Modeling the Washington State Energy Code - 2006 & 2018 Baseline Energy Consumption

ECOTOPE

Final Report

Prepared for:

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State of Washington

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Commercial energy modeling was led by O'Brien360. Ecotope completed residential modeling and provided overall project direction and data analysis.

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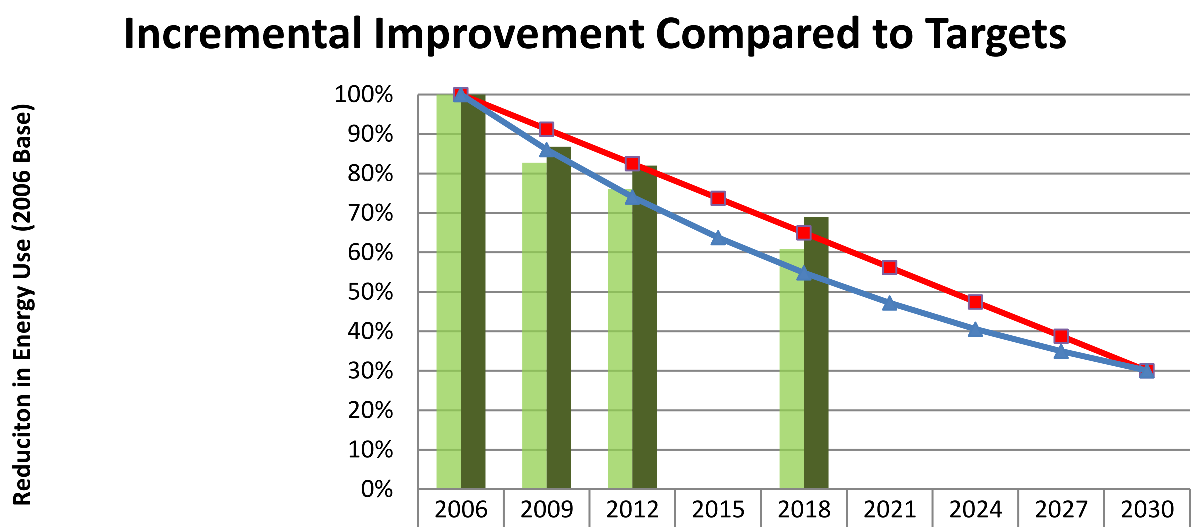
EXECUTIVE SUMMARY

Washington State law (RCW 19.27A.160) mandates that buildings built to the 2031 energy code use 70% less net-energy when compared to 2006-era buildings. The purpose of this study was twofold: first, it sought to establish the 2006 baseline energy use for the residential and commercial sectors and to provide a starting point for measuring our progress towards the mandated reductions. Secondly, it set out to determine how far the energy code has come in contributing to those reductions. As originally conceived, this study was designed specifically to assess changes in code stringency that contribute to the overall building sector goal of a 70% energy use reduction by 2031. Additional work may be undertaken to examine other market impacts during that period that influence overall building energy use patterns.

Different modeling software was used for each sector, but the approach remained the same. Residential and commercial prototypes, developed by the Regional Technical Forum (RTF), were sourced for the majority of the modeled buildings in this study, with a few specific building types (mid- and high-rise multifamily, outpatient healthcare, and a 5000sf single family home) added to capture more of the building sector. Statewide building trends were developed from regional building stock assessments and field studies to develop a saturation of common building types (by primary occupancy), HVAC systems, and location within the state (climate zone 5B or 4C). With prototypes developed and all weighting estimates developed, the project team then applied all prescriptive requirements from the 2006 and 2018 Washington State Energy Code (WSEC) to determine the expected energy consumption under each code cycle.

This study focused on showing the measurable energy savings purely brought by the energy code (or other required documents, such as state law) to the greatest extent possible. One such example was heating fuel sources—this study assumed the code does not affect which fuel source is chosen by builders or design teams, therefore primary heating fuel source was kept constant between the two analysis years. Beginning with the 2018 code, however, the code has begun to account for site carbon emissions as opposed to solely site energy use. While this should be accounted for in future studies, any adjustment to commonly selected heating fuel source must be informed by building surveys to document any measurable change in building trends.

Modeling results show that residential estimated energy consumption under the 2018 WSEC is approximately 61% of the 2006 WSEC (Figure 1). Commercial sector modeled energy consumption is estimated at 69% of 2006 levels. Energy savings estimates for 2009 and 2012 are sourced from previous legislative reports – no values have been provided for 2015.



	2006	2009	2012	2015	2018	2021	2024	2027	2030
Residential	100%	82.7%	76.1%		60.8%				
Commercial	100%	86.8%	82.0%		69.0%				
Target: 8.75 % savings compared to the 2006 WSEC	100%	91%	83%	74%	65%	56%	48%	39%	30%
Target: 14% savings compared to each previous code	100%	86%	74%	64%	55%	47%	41%	35%	30%

Figure 1. Progress of the Residential and Commercial Energy Codes Towards RCW 19.27A Targets

This research shows that the WSEC has made steady progress toward the State goal of 70% energy use reductions in new code-compliant buildings. However, the commercial results indicate that the changes driven by the Washington State energy code alone may be lagging the targeted rate of improvements in the commercial sector. Furthermore, assumptions in the prototypes about magnitude and characteristics of unregulated energy uses (such as plug loads) may be skewing modeling results away from observed market practice. This warrants more research to determine how other non-code related changes in the building industry may have impacted the overall energy use of the commercial sector. This study has focused explicitly on idealized energy use predictions from modeled prototypes; further research is warranted to determine how well these modeled predictions align with real world building performance.

INTRODUCTION

In 2018, the Washington State Legislature recognized the need to establish a fixed 2006 code building energy use baseline in order to be able measure progress toward the goals of RCW 19.27A. The law states that the energy code shall be designed to construct increasingly energy efficient homes and buildings that help achieve the broader goal of building zero fossil-fuel greenhouse gas emission homes and buildings by the year 2031. For the State to be able to reach this 70% goal, a baseline energy consumption estimate is needed. This baseline will determine how to achieve the State's reduction targets.

The goal of this study was to model the average annual energy consumption of newly constructed residential and commercial buildings under the Washington State Energy Code (WSEC), both in 2006 and 2018. Outlined in this report are estimates of overall and detailed building sector energy consumption, intended for legislators and State Building Code Council (SBCC) members to gauge progress and set stringency requirements for upcoming code development. Also included are detailed processes for future consultants to reference, in order to repeat similar analyses of future code editions.

Our modeling method for both the residential and commercial sectors follows the framework developed by the Regional Technical Forum (RTF), as well as processes used to develop the State's residential energy code. Historical studies including building stock assessments, metering studies, and surveys were used to inform the 2006 modeling inputs, which were then updated to show expected savings achieved by the 2018 code.

While builders and designers have the option to comply with code via several methods (i.e. prescriptive and whole-building performance methods), all buildings included in this study were assumed to comply with energy code through the prescriptive path only. This provides a well-defined list of inputs between any given analysis year and gives a clear view of code stringency.

When complying prescriptively, the 2006 code limited builders to a single pathway to compliance within both sectors. In 2018, by contrast, builders and design teams have a plethora of options to choose from, primarily within Section C406 and R406. These sections were introduced into the residential and commercial codes in 2009 and 2015, respectively, to bring increased savings while allowing for design freedom. The various option paths are a great benefit to design teams and builders, but they also introduce more uncertainty when attempting to model energy savings.

For this exercise, assumptions regarding selected options under Section R406 in 2018 were informed by an ongoing field study funded by the Northwest Energy Efficiency Alliance (NEEA) to establish code-compliance trends and characteristics of housing permitted under Washington's 2015 residential energy code; all options modeled were aimed to reflect lowest first cost to the builder. Commercial measures under Section C406 were selected through design experience and engineering judgement regarding the most common and cost-effective solutions.

MODELING METHOD

The modeling process and selection of prototypes remained consistent with the framework developed by the Regional Technical Forum (RTF) and the Northwest Power and Conservation Council (NPCC) for energy forecasting for the region's utilities. The residential modeling process was the same as that used to develop and evaluate Washington State's residential energy code as well as to measure the effectiveness of other regional residential energy codes (NEEA, 2019).

The energy consumption of any given building is affected by several inputs, some predicable (i.e. code-mandated) and others irregular. However, to model overall energy performance improvements associated with code-mandated savings, it is important to keep any inputs not directly regulated by code constant.

To accomplish this, the study sought first to establish all the modeling constants which remained unchanged between the analysis years. The constants represent specific building prototypes, distributions of characteristics (total floor area by occupancy, HVAC system type, location), schedules and unregulated loads across the sectors. These details were found through various regional field surveys, building stock assessment studies, and RTF default assumptions.

After building prototypes were established and representative saturation values determined, then the code-mandated savings were modeled. The savings estimates are limited to regulated end-uses such as envelope insulation, heating, cooling, ventilation, lighting, hot water systems, and appliances (credits now honored in both codes for EnergyStar appliances). Explicit requirements (and optional measures) affecting the energy consumption for those end-uses can be found in the energy code and other compulsory documents, such as:

2006 Washington State Energy Code
2006 Washington State Ventilation and Indoor Air Quality Code
2018 Washington State Energy Code
2018 International Mechanical Code with Washington Amendments
2018 International Residential Code with Washington Amendments
National Appliance Energy Conservation Act (NAECA)
HB 1444 – Washington State Appliance Efficiency Standards

The team used EnergyPlus and Simple Energy Enthalpy Model (SEEM) programs, for the commercial and residential code respectively, to produce annual energy use estimates from all the regulated and unregulated loads. Batch modeling processes were used to complete over 200 residential and 90 commercial modelling runs to simulate each prototype under the various combinations of location, HVAC system, and code year.

RESIDENTIAL BUILDING ENERGY MODELING

Residential Prototype Development

The residential building provisions for the WSEC apply to site-built one- or two-family detached dwellings, multiple single family attached dwellings (townhomes), and group R-2, 3, 4 construction (three stories or less). Prototypical representative characteristics include occupancy, house size, and ground contact type (slab, crawl, or basement).

The building prototypes used in this study are meant to reflect the varying sizes and styles within the residential sector. Except for the 5,000sf home, all are standard analytical prototypes used by the RTF and NPCC to develop and evaluate energy forecasts and conservation plans for the region's utilities. In total, there are six distinct building prototypes for single family and two for multifamily, including townhomes (see Table 1).

Distributions of the prototypical foundation type, heating system, and building size are drawn from two important studies completed by RLW Analytics in 2007 which aimed to develop a representative sample of residential construction characteristics for single-family and low-rise multifamily homes built between 2004 and 2005 (RLW Analytics, 2007). Each prototype is assigned a weight in proportion to its frequency of occurrence in the building population (see the *Weighting* section below*)*.

Table 1. Residential Prototype Characteristics

2018 WSEC Classification (Section R406)	**Small Dwelling Unit**		**Medium Dwelling Unit**					**Large Dwelling Unit**	**Group R-2**		
Prototypes	1344c	1344s	1500c	1500s	2200c	2200s	2688b	5000b	1000c	952c	952s
Building Type Single Family Detached (SF) or Multi-family (MF)	SF	SF	SF - Town-home	SF – Town-home	SF	SF	SF	SF	MF – Double Loaded Corridor	*MF – Garden Style*	*MF – Garden Style*
Heated Area (ft^2)	1,344	1,344	1,500	1,500	2,200	2,200	2,688	5,000	26,400	7,616	7,616
# of Units	1	1	2	2	1	1	1	1	24	8	8
Foundation Type	Crawl	Slab	Crawl	Slab	Crawl	Slab	Bsmt	Bsmt	Crawl	Crawl	Slab
Floors	1	1	3	3	2	2	2	3	3	2	2
Occupants/ Unit	2.0	2.0	1.7	1.7	2.7	2.7	3.5	4.0	1.7	1.7	1.7

The relatively limited number of HVAC options available to residential builders allows this sector to be well represented with four common HVAC systems as described in Table 2. Associated weights, derived from the 2007 RLW report, are shown in Table 4.

