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2018 Washington State Energy Code Energy Savings Analysis for Nonresidential Buildings

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Table of Contents

Table of Tables

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Executive Summary

The Northwest Energy Efficiency Alliance (NEEA) provides technical assistance to Washington state to achieve its energy policy goals. As part of this support, NEEA evaluates code-to-code energy savings from new editions of the Washington State Energy Code (WSEC). The 2018 WSEC (SBCC 2020) was adopted by the Washington State Building Code Council and went into effect on February 1, 2021. NEEA contracted with NORESCO to conduct this study to evaluate the energy savings from the commercial provisions of the 2018 WSEC relative to the 2015 WSEC (SBCC 2017). The analysis also evaluated the 2018 WSEC energy savings relative to the 2006 WSEC to determine progress toward Washington state's legislative goal[1] of reducing annual net energy consumption for commercial buildings under the 2030 energy code by 70% relative to the 2006 WSEC (SBCC 2007).

The 2018 WSEC is an overlay of the 2015 WSEC and the 2018 International Energy Conservation Code (IECC) (ICC 2018), with additional Washington-specific amendments that increase the stringency beyond either of the two codes. The 2018 edition added several new requirements with the most notable being the total system performance ratio (TSPR) requirement for HVAC systems, reduction of the interior and exterior lighting power allowances, and improved fenestration performance.

NORESCO conducted the analysis in two phases: a qualitative analysis phase followed by a quantitative analysis phase. The team performed the qualitative analysis first to determine those code requirements that 1) affect energy consumption, 2) are applicable to selected building types and their features, and 3) can be modeled. This analysis represents a conservative estimate of savings from the new energy code because some building types and systems are not represented in the analysis and therefore are not accounted for in the savings estimate. Additionally, changes in 2018 WSEC from federal standards were not accounted for in the 2018 WSEC impact relative to 2015 WSEC (but they were accounted for in the comparison with 2006 WSEC). The second phase, the quantitative analysis, compares the energy consumption of the prescriptive and mandatory requirements of the 2015 WSEC with the prescriptive and mandatory requirements of the 2018 WSEC. The team performed this analysis using whole building energy modeling, using EnergyPlus, and by using prototypical building energy models (prototype models) that represent the building stock in Washington. The annual site energy

[1] Revised Code of Washington (RCW) 19.27A.160.

savings per square foot from prototype models were expanded to annual statewide energy savings estimates by applying annual new construction floor area forecast to the unit savings. The floor area forecast is an annual average of the forecasted floor area for each year from 2022 to 2041 and uses data from Dodge and the Northwest Power and Conservation Council.

Qualitative Analysis Results

Table 1 shows the results of the qualitative analysis. The team compared the two WSEC code editions—2015 and 2018—to determine all changes between the two codes, and then analyzed each change to determine whether it impacted the energy consumption. For changes to be included in the quantitative analysis, they must not only impact energy consumption; they must also be applicable to the prototype buildings selected for the analysis. The team identified a total of 64 unique measure changes as impacting energy consumption, of which 27 were captured in the quantitative analysis. Those changes not quantified were omitted primarily because they were not applicable to the selected prototypes.

Table 1. Qualitative Analysis Summary

Change Category	Total Number of Measures
Direct Energy Impact	64
Impact Quantified	27
Impact Not Quantified*	37

**Note:* These changes did not have their impacts quantified for one of the following reasons: the change was not applicable to the prototypes, the change was assumed to be standard practice, or the change could not be modeled due to complexity or simulation engine limitations.

Quantitative Analysis Results

The quantitative analysis modeled the quantifiable changes between the 2015 and 2018 WSEC using the prototype models. Table 2 shows the list of selected prototypes and the percent site energy savings by prototype. After weighting across prototypes and climate zones, the statewide increase in stringency between the 2018 and 2015 WSEC on a site energy basis was estimated to be **7.7%.**

Table 2. 2018 WSEC Percent Change in Stringency

Prototype	Fuel Source-Weighted Savings			
	Electricity, kWh/sf	Natural Gas, therms/sf	Total, kBtu/sf	% Savings
Large Office	0.261	0.004	1.3	2.6%
Medium Office	0.592	0.000	2.0	7.4%
Small Office	0.347	0.001	1.3	5.2%
Standalone Retail	1.158	0.015	5.4	14.5%
Strip Mall Retail	0.971	-0.003	3.0	5.7%
Sit-down Restaurant	0.281	-0.003	0.7	0.2%
Fast-food Restaurant	1.554	-0.004	4.9	1.0%
Warehouse	0.260	0.005	1.4	13.8%
Secondary School	0.873	0.001	3.1	9.9%
Primary School	0.574	-0.002	1.8	4.2%
Hospital	-0.715	0.013	-1.1	-1.0%
Outpatient Healthcare	0.179	0.013	2.0	1.8%
Large Hotel	0.245	0.004	1.2	1.8%
Small Hotel	0.223	-0.001	0.7	0.9%
High-rise Residential	0.746	0.006	3.1	8.3%
Mid-rise Residential	0.402	0.003	1.7	4.8%
		Statewide Weighted Savings		**7.7%**

Table 3 shows estimated annual statewide electricity and natural gas savings by prototype. The **estimated annual statewide savings** between 2015 WSEC and 2018 WSEC are **16,036,127 kWh and 122,217 therms**. These estimated savings have uncertainty associated with them arising from uncertainty around the fuel mix estimates, floor area forecast uncertainty and the fact that the floor areas are limited to new construction and additions and do not include alterations that trigger the code.

Table 3. Forecasted Annual Statewide Electricity and Natural Gas Savings

Prototype	Statewide Savings Electricity, kWh/year	 Natural Gas, therms/year
Large Office	517,606	7,484
Medium Office	891,063	160
Small Office	420,235	1,001
Standalone Retail	594,840	7,463
Strip Mall Retail	320,747	-925
Sit-down Restaurant	15,483	-151
Fast-food Restaurant	85,518	-242
Warehouse	1,286,559	24,364
Secondary School	2,209,891	2,845
Primary School	1,283,706	-3,835
Hospital	-236,115	4,437
Outpatient Healthcare	171,071	12,820
Large Hotel	287,315	4,619
Small Hotel	24,514	-90
High-rise Residential	7,470,297	57,184
Mid-rise Residential	693,398	5,082
Total Statewide Savings	**16,036,127**	**122,217**

Progress Toward 2030 Targets

Tracking progress toward Washington's 2030 legislative goals is one of the objectives of this report. Table 4 shows the results of the analysis comparing 2018 WSEC to 2006 WSEC. The analysis comprises weighting for heating fuel sources (gas, electric resistance, and heat pump) and climate zones to estimate the statewide savings for each prototype as well as weighting of the prototypes to determine the weighted statewide savings. The analysis shows that the 2018 WSEC saves 28% of site energy relative to the 2006 WSEC. The State Building Code Council (SBCC) estimated the relative increase in stringency between 2018 WSEC and 2006 WSEC to be 31% (Odum, et al. 2020). The estimated increase in stringency calculated in this analysis is close to this percentage, but slightly lower. The primary differences between this analysis and the SBCC analysis appear to be floor area weighting, choice of prototype models, and HVAC system selection. Other differences in the modeling approaches likely exist as well.

Table 4. 2018 WSEC Percent Improvement Relative to 2006 WSEC

	Weights		Weighted Consumption		Weighted Savings	
			2006	2018		
Prototype	4C	5B	kBtu/sf	kBtu/sf	Total, kBtu/sf	% Savings
Large Office	5.87%	0.81%	62.0	48.5	13.5	21.8%
Medium Office	4.45%	0.61%	42.8	25.5	17.4	40.5%
Small Office	3.59%	0.49%	38.9	23.1	15.8	40.6%
Standalone Retail	1.52%	0.21%	57.9	31.8	26.1	45.0%
Strip Mall Retail	0.98%	0.13%	74.4	49.7	24.7	33.2%
Sit-down Restaurant	0.16%	0.02%	357.9	311.6	46.3	12.9%
Fast-food Restaurant	0.16%	0.02%	536.0	496.4	39.7	7.4%
Warehouse	14.67%	2.02%	14.1	8.6	5.4	38.5%
Secondary School	7.50%	1.03%	53.1	28.1	25.0	47.1%
Primary School	6.63%	0.91%	57.5	41.2	16.3	28.3%
Hospital	0.98%	0.13%	152.5	114.9	37.6	24.7%
Outpatient Healthcare	2.82%	0.39%	125.2	104.5	20.7	16.5%
Large Hotel	3.48%	0.48%	96.6	68.1	28.5	29.5%
Small Hotel	0.33%	0.04%	83.9	72.2	11.7	13.9%
High-rise Residential	29.66%	4.08%	41.9	34.3	7.6	18.1%
Mid-rise Residential	5.11%	0.70%	39.4	33.1	6.3	15.9%
				Statewide Weighted Savings		**28%**

Introduction

The Northwest Energy Efficiency Alliance (NEEA) provides technical assistance to Washington state to achieve its energy policy goals. As part of this support, NEEA evaluates code-to-code energy savings from new editions of the Washington State Energy Code (WSEC). The 2018 WSEC (SBCC 2020) was adopted by the Washington State Building Code Council and went into effect on February 1, 2021. NEEA evaluated the energy savings from the commercial provisions of the 2018 WSEC, the current energy code, relative to the 2015 WSEC (SBCC 2017), the previous energy code. This report describes the results of the analysis, the methodology used, and the statewide energy savings impact from the adoption of the 2018 WSEC. The analysis also evaluated the 2018 WSEC energy savings relative to the 2006 WSEC to determine progress toward Washington state's legislative goal[2] of reducing annual net site energy consumption for commercial buildings under the 2030 energy code by 70% relative to the 2006 WSEC (SBCC 2007).

The analysis is focused on the commercial provisions of the WSEC that are applicable to newly-constructed nonresidential buildings and multifamily buildings three stories or higher. The 2018 WSEC is an overlay of the 2015 WSEC and the 2018 International Energy Conservation Code (IECC) (ICC 2018), with additional Washington-specific amendments that increase the stringency beyond either of the two codes. The 2018 WSEC added several new requirements with the most notable being the total system performance ratio (TSPR) requirement for HVAC systems, reduction of the interior and exterior lighting power allowances, and improved fenestration performance, among others.

NEEA has conducted similar analyses in the past, the latest one being the analysis of the 2015 WSEC relative to the 2012 WSEC (Kennedy 2021). The current analysis builds on the previous analysis by incorporating data sources and assumptions, while it differs from the previous one in that "current practice" savings[3] have not been evaluated. This work also relies on prototypical energy models from Pacific Northwest National Laboratory (PNNL) and previous work conducted by PNNL in developing modeling strategies to capture code-to-code changes.

NORESCO was sponsored by NEEA to conduct this analysis. A simulation infrastructure was used to perform energy modeling of multiple prototypes, in two climate zones, and for three code editions. Savings from individual prototype models were mapped to building types, and a construction forecast from Dodge and Northwest Power and Conservation Council (NPCC)'s draft 2021 Power Plan was used to estimate statewide savings.

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[2] Revised Code of Washington (RCW) 19.27A.160.

[3] Current practice savings incorporate the impact of current building practices that are equal to or better than the new code requirements (generally resulting in lower savings).

Methodology

The methodology used to evaluate savings between the 2015 and 2018 WSEC editions is similar to that used by the United States Department of Energy (U.S. DOE) to evaluate the code-to-code savings between the national commercial model energy codes—ASHRAE Standard 90.1 and the IECC. The analysis is intended to provide an estimate of code-to-code energy savings while accounting for market trends in the choice of fuel for space heating.

Overall Approach

The WSEC has two major paths—the prescriptive path and the performance path—and this analysis evaluated the change in stringency of the prescriptive path. The analysis consisted of two major phases: a qualitative analysis phase followed by a quantitative analysis phase. The qualitative analysis was performed first to determine those code requirements that 1) affect energy consumption, 2) are applicable to selected building types and their features, and 3) can be modeled. The energy code consists of many requirements that do not directly affect energy consumption and are therefore not captured in a quantitative analysis (for example, documentation or labeling requirements). The energy code also has requirements for building systems or features that are not included in the building types used in the evaluation. For example, parking garages have code requirements but because parking garages were not among the building types selected for this analysis, the energy savings from changes to the parking garage requirements were not evaluated. Another example would be heat rejection bypass requirements for water-loop heat pump systems (WLHP), which save energy but are not captured because WLHPs are not included in the HVAC systems in the prototypes. Finally, certain requirements may impact the selected building types, but they cannot be modeled due to limitations of the simulation engine or due to resource constraints. Thus, the quantitative analysis represents a conservative estimate of savings from the new energy code.

The savings analysis comparing 2015 WSEC to 2018 WSEC excluded federally mandated changes to equipment efficiency—for example, chillers, air conditioners, motors, and other equipment regulated by federal standards—from the savings calculation. This is because savings from those changes are assumed to be unattributable to the 2018 WSEC (NEEA may evaluate the impact of those savings separately). To exclude the savings impact, the equipment efficiencies were held to the 2018 WSEC levels for both the 2018 and 2015 WSEC editions. For comparison to 2006 WSEC, the objective was to track progress toward the 2030 goal including all code changes; therefore, the impact of changes to federally mandated efficiencies was captured.

The quantitative analysis compares the energy consumption of the prescriptive and mandatory requirements of the 2015 WSEC with the prescriptive and mandatory requirements of the 2018 WSEC. The analysis was performed using whole building energy modeling and using prototypical building energy models (prototype models) that represent the building stock in Washington state. The annual site energy savings (per square foot) from prototype models were then expanded to a statewide energy savings estimate by applying forecasted floor area estimates to the per square foot savings. Additional details about the methodology are presented below.

The approach to determine the prototypes' 2006 WSEC energy consumption was similar to that used for the 2015 and 2018 editions. A qualitative analysis previously performed for the 2006 WSEC (Athalye, Shadd and Arent, Washington State Commercial Energy Code Technical Roadmap 2020), was reused and expanded to several more prototypes beyond the five used for the Roadmap analysis.

Prototypes and Climate Zones

The U.S.DOE EnergyPlus (DOE 2021) program (Version 9.0) was chosen to perform the energy modeling. EnergyPlus is a state-of-the-art whole building simulation engine that allows the modeling of various energy saving features in buildings. A simulation infrastructure was used to perform parametric simulations for multiple prototype models, two climate zones, and three code editions, and the results were aggregated for further analysis.

Prototypes. PNNL publishes prototype models for various IECC editions (PNNL 2021). These prototype models were used as the starting point for the analysis and were modified further to represent the Washington state building stock. These prototype models were selected because the building types they represent account for approximately 80% of the projected building stock floor area within Washington state. Table 5 shows the prototype models used for the analysis.

Table 5. Prototype Models Used for the Analysis

Prototype	Floor Area, ft^2	Number of Stories
Mid-rise Residential	33,740	4
High-rise Residential	84,360	10
Large Office	498,640	12
Medium Office	53,630	3
Small Office	5,500	1
Standalone Retail	24,690	1
Strip Mall Retail	22,500	1
Primary School	73,970	1
Secondary School	210,910	2
Warehouse	52,050	1
Sit-down Restaurant	5,500	1
Fast-food Restaurant	2,500	1
Large Hotel	122,120	6
Small Hotel	43,210	4
Hospital	241,410	5
Outpatient Healthcare	40,950	3

The base IECC prototypes from PNNL were edited to incorporate the mandatory and prescriptive requirements of the three WSEC editions (2006, 2015, and 2018). Additional adjustments were made to the prototypes to make them more representative of the Washington state building stock. These adjustments were summarized in a memo, which has been included in this report in

Appendix A: Prototype Adjustments Memo. The key adjustments made to the prototype models follow:

1. Mechanical ventilation rates were changed to meet the requirements of the amended International Mechanical Code, prescribed in the Washington Administrative Code (WAC) Chapters 51–52 and the Ventilation and Indoor Air Quality Code of 2006 (for the 2006 WSEC).
2. HVAC system type adjustments were made to make the models more representative of the Washington state building stock. This was based on data from NEEA's Washington 2015 Commercial Construction Code Evaluation Study (yet to be published), a past energy savings analysis (Kennedy 2021), a previous stock assessment funded by NEEA (Baylon and Kennedy 2008), NEEA's 2019 Commercial Building Stock Assessment (NEEA 2020), and the 2016–2017 Residential Building Stock Assessment (NEEA 2017).

