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Washington State Commercial Energy Code Technical Roadmap Report

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Executive Summary

Background

Washington State has set a legislative goal to reduce annual net site energy consumption for commercial buildings under the 2030 energy code by 70% relative to the 2006 Washington State Energy Code (WSEC). Northwest Energy Efficiency Alliance (NEEA) has provided technical support to assist the state in achieving its goals. As part of this support, NEEA and the Washington State Department of Commerce developed a WSEC Technical Roadmap ("the Roadmap") that identifies a set of technologies and building strategies to achieve the 2030 goal. The intention with this Roadmap is to create a pool of measures that can guide the code development process over the next four code cycles. The Roadmap focuses on four building types: Office, Retail, K-12 School, and Multifamily.

The objectives of the roadmap are as follows:

1. Analyze the 2006 WSEC energy consumption to determine the 2030 annual energy consumption target for the four selected building types.
2. Based on the 2030 WSEC target, identify building strategies and associated technologies that can together achieve the 70% site energy reduction target. Identify market barriers such as cost, market penetration, and technical maturity, and identify how and when the building strategies could be incorporated into future WSEC cycles.
3. Analyze the energy savings potential for each measure and from the package of measures.
4. Create a technical support document describing the savings potential from the measures and the methodology used to estimate savings.
5. Gather feedback and support from key code stakeholders, utilities, and industry partners at key phases of the project.

Methodology

Five prototype building models were used to evaluate the four building types: Large Office, Medium Office, Standalone Retail, Secondary School, and Mid-rise Apartment. These prototypes were modeled using the United States (US) Department of Energy's (DOE) EnergyPlus simulation software. The followed methodology was applied to accomplish the objectives:

1. **Evaluate the 2006 and 2018 WSEC energy consumption**: The prescriptive and mandatory requirements of the 2006 and 2018 WSEC were applied to the prototype building models to determine the energy consumption. The 2006 WSEC energy consumption sets the baseline for achieving the 70% site energy savings target and the 2018 WSEC indicates the progress made towards the target since 2006. Finally, the 2018 WSEC end-use distribution guides the identification of the most impactful energy reduction strategies.
2. **Identify building strategies and technologies for 2030**: Based on the 2006 and, in particular, the 2018 WSEC end-use distribution, a list of building-specific strategies were identified. From the larger list of strategies, two major packages of measures were finalized for 2030. A technology matrix was created that described the strategies, associated technologies, their savings potential, cost impact, technical maturity, market penetration, and potential barriers. Feedback from NEEA and WSEC code development stakeholders was incorporated into the technology matrix.
3. **Analyze 2030 measures and packages**: In this step, the finalized list of measures and packages of measures were modeled to determine their energy savings relative to the 2018 and 2006 WSEC.

Results

The technology matrix spreadsheet with detailed measure descriptions and characterization has been provided in Appendix A of the report. Table ES1 shows the energy use intensity (EUI) for the 2006, 2018, and 2030 WSEC editions for the five prototypes. Multiple HVAC systems were analyzed for the 2018 and 2030 WSEC editions and the results for each system are shown separately in Table ES1. Figure ES1 and Figure ES2 show the end-use distribution for the five prototypes in climate zone 4C and 5B for heat pump (HP) based systems. Results are similar for gas-based systems and further detailed results have been provided in Appendix B.

The end-use distribution for the 2018 WSEC edition shows that plug and process loads (PPL) occupy a significant proportion of the total consumption in all prototypes. Deep reductions in heating, cooling, and fan consumption were achieved in the 2018 WSEC relative to the 2006 edition. This makes future HVAC and envelope measures less impactful.

The two office prototypes achieve the 70% site energy reduction target, whereas the remaining three prototypes are very close to the target. Several measures were developed for the 2030 WSEC that attempted to reduce the PPL consumption, but they still remain a significant proportion of the total consumption in 2030 for the Standalone Retail, Secondary School, and Mid-rise Apartment prototypes.

TABLE ES1: PROTOTYPE ANNUAL EUI FOR 2006, 2018, AND 2030 ESEC EDITIONS

Prototype	Code Edition	Case	4C		5B	
			EUI, kBtu/sf	% EUI Savings	EUI, kBtu/sf	% EUI Savings
Large Office	2006	Base	64.28		67.49	
	2018	WSHP	44.47	31%	45.33	33%
	2030	WSHP	11.37	82%	12.21	82%
	2030	Radiant Floor	10.87	83%	11.42	83%
Medium Office	2006	Base	42.23		47.14	
	2018	WSHP	26.22	38%	26.96	43%
	2030	WSHP	9.35	78%	10.77	77%
	2030	Radiant Floor	8.33	80%	9.28	80%
Standalone Retail	2006	Base	58.03		69.45	
	2018	PSZ HP	29.60	49%	32.73	53%
	2018	PSZ DX AC/Gas Furnace	29.45	49%	34.97	50%
	2030	PSZ HP	21.44	63%	23.88	66%
	2030	PSZ DX AC/Gas Furnace	21.59	63%	23.91	66%
Secondary School	2006	Base	52.82		61.37	
	2018	PSZ HP	30.58	42%	33.59	45%
	2018	PSZ DX AC/Gas Furnace	31.83	40%	35.03	43%
	2030	PSZ HP	18.02	66%	19.87	68%
	2030	PSZ DX AC/Gas Furnace	19.66	63%	22.29	64%
Mid-rise Apartment	2006	Base	40.91		46.74	
	2018	Split HP	31.86	22%	33.40	29%
	2018	Split DX/Gas Furnace	32.59	20%	35.75	24%
	2030	Split HP	16.19	60%	17.62	62%
	2030	Split DX/Gas Furnace	18.16	56%	20.25	57%
	2030	VRF	16.09	61%	16.90	64%

WSHP: water-source heat pump; PSZ: packaged single zone; HP: heat pump; DX: direct expansion; AC: air conditioner; VRF: variable refrigerant flow.

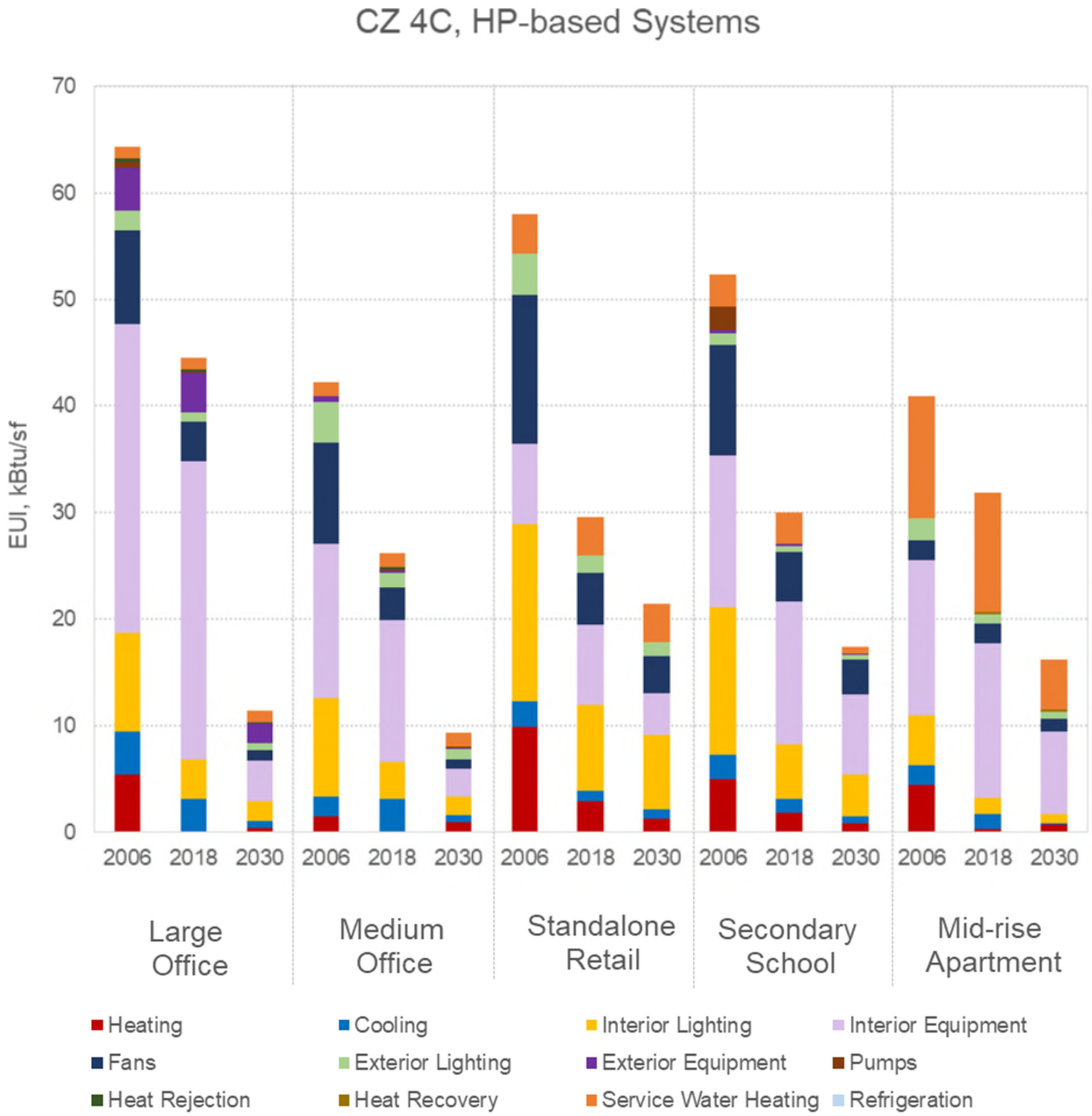

FIGURE ES1: CLIMATE ZONE 4C END-USE DISTRIBUTION FOR HP-BASED SYSTEMS

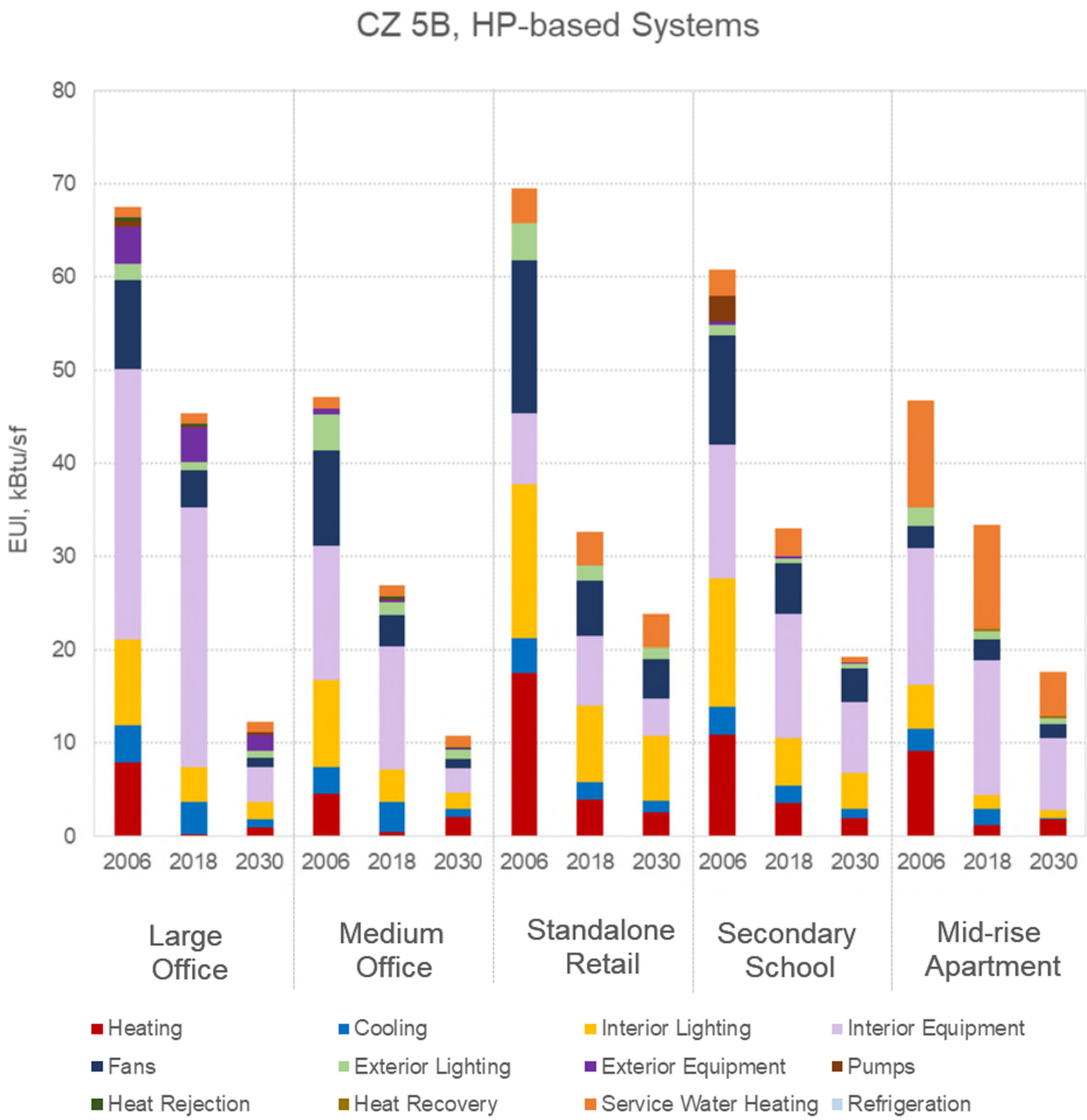

FIGURE ES2: CLIMATE ZONE 5B END-USE DISTRIBUTION FOR HP-BASED SYSTEMS

Roadmap to 2030 WSEC

Several measures were evaluated in the analysis and for each measure, a recommendation on how and when the measure should be incorporated into the code has been provided based upon the cost, technical maturity, and market penetration of the measure or technology. Some measures, such as fenestration orientation, have been present in other codes for a few cycles and pose no real barriers to incorporation into the 2021 WSEC. Some other measures require market transformation before they can be incorporated into the code. For example, the shift to task lighting from general lighting or lowering the fan static pressure. Current code avenues, such as performance budget methods (total system performance ratio) or the optional efficiency package path (C406), could be used to promote a measure that may not yet be part of mainstream design. Finally, there are other measures, such as LED efficacy improvement and ultra-high R/inch insulation that are emerging technologies, but may become mainstream in 10 years, given the right set of circumstances and support. These measures are intended to be used to seed the code development effort over the next few code cycles.

Except for the Standalone Retail prototype, PPLs constitute more than a third and, in the case of the Large Office, more than two thirds of the total energy consumption in the prototypes. Therefore, the strategy to achieve a 70% site energy reduction by 2030 must include a plan to tackle PPLs:

1. The code must further regulate PPLs by first, establishing a PPL budget by building type and based on the existence of certain features (a commercial kitchen, for example). A separate budget could be established for off-hour usage.
2. Proper functioning of PPL controls (such as night-time turn off) must be part of the commissioning requirements.
3. The metering requirement threshold, currently set to buildings larger than 50,000 sf (C409.1 in 2018 WSEC), should be evaluated in the context of national model codes together with other requirements to support the regulation of PPLs.
4. Finally, the PPL budget verification and improvement requirements must be part of existing building benchmarking and improvement laws, such as HB1257[1] so that buildings may be evaluated and continuously commissioned on an annual basis.

[1] The Washington Department of Commerce is currently engaged in drafting a standard to enforce HB1257: https://www.commerce.wa.gov/growing-the-economy/energy/buildings/

1.0 Introduction

Washington State set a legislative goal[2] to reduce annual net site energy consumption for commercial buildings under the 2030 energy code by 70% relative to the 2006 Washington State Energy Code (WSEC) (SBCC 2007). The 2018 edition of the Washington State Energy Code (SBCC 2020), which is based on the 2018 International Energy Conservation Code (IECC), has several amendments likely to increase savings above the 2018 IECC. Thus, Washington is well on its way towards achieving its 2030 legislative goals (State of Washington 2009).

