
C406.3 Reduced lighting power	Requires lighting power be at least 25% below code allowance and requires 95% of permanently-installed multifamily fixtures have lamps with efficacy of 60 lumens/watt or greater.		Modeled
C406.4 Enhanced digital lighting controls	Digital addressable lighting controls. This may see some adoption with lighting getting so much tougher and control requirements ratcheting up. Significant adoption of LLLC control is likely.	Need to compare this to LLLC control and see where LLLC is adequate. The one thing observed is that this indicates the controls need to be set up to deliver code control and to make fixtures individually dimmable, where LLLC only requires capability. LLLC requires OS and daylight sensors and control logic to be embedded where C406.4 doesn't.	Engineering

Section	Description	Comment	Evaluation Method
C406.5 Onsite Renewable	Requires minimum amount of renewable energy. Language here is terrible. This is annual energy production.	PV installed for this option likely qualifies the project for exception from some HVAC requirements where there is an exemption when solar/renewable make up some percent of particular end uses. This same trick might allow a project to quality for this and the efficient SWH option at the same time. This would decrease savings, but it is not assumed in the evaluation.	Engineering
C406.6 DOAS	90% of "occupied" floor area must have DOAS.	Provision encourages HVAC system change. Some RTU systems may stay the same, but many buildings will go with VRF, chilled beam, and other systems that are more natural fits with DOAS.	Model
C406.7 Reduced energy use in service water heating	In high SWH buildings, must have 60% of water delivered by HP with cop >= 3 or waste heat recovery, or solar.	Considerable conflict and overlap with other sections of the code greatly decrease savings. Language tries to increase requirement when C403.5.4 already requires heat recovery, but misses the mark in several respects and totally misses C403.5.5 overlap. Increased percentage applies to buildings subject to C403.5.4, but one of the exceptions in C403.5.4 is for sites with heat recovery. So if there is heat recovery then it is not subject to C403.5.4, and therefore it only needs 60%, even though 60% heat recovery is what was required by C403.5.4.	Engineering
C406.8 Enhanced envelope performance	Requires envelope to have 15% better UA	Will interact strongly with HVAC, not with renewables or hot water, and moderately with the other options.	Model
C406.9 Reduced air infiltration	Reduces infiltration level to 0.25 cfm/ft^2	Will interact strongly with HVAC, not with renewables or hot water, and moderately with the other options. Different exception than main requirement.	Model

Section	Description	Comment	Evaluation Method
C408 Commissioning	Mechanical systems commissioning thresholds are lowered to < 240,000 Btu/h cooling capacity or < 300,000 Btu/h heating capacity from 480,000 Btu/h or 600,000 Btu/h respectively. But the mere presence of economizer no longer triggers commissioning. Lighting commissioning threshold is changed to require commissioning when lighting power is both over 20 kW AND more than 10 kW of lighting controlled by automatic occupancy sensors or daylight controls. The WSEC 2012 required commissioning if lighting power was over 20 kW OR if more than 10 kW of lighting is controlled by occupancy sensors and automatic daylight controls. Details of commissioning requirements are also changed. The commissioning agent is required to be a certified commissioning agent or can be the "engineer of record if she/he is qualified to perform commissioning services for the whole commissioning process." The WSEC 2012 allowed the plan to be developed and report certified by "a registered design professional or approved agency."	While the cooling threshold is lowered, for buildings with capacity below the threshold having economizers, commissioning is no longer required. There is some question whether code officials were requiring this, though. The lighting thresholds are inadvertently raised. A small 15,000 ft^2 office might have OS control of all lighting which would have triggered commissioning based upon kW under OS control, but in the WSEC it is 20 kW. Change in commissioning requirements are very likely a substantial improvement (third time's a charm?), but assessing how wording changes and impacts the commissioning savings is well outside the analysis conducted here.	Modeled + engineering
C409.1 General	Expanded to require metering in additions 50,000 ft^2 or greater—though previously may have been interpreted to require it. Exception 1 changed from exempting all tenant spaces to just exempting tenant spaces < 50,000 ft^2.	Savings from metering were evaluated in WSEC 2012. To the extent this changes the population an adjustment is warranted, but without better information on interpretation related to additions, it is hard to evaluate this.	Not evaluated
C410.1.1 Refrigeration equipment performance with Tables C410.1.1(1) & (2)	Requires commercial refrigeration equipment, refrigerators and display cases, to comply with minimum efficiency requirements.	Significant addition. This is also a federal appliance standard. Probably only non-compliance will be when equipment is reused. The DOE Reference model would need extensive work-up to get proper deltas for this.	Not evaluated
C410.2.2 Refrigerated display cases	Regulates case lighting, defrost, and antisweat controls. Requires time switch or motion sensor lighting control, temperature-based defrost control with temperature and time limit bounds, humidity-based anti-sweat heater controls.	Significant addition. This is also a federal appliance standard. Probably only non-compliance will be when equipment is reused. The DOE Reference model would need extensive work-up to get proper deltas for this.	Not evaluated