3. An advanced algorithm within EnergyPlus—KIVA—was used to perform ground heat transfer calculations for a few prototypes (Primary School, Secondary School, Standalone Retail, Strip Mall Retail, and Warehouse) for which ground heat transfer was deemed a significant portion of overall envelope heat transfer.

Climate Zones. The Adjustments Memo (Appendix A) also describes an analysis of weather and climate zone mapping in Washington state, particularly the mapping of counties in southeastern Washington that appear to have somewhat distinct weather relative to northeastern Washington, represented by Spokane. The analysis concluded that two weather locations (one for western Washington and one for eastern Washington) would be sufficient to capture most of the impacts from newly-constructed buildings within the state.

Table 6 shows the selected weather locations and weather files. Each prototype model was simulated in the two weather locations.

Table 6. Weather Locations and Files

Climate Zone	Location	Weather Station	EPW Filename
4C	Seattle	Seattle-Tacoma International Airport – 727930	USA_WA_Seattle-Tacoma.Intl.AP.727930_TMY3.epw
5B	Spokane	Spokane International Airport – 727850	USA_WA_Spokane.Intl.AP.727850_TMY3.epw

Construction Area Projection

After the annual unit energy savings were calculated for each prototype, a future floor area forecast was applied by climate zone to each prototype to estimate the projected statewide savings from 2018 WSEC relative to 2015 WSEC. The floor area forecast for new construction buildings was based on the floor area forecast from the Northwest Power and Conservation Council's draft 2021 Power Plan (NPCC 2021) and the 2015–2020 construction starts data from Dodge (Dodge 2021) provided by NEEA. An average of the annual total forecasted floor area from 2022 through 2041 from the NPCC was used to smooth out year-to-year variations. The Dodge construction starts data were mapped to the prototypes and to counties and climate zones. The average annual total floor area forecast from NPCC was applied to each prototype, and the climate zone distribution derived from the Dodge data was used to calculate the floor space attributed to each prototype in each climate zone.

Heating Fuel Mix Adjustment

Past analyses of WSEC energy savings (Kennedy 2021) have performed an engineering calculation to determine the electric and gas savings from the use of different heating fuel types (natural gas, electric resistance, and heat pump). A similar approach was employed in this analysis, where conversion factors were used to convert from one fuel type to the other. The modeled HVAC system type for each prototype was based on analysis of dominant HVAC system types in the Washington state building stock. This analysis is described in

Appendix A: Prototype Adjustments Memo. The heating fuel source was held constant between 2015 and 2018 WSEC, and also between 2006 and 2018 WSEC. The analysis does not account for changes in site energy associated with changing heat fuels. As a result, savings estimates in this report do not capture any impacts from possible increased use of heat pump technologies driven by the 2015 and 2018 WSEC editions.

Table 7 shows the selected HVAC system type for each prototype as well as the dominant heating source in each prototype, which was used in the heating source conversions.

Table 7. Prototype Dominant Heating Source

Prototype	Selected HVAC System Type	Dominant Heating Source	Ventilation
Mid-rise Residential	Split system, DX cooling and electric resistance heating. Common areas with DX cooling and furnace heating.	Electric Resistance	Balanced ventilation system for each unit
High-rise Residential	Dwelling unit HVAC is packaged AC/electric resistance and common areas have single zone packaged AC/furnace.	Electric Resistance	Balanced ventilation system for each unit
Large Office	Built-up VAV, HW reheat, chiller and boiler	Gas	Through the VAV system
Medium Office	Packaged single-zone AC/gas furnace	Gas	2006: Through the packaged system. 2015/2018: Dedicated outdoor air systems (DOAS)
Small Office	Split heat pumps	Heat Pump	2006: Through the split system. 2015/2018: DOAS
Standalone Retail	RTU DX cooling and gas furnace heating	Gas	2006: Through the RTU. 2015/2018: DOAS
Strip Mall Retail	Split heat pumps	Heat Pump	2006: Through the split system. 2015/2018: DOAS
Secondary School	Single zone air handlers with hydronic heating and cooling	Electric Resistance	2006: Through the AHUs. 2015/2018: DOAS
Primary School	Packaged VAV, electric reheat, DX cooling, gas furnace central heating coil	Gas	2006: Through the AHUs. 2015/2018: DOAS
Warehouse	Gas furnace unit heater. Packaged DX cooling for office and fine storage.	Gas	Through the packaged system.
Sit-down Restaurant	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.	Gas	Through the packaged system
Fast-food Restaurant	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.	Gas	Through the packaged system
Large Hotel	Public spaces on ground floor and top floor: VAV with hot water reheating coils. Guest rooms: dedicated outside air system + four-pipe fan-coil units	Gas	DOAS for guest rooms and AHUs for common areas
Small Hotel	Guest rooms: PTAC with electric resistance heat. Common areas: packaged AC with furnace.	Electric Resistance	Through the PTACs
Hospital	Medical critical zones: AHUs with hot water reheating and electric stream humidifiers, either CAV or VAV with reheat depending on codes and standards.	Gas	Through the AHUs
Outpatient Healthcare	VAV terminal box with damper and hot water reheating coil, DX cooling. Electric resistance reheat in one AHU.	Gas	Through the AHUs

The assumed heating efficiency for gas was 0.8 and for electric resistance was 1.0. An annual weighted-average heating COP was calculated for heat pumps[4] based on the results from the Small Office prototype, which uses the split heat pump system (with code minimum values for EERs). These efficiencies were used to calculate the heating source conversion factors. This method is a first order approximation intended to provide an estimate of the impact of different heating sources. To calculate the weighted heating end-use savings, savings from individual fuel sources were weighted by the fraction of the floor area assumed to be served by each fuel source for a given prototype. These heating source weighting factors (or “saturations”) were developed using the 2015 WSEC analysis (Kennedy 2021) and a previous analysis performed for NEEA (Baylon and Kennedy 2008).

Modeling Implementation

NORESCO used a modeling and simulation infrastructure to perform parametric simulation analysis. This analysis included 16 prototype models, two climate zones, and three code editions. The prototype models were parameterized using variables to allow simulation of the various models across code editions and climate zones. For each code requirement identified for inclusion in the quantitative analysis, a modeling strategy was developed that identifies its applicability within prototypes and the values to be used as the model input for various code editions. After testing the correct operation of the requirement within the model, the entire model was simulated. Results were aggregated and prepared for presentation in the report and elsewhere.

Data Sources

1. **Codes and Standards:** The three WSEC code editions, 2006, 2015, and 2018, were used to perform the qualitative and quantitative analyses. In addition, the Washington Administrative Code (WAC) Chapters 51–52 and the Ventilation and Indoor Air Quality Code of 2006 (for the 2006 WSEC) were used for determining the ventilation requirements.
2. **Prototype Models:** PNNL’s IECC-based prototype models were used as the starting point for the analysis (PNNL 2021).

[4] This is an approximation; other types of heat pump systems, including water loop heat pumps, may function differently from a split heat pump.

3. **HVAC System Selection:** Data from NEEA's 2019 CBSA (NEEA 2020) and 2016–2017 RBSA (NEEA 2017) were used to inform the HVAC system choices for each prototype.
4. **Construction Forecast:** The Northwest Power and Conservation Council's floor area forecast for new construction for nonresidential and residential buildings in its draft 2021 Power Plan was combined with Dodge construction starts data to develop the construction forecast used for this analysis.
5. **Model Inputs:**
    a. Several other data sources were used in the development of modeling inputs, including past technical support documents from PNNL as well as previous WSEC energy savings analysis reports.
    b. For choosing the additional efficiency package options (C406) in the 2015 and 2018 WSEC editions, the 2015 WSEC energy savings analysis report (Kennedy 2021) and the preliminary results from NEEA's Washington 2015 Commercial Construction Code Evaluation Study (yet to be published) were used.

Results

Qualitative Analysis Results

The results of the qualitative analysis are presented in The following 13 pages consist of a memo written by NORESCO in September 2021, while the researchers were performing the analysis. The memo is included as-written, with a few clarifying edits made; as such, the table numbers and figure numbers are separate from those in the rest of this report.

MEMO: ADJUSTMENTS TO PROTOTYPE MODELS

2018 WSEC Commercial Energy Savings Analysis

24 September 2021

Rahul Athalye and Eric Shadd

Background and Objective

NEEA contracted NORESCO to develop an estimate of energy savings and percent improvement of the newly adopted 2018 Washington State Energy Code (WSEC), Commercial Provisions, which went into effect on February 1, 2021 with respect to the commercial provisions of the 2015 WSEC. As part of this project, prototypical energy models from Pacific Northwest National Laboratory (PNNL) would be used to determine the energy savings. A secondary objective of this analysis is to develop the statewide energy consumption using prototype models for the 2006 WSEC. The first task is to determine the adjustments needed to the prototype models to align the models with Washington's fuel mix and mechanical ventilation requirements and also consider other adjustments to improve model accuracy. The adjustments under consideration are as follows:

1. Fuel mix adjustments for space and water heating and cooking.
2. Ground contact algorithm.
3. Mechanical ventilation.

This memo summarizes the adjustments that will be performed to the prototype models.

Fuel Mix Adjustments

To accurately calculate the statewide electricity and gas savings from the 2018 WSEC relative to the 2015 WSEC, the prevalent fuel mix within the building stock, and in particular, the forecasted new construction fuel mix must be used in combination with electricity and gas savings from the prototype models. The energy savings calculation would look like this:

Statewide savings per climate zone =

Prototype electricity savings per ft^2 x Projected floor area with electric-based systems per climate zone

+

Prototype gas savings per ft^2 x Projected floor area with gas-based systems per climate zone

To develop the prototype electricity and gas savings, heating, ventilating, and air conditioning (HVAC), service water heating (SWH), and cooking system savings must be individually developed for electric-based systems and gas-based systems. The methodology for calculating these electric and gas system savings is described below.

HVAC Systems

HVAC systems are the main consideration for the fuel mix adjustment. Heating can be provided by gas furnaces and boilers resulting in gas use, or by electric resistance and heat pumps resulting in electricity use. The approach used to determine electricity and gas savings is to model either an electric- or gas-based system in each prototype (though there may be more than one HVAC system type in each prototype), and then apply a conversion factor outside of the model to the heating end-use calculated from the model to determine savings from the other fuel type. For example, the Small Office prototype uses a single-zone heat pump as its HVAC system. To develop the energy savings between 2015 and 2018 WSEC for a Small Office prototype with a gas furnace, a conversion factor will be applied to the heating end-use consumption of both the 2015 and 2018 cases with the heat pump system.

The conversion factor will be determined from past comparisons of electric- and gas-based systems. The step-by-step process is as follows:

1. Begin with HVAC systems in the PNNL model.
2. Change the HVAC system types in the PNNL models to match HVAC systems typically used in Washington for various building types.
3. Use the 2030 WSEC Roadmap Results to develop conversion factors between gas-based and heat pump-based systems.
4. Apply the conversion factors to the appropriate end-uses. The conversion factors will be evaluated and applied to the heating fans, pumps, and other appropriate end-uses.

For example, the Small Office prototype uses split heat pumps as its HVAC system. The model output would be analyzed to determine the average difference in heat delivery efficiency between a heat pump-based system and a gas furnace, whose efficiency is typically 80%. For a heat pump, the coefficient of performance (COP) varies with temperature and decreases with colder temperatures, as shown in Figure 1.

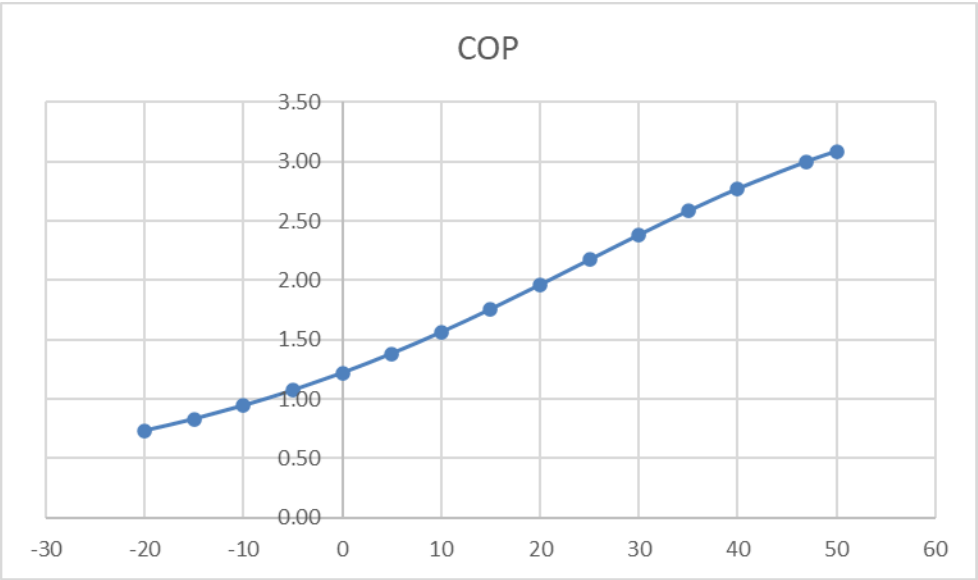

Figure 1: Example of COP change with outside air temperature.

An annual weighted-average heating COP will be calculated for the heat pump system using the Small Office prototype. The effective COP of the heat pump including the supplementary coil was calculated for each hour and each system in the prototype, and then an annual weighted-average COP for the entire prototype was calculated by weighting the COP for each hour with the delivered heating. These average COPs were calculated for 5B and 4C, and the lower value was used for the conversion factor. To determine the heating end-use consumption for a gas system, a conversion factor will be applied to the heat pump consumption as follows:

Gas furnace heating consumption = Heat pump heating consumption x average heating COP / furnace efficiency

Table 1 shows the HVAC systems selected for this analysis. In many prototypes, the HVAC systems differ from the base HVAC systems in the PNNL prototypes. These adjustments to the HVAC systems will be made during Task 2 of the project, where code requirements for the three code editions (2006, 2015, and 2018) are modeled within the prototype buildings. Table 1 also shows HVAC systems from the 2015 WSEC Commercial code savings analysis and the TSPR Standard Reference Systems because they were considered as alternatives during the HVAC system selection process.