Table 2. HVAC System Types for Residential Prototypes

System Type	Description
GFNC – Gas furnace	Central gas furnace with distribution ductwork
GFAC – Gas furnace with air-conditioning	Central gas furnace and air-conditioning
HP – Central heat pump	Central heat pump with distribution ductwork and electric resistance backup
ZONL – Electric zonal heating	Electric baseboard heating. For 2018 analysis, houses with electric zonal required to have Ductless Heat Pump in main living area

WEIGHTING

Aggregating the modeling results down to representative energy consumption estimates (i.e. small home energy use or low-rise multifamily use) is referred to as weighting. A fundamental assumption in this study is that the distribution of prototypical characteristics, like house size or heating system type, remains constant between code years. By keeping the weights constant, code-mandated savings are better represented. But this assumption implies that builders will always build the same types of homes and that the energy code will not measurably affect a builder's choice of heating fuel.

Without current permit data to define market trends, the previously mentioned characteristic study (RLW Analytics, 2007) remains as the most reliable source of documented residential building trends in Washington State – the prototypical weighting sourced from this study were held constant between both code analysis years. Climate zone weights (Table 5) sourced from the RLW (2007) study are in concordance with respective county-by-county population weighting values from 2010 Washington State census.[1]

The following tables (Table 3 through Table 6) provide all constants used to weight the 140 individual modeling results down to representative values presented in this report.

Table 3. Residential Weighting by House Size

Prototype	SF 1344c	SF 1344s	SF 2200c	SF 2200s	SF 2688b	SF 5000b	SF 1500c	SF 1500s	MF 1000c	MF 952c	MF 952s
Weight	8%	2%	57%	10%	11%	2%	8%	2%	24%	31%	45%
	* Single family and multifamily each sum to 100%										

[1] Washington Office of Financial Management. https://www.ofm.wa.gov/washington-data-research/population-demographics/decennial-census/census-2010/census-2010-data

Table 4. Residential Weighting by Heating System Type

Heat Fuel	System	Single-family (SF)	SF – Townhomes	Multifamily R-2 (MF)
Gas	Furnace (no A/C)	55%	61%	0%
Gas	Furnace (w/ A/C)	28%	1%	0%
Elec	Air-source Central HP	13%	5%	0%
Elec	Electric Zonal (w/ DHP in 2018)	4%	33%	100%

Table 5. Residential Weighting by Climate Zone

IECC Climate Zone	Single- and Multifamily
4C (Seattle)	77%
5B (Spokane)	23%

Table 6. Single-family and Multifamily Weighting by Total Residential Floor Area

Occupancy Type	Weighting
Single Family	78.5%
Low-rise Multifamily	21.5%

Residential Building Modeling Inputs

Modeling inputs encompass all the variables that are applied to each prototype in order to reach the final annual energy consumption estimate. In large part, these variables influence regulated loads (heating, cooling, ventilation, lighting, and hot water), which are updated between different code analysis years to show code-mandated savings. These variables are either required by code or law and are irrespective of market trends or occupant behavior.

Heating and Cooling

For heating and cooling equipment efficiencies (as shown in Table 10), these are defined by NAECA federal equipment standards and optional measures from Section R406 of the 2018 WSEC.

Lighting

Lighting runtime was modeled as 1.8 hr/day average for all fixtures (RBSA, 2014). There are no requirements for lighting in residential occupancies in 2006; therefore baseline assumptions were taken from the RLW (2007) reports, with incandescent bulbs (65 W/bulb) making-up the majority of lighting in single family and multifamily and only 15% of the installed bulbs qualifying as high efficacy lighting. In contrast, Section R404 of the 2018 WSEC requires 90% of fixtures be high efficacy. With the market penetration of LED lighting in recent years, high efficacy lighting was modeled as compact fluorescent bulbs (14 W/bulb) in 2006 and changed to LED lighting (10 W/bulb) in 2018.

Domestic Hot Water

Heating fuel source for domestic water heaters was assumed to match the space heating fuel source for all prototypes and analysis years. Equipment efficiencies and occupant densities were applied to baseline annual energy consumption[2] data sourced from the RBSA metering study (RBSA, 2014). A 10% reduction in daily hot water use was granted for low-flow showerheads[3] in the 2018 WSEC analysis due to the 2019 Appliance Efficiency Standards law.[4]

For 2018 code compliance, high efficiency water heating equipment measures were selected for all prototypes except for small dwelling units (1,344sf prototype). Gas-heated homes were never assumed to select heat pump water heaters in any runs. Summary of water heating efficiencies can be found in Table 10.

Appliances and Plugs

Unregulated loads have a growing impact on annual energy consumption but largely remain outside the authority of the energy code, although the 2018 WSEC now honors credits for EnergyStar appliances and ventless dryers. These end-uses represent plug loads, consumer electronics (TV, game consoles, computers), cooking, and other appliances. There was no explicit differentiation between gas and electric use (i.e. cooking) within this category and all end-uses are incorporated as equivalent kWh/yr of electric energy use. Internal gains from these miscellaneous loads (lights, and occupants) are included in the SEEM modeling runs by averaging the daily internal gains and normalizing on an average hourly basis, but final annual energy use numbers shown are applied at a post-process calculation. The baseline energy use estimates used in this study are sourced from the 2014 Residential Building Stock Assessment (RBSA) Metering Study (RBSA, 2014) and are summarized in Table 9 for each predominant housing type.

Section R406 Measures (2018 WSEC)

As previously mentioned, the 2018 code presents builders with many more options for prescriptive code compliance when compared to the 2006. In 2018, the option table in Section R406 defines different energy conservation measures and pairs them with a credit value. Each home, depending on size and occupancy type, is required to choose a minimum number of credits to comply with code. This section is used to increase the savings brought by each code cycle while allowing builders to have options for compliance. Table 7 provides a summary of each optional measure and associated credits within the 2018 code.

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[2] From 2014 RBSA: $Q_{DHW} = 570 + 1034 * \#occ$ (kWh/yr)

[3] RTF UES Measure. https://rtf.nwcouncil.org/measure/showerheads

[4] Washington House Bill, as accessed 3/2020. http://lawfilesext.leg.wa.gov/biennium/2019-20/Pdf/Bills/Session%20Laws/House/1444-S2.SL.pdf?q=20200318222309

Table 7. Summary of the Option Table (Table R406.3) from the 2018 Residential Energy Code

Option	Description	Credits (All Other)	Credits (Group R-2)
1.1	Glazing at U-0.24	0.5	0.5
1.2	Glazing at U-0.20	1.0	1.0
1.3	5% UA reduction	0.5	N/A
1.4	15% UA reduction	1.0	1.0
1.5	30% UA reduction	2.0	1.5
1.6	40% UA reduction	3.0	2.0
1.7	Adv. framing, raised heel trusses (R-49) and glazing at U-0.28	0.5	0.5
2.1	3 ACH50 and 0.35 W/cfm whole-house fan	0.5	1.0
2.2	2 ACH50 and HRV at 65% sensible recovery	1.0	1.5
2.3	1.5 ACH50 and HRV at 75% sensible recovery	1.5	2.0
2.4	0.6 ACH50 and HRV at 80% sensible recovery	2.0	2.5
3.1	95% AFUE furnace	1.0	1.0
3.2	Air-source heat pump at 9.5 HSPF	1.0	N/A
3.3	Ground source heat pump at 3.3 COP	1.5	1.0
3.4	DHP at 10 HSPF	1.5	2.0
3.5	Air-source heat pump at 11.0 HSPF	1.5	N/A
3.6	DHP at 10 HSPF for entire dwelling unit	2.0	3.0
4.1	Deeply buried ducts	0.5	0.5
4.2	Ducts inside	1.0	N/A
5.1	Drain water heat recovery	0.5	0.5
5.2	Gas water heater at 0.8 UEF	0.5	0.5
5.3	Gas water heater at 0.91 UEF	1.0	1.0
5.4	Heat pump water heater at NEEA Tier I	1.5	2.0
5.5	Heat pump water heater at NEEA Tier III	2.0	2.5
5.6	Split-system Heat pump water heater	2.5	3.0
6.1	1,200 kWh/yr renewable energy generation (max 3 credits)	1.0	1.0
7.1	EnergyStar appliances and ventless dryer	0.5	1.5

Table 8 below lists the selected measures under Section R406 for this study. While this study did not complete an economic analysis of the option table, the credits were selected on the basis of anticipated least first cost to the builder. All measure packages include requisite Fuel Normalization credits from Table R406.2, aligned with the dominant space heating fuel/system type.

Table 8. Selected Measures from Table R406.3 for Each Prototype in 2018

Small Dwelling <1500 ft^2 (needs 3.0 Credits)				
Heating System	Selected Measures			
GFNC	1.3	2.1	3.1	4.2
GFAC	1.3	2.1	3.1	4.2
ASHP	3.2	4.2		
ZONL	2.1	3.4		

Medium Dwelling 1500 - 5000 ft² (needs 6 Credits)						
Heating System	Selected Measures					
GFNC	1.5	2.1	3.1	4.2	5.3	7.1
GFAC	1.5	2.1	3.1	4.2	5.3	7.1
ASHP	2.1	3.2	4.2	5.5	7.1	
ZONL	1.2	3.4	5.5	7.1		
Large Dwelling > 5000 ft² (needs 7 Credits)						
Heating System	Selected Measures					
GFNC	1.5	2.3	3.1	4.2	5.3	7.1
GFAC	1.5	2.3	3.1	4.2	5.3	7.1
ASHP	1.1	2.1	3.5	4.2	5.5	7.1
ZONL	1.5	2.2	3.4	5.5		
Multifamily (R-2) (needs 4.5 Credits)						
Heating System	Selected Measures					
ZONL (no DHP)	1.1	2.2	5.5			

Table 8 above shows assumed common cost-effective pathways to code compliance for each prototype. However, this is based on conjecture as these buildings have not been built at the time of this report. To confirm if these measures are in fact the most commonly selected measures by builders, insight from a future modern building stock assessment would provide invaluable clarity into current building trends and help deliver a more accurate estimate of 2018 code savings.

Residential Building Modeling Process

Residential batch modeling relied on the Simple Energy Enthalpy Model (SEEM)[5] software for single-family and low-rise multifamily buildings. The analysis tool, used by the RTF and the NPCC for parametric energy analysis in the region, simulates hourly heating, cooling, lighting, and ventilation energy use from inputs including building shell characteristics, occupancy and building schedules, heating and cooling systems, duct parameters, and weather files. Energy consumption for all other end-uses was determined through engineering calculations supported by field studies and survey data.

Besides regulated end uses (regulated by code and/or law), no inputs were changed between the code years. This includes building weights, internal gains assumptions, and miscellaneous plugs use for each prototype. Once all runs were completed, the results were consolidated down by the appropriate weights to representative values for the sector.

It should be noted that built-in assumptions about weighting of the population of different system types and other factors influence the magnitude of energy use and savings identified in the overall savings represented in Figure 2 below. Exploring the accuracy of systems weighting in modern construction, such as the current ratio of electric to gas heating systems installed by builders, would add clarity to the

[5] SEEM. https://rtf.nwcouncil.org/simplified-energy-enthalpy-model-seem

savings estimates shown in these types of modeling analyses. For this analysis, these weights were assumed to have remained unchanged from findings presented in the RLW (2007) report.

Residential Building Results and Analysis

The average site Energy Use Intensity (EUI), a measure of energy consumption normalized per square foot of conditioned floor area, for the residential sector in 2018 is 61% of that in 2006 (Figure 2).