Section	**Description**	**Comment**	**Evaluation Method**
C410.3.1 Condensers serving refrigeration systems	Regulates the design saturated condensing temperatures for air-cooled condensers and fan motors in all cases	Grocery prototype not developed	Not evaluated
C410.3.2 Compressor systems	Requires floating suction pressure control logic, liquid sub-cooling, insulating liquid lines, and crankcase heater controls	Grocery prototype not developed	Not evaluated
C503.3.1 Roof replacement	Previously if the sheathing was exposed, roof had to comply. Now it only needs to comply if the sheathing is exposed AND the roof "contains insulation entirely above the roof deck."	Technically a totally uninsulated roof would not trigger the insulation requirement. Only those with some insulation on the roof deck and none in the cavity.	Not evaluated
C503.6 Lighting and motors	Lowers % luminaires replaced threshold for LPA compliance from 60% to 50%. Adds treatment of exterior lighting and garage (not enclosed by walls, so previous language made little sense).		Not evaluated
C504.2 Application	Defines cases that are "repairs" and therefore not subject to code. List is slightly less inclusive than WSEC 2012.	The new language references the definition of repair, which is completely open: REPAIR. The reconstruction or renewal of any part of an existing building.	Not evaluated

Appendix C. Base Model Adjustments

The study team spent a great deal of development effort to prepare the base models and the modeling framework for evaluating new building energy codes. The base models were developed to model existing "real" buildings and did not have many of the controls required of new buildings. Work included:

- Adding a large number of new parameters required to model codes
- To facilitate system modeling, the system assignment portion of each prototype template was rewritten so there was only a single occurrence of each system specification. This was required to keep input manageable.
- Added skylights and daylighting to most single-story prototypes with the ability to specify whether skylights exist and the skylight-to-roof ratio for the daylit zones
- Added ability to specify the window-to-wall ratio and have the geometry automatically adjust
- Added ability to add conference rooms and specify the percent conference room in the medium and large offices to explore issues related to VRP sizing
- Implemented a new infiltration treatment based on NIST research
- Developed new inputs for outdoor air requirements

This appendix addresses several aspects of the prototypes that were changed to better represent new construction. This is not a complete listing. In particular, Appendix A addresses several additional base model changes in discussing specific code provisions.

C.1. Prototype Window-to-Wall Ratio (WWR)

A building's gross wall, roof, and floor areas are determined by the prototype geometry. However, the prototype geometry has significantly less surface area (roof and wall) per unit floor area than the NEEA 2004 NC data set. The regional average wall area per square foot of floor area is ~30% higher than represented by the prototypes. The regional average roof area is ~10% higher than the prototypes. Since code limits glazing as a percentage of wall area, window area is also 30% higher. In the WSEC 2012 evaluation, prototype heat loss rates were adjusted so that the model heat loss rate per unit floor area agreed with the average code heat loss rate calculated from the NEEA 2004 NC data. This corrects for the difference in conduction but does not adjust for the large difference in solar.

The NEEA 2004 NC data—the basis for change—has not been updated in 12 years and represents 2002–2004 construction practices. Regional average surface area per unit floor area is likely larger than that captured by the prototype geometry, but this is uncertain given that building geometry is shifting over time.