Table 1: Prototype HVAC system evaluation and final selection

Prototype	2015 WSEC Energy Savings Analysis HVAC System	2018 TSPR Standard Reference Design System	HVAC System Selected for Analysis	Selection Basis (Source)
Mid-rise residential	Electric resistance heat and no cooling in the dwelling units and single zone packaged AC/furnace in the common area.	Not in WSEC. Seattle Energy Code, TSPR: Single-zone split heat pumps.	Split system, DX cooling and electric resistance heating. Common areas with DX cooling and furnace heating.	RBSA II and preliminary findings from NEEA's 2021 code implementation study
High-rise residential	Dwelling unit HVAC is packaged AC/ electric resistance and common areas have single zone packaged AC/furnace.	Not in WSEC. Seattle Energy Code, TSPR: Single-zone split heat pumps.	Dwelling unit HVAC is packaged AC/ electric resistance and common areas have single zone packaged AC/furnace.	RBSA II and preliminary findings from NEEA's 2021 code implementation study
Office – large	VAV with series fan powered terminals on perimeter and pinch boxes in the core with electric resistance reheat.	Water-source heat pump.	Built-up VAV, HW reheat, chiller and boiler.	2019 CBSA
Office – medium	Packaged single-zone AC/gas furnace	Water-source heat pump.	Packaged single-zone AC/gas furnace.	2015 WSEC Analysis
Office – small	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	Split HPs.	PNNL Prototype system
Retail – large	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	RTU DX cooling and gas furnace heating.	2019 CBSA
Retail – small	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	Split HPs	PNNL Prototype system
School – secondary	Single zone air handlers with hydronic heating and cooling	Packaged air-source heat pump.	Single zone air handlers with hydronic heating and cooling	2015 WSEC Analysis
School – primary	VAV with pinch boxes and electric hydronic reheat in classrooms. Single-zone air handlers with hydronic heating and cooling for common areas.	Packaged air-source heat pump.	Packaged VAV, electric reheat, DX cooling, gas furnace central heating coil	2019 CBSA and 2015 WSEC Analysis
Warehouse	Packaged single-zone AC, gas furnace in office. Gas fired unit heaters in storage.	NA	Gas furnace unit heater. Packaged DX cooling for office and fine storage.	PNNL Prototype system
Restaurant – sit-down	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.	NA	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.	2019 CBSA and 2015 WSEC Analysis
Restaurant – fast food	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.	NA	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.	2019 CBSA and 2015 WSEC Analysis
Lodging – Hotel	Common areas: single zone air handlers Guest rooms: four pipe fan coils.	NA	Public spaces on ground floor and top floor: VAV with hot water reheating coils. Guest rooms: dedicated outside air system + four-pipe fan-coil units.	2019 CBSA
Lodging – Motel	Common areas: packaged single-zone AC, gas furnace	NA	Guestrooms: PTAC with electric resistance heat.	2019 CBSA

Prototype	2015 WSEC Energy Savings Analysis HVAC System	2018 TSPR Standard Reference Design System	HVAC System Selected for Analysis	Selection Basis (Source)
	Guest rooms: PTAC		Common areas: Packaged AC with furnace.	
Hospital	CAV and VAV with pinch terminals. Gas boiler, hot water reheats.	NA	Medical critical zones: AHUs with hot water reheating and electric stream humidifiers, either CAV or VAV with reheat depending on codes and standards.	PNNL Prototype system
Outpatient Healthcare	Not modeled	NA	VAV terminal box with damper and hot water reheating coil, DX cooling Electric resistance reheat in one AHU.	PNNL Prototype system

Findings from RBSA and other studies indicate that a large proportion of mid- and low-rise multifamily buildings do not have cooling systems. This trend is changing with new construction. For this analysis, an assumption is made that there is a cooling system prevalent in the Mid-rise Apartment prototype, so that the impact of 2018 WSEC on future new construction stock can be fully accounted.

SWH Systems

Table 2 shows the SWH systems within the PNNL prototypes. Within the prototypes, SWH system type and fuel type is based on common design practices. For example, most large SWH systems are gas fired, whereas smaller and distributed SWH systems are electric resistance. It is expected that a fuel mix adjustment will not be needed for SWH systems and that the choices within the prototypes are reasonably representative of the Washington building stock.

Table 2: SWH system types within prototype models

Prototype	System Description
Mid-rise residential	Individual electric resistance residential water heater with storage tank
High-rise residential	Central gas water heater with storage tank
Office – large	One main gas water heater with storage tank
Office – medium	One main gas water heater with storage tank
Office – small	One main electric resistance water heater with storage tank
Retail – large	One main gas water heater with storage tank
Retail – small	One main electric resistance water heater with storage tank
School – secondary	Natural gas (main); electric (dishwasher booster)
School – primary	Natural gas (main); electric (dishwasher booster)
Warehouse	Electric resistance storage
Restaurant – sit-down	Natural gas (main); electric (dishwasher booster)
Restaurant – fast food	Storage natural gas water heater
Lodging – Hotel	Main and central gas water heater with storage tank Electric dishwasher booster water heater Gas water heater for laundry with storage
Lodging – Motel	Main gas water heater and laundry water heater, both with storage tank
Hospital	Main and central gas water heater with storage tank Electric dishwasher booster water heater Gas water heater for laundry with storage
Outpatient Healthcare	One main gas water heater with storage tank

Cooking

Table 3 shows the cooking equipment and fuel type in each prototype. Similar to SWH, it is expected that there will be no further fuel mix adjustment for cooking equipment.

Table 3: Cooking equipment within prototypes

Prototype	Cooking Equipment
Mid-rise residential	Electric, merged with other plug and process loads
High-rise residential	Electric, merged with other plug and process loads
Office – large	None or small electric cooking equipment merged with other loads
Office – medium	None or small electric cooking equipment merged with other loads
Office – small	None or small electric cooking equipment merged with other loads
Retail – large	None or small electric cooking equipment merged with other loads
Retail – small	None or small electric cooking equipment merged with other loads
School – secondary	Kitchen natural gas cooking equipment
School – primary	Kitchen natural gas cooking equipment
Warehouse	None or small electric cooking equipment merged with other loads
Restaurant – sit-down	Kitchen natural gas cooking equipment
Restaurant – fast food	Kitchen natural gas cooking equipment
Lodging – Hotel	Kitchen natural gas cooking equipment
Lodging – Motel	Kitchen natural gas cooking equipment
Hospital	Kitchen natural gas cooking equipment
Outpatient Healthcare	No gas cooking equipment, but includes gas operating room equipment

Mechanical Ventilation

PNNL models use ventilation rates from ASHRAE Standard 62.1 or the International Mechanical Code (IMC), as appropriate, whereas Washington state requires compliance with the amended IMC. The amended requirements are stated within the Washington Administrative Code (WAC) Chapters 51-52. The requirements of WAC 51-52 will be followed for determining the ventilation rates as well as for other requirements, such as balanced ventilation systems for certain Group R occupancies. Ventilation rates will be held constant between the 2018 and 2015 code editions because changes to the ventilation rates are based on safety and health regulations and are not regulated by the energy code. For the 2006 WSEC edition, the ventilation rates will be based on the Ventilation and Indoor Air Quality Code of 2006.

Ground Contact Algorithm

For the roadmap analysis, NORESO used the GroundFCfactorMethod within EnergyPlus to implement the F-factor and C-factor requirements within various WSEC editions. This approach to modeling insulated slab-on-grade and underground wall constructions was developed specifically to capture the requirements within energy codes, where detailed layer-by-layer materials are not specified. NORESCO has used these approaches in the past in CBECC-Com compliance software and also for other projects. This approach simplifies the modeling of code requirements for multiple code editions, where different levels of insulation must be modeled.

A different, and arguably more detailed, approach involving the 'Slab' and 'Basement' Preprocessor Programs within EnergyPlus could also be used. The PNNL prototype models have used the 'Slab' and

'Basement' preprocessors in the past to calculate ground temperatures over a 10-year (even longer is possible) period, though more recently PNNL have switched to the GroundFCfactorMethod. The 10-year simulation period allows the ground temperatures to stabilize, providing greater accuracy and lower probability of convergence errors. Newer editions of EnergyPlus also include the Kiva ground temperature calculation algorithm, though past experience with this method has yielded unpredictable results.

NORESCO studied the three ground contact algorithms within EnergyPlus. The Primary School prototype was selected for the study because it is single-story and has an unusual shape with three finger-shaped classroom sections and a high exposed perimeter to floor area ratio, making it especially sensitive to different ground temperature calculation methods. Figure 2 shows the layout of the Primary School prototype.

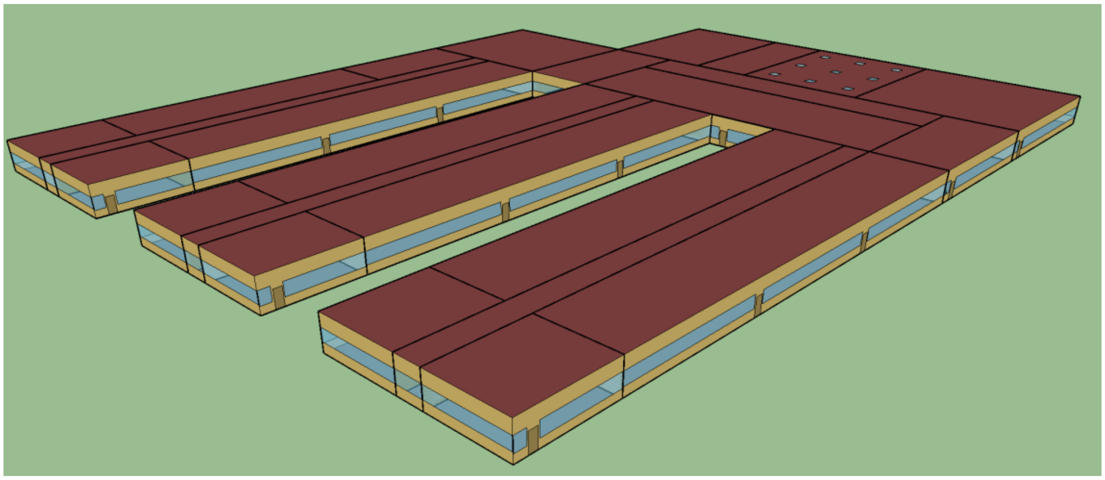

Figure 2: Primary School prototype layout

PNNL's 2018 IECC Primary School model was used and two levels of insulation were simulated:

1. R-0, i.e., no perimeter insulation.
2. R-10 for 24 inches.

The objective is to understand how the different algorithms affect the savings or the delta between the two levels of insulation and also the difference in absolute level of consumption. Incidentally, the insulation requirement between 2006, 2015, and 2018 WSEC does not change (R-10 for 24 inches).

Table 4 shows the results of the simulation. The delta or difference between the two insulation levels for the three algorithms is quite different and so is the absolute load presented by the Kiva method relative to the other methods, which is nearly 25% lower for Kiva compared to other methods. Given that there is no comparison to real-world consumption, it appears that the Kiva method is showing reasonable results because it is expected that an addition of R-10 for 24 inches along the perimeter of the Primary School prototype will have significant benefits.

Table 4: End-use results (kBtu/ft2) for three ground contact algorithms modeled using the 2018 IECC Primary School prototype

End-use ($kBtu/ft^2$)	R-0			R-10 for 24"			% Change Between Insulation Levels			% Change Relative to Kiva	
	Kiva	FCF	Slab PP	Kiva	FCF	Slab PP	Kiva	FCF	Slab PP	FCF	Slab PP
Heating	5.6	7.0	6.4	5.5	6.8	6.4	3.1%	2.5%	0.1%	-24.7%	-16.7%
Cooling	1.7	2.1	2.3	1.6	2.1	2.3	0.5%	-2.5%	0.0%	-28.3%	-36.9%
Fans	3.2	4.0	4.3	3.2	4.1	4.3	-0.2%	-1.5%	0.0%	-29.2%	-34.8%
Pumps	0.0	0.0	0.0	0.0	0.0	0.0	5.2%	1.6%	0.3%	-52.3%	-44.7%
Total HVAC	10.5	13.1	12.9	10.3	13.1	12.9	1.7%	0.5%	0.0%	-26.7%	-25.6%

There are other considerations when choosing the ground temperature algorithm.

1. Speed: the Kiva method took nearly double the time to complete relative to the other two methods.
2. Ease-of-use: Given the parametric nature of the simulations required for the analysis, the chosen method must lend itself to parameterization. This is not a problem for any of the three methods.
3. Level of effort: the PNNL models are currently using the FCfactor method and continuing to use this method will involve the lowest effort.

It would appear that for those prototypes, where ground heat transfer is a major pathway for heat transfer, the internal gains are low, or the building shape is non-rectangular, the Kiva method should be used. NORESCO intends to follow this approach and apply Kiva to the following prototypes:

1. Primary School
2. Secondary School
3. Standalone Retail
4. Strip Mall Retail
5. Warehouse

2006 WSEC Climate Zone and Weather Mapping

In 2006 WSEC, two climate zones are specified, climate zone (CZ) 1 and CZ 2, and counties are mapped to those climate zones, whereas the 2015 and 2018 WSEC editions map counties to ASHRAE CZs 4C and 5B. The county to CZ mapping is not perfectly aligned between the 2006 CZs and the 2015 and 2018 CZs. Most counties mapped to CZ 1 are also mapped to CZ 4C, but a significant proportion are mapped to 5B, and a few to 5C. All CZ 2 counties are mapped to CZ 5B (a very small proportion fall under CZ 6B, but they will be ignored for this study because of the very small forecasted new construction floor area).

Table 5 shows the forecasted floor area for each combination of new (2015 and 2018 WSEC) and old (2006 WSEC) county to climate zone mapping. More than 75% of the forecasted floor area is in CZ 4C and CZ 1. The floor area under CZ 5B is split between CZ 1 and CZ 2, with CZ 2 occupying more than 60%. The counties in CZ 1 and CZ 5B are located in the lower eastern part of Washington. In terms of weather, southeastern Washington can be characterized as much hotter and not as cold as the northern eastern part of Washington, which has the county with the highest population and most forecasted floor area, Spokane county.

The question is: are we capturing the impact of new construction in southeastern Washington and how big of an impact it is at the state level?

Table 5: Forecasted Washington State floor area (2020-2025) by climate zone

2015 and 2018 WSEC Climate Zone	2006 WSEC Climate Zone	Forecasted Floor Area (2020-2025)
4C		201,942
	1	201,942
5B		29,544
	1	11,537
	2	18,007
5C		4,046
	1	4,046
6B		149
	2	149
Grand Total		235,681

Figure 3 shows the proportion of forecasted floor area in each climate zone relative to the total. It indicates that from a statewide impact perspective, the proportion of floor area under CZ 5B and CZ 1 is small. Figure 4 shows a similar trend in floor area distribution in CZ 5B, where the majority of floor area is under CZ 2. Figure 5 and Figure 6 show the modeled results for Mid-Rise Apartment and Medium Office prototypes using the 2018 IECC vintage (from PNNL) weighted with the floor area for each CZ group. The intention here is to observe the weighted energy impact of the CZ 5B and CZ 1 group. Compared to just the floor area distribution, the relative floor area-weighted energy impact of the CZ 5B and CZ 1 grouping is smaller.

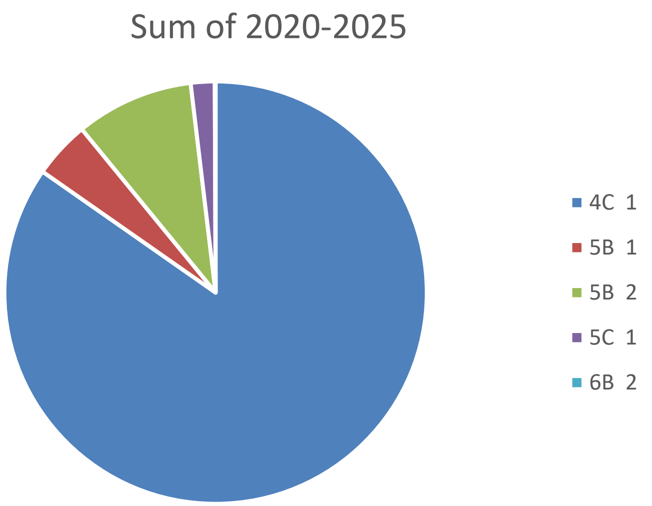

Figure 3: Relative proportion of forecasted floor area (2020-2025) among various climate zones

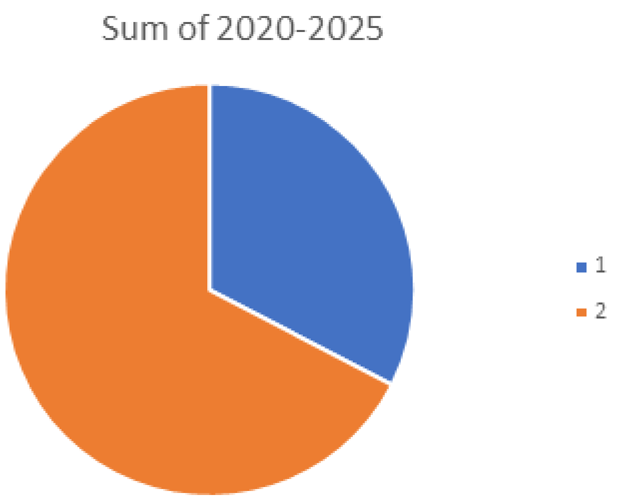

Figure 4: Proportion of forecasted floor area (2020-2025) in climate zone 5B.