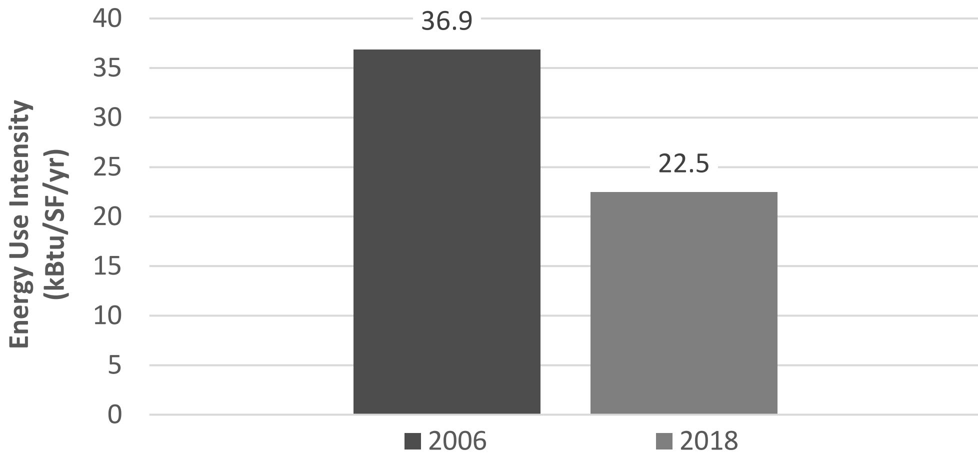

Figure 2. Residential Sector EUI by Code Year (2006 and 2018)

Figure 3 shows the EUI split into building types defined by the 2018 code within Section R406. Single-family medium dwellings represent 69% of the building types in the state and for this category the EUI in 2018 is 57% of that in 2006. Low-rise multifamily, representing 22% of all building types, show an EUI in 2018 that is 69% of 2006. Small homes show the least progress and remain at 78% of 2006 levels.

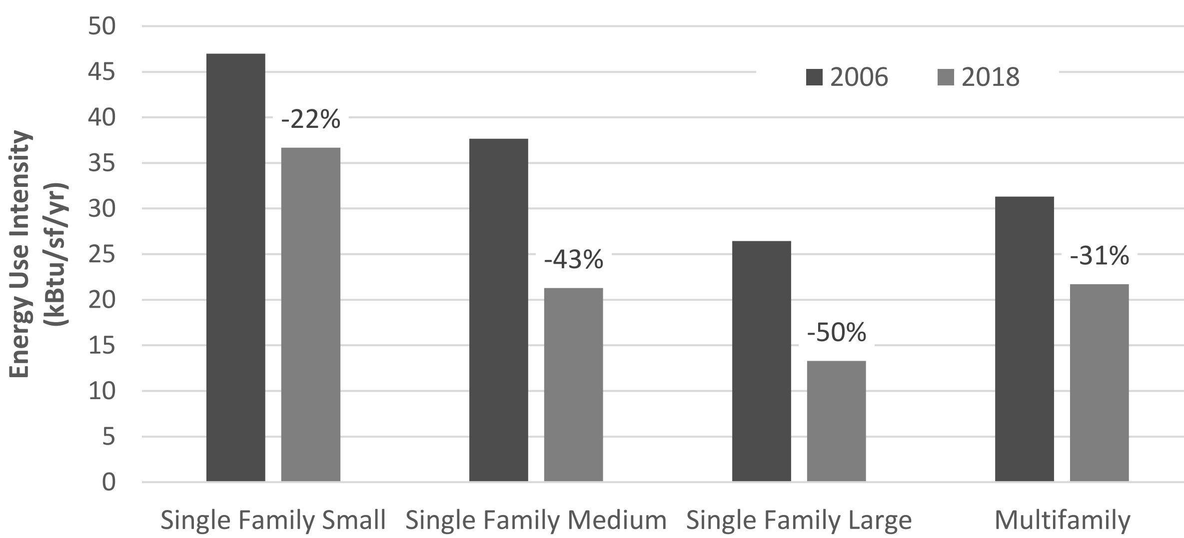

Figure 3. Residential EUI By Code Year and Percent Savings by Building Type

Figure 4 shows the EUI by end use for different building types. Lighting represents biggest percent reduction in end use, at 73% savings over the 2006 baseline. However, the greatest total energy savings are gained within the space heating end-use, where the average heating EUI in 2006 of 17 kBtu/sf/yr is reduced to 9 kBtu/sf/yr in 2018. Detailed modeling results can be found in Appendix B – Detailed Residential Modeling Results

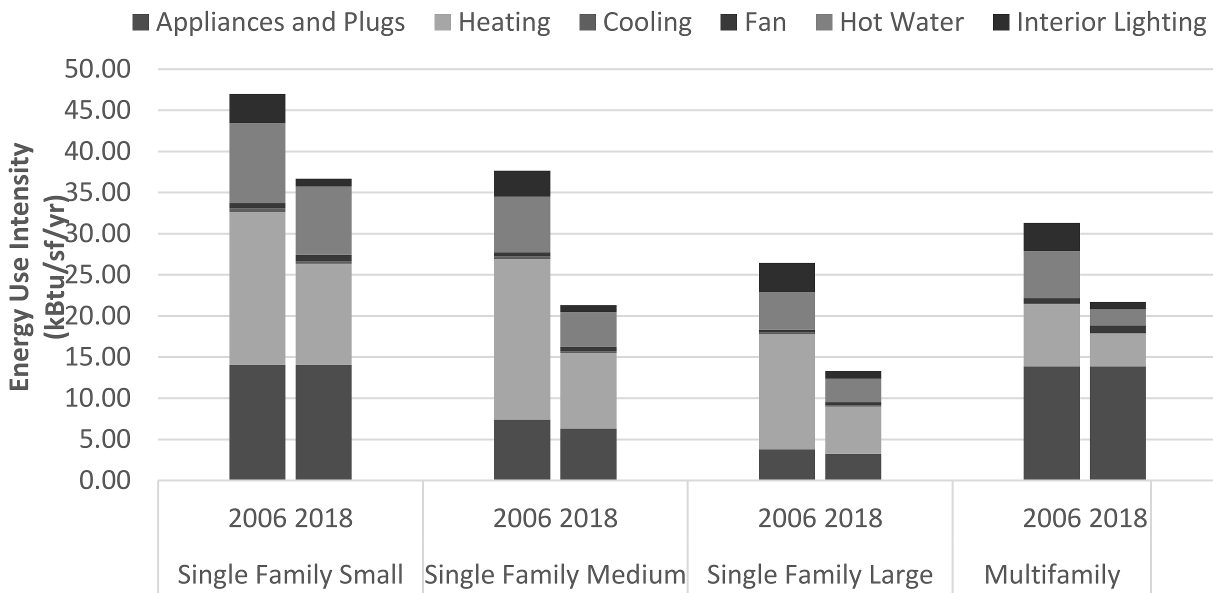

Figure 4. Residential End-use EUI by Building Type and Code Year

For prototypes which selected Option 7.1 (EnergyStar appliances and ventless dryer) from Table R406.3 in the 2018 code, an 840 kWh/yr savings was given for single family dwellings. Ventless dryers represent the bulk of these savings.[6] Modeled appliance and plug energy use is shown in the table below.

Table 9. Modeled Annual Energy Consumption of Appliance and Plug Loads by Housing Type by Year

Housing Type, Year	Appliance and Plug Energy Use (kWh/yr)
Single Family, Small - 2006	5,533
Single Family, Medium - 2006	5,533
Single Family, Large - 2006	5,533
Multifamily - 2006	4,121
Single Family, Small - 2018	5,533
Single Family, Medium - 2018	4,693
Single Family, Large - 2018	4,727
Multifamily - 2018	4,121

[6] RTF UES Measures. https://rtf.nwcouncil.org/measure/clothes-dryers-sf-mh-and-mf-unit

Other notable findings:

Required ventilation airflow rates dropped by 35% from 2006 to 2018, but fan modeled energy increases in 2018 due to a requirement for balanced ventilation systems in multifamily provided by heat recovery ventilators which are modeled to run 24/7. However, a net energy savings is expected from reducing the heating load through ventilation heat recovery and increased envelope air tightness.

While cooling efficiencies and duct leakage rates improve between 2006 and 2018, these savings are diminished by a higher saturation of homes with mechanical cooling. In the 2018 WSEC, single-zone ductless heat pumps (DHP) are required in electric resistance heated single family homes through Section R403.7.1, and it was assumed that if heat pumps are present they will be used for cooling as well. This introduces a cooling load that was not measurably present in 2006. Nevertheless, DHPs are a heating measure in our region and this study shows 22% total energy savings over the 2006 baseline for electric resistance heated homes.

Federal minimum equipment standards have had little improvement since 2006. Through Section R406 however, higher equipment efficiencies can be installed to achieve energy credits. These measures can often be the most economical and easiest to implement (for example, condensing gas furnaces for space heating); therefore, equipment measures were selected for all 2018-compliant prototypes. Table 10 below highlights the relative efficiencies of these select equipment measures.

Table 10. Federal Minimum Equipment Efficiencies compared to Table R406.3

System	2006 Federal Min Efficiency	2018 Federal Min Efficiency	2018 Table R406.3 Efficiency
Gas Furnace	78% AFUE	80% AFUE	Option 3.1: 95% AFUE
Central A/C	13 SEER	13 SEER	N/A
Central Heat Pump	13 SEER, 7.7 HSPF	14 SEER, 8.2 HSPF	Option 3.2: 14 SEER, 9.5 HSPF
Water Heater (Elec, < 55gal)	0.90 EF	0.94 EF	Option 5.5: Tier III Heat Pump Water Heater[7]
Water Heater (Gas, < 55 gal)	0.57 EF	0.59 EF	Option 5.3: 0.91 UEF

The study counted the 1500sf townhome prototype is as a medium sized home (per size requirements in Section R406) and modeled the prototype with 6 efficiency credits. If the conditioned square footage was 1,499sf, then it would qualify as a small home and only need 3 credits (reducing the cost to comply with the 2018 code). Current market data is needed to inform the average size of townhomes in order to provide a more accurate estimate of energy savings for this type of construction.

[7] NEEA. Advanced Water Heating Specification (as accessed March 2020). https://neea.org/our-work/advanced-water-heating-specification

In this analysis, assumptions about unregulated plug loads remained constant between 2006 and 2018 and are sourced from the metering study (RBSA, 2014). As regulated loads decrease through code advancement, the relative impact of unregulated loads on overall building performance increases. Appliance efficiency options being included in the 2018 code are a first step towards addressing this historically unmanaged energy load.

Per the RLW (2007) study, ~80% of single-family detached homes and ~60% of townhome dwellings were heated with fossil gas. This study assumes that the same distribution of heating sources continues in modern building trends.

As shown in Figure 5, electric (heat pump homes) have a far lower heating EUI than their fossil gas counterparts. Even when applying the carbon emissions factors (from Table R405.3 of the 2018 WSEC), heat pump heating releases less CO_2 than on-site gas furnaces.