Three cases were explored: No adjustment, adjustment for conduction differences, and adjustment for conduction and solar differences. The results are presented below:

Table 26. Total Building Energy Use for Alternative Envelope Treatments (kBtu/ft²)

Building & Input Type Case	WWR	Prototype UA/ft²	Site kBtu/ft²	HVAC kBtu/ft²
Stand-Alone Retail				
Compliant prototype envelope	8.1%	0.147	47.0	22.7
Conduction correction	8.1%	0.111	44.9	20.5
Conduction and solar correction	5.7%	0.111	45.1	20.5
Small Office				
Compliant envelope	18.4%	0.086	33.1	12.8
Conduction correction	18.4%	0.106	34.0	13.6
Conduction and solar correction	26.5%	0.106	34.0	13.7
Large Office				
Compliant envelope	41.1%	0.042	34.5	8.4
Conduction correction	41.1%	0.070	35.5	9.5
Conduction and solar correction	60.3%	0.070	35.4	9.3

Using the models as constructed would reduce the importance of envelope loads. Correcting U-values and window area so that heat loss rate and window area per unit floor area matches NEEA 2004 NC will better represent the envelope load. Rather than more exterior surface, the building will have surfaces with higher heat loss areas and solar gain. The team for this study chose to use the models with conduction and solar adjustments.

School Window Area

The NEEA 2004 NC data found the average WWR in schools was 12.3%. WWR in schools is almost certainly higher now than during the 2002–2004 period as a result of the emphasis on daylighting as a productivity enhancer. A spot check of two new schools found substantial window area, in the 25%–35% range, with high ceilings and window head heights. Another data point is the ASHRAE Standard 90.1 savings determination prototypes, which assume a WWR of ~35% for schools. The evaluation team has decided to double the window area for schools. After the adjustment of conduction and window area for the geometry differences, the modeled WWR is 33%.

Thermal Bridging

The BPA prototypes implemented framing correction factors based on detailed studies by Morrison-Hershfield[8]. For codes work, these thermal bridging factors were not implemented.

[8] https://morrisonhershfield.com/bpa_library/building-envelope-thermal-bridging-guide/

C.2. Entry Door and Vestibule Infiltration

The Params framework by Big Ladder Software[9] has an entry door/vestibule template based on the same source work as the PNNL entry door/vestibule inputs. The template produced huge entry zone infiltration many times higher than PNNL estimates, and was not utilized in the BPA models. For this work, several modifications were made to the Params template to bring it closer to the PNNL work, including: Setting door size to a single entry door rather than the total door area; using the PNNL peak people entering, rather than the summed zone occupancy for the number of door openings; and adjusting the calculation of the air flow coefficient to use interpolation/extrapolation at the lower and upper ends rather than relying on a curve fit. The template now produces values similar to PNNL, although some differences exist.

Deviations from the PNNL method include:

- Using straight line interpolation for hourly door openings below 30 results in flow coefficients very close to the values presented in the original work (RP-763). The PNNL values are as much as 100% higher for low numbers of door openings. PNNL likely used a curve fit or estimated the values from figures that lack precision rather than visiting the original data tables.
- Using a larger door size (30 ft^2 vs. 21 ft^2) in stand-alone retail, since in many cases the doors are a double slider rather than single-swing. This increases the infiltration in stand-alone retail by 43%.
- Spreading peak office entry over two hours rather than assuming everyone arrives at the same hour.

The assumptions used and resulting flows are presented in Table 27 below. Entry door infiltration is treated as additive with the envelope leakage, which is based on envelope leakage with the doors closed.