Northwest Energy Efficiency Alliance (NEEA) provides technical support in assisting the state to achieve its energy policy goals. As part of this support, NEEA and the Washington State Department of Commerce developed a WSEC Technical Roadmap ("the Roadmap") that identifies an optimum set of technologies and building strategies that will achieve the efficiency improvements necessary to meet the 2030 goal. The intention with this Roadmap is to create a pool of measures that can guide the code development process over the next few code cycles and serve as a technical blueprint. It will identify a group of building strategies and technologies that can achieve the 2030 WSEC goal of 70% annual net site energy reduction for four building types: Office, Retail, K-12 School, and Multifamily. Together these four building types represent 53% of average new construction floor space in Washington State based on construction starts from 2003-2018[3]. These building strategies and technologies will seed the code development in the 2021, 2024, 2027 and 2030 WSEC code cycles.

1.1 Objectives

The objectives of the Roadmap are as follows:

1. Determine the 2030 WSEC annual energy consumption target by analyzing the baseline energy consumption for the four building types using the prescriptive and mandatory requirements of the 2006 WSEC.

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

[3] Derived from table B1: https://www.energycodes.gov/sites/default/files/documents/Commercial_Weighting_Factors_2003_to_2018.pdf

2. Based on the 2030 WSEC target, identify building strategies and associated technologies that can together achieve the 70% site energy reduction target. Estimate the associated energy savings from individual building strategies.
3. Identify market barriers such as cost, market penetration, and technical maturity, and identify how and when the building strategies could be incorporated into future WSEC cycles.
4. Create a technical support document describing the savings potential from the building strategies and the methodology used to estimate savings.
5. Gather feedback and support from key code stakeholders, utilities, and industry partners at key phases of the project.

The metric used to evaluate the 2030 target was site energy because this is the metric used in the legislature text. Thus, all the analysis conducted in subsequent sections reports the impact in terms of annual site energy consumption.

A previous WSEC Roadmap report (Frankel and Edelson 2015) in 2015 provided recommendations for the WSEC, such as code structural changes to provide more flexibility, building-specific approaches, and for the code to lay the groundwork to naturally evolve from one cycle to the next. This Roadmap builds on the previous one and identifies building strategies that are specific to the selected building types, targets plug loads, and provides measures that would need to be implemented over multiple code cycles. It provides actionable measures that could be incorporated into the code over the next few cycles.

1.2 Technical Advisory Group

A technical advisory group (TAG) was formed together with NEEA, the Washington Department of Commerce, and WSEC experts to guide the development of the Roadmap. The TAG provided guidance at key intervals to shape the Roadmap. A broader group of stakeholders involved in the WSEC code development process was also engaged during the development of the Roadmap.

2.0 Methodology

To accomplish the objectives of this Roadmap, the following methodology was established:

1. **Evaluate the 2006 and 2018 WSEC energy consumption**: The 2006 WSEC sets the baseline for achieving the 70% site energy savings target and the 2018 WSEC would indicate the progress made since 2006. An understanding of the energy consumption and end-use distribution of both these code editions was needed. A qualitative and quantitative analysis was performed to determine the energy consumption for the four building types and the corresponding prototype models. By understanding the end-use distribution in 2006 and 2018, appropriate energy reduction strategies could be identified in the next step.
2. **Identify building strategies and technologies for 2030**: Based on the 2006 and, in particular, the 2018 WSEC end-use distribution, a list of building-specific strategies were identified. From the larger list of strategies, two major packages of measures were finalized for 2030. In addition, a technology matrix was created that described the strategies, associated technologies, their savings potential, cost impact, technical maturity, market penetration, and potential barriers. Feedback from WSEC code development stakeholders was collected on the technology matrix.
3. **Analyze 2030 measures and packages**: In this step, the finalized list of measures were modeled to determine their energy savings relative to both the 2018 and the 2006 WSEC editions.

2.1 Prototypes and Weather Locations

The United States (US) Department of Energy's (DOE) EnergyPlus (DOE 2020) program was chosen to perform the energy modeling to determine the energy consumption of the 2006 and 2018 WSEC and to analyze the energy savings from building strategies. For the four building types, five prototypes were selected as shown in Table 1. Pacific Northwest National Laboratory (PNNL) maintains a suite of prototype building energy models to support the development of nonresidential energy codes and standards. PNNL modified those prototypes to establish performance targets to be used in Washington State's adoption of the ASHRAE Standard 90.1 (ASHRAE 2019) Performance Rating Method (also known as Appendix G) for compliance with the 2018 WSEC. These prototypes were provided by PNNL and were used as the starting point for the analysis. The Medium Office and Secondary School prototypes were not part of PNNL's analysis, and so, the 2015 IECC prototypes from PNNL (PNNL 2020) were used as the basis.

Two of the selected prototypes, the Large Office and the Medium Office, represented the office building type. The Large Office was chosen to incorporate the impact of a data center, which is situated in the basement of the Large Office prototype. For the K-12 School building type, the Secondary School prototype was chosen because it has more diversity in its spaces relative to the Primary School prototype (not chosen) and because some alignment with higher education spaces was sought.

Pacific Northwest National Laboratory (PNNL) maintains a suite of prototype building energy models to support the development of nonresidential energy codes and standards. PNNL modified those prototypes to establish performance targets to be used in Washington State's adoption of the ASHRAE Standard 90.1 (ASHRAE 2019) Performance Rating Method (also known as Appendix G) for compliance with the 2018 WSEC. These prototypes were provided by PNNL and were used as the starting point for the analysis. The Medium Office and Secondary School prototypes were not part of PNNL's analysis, and so, the 2015 IECC prototypes from PNNL (PNNL 2020) were used as the basis.

TABLE 1: PROTOTYPE SELECTION FOR ROADMAP

Building Type	Prototype Model	Floor Area, ft^2	Number of Stories
Office	Large Office	498,640	12 (plus basement)
Office	Medium Office	53,600	3
Retail	Standalone Retail	24,690	1
K-12 School	Secondary School	210,910	2
Multifamily	Mid-rise Apartment	33,740	4

Two weather locations were selected for the analysis representing ASHRAE climate zone 4C and 5B (ASHRAE 2013), which are the predominant climate zones in Washington. Table 2 lists the weather station and EnergyPlus weather (EPW) file that was used in the analysis.

TABLE 2: WEATHER LOCATIONS AND WEATHER 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

3.0 Analysis and Results

In this section, each step of the analysis is described together with the results. Each step feeds into the next step of the analysis.

3.1 Qualitative Analysis of the 2006 and 2018 WSEC

The qualitative analysis analyzed every mandatory and prescriptive code requirement within the 2006 and 2018 WSEC. Many code requirements are editorial or administrative in nature and do not have an energy impact. A requirement may have an energy impact, but it may not be applicable to the selected prototypes. For example, the requirement to setback the thermostat setpoints in unoccupied guestrooms is applicable to hotels and motels, but not applicable to the building types selected for this analysis. A requirement may have an energy impact and be applicable to the selected prototypes, however, due to modeling limitations, it may not be possible to model it appropriately. One example is the 3- and 4-stage cooling requirement for direct expansion (DX) equipment larger than 65,000 Btu/h, which cannot be modeled in EnergyPlus due to the object limitations. With these limitations in mind, each requirement was examined to determine if the requirement:

1. has an energy impact,
2. applies to the selected prototypes, and
3. whether it can be captured in the prototype models.

Those requirements that met all three criteria were applied to the models in the quantitative analysis described below.

3.2 Quantitative Analysis

In this step, the requirements of the 2006 and 2018 WSEC editions that were identified for modeling in the qualitative analysis were modeled using the selected prototypes. A simulation structure was set up that parameterized the prototype models and allowed model inputs to be changed to capture the 2006 and 2018 WSEC requirements.

3.2.1 HVAC System Selection

Prototype HVAC system choices for the 2006 and 2018 WSEC editions were discussed within the TAG. Multiple options existed, including the default assumptions in the prototype models and data from NEEA's Commercial Building Stock Assessments (CBSA) (NEEA 2020). Table 3 shows the details of the final prototype HVAC system selection for the 2006 and 2018 WSEC editions. The 2030 prototype HVAC systems are discussed later in section 3.4.

Data from the Residential Building Stock Assessment (RBSA) II (NEEA 2017) showed that multifamily buildings prior to 2000 had cooling systems in only 29% of cases, whereas, since 2010 that number has risen to 59%. It was decided for the purpose of this analysis to hold the existence of a cooling system constant over the analysis period because it is not a feature regulated by the code. Thus, the Mid-rise Apartment prototype included a cooling system both in 2006 and 2018 WSEC editions.

Prototype HVAC systems for the 2018 WSEC were based on the standard designs specified by the total system performance ratio (TSPR) (Table D602.11 in the 2018 WSEC), except for the Mid-rise Apartment, to which TSPR requirements do not apply (except in the City of Seattle). The standard TSPR system is a cycling space conditioning heat pump combined with a DOAS with highly efficient sensible energy recovery. The 2018 HVAC system for the two office prototypes would be water-source heat pumps (WSHP), and for the Standalone Retail and Secondary School prototypes, it would be packaged single zone heat pumps. To provide a basis for savings for systems that use natural gas, systems using gas furnaces were added for the Standalone Retail and Secondary School prototypes. The WSHP already used gas boilers for backup heating. So, a separate gas-based system was not used for the 2018 WSEC for the Medium and Large Office prototypes. Additional measures were required for gas systems to meet the TSPR thresholds. Previous analysis performed by PNNL showed that higher efficiency gas furnaces together with lower fan power were required to meet the TSPR target and were modeled accordingly. In all 2018 WSEC models, ventilation was provided through a dedicated outdoor air system (DOAS) as specified by the standard TSPR design (Table D602.11 in the 2018 WSEC).

The 2018 WSEC TSPR requirement does not apply to the Mid-rise Apartment prototype. Therefore, ventilation need not be provided through DOAS. The prevalent ventilation system, especially in the early 2000s, was found to be one where air is exhausted using the bathroom exhaust fan, causing fresh air to be drawn in through trickle vents, either through the corridor or through the exterior. Changes in the 2018 Washington State Mechanical Code (SBCC 2020) required balanced and distributed ventilation, which meant a DOAS system would need to be used. For consistency, ventilation in the 2006 WSEC Mid-rise Apartment prototype was also assumed to be provided by DOAS though it does not have heat recovery (required in 2018 WSEC).

TABLE 3: PROTOTYPE HVAC SYSTEM SELECTION FOR THE 2006 AND 2018 WSEC EDITIONS

Prototype	Case	HVAC System Description	Heating System	Cooling System	Air Distribution	Ventilation System
Mid-rise Apartment	2006	Single-zone split system.	Electric resistance heat in dwelling units and gas furnace in common areas.	DX cooling in dwelling units and common area.	Cycling Fans	DOAS
	2018 System 1	Single-zone split heat pumps.	DX heating with electric resistance supplemental heat	DX cooling	Cycling fans	DOAS
	2018 System 2	Single-zone split system.	Gas furnace	DX cooling	Cycling fans	DOAS
Large Office	2006	Variable air volume (VAV) with series fan powered terminals on perimeter and pinch boxes in the core with electric resistance reheat. Built-up VAV with central plant--chiller, boiler, cooling tower.	Boiler, electric resistance reheat	Chiller, cooling tower	VAV with series fan powered terminals.	Through the VAV system
	2018	TSPR (Standard Reference Design): Water-source heat pump.	Heat pump with backup gas boiler	Heat pump with cooling tower	Single zone cycling fans	DOAS
Medium Office	2006	Package single-zone AC/gas furnace	Gas furnace	DX cooling	Single zone CAV	Through the CAV system
	2018	TSPR (Standard Reference Design): Water-source heat pump.	Heat pump with backup gas boiler	Heat pump with cooling tower	Single zone cycling fans	DOAS
Standalone Retail	2006	Package single-zone AC/gas furnace	Gas furnace	DX cooling	Single zone CAV	Through the CAV system
	2018 System 1	TSPR (Standard Reference Design): Packaged air-source heat pump.	DX heating	DX cooling	Single zone cycling fans	DOAS
	2018 System 2	Packaged air conditioner (AC) and gas furnace.	Gas furnace	DX cooling	Single zone cycling fans	DOAS
Secondary School	2006	Single zone air handlers with hydronic heating and cooling w/central plant.	Boiler	Air-cooled chiller	Single zone CAV	Through the CAV system
	2018 System 1	TSPR (Standard Reference Design): Packaged air-source heat pump.	DX heating	DX cooling	Single zone cycling fans	DOAS
	2018 System 2	Packaged AC and gas furnace.	Gas furnace	DX cooling	Single zone cycling fans	DOAS

There is some impact due to fuel switching occurring between 2006 and 2018, for example in the Standalone Retail (packaged AC/gas furnace in 2006 to packaged HPs in 2018) heat pumps provide all or most of the heating in 2018. Adding the gas system to 2018 WSEC models for the

Mid-rise Apartment, Standalone Retail, and Secondary School prototypes alleviates some of the reduction in site energy consumption from fuel switching. The two office prototypes have high internal loads and therefore have very low heating loads.

3.2.2 Quantitative Analysis Results

Table 4 summaries the energy use intensity (EUI) for the five prototypes for the 2006 and 2018 WSEC editions. Detailed results by end-use are provided in Appendix B. Figure 1 and Figure 2 show the end-use distribution for each prototype, code edition, and HVAC system type for climate zones 4C and 5B, respectively. The results for 2006 WSEC shown in Table 4 provide the basis for the EUI targets for 2030 WSEC. Table 5 shows these 2030 WSEC EUI targets for the five prototypes and two climate zones after applying a 70% reduction to the 2006 WSEC EUIs.

TABLE 4: PROTOTYPE ENERGY CONSUMPTION FOR 2006 AND 2018 WSEC

Prototype	Code Edition -- Case	4C		5B	
		EUI, kBtu/sf	% EUI Savings	EUI, kBtu/sf	% EUI Savings
Large Office	2006	64.28		67.49	
	2018 – WSHP	44.47	31%	45.33	33%
Medium Office	2006	42.23		47.14	
	2018 – WSHP	26.21	38%	26.96	43%
Standalone Retail	2006	58.03		69.45	
	2018 – PSZ[1] HP	29.60	49%	32.73	53%
	2018 – PSZ AC/Gas Furnace	29.45	49%	34.97	50%
Secondary School	2006	52.82		61.37	
	2018 – PSZ HP	30.58	42%	33.59	45%
	2018 – PSZ AC/Gas Furnace	31.83	40%	35.03	43%
Mid-rise Apartment	2006	40.91		46.74	
	2018 – Split HP	31.86	22%	33.40	29%
	2018 – Split AC/Gas Furnace	32.59	20%	35.74	24%

