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Preliminary Final Cost-Benefit Analysis of the 2021 WSEC Residential Provisions - Revised

Final Report

May 2023

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Prepared for
the Washington State Department of Enterprise Services

Pacific Northwest National Laboratory
Richland, Washington 99354

Executive Summary

This report is a revision to the *Final Cost-Benefit Analysis of the 2021 WSEC Residential Provisions Final Report February 2023.* The prior analysis and report were based on the energy credits in the 2021 WSEC-R Section R406 that were published on May 27, 2022. However, the energy credits table was later modified per the CR-103P published on January 3, 2023. The prior report thus did not account for the revised energy credits. This report presents revised energy savings and cost-effectiveness analyses that are amended to reflect the new R406 measures.

The state of Washington is updating their current state residential energy code. They will be moving from the 2018 Washington State Energy Code (2018 WSEC-R) to the 2021 WSEC-R. The Washington State Building Code Council (SBCC) requested that Pacific Northwest National Laboratory (PNNL) perform an independent analysis of the energy, economic, and emissions impacts of the code changes between the 2018 WSEC-R and 2021 WSEC-R. The objective was to review submitted data in the proposals, supplement and revise the economic impact analyses included in those proposals as needed, and review life-cycle cost analyses per state protocols or using alternative methods if necessary to provide improved and more accurate analysis.

PNNL reviewed the proposals listed in the following table as well as the R406 code language updates. The team analyzed a subset of these proposals and code changes using building energy simulation with Washington-specific inputs and following the Department of Energy (DOE) established methodology for cost-effectiveness.[1] Table ES-1 illustrates all proposals requested for analysis. For this report, proposals 1–8 were selected for the overall cost-effectiveness analysis by simulating the 2021 WSEC-R. However, proposals 4 and 8 were removed from the analysis because the SBCC voted to disapprove. PNNL reviewed proposals 9 through 16 in a qualitative analysis to provide feedback on the cost-benefit analyses provided by the proponents.

[1] https://www.energycodes.gov/methodology

Table ES-1. List of proposals for the 2021 WSEC-R analysis

Proposal	Section	Subject	Analysis
Proposal 1	R403.13, R405.2, R503.1.2	Heat Pump Space Heater	Simulation
Proposal 2	R403.5, R405.2, R503.1.3	Heat Pump Water Heater	Simulation
Proposal 1+2	R403.13, R405.2, R503.1.2, R403.5, R405.2, R503.1.3	Heat Pump Space Heating and Water Heating	Simulation
Proposal 3	R202, R401.1	Definitions Scope	Simulation
Proposal 4	Table R402.1.2	U-Factor Replacements	Disapproved by SBCC
Proposal 5	R405.3, R406, Chapter 6	Update Section R406	Simulation
Proposal 6	R403.5.1	Allowed Leakage Rates	Simulation
Proposal 7	R403.5.5	Water Heater Install Location	Simulation
Proposal 8	R403.3.2.1	Sealed Air Handler	Disapproved by SBCC
Proposal 9	R502	Additions	Review Only
Proposal 10	R402.4.1.2	Testing Agency Certification	Review Only
Proposal 11	R403.5.1	SWH Circulation System	Review Only
Proposal 12	Table 406.3	Energy Credit Options 3.1 & 3.2	Review Only
Proposal 13	Table 406.3 Option 3.2	HSPF of 9.5	Review Only
Proposal 14	Table 406.3 Option 3.5	HSPF of 11.0	Review Only
Proposal 15	Table 406.3 Option 3.6	HSPF of 10.0	Review Only
Proposal 16	R406 Option 3.2, 3.5	COP, HSPF	Review Only

The cost-effectiveness results for the 2021 WSEC-R compared to the 2018 WSEC-R are shown in Table ES-2 for various metrics. Details on the simulations that were used to determine the cost-effectiveness of each proposal in the 2021 WSEC-R can be found in the *Final Cost-Benefit Analysis of Select 2021 WSEC Residential Provisions*, which was submitted to the SBCC before this report.[1] When life-cycle cost savings are positive, a code change proposal or energy code is considered cost-effective. As shown in Table ES-2, when considering only market rate utility costs, the 2021 WSEC-R is cost-effective with $4,568 life-cycle cost savings over the 30-year analysis period. When the social cost of carbon (SCC) is also considered (as required by the state of Washington), the 2021 WSEC-R improves its cost-effectiveness with total life cycle cost savings of $5,927. The 2021 WSEC-R was found to increase electric energy consumption while eliminating fossil fuel consumption due to the code provisions requiring electric space heating and water heating.