[9] https://bigladdersoftware.com/projects/params/

Table 27. Entry Door Infiltration – Comparison of NEEA Models with PNNL

Facility	Door Area (ft^2)	Building height (ft)	Door-opening frequency		NEEA (cfm)				PNNL (cfm)			
					Infiltration with Vestibule		Infiltration without Vestibule		Infiltration with Vestibule		Infiltration without Vestibule	
			Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
Large office	21	156	970	92	9666	1367	13683	2085				
Medium office	21	39	105	10	1441	130	2189	213	1438	188	2210	318
Small office	21	10	9	1	114	13	187	21	162	21	275	40
Warehouse	21	28	23	2	296	26	485	42	374	49	612	88
Quick service restaurant	21	10	90	9	1212	114	1851	187	1237	162	1913	275
Sit-down restaurant	21	10	57	6	763	76	1189	125	826	108	1302	187
Strip mall, large	21	17	34	3	441	38	713	63	511	67	824	118
Strip mall, small	21	17	16	2	204	26	335	42	285	37	471	68
Stand-alone retail	30	20	153	15	2904	274	4363	450	1986	260	3006	432
Primary school	21	13	580	58	5877	779	8460	1212	6423	840	9205	1323
Secondary school	21	26	1041	104	9443	1414	13341	2149	10837	1417	15161	2179
Small hotel	21	38	90	9	1238	117	1890	191	1254	164	1940	279
Large hotel	21	71	254	25	3312	338	4909	553				
Hospital	40	78			0	0	0	0				
Outpatient healthcare	21	30	123	12	1668	155	2521	254	1646	215	2513	361
High-rise apartment	21	100	115	13	1642	169	2486	277				
Mid-rise apartment	21	40	46	5	623	65	983	106	694	91	1103	159
Grocery	30	20	153	15	2904	274	4363	450				

C.3. Envelope Infiltration

Infiltration levels in commercial buildings are highly uncertain. A simplified design flow rate method is used by both the DOE reference buildings and the ASHRAE Standard 90.1 savings determination modeling. The model takes a design flow rate, a scheduled multiplier, and four coefficients that determine wind and stack effect modifiers. The design flow rate and the coefficients are equal partners in the resulting infiltration. Unfortunately, coefficient inputs are not established based on much more than history, with projects assuming the original defaults used by older energy simulation programs (DOE2 or BLAST) or assuming constant infiltration (E+ default).

The DOE reference buildings and the BPA prototypes assume a constant flow of outdoor air with a design air leakage rate of 0.0595cfm per ft^2 of exterior surface (0.4 cfm/ft^2 above grade wall area at 75 Pa adjusted to 5 Pa). No variation exists due to wind speed or interior to exterior temperature difference. This is modified by an infiltration schedule that reduces the leakage 75% during HVAC equipment operation.

PNNL goes through a complicated analysis of the test leakage rate at 75 Pa to calculate a design flow. This design flow is developed based on the total above-ground surface area of the building, but for some reason is only applied to the walls. PNNL models also have additional entry zone infiltration, and there may be some justification for this. Even so, single-story buildings are predicted to have very low infiltration as a result of leaving out leakage through the roof. PNNL utilizes the DOE2 default coefficients, in which infiltration is 100% dependent upon wind speed. The calculated infiltration in each hour is the design rate times 0.224 times the wind speed, which is calculated at the building's location and average height (substantially less than at the weather tower at 30' located at an open airport, except for the large office).

While general agreement exists that pressurization due to operation of mechanical ventilation fans reduces infiltration, the average degree to which this is true is debatable. The DOE reference and ASHRAE Standard 90.1 savings determination prototypes assume a 75% reduction in infiltration in most building types when the fans are on. For retail and restaurant, they assume a 50% reduction in infiltration. The difference presumably accounts for entry door openings unaccounted for with a separate entry model in the high-traffic building types.

Neither the reference building nor the PNNL approach reflects the underlying physics. One method is constant flow with no change based on wind or stack; the other is 100% wind speed-dependent and assumes zero leakage through the ceiling. Building science indicates stack effect is the primary mover for most buildings, particularly smaller buildings that dominated the prototype suite. The stack effect is a function of the temperature difference between outdoors and the building interior, and the approach includes temperature difference in calculating the infiltration. While the team does not know why PNNL excluded ceiling leakage area (excluded fraction = gross roof area/(gross wall area + gross roof area), in the single-story prototypes this exclusion constitutes a huge reduction in leakage area, and is no doubt one reason PNNL infiltration is so low.

NIST recently developed a correlation among detailed multi-zone air flow model results, building traits, and the coefficients to use in the simplified infiltration model. The NIST model explicitly accounts for some building pressurization in the model, whereas the PNNL model uses a common modeling guess that infiltration during HVAC operation is reduced 75%. Based upon the required ventilation air and building shape, the NIST fan-on infiltration reduction varies. The reduction in small office is 35%–45%, in medium office is 60%–75%, and in stand-alone retail is 55%–60%. These results, based on detailed modeling with CONTAM,[10] show considerably smaller reductions due to HVAC operation than assumed by the PNNL modeling, which is based on the very common modeling assumption.