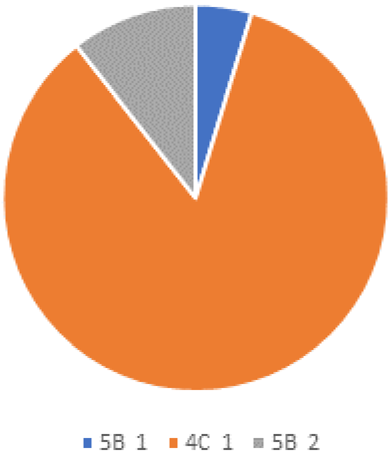

Figure 5: Mid-rise Apartment 2018 WSEC floor area-weighted energy consumption

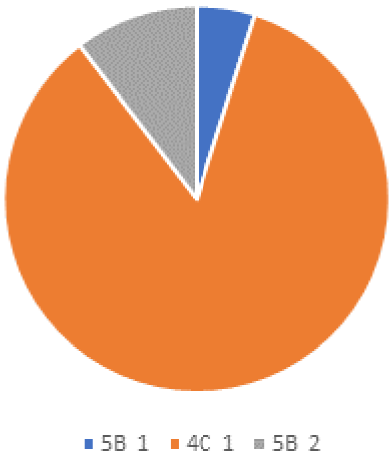

Figure 6: Medium Office 2018 WSEC floor area-weighted energy consumption

Table 6 shows the cooling degree days (CDD) and heating degree days (HDD) for the major population centers in eastern Washington. Considering the relative weights between Spokane county and lower eastern Washington counties, using Spokane to represent all of eastern Washington will provide an acceptable level of accuracy for the statewide impact.

Table 6: Cooling and heating degree days for various locations in eastern Washington (climate zone 5B)

Location	2015 and 2018 WSEC CZ/ 2006 CZ	Cooling Degree Days	Heating Degree Days	CDD % difference from Spokane	HDD % difference from Spokane
Spokane	5B/2	461	6627	0%	0%
Yakima	5B/1	556	5845	17%	-13%
Tri-cities	5B/1	815	4945	43%	-34%
Walla Walla	5B/1	924	4810	50%	-38%

Appendix B: Qualitative Analysis Results. The results show those changes between 2015 and 2018 WSEC that were determined to impact energy consumption. For cases in which the change was not captured in the quantitative analysis, the reason has been provided. The main reasons for not capturing a change were:

1. The impacted feature is not present in the prototype (applicable to a majority of changes),
2. The simulation engine did not support the modeling of the change, or
3. The change was too complex to capture in the models.

The choices for meeting the additional efficiency packages requirement in Section C406 of the 2015 and 2018 WSEC are presented in Appendix C: Additional Efficiency Package Selection. Table 8 summarizes the findings of the qualitative analysis. Of the 64 measures that had a direct energy impact, 27 measures were quantified in the energy savings analysis. The main reason for not quantifying the savings was that the change did not apply to the prototypes.

Table 9 provides a summary of the most impactful changes between the 2015 and 2018 WSEC editions that were captured in the quantitative analysis.

Table 8. Qualitative Analysis Summary

Change Category	Total Number of Measures
Direct Energy Impact	64
Impact Quantified	27
Impact Not Quantified*	37

**Note:* For these changes, the impact was not quantified for one of the following reasons: the change was not applicable to the prototypes, the change was assumed to be standard practice, or the change could not be modeled due to complexity or simulation engine limitations.

Table 9. Summary of High-impact Changes between 2015 and 2018 WSEC

2018 Section	Description of Change	Impact Summary
C402.5.1.2 Building Test	Air leakage test required to meet 0.25 cfm/sf. Down from 0.40 cfm/sf.	Impacts all prototypes. Significant impact on load, and therefore, on the heating, cooling, and fan consumption.
C403.1.1 HVAC total system performance ratio (TSPR)	Specifies that HVAC systems serving office, retail, library, and education occupancies and buildings must meet the DOAS requirements in C403.3.5 and meet the TSPR as calculated by Appendix D.	Impacts Small Office, Medium Office, Large Office, Standalone Retail, Strip Mall Retail, Primary School, and Secondary School prototypes. Significantly improves the efficiency of heating and cooling systems in these prototypes. Has a large statewide impact because these prototypes occupy a large portion of the forecasted floor area.
C403.3.6 Ventilation for Group R-2 occupancy	Requires balanced ventilation and heat recovery with a minimum sensible effectiveness of 60%.	Impacts the Mid-rise and High-rise Apartment prototypes. Significantly reduces the heating load.
C405.4.2 Interior lighting power allowance	Lowers lighting power allowances for certain building types and space types in Table C405.4.2(1) and Table C405.4.2(2).	Impacts all prototypes. Significantly lowers interior lighting power consumption and also causes a lower cooling load, which is beneficial in several prototypes that are internal gain dominated.
C405.5.3 Exterior lighting power allowance	Lowers exterior lighting power allowances for certain categories.	Impacts all prototypes. Significantly lowers exterior lighting power consumption.
C406.1 Additional energy efficiency credit requirements	Specifies that projects achieve a total of six credits from the available options.	Impacts all prototypes. Provides large increase in stringency over existing code requirements.

Quantitative Analysis Results

Comparison to 2015 WSEC

The quantitative analysis incorporates changes between 2015 and 2018 WSEC, identified by the qualitative analysis, using the prototype models to evaluate energy savings. Table 10 and Table 11 show the site energy consumption, site energy savings, and forecasted statewide savings by prototype for climate zones 4C and 5B, respectively. The savings have been split into electricity and natural gas savings. Table 12 shows the total statewide energy savings for electricity and natural gas. The **total forecasted annual statewide savings** between 2015 WSEC and 2018 WSEC are **16,036,127 kWh and 122,217 therms**.

The energy consumption for individual prototypes in Table 10 and Table 11 (columns 2–5) is a weighted average after the fuel mix adjustment, i.e., the modeled heating consumption is converted to other heating sources, as described previously in the heating fuel mix adjustment section, and then weighted with the assumed fuel mix for the prototype. The energy savings (columns 6 and 7) are calculated as the difference between the 2015 and 2018 consumption for each fuel. The statewide savings (last two columns) are the product of the savings and the forecasted floor area for the prototype.

Table 10. Climate Zone 4C Energy Consumption and Savings by Prototype

	Consumption				Savings		Statewide Savings	
	2015		2018					
Prototype	kWh/sf	therms/sf	kWh/sf	therms/sf	kWh/sf	therms/sf	kWh	therms
Large Office	13.92	0.0176	13.67	0.0139	0.25	0.0037	433,794	6,497
Medium Office	7.50	0.0164	6.93	0.0164	0.57	0.0001	756,207	91
Small Office	6.70	0.0084	6.35	0.0077	0.34	0.0007	364,853	737
Standalone Retail	8.25	0.0842	7.11	0.0703	1.14	0.0139	512,545	6,271
Strip Mall Retail	13.02	0.0666	12.08	0.0701	0.95	-0.0034	275,006	-1,001
Sit-down Restaurant	43.15	1.5983	42.87	1.6006	0.29	-0.0024	13,886	-114
Fast-food Restaurant	51.54	3.1637	49.98	3.1698	1.55	-0.0060	75,043	-292
Warehouse	2.46	0.0163	2.20	0.0114	0.26	0.0049	1,130,886	21,416
Secondary School	7.42	0.0545	6.56	0.0535	0.86	0.0010	1,920,663	2,180
Primary School	8.74	0.1214	8.18	0.1241	0.56	-0.0027	1,106,712	-5,326
Hospital	20.82	0.4174	21.55	0.4042	-0.73	0.0132	-211,034	3,818
Outpatient Healthcare	23.74	0.2470	23.54	0.2324	0.20	0.0146	165,660	12,277
Large Hotel	12.99	0.2475	12.76	0.2438	0.23	0.0037	233,260	3,818
Small Hotel	13.63	0.2533	13.41	0.2541	0.22	-0.0008	21,182	-77
High-rise Residential	6.62	0.1413	5.92	0.1360	0.70	0.0054	6,198,694	47,132
Mid-rise Residential	9.93	0.0039	9.57	0.0012	0.36	0.0027	547,594	4,027
						Total	**13,544,952**	**101,453**

Table 11. Climate Zone 5B Energy Consumption and Savings by Prototype

Prototype	Consumption 2015		Consumption 2018		Savings		Statewide Savings	
	kWh/sf	therms/sf	kWh/sf	therms/sf	kWh/sf	therms/sf	kWh	therms
Large Office	14.94	0.0240	14.59	0.0199	0.35	0.0041	83,812	987
Medium Office	7.91	0.0247	7.17	0.0244	0.74	0.0004	134,855	69
Small Office	7.64	0.0348	7.26	0.0330	0.38	0.0018	55,382	264
Standalone Retail	9.20	0.1065	7.88	0.0874	1.32	0.0192	82,295	1,193
Strip Mall Retail	15.01	0.1377	13.86	0.1358	1.14	0.0019	45,741	76
Sit-down Restaurant	47.95	1.8689	47.71	1.8746	0.24	-0.0056	1,596	-37
Fast-food Restaurant	54.15	3.8185	52.58	3.8110	1.57	0.0075	10,475	50
Warehouse	2.46	0.0163	2.20	0.0114	0.26	0.0049	155,674	2,948
Secondary School	7.93	0.0711	6.98	0.0690	0.94	0.0022	289,228	665
Primary School	9.34	0.1834	8.68	0.1778	0.65	0.0055	176,994	1,491
Hospital	22.28	0.4523	22.91	0.4368	-0.63	0.0155	-25,081	619
Outpatient Healthcare	24.63	0.2791	24.58	0.2744	0.05	0.0047	5,411	543
Large Hotel	13.40	0.2529	13.02	0.2473	0.38	0.0056	54,054	801
Small Hotel	15.09	0.2863	14.84	0.2872	0.25	-0.0009	3,333	-12
High-rise Residential	7.76	0.1627	6.71	0.1544	1.05	0.0083	1,271,602	10,052
Mid-rise Residential	11.06	0.0097	10.36	0.0047	0.70	0.0051	145,803	1,055
						Total	**2,491,175**	**20,763**

Table 12. Annual Statewide Energy Savings Forecast by Climate Zone

Climate Zones	Electricity Savings, kWh	Natural Gas Savings, therms
4C	13,544,952	101,453
5B	2,491,175	20,763
Total	**16,036,127**	**122,217**

Table 13 shows floor-area weighted statewide site energy savings. On a floor-area weighted statewide average basis, the 2018 WSEC saves **7.7% site energy** relative to the 2015 WSEC. The consumption is weighted across climate zones only, not across prototypes.

Table 13. 2018 WSEC Weighted Statewide Site Energy Savings Relative to 2015 WSEC

Prototype	Statewide Weights		Weighted Consumption		Weighted Savings	
	4C	5B	2015 kBtu/sf	2018 kBtu/sf	Total, kBtu/sf	% Savings
Large Office	5.87%	0.81%	49.8	48.5	1.3	2.6%
Medium Office	4.45%	0.61%	27.5	25.5	2.0	7.4%
Small Office	3.59%	0.49%	24.4	23.1	1.3	5.2%
Standalone Retail	1.52%	0.21%	37.2	31.8	5.4	14.5%
Strip Mall Retail	0.98%	0.13%	52.8	49.7	3.0	5.7%
Sit-down Restaurant	0.16%	0.02%	312.3	311.6	0.7	0.2%
Fast-food Restaurant	0.16%	0.02%	501.2	496.4	4.9	1.0%
Warehouse	14.67%	2.02%	10.0	8.6	1.4	13.8%
Secondary School	7.50%	1.03%	31.2	28.1	3.1	9.9%
Primary School	6.63%	0.91%	43.0	41.2	1.8	4.2%
Hospital	0.98%	0.13%	113.8	114.9	-1.1	-1.0%
Outpatient Healthcare	2.82%	0.39%	106.5	104.5	2.0	1.8%
Large Hotel	3.48%	0.48%	69.3	68.1	1.2	1.8%
Small Hotel	0.33%	0.04%	72.8	72.2	0.7	0.9%
High-rise Residential	29.66%	4.08%	37.5	34.3	3.1	8.3%
Mid-rise Residential	5.11%	0.70%	34.8	33.1	1.7	4.8%
				Statewide Weighted Savings		**7.7%**

Comparison to 2006 WSEC

Another objective of this study was to analyze the increase in stringency achieved by the 2018 WSEC relative to the 2006 WSEC for newly-constructed commercial buildings. The results will help track the progress made by the 2018 WSEC relative to the 2006 WSEC toward achieving the Washington state legislative goal of 70% net site energy reduction from the energy code for newly-constructed commercial buildings.

Table 14 shows the percent site energy use intensity (EUI) savings from the 2018 WSEC relative to the 2006 WSEC. Weighted across prototypes and climate zones, the **statewide site energy savings between the 2006 and 2018 WSEC** editions are **28%.** These savings are relatively close to the SBCC estimate of 31% savings between 2006 and 2018 editions (Odum, et al. 2020). The heating fuel sources were held constant between 2006 and 2018 WSEC and the assumed fuel mix for each prototype was also held constant, discounting savings from increased use of heat pump technologies driven by TSPR and other requirements in the 2018 WSEC. The shift toward heat pumps, not accounted for here, would increase savings somewhat. Further adoption of heat pump technology would reduce site energy significantly. To achieve the target of 70% annual net site energy savings by 2030, the next three code cycles must achieve deep reductions in end uses other than HVAC, as described in the Roadmap report (Athalye, Shadd and Arent, Washington State Commercial Energy Code Technical Roadmap 2020).

Table 14. 2018 WSEC Weighted Statewide Site Energy Savings Relative to 2006 WSEC

Prototype	Weights		Weighted Consumption		Weighted Savings	
			2006	2018		
	4C	5B	kBtu/sf	kBtu/sf	Total, kBtu/sf	% Savings
Large Office	5.87%	0.81%	62.0	48.5	13.5	21.8%
Medium Office	4.45%	0.61%	42.8	25.5	17.4	40.5%
Small Office	3.59%	0.49%	38.9	23.1	15.8	40.6%
Standalone Retail	1.52%	0.21%	57.9	31.8	26.1	45.0%
Strip Mall Retail	0.98%	0.13%	74.4	49.7	24.7	33.2%
Sit-down Restaurant	0.16%	0.02%	357.9	311.6	46.3	12.9%
Fast-food Restaurant	0.16%	0.02%	536.0	496.4	39.7	7.4%
Warehouse	14.67%	2.02%	14.1	8.6	5.4	38.5%
Secondary School	7.50%	1.03%	53.1	28.1	25.0	47.1%
Primary School	6.63%	0.91%	57.5	41.2	16.3	28.3%
Hospital	0.98%	0.13%	152.5	114.9	37.6	24.7%
Outpatient Healthcare	2.82%	0.39%	125.2	104.5	20.7	16.5%
Large Hotel	3.48%	0.48%	96.6	68.1	28.5	29.5%
Small Hotel	0.33%	0.04%	83.9	72.2	11.7	13.9%
High-rise Residential	29.66%	4.08%	41.9	34.3	7.6	18.1%
Mid-rise Residential	5.11%	0.70%	39.4	33.1	6.3	15.9%
				Statewide Weighted Savings		**28%**

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Appendix A: Prototype Adjustments Memo

The following 13 pages consist of a memo written by NORESCO in September 2021, while the researchers were performing the analysis. The memo is included as-written, with a few clarifying edits made; as such, the table numbers and figure numbers are separate from those in the rest of this report.