[1]PSZ: packaged single zone

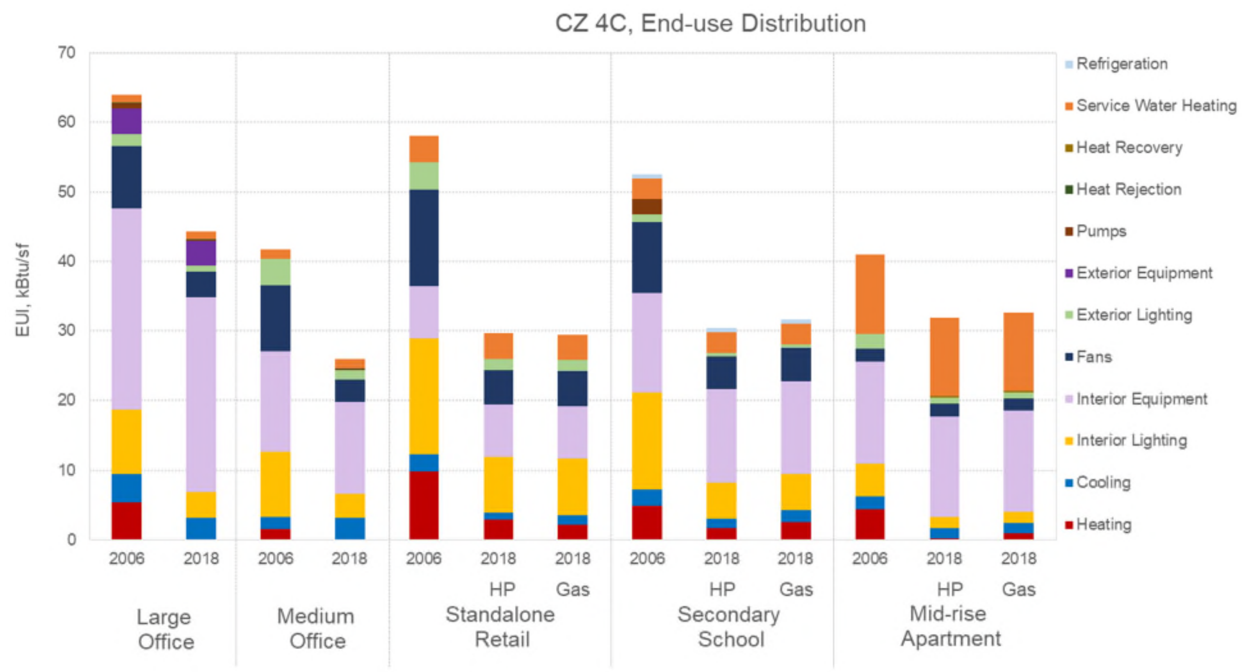

FIGURE 1: CLIMATE ZONE 4C PROTOTYPE END-USE DISTRIBUTION FOR 2006 AND 2018 WSEC EDITIONS

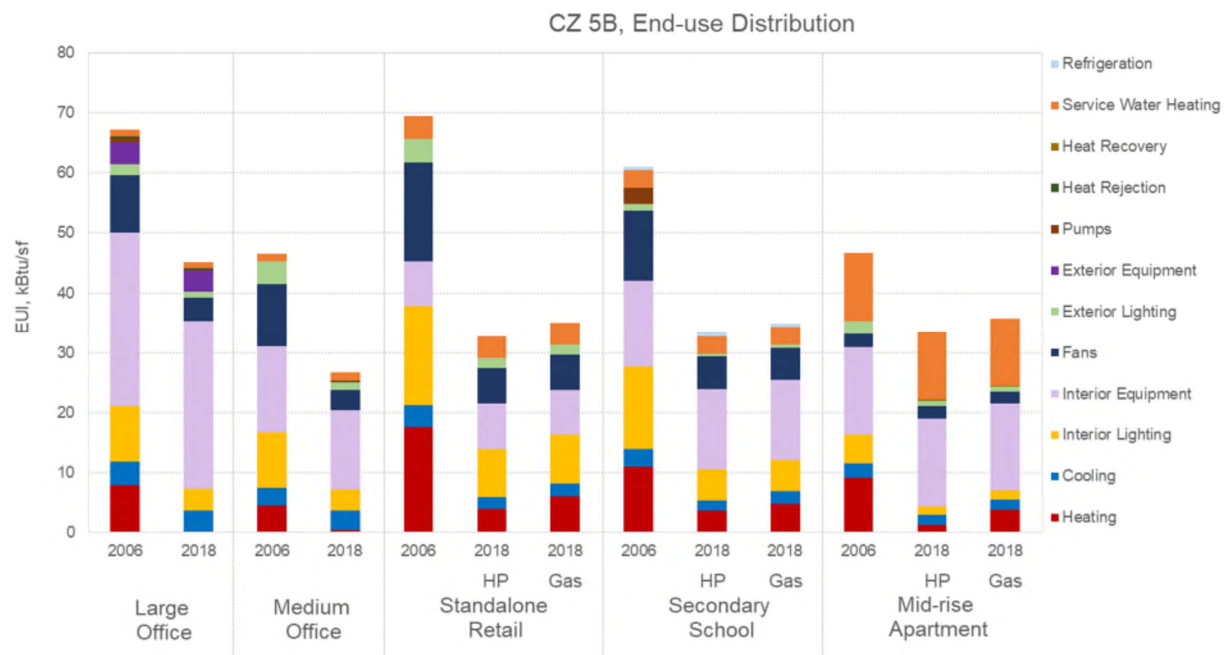

FIGURE 2: CLIMATE ZONE 5B PROTOTYPE END-USE DISTRIBUTION FOR 2006 AND 2018 WSEC EDITIONS

TABLE 5: 2030 WSEC EUI TARGETS

Prototype	4C		5B	
	EUI, kBtu/sf	2030 EUI Target, kBtu/sf	EUI, kBtu/sf	2030 EUI Target, kBtu/sf
Large Office	64.28	19.28	67.49	20.24
Medium Office	42.23	12.67	47.14	14.14
Standalone Retail	58.03	17.41	69.45	20.84
Secondary School	52.82	15.85	61.37	18.41
Mid-rise Apartment	40.91	12.27	46.74	14.02

A few observations based on the 2006 and 2018 WSEC results are described below:

Plug and Process Loads (PPL) Constitute Significant Proportion of the Consumption.

1. Table 6 shows the PPL EUI and the proportion of PPL consumption out of the total consumption in the 2018 code edition. For the Large Office prototype, the proportion of PPL load out of the total consumption is 71% (climate zone 4C). This high fraction is due to the presence of the data center. The Standalone Retail prototype has the lowest proportion of PPLs amongst the five prototypes with approximately a quarter of the total energy being consumed by PPLs.

   End-uses included in PPLs are: plug loads connected to standard receptacle outlets (computers, monitors, copiers, water coolers, vending machines, coffee makers, and other miscellaneous electrical loads), elevators, data centers and information technology (IT) closets (Large Office only), kitchen cooking equipment (Secondary School only), and household appliances (Mid-rise Apartment only) such as stove, oven, dishwasher, washer, and dryer.

TABLE 6: PPL CONSUMPTION RELATIVE TO TOTAL CONSUMPTION

Prototype	Code Edition – Case	4C		5B	
		PPL EUI, kBtu/sf	% PPL EUI	PPL EUI, kBtu/sf	% PPL EUI
Large Office	2018 – WSHP	31.53	71%	31.53	70%
Medium Office	2018 – WSHP	13.26	51%	13.26	49%
Standalone Retail	2018 – PSZ HP	7.52	25%	7.52	23%
Secondary School	2018 – PSZ HP	13.38	44%	13.38	40%
Mid-rise Apartment	2018 – Split HP	14.49	45%	14.49	43%

2. **Key End-Uses for Future Code Development**. The end-use distribution in the 2018 WSEC provided guidance about the end-uses that should be targeted moving forward.
    a. Large Office: The data center and other PPLs constitute 71% of the total energy consumption in 2018. This is extremely high and any approach to meeting the 70% energy reduction target must include measures to reduce the data center and PPL consumption.
    b. Medium Office: PPLs are half the total energy consumption and together with cooling, which is again directly impacted by PPLs, constitute the largest end-uses.
    c. Standalone Retail: The heating and lighting end-uses continue to be significant in 2018. A reduction in the lighting end-uses in future code cycles is likely to make heating even more significant. Envelope measures that reduce heat loss and higher heating efficiency measures will lead to significant savings.
    d. Secondary School: PPLs occupy more than a third of the consumption though are not very well defined in the model (PPL measure description in Appendix C provides further detail). Improvements related to heating and fan end-use will be significant.
    e. Mid-rise Apartment: A little less than half the consumption is PPLs, with the other major end-use being domestic water heating (DWH).
3. **WSHP Eliminates Heating in Medium and Large Office Prototypes**. The switch to WSHPs combined with heat recovery ventilators (HRV) as specified by the TSPR standard design system nearly eliminates all heating consumption in the two office prototypes. The WSHPs prove to be exceptionally efficient at moving heat from the core zones to the perimeter zones using the water loop, with almost no usage of the backup gas boiler to bring up the loop temperature.
4. **Medium Office Cooling Consumption Increases in 2018**. There is a slight increase in cooling consumption in 2018 WSEC for the Medium Office prototype. The zonal HPs in the WSHP system do not employ air-side economizers (as specified by TSPR). In addition, the Medium Office 2006 baseline uses an air-source DX system, which uses a curve-based model for part-load performance in EnergyPlus, whereas the water-source DX uses a coefficient-based model for part-load performance. Past experience with the water-source model indicates that it may show artificially poor performance relative to the air-source model. This may need to be investigated further.

3.3 Building Strategies Development

In this step of the analysis, building strategies were collected for all end-uses of the five prototype buildings. High-performance buildings, and indeed, zero net energy buildings are being designed and have been in operation for many years. Some states and local jurisdictions, such as Washington, New York, California, and City of Seattle, have goals for achieving deep energy savings in commercial buildings in the upcoming years. This broad push has resulted in a rich body of work that was harvested to collect measures for this analysis. The end-use distribution for the 2018 WSEC served as a guide to determine the most impactful strategies.

One of the objectives of this analysis is to seed the code development efforts in future code cycles. For a measure to be incorporated into the code, it should result in significant energy savings, be cost-effective, use technically mature and stable technologies, and have significant market penetration. These factors were evaluated for each measure. A technology matrix was created that identified the technologies associated with the strategy and that subjectively characterized the energy savings potential, cost, technical maturity, market penetration, and technical and market barriers for each strategy. This technology matrix is provided in Appendix A.

Using the matrix, strategies were ranked to determine those that are most applicable to the prototypes and to the existing market in Washington State. The matrix and list of measures was sent to external stakeholders for feedback and for ranking the strategies. Some technologies would be ready for adoption in the 2021 cycle simply by virtue of being specific to a building type, i.e., the question of applicability and cost would be removed by applying it only to specific building types. Others may need more market penetration, such as luminaire level lighting controls (LLLC), which could be achieved through market transformation. These technologies could then be incorporated into future code cycles.

Using the technology matrix and the list of measures, a shorter list was created by ranking all the measures in order of priority. The final package of selected measures is shown in Table 7 together with the applicability to the five prototypes. Detailed measure specification for each measure is provided in Appendix C. The specification describes the source of the measure, the assumptions, the baseline and advanced levels for the measure, and notes on how it was modeled (where appropriate).

TABLE 7: FINAL 2030 MEASURES SELECTED FOR ANALYSIS

Building Component	Measure Short Name	Measure Specification	LO[1]	MO[1]	SR[1]	SS[1]	MA[1]
Building Envelope	UltraWallRoofR	Use ultra-high R/inch (R12/inch) materials. Double the R-value for the same depth of insulation.	X	X	X	X	X
	ThermalBridging	Use highest-performance assemblies from the BCHydro Thermal Bridging Guide.	X	X	X	X	X
	Infiltr	Reduced infiltration, 0.10 cfm/sf.	X	X	X	X	X
	LowSHGCHighLSG	High LSG windows. SHGC = 0.20, VT/SHGC = 2.5.	X	X	X	X	X
	LowWindowU	Triple-glazed or skinny triple windows, U = 0.20.	X	X	X	X	X
	FenOrient[2]	Based on Standard 90.1-2019, Aw and Ae <= At/4.	X	X	X	X	X
Daylighting	OptDaylighting[2]	Based on AEDG. Improved geometry and daylighting design for offices and schools.	X	X		X	
	DayltgInpPwr	Daylighting control by fixture. See LLLC measure below. More area controlled by DL sensors.	X	X	X	X	
Lighting	OccSensor	Occupancy sensors in all spaces.	X	X		X	
	OccSensor	LLLC: Increased occupancy sensor and DL savings. Merge with occupancy sensors measure.	X	X	X	X	
	LPD2030	Based upon DOE's Lighting Technology Roadmap and projected future improvements in efficacy of LED sources.	X	X	X	X	X
	LPD2030Task	ASHRAE Standard RP-1651 spec. Approximately 50% reduction in general lighting power.	X	X		X	
	ExtLPD2030	Based upon DOE's Lighting Technology Roadmap and projected future improvements in efficacy of LED sources.	X	X	X	X	X
HVAC	DCV1000	Apply demand-controlled ventilation (DCV) to all spaces.	X	X	X	X	X
	FanStatic	NEEA VHE DOAS specification for DOAS fans. Space conditioning fan static based upon engineering judgment.	X	X	X	X	X
	High-DXCOP	15% improvement over 2018 WSEC requirements.	X	X	X	X	X
	ERVEff	Increase ERV effectiveness to 82%, per NEEA VHE DOAS specification.	X	X	X	X	X
	RadFlr	Apply radiant floor system based on 50% Small to Medium Office AEDG.	X	X			
	VRF	Apply VRF with refrigerant heat recovery system. Use CBECC-Com specification.					X
	ChilledBeam[2]	Apply chilled beam system with a high-efficiency chiller and boiler.				X	
	TowerEff	Increase tower efficiency to 80 gpm/hp.	X	X			
Water Heating	HPWH	NEEA specification for heat pump water heaters (HPWH).				X	X
Plug and Process Loads	EffPlugLoad	ENERGY STAR equipment, reduction based on future projected efficiency improvements in miscellaneous electrical loads (MELs).	X	X	X	X	X
	NetworkCPU	Night-time turn off of nearly all plug load.	X	X		X	
	TracElev	Next generation traction type with regenerative drive.	X	X		X	X

Building Component	Measure Short Name	Measure Specification	LO[1]	MO[1]	SR[1]	SS[1]	MA[1]
	HighEffDTC	High-efficiency data center servers. Load reduction by 90%.	X				
	HighEffKitchen	High-efficiency kitchen equipment based on 50% AEDG for Restaurants. High-efficiency kitchen exhaust fans.				X	

[1] LO: Large Office, MO: Medium Office, SR = Standalone Retail, SS = Secondary School, MA: Mid-rise Apartment.
[2] Measure was not included in the 2030 modeling analysis (section 3.4). Fenestration orientation was analyzed but not modeled (see description in Appendix C).

3.4 2030 Measure and Package Analysis

Each measure listed in Table 7 was modeled individually for each prototype, climate zone, and HVAC system. Next, the complete package of measures as well as a few sub-packages were modeled. The detailed end-use results are provided in Appendix B. The major packages modeled were as follows:

1. All package: includes all measures, except the thermal bridging measure, which was evaluated separately. Separate packages were developed by system type. For example, there are two 'all measures' packages for the Standalone Retail prototype for each climate zone, one with the packaged HP system and the other with the packaged AC and gas furnace system.
2. Envelope package: includes all envelope measures. In some instances, individual envelope measures with negative energy savings for a climate zone were excluded from the package for that climate zone.
3. PPL package: includes all PPL measures applicable to the prototype.
4. Envelope plus PPL package: includes all envelope measures and PPL measures. In this package, the envelope measures with negative savings were also included. It was found that in the presence of the PPL package, which results in substantially lower internal heat gain in the model, the envelope measures become more impactful.
5. All measures except PPL measures package: This package includes all measures except the PPL measures. The intention was to capture the total 2030 WSEC savings in the absence of PPL measures.

Additionally, the plug load reduction measure was modeled at two levels of plug loads for the office spaces, 0.26 W/sf and 0.40 W/sf. The 0.26 W/sf level results in a 65% reduction in plug load intensity in these spaces. A more conservative estimate of 0.40 W/sf, based on today's

(2020) state-of-the-art net zero energy buildings, was also evaluated. This impacts the plug load in the Medium and Large Office prototypes.

Two measures in the specification list above were not included: chilled beams and optimum daylighting design due to time and resource constraints.

3.4.1 2030 Package Results

Individual measure results are too numerous to discuss here. They are available in detailed format in Appendix B. The results shown below include package measures, as well as a discussion of a few sub-packages. Table 8 shows the 2006, 2018, and 2030 WSEC EUI for all prototypes and the major HVAC systems. The package savings range from a high of 83% for the Large Office to a low of 56% for the Mid-rise Apartment prototype. The two office prototypes have significant savings from PPLs, especially the Large Office which has a data center measure that reduces the IT load by 90%. The Mid-rise Apartment includes a significant amount of PPLs, even after applying PPL reduction strategies. Overall, systems using gas furnaces achieve parity with their all-electric counterparts, though in some cases, additional measures may be required.

For the three prototypes that do not reach the 70% target—Standalone Retail, Secondary School, and Mid-rise Apartment—the remaining energy savings needed to achieve the 70% site energy savings target could be achieved through the addition of renewable sources. Table 9 shows the additional annual electricity generation from a roof-mounted photovoltaic (PV) system required to meet the 70% target and the associated roof area. The PVWatts Calculator (NREL 2020) was used to develop the annual electricity generation per unit area of PV panels. The amount of PV needed varies by building type, system type, and climate zone. For all three prototypes, using the most efficient system type results in roof area coverage much smaller than the total roof area of the prototype, which means it could be practically achievable considering the roof space constraints imposed by other equipment on the roof (HVAC equipment, skylights, etc.).