[10] https://www.nist.gov/services-resources/software/contam

Another feature of the NIST coefficients is that infiltration is dependent upon wind and temperature, whereas the PNNL coefficients are dependent only on wind. As a result, in the Seattle climate, infiltration in the NIST building varies winter to summer by a factor of 2. The PNNL building has one month, September, that is half of the peak, April, but all other months are within 8% or less of the mean. In the small office prototype, this leads to a much larger heating energy impact from the NIST method vs. PNNL's method.

Table 28 shows a comparison of average annual air changes per hour of the various approaches. The Whole Building results include the envelope infiltration and added infiltration in the entrance zone from door operation. The entry zone leakage is for an entry without a vestibule. The Building without Entry Zone results exclude the entry zone and yield a good comparison of the envelope models. The assumed whole building tested leakage rate is 1.0 cfm/ft^2.

Table 28. Envelope Infiltration—Comparison of NIST Models with PNNL

Case		**Small Office**	**Medium Office**	**Stand-Alone Retail**
Whole Building	BPA Assumption	0.14	0.08	0.23
	PNNL	0.08	0.07	0.13
	NIST	0.40	0.07	0.26
	PNNL adjusted	0.15	0.07	0.24
Building without Entry Zone	BPA Assumption	0.13	0.07	0.23
	PNNL	0.04	0.03	0.02
	NIST	0.34	0.03	0.09
	PNNL adjusted	0.11	0.03	0.07

Small office whole-building infiltration varies by a factor of 5 between the NIST results and the PNNL method. For perspective, if the small office with a tested leakage of 1.0 cfm/ft^2 were treated as a single-family residence, the expected annual average infiltration would be approximately 0.35 air changes per hour. Pressurization from mechanical ventilation would be expected to reduce this value and infiltration from door operation would increase it (significantly so in retail and food service establishments). The medium office results are very similar between the models, presumably because of the reduced importance of the roof leakage. Stand-alone retail experiences an intermediate impact.

The PNNL adjusted case assumes leakage through the walls and ceilings rather than just the walls, and the vestibule model is modified as discussed in the vestibule section. The difference between the PNNL results and PNNL adjusted results is primarily driven by including roof leakage area; this helps to explain some of the differences between PNNL and the other methods in the small office and stand-alone retail models, which are single-story and have ceiling areas that make up a large portion of the exterior above-grade surface area.

The NIST prediction is at the upper end of realistic values for the small office but produces more mid-range values for the other building types. This work chose to use the NIST model for the following reasons:

- Based on detailed room-by-room air flow models
- Accounts for leakage of walls and roof rather than just walls
- Accounts for stack effect with higher leakage in winter
- Higher infiltration rates seem closer to truth than very low rates in small offices
- As discussed in the UA section, real-world wall and ceiling area is likely underestimated by the prototypes. Underrepresenting the wall and ceiling area per unit floor area will result in decreased infiltration. Choosing a method that produces a higher infiltration level will partially offset that.

The baseline leakage rates also generate considerable uncertainty. The primary air leakage data set includes buildings from the whole country and is dominated by east coast buildings, particularly buildings in Florida. The data set also includes very few new buildings, although the data that is present shows no diminishment of leakage in new buildings. Second, the performance of the material and sealing paths in older codes and the requirement for an air barrier are highly uncertain.

A data set of 47 new building air leakage tests (Emmerich et al. 2005) were used in the ASHRAE Standard 90.1-2010 savings determination. The data set characterizes leakage data on the basis of cfm per square foot of building surface area. These data show a mean leakage of 1.8 cfm/ft^2 at 75 Pa, although three extreme outliers in the data are responsible for moving the average from 1.0 cfm/ft^2 to 1.8 cfm/ft^2. The median is also 1.0 cfm/ft^2. The 2005 NIST paper (Emmerich and Persily 2005) determined a mean of 1.54 cfm/ft^2 (area does not include floor), with higher levels in warehouse and lower levels in office for all climates. The paper also shows a strong correlation between air tightness and heating degree days, with much lower leakage rates in colder climates. The data show an average of 0.99 cfm/ft^2 for climates with > 2,000 heating degree days, with the caveat that they have little data for the western US.