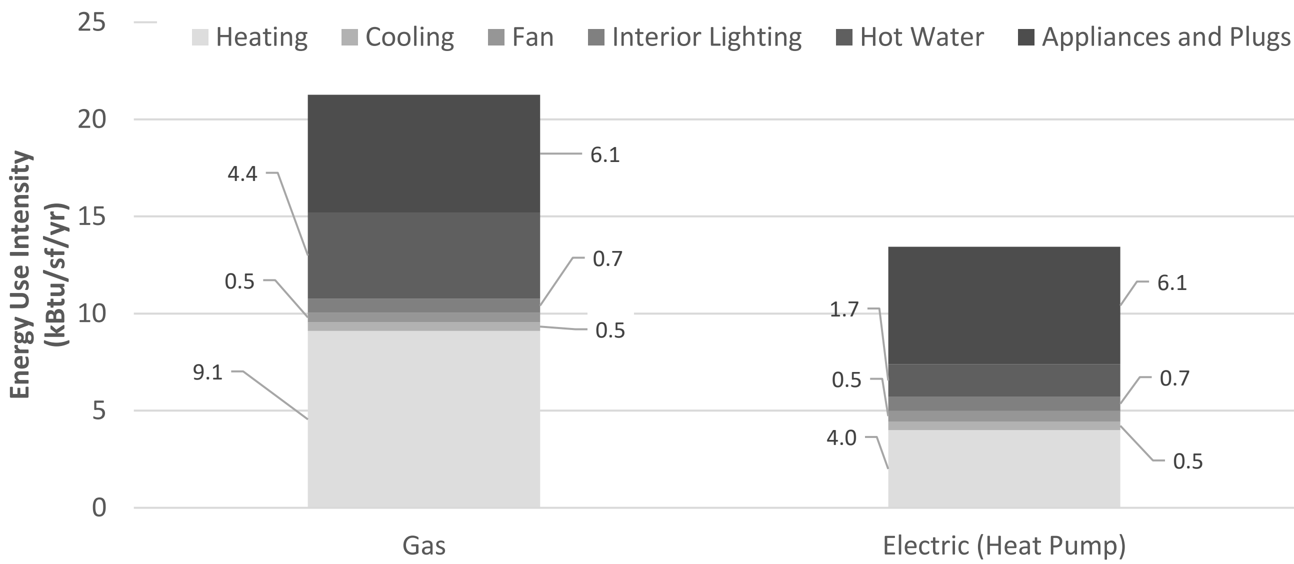

Figure 5. Average Modeled EUI of a Single-Family Dwelling (by EUI) in 2018 –Gas vs Electric Heating Source

COMMERCIAL BUILDING ENERGY MODELING

This study is designed to establish a performance baseline for the 2006 WSEC, and to assess the savings that have been achieved in the energy code compared to that baseline in the 2018 version of the WSEC. Although the state building performance mandate is focused on overall building performance improvement, this study was designed primarily to identify the performance impacts of the WSEC on overall building performance. Changes in market practice also have an impact on overall building energy performance, but these impacts were not evaluated in this phase of the analysis. Additional work to assess market impacts is described at the end of this report.

The 2018 Commercial WSEC allows for two avenues for compliance: prescriptively and the Total Building Performance (TBP) path. The prescriptive path is a clearly documented approach to compliance: a building simply needs to meet all mandatory code sections to meet code. Whereas the TBP path, outlined in Section C407, provides an alternate compliance path for commercial buildings in which building energy models are submitted to demonstrate the proposed building has a lower modeled energy usage than a code-defined baseline building. It is intended that this path leads to energy savings that are roughly equivalent to the prescriptive path, however there is no distinct evidence that suggests it does.

Regardless, in the commercial sector, the vast majority of new buildings follow the prescriptive code to demonstrate energy code compliance. The City of Seattle, which has more performance submittals than most jurisdictions in the country, sees only about 5% of commercial projects using the performance pathway, according to Duane Jonlin at the City of Seattle. This analysis is focused on the energy performance impacts of the prescriptive pathway in the WSEC.

Commercial Building Prototype Development

For this analysis, existing building prototypes developed by the Northwest Power Planning Council's (NPCC) Regional Technical Forum (RTF) to estimate the energy savings potential of efficiency measures in buildings in the Pacific Northwest were used as the basis of the evaluation.[8] These basic prototypes have been used in multiple analyses over the years in this region and therefore provide consistent comparisons across various evaluations. The models are largely derivatives of the Department of Energy's (DOE) Commercial Reference Building models[9], revised to reflect data gathered in the 2014 Northwest Commercial Building Stock Assessment (Navigant, 2014) and the Northeast Energy Efficiency Partnerships (NEEP) lighting load shape project (KEMA, 2011).

The RTF suite of commercial building models, used as prototype models in this study, currently includes 15 commercial building prototypes. Three additional prototypes, representing mid-rise multifamily, high-rise multifamily, and outpatient healthcare included in the DOE CRB set were added to the analysis, together representing over 12% of building stock floor area in the region (Navigant, 2014). With all 18

[8] RTF standard prototypes (as accessed March/2020): https://rtf.nwcouncil.org/work-products/supporting-documents

[9] U.S. Department of Energy (U.S. DOE), Energy Efficiency & Renewable Energy. *Commercial Reference Building models*. https://www.energycodes.gov/development/commercial/prototype_models

prototypes, the commercial sector is believed to be well represented. The following building types were included in this study:

Small Office
Medium Office
Large Office
Stand-alone Retail
Strip Mall
Supermarket
Primary School
Secondary School
Small Hotel
Large Hotel
Hospital
Warehouse (non-refrigerated)
Quick Service Restaurant
Full Service Restaurant
Outpatient Healthcare
Mid-rise Apartment
High-rise Apartment
Residential Care

Additional description of building types is included in Appendix D – Commercial Building Type Descriptionsand Appendix E – Commercial Building Modeling Inputs.

The selection of HVAC systems for the commercial prototypes has a major influence on the modeling results since each system type has different influences on other end uses in the model, and therefore can result in significantly different annual energy end-use consumption estimates (such as fans, pump, compressors, boilers, and cooling towers if present). This analysis maintained a consistent ratio between 2006 and 2018 assumptions about system type distributions, and not all possible system types were modeled. Designers and engineers have an abundance of combinations to choose from, between primary heat source (gas, electric, air-source or ground-source heat pump), secondary heating source, distribution methods (air or hydronic), ventilation design (Variable Air Volume, dedicated outdoor air system, heat recovery, 100% outside air), and associated control strategies to manage these highly engineered systems. These variables introduce uncertainty into the results that can only be resolved with more detailed field studies to identify deployment rates of different system types, and any changes that might have occurred in system preference in the market between 2006 and 2018. Due to time and budget constraints and the large number of different prototypes and combinations in this study, only the most common HVAC systems were modeled.

Adding to the determination of HVAC systems are the requirements driven by climate, such as cooling for multifamily apartments buildings found commonly in Eastern Washington, but less so in Western Washington. For the purposes of this study, models with fossil-fuel space and water heating equipment are all assumed to use fossil gas, as it is the most common fossil fuel used for these applications in Washington State.

2006 HVAC System Selection

For the 2006 baseline models, the project team sourced the HVAC system selections from the RTF prototypes and then corroborated those assumptions with a 2002-2004 field study of the nonresidential sector in the Pacific Northwest (Ecotope, 2008). This study documented building characteristics of a regional sample of commercial buildings permitted between 2002-2004, thus providing the clearest representation of commercial building practices for the 2006 baseline.

The comparison of the RTF HVAC systems to those recorded in the 2002-2004 nonresidential sector study revealed a few prototypes in which the single RTF HVAC system would not adequately capture the market in 2006. In these instances, the project team elected to model two scenarios that utilize the same HVAC system type but differ by primary heating energy source (fossil fuel or electricity), such as a packaged single zone rooftop unit with a gas furnace and an air-source direct expansion (DX) cooling coil or an air-source DX heat pump.

For the three prototypes not covered by the RTF suite of models (mid- and high-rise multifamily, and outpatient healthcare), the modeled HVAC systems include: the Department of Energy (DOE) default of water-source heat pumps in high-rise multifamily, packaged terminal air conditioners (PTACs) with electric heat and whole house exhaust fans for the mid-rise multifamily, and chilled water as opposed to air-cooled direct expansion (DX) cooling for outpatient healthcare. See Table 17 for a summary of the 2006 HVAC systems and associated saturations.

2018 HVAC System Selection

The project team emphasized modeling the same HVAC systems between each code year, and at a minimum, keeping each prototype's heating fuel source (electricity vs. natural gas) unchanged. The detail of heating fuel selection is crucial because any estimate of code-mandated energy savings would be heavily skewed by a switch from one to another (since heat pump efficiencies are higher than gas). Historically the code has never addressed the selection of heating fuel, although for the first time, the 2018 WSEC incorporates the use of carbon emissions as the metric for determining compliance in two important sections of the code: Section C407: Total Building Performance and Section C403.1.1: Total System Performance Ratio (TSPR). Without field survey data to substantiate a significant shift in fuel sources used in new buildings, this analysis assumes that heating fuel source remains unchanged between analysis years. However, it does account for changes in heating source efficiency driven by the code, primarily TSPR, in that heat pumps are the principal electric heating equipment as opposed to electric resistance.

Another important consideration in the selection HVAC systems is the introduction of the dedicated outdoor air system (DOAS) requirements in the 2015 WSEC for office, retail, library, fire station, and education occupancies. In the 2018 WSEC, DOAS requirements are expanded through Section C403.3.5 to cover more building occupancy types, along with balanced mechanical ventilation with heat recovery prescribed by Section C403.3.6 for the Group R-2 occupancy. Combined with the TSPR requirement, these two provisions will likely have a tangible impact on HVAC system selection for many building types.

In this study, 10 of the 18 prototypes are impacted by 2018 DOAS requirements with 8 of those 10 requiring compliance with TSPR. Aside from the inclusion of DOAS, the project team assumed the same heating/cooling equipment types as 2006 for all prototypes except for primary schools, secondary schools, medium offices, and large offices. For the 2006 vintage, these four prototypes were modeled with a multi-zone variable air-volume (VAV) system. A 2018 code-compliant VAV system is believed to be more costly than DOAS-compliant systems, and therefore, it was assumed these prototypes utilized DOAS with a zonal heating/cooling system.

In the end, the same overall heating and cooling system was modeled for 14 of the 18 total prototypes, with the significant energy-savings impacts of DOAS captured in all of the impacted prototypes. Eight prototypes' HVAC systems were altered for 2018 based on C403.3.5 Dedicated Outdoor Air Systems (DOAS): Small Office, Medium Office, Large Office, Stand-alone Retail, Strip Mall, Supermarket, Primary School, and Secondary School.

Two prototypes' HVAC systems were altered based on C403.3.6 Ventilation for Group R-2 Occupancies: Mid-rise Apartment and High-rise apartment.

Finally, eight prototypes kept the same HVAC system: Small hotel, Large hotel, Hospital, Warehouse (non-refrigerated), Quick Service Restaurant, Full Service Restaurant, Outpatient Healthcare, and Residential care. Although, it should be noted that energy savings from a heat recovery chiller was added to the hospital based on requirements from C403.9.2 Heat Recovery through Post Processing.

WEIGHTING

Statewide floor area of commercial building types is sourced from the 2014 Commercial Building Stock Assessment (Navigant, 2014) with the distribution remaining constant between the two analysis years. Refer to Appendix D – Commercial Building Type Descriptions for comparison of modeled prototype occupancies to CBSA classifications.

Table 11. Statewide Commercial Weighting by Building Floor Area

Building Type	Fraction of Total Floor Area
Stand-Alone Retail	18.1
Warehouse	14.2
Large Office	10.7
Small Office	7.8
Medium Office	7.4
Mid-Rise Apartment	6.2
Primary School	5.7
Outpatient Healthcare	5.6
Large Hotel	5.2
Residential Care	4.8
Hospital	3.4
Strip Mall	2.6
Secondary School	2.4
Supermarket	2.4

Full-Service Restaurant	1.5
Small Hotel	0.7
High-Rise Apartment	0.7
Quick Service Restaurant	0.5

The CBSA does not have the required data to split total building floor area between the two primary climate zones in Washington; to protect building identity, no location data was recorded. Therefore, to split the total building floor areas between the Spokane and Seattle climate zones, an assumption was made that commercial building square footage was directly correlated to population. Based on census data, 75% of the population lives west of the Cascade Mountains (climate zone 4C) and 25% lives east of the Cascades (climate zone 5B) – this closely matches the residential climate zone weighting. While this is a simplified assumption, it is important to remember that this weighting was kept the same between each code analysis year, further reinforcing the focus on model-to-model savings.