MEMO: ADJUSTMENTS TO PROTOTYPE MODELS

2018 WSEC Commercial Energy Savings Analysis

24 September 2021

Rahul Athalye and Eric Shadd

Background and Objective

NEEA contracted NORESCO to develop an estimate of energy savings and percent improvement of the newly adopted 2018 Washington State Energy Code (WSEC), Commercial Provisions, which went into effect on February 1, 2021 with respect to the commercial provisions of the 2015 WSEC. As part of this project, prototypical energy models from Pacific Northwest National Laboratory (PNNL) would be used to determine the energy savings. A secondary objective of this analysis is to develop the statewide energy consumption using prototype models for the 2006 WSEC. The first task is to determine the adjustments needed to the prototype models to align the models with Washington's fuel mix and mechanical ventilation requirements and also consider other adjustments to improve model accuracy. The adjustments under consideration are as follows:

4. Fuel mix adjustments for space and water heating and cooking.
5. Ground contact algorithm.
6. Mechanical ventilation.

This memo summarizes the adjustments that will be performed to the prototype models.

Fuel Mix Adjustments

To accurately calculate the statewide electricity and gas savings from the 2018 WSEC relative to the 2015 WSEC, the prevalent fuel mix within the building stock, and in particular, the forecasted new construction fuel mix must be used in combination with electricity and gas savings from the prototype models. The energy savings calculation would look like this:

Statewide savings per climate zone =

Prototype electricity savings per ft^2 x Projected floor area with electric-based systems per climate zone

+

Prototype gas savings per ft^2 x Projected floor area with gas-based systems per climate zone

To develop the prototype electricity and gas savings, heating, ventilating, and air conditioning (HVAC), service water heating (SWH), and cooking system savings must be individually developed for electric-based systems and gas-based systems. The methodology for calculating these electric and gas system savings is described below.

HVAC Systems

HVAC systems are the main consideration for the fuel mix adjustment. Heating can be provided by gas furnaces and boilers resulting in gas use, or by electric resistance and heat pumps resulting in electricity use. The approach used to determine electricity and gas savings is to model either an electric- or gas-based system in each prototype (though there may be more than one HVAC system type in each prototype), and then apply a conversion factor outside of the model to the heating end-use calculated from the model to determine savings from the other fuel type. For example, the Small Office prototype uses a single-zone heat pump as its HVAC system. To develop the energy savings between 2015 and 2018 WSEC for a Small Office prototype with a gas furnace, a conversion factor will be applied to the heating end-use consumption of both the 2015 and 2018 cases with the heat pump system.

The conversion factor will be determined from past comparisons of electric- and gas-based systems. The step-by-step process is as follows:

5. Begin with HVAC systems in the PNNL model.
6. Change the HVAC system types in the PNNL models to match HVAC systems typically used in Washington for various building types.
7. Use the 2030 WSEC Roadmap Results[5] to develop conversion factors between gas-based and heat pump-based systems.
8. Apply the conversion factors to the appropriate end-uses. The conversion factors will be evaluated and applied to the heating fans, pumps, and other appropriate end-uses.

For example, the Small Office prototype uses split heat pumps as its HVAC system. The model output would be analyzed to determine the average difference in heat delivery efficiency between a heat pump-based system and a gas furnace, whose efficiency is typically 80%. For a heat pump, the coefficient of performance (COP) varies with temperature and decreases with colder temperatures, as shown in Figure 1.

[5] NORESCO developed a roadmap for achieving the 70% site energy reduction target in the 2030 WSEC for newly constructed buildings in Washington relative to the 2006 WSEC. As part of this analysis, both gas and electric (heat pumps) were analyzed for the same prototype models. These results will be used to determine conversion factors between gas-based systems and heat pumps, and vice-versa.

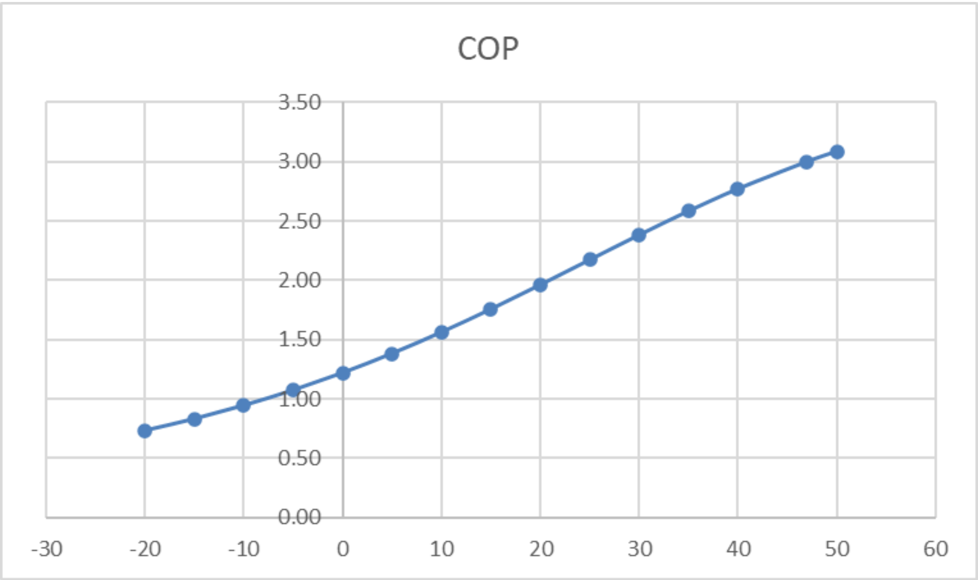

Figure 1: Example of COP change with outside air temperature.

An annual weighted-average heating COP will be calculated for the heat pump system using the Small Office prototype. The effective COP of the heat pump including the supplementary coil was calculated for each hour and each system in the prototype, and then an annual weighted-average COP for the entire prototype was calculated by weighting the COP for each hour with the delivered heating. These average COPs were calculated for 5B and 4C, and the lower value was used for the conversion factor. To determine the heating end-use consumption for a gas system, a conversion factor will be applied to the heat pump consumption as follows:

Gas furnace heating consumption = Heat pump heating consumption x average heating COP / furnace efficiency

Table 1 shows the HVAC systems selected for this analysis. In many prototypes, the HVAC systems differ from the base HVAC systems in the PNNL prototypes. These adjustments to the HVAC systems will be made during Task 2 of the project, where code requirements for the three code editions (2006, 2015, and 2018) are modeled within the prototype buildings. Table 1 also shows HVAC systems from the 2015 WSEC Commercial code savings analysis[6] and the TSPR Standard Reference Systems because they were considered as alternatives during the HVAC system selection process.

[6] Mike Kennedy performed the 2015 WSEC Commercial Energy Savings analysis. Accessed here: https://neea.org/resources/2015-washington-state-energy-code-energy-savings-analysis-commercial-provisions

Table 1: Prototype HVAC system evaluation and final selection

Prototype	2015 WSEC Energy Savings Analysis HVAC System	2018 TSPR Standard Reference Design System	HVAC System Selected for Analysis	Selection Basis (Source)
Mid-rise residential	Electric resistance heat and no cooling in the dwelling units and single zone packaged AC/furnace in the common area.	Not in WSEC. Seattle Energy Code, TSPR: Single-zone split heat pumps.	Split system, DX cooling and electric resistance heating. Common areas with DX cooling and furnace heating.	RBSA II[7] and preliminary findings from NEEA's 2021 code implementation study
High-rise residential	Dwelling unit HVAC is packaged AC/ electric resistance and common areas have single zone packaged AC/furnace.	Not in WSEC. Seattle Energy Code, TSPR: Single-zone split heat pumps.	Dwelling unit HVAC is packaged AC/ electric resistance and common areas have single zone packaged AC/furnace.	RBSA II[8] and preliminary findings from NEEA's 2021 code implementation study
Office – large	VAV with series fan powered terminals on perimeter and pinch boxes in the core with electric resistance reheat.	Water-source heat pump.	Built-up VAV, HW reheat, chiller and boiler.	2019 CBSA[9]
Office – medium	Packaged single-zone AC/gas furnace	Water-source heat pump.	Packaged single-zone AC/gas furnace.	2015 WSEC Analysis
Office – small	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	Split HPs.	PNNL Prototype system
Retail – large	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	RTU DX cooling and gas furnace heating.	2019 CBSA
Retail – small	Packaged single-zone AC/gas furnace	Packaged air-source heat pump.	Split HPs	PNNL Prototype system
School – secondary	Single zone air handlers with hydronic heating and cooling	Packaged air-source heat pump.	Single zone air handlers with hydronic heating and cooling	2015 WSEC Analysis
School – primary	VAV with pinch boxes and electric hydronic reheat in classrooms. Single-zone air handlers with hydronic heating and cooling for common areas.	Packaged air-source heat pump.	Packaged VAV, electric reheat, DX cooling, gas furnace central heating coil	2019 CBSA and 2015 WSEC Analysis
Warehouse	Packaged single-zone AC, gas furnace in office. Gas fired unit heaters in storage.	NA	Gas furnace unit heater. Packaged DX cooling for office and fine storage.	PNNL Prototype system
Restaurant – sit-down	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.	NA	Packaged single-zone AC, gas furnace in dining. Gas fired make-up air units for kitchen.	2019 CBSA and 2015 WSEC Analysis
Restaurant – fast food	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.	NA	Packaged single-zone AC, gas furnace in dining. Gas fire make-up air units for kitchen.	2019 CBSA and 2015 WSEC Analysis

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[7] Data from the Residential Building Stock Assessment was used. Accessed here: https://neea.org/data/residential-building-stock-assessment

[8] Data from the Residential Building Stock Assessment was used. Accessed here: https://neea.org/data/residential-building-stock-assessment

[9] Data from the 2019 Commercial Building Stock Assessment was used. Accessed here: https://neea.org/data/residential-building-stock-assessment

Prototype	2015 WSEC Energy Savings Analysis HVAC System	2018 TSPR Standard Reference Design System	HVAC System Selected for Analysis	Selection Basis (Source)
Lodging – Hotel	Common areas: single zone air handlers Guest rooms: four pipe fan coils.	NA	Public spaces on ground floor and top floor: VAV with hot water reheating coils. Guest rooms: dedicated outside air system + four-pipe fan-coil units.	2019 CBSA
Lodging – Motel	Common areas: packaged single-zone AC, gas furnace Guest rooms: PTAC	NA	Guestrooms: PTAC with electric resistance heat. Common areas: Packaged AC with furnace.	2019 CBSA
Hospital	CAV and VAV with pinch terminals. Gas boiler, hot water reheats.	NA	Medical critical zones: AHUs with hot water reheating and electric stream humidifiers, either CAV or VAV with reheat depending on codes and standards.	PNNL Prototype system
Outpatient Healthcare	Not modeled	NA	VAV terminal box with damper and hot water reheating coil, DX cooling Electric resistance reheat in one AHU.	PNNL Prototype system

Findings from RBSA and other studies indicate that a large proportion of mid- and low-rise multifamily buildings do not have cooling systems. This trend is changing with new construction. For this analysis, an assumption is made that there is a cooling system prevalent in the Mid-rise Apartment prototype, so that the impact of 2018 WSEC on future new construction stock can be fully accounted.

SWH Systems

Table 2 shows the SWH systems within the PNNL prototypes. Within the prototypes, SWH system type and fuel type is based on common design practices. For example, most large SWH systems are gas fired, whereas smaller and distributed SWH systems are electric resistance. It is expected that a fuel mix adjustment will not be needed for SWH systems and that the choices within the prototypes are reasonably representative of the Washington building stock.

Table 2: SWH system types within prototype models

Prototype	System Description
Mid-rise residential	Individual electric resistance residential water heater with storage tank
High-rise residential	Central gas water heater with storage tank
Office – large	One main gas water heater with storage tank
Office – medium	One main gas water heater with storage tank
Office – small	One main electric resistance water heater with storage tank
Retail – large	One main gas water heater with storage tank
Retail – small	One main electric resistance water heater with storage tank
School – secondary	Natural gas (main); electric (dishwasher booster)
School – primary	Natural gas (main); electric (dishwasher booster)
Warehouse	Electric resistance storage
Restaurant – sit-down	Natural gas (main); electric (dishwasher booster)
Restaurant – fast food	Storage natural gas water heater
Lodging – Hotel	Main and central gas water heater with storage tank Electric dishwasher booster water heater Gas water heater for laundry with storage
Lodging – Motel	Main gas water heater and laundry water heater, both with storage tank
Hospital	Main and central gas water heater with storage tank Electric dishwasher booster water heater Gas water heater for laundry with storage
Outpatient Healthcare	One main gas water heater with storage tank

Cooking

Table 3 shows the cooking equipment and fuel type in each prototype. Similar to SWH, it is expected that there will be no further fuel mix adjustment for cooking equipment.

Table 3: Cooking equipment within prototypes

Prototype	Cooking Equipment
Mid-rise residential	Electric, merged with other plug and process loads
High-rise residential	Electric, merged with other plug and process loads
Office – large	None or small electric cooking equipment merged with other loads
Office – medium	None or small electric cooking equipment merged with other loads
Office – small	None or small electric cooking equipment merged with other loads
Retail – large	None or small electric cooking equipment merged with other loads
Retail – small	None or small electric cooking equipment merged with other loads
School – secondary	Kitchen natural gas cooking equipment
School – primary	Kitchen natural gas cooking equipment
Warehouse	None or small electric cooking equipment merged with other loads
Restaurant – sit-down	Kitchen natural gas cooking equipment
Restaurant – fast food	Kitchen natural gas cooking equipment
Lodging – Hotel	Kitchen natural gas cooking equipment
Lodging – Motel	Kitchen natural gas cooking equipment
Hospital	Kitchen natural gas cooking equipment
Outpatient Healthcare	No gas cooking equipment, but includes gas operating room equipment

Mechanical Ventilation

PNNL models use ventilation rates from ASHRAE Standard 62.1 or the International Mechanical Code (IMC), as appropriate, whereas Washington state requires compliance with the amended IMC. The amended requirements are stated within the Washington Administrative Code (WAC) Chapters 51-52. The requirements of WAC 51-52 will be followed for determining the ventilation rates as well as for other requirements, such as balanced ventilation systems for certain Group R occupancies. Ventilation rates will be held constant between the 2018 and 2015 code editions because changes to the ventilation rates are based on safety and health regulations and are not regulated by the energy code. For the 2006 WSEC edition, the ventilation rates will be based on the Ventilation and Indoor Air Quality Code of 2006.

Ground Contact Algorithm

For the roadmap analysis, NORESO used the GroundFCfactorMethod within EnergyPlus to implement the F-factor and C-factor requirements within various WSEC editions. This approach to modeling insulated slab-on-grade and underground wall constructions was developed specifically to capture the requirements within energy codes, where detailed layer-by-layer materials are not specified. NORESCO has used these approaches in the past in CBECC-Com compliance software[10] and also for other projects. This approach simplifies the modeling of code requirements for multiple code editions, where different levels of insulation must be modeled.

[10] CBECC-Com is the approved compliance software for California and has been in use since 2013. It uses EnergyPlus to perform the baseline and proposed model simulations.

A different, and arguably more detailed, approach involving the 'Slab' and 'Basement' Preprocessor Programs within EnergyPlus could also be used. The PNNL prototype models have used the 'Slab' and 'Basement' preprocessors in the past to calculate ground temperatures over a 10-year (even longer is possible) period, though more recently PNNL have switched to the GroundFCfactorMethod. The 10-year simulation period allows the ground temperatures to stabilize, providing greater accuracy and lower probability of convergence errors. Newer editions of EnergyPlus also include the Kiva ground temperature calculation algorithm, though past experience with this method has yielded unpredictable results.

NORESCO studied the three ground contact algorithms within EnergyPlus. The Primary School prototype was selected for the study because it is single-story and has an unusual shape with three finger-shaped classroom sections and a high exposed perimeter to floor area ratio, making it especially sensitive to different ground temperature calculation methods. Figure 2 shows the layout of the Primary School prototype.