TABLE 8: 2030 WSEC PACKAGE RESULTS INCLUDING ALL MEASURES

Prototype	Code Edition	Case	4C EUI, kBtu/sf	4C % EUI Savings	5B EUI, kBtu/sf	5B % EUI Savings
Large Office	2006	Base	64.28		67.49	
	2018	WSHP	44.47	31%	45.33	33%
	2030	WSHP	11.37	82%	12.21	82%
	2030	Radiant Floor	10.87	83%	11.42	83%
Medium Office	2006	Base	42.23		47.14	
	2018	WSHP	26.22	38%	26.96	43%
	2030	WSHP	9.35	78%	10.77	77%
	2030	Radiant Floor	8.33	80%	9.28	80%
Standalone Retail	2006	Base	58.03		69.45	
	2018	PSZ HP	29.60	49%	32.73	53%
	2018	PSZ DX AC/Gas Furnace	29.45	49%	34.97	50%
	2030	PSZ HP	21.44	63%	23.88	66%
	2030	PSZ DX AC/Gas Furnace	21.59	63%	23.91	66%
Secondary School	2006	Base	52.82		61.37	
	2018	PSZ HP	30.58	42%	33.59	45%
	2018	PSZ DX AC/Gas Furnace	31.83	40%	35.03	43%
	2030	PSZ HP	18.02	66%	19.87	68%
	2030	PSZ DX AC/Gas Furnace	19.66	63%	22.29	64%
Mid-rise Apartment	2006	Base	40.91		46.74	
	2018	Split HP	31.86	22%	33.40	29%
	2018	Split DX/Gas Furnace	32.59	20%	35.75	24%
	2030	Split HP	16.19	60%	17.62	62%
	2030	Split DX/Gas Furnace	18.16	56%	20.25	57%
	2030	VRF	16.09	61%	16.90	64%

TABLE 9: ROOF AREA REQUIRED FOR PV

Prototype	Case	Additional EUI Needed from PVs, kBtu/sf		Total Annual Generation Needed, kWh		Annual Generation, kWh/sf of PV[1]		Roof Area Required, sf	
		4C	5B	4C	5B	4C	5B	4C	5B
Standalone Retail	PSZ HP	4.06	2.78	342,266	234,070	20.55	22.97	16,652	10,190
	PSZ DX AC/Gas Furnace	4.06	2.78	342,266	234,070	20.55	22.97	16,652	10,190
Secondary School	PSZ HP	2.11	1.23	1,520,403	883,256	20.55	22.97	73,971	38,453
	PSZ DX AC/Gas Furnace	3.7	3.68	2,660,705	2,649,767	20.55	22.97	129,450	115,358
Mid-rise Apartment	Split HP	4.09	3.74	471,015	430,511	20.55	22.97	22,916	18,742
	Split DX/Gas Furnace	5.73	6.08	659,421	699,580	20.55	22.97	32,083	30,456
	VRF	3.68	2.8	423,914	322,883	20.55	22.97	20,624	14,057

[1] Calculated from PVWatts, assuming 19% panel efficiency and a panel tilt of 35 degrees from horizontal.

3.4.1.1 PPL Measure Impact

Table 10 shows the 2006 and 2030 EUIs when PPL measures are excluded from the 2030 packages. Whole building consumption and savings are shown together with consumption and savings excluding the interior and exterior end-use categories. It should be noted that portions of the interior and exterior end-uses are regulated by the code (for example, receptacle control and transformer minimum efficiency).

TABLE 10: 2030 WSEC PACKAGE RESULTS EXCLUDING PPL MEASURES

			4C				5B			
Prototype	Code Edition	Case	Whole Building EUI, kBtu/sf	% Whole Building EUI Savings	EUI without PPLs[1], kBtu/sf	% No PPL EUI Savings	Whole Building EUI, kBtu/sf	% Whole Building EUI Savings	EUI without PPLs[1], kBtu/sf	% No PPL EUI Savings
Large Office	2006	Base	64.28		31.35		67.49		34.56	
	2018	WSHP	44.47	31%	12.79	59%	45.33	33%	13.65	61%
	2030	WSHP	38.28	40%	8.46	73%	38.64	43%	8.82	74%
	2030	Radiant Floor	37.62	41%	7.80	75%	37.98	44%	8.16	76%
Medium Office	2006	Base	42.23		27.23		47.14		32.14	
	2018	WSHP	26.22	38%	12.66	53%	26.96	43%	13.40	58%
	2030	WSHP	18.72	56%	7.38	73%	18.85	60%	7.51	77%
	2030	Radiant Floor	17.71	58%	6.37	77%	17.79	62%	6.45	80%
Standalone Retail	2006	Base	58.03		50.51		69.45		61.93	
	2018	PSZ HP	29.60	49%	22.08	56%	32.73	53%	25.21	59%
	2018	PSZ DX AC/Gas Furnace	29.45	49%	21.93	57%	34.97	50%	27.45	56%
	2030	PSZ HP	25.29	56%	17.77	65%	27.46	60%	19.94	68%
	2030	PSZ DX AC/Gas Furnace	25.44	56%	17.92	65%	27.49	60%	19.97	68%
Secondary School	2006	Base	52.82		38.20		61.37		46.75	
	2018	PSZ HP	30.58	42%	17.02	55%	33.59	45%	20.03	57%
	2018	PSZ DX AC/Gas Furnace	31.83	40%	18.27	52%	35.03	43%	21.47	54%
	2030	PSZ HP	24.18	54%	10.62	72%	26.02	58%	12.46	73%
	2030	PSZ DX AC/Gas Furnace	25.26	52%	11.70	69%	27.38	55%	13.82	70%
Mid-rise Apartment	2006	Base	40.91		26.29		46.74		32.12	
	2018	Split HP	31.86	22%	17.37	34%	33.40	29%	18.91	41%
	2018	Split DX/Gas Furnace	32.59	20%	18.10	31%	35.75	24%	21.26	34%
	2030	Split HP	20.09	51%	8.25	69%	21.31	54%	9.47	71%
	2030	Split DX/Gas Furnace	21.15	48%	9.31	65%	23.03	51%	11.19	65%
	2030	VRF	20.08	51%	8.24	69%	20.88	55%	9.04	72%

[1]Excludes interior and exterior equipment end-use consumption.

The 2030 EUIs for the two office prototypes are much lower (below 10 kBtu/sf in some cases) than what is observed in the highest-performing buildings today (2020). The main reason for the low EUIs is the plug load measure, which reduced the plug load from 0.75 W/sf in 2006 to 0.26 W/sf in 2030. For reference, the 50% Medium Office AEDG (Thornton, Wang and Lane, et al. 2009) reduced the plug load to 0.55 W/sf from the baseline of 0.75 W/sf in 2009. To bound the range of savings, a higher plug load intensity of 0.40 W/sf was also simulated for the 2030 WSEC (the Large Office data center PPL reduction measure was left in place). In addition, all individual measures for the Medium Office prototype were also simulated with the 2018 WSEC (baseline) at 0.40 W/sf to understand the impact of lower internal heat gains on individual measure savings (included in detailed results in Appendix C). Table 11 shows the 2030 EUIs with two plug load intensities: 0.26 W/sf and 0.40 W/sf. The higher plug load level results in a small increase in the EUI and reduction in savings, though the 2030 package still meets the 70% target in all climate zones and for both system types.

TABLE 11: MEDIUM OFFICE AND LARGE OFFICE 2030 WSEC PACKAGE RESULTS AT TWO PLUG LOAD REDUCTION LEVELS

			4C				5B			
Prototype	Code Edition	Case	Plug Load 0.26 W/sf, EUI, kBtu/sf	% EUI Savings	Plug Load 0.40 W/sf, EUI, kBtu/sf	% EUI Savings	Plug Load 0.26 W/sf, EUI, kBtu/sf	% EUI Savings	Plug Load 0.40 W/sf, EUI, kBtu/sf	% EUI Savings
Large Office	2030	WSHP	11.37	82%	12.42	81%	12.21	82%	13.12	81%
	2030	Radiant Floor	10.87	83%	12.08	81%	11.42	83%	12.49	81%
Medium Office	2030	WSHP	9.35	78%	10.24	76%	10.77	77%	11.54	76%
	2030	Radiant Floor	8.33	80%	9.33	78%	9.28	80%	10.16	78%

3.4.1.2 2030 End-use Distribution

Figure 3 and Figure 4 show the end-use distribution for climate zones 4C and 5B, respectively, for the three WSEC editions. For the 2018 and 2030 cases, only the HP-based systems are shown. The end-use distribution is similar for gas furnace-based systems and for VRF and radiant floor systems. Significant reductions are achieved in all end-uses, and in particular, those that occupied a higher proportion of the total in the 2018 WSEC edition.

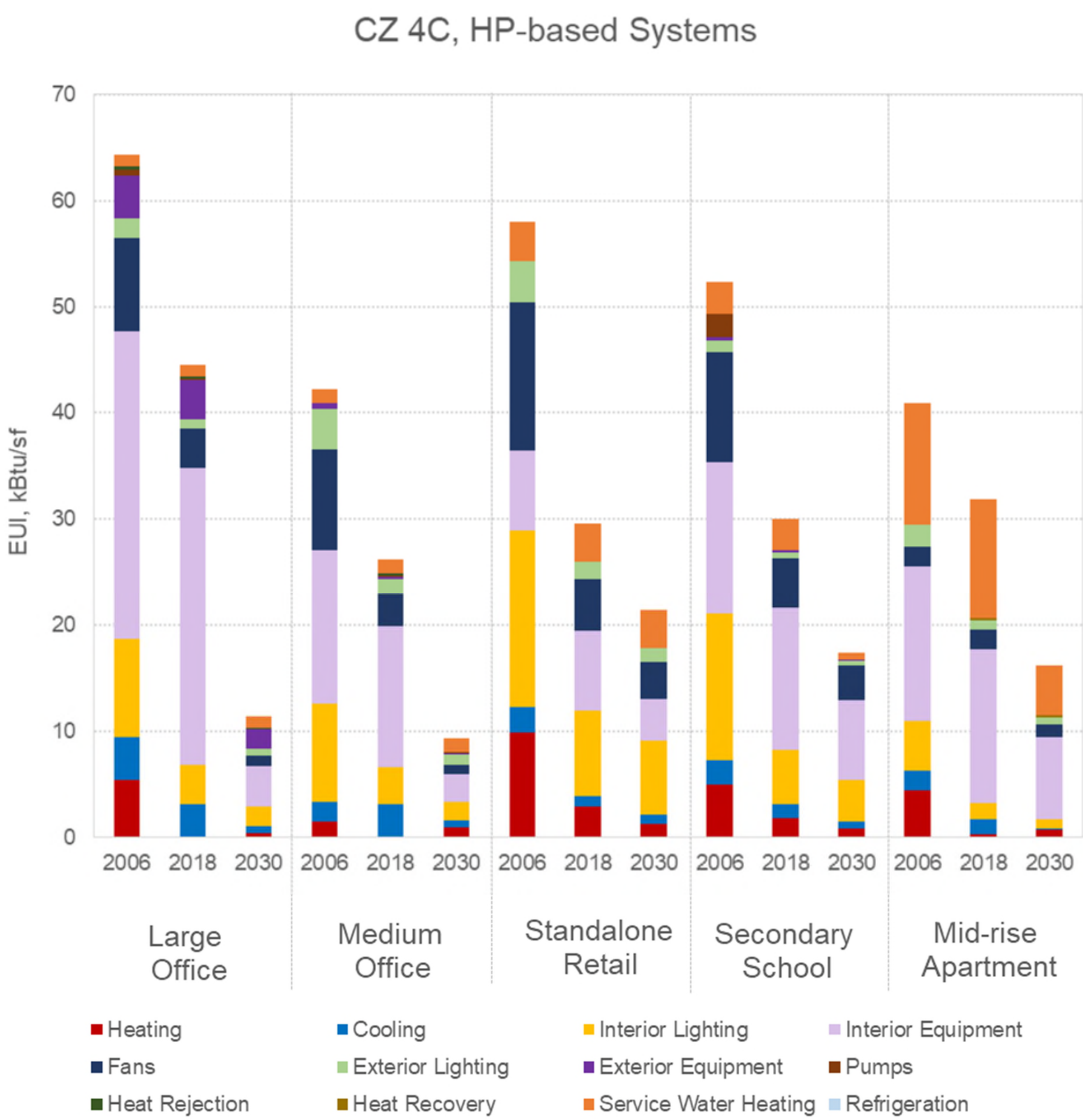

FIGURE 3: 2006, 2018, AND 2030 END-USE DISTRIBUTION FOR CLIMATE ZONE 4C

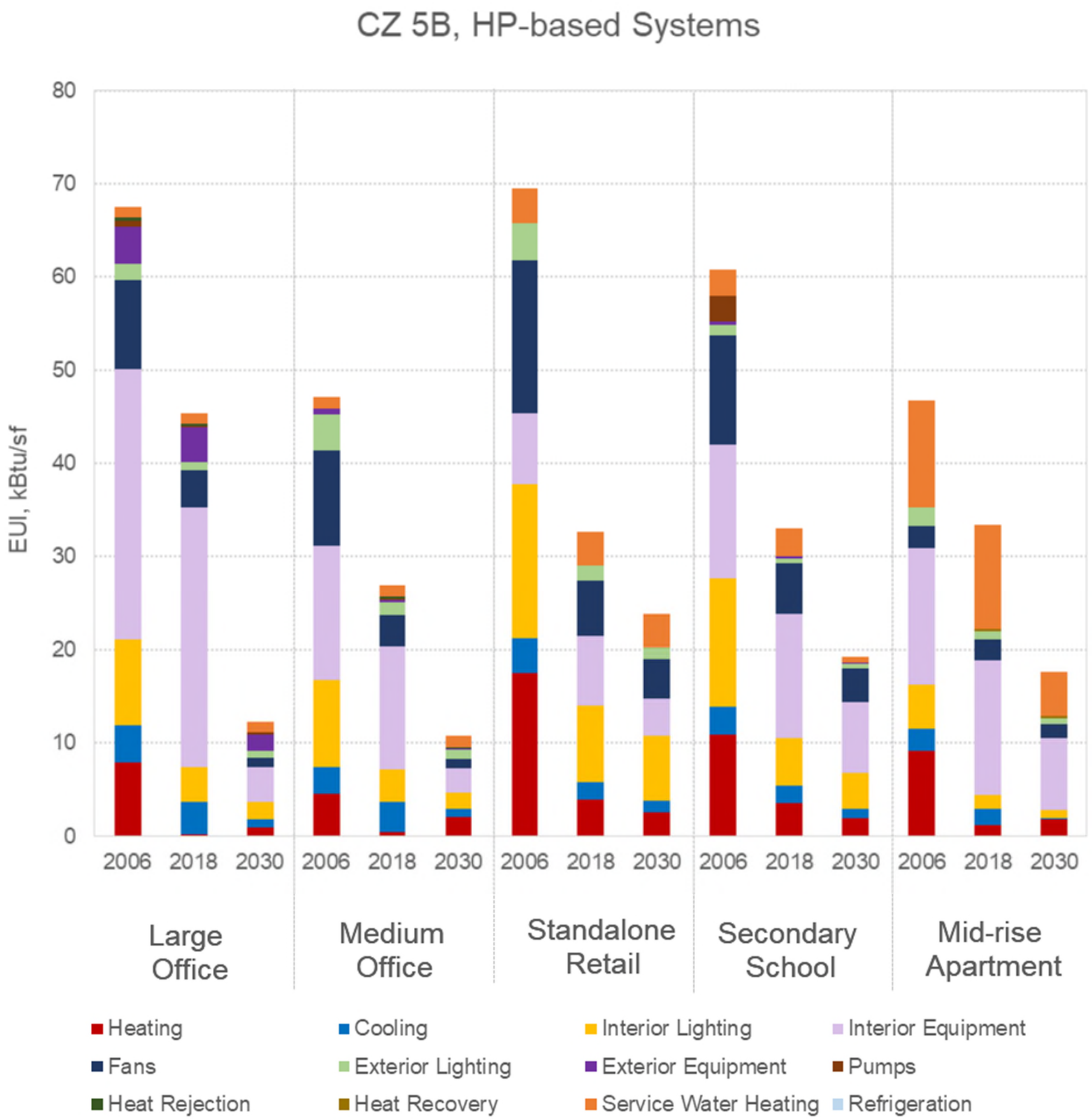

FIGURE 4: 2006, 2018, AND 2030 END-USE DISTRIBUTION FOR CLIMATE ZONE 5B

3.4.1.3 High-Efficiency Data Center

Figure 5 shows the impact of the Large Office data center measure, which reduces the IT load by 90%. The middle bar in Figure 5 shows that 55% whole-building-EUI savings are being achieved versus 2006 WSEC with all measures, including the plug load measure, but excluding the data center IT load measure. The Large Office EUI target for 2030 was 19.28 kBtu/sf in climate zone 4C and 20.24 kBtu/sf in climate zone 5B (section 0). The data center IT consumption itself is 17.77 kBtu/sf. Without a meaningful reduction in the IT load, it would not be possible to meet the 2030 target. A few other options for characterizing the data center category and consumption are discussed in section 4.3.1.