As mentioned, any relevant HVAC weights were sourced from NEEA's 2002-2004 baseline nonresidential characteristics survey (Ecotope, 2008), with primary heating fuel sources remaining constant between analysis years (see *2006 and 2018 HVAC System Selection* sections above). In this study, thirteen of the eighteen building prototypes were modeled with a single HVAC system. Due to the high costs of code-compliant Variable Air-Volume systems in 2018, paired with the rapid adoption of the market to variable refrigerant flow (VRF) heat pump systems (cost, savings, and simplicity of install and commissioning), the study assumed that VRF has replaced VAV systems for medium and large offices. While alternative heating/cooling systems can be paired with a code-required DOAS system, there is no current market data that would better inform a representative split between HVAC system types for offices (or any building type included in this study). Most importantly, energy savings associated with decoupling of the ventilation system is captured in the 2018 analysis. See Appendix C – Commercial HVAC System Types for all HVAC systems and weighting.

Commercial Building Modeling Inputs

A commercial modeling input summary for all modeled prototypes is summarized in **Error! Reference source not found.**.

The first step in the modeling process was creating a baseline model based on the 2006 WSEC that included all energy code requirements for envelope, mechanical systems, service water, and lighting. All unregulated loads such as plug loads, cooking equipment, and refrigeration equipment are sourced RTF and DOE prototype model defaults and held constant since these end-uses remain outside the scope of the WSEC.

Then a WSEC 2018 model was created by updating envelope, mechanical systems, service water, lighting, and adding in selected C406 measures. Changes in ventilation requirements from the Washington State Ventilation and Indoor Air Quality Code, required in 2006, and the 2018 International Mechanical Code are also included.

Table 12. Summary of Significant Code Changes Between 2006 and 2018 Commercial Building Models

Code Section	WSEC 2006 Baseline	WSEC 2018 Current Savings
Section C402 – Envelope	Table 5-1, 5-2: Thermal Envelope Requirements for Group R Occupancies by climate zone. Table 13-1, 13-2: Building Envelope Requirements by climate zone.	Table C402.1.4: Opaque Thermal Envelope Requirements. Table C402.4: Building Envelope Fenestration Maximum U-Factor and SHGC Requirements. C402.5: Air Leakage; 0.40 cfm/sf at 0.3 in wg.
Section C403 – Mechanical	Section 303: Ventilation per VIAQ. Table 14-1 (A-G): Equipment Performance	C403.2.2.1: Ventilation per IMC 2018. C403.3.2: Equipment Performance. C403.5: Occupancy classifications requiring DOAS. C403.5.1: Energy Recovery Ventilation with DOAS. C403.3.6 Balanced ventilation with 60% efficient senisble ERV required for Group R-2 occupancy
Section C404 – Service Water	Table 14-1 (A-G): Equipment Performance	Table C404.2: Minimum Performance of Water Heating Equipment
Section C405 – Lighting	Table 15-1: Interior LPD	Interior Lighting: 2006; 2018 Table C405.4.2(1), Table C405.4.2(2) Exterior Lighting: 2006 table 15-2; 2018 Table C405.5.3(2)

Starting in the 2015 WSEC and expanded in 2018, the WSEC includes Section C406 (Efficiency Packages), which requires new buildings and substantial alterations to include a total of six additional efficiency credits. Similar to the residential code, the package(s) selection is determined by design teams, and therefore all the possible code-compliant credit permutations result in a large number of models. Given the available time and project budget, this study was limited to modeling one combination measures that achieve exactly six credits for each prototype. In theory, this assumption is justified by the fact that in 2018, C406 credit points better correlate to the energy savings they represent for each of the building occupancies classifications. Below is a list of the available C406 options and a very brief description, while Table 13 identifies the selected credits for each prototype.

Section C406: Efficiency Packages (refer to 2018 WSEC Table C406.1 for credit values)

Section C406.2: Efficient HVAC performance at 15% better than federal minimum requirements
Section C406.3.1: Reduced lighting power at 10% better than Section C405.4.1
Section C406.3.2: Reduced lighting power: 20% better than Section C405.4.1
Section C406.4: Enhanced lighting controls
Section C406.5: On-site supply of renewable energy by total conditioned floor area
Section C406.6: Dedicated outdoor air system (DOAS) for non-required building types
Section C406.7: DOAS at 80% sensible recovery and 0.5 W/cfm (for all building types)
Section C406.8.1 and C406.8.2: High-efficiency service water heating at COP 3
Section C406.9: High performance service water heating in multi-family buildings
Section C406.10: Enhanced envelope performance at 15% better UA than code minimum
Section C406.11: Reduced envelope air barrier infiltration tested at 0.17 CFM/sf
Section C406.12: Enhanced commercial kitchen equipment (Energy Star)

Table 13. Modeled C406 Measures by Prototype

DOE Reference Building	Occupancy Type	Additional Efficiency Credits Modeled
Small Office	B	2,5,11
Medium Office	B	2,5,11
Large Office	B	2,5,11
Stand-alone Retail	M	2,10
Strip Mall	M	2,10
Supermarket	M	2,10
Primary School	E	2,5,11
Secondary School	E	2,5,11
Small Hotel	R-1	1,2,5
Large Hotel	R-1	1,2,5
Hospital	Other	2,10
Warehouse (non-refrigerated)	Other	2,10
Quick Service Restaurant	Other	2,10
Full-Service Restaurant	Other	2,10
Outpatient Healthcare	Other	2,10
Mid-rise Apartment	R-2	6,11
High-rise Apartment	R-2	6,11
Residential Care	Other	2,10

New to the 2018 commercial energy code is *Section C403.1.1: HVAC Total System Performance Ratio (HVAC TSPR)*, an innovative endeavor to address inherent system efficiencies of various HVAC systems for impacted building types (office, retail, library, and education). The TSPR is the ratio of the sum of a building's annual heating and cooling load (in kBTUs) to the sum of the annual carbon emissions (in pounds CO_2) from energy consumption of the building's modeled HVAC system. The project team participated in the beta-version of the online modeling tool, developed by Pacific Northwest Laboratories, to confirm the selected 2018 HVAC systems are compliant with this new code section. The team found that the code-mandated Dedicated Outdoor Air Systems (DOAS) for these building types, with fan power and heat recovery efficiencies that match the TSPR defaults (0.82 W/CFM and 70% recovery efficiency) were two primary drivers to compliance with this section.

Commercial Building Modeling Process

Energy use of regulated loads was predicted by a combination of numerical simulations using energy modeling software—EnergyPlus (v9.0.1)—and engineering calculations. EnergyPlus was used to simulate heating, cooling, lighting, and ventilation energy use from inputs including building shell characteristics, occupancy and building schedules, HVAC systems, and hourly weather files.

Batch processing of the prototype models was performed using CBECC-Com[10], an open-source energy code compliance tool (BEE Software) funded primarily by the California Energy Commission (CEC) for California Title 24 (T24) code compliance. CBECC-com is a robust, easy-to-use interface for generating EnergyPlus input files (via DOE's OpenStudio software)[11], as it can be used to automate a number of steps, such as HVAC sizing runs, and populating HVAC equipment efficiencies and performance curves needed for simulation. CBECC-Com has been developed and used for performance-based energy code compliance modeling in California since 2013, and in addition to being tested and used by the design and engineering community for this purpose, it also actively used as a starting point for T24 Codes and Standards Enhancement (CASE) studies. In addition to being developed for T24 code compliance analysis, the Pacific Northwest National Laboratory (PNNL) funded a demonstration of using the CBECC-Com open-source framework for ASHRAE 90.1-2010 Appendix G modeling as part of developing the Performance Rating Method Reference Manual (PRMRM). [12]

O'Brien360 has been a core member of the CBECC-Com software development team since its inception in 2011. The version of CBECC-Com used for this study utilizes software code developed for performing ASHRAE 90.1-2010 Appendix G analysis, which has been adapted and enhanced by O'Brien360 for modeling the 2006 and 2018 WSEC prototypes. The EnergyPlus simulations performed using CBECC-Com were supplemented by side calculations and post-processing of modelling outputs in cases where either a) hourly simulations were not necessary for estimating the energy impacts, such as parking lot/garage lighting use, or b) where modeling the technology was not directly supported by CBECC-Com, such as heat recovery chillers.

The WSEC prototype models and results were developed in the following high-level steps:

1. Create the 2006 prototype from each building type, using the RTF or DOE prototype EnergyPlus input files (IDF) the starting point. These IDFs were translated into CBECC-Com input files using the OpenStudio software.
2. Populate the CBECC-Com models with the unregulated internal load assumptions and schedules defined in the RTF or DOE models, as well as the 2006 HVAC systems defined for this study.
3. Apply WSEC 2006 efficiency and ventilation provisions to the model inputs. These provisions included differences based on HVAC system type, and climate zone.
4. Modify the 2006 models to reflect 2018 efficiency and ventilation requirements, including the selected C406 efficiency packages.
5. Debug the simulations, i.e. review the calculated energy-end-use and other simulation outputs for consistency with expected values and make corrections/modifications to the models as needed.
6. Apply side calculations and post-processing of simulation results to arrive at the final energy performance calculations, prior to weighting by building type, HVAC system type, and climate zone.

[10] California Energy Commission's CBECC-Com project website. http://bees.archenergy.com/
[11] U.S Department of Energy OpenStudio project website. https://www.energy.gov/eere/buildings/downloads/openstudio-0
[12] https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-25130.pdf

Post Processing Calculations

A small subset of energy code requirements could not be model through CBECC-comm directly, so separate calculations were performed to capture their effect on energy consumption for various prototypes. The five post processing calculation needed were: exterior lighting, on-site renewables, hot water use reduction, heat recovery chillers in hospital, and condenser heat recovery in supermarket. Only exterior and garage lighting calculations were applied to the 2006 baseline models, whereas all five of the post processing were applied to 2018 runs.

Since the protypes did not include parking, parking lot areas represented as a ratio of the building-type conditioned floor area, sourced from the 2002-2004 baseline characteristic study (Ecotope, 2008), were applied. Lighting power density limits as defined in Section 1532 of the 2006 WSEC, were applied to the modeled parking area. For 2018, the lighting power was adjusted down based on the percent difference of allowed lighting power between the 2006 and 2018 WSEC. Results were then added to CBECC-comm models under a separate Exterior Lighting end-use with RTF default schedules.

For building types that were modeled to select the 2018 optional measure from Section C406.5: On-site renewable energy (see Table 13), a post processing calculation was completed to account for energy produced from solar photovoltaics as a separate, negative, end use to the results. Average annual solar production was average between Spokane and Seattle, as informed by PV Watts[13], to be roughly 1,100 kWh/yr/kW installed capacity.

Hot water flow reduction for low-flow fixtures in 2018 was applied to mid-rise and high-rise apartment models. This calculation followed the same process as the residential modeling (low-flow showerheads mandated by HB 1444 and flow reduction informed by RTF UES Measure workbooks). This resulted in a 10% decrease in hot water energy consumption.[14]

Post processing to estimate savings from adding a heat recovery chiller to the hospital model was done using hourly plant heating and cooling energy consumption. Section *C403.9.2 Heat Recovery from Space Heating,* in the 2018 WSEC, requires most hospitals to install heat recovery chillers. A heat recovery chiller is a water-to-water heating and cooling device that, in buildings with significant simultaneous heating and cooling, has potential to save a significant amount of energy. An hourly calculation was performed to determine the simultaneous heating and cooling occurring in the building that could be met through a heat recovery chiller, and the amount of additional heating that could be provided through heat recovery of exhaust air through the heat recovery chiller. This resulted in a 15 EUI savings for both Seattle and Spokane climates. Many hospitals use a heat recovery chiller and condensing boilers to pass the Total System Performance compliance path (C407).