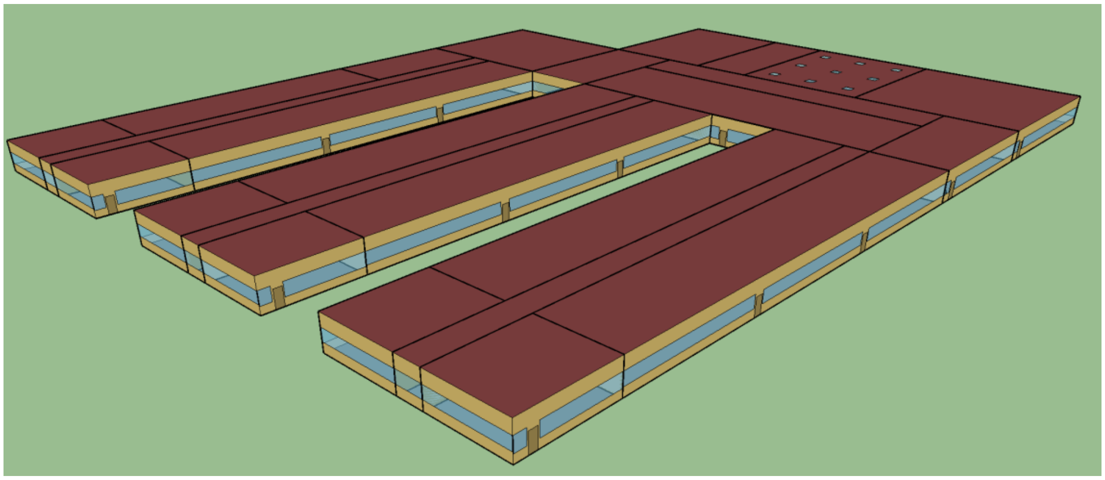

Figure 2: Primary School prototype layout

PNNL's 2018 IECC Primary School model was used and two levels of insulation were simulated:

3. R-0, i.e., no perimeter insulation.
4. R-10 for 24 inches.

The objective is to understand how the different algorithms affect the savings or the delta between the two levels of insulation and also the difference in absolute level of consumption. Incidentally, the insulation requirement between 2006, 2015, and 2018 WSEC does not change (R-10 for 24 inches).

Table 4 shows the results of the simulation. The delta or difference between the two insulation levels for the three algorithms is quite different and so is the absolute load presented by the Kiva method relative to the other methods, which is nearly 25% lower for Kiva compared to other methods. Given that there is no comparison to real-world consumption, it appears that the Kiva method is showing reasonable results because it is expected that an addition of R-10 for 24 inches along the perimeter of the Primary School prototype will have significant benefits.

Table 4: End-use results (kBtu/ft2) for three ground contact algorithms modeled using the 2018 IECC Primary School prototype

End-use (kBtu/ft^2)	**R-0**			**R-10 for 24"**			**% Change Between Insulation Levels**			**% Change Relative to Kiva**	
	Kiva	FCF	Slab PP	Kiva	FCF	Slab PP	Kiva	FCF	Slab PP	FCF	Slab PP
Heating	5.6	7.0	6.4	5.5	6.8	6.4	3.1%	2.5%	0.1%	-24.7%	-16.7%
Cooling	1.7	2.1	2.3	1.6	2.1	2.3	0.5%	-2.5%	0.0%	-28.3%	-36.9%
Fans	3.2	4.0	4.3	3.2	4.1	4.3	-0.2%	-1.5%	0.0%	-29.2%	-34.8%
Pumps	0.0	0.0	0.0	0.0	0.0	0.0	5.2%	1.6%	0.3%	-52.3%	-44.7%
Total HVAC	10.5	13.1	12.9	10.3	13.1	12.9	1.7%	0.5%	0.0%	-26.7%	-25.6%

There are other considerations when choosing the ground temperature algorithm.

4. Speed: the Kiva method took nearly double the time to complete relative to the other two methods.
5. Ease-of-use: Given the parametric nature of the simulations required for the analysis, the chosen method must lend itself to parameterization. This is not a problem for any of the three methods.
6. Level of effort: the PNNL models are currently using the FCfactor method and continuing to use this method will involve the lowest effort.

It would appear that for those prototypes, where ground heat transfer is a major pathway for heat transfer, the internal gains are low, or the building shape is non-rectangular, the Kiva method should be used. NORESCO intends to follow this approach and apply Kiva to the following prototypes:

6. Primary School
7. Secondary School
8. Standalone Retail
9. Strip Mall Retail
10. Warehouse

2006 WSEC Climate Zone and Weather Mapping

In 2006 WSEC, two climate zones are specified, climate zone (CZ) 1 and CZ 2, and counties are mapped to those climate zones, whereas the 2015 and 2018 WSEC editions map counties to ASHRAE CZs 4C and 5B. The county to CZ mapping is not perfectly aligned between the 2006 CZs and the 2015 and 2018 CZs. Most counties mapped to CZ 1 are also mapped to CZ 4C, but a significant proportion are mapped to 5B, and a few to 5C. All CZ 2 counties are mapped to CZ 5B (a very small proportion fall under CZ 6B, but they will be ignored for this study because of the very small forecasted new construction floor area).

Table 5 shows the forecasted floor area for each combination of new (2015 and 2018 WSEC) and old (2006 WSEC) county to climate zone mapping. More than 75% of the forecasted floor area is in CZ 4C and CZ 1. The floor area under CZ 5B is split between CZ 1 and CZ 2, with CZ 2 occupying more than 60%. The counties in CZ 1 and CZ 5B are located in the lower eastern part of Washington. In terms of weather, southeastern Washington can be characterized as much hotter and not as cold as the northern eastern part of Washington, which has the county with the highest population and most forecasted floor area, Spokane county.

The question is: are we capturing the impact of new construction in southeastern Washington and how big of an impact it is at the state level?

Table 5: Forecasted Washington State floor area (2020-2025) by climate zone

2015 and 2018 WSEC Climate Zone	2006 WSEC Climate Zone	Forecasted Floor Area (2020-2025)
4C		201,942
	1	201,942
5B		29,544
	1	11,537
	2	18,007
5C		4,046
	1	4,046
6B		149
	2	149
Grand Total		235,681

Figure 3 shows the proportion of forecasted floor area in each climate zone relative to the total. It indicates that from a statewide impact perspective, the proportion of floor area under CZ 5B and CZ 1 is small. Figure 4 shows a similar trend in floor area distribution in CZ 5B, where the majority of floor area is under CZ 2. Figure 5 and Figure 6 show the modeled results for Mid-Rise Apartment and Medium Office prototypes using the 2018 IECC vintage (from PNNL) weighted with the floor area for each CZ group. The intention here is to observe the weighted energy impact of the CZ 5B and CZ 1 group. Compared to just the floor area distribution, the relative floor area-weighted energy impact of the CZ 5B and CZ 1 grouping is smaller.

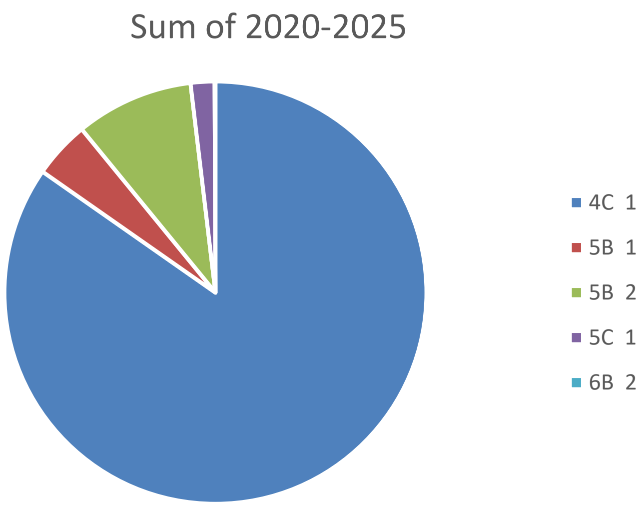

Figure 3: Relative proportion of forecasted floor area (2020-2025) among various climate zones

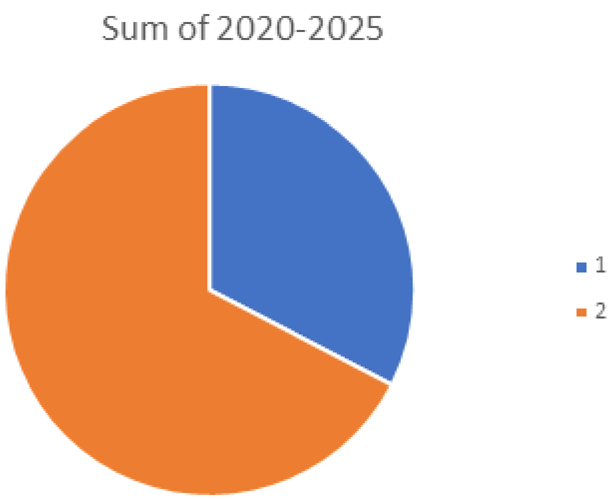

Figure 4: Proportion of forecasted floor area (2020-2025) in climate zone 5B.

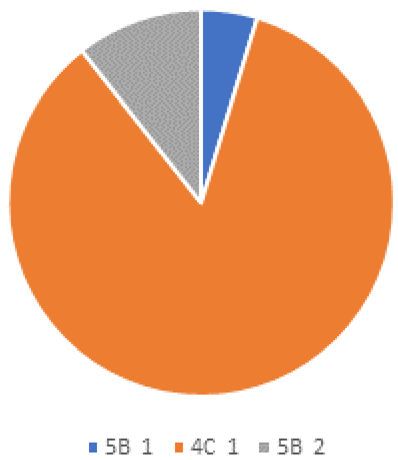

Figure 5: Mid-rise Apartment 2018 WSEC floor area-weighted energy consumption

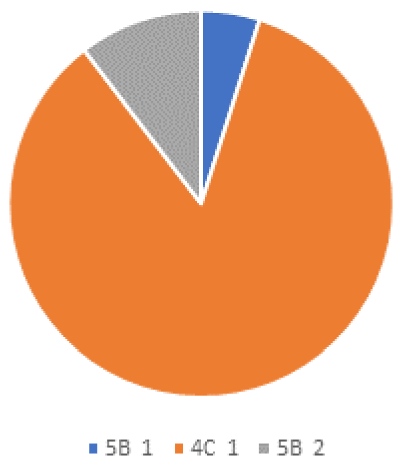

Figure 6: Medium Office 2018 WSEC floor area-weighted energy consumption

Table 6 shows the cooling degree days (CDD) and heating degree days (HDD) for the major population centers in eastern Washington. Considering the relative weights between Spokane county and lower eastern Washington counties, using Spokane to represent all of eastern Washington will provide an acceptable level of accuracy for the statewide impact.

Table 6: Cooling and heating degree days for various locations in eastern Washington (climate zone 5B)

Location	2015 and 2018 WSEC CZ/ 2006 CZ	Cooling Degree Days	Heating Degree Days	CDD % difference from Spokane	HDD % difference from Spokane
Spokane	5B/2	461	6627	0%	0%
Yakima	5B/1	556	5845	17%	-13%
Tri-cities	5B/1	815	4945	43%	-34%
Walla Walla	5B/1	924	4810	50%	-38%

Appendix B: Qualitative Analysis Results

This section describes the results of the qualitative analysis comparing the 2015 and 2018 WSEC editions.[11]

Table 15 below shows the 2018 WSEC changes to the mandatory and prescriptive requirements that impact energy consumption. Numerous other changes occurred between 2015 and 2018 WSEC, such as administrative changes, clarifications, and changes in wording that do not materially impact energy consumption, and these changes have not been listed in the table below (although they were evaluated initially as part of this analysis to determine whether they impact energy consumption). The 2018 WSEC has a large number of changes in which language was simply moved to a different location in the code or reworded for clarity.

Table 15 describes whether each requirement was captured in the quantitative analysis, provides the reason for those not captured, and provides a qualitative assessment of the statewide impact of the change. Table 16 shows the applicability of measures that have an energy impact to the prototypes. The qualitative statewide impact is divided into the following categories:

1. Very high: These changes are applicable across multiple prototypes and have significant savings within each prototype. TSPR, interior lighting power allowance, and the C406 requirements have been classified as having very high statewide impact.
2. High: These changes are also applicable across multiple prototypes and have significant savings. Air leakage, balanced ventilation, and exterior lighting power have been classified as having high statewide impact.
3. Medium: These changes are not applicable across multiple prototypes but may have significant energy savings.
4. Low: These changes are not applicable across multiple prototypes and have small energy savings impacts.

[11] The changes between 2006 and 2018 WSEC are not described here. The Roadmap work (Athalye, Shadd and Arent, Washington State Commercial Energy Code Technical Roadmap 2020) describes that analysis, as well as past code impact analyses for the 2009, 2012, and 2015 WSEC editions.

Table 15. Qualitative Characterization of 2018 WSEC Changes that Impact Energy Consumption