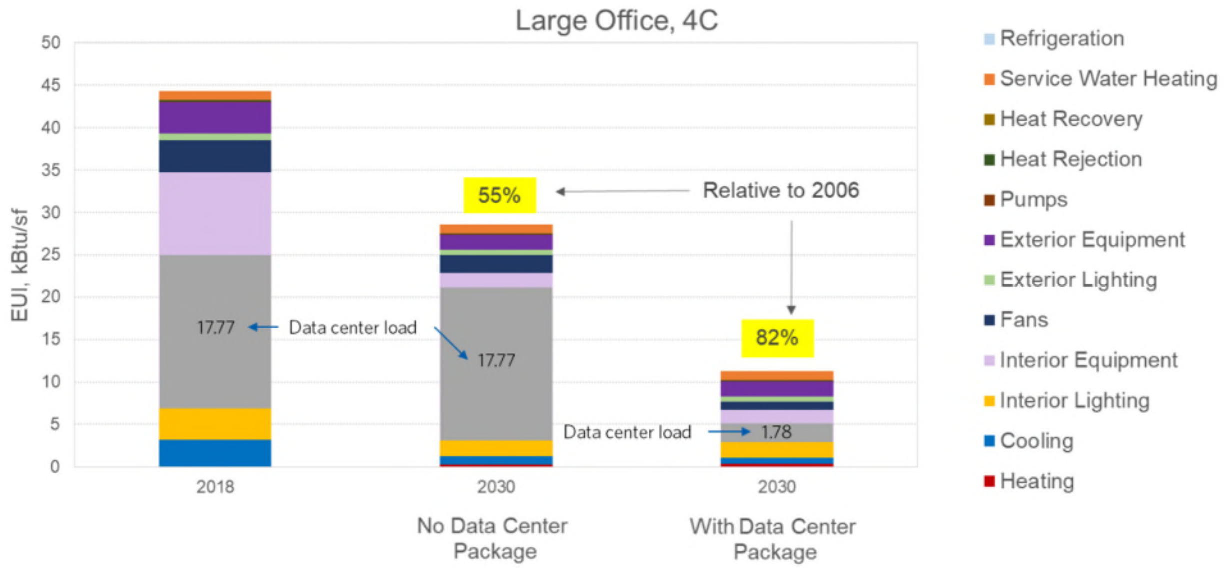

FIGURE 5: LARGE OFFICE DATA CENTER MEASURE RESULTS

3.4.1.4 Impact of PPLs on Envelope Measures

Table 12 shows the impact of internal gains on the savings from envelope measures. Three measures, lower window U-factor, higher wall and roof insulation, and reduced infiltration, increase the energy consumption of the Medium Office prototype. This is because there is so much internal gain that adding impedance to heat flow out of the building results in higher cooling and no gain in heating, which is almost zero in the base 2018 WSEC model. The infiltration measure appears to be providing free cooling in the mild climate zone 4C.

Comparing the last two rows of Table 12, it can be seen that all envelope measures in combination with the PPL measure results in higher savings than when the envelope measures with negative savings are excluded from the package. The reason is that with reduced internal gain from the PPL measure, the envelope measures that on their own resulted in higher consumption, now provide benefit.

TABLE 12: IMPACT OF PPL ON ENVELOPE MEASURES IN MEDIUM OFFICE PROTOTYPE IN CLIMATE ZONE 4C

Measure/Package	Measures Excluded	% Savings v 2018
LowWindowU		-2.7%
UltraWallRoofR		-1.1%
Infiltr		-0.4%
LowSHGCHighLSG		3.1%
ENV+PPL Package—not including negative savings measures	LowWindowU, UltraWallRoofR, Infiltr	36%
ENV+PPL Package—all ENV measures	None	46%

The conclusion is that envelope measures must not be discounted in future code cycles because their impact is closely tied to the internal gain assumptions in the prototype models. Real buildings may have a range of internal gains and with efforts to reduce PPLs and other internal gains (e.g. lighting) in future code cycles, the envelope measures become more important. Another reason to not discount envelope measures is that if a building includes an economizer, the effect of more insulation resulting in higher cooling energy will be reduced.

4.0 Roadmap to 2030

This section builds upon the results and findings and provides the major steps towards achieving the 2030 goal. It describes the actions needed to incorporate the selected measures into future WSEC editions, details a PPL strategy, and provides other actions that may be useful in improving the code development process.

4.1 Measure Actions

Table 13 provides an overview of the short-, medium-, and long-term actions for each measure. Except for the ultra-high R/inch wall and roof insulation material measure and the 2030 lighting power density (LPD) measure, all measures are technically mature today. Some of them will require market transformation to improve penetration; others may need to be phased into the code over two or three code cycles; some measures may need both. A description of the set of actions to be taken for each measure is provided below.

Ultra-high R/inch Insulation: Research related to ultra-high R/inch materials must be tracked because it is an emerging technology. Demonstration projects may be needed in Washington State. This is a long-term measure, and as it is with emerging technologies, it may never make it to large-scale market adoption. However, results, especially with lower PPLs, show that an improved envelope results in less energy use, and so, where cost-effective, higher levels of insulation should be pursued in the next few code cycles.

Thermal Bridging: The 2018 WSEC currently requires higher R-values for metal penetrations of continuous insulation above a certain cross-sectional area. However, no such requirement exists for the U-factor path. Addendum AV (in progress) to ASHRAE Standard 90.1-2019 (ASHRAE 2019), which enacts detailed thermal bridging requirements, could serve as a blueprint for enacting a thermal bridging requirement in the WSEC. A phased approach is recommended, where designers and architects are allowed to first get familiar with thermal bridging calculations in one code cycle, before mitigation strategies are required in the next code cycle.

Low Infiltration: The 2018 WSEC already has one of the lowest infiltration rate requirements in the US. It is possible to lower the infiltration rate further as has been demonstrated by the U.S. Army Corps of Engineers and buildings meeting the Passive House standard. This measure becomes more important in those buildings where internal gains are low. A phased

TABLE 13: SHORT-, MEDIUM-, AND LONG-TERM ACTIONS FOR EACH 2030 WSEC MEASURE

Building Component	Measure Short Name	Measure Specification	Short Term	Medium Term	Long Term
Building Envelope	UltraWallRoofR	Use ultra-high R/inch (R12/inch) materials. Double the R-value for the same depth of insulation.	Enable technical maturity	Market transformation	Code implementation
	ThermalBridging	Use highest-performance assemblies from the BCHydro Thermal Bridging Guide.	Code implementation	Code implementation	
	Infiltr	Reduced infiltration, 0.10 cfm/sf.	Code implementation	Code implementation	
	LowSHGCHighLSG	High LSG windows. SHGC = 0.20, VT/SHGC = 2.5.	Code implementation	Code implementation	
	LowWindowU	Triple-glazed or skinny triple windows, U = 0.20.	Code implementation	Code implementation	
	FenOrient	Based on Standard 90.1-2019, Aw and Ae <= At/4.	Code implementation		
Daylighting	OptDaylighting	Based on AEDG. Improved geometry and daylighting design for offices and schools.	Market transformation	Code implementation	
	DayltgInpPwr	Daylighting control by fixture. See LLLC measure below. More area controlled by DL sensors.	Code implementation		
Lighting	OccSensor	Occupancy sensors in all spaces.	Code implementation		
	OccSensor	LLLC: Increased occupancy sensor and DL savings. Merge with occupancy sensors measure.	Code implementation	Code implementation	
	LPD2030	Based upon DOE's Lighting Technology Roadmap and projected future improvements in efficacy of LED sources.	Code implementation	Code implementation	Code implementation
	LPD2030Task	ASHRAE Standard RP-1651 spec. Approximately 50% reduction in general lighting power.	Market transformation	Code implementation	
	ExtLPD2030	Based upon DOE's Lighting Technology Roadmap and projected future improvements in efficacy of LED sources.	Code implementation	Code implementation	Code implementation
HVAC	DCV1000	Apply DCV to all spaces.	Code implementation	Code implementation	
	FanStatic	NEEA VHE DOAS specification for DOAS fans. Space conditioning fan static based upon engineering judgment.	Code implementation	Code implementation	
	High-DXCOP	15% improvement over 2018 WSEC requirements.	Market transformation	Code implementation	Code implementation
	ERVEff	Increase ERV effectiveness to 82%, per NEEA VHE DOAS specification.	Market transformation	Code implementation	

Building Component	Measure Short Name	Measure Specification	Short Term	Medium Term	Long Term
	RadFlr	Apply radiant floor system based on 50% Small to Medium Office AEDG.	Market transformation	Code implementation	Code implementation
	VRF	Apply VRF with refrigerant heat recovery system to Mid-rise Apartment. Use CBECC-Com specification.	Market transformation	Code implementation	Code implementation
	ChilledBeam	Apply chilled beam system for Secondary School with a high-efficiency chiller and boiler.	Market transformation	Code implementation	Code implementation
	TowerEff	80 gpm/hp.	Code implementation	Code implementation	
Water Heating	HPWH	NEEA specification for HPWH.	Market transformation	Code implementation	
Plug and Process Loads	EffPlugLoad	ENERGY STAR equipment, reduction based on future projected efficiency improvements in MELs.	Market transformation	Code implementation	Code implementation
	NetworkCPU	Night-time turn off of nearly all plug load.	Code implementation	Code implementation	
	TracElev	Next generation traction type with regenerative drive.	Market transformation	Code implementation	
	HighEffDTC	High-efficiency data center servers for Large Office. Load reduction by 90%.	Code implementation		
	HighEffKitchen	High-efficiency kitchen equipment for Secondary School based on 50% AEDG for Restaurants. High-efficiency kitchen exhaust fans.	Code implementation		

approach, where the allowed maximum infiltration rate is reduced over two or three code cycles would allow construction quality to improve over time.

High Light to Solar Gain (LSG) Ratio Windows: High LSG windows are available in the market today and this measure is ready to be implemented in the next code cycle. SHGC reduction below current code level generates significant savings and is likely to be cost-effective, particularly on the east- and west-facing orientations. Reducing fenestration heat gain should be a high priority item in the upcoming code cycles.

Low Window U-factor: The current code requirement of U-0.30 is already quite low, but further improvements do result in savings, especially in buildings with lower internal gains. The technology for U-factors below 0.30 exists but tends to be expensive. Market transformation for skinny triple and regular triple-glazed windows is needed to improve market penetration and lower costs.

Fenestration Orientation: Previous analysis for ASHRAE Standard 90.1 (ASHRAE 2019) has shown savings for climate zones 4C and 5B by limiting the amount of fenestration heat gain through the east and west façade. This measure is ready for code implementation in the next code cycle.

Daylighting Controls: Daylighting controls that dim to off and LED luminaires with controls that dim down to 10 percent of input power are available in the market today and this measure is ready to be implemented in the next code cycle.

Occupancy Sensors and LLLC: This measure combines the measure requiring occupancy sensors in all spaces (where possible) with the LLLC measure. C405.2 in the 2018 WSEC specifies control requirements when LLLC are used. The next few code cycles should incorporate LLLC as the primary path and add more requirements when not using LLLC to offset the difference. The lighting system performance method (annual kWh method), if incorporated, should include LLLC and occupancy sensors, where possible, as the primary pathway to set the budget.

Lower Lighting Power: This measure is always included in each code development cycle. LED efficacies are expected to continue increasing, with improvements in package efficacy, thermal and optical performance, and color. Both interior and exterior LED fixtures are expected to have efficiency gains in the next decade and the energy code should track those changes.

Shift to Task Lighting: This measure should be incorporated in phases, with an initial incentive to shift to task lighting that would fade away in subsequent cycles. The first phase could be the addition of an optional efficiency package (C406). The newest CBSA (NEEA 2020) may shed light on the degree to which this design approach is being used in buildings. Together with LLLC, this measure can result in large lighting energy savings.

Demand Controlled Ventilation (DCV) in All Spaces: DCV is an established technology for reducing ventilation loads and fan power during off-peak periods. Spaces with variable occupancy can use CO_2 sensors, with a high limit of 1,000 parts per million (ppm) corresponding to the minimum required ventilation rate. Spaces with intermittent occupancy can use occupancy sensors to turn down the ventilation to the minimum when unoccupied. Newer, dedicated outside air systems (DOAS) should be configured to use variable-speed drives for variable air volume control. The current limit of 25 people per 1,000 square feet (sf) should be reduced to 10 people per 1,000 sf.

Lower Fan Static: While fan static pressure is design-dependent, the static pressure can be lowered with good design practice to a pressure drop of 0.08 inches water column (w.c.) per 100 feet of duct through higher fan efficiency and by paying careful attention to minimize duct transitions. For most buildings, total fan static can be minimized by avoiding the use of any return fans, and specifying powered exhaust fans that run intermittently. The lower fan static requirement could be incorporated into TSPR.

Improved Peak and Part-load Performance: Best in class DX systems, air-source or water-source, have marginal full load efficiency improvements over federal minimums, but dramatic part-load efficiency improvements. The part-load efficiency of the highest performance DX systems can have 50% to 75% improvement in cooling efficiency. These improvements could be incorporated into the TSPR metric, and where allowed by federal standards, be required in the prescriptive section of the code.

ERV Efficiency: While the 82% effectiveness is specified in NEEA's VHE DOAS specification (NEEA 2020), it may need to have improved market penetration before becoming a code minimum requirement. It could be incorporated into TSPR standard designs.

Cooling Tower Efficiency: Cooling tower efficiency improvements were based on California Title 24 codes and standards enhancement (CASE) studies for the 2019 code update (Gracik, Dehghani and Brannon 2017). A tower efficiency of 80 gpm/hp was generally cost-effective, especially for buildings with a water-side economizer that results in a higher number hours of tower operation. This measure is ready for the next code cycle.

Radiant Floor System: The radiant floor system is a high-performance alternative system for the secondary school prototype. It uses radiant panels for heating and cooling, and a dedicated outside air system for ventilation. The savings come from eliminating the fan energy associated with a zonal system and relaxed dry bulb temperature setpoints (equivalent to operative temperature achieved by air systems). Also, the chilled water supply temperature can be much higher than that of a central plant system, leading to higher energy efficiency on the cooling side. This measure may be appropriate for the optional efficiency package (C406 in 2018 WSEC) or as a standard design system in TSPR.

Variable Refrigerant Flow (VRF) System: The VRF system is a high-performance alternative system often installed in multifamily apartment buildings and small commercial buildings. Similar to the radiant floor system, it could be provided as an optional efficiency package (C406 in 2018 WSEC) or be used as the standard design system for multifamily buildings in TSPR.

Chilled Beam System: The chilled beam system is a high-performance alternative system, applicable for a variety of building types, including schools and offices. It uses chilled beams for heating and cooling and a dedicated outside air system for ventilation. Similar to the radiant floor system, it could be provided as an optional efficiency package (C406 in 2018 WSEC) or be used as the standard design system for school buildings in TSPR.

Heat Pump Water Heaters (HPWH): The optional efficiency package path, C406, in the 2018 WSEC already includes a HPWH option. High-efficiency heat pump water heaters are available on the market today. Currently, they represent less than 10% of the water heater market in Washington, primarily driven by new construction (Cadeo 2018). An obstacle limiting market adoption is the practice of not itemizing equipment and installation costs in bids. Therefore, some amount of market transformation may need to take place before HPWH becomes the main pathway in the code. A related effort may be needed to translate HPWH specifications into modeling guidelines, including the development of performance curves for HPWHs.