[1] https://sbcc.wa.gov/sites/default/files/2023-01/PNNL_2021WashingtonResidentialEnergyCodeAnalysis.pdf

Table ES-2. Individual Consumer Impact of Combined Proposals for the 2021 WSEC-R

Metric	Compared to the 2018 WSEC-R
Annual (first year) energy cost savings ($)	$170
Life-cycle cost savings ($)	$4,568
SCC life-cycle cost savings ($)	$1,359
Total life-cycle cost ($)	$5,927
Added construction cost ($)	$471
First year carbon emissions savings (tons)	30.5
Simple payback period (yrs)	2.8
Annual electric savings (kWh)	–915
Annual gas savings (therms)	243
Annual fuel oil savings (gallons)	0.47

The 2021 WSEC-R will result in statewide societal benefits such as cost savings, reduced greenhouse gas emissions, and job creation. As shown in Table ES-3, Washington residents could expect to save $2 billion in energy costs and reduce statewide CO_2e emissions over 30 years by 17,050,000 metric tons, equivalent to the annual CO_2e emissions of 3,708,000 cars on the road (1 MMT CO_2 = 217,480 cars driven/year).

Table ES-3. Washington Statewide Societal Benefits

Statewide Impact	First Year	30 Years Cumulative
Energy cost savings, $	5,739,000	2,005,000,000
CO_2e emission reduction, metric tons	36,900	17,050,000

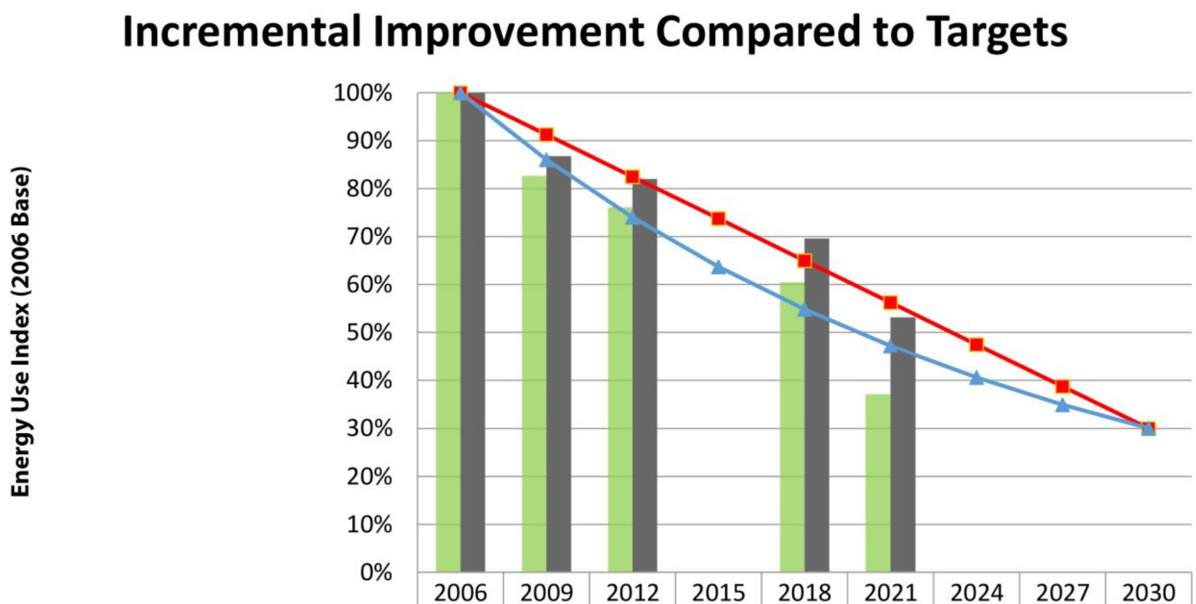
Updating the Washington State energy code to the 2021 WSEC-R will also stimulate the creation of high-quality jobs across the state. As outlined in Table ES-4, the impact on utility bills and construction-related activities from adopting the 2021 WSEC-R will lead to over 10,000 jobs created in Washington over the next 30 years.