Condenser heat recovery is required per 2018 WSEC *C403.9.2.3 Refrigeration Condenser Heat Recovery* in supermarkets. Heat is recovered from refrigeration systems to heat hot water through desuperheaters (ASHRAE, AEDG Grocery Stores). Since most desuperheaters consist of a tank of water with a refrigerant coil used to preheat incoming hot water, they are limited to 100°F as the maximum

[13] https://pvwatts.nrel.gov/
[14] RTF UES Measure. https://rtf.nwcouncil.org/measure/showerheads

preheat temperature reasonable achieved (Fricke, 2011). This corresponds to 56% reduction in hot water heating energy for supermarkets in this study.

Summary

In total, 90 different combinations of building prototypes, HVAC systems, and climate zones were simulated. To the maximum extent possible, the definition of model inputs was automated using CBECC-Com's 'ruleset' programming framework. The ruleset is compilation of software code, libraries, and tables that were brought together for this Washington code baseline project and read by the CBECC-Com software when processing the models. Once the CBECC-Com model input files and ruleset framework was set-up, the models were run as a "batch", meaning the assignment of inputs, and running of all 90 simulations was performed automatically by the software, taking roughly five hours. The results are output by the program to a CSV formatted data file, which was processed into the final results as presented in following sections.

Commercial Building Results and Analysis

To provide context for the modeling analysis of the 2006 WSEC, data from other modeling studies and measured data was compared to the results for reach building type. Figure 6 below shows this comparison, including modeled analysis of ASHRAE 90.1 for the years 2007 and 2013, and benchmarking data from the City of Seattle in 2016.

The comparisons to versions of ASHRAE 90.1 (based on determination analyses conducted by PNNL of these code versions) allows a comparison of the WSEC 2006 to the stringency of national code values from a similar time period. The code community in Washington has generally considered the state code to be more stringent than the contemporary national code version. This data bears that out for some, but not all, building types when the WSEC 2006 is compared to ASHRAE 90.1-2007.

Comparing the results to actual measured performance data is also an informative touch point, but the Seattle data is for all building ages, so the measured data is not necessarily a reflection of code impact.

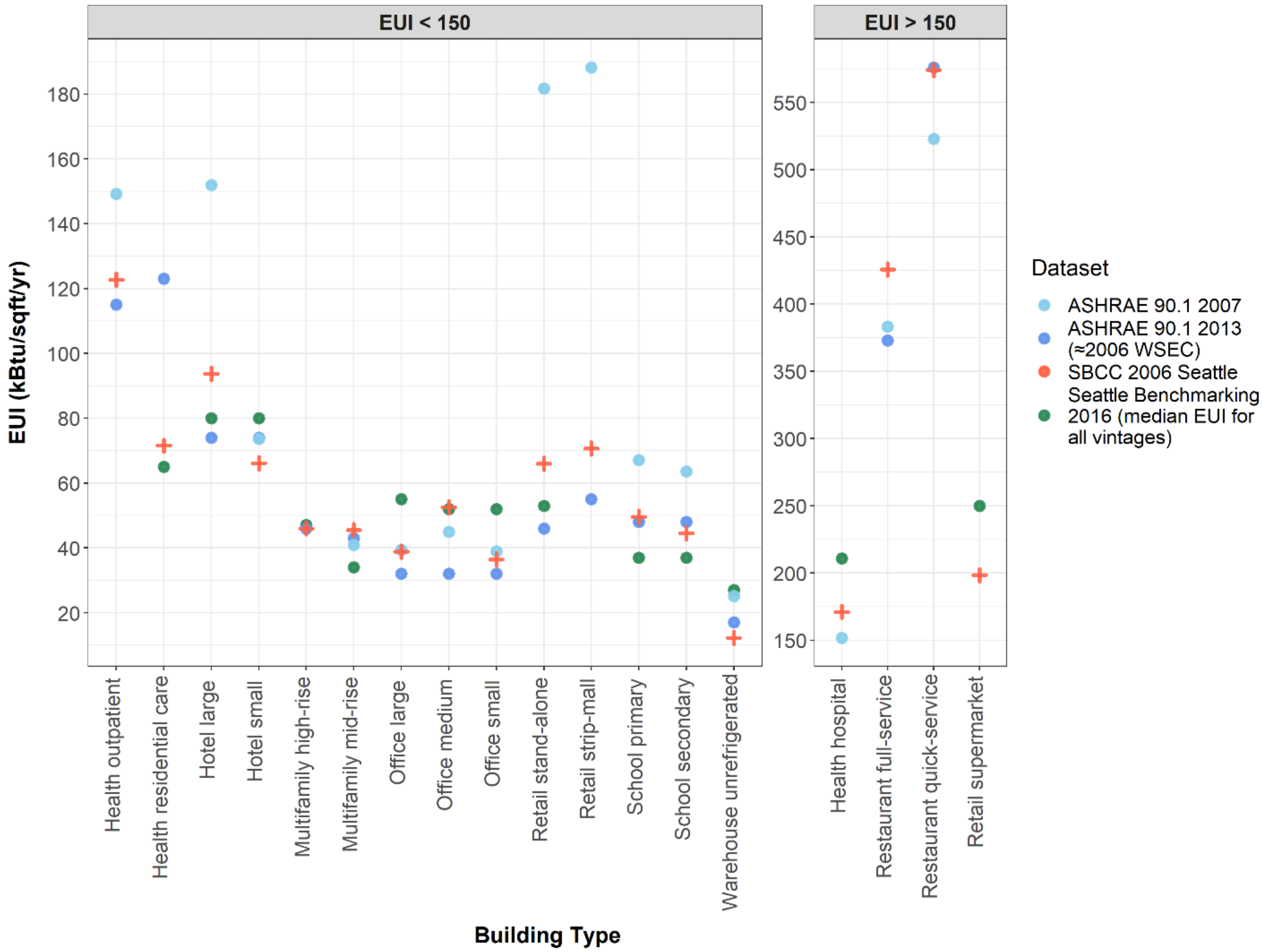

Figure 6. 2006 Commercial Building Modeling Results (4C Climate) with Comparison Datasets

Although patterns of higher and lower energy use between building types show consistency across most data sets, the data shows significant variability within several prototypes, and more moderate variability in a wider range of prototypes. There are multiple drivers of this variability. For example:

1. Certain prototypes may be defined with substantially different components and operating characteristics in the different data sets. For example, restaurant, retail, hospitality and health care energy use is substantially driven by occupancy and process load characteristics. In some cases, retail may include refrigeration, while in restaurants the type of food served and number of diners can significantly impact energy use modeling and outcomes. Hotels and residential care facilities can include a range of different services that vary widely among individual facilities. A single prototype is not able to capture this range of potential outcome, and variability among different analyses and measured data is expected.

2. Key assumptions about unregulated loads may vary between analyses and may differ significantly from actual buildings. Since unregulated loads represent the largest end use in

most of these building types, modeling assumptions about these loads have a major impact on prediction results. This suggests that a range of operating parameters should be considered in considering the implications of modeling results.

3. Modeling does not capture operating problems like equipment malfunctions, control failures, or unanticipated zone interactions. These factors contribute to wide variation in actual building performance, compared to modeled predictions.

In cases where a wide range of performance is evident within individual prototypes, additional analysis of what is driving this variability might be warranted.

COMPARING 2006 AND 2018 WSEC RESULTS

Another focus of this study was to compare code-to-code changes from 2006 to 2018. The analysis indicated performance improvement in all building types. Figure 7 shows the change in EUI predicted for each prototype based on the modeling assumptions used in the study.

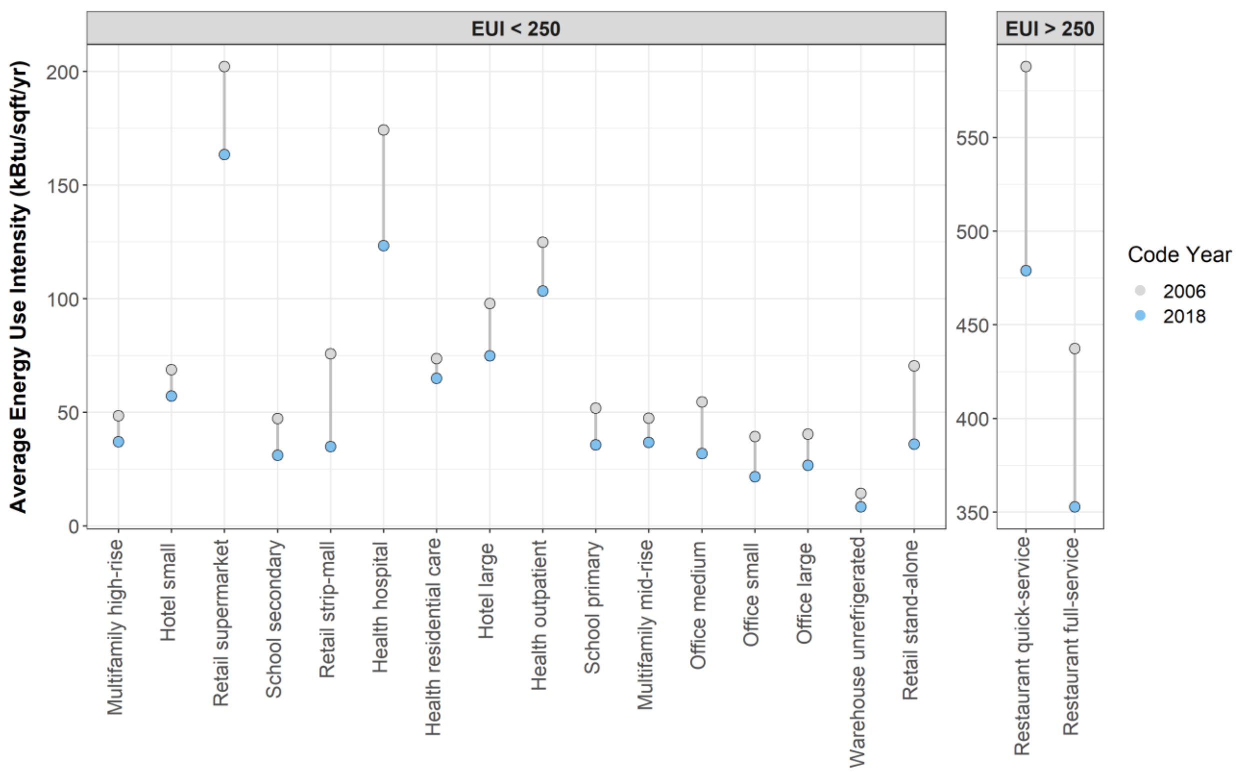

Figure 7. Commercial Modeled EUI Comparison by Building Type by Code Year

Although all building types have shown some reduction in energy use intensity from 2006 to 2018, some reductions have been of greater magnitude than others. Table 14 below shows the specific predicted change in EUI between 2006 and 2018 from this analysis for each prototype, along with the percent change in total energy use.

Part of this difference is the result of code adoption of significant performance improvement requirements that apply unevenly to different building types. For example, the requirement for DOAS ventilation systems has a significant energy impact on office buildings but little or no impact on multifamily and warehouse buildings. The difference can also be attributed to the fact that these building types have different levels of unregulated loads so code measures that impact regulated building features have a smaller overall energy impact on total load in some building types compared to others. This variability is exacerbated by the fact that unregulated loads interact with regulated loads differently in different building types. For example, if unusually high equipment loads are assumed in the modeling, the internal gains from this equipment has an outsized impact on heating and cooling loads, while project types with lower internal gains are not affected to the same degree.