Reduce Plug Loads: An optional ENERGY STAR package could be added to Section C406, Efficiency Packages, similar to the commercial kitchen equipment package (C406.12). Additionally, a PPL budget should be established, together with a separate off-hour budget. A phased approach would first lower the sub-metering requirement to buildings 25,000 square feet (sf) or larger, followed by the benchmarking of on- and off-hour PPL usage, and finally a regulation aimed at capping the maximum PPL usage.

Off-hour Plug Load Controls: Multiple technologies are available to turn off computers at night. A plan that centralizes the operation of PPLs in each building must be required by code. Off-hour usage should be monitored, benchmarked, and regulated. The savings from the receptacle control measure should also be studied.

Traction Elevators: Most manufacturers now produce traction elevators even for two or three story buildings. While regenerative drives are a premium offering, they could become the norm through market transformation. The code should encourage the use of regenerative drives and smart dispatch algorithms that reduce elevator travel times.

High-efficiency Data Center: If the energy code is to regulate IT efficiency, the data center industry should be involved in the process of determining the requirements. The current requirements in the 2018 WSEC focus on the mechanical systems (data center MLC). Optimization of mechanical systems is possible through a number of measures related to how servers are situated in the space and how they are operated. The code must focus on efficient removal of heat through optimized layout of servers, even as the server performance per watt improves at an exponential rate. Modern CPUs are also able to operate at significantly higher temperatures, and basing MLC requirements on a higher thermostat setpoint (27°C) could be a code measure in the near term.

High-Efficiency Kitchen Cooking Equipment: This measure specifies ENERGY STAR equipment and high-efficiency exhaust hoods (Zhang, et al. 2010). One of the sections in the optional efficiency package section (C406) is enhanced commercial kitchen equipment. Thus, this measure is already part of the energy code as an option. Similar to the 'Reduce Plug Load' measure, a cooking equipment energy usage budget could be established.

4.2 PPL Strategy

PPLs are within the scope of energy codes and have been for a few code cycles, however, there are only a handful of requirements related to PPLs in the code. The results of the analysis show that PPLs will play a significant role in achieving the 70% reduction target. There are several avenues to regulate PPLs further: directly through the code, through appliance standards, or by setting PPL budgets in the code. ENERGY STAR requirements and regulation through appliance standards are already well-established pathways in other codes and standards, and indeed, one of the options in the optional efficiency path in the 2018 WSEC (C406) is ENERGY STAR commercial kitchen equipment. The strategy to achieve a 70% site energy reduction by 2030 must include an approach to tackle PPLs.

Following existing performance budget approaches in the 2018 WSEC, such as TSPR, a PPL budget should be set for each building, and for buildings that exceed the allotment, the remainder would need to be covered using renewable sources. The PPL budget should be based on building type and on certain building features (existence of a commercial kitchen, for example). Commissioning requirements already include a check for receptacle control and metering requirements, and additional checks should be added for the night-time turn off controls. Finally, the PPL budget and verification requirements must be part of existing building benchmarking and improvement laws, such as HB1257[4]. The buildings would then be evaluated and continuously commissioned every year through building benchmarking laws.

The metering requirement threshold, currently set to buildings larger than 50,000 sf (C409.1 in 2018 WSEC), should be lowered to 25,000 sf (aligned with ASHRAE Standard 90.1-2019), which is considered to be the threshold where building control automation systems are installed.

Lastly, plug load assumptions in the prototypes should be revised based on the newest CBSA (NEEA 2020). The PPL assumptions play a very important role, as can be seen through the impact on envelope-related measures. Perhaps, measure evaluations must include a range of scenarios for PPLs, thereby capturing the variation that may be seen in real buildings or in the future. Envelope measures that target the heating load show negative savings in many instances, but they must not be discounted because assumptions about internal gains drive the results for envelope measures. The envelope is the longest lasting component of the building, and if PPL and lighting power reductions are realized in the future, the importance of the envelope will be elevated.

4.3 Other Code Development Actions

The recommendations in this section focus on the code development process.

4.3.1 Data Center in Large Office Prototype

It may be worth considering either:

- removing the data center from the Large Office prototype and developing one or two data center-specific prototype buildings, or,
- expanding the level of detail in the Large Office prototype related to server and cabinet layout, and other IT parameters, such as server utilization, the amount of data storage, and the UPS load.

There is a trend towards consolidating data centers from buildings, such as large offices, into consolidated data center facilities (Shehabi, et al. 2016). Most IT needs in office buildings will be

[4] The Washington Department of Commerce is currently engaged in drafting a standard to enforce HB1257: https://www.commerce.wa.gov/growing-the-economy/energy/buildings/

served with IT closets with possibly more intensive network loads. The newest CBSA (NEEA 2020) will provide more information on this trend in the Pacific Northwest. It may be worth considering removing the data center from the Large Office prototype based on these trends.

The second option of expanding the level of detail in the current prototype model will enable the capturing of IT- and HVAC-related energy saving features for data centers. Most new data centers rely on hot aisle-cold aisle space layout to improve the efficiency of heat removal. Liquid-cooled systems, where the CPU heat sink to air interface is replaced by heat sink to liquid coolant interface (Capozzoli and Primiceri 2015), is also a strategy used by some data centers. Server utilization, and storage and UPS efficiency improvements could also be modeled separately.

Finally, the data center space and IT closet space intensity in the Large Office model should be revisited because the performance/watt of today's servers is exponentially higher than in 2013, when the assumptions were put in place. Intensities as high as 1,100 W/sf are possible today, whereas the prototype assumes 45 W/sf. Literature indicates that the intensity metric itself may need to change to a watts per cabinet metric to better align with how data centers are designed (Rasmussen 2020).

4.3.2 WSHP in TSPR

The WSHP system represents the TSPR standard design for large and medium office buildings (> 50,000 sf) (Table D602.11 in 2018 WSEC). In the quantitative analysis of 2006 and 2018 WSEC (section 0), the cooling consumption in the Medium Office prototype increased from 2006 to 2018. The 2006 model used packaged air-source DX as the cooling source, whereas the 2018 model used the water-source HP system specified by TSPR. This cooling increase is not seen in the Large Office, which uses the same WSHP system as the Medium Office in 2018, but uses a built-up VAV system with a chiller in 2006. Therefore, it appears that there is a problem when comparing the WSHP model to the air-source DX model in EnergyPlus. This should be investigated further because this comparison between air-source DX and the WSHP is likely to occur frequently in the TSPR tool.

4.3.3 Improved Evaluation of Plug Loads

The 2030 results (section 3.4.1) show that PPLs have a significant impact on not only the total energy reduction possible, but also the savings from envelope measures, which can flip from negative savings (a penalty) to positive savings depending upon the amount of internal gains in the building. As a result, the TAG suggested using a plug load range to evaluate the impact in this analysis. A similar range or distribution should be used in the code development process, especially when evaluating envelope-related measures.

5.0 Conclusions and Future Work

The main objective of the technical Roadmap was to develop a set of measures to achieve 70% reduction in site energy consumption by the 2030 WSEC. Results presented in section 3.4.1 show that it is possible to get very close or even exceed the 70% site energy reduction target when PPLs not currently regulated by the energy code are brought under its purview. This conclusion is aligned with the existence of low-EUI, high-performance buildings that use an integrated design, close control of PPLs, and high-performance envelope, lighting, and HVAC systems.

The measures presented in this analysis could be employed to directly enact new or improved requirements in the code, or they could be used to lower the performance budgets by building type. Appendix B provides end-use results for each measure and measure packages, and Appendix C provides measure specifications. Together, the information in the two appendices could be used for code development in the next three to four code cycles. PPL energy consumption and measures to reduce PPLs will play a major role in whether the 70% site energy reduction target can be achieved.

5.1 Future Work

The following analysis could be part of the follow-up to supplement the current results:

1. **Cost Assessment:** A cost-effectiveness analysis of code measures could be conducted in future code cycles for the measures listed in this analysis.
2. **Incorporate 2020 CBSA Findings:** The latest CBSA (NEEA 2020) was published in May 2020. It would have data on PPLs, data centers, as well as the types of HVAC systems being installed in multifamily buildings. Incorporating these and other data into prototype models for Washington State will result in improved alignment with the building stock and result in more accurate energy savings results from the various measures considered in this analysis as well as in future code development efforts.
3. **Improve PPL Modeling:** There is very little detail on the type of equipment that makes up the plug load in Standalone Retail and the Secondary School models. A built-up model for plug loads (one where breakdown of individual equipment comprising the total load is documented) for those two prototypes would enable capturing of savings from future measures in a more accurate manner. The other improvement would come from modeling a range of PPLs and not a single value for each prototype. This would capture

the variation seen in the actual operation of buildings. Determining the range and composition of PPLs representing the range would support future code development efforts.

4. **Improve Data Center Model:** As stated in section 4.3.1, the data center in the Large Office prototype does not carry sufficient detail to apply energy saving features to either the IT load or the mechanical system. Improving this level of detail, or simply developing a new data center prototype is needed.
5. **Investigate WSHP EnergyPlus Model:** As explained in section 4.3.2, the WSHP model in EnergyPlus does not compare well with the air-source DX model for cooling consumption. This should be investigated further because WSHP is the TSPR standard design system for medium and large office buildings.
6. **Expand Analysis to Other Prototypes:** While the four building types investigated in this analysis (Office, Retail, K-12 School, and Multifamily) occupy a large percentage of new construction floor area, the analysis could be expanded to other building types, such as hotels, healthcare, warehouse, and others, to evaluate the impact of building type-specific measures.

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Appendix A: Technology Matrix

https://neea.org/img/documents/WSEC-Technical-Roadmap-Appendix-A.xlsx

Appendix B: Detailed Energy Modeling Results

https://neea.org/img/documents/WSEC-Technical-Roadmap-Appendix-B.xlsx

Appendix C: Measure Specifications and Modeling Assumptions

Ultra-high R/inch Insulation: Oak Ridge National Laboratory (ORNL) has been conducting research into new materials and composites that deliver at least twice the current R-value per inch of insulation in a cost-effective manner (Biswas 2019). The New York State Energy and Research Development Authority (NYSERDA) conducted a demonstration project to verify the performance of insulated metal panels using modified atmosphere insulation (MAI), which is a form of vacuum insulated panel (Thompson 2016). The measured effective R/inch value was approximately R-11.1 per inch, which is 50% to 80% higher than what is available today (R-5.5 to R-6.0 per inch).

To model the measure, it was assumed that the wall and roof thickness would remain the same, but instead the R-value of the insulation layer would be doubled. The revised R-value was used as the input to the insulation layer in the model.

Thermal Bridging: To capture the impact of this measure, the wall U-factors for the 2006, 2018, and 2030 models were revised based on thermal bridging assumptions:

- 2006: unmitigated assemblies. No thermal bridging requirements exist.
- 2018: moderately mitigated assemblies. There are limits on amount of allowed metal penetrations of the continuous insulation in the R-value approach in 2018 WSEC (footnotes to Table C402.1.3), but there are no such requirements for the U-factor approach. It was assumed that there will be some impact from the requirements in the 2018 WSEC, and so, a moderate amount of mitigation was assumed (details below).
- 2030: highest performing assemblies from the BCHydro Thermal Bridging Guide (BC Hydro 2019) were used for the 2030 models.

Only three types of thermal bridges were assumed: roof to wall intersection, intermediate floor to wall intersection, vertical fenestration to wall intersection. In real buildings, there are likely to be many more thermal bridges in the wall assembly. Addendum AV (in development) to ASHRAE Standard 90.1-2019 is an addendum that adds thermal bridging requirements to Standard 90.1. It is in the process of publication as of the publication of this report. Default unmitigated (2006 WSEC) and mitigated (2018 WSEC) psi-factors from addendum AV are used. Highest-performing assembly psi-factors from the BC Hydro Guide (BC Hydro 2019) were used for the 2030 measure. Table 14 shows the U-factors resulting from clear-field (continuous insulation), thermal bridging only, and the combined assembly U-factor including thermal bridging. The ‘Adv’ category represents highest performing thermal bridging assemblies with 2018 insulation requirements. The ‘Adv-PKG’ category represents the 2030 package case with ultra-high R/inch insulation measure.

TABLE 14: WALL U-FACTORS AFTER INCORPORATING THERMAL BRIDGING

Prototype	Type	Climate Zone 4C			Climate Zone 5B		
		Clear field U-factor (code)	TB only U-factor	Total U-factor	Clear field U-factor (code)	TB only U-factor	Total U-factor
Medium Office	Unmtg (2006)	0.109	0.128	0.237	0.084	0.128	0.212
	Mtg (2018)	0.044	0.050	0.094	0.044	0.050	0.094
	Adv (2030)	0.044	0.013	0.057	0.044	0.013	0.057
	Adv-PKG (2030)	0.023	0.013	0.036	0.023	0.013	0.036
Large Office	Unmtg (2006)	0.150	0.132	0.282	0.150	0.132	0.282
	Mtg (2018)	0.088	0.074	0.162	0.088	0.074	0.162
	Adv (2030)	0.088	0.013	0.102	0.088	0.013	0.102
	Adv-PKG (2030)	0.048	0.013	0.061	0.048	0.013	0.061
Secondary School	Unmtg (2006)	0.109	0.112	0.221	0.084	0.112	0.196
	Mtg (2018)	0.047	0.043	0.090	0.047	0.043	0.090
	Adv (2030)	0.047	0.012	0.059	0.047	0.012	0.059
	Adv-PKG (2030)	0.025	0.012	0.037	0.025	0.012	0.037
Standalone Retail	Unmtg (2006)	0.150	0.033	0.183	0.150	0.033	0.183
	Mtg (2018)	0.104	0.010	0.114	0.104	0.010	0.114
	Adv (2030)	0.104	0.001	0.105	0.104	0.001	0.105
	Adv-PKG (2030)	0.057	0.001	0.058	0.057	0.001	0.058
Mid-rise Apartment	Unmtg (2006)	0.057	0.100	0.157	0.054	0.100	0.154
	Mtg (2018)	0.047	0.038	0.085	0.047	0.038	0.085
	Adv (2030)	0.047	0.010	0.056	0.047	0.010	0.056
	Adv-PKG (2030)	0.025	0.010	0.034	0.025	0.010	0.034

Heat flow through thermal bridges constitutes up to 70% of the total heat flow through the envelope in most buildings[5]. Unmitigated assembly U-factors calculated for this measure are approximately two times higher than the code U-factor. This results in significant degradation of the envelope performance. Therefore, this measure was implemented separately, i.e., its impact is evaluated separately from the other measures. A separate set of cases for 2006, 2018, and

[5] Personal correspondence with Morrison Hershfield staff who worked on the Building Envelope Thermal Bridging Guide.

2030 WSEC was created to evaluate the impact of thermal bridging, and other measures were analyzed relative to 2018 WSEC without thermal bridging.

Low Infiltration: The U.S. Army Corps of Engineers (USACE) established a 0.25 cfm/sf test requirement and have shown that they can achieve leakage rates lower than 0.10 cfm/sf[6]. Similarly, the Passive House Standard (PHUIS 2015) allows a maximum air infiltration rate of 0.05 cfm/sf. A conservative threshold of 0.10 cfm/sf was used in the measure, assuming that a slow progression from the current 0.25 cfm/sf to 0.10 cfm/sf could be achieved by the 2030 code cycle.

High LSG Windows: A target SHGC of 0.20 with an LSG of 2.5 was chosen for this measure. Low SHGC and high VT windows are a premium product, but there are no technology concerns with this measure. The measure is especially effective in high internal gain buildings.

Low Window U-factor: Skinny triple windows with a thin glass layer between a standard double-glazed windows shows promising performance with up to R-5 or R-7 a possibility (Selkowitz, Hart and Curcija 2018). These, together with standard triple-glazed windows available from multiple manufacturers, form the basis of the R-5 (U-0.20) specification for this measure.

Fenestration Orientation: ASHRAE Standard 90.1-2019 (ASHRAE 2019) puts limits on east- and west-facing fenestration heat gain, either by limiting the area or the fenestration SHGC. The requirements were applied to the prototypes for this measure. All the prototypes have default orientations that already meet the requirements in Standard 90.1-2019, and therefore, no changes were required to the models and this measure has no impact. However, real buildings will see an impact from this measure and therefore, this measure should be included in the WSEC.