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C202 Definitions	Adds or revises following definitions that impact energy consumption: 1. Semi-heated space 2. Data center 3. HVAC TSPR	Yes	Medium	Yes.
C202 General Definitions	Specifies maximum installed output capacity (C202) for the semi-heated classification.	Yes	Low	No, because the semi-heated classification for the Warehouse prototype is fixed for the analysis.
C402.1.1.3 Greenhouses	Specifies envelope requirements for greenhouses.	Yes	Medium	No, because greenhouses are not part of the selected group of prototypes.
C402.1.2.1 Standalone Elevator Hoistways	Specifies that elevator hoistways are exempt from envelope requirements provided they meet other requirements.	Yes	Low	No, because elevator hoistways are not explicitly zoned and modeled in prototypes. It is assumed that they meet the requirements of the building envelope.
C402.1.3 Insulation component R-value method	Specifies insulation R-values for building envelope assemblies.	Yes	Low	No, because U-factor method (C402.1.4) is used.
C402.1.4 Assembly U-factor, C-factor, or F-factor based method	Requirements for envelope assembly performance. Wood-framed wall U-factor for Group R was lowered to U-0.051 from U-0.054. Intermediate concrete floors required to meet insulation requirement.	Yes	Low	No wood-framed Group R prototype. Analysis assumes that intermediate concrete floors already meet the insulation requirement.
C402.4 Fenestration	Specifies lowering the solar heat gain coefficient (SHGC) from 0.40 to 0.38.	Yes	Medium	Yes.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C402.4.1 Maximum Area	Skylight area increased from 3% to 5%	Yes	Low	Maximum area does not exceed 5% in any prototype.
C402.5.1.2 Building Test	Air leakage test required to meet 0.25 cfm/sf. Down from 0.40 cfm/sf.	Yes	High	Yes.
C402.5.6 Loading dock weather seals	Requires providing direct contact along top and sides of vehicles.	Yes	Low	No, analysis assumes that requirement is met as part of standard practice.
C403.1.1 HVAC total system performance ratio (TSPR)	Specifies that HVAC systems serving office, retail, library, and education occupancies and buildings must meet the DOAS requirements in C403.3.5 and meet the TSPR as calculated by Appendix D.	Yes	Very high	Yes.
C403.1.3 Data centers	Requires data centers to meet ASHRAE Standard 90.4 with revised design and annualized MLC values.	Yes	Medium	No, not modeled due to complexity.
C403.3.2 HVAC equipment performance requirements	Equipment efficiency regulated by federal standards.	Yes	Medium	No, federal efficiency levels maintained at the same requirement for both 2018 and 2015 WSEC.
C403.3.2.1 Chillers	Allows air-to-water heat pump units as an exemption to the chiller plant requirement.	Yes	Low	No; no air-to-water heat pump units in prototype HVAC systems.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C403.3.5 DOAS	Changed from requiring DOAS for building types to occupancy types for several occupancies with specific exemptions. Prescribes maximum of 1 W/cfm fan power for DOAS having total fan system nameplate hp less than 5 hp.	Yes	Medium	Yes.
C403.3.5.1 Energy recovery ventilation with DOAS	Increases effectiveness from 50% to 60%.	Yes	Medium	Yes.
C403.3.5.3 Decoupled DOAS supply air	Requires DOAS supply air to be delivered directly to the space without terminal unit heating or cooling.	Yes	Low	No, because this is assumed to be standard practice.
C403.3.6 Ventilation for Group R-2 occupancy	Requires balanced ventilation and heat recovery with a minimum sensible effectiveness of 60%.	Yes	High	Yes.
C403.4.1 Thermostatic controls for DOAS	Section 3 specifies supply air temp control for DOAS.	Yes	Low	No, DOAS control already meets this requirement.
C403.4.1.4 Heated or cooled vestibules	Requires vestibule heating system to shut off when outdoor air temperature is above 45 F. Also requires the vestibule heating system to limit heating above 60 F and cooling below 85 F.	Yes	Low	Yes.
C403.4.1.6 Door switches for HVAC system thermostatic control.	Requires HVAC system interlock with doors opening to the outdoors from a conditioned space. When doors have been open for 5 minutes, the heating setpoint must be reset to 55 F and cooling setpoint must be reset to 85 F.	Yes	Low	Yes.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C403.4.2.3 Automatic start and stop	Requires the HVAC system daily start time to be adjusted in response to space temperature and occupied and unoccupied setpoints.	Yes	Low	Yes.
C403.4.2.4 Exhaust system off-hour controls.	Requires exhaust systems, except Group R, to follow the same schedule as the HVAC system providing makeup air.	Yes	Low	No, prototype exhaust systems already meet this requirement.
C403.4.2.5 Transfer and destratification fan system off-hour controls	Requires transfer air and destratification systems, except in Group R, to follow same schedule as HVAC system providing makeup air.	Yes	Low	No, prototype exhaust systems already meet this requirement.
C403.4.3.3.2 Heat rejection	Specifies heat rejection bypass control for water loop heat pump (WLHP) systems.	Yes	Low	No, WLHP not part of prototype HVAC systems.
C403.4.4 Part load controls	Reduces pump capacity threshold from 3 hp to 2 hp for when hydronic systems are required to reduce flow rate as a function of load.	Yes	Low	No, not modeled due to complexity.
C403.4.4 Part load controls	Specifies that variable speed drives are required for heating water, chilled water, and heat rejection loop pumps above 7.5 hp.	Yes	Low	Yes.
C403.4.7.1 Combustion decorative vented appliance, combustion fireplace and fire pit controls	Requires local control of decorative vented appliances, fireplaces, and fire pits that turns off the appliance within one hour without override or turns off the appliance within 15 minutes of occupants leaving the space.	Yes	Low	No, these appliances are not modeled in the prototypes.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C403.5 Economizers	Specifies several changes to the exceptions section, clarifying existing requirements and expanding requirements for systems utilizing heat recovery from heat rejection systems.	Yes	Low	No, heat recovery from heat rejection systems is not part of the prototype models.
C403.5.3.3 High-limit shutoff	Specifies economizer controls for cycling HVAC systems that only meet load and do not provide ventilation air.	Yes	Low	No, too complex to model. Prototypes generally use differential dry bulb economizer. Would need to develop a program on a timestep basis to correctly capture this impact. However, impact is relatively small given that the economizer is able to function per the 2015 WSEC specification.
C403.6.1 VAV and multiple zone systems	Specifies 20% minimum for reheat, lowered from 30%.	Yes	Low	Yes.
C403.6.6 Parallel-flow fan-powered VAV air terminal control	Specifies controls for parallel fan-powered terminal units.	Yes	Low	No, parallel fan-powered terminal units in prototypes.
C403.6.10 High efficiency VAV systems	Specifies requirements for high-efficiency VAV systems.	Yes	Low	No, the specified changes are assumed to be standard practice and the prototype systems are already configured to meet those requirements.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C403.7.2 Occupancy sensors	Requires occupancy sensors in spaces with more than 25 people per 1000 sf to turn off ventilation when the space is unoccupied.	Yes	Low	DCV already modeled for such spaces, except in office prototypes where it is difficult to separate conference room ventilation from the zone ventilation.
C403.7.3 Ventilation air heating control	Specifies that units providing ventilation air to multiple zones with zone heating and cooling systems shall not heat ventilation air above 60 F.	Yes	Low	No, assumed to be standard practice.
C403.7.4 Automatic control of HVAC systems serving guest rooms.	Specifies deeper setback for unrented guest rooms with heating setback to 60 F and cooling to 80 F.	Yes	Low	Yes.
C403.7.4.2 Ventilation controls	Specifies that ventilation be shut off within 30 minutes of occupants leaving the guest room.	Yes	Low	Yes.
C403.7.6 Energy recovery ventilation systems	Specifies different thresholds for when ERV is required.	Yes	Medium	Yes.
C403.7.7.3 Transfer air	Requires transfer air for any space with a mechanical exhaust.	Yes	Medium	No. This would impact restroom spaces in all prototypes. In most cases, these spaces are not defined as separate zones and therefore it is too complex to separate out the ventilation of the restroom from the rest of the zone and apply transfer air to that portion.
C403.8.4 Group R occupancy exhaust fan efficacy	Specifies cfm/W for residential exhaust fans providing ventilation.	Yes	Low	No, separate exhaust fans not modeled for residential spaces (part of balanced ventilation).

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C403.9.1.1 Fan speed control	Requires variable speed fans above 5 hp instead of 7.5 hp in 2015 WSEC.	Yes	Low	Yes.
C403.9.2 Heat Recovery	Specifies requirements for steam condensate systems, refrigeration condenser recovery, water-source condenser heat recovery, and process heat recovery.	Yes	Low	No. Some of the systems, such as steam condensate systems, are not in prototype models, and for others, the capacity threshold is not exceeded in the prototypes.
C403.10.1 Duct and plenum insulation and sealing	Specifies duct sealing and insulation requirements for ducts exposed to the exterior.	Yes	Low	No, ducts are assumed to be inside the conditioned envelope.
C404.2 Service water-heating equipment performance efficiency	Specifies efficiency and performance requirements for water heating equipment.	Yes	Medium	Yes, the requirements are modeled, but they are modeled the same as for 2015 WSEC so the savings from federal standards are not credited to the 2018 WSEC.
C404.2.1 High input-rated service water heating systems for other than Group R-1 and R-2 occupancies	Allows an air-source heat pump with a COP of 2.0 to meet the requirement. A fossil fuel boiler with a rated Et of 90% is still allowed.	Yes	Low	No, prototype SWH systems do not exceed the capacity threshold.
C404.2.2 High-input rate service water heating systems for Group R-1 and R-2 occupancies	Requires 25% of annual water heating energy to be provided by either renewable sources or through site recovered energy when installed service water heating capacity exceeds 1 million Btu/h.	Yes	Low	No, capacity threshold is not exceeded in the prototypes.
C404.13 Service water pressure-booster systems.	Specifies control and sensing requirements for pressure-booster systems.	Yes	Low	No, prototypes assume required operation.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C405.1.1 Dwelling and sleeping unit lighting efficacy	Specifies that at least 90% of lamps in dwelling or sleeping units shall have an efficacy of T8 lamps or higher, whereas 2015 WSEC required only 75% of lamps to meet this requirement.	Yes	Medium	Yes.
C405.2.1 Occupant sensor controls	Specifies occupancy sensors for open offices, stairways, service corridors, and service parking areas.	Yes	Low	Yes.
C405.2.1.1 Occupant sensor control function	Specifies lights to be turned off within 20 minutes of occupants leaving the room, whereas 2015 WSEC allowed 30 minutes to turn off lights.	Yes	Low	No, because savings between 20 minutes and 30 minutes to turn off for these spaces are difficult to quantify.
C405.2.1.3 Occupant sensor control function in open plan office areas	Specifies occupancy sensor control for open plan office areas.	Yes	Low	Yes.
C405.2.1.4 Occupant sensor control function in parking garage	Specifies occupancy sensor control for parking garages.	Yes	Low	No, parking garage is not included in the analysis.
C405.2.1.3 Occupant sensor control function in stairways	Specifies occupancy sensor control for stairways.	Yes	Low	Yes.
C405.2.3 Manual controls	Specifies maximum space area controllable from a manual lighting control device.	Yes	Low	No, assumes that prototype spaces meet the requirement as part of standard practice.
C405.4.1 Total connected interior lighting power	Specifies a different equation for calculating total connected interior lighting power.	Yes	Low	No, does not change how lighting power is calculated for each zone in the prototype models.

2018 Section	Description of Change	Impacts Energy?	Qualitative Statewide Impact	Captured in Quantitative Analysis?
C405.4.2 Interior lighting power allowance	Lowers lighting power allowances for certain building types and space types in Table C405.4.2(1) and Table C405.4.2(2).	Yes	Very high	Yes.
C405.4.2.2.1 Additional interior lighting power	Lowers additional allowance for retail spaces	Yes	Low	Yes.
C405.5.1 Exterior building grounds lighting	Specifies building grounds luminaires 50 watts or higher to have an efficacy of at least 100 lumens/W instead of 80 lumens/W in 2015 WSEC.	Yes	Low	No, because prototypes meet the exterior lighting power density (LPD) requirement.
C405.5.3 Exterior lighting power allowance	Lowers exterior lighting power allowances for certain categories.	Yes	High	Yes.
C405.6 Electrical transformers	Specifies federal efficiencies for building distribution transformers.	Yes	Low	No, federal efficiency levels maintained at the same requirement for both 2018 and 2015 WSEC.
C405.8 Electric motor efficiency	Specifies federal efficiencies for electric motors.	Yes	Medium	No, federal efficiency levels maintained at the same requirement for both 2018 and 2015 WSEC.
C406.1 Additional energy efficiency credit requirements	Specifies that projects achieve a total of six credits from the available options.	Yes	Very high	Yes.

Table 16. Prototypes Impacted by 2018 WSEC Changes

2018 Section	Description of Change	HR Apt	MR Apt	Lg Off	Md Off	Sm Off	Std Rtl	SM Rtl	P Sch	S Sch	Whse	SD Rest	FF Rest	Lg Htl	Sm Htl	Hosp	Opt Hlth
C402.4 Fenestration	Specifies lowering the solar heat gain coefficient (SHGC) from 0.40 to 0.38.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C402.5.1.2 Building Test	Air leakage test required to meet 0.25 cfm/sf. Down from 0.40 cfm/sf.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C403.1.1 HVAC total system performance ratio (TSPR)	Specifies that HVAC systems serving office, retail, library, and education occupancies and buildings must meet the DOAS requirements in C403.3.5 and meet the TSPR as calculated by Appendix D.			X	X	X	X	X	X	X							
C403.3.5 DOAS	Changed from requiring DOAS for building types to occupancy types for several occupancies with specific exemptions. Prescribes maximum of 1 W/cfm fan power for DOAS having total fan system nameplate hp less than 5 hp.			X	X	X	X	X	X	X							
C403.3.5.1 Energy recovery ventilation with DOAS	Increases effectiveness from 50% to 60%.			X	X	X	X	X	X	X							
C403.3.6 Ventilation for Group R-2 occupancy	Requires balanced ventilation and heat recovery with a minimum sensible effectiveness of 60%.	X	X														
C403.4.1.4 Heated or cooled vestibules	Requires vestibule heating system to shut off when outdoor air temperature is above 45 F. Also requires the vestibule heating system to limit heating above 60 F and cooling below 85 F.						X										
C403.4.1.6 Door switches for HVAC system thermostatic control.	Requires HVAC system interlock with doors opening to the outdoors from a conditioned space. When doors have been open for 5 minutes, the heating setpoint must be reset to 55 F and cooling setpoint must be reset to 85 F.	X												X			

2018 Section	Description of Change	HR Apt	MR Apt	Lg Off	Md Off	Sm Off	Std Rtl	SM Rtl	P Sch	S Sch	Whse	SD Rest	FF Rest	Lg Htl	Sm Htl	Hosp	Opt Hlth
C403.4.2.3 Automatic start and stop	Requires the HVAC system daily start time to be adjusted in response to space temperature and occupied and unoccupied setpoints.			X	X		X		X	X				X		X	X
C403.4.4 Part load controls	Specifies that variable speed drives are required for heating water, chilled water, and heat rejection loop pumps above 7.5 hp.			X													
C403.6.1 VAV and multiple zone systems	Specifies 20% minimum for reheat, lowered from 30%.			X					X	X				X		X	X
C403.7.2 Occupancy sensors	Requires occupancy sensors in spaces with more than 25 people per 1000 sf to turn off ventilation when the space is unoccupied.			X	X				X	X				X			
C403.7.4 Automatic control of HVAC systems serving guest rooms.	Specifies deeper setback for unrented guest rooms with heating setback to 60 F and cooling to 80 F.													X	X		
C403.7.4.2 Ventilation controls	Specifies that ventilation be shut off within 30 minutes of occupants leaving the guest room.													X	X		
C403.7.6 Energy recovery ventilation systems	Specifies different thresholds for when ERV is required.			X	X	X	X	X	X	X	X	X	X	X	X	X	X
C403.8.4 Group R occupancy exhaust fan efficacy	Specifies cfm/W for residential exhaust fans providing ventilation.	X	X														
C403.9.1.1 Fan speed control	Requires variable speed fans above 5 hp instead of 7.5 hp in 2015 WSEC.			X	X		X		X	X				X		X	X

2018 Section	Description of Change	HR Apt	MR Apt	Lg Off	Md Off	Sm Off	Std Rtl	SM Rtl	P Sch	S Sch	Whse	SD Rest	FF Rest	Lg Htl	Sm Htl	Hosp	Opt Hlth
C404.2 Service water-heating equipment performance efficiency	Specifies efficiency and performance requirements for water heating equipment.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C405.1.1 Dwelling and sleeping unit lighting efficacy	Specifies that at least 90% of lamps in dwelling or sleeping units shall have an efficacy of T8 lamps or higher, whereas 2015 WSEC required only 75% of lamps to meet this requirement.	X	X														
C405.2.1 Occupant sensor controls	Specifies occupancy sensors for open offices, stairways, service corridors, and service parking areas.			X	X				X	X				X			X
C405.2.1.3 Occupant sensor control function in open plan office areas	Specifies occupancy sensor control for open plan office areas.			X	X				X	X							
C405.2.1.3 Occupant sensor control function in stairways	Specifies occupancy sensor control for stairways.													X			X
C405.4.2 Interior lighting power allowance	Lowers lighting power allowances for certain building types and space types in Table C405.4.2(1) and Table C405.4.2(2).			X	X	X	X	X	X	X	X	X	X	X	X	X	X
C405.4.2.2.1 Additional interior lighting power	Lowers additional allowance for retail spaces						X	X									
C405.5.3 Exterior lighting power allowance	Lowers exterior lighting power allowances for certain categories.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

2018 Section	Description of Change	HR Apt	MR Apt	Lg Off	Md Off	Sm Off	Std Rtl	SM Rtl	P Sch	S Sch	Whse	SD Rest	FF Rest	Lg Htl	Sm Htl	Hosp	Opt Hlth
C406.1 Additional energy efficiency credit requirements	Specifies that projects achieve a total of six credits from the available options.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C406.1.1 Tenant spaces	Specifies that at initial tenant improvement, a total of six credits must be achieved. This differed from 2015 WSEC, in which only two requirements had to be met and the type of requirements available to tenant spaces were specified.			X	X			X									

Appendix C: Additional Efficiency Package Selection

Section C406 in the 2015 and 2018 WSEC requires buildings to include optional efficiency measures. The 2015 WSEC required selection of up to two options. In addition, the number of options required could vary depending on whether the project was permitted as a "shell and core," with follow-on initial tenant improvement permits, or was permitted all at once. Initial tenant improvement projects required the choice of only one option, and if the building complied with the Section C406.5, C406.8 or C406.9 options, then the tenant improvement did not need an additional option. So, a building that was built and permitted in one phase required two options, while a building permitted as a shell with tenant permits required two options for the "shell and core" areas, but one or none for the tenant areas.

In 2018 WSEC, in lieu of 2015's two options, a total of six credits were required to be selected. The optional efficiency measures available in Section C406 provide from one to eight credits, and individual measures could be mixed and matched to achieve a minimum of six credits. Lastly, 2018 WSEC's six credit total was not dependent on the method of permitting—all spaces required a total of six credits regardless of permit type.