PNNL chose to use the mean value of the aforementioned data set (1.8 cfm/ft^2) as the baseline. PNNL assumed that the code air barrier and envelope sealing requirements in the code would reduce the infiltration by 45% to 1.0 cfm/ft^2, and that a testing requirement would be needed to reduce leakage further.

The current analysis assumes a baseline leakage of 1.0 cfm/ft^2 of exterior surface. Air barrier, sealing, and material language will be assumed to achieve a 45% reduction, and codes with testing requirements will be assumed to achieve the leakage consistent with the maximum allowed test result. This is “conservative” in that the lower baseline assumption means the sealing language will be assumed to reduce infiltration by 0.45 cfm/ft^2 compared with the 0.8cfm/ft^2 increment used in the ASHRAE Standard 90.1 savings determination. In terms of a real baseline, this value may yet prove to be high.

For the WSEC 2012 code with testing requirements, the design leakage rate is assumed to be 0.0595 cfm per ft^2 of exterior surface (0.4 cfm/ft^2 above-grade wall and roof area at 75 Pa adjusted to 4 Pa).

C.4. Mechanical

C.4.1. Mechanical Ventilation

The BPA prototype mechanical ventilation levels in the base models do not reflect IMC code ventilation rates, and where exhaust hoods are present, the modeling of the hood is incorrect as it underestimates the fan power. Demand control ventilation is also not implemented in the templates.

Mechanical ventilation has a large impact on energy use and savings. During WSEC 2015 deliberations, Ecotope claimed that buildings are over-ventilated. Ecotope based its claim on spot field measurements of outdoor air from rooftop units with an assumption of occupancy type and density. The actual required ventilation rates were never calculated, fans operating continuously during ventilation were assumed (although many weren’t), and the measurement system used was deemed likely flawed for the application by the manufacturer of the flow testing device. A study in California found real-world ventilation in 40 buildings to be all over the map. On average, it found ventilation rates in approximately half the buildings to be less than the ASHRAE 62.1 requirements at default occupancy. This under-ventilation resulted from a myriad of causes, ranging from fans not operating during ventilation to inadequate damper settings. Unfortunately, the study did not report the average ventilation rate related to average ASHRAE 62.1 requirements.

Given the lack of data, ventilation has been assumed to comply with the IMC minimum requirements at IMC default occupancies for the space types. IMC minimum occupancy rates and required outdoor air volumes were calculated for each prototype based on the actual mix of spaces for which the model is explicit (e.g., schools) and upon a weighted average of assumed spaces where the prototype is not specific (e.g., office).

To allow EnergyPlus to size ventilation and properly handle DCV and multi-zone variable rate procedure calculations, the peak occupancy rates and per-person and area rates were input into the EnergyPlus models. Since the peak occupancy rates were often considerably higher rates assumed by the BPA/DOE reference models, for thermal gain purposes the occupancy schedules were scaled so that non-design schedules produced the same net occupancy as the model default occupancy rate and schedule.

C.4.2. Demand Control Exhaust Hoods

The kitchen hood modeling was corrected in all prototypes with hoods. Explicit transfer air and dummy exhaust air flow parameters were added to the framework, and all flows were specified.

Table 29. Exhaust Hood Assumptions

Prototype	Hood Exhaust (cfm)	Kitchen MUA (cfm)	Transfer Zone: Transfer Zone	Transfer Zone: Supply OA (cfm)	Transfer Zone: Transfer Air (cfm)
Restaurant, full service	5400	3208	Dining	2192	2192
Restaurant, quick service	3300	2434	Dining	866	866
Hotel, large	4000	2000	Dining	2000	2000
School, primary, kitchen	4500	1500	Cafeteria	3154	3000
School, primary, bathroom	600	0	Gym	1153	600
School, secondary, kitchen	5400	1400	Cafeteria	6247	4000
School, secondary, bathroom	1200	0	Gym	10412	1200
Hospital	7200	3200	Dining	5286	4000
Retail, supermarket—deli	3000	290	Sales	3003	2710
Retail, supermarket—bakery	750	270	Produce	919	480
Residential care	3000	2400	Dining	1115	600