Table 14. Energy Use Intensity and Percent Change by Commercial Building Type - 2006 and 2018

Building Type	2006 EUI	2018 EUI	% Change EUI
Retail stand-alone	70	36	-49
Warehouse unrefrigerated	14	8	-42
Office large	40	27*	-34
Office small	39	22*	-45
Office medium	55	32*	-42
Multifamily mid-rise	47	37	-22
School primary	52	36*	-31
Health outpatient	125	103	-17
Hotel large	98	75*	-23
Health residential care	74	65	-12
Health hospital	174	123	-29
Retail strip-mall	76	35	-54
School secondary	47	31*	-34
Retail supermarket	202	163	-19
Restaurant full-service	437	353	-19
Hotel small	69	57*	-17
Multifamily high-rise	48	37	-23
Restaurant quick-service	588	479	-19

*Includes solar offset From Section R406.5

The modeling results for all of the prototypes are combined into a weighted overall value in Figure 8. The individual prototype results are weighted by population as described earlier in the report, and this represents the weighted performance of the entire commercial sector, comparing 2006 results to 2018.

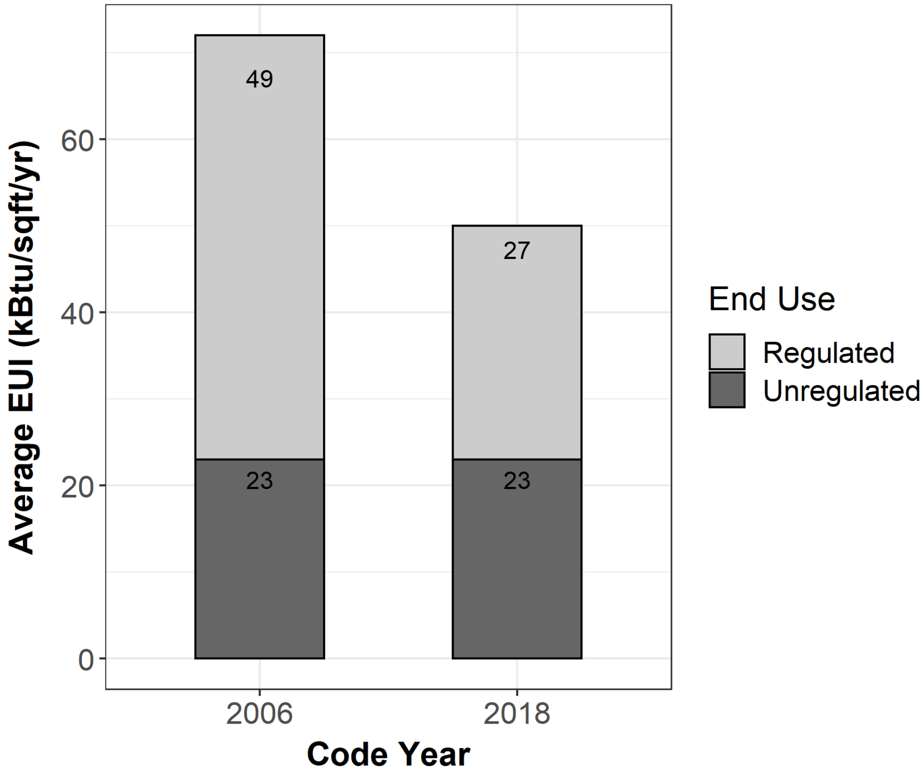

Figure 8. State Comparison Including Regulated and Unregulated End Uses

The overall improvement in code stringency is approximately 31% (including some PV offset from option measures modeled under Section R406.5, as shown in Table 14. This figure also shows that unregulated loads were assumed to remain unchanged between the two code cycles, emphasizing that the impact of unregulated loads on overall building performance patterns is evolving. For Washington to achieve a 70% reduction in overall building energy use, strategies to reduce unregulated energy use must be identified and deployed.

CONCLUSION

This study focused on capturing all savings directly attributed to the Washington's energy code and other mandatory compliance (state laws, mechanical codes). The annual energy consumption and estimated savings between 2006 and 2018, represent regulated energy loads (lighting, HVAC, and service water heating) since they are governed by the energy code.

The study is informed by several building stock assessments that were conducted around the time that the 2006 Washington State Energy Code came into effect. This provided a fairly robust set of references in which to source prototypical data, such as building type weighting by floor area, common heating fuel sources, and a reference to metered and bill utility data (for unregulated loads). However, for the 2018 analysis, comparable data about current building trends does not exist. In the absence of this data, this study elected to keep values for unregulated loads, fuel selection, and other building characteristics consistent between the 2006 and 2018 analysis.   This suggests that additional performance improvements adopted by the market might not be reflected in the 2018 analysis.

The residential energy code has a narrower focus when compared to commercial since it is focused on only two building types – single family and low-rise multifamily. As such, from a code analysis standpoint, predicting end-use consumption is much more straightforward. There are only four predominant HVAC systems, associated control systems are simple, occupant behavior is more-or-less predictable, there is less interaction between system selection and energy consumption, and unregulated process loads are more consistent. All these traits mean that a well-developed residential code can be relied upon to bring energy cost savings across the sector.

The commercial sector, on the other hand, encompasses a wide range of building types, each with substantially different annual energy end-use characteristics.

A key assumption in this study (and a common assumption among similar studies) is that the energy code does not directly incentivize fuel switching. The code mandates the efficiency of equipment and guides the design of selected systems, but does it not directly affect designer's or builder's preference on heating source (fossil-gas vs. electricity). Without building stock surveys and supporting data showing a noticeable deviation in standard building practice, fuel sources were kept constant across both 2006 and 2018 code years. It is expected that future modeling studies of code savings will need to account for evolving fuel choices as the focus turns to carbon emissions as opposed to site energy consumption.

FURTHER STUDIES

The initial goal of this analysis was to provide an evaluation of the baseline code upon which state building policy is based (2006) and to assess the degree to which current 2018 code improvements have followed the performance trajectory identified in the policy. This analysis was defined as a 'model-to-model' analysis of the impact of code improvements on building energy performance, independent of market and building stock changes occurring simultaneously to the code development period identified in the analysis. Although the analysis has helped to inform us about energy code progress over this time period, specific limitations and potential inaccuracies of this approach have become apparent through the modeling process.

Of particular concern is the impact that assumptions about plug loads and other unregulated loads are having on model outcomes. The initial prototypes were defined to include substantial plug and equipment loads taken from the regionally accepted RTF prototype assumptions. Because equipment loads represent internal gains in the buildings, the modeling predicts that these loads are significantly offsetting the need for heat in the modeled prototypes. Several of the prototype models suggest that certain building types in 2018 require very little heating, or even no heating at all, through the course of a year. This is often at odd with billing analyses of new buildings that show significant heating energy being used in our climate.

The potential implications of these assumptions on code and policy development are significant. It could be assumed from the raw results presented here that no significant additional savings are available from energy conservation measures targeting heating energy use reduction, and that the code should focus elsewhere. But Ecotope's experience with building performance suggests that very few buildings actually include such high levels of internal gains, and the internal gains that are present are not available for even distribution around the building to offset heating loads. De-emphasizing the role of building heating loads in future code requirements could miss significant opportunities for real energy use reductions. And if in the future successful strategies are developed to more effectively manage or limit equipment loads that lead to internal gains, the 'missing' heating loads will quickly reappear in these buildings.

To highlight the significance of this issue, Ecotope evaluated the impact of a range of assumptions about interior equipment loads on the primary school building prototype. We found that varying interior equipment loads through a range of equipment density can change the anticipated heating energy needed in the primary school prototype by a factor of four. This result is shown in Figure 9. At the high end of interior equipment values are the assumptions provided by the RTF for this analysis. At the low end are interior equipment values aligned with a recently built school project completed by Ecotope.

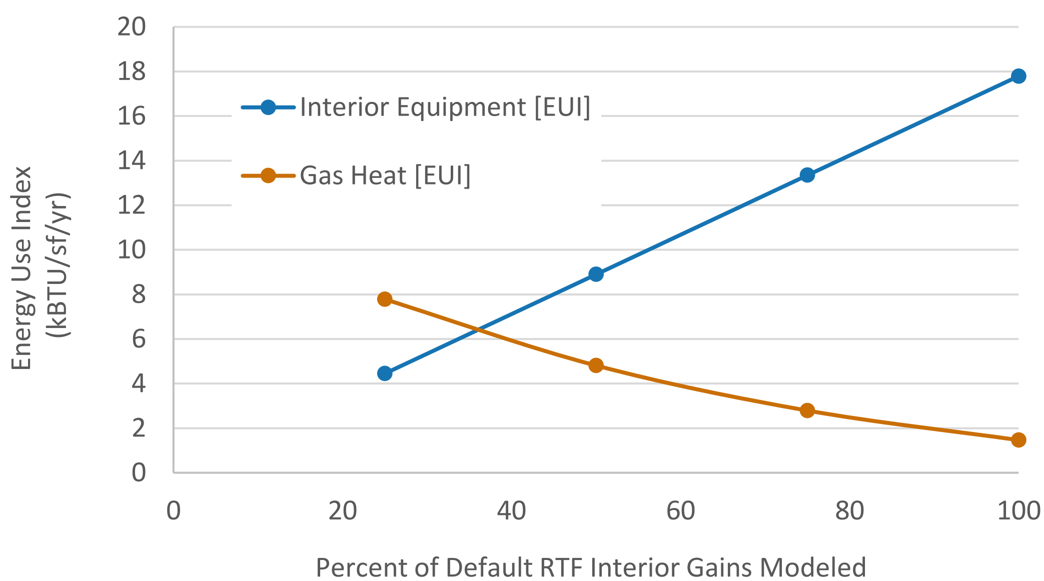

Figure 9. Impacts of Internal Gains on Heating Energy Use for the Primary School Prototype with Gas Heating

In addition to impacting assumptions about heating (and cooling) loads, various assumptions in the energy models about unregulated loads contribute significant direct impacts to building energy use assumptions. In an office prototype, the inclusion of a data center can boost building energy use by 10% or more on its own. Yet much of the market is rapidly transitioning to cloud computing strategies that can substantially reduce or eliminate these loads at the building level (and associated internal gains). It is clear that more attention is needed in the modeling analysis to a number of input assumptions that were provided to the project as 'outside fixed variables', but that can significantly drive modeling results, and the policy decisions which might be based upon such an analysis.

Other examples of prototype assumptions which can drive energy use outcomes and may be transitioning in the marketplace include:

- Trends in HVAC equipment selection
- Changes in occupant density or remote work habits
- Computer workstation configuration
- Control capabilities and ‘Internet of Things’ (IoT) integration
- Changing seasonal weather patterns
- Compliance with Energy Codes from other local jurisdictions (Seattle Energy Code)

To resolve these issues, various stakeholders have expressed interest in an additional phase of analysis that can lead to a better understanding of actual building characteristics. Which take into account all effects on energy consumption in the built environment (not just code-mandated savings) which would produce a more accurate estimate of our 2006 baseline and how far we have come in realizing Washington State’s 70% reduction targets.