Daylighting Controls: Daylighting controls that dim to OFF are given a lighting power credit in Title 24 2019, Part 6 (CEC 2018). Daylighting controls that dim LEDs down to 10 percent are currently being proposed for inclusion in the 2022 edition of Title 24, Part 6. This 2030 measure applies the OFF step as well as dimming capability down to 10% power. In addition, for the Medium and Large Office prototypes, the measure assumes the entire “daylight-able” area of the perimeter zone (80%) is daylit (Halverson, et al. 2014). This increased area under daylight control is a proxy for improved daylighting design through improved space layout, lightshelves, etc., a measure that was not explicitly modeled.

[6] Test data shared with the ASHRAE SSPC 90.1 Envelope Subcommittee.

Occupancy Sensors and LLLC: This measure combines the measure requiring occupancy sensors in all spaces (where possible) with the LLLC measure. Occupancy sensor savings were developed for each space type by using the control reduction factors from Table G3.7 in Appendix G of ASHRAE Standard 90.1-2019 and applying them to the occupied hour lighting schedule fractions. Footnote 'b' in Table G3.7 allows a multiplier of 1.25 when manual ON or partial ON control is required. An additional 59% savings are taken for those spaces with LLLC (Snyder 2018). For example, the enclosed office space has a 30% occupancy sensor savings from Table G3.7 in Appendix G of 90.1-2019 and a partial ON control. The lighting schedule multiplier would be calculated as follows:

Enclosed office occupied hours multiplier = 1 – (0.30 x 1.25).

This multiplier would be applied to occupied hours in the lighting schedule for enclosed offices. Occupancy sensor savings for 2018 WSEC requirements were calculated in a similar manner. LLLC savings were applied to the following spaces: computer room, open office, corridor, and libraries. Table 15 shows the occupancy sensor requirements and 2030 measure specifications and how they were applied to space types in the prototypes.

The 2018 WSEC requires the maximum LPD during scheduled unoccupied hours to not exceed 0.02 W/sf. This same level is applied for 2030, and given the LPD reductions in 2030, separate unoccupied hour multipliers are calculated for 2030 for general lighting and when general lighting is reduced by the shift to task lighting. Separate schedules were developed, if needed, for individual zones in the prototypes if they required occupancy sensors but others zones did not and when all the zones were sharing a single building lighting schedule. Table 16 shows the prototype zone to space mapping and the occupied and unoccupied lighting schedule multipliers for the 2006, 2018, and 2030 models. Additional calculations were made for the 2030 unoccupied multiplier when using the shift to task lighting measure.

TABLE 15: 2006 AND 2018 WSEC OCCUPANCY SENSOR REQUIREMENTS AND 2030 MEASURE SPECIFICATION

Space Type	Occupancy Sensor Savings During Occupied Hours[1], %	2006 WSEC	2018 WSEC		2030 WSEC		
		Auto OFF	Auto OFF or Partial OFF	Manual ON or Partial ON	Auto OFF or Partial OFF	Manual ON or Partial ON	LLLC Occ Sensor Savings Adder
Computer room, data center	35%	No	No	No	Yes	Yes	Yes
Office -- open office	15%	No	Yes	No	Yes	No	Yes
Office -- Lunch/Break room	15%	No	No	Yes	No	Yes	No
Conference/meeting rooms	33%	No	No	Yes	No	Yes	No
Office--enclosed < 250 sf	30%	Yes	Yes	Yes	Yes	Yes	No
Corridor—otherwise	25%	No	Yes	No	Yes	No	Yes
Classroom—otherwise	32%	No	No	Yes	No	Yes	No
Lobby—otherwise	25%	No	No	No	Yes	No	No
Restroom-otherwise	45%	No	Yes	Yes	Yes	Yes	No
Gym--in a playing area	35%	No	No	No	Yes	Yes	No
Audience--in an auditorium	10%	No	No	No	Yes	Yes	No
Food preparation	30%	No	No	No	Yes	Yes	No
Library--in a reading area	15%	No	No	No	Yes	No	No
Library--in the stacks	15%	No	No	No	Yes	No	Yes
Dining area--in a café	35%	No	No	No	Yes	No	No
Electrical/mechanical	30%	No	No	No	Yes	Yes	No
Storage	45%	No	Yes	Yes	Yes	Yes	No
Sales Area	15%	No	No	No	No	No	No

[1]Table G3.7 Appendix G, Standard 90.1-2019

TABLE 16: OCCUPIED AND UNOCCUPIED LIGHTING SCHEDULE MULTIPLIERS

Prototype	Zone	Space Type	2006 WSEC		2018 WSEC		2030 WSEC	
			Occ	Unocc	Occ	Unocc	Occ	Unocc
Large Office	All Datacenter zones	Computer room, data center	1.0000	1.0000	1.0000	0.4255	0.3560	0.5940
	All Other Zones	Office -- Building Area Category	0.9400	1.0000	0.7580	0.6250	0.7079	0.8677
Medium Office	All Zones	Office -- Building Area Category	0.9400	1.0000	0.7580	0.6250	0.7079	0.8677
Mid-rise Apartment	All Apartment Zones	None	NA	NA	NA	NA	NA	NA
	Office	Office--enclosed < 250 sf	0.7000	1.0000	0.6250	0.1684	0.6250	0.2327
	Corridor	Corridor--otherwise	1.0000	1.0000	0.8750	0.0488	0.7275	0.0651
Secondary School	Classrooms	Classroom--otherwise	1.0000	1.0000	0.9200	0.1589	0.9200	0.2203
	Corridor	Corridor--otherwise	1.0000	1.0000	0.8750	0.2751	0.7275	0.3804
	Lobby	Lobby--otherwise	1.0000	1.0000	1.0000	0.1343	0.7500	0.1855
	Bathrooms	Restroom-otherwise	1.0000	1.0000	0.4375	0.1791	0.4375	0.2439
	Office	Office -- Building Area Category	0.9400	1.0000	0.7580	0.1763	0.7079	0.2447
	Gym	Gym--in a playing area	1.0000	1.0000	1.0000	0.1327	0.7375	0.1806
	Auditorium	Audience--in an auditorium	1.0000	1.0000	1.0000	0.1849	0.8750	0.2521
	Kitchen	Food preparation	1.0000	1.0000	1.0000	0.1035	0.6250	0.1446
	Library/Media Center	Library--in a reading area	1.0000	1.0000	1.0000	0.1439	0.8500	0.1976
	Café	Dining area--in a café	1.0000	1.0000	1.0000	0.2820	0.8250	0.3864
	Mechanical Rooms	Electrical/mechanical	1.0000	1.0000	1.0000	0.2623	0.6250	0.3677
Standalone Retail	BACK_SPACE	Storage	1.0000	1.0000	0.5657	0.8130	0.5456	1.1239
	CORE_RETAIL	Sales Area	1.0000	1.0000	1.0000	0.3810	1.0000	0.5243
	POINT_OF_SALE	Sales Area	1.0000	1.0000	1.0000	0.3810	1.0000	0.5243
	FRONT_RETAIL	Sales Area	1.0000	1.0000	1.0000	0.3810	1.0000	0.5243
	FRONT_ENTRY	Corridor--otherwise	1.0000	1.0000	0.8750	0.9756	0.7275	1.3487

Lower Lighting Power: This measure description includes both interior and exterior LPDs. DOE's projections of future LED efficacy improvements (Yamada, et al. 2019) forms the basis of this measure. PNNL staff[7] provided guidance on how future efficacy projections could be converted to space LPDs. There are five major variables that have a significant impact on a space LPD in the context of energy codes:

[7] Email correspondence with Michael Myer, PNNL.

- Illuminance Level (fc): This is specified by the Illuminating Engineering Society (IES) Lighting Handbook. The assumption for this analysis is that illuminance targets for spaces remain constant between 2018 and 2030.
- Room Surface Dirt Depreciation (RSDD): It was assumed that this remains constant.
- Coefficient of Utilization (CU): This variable represents how much of the light leaving the fixture falls on the work plane. Presumably, the CU would vary in the future with new optics and fixture design and is likely to improve. But for the purpose of this analysis, it is assumed to remain constant.
- Lumen Depreciation: This variable indicates the reduction in light output over time, which again is assumed the same between now and 2030 but is likely to improve in the future.
- Fixture Efficacy: This parameter is varied between now and 2030 based on DOE projections.

Thus, the LPD in 2030 scales with fixture efficacy; all other variables are held constant. There is likely to be variation introduced by choosing different types of fixtures, even within a fixture category, when finalizing code requirements. For example, higher efficacy fixtures may be rejected because they do not meet the color requirements or because not all manufacturers are able to produce them.

Anecdotal evidence suggests that DOE underestimates efficacy improvements. Also, the DOE projections are average numbers for a given category. Therefore, it was deemed appropriate to use the DOE projections of fixture efficacy to calculate 2030 LPDs. The steps used to calculate the LPD are as follows:

1. Map fixture types from DOE's projections to prototype spaces.
2. Use 2030 DOE estimates from Table 17.
3. Use percent improvement in efficacy by fixture type to adjust LPD of the spaces.

Table 17 shows DOE's LED efficacy improvement projections from 2017 through 2035. Fixture categories from this table were mapped to the prototype spaces. The improvement from 2020 to 2030 formed one measure, whereas the improvement from 2020 to 2035 formed another measure. These two measures and their results were modeled separately (results in Appendix B). For the packages, the 2030 efficacy improvement was used.

Table 18 shows the LPDs for 2006, 2018, and the 2030 models. The LPDs for the task lighting measure are also shown and the calculation approach is provided in the measure description below. The Medium and Large Office prototypes have amorphous zones with no clear mapping to space types. An assumption was made regarding the mix of spaces in those: open office

(40%), enclosed office (20%), conference/meeting rooms (10%), lunch/break rooms (5%), corridor (10%), storage (10%), and restroom (5%).

TABLE 17: LED EFFICACY IMPROVEMENT PROJECTION 2017-2035 (YAMADA, ET AL. 2019)

Fixture Type	2017	2020	2025	2030	2035	Percent Improvement 2020-2030	Percent Improvement 2020-2035
General Purpose	93	105	122	136	147	30%	40%
Linear Fixture	96	109	126	140	152	28%	39%
Decorative	87	97	111	123	133	27%	37%
Downlight / Track - large	74	83	95	105	113	27%	36%
Downlight / Track – small	51	57	64	71	76	25%	33%
Low/High Bay	118	132	152	167	181	27%	37%
Area / Roadway	107	120	138	152	165	27%	38%
Parking Lot	107	120	138	152	165	27%	38%
Garage	103	114	129	141	151	24%	32%
Building Exterior	106	115	130	142	152	23%	32%

Shift to Task Lighting: This measure is based on the description provided in ASHRAE Research Project (RP) 1651 (Glazer 2016)**.** With a shift to task lighting, the main assumption is that desk illumination can almost fully be supplied through task lighting, allowing the general lighting system to provide substantially less light output. Glazer (2016) reviewed literature and found that general lighting can be reduced by more than half in most cases, with modest amounts of task lighting. For this measure, it was assumed that general lighting power would be reduced by half, and task lighting of 0.068 W/sf would be added. This measure was only applied to the computer room and office spaces.

DCV in All Spaces: DCV was specified in all spaces with a design occupancy of at least 10 people per 1,000 sf and a peak design occupancy of at least 10 persons. This measure is applicable to all zones in the two office prototypes and Standalone Retail (except the Front_Entry zone), and in all zones in Secondary School except those where DCV was previously required (classrooms, cafeteria, gymnasium, and auditorium).

Lower Fan Static: A reduction in fan static is proposed for all zonal heating and cooling systems as well as DOAS systems that provide ventilation. Fan static for zonal systems are based on the PNNL Technical Support Document for 50% Energy Savings for Small Office Buildings (Thornton, Wang and Huang, et al. 2010), and for the NEEA Specification for Very High Efficiency (VHE) DOAS Systems for Commercial Buildings (NEEA 2020) is used for DOAS systems. Table 19 shows the fan static pressure used in the 2030 WSEC models.

TABLE 18: 2006, 2018, AND 2030 WSEC LPD

Prototype	Zone	Space Type 1	2006 LPD	2018 LPD	2030 LPD, W/sf	2030 LPD with Task LTG, W/sf
Large Office	All Datacenter zones	Computer room, data center	1.00	0.94	0.67	0.41
	All Other Zones	Office -- Building Area Category	1.00	0.64	0.46	0.30
Medium Office	All Zones	Office -- Building Area Category	1.00	0.64	0.46	0.30
Mid-Rise Apartment	All Apartment Zones	None	NA	NA	NA	NA
	Office	Office--enclosed < 250 sf	1.00	0.66	0.48	NA
	Corridor	Corridor--otherwise	0.80	0.41	0.31	NA
Secondary School	Classrooms	Classroom--otherwise	1.20	0.71	0.51	NA
	Corridor	Corridor--otherwise	0.80	0.41	0.30	NA
	Lobby	Lobby--otherwise	1.20	0.84	0.61	NA
	Bathrooms	Restroom-otherwise	0.80	0.63	0.46	NA
	Office	Office -- Building Area Category	1.00	0.64	0.46	0.30
	Gym	Gym--in a playing area	1.00	0.85	0.62	NA
	Auditorium	Audience--in an auditorium	1.20	0.61	0.45	NA
	Kitchen	Food preparation	1.30	1.09	0.78	NA
	Library/Media Center	Library[1]	1.30	0.784	0.57	NA
	Café	Dining area--in a café	1.30	0.40	0.29	NA
	Mechanical Rooms	Electrical/mechanical	0.80	0.43	0.31	NA
Standalone Retail	BACK_SPACE	Storage[2]	0.70	0.49	0.36	NA
	CORE_RETAIL	Sales Area	1.50	1.05	0.76	NA
	POINT_OF_SALE	Sales Area	1.50	1.05	0.76	NA
	FRONT_RETAIL	Sales Area	1.50	1.05	0.76	NA
	FRONT_ENTRY	Corridor/Common spaces	0.80	0.41	0.30	NA

[1] Library stacks and reading area LPD weighted 60% and 40%, respectively.

[2] Storage and enclosed office LPD weighted 60% and 40%, respectively.

TABLE 19: FAN STATIC PRESSURE FOR 2030 MODELS

Fan	Fan Static Pressure, in. w.g.	Source	Prototypes Affected
WSHP Zonal Fans	1.25	Engineering judgment	Large Office, Medium Office
Packaged System Fans	1.74	50% Small Office AEDG TSD (Thornton, Wang and Huang, et al. 2010)	Standalone Retail, Secondary School, Mid-rise Apartment (split systems)
DOAS Fans	2.92	NEEA VHE DOAS Specification (NEEA 2020)	All prototypes

Improved Peak and Part-load Performance: Improved peak performance is based on the 15% improvement required in optional efficiency package, C406.2. The heat pump cooling and heating COPs are increased by 15% for 2030. Chiller COPs used in the radiant floor system and VRF COPs are increased by 15% also relative to 2018 WSEC requirements. Gas boilers (97%) and furnaces (93%) are assumed to be high-efficiency condensing units.

Part-load performance is based on a SEER-20 or IEER-20 equivalent part-load efficiency rating. To simulate improved part-load cooling efficiency, the performance curve data from an advanced Carrier unit with a part-load cooling efficiency rating, IEER 20, was used. While it may not be appropriate to base performance on a single model's performance data, there are at least two other manufacturers that meet this performance criteria. This part-load improvement would also result in a heating energy savings for HP systems, but performance data on the heating side of the HP was not in a usable format. Therefore, only the cooling energy improvements were modeled (the heating energy consumption is also very low for the prototype models).

ERV Efficiency: This measure requires a higher energy recovery efficiency for DOAS equipment of 82%, as specified by the NEEA VHE DOAS specification (NEEA 2020). The higher recovery efficiency can eliminate the need for supplemental heating or cooling.

Cooling Tower Efficiency: This measure specifies an increase in required cooling tower efficiency to 80 gpm/hp, for the Large and Medium Office prototypes, and is based on a measure developed for Title 24, Part 6, for the 2019 code edition (Gracik, Dehghani and Brannon 2017). The 80 gpm/hp compares to a tower efficiency of 38.2 gpm/hp in the 2018 WSEC.