C.4.3. Fan Power

The fan efficiency and total static are meant to capture the range of actual fan conditions and equipment sizes found in a given situation rather than the specific size of equipment that happens to get sized for the specific model zone. Model zoning and zone sizes are in no way typical of what is often installed. Small office systems often consist of a single air handler and rarely more than four; however, the small office prototype has five zones. Consequently, the equipment that gets sized by the model is smaller than the average installed unit. Assigning values meant to be sector averages eliminates this issue.

Fan power assignment was handled differently based on system type. The static pressure is consistent among prototypes. Hospital is an exception for which model static fan and fan motor efficiencies were not changed.

Non-hospital VAV systems were assigned fan efficiency and total static pressure consistent with code maximum fan power allowances for those systems, assuming no credits for filtration, heat recovery, or fully ducted return and no debits for lacking a cooling coil.

Single-zone systems were assigned based on the equipment typically installed in the spaces. Internal and external static pressures are highly variable and are not well-characterized. In general, the larger the equipment, the higher the internal and external static pressure.

Researchers collected detailed test data for single-zone air handlers including total static pressure during development of the most recent California Database of Energy Efficiency Resources (DEER). For tests of 5–20-ton equipment, the average total static at the rated testing point was 1.7 inches. For equipment over 20 tons, the average total static was 2.8 inches. Both of these are from Air-Conditioning, Heating, and Refrigeration Institute (AHRI) testing data. These tests presumably reflect the lowest external static pressures allowed by AHRI for rating tests, which in general are very low, starting at 0.25 inches for 5-ton equipment. To make pressure drops more representative of typical installations, the modeling team added external static pressure to the above numbers. Small equipment (1–7 tons) was assumed to have an additional half inch, medium equipment (7–12 tons) was assumed to have an extra inch, and large equipment was assumed to have an additional 1.5 inches. This resulted in total pressure drops of 2.2, 2.7, and 2.9, respectively. These values were assigned by the modeling team based on the prototype and the area type served.

C.5. Lighting Controls

The BPA prototype buildings were meant to capture controls reflective of existing construction with relatively poor controls. The lighting schedules were derived from a large-scale metering project (by Northeast Energy Efficiency Partnerships (NEEP)) and the operating hours stretched or shrunk in response to CBSA hours of operation data. They do not represent new code-compliant lighting controls.

Past Pacific Northwest code evaluations have estimated savings from controls by applying field study savings factors to the model lighting EUI rather than developing detailed schedules.

For this evaluation, new lighting schedules were developed. Schedules representing ASHRAE Standard 90.1-2007 from the savings determination were edited to capture adjustments for CBSA operating hours and also changed where the modeling team felt strongly that the schedule was inappropriate for the situation. The adjustments include:

- Large hotel corridor schedule set to always on rather than varying down to 10% at night
- Stand-alone retail hours extended ~3 hours earlier in the day per the BPA project and CBSA
- Strip mall retail maintained BPA schedules that are shorter and simpler than PNNL schedules. Shorter is supported by CBSA data on small retail. In addition, adopting PNNL schedules add significant complexity by establishing three different operating profiles in various spaces that would require changing all schedules.
- Midrise apartment residence schedule fractions, which range from 0.02 to 0.32 in the PNNL schedule, are quite low. The DOE reference building schedules are quite high. The two schedules were averaged to get schedule fractions from 0.0435 to 0.66.
- Schools: The BPA work established school operating schedules relying on CBSA hours of operation and the NEEP monitoring data. Both of these sources lead to schedules much shorter than the DOE/PNNL schedules. For this codes work, the PNNL schedules served as the starting point. All lighting schedules except the secondary school gym, and corridors and lobby in both schools, were reduced from 14 hours per weekday to 11 hours assuming the unoccupied period begins at 5pm rather than 9pm as assumed in the DOE/PNNL models. Corridor and lobby space occupied periods were reduced from 14 hours per day to 12 hours. The gym was maintained at 14 hours per day. The summer schedules were reduced from 12 hours per day semi-occupied to 8 hours semi-occupied.
- Hospital schedule occupied hours were increased in corridor and lobby spaces. Separate schedules were developed for patient areas and other critical care areas, with patient areas having a reduced fraction of lighting on and other critical care areas having a higher fraction.