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APPENDIX A – DETAILED RESIDENTIAL BUILDING INPUTS

Table 15. Residential Building Prototypical Characteristics

Prototype	Descr	Bed/ Unit	Occ/ Unit	Total Units	Found Type	Cond Area, CFA (sf)	Vol (ft^3)	Ext Floor Area (sf)	Ext Wall Area (sf)	Roof Area (sf)	Glazing % CFA	Door Area (sf)	2006 Vent CFM	2018 Vent CFM	Supply Duct Loc	Return Duct Loc
1344c	sf home	3	2	1	Crawl	1344	10752	0	1184	1344	13%	40	75	45	Crawl	Attic
1344s	sf home	3	2	1	Slab	1344	10752	0	1184	1344	13%	40	75	45	Attic	Attic
2200c	sf home	4	2.8	1	Crawl	2200	18700	200	2210	1784	16.6%	40	100	65	Crawl	Attic
2200s	sf home	4	2.8	1	Slab	2200	18700	200	2210	1784	16.6%	40	100	65	Attic	Attic
2688b	sf home	4	3.5	1	Bsmt	2688	22848	0	1480	1344	14%	40	105	70	In	Attic
5000b	sf home	4	4	1	Bsmt	5000	40100	200	2788	1800	15%	40	125	90	In	Attic
1500c	townhome	3	1.7	1	Crawl	1500	14250	0	1259	500	13%	40	75	45	Crawl	Attic
1500s	townhome	3	1.7	1	Slab	1500	14250	0	1259	500	13%	40	75	45	Attic	Attic
1000c	Dbl loaded corridor	2	1.7	24	Crawl	26400	237600	0	10152	8800	15%	84	1680	960	In	In
0952s	garden style	2	1.7	8	Slab	7616	64736	0	6528	3808	15%	160	440	280	In	In
0952c	garden style	2	1.7	8	Crawl	7616	64736	0	6528	3808	15%	160	440	280	Crawl	Attic

Table 16. Residential Building Code Minimum Default Inputs by Code Year

Code Year	IECC Climate Zone	Roof Ins (R-val)	Wall Ins (R-val)	Wall Framing Type	Floor Ins (R-val)	Bsmt Wall Ins (R-val)	Slan Ins (R-val, ft)	Glazing (U-val, SHGC)	Door (U-val)	Duct Ins (R-val)	Duct Leak (CFM/ 100sf)	Env Infil (ACH50)	Exhaust Fan Eff (CFM/W)
WA06	4C	38	21	std	30	19	10, 2ft	0.35, 0.32	0.2	8	0.12	7	0.86
WA06	5B	38	19 +5ci	std	30	19	10, 2ft	0.32, 0.31	0.2	8	0.12	7	0.86
WA18	4C	49	21	int	30	21	10, 2ft	0.3, 0.3	0.3	8	0.04	5	1.4
WA18	5B	49	21	int	30	21	10, 2ft	0.3, 0.3	0.3	8	0.04	5	1.4

APPENDIX B – DETAILED RESIDENTIAL MODELING RESULTS

Run Label	Dwelling Size (Section R406)	Heating Fuel	Heat, kWh	Heat, Therm	Cool, kWh	Fan, kWh	Lights, kWh	DHW, kWh (Therm)	Appliances and Plugs, kWh	Total kWh	Total Therms	Total kWh/Unit Equiv
WA06_0	Single Family Small	gas	167	272	140	255	1,397	(140)	5,533	7,491	412	19,564
WA06_0	Single Family Small	elec	3,339		336	255	1,397	2,499	5,533	13,359		13,359
WA06_0	Single Family Medium	gas	357	538	202	342	2,358	(187)	5,533	8,792	725	30,024
WA06_0	Single Family Medium	elec	6,280		470	342	2,358	3,337	5,533	18,320		18,320
WA06_0	Single Family Large	gas	578	761	278	424	5,197	(246)	5,533	12,010	1007	41,508
WA06_0	Single Family Large	elec	9,151		626	424	5,197	4,400	5,533	25,330		25,330
WA06_0	Multifamily (R-2)	elec	2,272			210	1,015	1,703	4,121	9,320		9,320
WA18_1	Single Family Small	gas	131	181	96	276	3,68	(119)	5,533	6,404	300	15,185
WA18_1	Single Family Small	elec	1,957		236	495	3,68	2,272	5,533	10,860		10,860
WA18_1	Single Family Medium	gas	196	250	128	403	6,22	(121)	4,693	6,043	371	16,917
WA18_1	Single Family Medium	elec	3,599		326	503	6,22	1,153	4,693	10,896		10,896
WA18_1	Single Family Large	gas	270	301	191	563	1,371	(160)	4,693	7,088	461	20,604
WA18_1	Single Family Large	elec	5,315		459	552	1,371	1,520	4,893	14,109		14,109
WA18_1	Multifamily (R-2)	elec	1,191			272	273	588	4,121	6,445		6,445

APPENDIX C – COMMERCIAL HVAC SYSTEM TYPES

Table 17. Modeled 2006 Commercial HVAC System by Prototype

	WSEC 2006 HVAC Systems	
Prototype Model Weights (if applicable)	**HVAC System - A**	**HVAC System - B**
Small Office System A = 75% System B = 25%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Medium Office	Central VAV† Heating: elec central + elec VAV boxes Cooling: DX + economizer	
Large Office	Central VAV† Heating: elec central + elec VAV boxes Cooling: DX + economizer	
Stand-alone Retail System A = 85% System B = 15%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Strip Mall System A = 85% System B = 15%	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	Packaged RTU Single zone Heating: HP Cooling: DX + economizer
Supermarket	Packaged RTU Single zone† Heating: Gas Cooling: DX + economizer	
Primary School	VAV serving corridors and classrooms† Heating: HW boiler central Cooling: CHW with cooling tower, economizers (30% min damper) Single-zone RTUs for all other spaces† Heating: Gas furnace Cooling: DX, economizers	
Secondary School	VAV serving corridors and classrooms† Heating: HW boiler central Cooling: CHW with cooling tower, economizers (30% min damper) Single-zone RTUs for all other spaces† Heating: Gas furnace Cooling: DX, economizers	
Small Hotel	Guestrooms: PTHPs w/ electric backup heat† Common areas: Split AC/furnace Vent = bathfan @ const volume	
Large Hotel	Guestrooms: FPFCs with DOAS† Common areas: Single-duct VAV systems, HW Reheat Heating: Gas Boiler Cooling: Chiller and Cooling Tower, economizer	

	WSEC 2006 HVAC Systems (Continued)	
Prototype Model	HVAC System - A	HVAC System - B
Hospital	Both constant air volume (CAV) and VAV systems† All system use ChW/HW with hydronic reheat.	
Warehouse (non-refrigerated)	Office/fine storage: Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer Bulk storage: Gas unit heater (CV fan) †	
Quick Service Restaurant	Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer	
Full-Service Restaurant	Packaged RTU Single zone† Heat: Gas Cooling: DX + economizer	
Outpatient Healthcare	Central VAV - Hydronic heating and cooling. Heating: Hydronic reheat	
Mid-rise Apartment	Zone Exhaust PTAC Heating: Elec Resist Cooling: DX	
High-rise Apartment	Zone Exhaust WSHPs on condensor loop (Cali HP loop) Heat: Boiler, zonal HPs Cooling: Cooling tower, zonal HPs	
Residential Care	Zone Exhaust† PTAC Heat: Elec Resist Cooling: DX Common area: VAV w/ elec resistance reheat	
† Consistent with RTF default HVAC assumptions		

Table 18. Modeled 2018 Commercial HVAC System by Prototype

	WSEC 2018 HVAC Systems	
Prototype Model Weights (if applicable)	**HVAC System - A**	**HVAC System - B**
Small Office System A = 75% System B = 25%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Medium Office	DOAS with ERV - elec tempering VRF FCUs Heating: VRF Cooling: VRF	
Large Office	DOAS with ERV - elec tempering VRF FCUs Heating: VRF Cooling: VRF	
Stand-alone Retail System A = 85% System B = 15%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Strip Mall System A = 85% System B = 15%	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	DOAS with ERV - elec tempering Packaged Single Zone System Heating: HP Cooling: DX
Supermarket	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Primary School	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Secondary School	DOAS with ERV - elec tempering Packaged Single Zone System Heating: Gas Cooling: DX	
Small Hotel	Guestrooms: PTHPs w/ electric backup heat Common areas: Split AC/furnace Vent = bathfan @ const volume	
Large Hotel	Guestrooms: FPFCs with DOAS Common areas: Single-duct VAV systems, HW Reheat Heating: Gas Boiler Cooling: Chiller and Cooling Tower, economizer	

	WSEC 2018 HVAC Systems (Continued)	
Prototype Model	HVAC System - A	HVAC System - B
Hospital	Both constant air volume (CAV) and VAV systems depending on the zone. All systems use ChW/HW with hydronic reheat. HRC post processing calculation per C403.9.2.4	
Warehouse (non-refrigerated)	Office/fine material storage: Packaged RTU Single zone Heat: Gas Cooling: DX + economizer Bulk storage: Gas unit heater (CV fan)	
Quick Service Restaurant	Packaged RTU Single zone Heat: Gas Cooling: DX + economizer	
Full-Service Restaurant	Packaged RTU Single zone Heat: Gas Cooling: DX + economizer	
Outpatient Healthcare	Central VAV - Hydronic heating and cooling. Heating: Hydronic reheat	
Mid-rise Apartment	Balanced Zone Ventilation, ERV 60% sensible PTAC Heating: Elec Resist Cooling: DX	
High-rise Apartment	Balanced Zonal Ventilation, ERV 60% sensible WSHPs on condensor loop (Cali HP loop) Heat: Boiler, zonal HPs Cooling: Cooling tower, zonal HPs	
Residential Care	Zone Exhaust PTAC Heat: Elec Resist Cooling: DX Common area: VAV w/ elec resistance reheat	

APPENDIX D – COMMERCIAL BUILDING TYPE DESCRIPTIONS

Table 19. Commercial Building Prototype Descriptions Compared to CBSA Building Types

Commercial Prototypes	CBSA Detailed Building Type Included	Other Criteria
Small Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	Less than 20,000 square feet
Medium Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	20,001 - 100,000 square feet
Large Office	office- admin, professional, government, financial; call center; city hall; retail banking; sales office; other office	Greater than 100,000 square feet
Stand-alone Retail	auto parts; auto/boat dealer/ show room; beauty / barber; car wash; clothing; department store; dry cleaner; electronics/appliances; florist, nursery; hardware; home improvement; laundromat (self-service); pharmacy; post office; rental center; repair shop; studio/gallery; vehicle repair; warehouse club; other specialty merchandise	Single stand-alone building
Strip Mall	auto parts; auto/boat dealer/ show room; beauty / barber; car wash; clothing; department store; dry cleaner; electronics/appliances; florist, nursery; hardware; home improvement; laundromat (self-service); pharmacy; post office; rental center; repair shop; studio/gallery; vehicle repair; warehouse club; other specialty merchandise	Part of larger mixed-use building
Supermarket	grocery	
Primary School	elementary school; middle school; pre-school; other k-12 school	
Secondary School	high school	
Small Hotel	motel; bed & breakfast; boarding/rooming house, apt hotel	
Large Hotel	hotel; hotel - resort	
Hospital	hospital	
Warehouse (non-refrigerated)	ministorage; warehouse, distribution; warehouse, storage; other warehouse	

Commercial Prototypes	CBSA Detailed Building Type Included	Other Criteria
Quick Service Restaurant	cafeteria; catering service; coffee, doughnut, or bagel shop; fast food restaurant; ice cream or frozen yogurt shop; take-out restaurant; truck stop	
Full-Service Restaurant	bar, pub, lounge; sit down restaurant; other restaurant	
Outpatient Healthcare	dental office; medical clinic / outpatient medical; medical office; medical urgent care clinic; outpatient rehab; veterinarian office/clinic	
Mid-rise Apartment	Not included in CBSA. Should represent all high rise (up to 4 stories) apartment buildings.	Census Data used to estimate number of apartments and square footage. Seattle Benchmarking Data used to estimate high rise to mid-rise split in urban area.
High-rise Apartment	Not included in CBSA. Should represent all low rise (greater than 4 story) apartment buildings.	Census Data used to estimate number of apartments and square footage. Seattle Benchmarking Data used to estimate high rise to mid-rise split in urban area.
Residential Care	assisted living; in-patient rehab; nursing home; retirement home; other residential care	

APPENDIX E – COMMERCIAL BUILDING MODELING INPUTS

Commercial building modeling inputs are summarized in a corresponding document.