The C406 options listed in Table 17 were included in the prototypes and accounted for in the energy impact. The WSEC edition listed for a prototype indicates whether that option or credit was included for that prototype and the code edition. 2015 WSEC options were included in the 2015 WSEC energy calculation and 2018 WSEC credits were included in the 2018 WSEC energy calculation. Any differences between the requirements of a 2015 WSEC option and its corresponding 2018 WSEC credit are listed in Table 17.

If an entry includes "-core only" it indicates that only the core of the prototype uses this option. In the cases for which this occurred, the 2015 WSEC count and "Comments" column provide further details on the rationale.

For this analysis, credits were selected considering the following:

1. The frequencies of 2015 C406 options in NEEA's Washington 2015 Commercial Construction Code Evaluation Study guided the 2018 WSEC C406 credits chosen for this analysis. The frequencies over all building types in the study constituted the main consideration. Categories of frequency level for the different 2015 C406 options from the study appear at the top of Table 17 as "Code Implementation Study Frequency." This served as guidance for how often a C406 option was chosen for the 2018 WSEC. For example, the study found that the lighting power density (LPD) measure had a high frequency of occurrence in buildings and so it was added to all the prototypes. To a lesser extent, the frequencies within the study's building types provided guidance. However, due to the small sample size within building categories, this was a secondary consideration.
2. An attempt was also made to align with choices made for the 2015 WSEC energy savings analysis (Kennedy 2021).
3. The 2015 WSEC allowed the C406 DOAS option to be counted even if DOAS was already prescriptively required by the code. Therefore, where DOAS was prescriptively required in 2015 WSEC, it was also chosen for the C406 option. In 2018 WSEC, this was no longer allowed. The implication is that for buildings that required DOAS in both 2015 and 2018 WSEC, the 2018 WSEC building would likely save more energy as it would have both DOAS and another energy efficiency measure from C406. Note that the high-performance DOAS option under C406.7 in the 2018 WSEC was not chosen for any of the prototypes.
4. The construction phases for building types with tenant spaces were considered. For example, medium-sized office buildings are usually built as shell and core, and tenants later occupy the office spaces. In this case, credits may be split among the phases depending on the requirements for the given phase. The comments column in Table 17 provides further details.
5. Once the preceding factors were accounted for, to streamline modeling, selection of energy efficiency options sought to minimize the number of chosen options and credits, i.e., selecting two items (e.g. HVAC and LPD) from the list of credits for 2018 WSEC to accrue the six credits if possible and utilizing the same options in 2015, where possible and appropriate.

Table 17. C406 Options Chosen for the Analysis

	HVAC (C406.2)	LPD (C406.3.2)	Lighting Controls (C406.4)[12]	PV (C406.5)	DOAS (C406.6)	Hot Water (C406.8)	High Perf. Envelope (C406.10)	Infiltration (C406.11)	2015 Options	2018 Credits	Comments
Code Implementation Study Frequency	*Low*	*High*	*Average*	*None*	*Average*	*None*	*None*	*Low*			
Apartment Midrise	2015, 2018	2015, 2018							2	6	
Apartment Highrise	2015, 2018	2015, 2018							2	6	
Outpatient Healthcare		2015, 2018	2015, 2018					2018	2	6	
Hospital		2015, 2018	2015, 2018					2018	2	6	
Large Hotel		2015, 2018				2015, 2018			2	6	
Small Hotel		2015, 2018				2015, 2018			2	6	
Large Office		2015, 2018	2015—core only, 2018					2018	2-core, 1-tenant	6	Shell & Core Phase: LPD + Lighting Controls (HP VAV not DOAS) TI Phase: LPD
Medium Office		2015—core only, 2018	2018		2015			2018	2-core, 1-tenant	6	Shell & Core Phase: LPD + DOAS TI Phase: Inherits DOAS
Small Office		2015, 2018	2018		2015			2018	2	6	Whole building (Not a TI)
Sit-down Restaurant	2015, 2018	2015, 2018							2	6	
Fast-food Restaurant	2015, 2018	2015, 2018							2	6	
Standalone Retail		2015, 2018			2015				2	6	Whole building (Not a TI)

[12] C406.4 Lighting controls only included a credit for manual dimming.

	HVAC (C406.2)	LPD (C406.3.2)	Lighting Controls (C406.4)[12]	PV (C406.5)	DOAS (C406.6)	Hot Water (C406.8)	High Perf. Envelope (C406.10)	Infiltration (C406.11)	2015 Options	2018 Credits	Comments
Code Implementation Study Frequency	*Low*	*High*	*Average*	*None*	*Average*	*None*	*None*	*Low*			
Strip Mall Retail		2015, 2018			2015				2	6	Shell & Core Phase: LPD + DOAS TI Phase: Inherits DOAS
Primary School		2015, 2018	2018		2015			2018	2	6	
Secondary School		2015, 2018	2018		2015			2018	2	6	
Warehouse	2015, 2018	2015, 2018							2	6	

Note: The PV and High Performance Envelope (HPE) measures are listed as available options that buildings can choose to meet C406 requirements. This table shows that NORESCO chose other available options (e.g., LPD) over the PV and HPE measures to perform energy savings analyses.

Appendix D: Modeling Implementation

This Appendix provides details of the modeling approaches and assumptions used to capture the changes between 2015 and 2018 WSEC. It also describes key modeling inputs for the 2006 WSEC. Table 16 in Appendix B identifies the prototypes affected by each change in the 2018 WSEC relative to 2015 WSEC.

Envelope

Opaque envelope. The opaque envelope code U-factor requirements for various roof and wall assemblies and walls were used to determine the cavity and continuous insulation R-value to be used in the model. Each prototype has its own assembly type for roofs and walls, and the insulation layer R-value was calculated from the U-factor using the assembly layers. The F-factor requirements were used for perimeter slab insulation, except where KIVA was used to perform the ground heat transfer calculations; in those cases, the R-value and insulation depth were directly input into the model.

Fenestration properties. The simple glazing method within EnergyPlus was used to model the U-factor, solar heat gain coefficient (SHGC), and visible transmittance (VT) requirements specified by the three code editions.

Window-to-wall ratio. The WWR of the Medium Office, Large Office, Primary School, and Secondary School prototypes is greater than 30%. The WWR for these prototypes was lowered to 30% as required by the 2015 and 2018 WSEC editions.

Air leakage. Air barriers were not required in the 2006 WSEC, whereas they are required in the 2015 and 2018 WSEC editions. Table 18 shows the assumed air leakage rates for the three code editions and the converted rates for input into EnergyPlus.

Table 18. Modeled Air Leakage Rates and Conversions

Leakage Rate	No air barrier (2006 WSEC)	With air barrier	Test (2015 WSEC)	Test (2018 WSEC)	Test (2018 WSEC)
Leakage Rate, cfm/sf	1.8	1.0	0.4	0.25	0.17
Conversion to cfm/sf of exterior surface area	0.2016	0.112	0.0448	0.028	0.01904

Vestibules. Vestibules were not required in 2006 WSEC but are required in 2015 and 2018 WSEC. Vestibules result in reduced infiltration, particularly in tall buildings. A past PNNL study on vestibule infiltration (Cho, Gowri and Liu 2010) was used to determine the infiltration levels and schedules with and without vestibules and the inputs were applied to the various prototypes and code editions.

Mechanical

TSPR. The 2018 WSEC requires HVAC systems in certain building types to meet the TSPR requirements specified in Appendix D. In the Roadmap analysis (Athalye, Shadd and Arent, Washington State Commercial Energy Code Technical Roadmap 2020), the TSPR Standard Reference Design systems specified in Appendix D of the 2018 WSEC were explicitly modeled in the prototypes, thereby meeting the TSPR requirements. For this analysis, the project team decided to hold the HVAC systems constant among the three code editions, and therefore, the HVAC systems differed in all cases from the TSPR Standard Reference Design systems. To meet the TSPR requirement, each prototype system where TSPR was applicable, was modeled using the online Washington state TSPR tool.[13] The equipment efficiency, fan power, and ERV effectiveness were adjusted to meet the TSPR requirement. Results from TSPR modeling are included in Appendix E: TSPR Tool Results.

Equipment efficiency. Equipment efficiencies for air conditioners, heat pumps, packaged and rooftop units, gas furnaces and boilers, chillers, cooling towers, and other HVAC equipment that is governed by federal standards were incorporated into the models. As described earlier, the equipment efficiencies for the 2015 and 2018 WSEC were held constant to the 2018 WSEC levels to remove the credit from changes to federally mandated equipment efficiencies. The impacts from changes to these efficiency levels between 2006 and 2018 WSEC were captured by using the efficiencies specified by 2006 WSEC.

System design. The primary HVAC system attributes have been described in Table 7**.** These attributes remain constant through the three code editions modeled in the analysis, except for the ventilation system, which changes for some prototypes in the 2015 edition to a DOAS. Other HVAC system attributes, such as energy recovery ventilators, demand-controlled ventilation (DCV), optimum start, variable speed controls, economizer controls, motorized dampers, and other features were evaluated on a model-by-model basis based on system sizing outputs.

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[13] Available here: https://energycode.pnl.gov/HVACSystemPerformance/

These attributes were automatically adjusted based upon the outputs (capacity, airflow, and others) of a sizing simulation. Fan power, motor efficiency, and equipment efficiency were also automatically determined using a sizing script based on the sizing simulation output.

Ventilation. The 2018 Washington Mechanical Code (SBCC 2020) was used for the ventilation rates for the 2015 and 2018 WSEC editions—the rates do not change between those two code editions. The 2006 WSEC used ventilation rates specified in the Washington State Ventilation and Indoor Air Quality Code (SBCC 2006).

For the Mid- and High-rise Apartment prototypes, an in-unit ventilator was used for all three code editions. This unit ventilator meets the balanced ventilation requirements introduced in the 2018 WSEC. Balanced ventilation is not required in the 2006 or the 2015 WSEC. Given that the HVAC systems were held constant across code vintages in this analysis, the balanced ventilation system was also held constant, though data suggests that apartment buildings constructed in the late 2000s did not use balanced ventilation systems. In the 2018 WSEC, ERVs are required in the apartment prototypes and therefore, the unit ventilators were modeled with ERVs for 2018 WSEC.

DOAS. A new feature introduced in EnergyPlus v9.0 allows more than one air system to serve a single zone. In previous editions, only one air system was allowed per zone. This limited DOAS to zonal systems such as fan coil units, thus necessitating workarounds to model DOAS systems with, say, a rooftop DX unit. The new feature renders modeling DOAS systems much easier; this is especially important when modeling the mechanical requirements specified by the 2015 and 2018 WSEC, where DOAS is required with traditional air systems. In several prototypes, DOAS was combined with packaged and single zone systems that cycle with the load while ventilation is provided by the DOAS system.

Kitchen ventilation and transfer air. Kitchen ventilation requirements are more stringent in the 2015 and 2018 WSEC relative to the 2006 WSEC. The newer code editions require 50% of the exhaust air to be transferred from another zone. This was accomplished the restaurant and school prototypes by balancing the exhaust from the kitchen zone with 50% of transfer air from the neighboring zones. The neighboring zones were provided with a dummy exhaust fan that exhausted the air that was considered to be transferred to the kitchen zone.

Controls. Past PNNL analysis (Thornton, et al. 2009) (Halverson, et al. 2014) (Athalye, Halverson, et al. 2017) (Zhang, et al. 2015) provided the modeling strategies from implementing various controls, including boiler turndown, DOAS supply temperature and ERV bypass, thermostat setback, vestibule heating, supply air temperature reset, door switches for HVAC lockout, optimum start, cooling tower operation, pump flow operation, multi-zone VAV ventilation optimization, and fan speed control. The modeling strategies were adopted for implementation of the WSEC requirements in the prototype models.

Lighting

Interior lighting power. For 2015 and 2018 WSEC, the space-by-space method was used to determine the LPD for all prototypes except the Small Office, Medium Office, and Large Office, where the building area method was used to determine the interior lighting power density (LPD). The 2006 WSEC used the LPDs by building categories. A few zones in the some of the prototypes, such as the 'Basement' zone in the Large Hotel prototype, used the building area method.

The LPDs specified in the space-by-space and building area methods were lowered further in the 2015 and 2018 WSEC editions through the use of C406 LPD options. A further modification was made to the open office, private office, conference room, and classroom LPDs to claim credit from the digital lighting control option in the C406 section of the 2018 WSEC.

Interior lighting controls. Occupancy sensor controls and automatic ON and partial ON controls were modeled using schedule value reductions in the 2015 and 2018 WSEC models relative to the 2006 WSEC models. The schedule value reduction fractions were based on savings factors in ASHRAE Standard 90.1—2019 Appendix G (ASHRAE 2019).

Exterior lighting power. Each prototype was assigned a mix of exterior lighting zones 2, 3, and 4. The exterior lighting power was then calculated as an average of the assigned zones. Assumptions about the walkways, canopies, entrances, and parking area were based on a PNNL study (Thornton, et al. 2009). The total exterior lighting power was calculated for each lighting zone and prototype using the lighting power allowances specified in the three WSEC editions.

Exterior lighting controls. Astronomical time clock controls are required in all three code editions and were modeled. For the 2015 and 2018 WSEC editions, the building façade lighting power was split from the total exterior lighting power into a separate EnergyPlus object so that façade lighting control could be appropriately modeled. The façade lighting control is modeled using a schedule and is based on the requirements specified in the 2015 and 2018 WSEC. An astronomical clock control was implemented for 2006 WSEC.

Service Water Heating

Water heater efficiency. Water heater efficiency is federally regulated, and it also did not change for natural gas and electric resistance water heaters. In addition to the heater efficiency, the maximum allowed tank loss is also specified in the code. The tank loss was held constant between 2015 and 2018 WSEC, but the differences between 2006 WSEC and 2018 WSEC were modeled and the impact was captured.

Heat pump water heaters. Heat pump water heaters (HPWH) are one of the available additional efficiency measures in section C406 for both the 2015 and 2018 WSEC. HPWHs were modeled in both the Large and Small Hotel prototypes as one of the options under C406. Water heating is a significant energy use for these prototypes and HPWHs have higher efficiency than gas or electric resistance water heaters. For the Large Hotel, a central HPWH was modeled to meet the guest room loads. Other SWH loads in the Large Hotel are from the kitchen and laundry spaces but these were modeled as natural gas water heaters because section C406.8 requires only 60 percent of the building's SWH load to be met by HPWHs. For the Small Hotel, all SWH loads were modeled with a central HPWH. The HPWHs were modeled using the minimum required 3.0 COP as specified in section C406.8.

Power and Other Requirements

Receptacle control. At least 50% of receptacles are required to be controlled using occupancy sensors in offices (open offices only in 2018 WSEC), conference rooms, copy rooms, break rooms, and classrooms in the 2015 and 2018 WSEC. The modeling strategy was derived from a PNNL report (Halverson, et al. 2014) and applied to the prototypes where these spaces are found.

Motor and transformer efficiency. Motor efficiencies are federally regulated and therefore, they were set to the values specified in the 2018 WSEC for both the 2018 and 2015 WSEC models. For 2006 WSEC, the values are not directly specified in the code and therefore, values from ASHRAE Standard 90.1—2007 (ASHRAE 2007) were used. Motor efficiencies were calculated based on the sizing simulation run and assigned automatically.

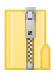
Transformer efficiency, like motors, is federally regulated. Existing objects within the PNNL models were used to model transformer efficiency.

Elevators. Elevator cab exhaust fans and lights are required to have automatic shutoff controls and maximum allowed fan power and lighting efficacy is also specified in the 2015 and 2018 WSEC editions. These were modeled as exterior equipment objects within EnergyPlus.

Appendix E: TSPR Tool Results

The zip file below has PDF results from the online PNNL TSPR tool for Washington State. Each prototype was modeled using the online tool and inputs were adjusted until the TSPR requirements were met for the prototype. The adjusted inputs were then used in the EnergyPlus model for the quantitative analysis.

File: TSPR_Results.zip.



TSPR_Results.zip