Radiant Floor System: The radiant floor system is an alternative system for the Medium and Large Office prototypes. It consists of a central air-cooled chiller and hot water boiler delivering cool or warm water to the coils located in the floors of the zones. A dedicated outside air system delivers ventilation air to each zone. The system configuration was based on the 50% Medium Office AEDG specification (Thornton, Wang and Lane, et al. 2009).

VRF System: The VRF system is an alternative system applied to the Mid-rise Apartment prototype. It is modeled as one condenser serving several indoor units, with the condensing unit sized to account for some diversity. The system uses a good practice COP for heating (4.55) and cooling (4.89), and heat recovery between heating zones and cooling zones. Performance curves were developed for California's energy code compliance software (CBECC-Com) using performance data from multiple manufacturers (CBECC 2020). These curves were used for the VRF system and are available through CBECC-Com.

Chilled Beam System: A chilled beam system was specified as an alternative system for the Secondary School prototype. However, it was not modeled.

The system would include an air-cooled chiller and boiler, and passive chilled beams at each of the zones (or classrooms). The chilled beams use a moderate chilled water supply temperature, which allows for a much higher chilled water temperature than an air-based system. Dedicated outside air unit(s) would supply tempered ventilation air to the zones. The savings come from eliminating the fan energy associated with a zonal system. Also, the chilled water supply temperature can be much higher than that of a central plant system, leading to higher energy efficiency on the cooling side. A key difference of this type of radiant system is that it cannot remove latent loads from the space.

HPWH: A HPWH system is a high-performance alternative to the electric resistance storage water heaters in the Mid-rise Apartment and Secondary School prototypes. The HPWH measure incorporates the recommendations of the highest tier in the NEEA Advanced Water Heating Specification (NEEA 2019), Tier 5 efficiency and performance requirements. A COP of 3.5 is used. Section C406.9, which provides a HPWH option in the 2018 WSEC, requires a COP of 3.0.

In both the prototypes, the HPWH units are located inside the zone (one per dwelling unit in the Mid-rise Apartment), and they provide a mild cooling benefit, especially in the Mid-rise Apartment prototype. The cut-in, cut-out, and storage water heater setpoint (temperature at which backup heating turns on) are shown in Table 20. Default curves from the EnergyPlus heat pump water heater objects were used to simulate the part-load performance.

TABLE 20: HPWH WATER HEATING TEMPERATURE SETPOINTS

Prototype	Cut-out temperature, C (F)	Cut-in Temperature, C (F)	Storage Water Heater Setpoint, C (F)
Secondary School	65.0 (149)	64.9 (147)	60.0 (140)
Mid-rise Apartment	62.8 (145)	61.7 (143)	60.0 (140)

Reduce Plug Loads: For the Medium and Large Office prototypes, the plug load breakdown is available (Thornton, Wang and Lane, et al. 2009). This breakdown shows the power for individual equipment as well as the number of pieces of individual equipment that make up the total W/sf input in the 2006 and 2018 WSEC models. Table 21 shows the 2006, 2018, and 2030 plug load intensity (W/sf) for the Medium and Large Office prototypes. This measure was also applied to the office spaces in the other three prototypes.

For this measure, best-in-class ENERGY STAR equipment was used where available. For some equipment, it was difficult to translate ENERGY STAR ratings to peak power. However, it was found that in all instances, ENERGY STAR equipment today is more efficient than 10 years ago. Therefore, for equipment where a definite peak power could not be established through ENERGY STAR ratings, a 40% reduction was assumed over the 50% Medium Office AEDG assumptions (Thornton, Wang and Lane, et al. 2009). This reduction fraction is the same as that applied to the miscellaneous plug loads in the Standalone Retail and Secondary School prototypes (described below). These equipment, for which the 40% reduction was applied, are marked by footnote 1 in Table 21. It is also assumed that servers, which use the same W/unit as desktops, are no longer present in the building, and instead, that service is provided by other means external to the building (for example, the Cloud). The number of desktops were reduced from 134 to 50, and the number of laptops were increased by the same number to 218.

Given the impact of the plug loads on other measures, the TAG recommended a second level of 0.40 W/sf together with 0.26 W/sf to bound the impact of plug loads. Thus, for the Medium and Large Office prototypes, this measure is composed of two sub-measures using two different plug load intensities.

TABLE 21: PLUG LOAD CALCULATION FOR THE 2030 OFFICE PLUG LOAD REDUCTION

Plug Load Equipment Inventory	2006 and 2018 WSEC Models			2030 WSEC Models		
	Quantity	Plug load per unit (W/unit)	Plug load (W)	Quantity	Plug load per unit (W/unit)	Plug load (W)
Computers – servers	8	65	520	0	0	0
Computers – desktop	134	65	8,710	50	13.5	675
Computers – laptop	134	19	2,546	218	4.25	927
Monitors – server – LCD	8	35	280	0	0	0
Monitors – desktop – LCD	268	35	9,380	268	9.12	2,444
Laser printer – network[1]	8	215	1,720	8	108	864
Copy machine[1]	4	1,100	4,400	4	300	1,200
Fax machine[1]	8	35	280	0	0	0
Water cooler[1]	8	350	2,800	8	115.8	926
Refrigerator[1]	8	76	608	8	39	312
Vending machine[1]	4	770	3,080	4	462	1,848
Coffee maker	4	1,050	4,200	4	1,050	4,200
Portable HVAC (heaters, fans) [2]	30	30	900	0	0	0
Other small appliances, chargers[1]	250	4	1,000	250	2.4	600
Total plug load (W)			**40,424**			**13,996**
Plug load density, W/ft^2			**0.75**			**0.26**

[1] Assume 40% reduction in peak power.
[2] Assume that there are no portable heaters or fans in the office spaces.

For the Standalone Retail and Secondary School prototypes, an equipment breakdown was not available for the prototype models. The plug load input values in the prototype models could be traced back to the original DOE Reference Building Prototypes (Deru, et al. 2011). The 50% Retail AEDG (E. Bonnema, M. Leach and S. Pless, et al. 2013) recommends a 25% reduction in plug load and the 50% School AEDG (E. Bonnema, M. Leach and S. Pless, et al. 2013) recommends a 37.5% reduction in plug load. A literature search provides even lower reductions in Retail and School Buildings (HPB 2020). A 40% reduction is assumed for both the Standalone Retail and Secondary School prototypes, relative to the default prototype assumptions, which have been in place since at least 2011, if not earlier.

The Mid-rise Apartment prototype uses modified Building America assumptions (Hendron 2008). The Building America assumptions provide a breakdown of kWh usage for various appliances, including refrigerator, clothes washer, clothes dryer, dishwasher, and cooking range. Best-in-class ENERGY STAR appliances were used to replace the existing appliances. There is a category of miscellaneous electric loads (MELs), which was reduced by 50% based on the findings of Kwatra, Amann and Sachs (2013), which show that MELs typically found in residences could be reduced by 90% to 30%, depending upon the equipment. This estimate is based on data prior to 2013. The assumptions result in an overall plug load reduction of 37% in dwelling units of the Mid-rise Apartment prototype.

Off-hour Plug Load Controls: Multiple technologies are available to turn off computers at night. In addition, phantom loads occurring from appliances that are plugged in and drawing a minimal amount of power can be large. This measure aims to reduce off-hour plug load consumption. For the Medium and Large Office, plug load equipment breakdown is available, and therefore, individual schedules were developed for each piece of equipment and then a weighted hourly schedule was created based on the proportion of the peak power of each equipment. Table 22 shows the hourly schedule values for 2006 and 2018 WSEC models (first row after header row), and the 2030 weighted schedule (last row). The weighted schedule resulted in significant on-hour reduction as well as can be seen in Figure 6. Some amount of diversity has been added to the laptop and monitor schedule during on-hours assuming that some people will be away from their desks resulting in laptops and monitors switching into sleep or low-power mode.

For the Standalone Retail and Secondary School prototypes, a nominal amount of plug load, 5%, is assumed to be ON during off-hours (midnight to 5 am). Ramp up during morning hours and evening hours is added.

TABLE 22: HOURLY SCHEDULE VALUES FOR PLUG LOAD EQUIPMENT IN OFFICE SPACES

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2006 Sch	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.40	0.40	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.4
2018 Sch	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.38	0.38	0.85	0.85	0.85	0.85	0.75	0.85	0.85	0.85	0.85	0.48	0.38	0.38	0.38	0.38	0.38
Computers – servers	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Computers – desktop	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.4	0.8	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.6	0.4	0.1	0.1	0.1	0.1
Computers – laptop	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.4	0.1	0.1	0.1	0.1
Monitors – server – LCD	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.4	0.1	0.1	0.1	0.1
Monitors – desktop – LCD	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.4	0.1	0.1	0.1	0.1
Laser printer – network	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Copy machine	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0.05	0.05
Fax machine	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Water cooler	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Refrigerator	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Vending machine	0	0	0	0	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0	0
Coffee maker	0	0	0	0	0	0	0	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0	0	0	0	0	0	0	0
Portable HVAC (heaters, fans)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other small appliances, chargers	0.2	0.2	0.2	0.2	0.2	0.2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0.2	0.2	0.2	0.2
2030 Weighted SCH	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.17**	**0.40**	**0.50**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.47**	**0.38**	**0.38**	**0.32**	**0.26**	**0.13**	**0.13**	**0.13**	**0.13**

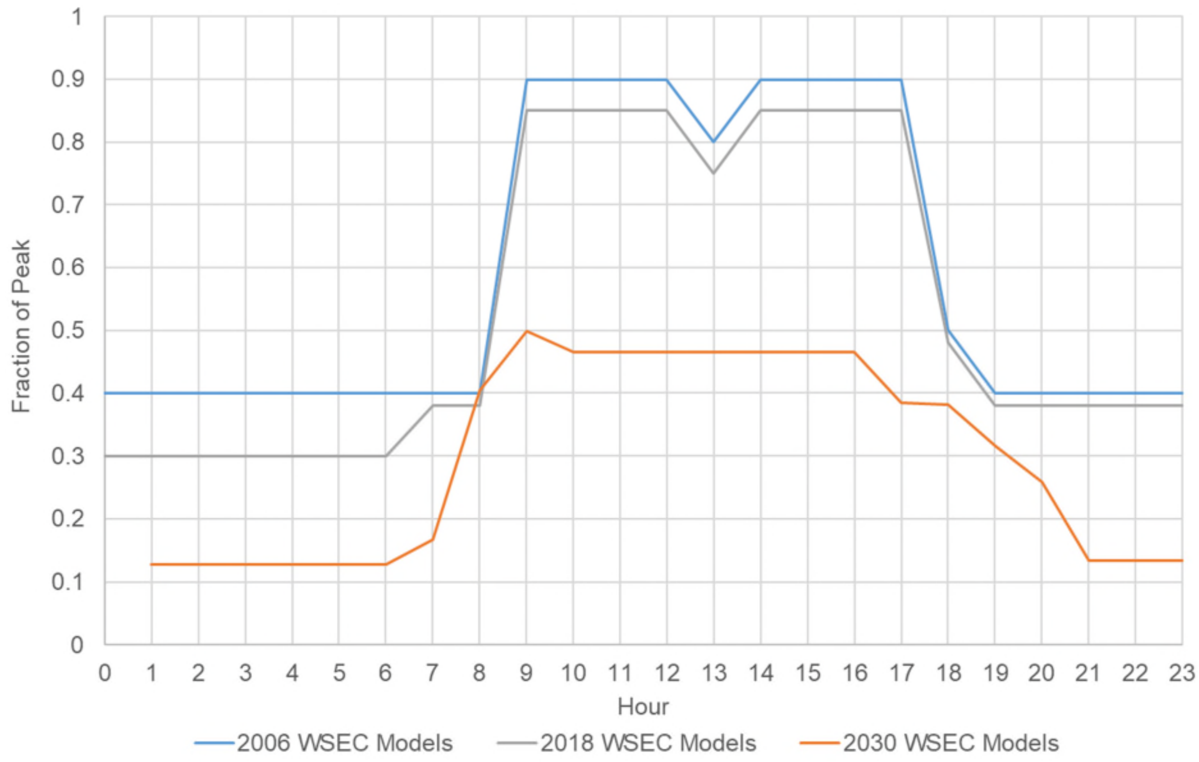

FIGURE 6: OFFICE PLUG LOAD SCHEDULE

Traction Elevators: Most manufacturers now produce traction elevators even for two- or three-story buildings. The savings percentage for gearless traction elevators with regenerative drive range from 75% to 30% depending upon the baseline condition. Table 23 shows the range of savings found across several sources.

TABLE 23: SAVINGS FROM REGENERATIVE DRIVE COMPARED TO STANDARD ELEVATORS

Source	Regenerative Drive Savings, %	Base Case
Otis Gen2 brochure	62%	Geared induction motor
Schindler brochure	40%	Geared traction
ACEEE 2005 (Sachs 2005)	30%	Geared traction
ACEEE 2015 (Sachs, et al. 2015)	40%	Average
Otis Gen2 brochure	75%	Hydraulic

Except the Large Office prototype, the other multistory prototypes use hydraulic elevators. For those prototypes, a 75% reduction in elevator peak power is applied assuming gearless traction elevators with regenerative drive. For the Large Office, a 50% reduction in peak power is applied, assuming lower savings from geared traction type to gearless traction type with regenerative drive.

High-efficiency Data Center: The increase in performance per watt from data centers has been exponential over the past decade (Pflueger 2010) (Giri and Vanchi 2010). For the purpose of this analysis, it is assumed that the amount of computing needed remains constant, and therefore, the amount of power used to perform the computations reduces exponentially over time. For the 2030 model, 1/10th of the power of the 2018 (and 2006) WSEC edition is assumed.

In reality, higher performance per watt has resulted in more servers being packed into the same amount of space. Data center intensities as high as 1,100 W/sf are not uncommon in 2020 (Hami 2018). There is also a trend towards centralization of data centers (Shehabi, et al. 2016). Thus, it may be appropriate to adjust the data center assumptions in the Large Office prototype by removing the data center altogether or adjusting its load to reflect a higher networking load carried by an IT closet. Further discussion on this topic is in section 4.3.1and 5.1 of this report.

ENERGY STAR has a host of recommendations for improving the data center IT consumption as well as the mechanical system consumption (ENERGY STAR 2020). However, without a fully defined layout of the servers, it was difficult to implement the recommended HVAC measures. One measure that was implemented is the use of higher dry bulb setpoint temperature because today's CPUs are capable of operating at higher temperatures. The cooling setpoint for the 2030 models was set to 27 C, as opposed to 21.1 C for the 2018 and 2006 models.

School High-Efficiency Kitchen Cooking Equipment: The Secondary School has a full commercial kitchen. However, a detailed breakdown of the equipment is not available, except for the reach-in freezer and reach-in refrigerator, which are separately modeled. For the reach-in freezer and refrigerator, the 50% Quick Service Restaurant (QSR) AEDG (Zhang, et al. 2010) was used to determine the percent reduction in peak power. For the miscellaneous loads, the 50% K-12 School AEDG (E. Bonnema, M. Leach and S. Pless, et al. 2013) was used to calculate aggregate equipment savings. The miscellaneous gas peak power is reduced by 20% and peak electric power is reduced by 15%. Table 24 shows the inputs for various kitchen equipment objects in the model.

TABLE 24: SECONDARY SCHOOL COOKING EQUIPMENT MODEL INPUTS

Model Input	Type of Load	2006 and 2018 WSEC, W	2030 WSEC, W	Percent Reduction, %	Source
Reach-in Freezer	Electric	915	499	45%	50% QSR AEDG TSD
Reach-in Refrigerator	Electric	570	290	49%	50% QSR AEDG TSD
Electric Misc.	Electric	47,995	40,796	15%	50% School AEDG TSD
Café Misc.	Electric	48,004	40,804	15%	50% School AEDG TSD
Gas Misc.	Gas	362,577	290,062	20%	50% School AEDG TSD

The 50% Quick Service Restaurant AEDG (Zhang, et al. 2010) also recommends a high-efficiency exhaust hood with an exhaust rate of 150 cfm/linear foot of exhaust hood, whereas the current model assumes an exhaust rate of 300 cfm/ft. This results in the kitchen exhaust flow rate to be reduced by half in the 2030 models.