The team made further changes to reflect WSEC 2012 control provisions by applying savings factors to the ASHRAE Standard 90.1-2007 schedule values. The team applied factors to occupied and/or unoccupied hours. For consistency with national determinations, savings factors utilized by PNNL were used unless specific concerns led to use of a different factor. PNNL documentation indicates that the occupancy sensor control factors impact occupied and unoccupied hours, but based on the PNNL published models, this was inconsistently applied (e.g., school classroom and enclosed office factors are applied only to occupied hours, but large hotel storage is applied to occupied and unoccupied hours). This evaluation has tried to be consistent with the PNNL models. The final lighting schedules were used for the WSEC 2012 base lighting schedules and further changes were made to reflect WSEC 2015.

Hotel/Motel Unit Controls
The WSEC 2012 requires hotel/motel sleeping units to have a master switch at the door and in addition requires all units in buildings with over 50 units to have OS or captive key controls. PNNL evaluated OS control of bathroom lights for the 90.1-2010 and bathroom OS control with captive key/OS control for the rest of unit for 90.1-2013. Curves were taken from the ASHRAE 50% Advanced Energy Design Guide savings determination work.

Since the WSEC implements the captive key/OS control for the unit, but not separate OS control for the bathroom, the difference between the two schedules was applied to the baseline code to get a WSEC 2012 lighting schedule. PNNL savings would be the difference between the unit OS and the bathroom-OS-only schedules (~26%). For context, the CEC chose savings of ~16% for unit OS, which they state is conservative. PNNL also modeled at 17% reduction in plug loads for the switched receptacles.

In the course of this work, the researchers realized that this measure had never been evaluated since at the time, the model set being used did not include lodging. The team therefore made a retroactive savings calculation for this measure and used the post-measure condition as the base for WSEC 2012.

Table 30. Lighting Control Savings Factors

WSEC 2012 Control Requirements	PNNL	Savings Fraction Assumed in Previous WSEC Evaluations	Adjustment Applied to 90.1-2007 Schedule
Classroom OS (includes lab classrooms)	32% (all hours)	10% (all hours)—CEC work found savings of 32%, but this assumed savings over no automated control rather than spaces with sweep controls. OS assumed to save an additional 10% beyond sweep control.	10%
Enclosed office OS	22% (all hours)	20%	20%
Healthcare exam rooms OS	22% (all hours)	Not evaluated	11%
Restroom OS	34% (all hours)	Not evaluated	34%
Storage OS	48% (all hours)	Not evaluated	48%
Warehouse OS (100% reduction - 2012)	20% (occupied hours)	28%	20%
Manual light reduction controls where no OS control	Not evaluated	5%—CEC work found 8% savings in classroom and 18% in office. Several concerns with the CEC resulted in the WSEC analysis using the lower number, though an even lower number (2.4%) was possibly indicated.	Not accounted for
Manual or 50% automatic on in OS controlled spaces	Evaluated only in daylit perimeter enclosed offices. Whole building schedule reduced 2.9%, 1.7%, and 1.3% in small, medium and large office, respectively.	Not previously captured	Assuming bi-level control research is correct, this should save energy in more than just daylit office spaces.
Manual light reduction control in non-OS controlled areas	Not evaluated	Assumed to save 5%	
Egress Lighting	The preliminary ASHRAE Standard 90.1-2016 savings determination does a detailed analysis to ensure no more than 0.02W/ft^2 is on at night.	Egress controls have been specified since the WSEC 2009, which required them to be off. Savings were estimated at 4% of total lighting energy. The WSEC 2012 adopted less stringent requirements that allowed 0.05W/ft^2 in the hope it would lead to better adoption. The WSEC 2015 decreased the allowed egress lighting to 0.02W/ft^2. Since savings were accounted for in the 2009 evaluation, egress lighting control is assumed in the base case.	Savings already claimed. WSEC 2012 is assumed to have 20% lower lighting during occupied hours.