Table ES-4. Statewide Impact on Washington Jobs

Statewide Impact	First Year	30 Years Cumulative
Jobs created due to construction-related activities and reduced utility bills	365	10,300

Based on the current analysis conducted by PNNL comparing the 2021 WSEC-R to the 2018 WSEC-R, the statewide weighted average whole building energy savings of 2021 WSEC-R relative to 2018 WSEC-R is 38.5%. As shown in Table ES-5, the energy use index for the 2018 WSEC-R compared to the 2006 WSEC-R is 60.5%. Multiplying the 60.5% energy use index (2018 WSEC-R compared to 2006 WSEC-R) with the 38.5% savings (2021 WSEC-R relative to 2018 WSEC-R) yields a 23.3% reduction over the 2018 WSEC-R energy use index. The 2018 WSEC-R energy use index of 60.5% minus the 23.3% reduction yields the new 2021 WSEC-R energy use index of 37.2% relative to the 2006 WSEC-R. Table ES-5 below shows the current 2021 WSEC-R energy use index compared to previous editions of the WSEC.

Table ES-5. Energy Use Index of the 2021 WSEC-R compared to previous editions of WSEC



	2006	2009	2012	2015	2018	2021	2024	2027	2030
Residential	100%	82.7%	76.1%		60.5%	37.2%			
Commercial	100%	86.8%	82.0%		69.6%	53.0%			
Target: 8.75 % savings compared to the 2006 WSEC	100%	91%	83%	74%	65%	56%	48%	39%	30%
Target: 14% savings compared to each previous code	100%	86%	74%	64%	55%	47%	41%	35%	30%

Contents

Tables

1.0 Introduction

The state of Washington is updating their current state residential energy code—the 2018 Washington State Energy Code (2018 WSEC-R)—to an updated 2021 WSEC-R version. This report evaluates the life cycle and greenhouse gas emission impacts of the 2021 WSEC-R. The Washington State Building Code Council (SBCC) requested an analysis of the energy and economic impacts of the proposed amendments to the 2018 WSEC-R. The specific request asked Pacific Northwest National Laboratory (PNNL) to look at the energy and economic impact of the 2021 WSEC-R over the 2018 WSEC-R. This report builds upon the previous report submitted to the SBCC, *Final Cost-Benefit Analysis of Select 2021 WSEC Residential Provisions*, that detailed the cost-effective analyses of individual proposals that made up the 2021 WSEC-R.[1]

1.1 2021 WSEC-R Proposals

PNNL reviewed the proposals listed in the following table. The team analyzed a subset of these proposals using large-scale simulation following the DOE established methodology for cost-effectiveness.[2] Table 1 illustrates all proposals requested for analysis. For this report, proposals 1-8 were combined for a cost-effectiveness analysis by simulation. However, proposals 4 and 8 were removed from analysis due to the Washington State Building Code Council (SBCC) vote to disapprove. PNNL performed a qualitative review of proposals 9-16 in this report to evaluate the cost-effective analyses provided by the proponents.

[1] https://sbcc.wa.gov/sites/default/files/2023-01/PNNL_2021WashingtonResidentialEnergyCodeAnalysis.pdf

[2] https://www.energycodes.gov/sites/default/files/2021-07/residential_methodology_2015.pdf

Table 1. Proposal Summary for the 2021 WSEC-R

Proposal	Section	Subject	Analysis
Proposal 1	R403.13, R405.2, R503.1.2	Heat Pump Space Heater	Simulation
Proposal 2	R403.5, R405.2, R503.1.3	Heat Pump Water Heater	Simulation
Proposal 3	R202, R401.1	Definitions Scope	Simulation
Proposal 4	Table R402.1.2	U-Factor Replacements	Disapproved by SBCC
Proposal 5	R405.3, R406, Chapter 6	Update Section R406	Simulation
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Proposal 15	Table 406.3 Option 3.6	HSPF of 10.0	Review Only
Proposal 16	R406 Option 3.2, 3.5	COP, HSPF	Review Only

COP: coefficient of performance. HSPF: heating seasonal performance factor. SWH: service water heating.

2.0 Cost-effectiveness Analysis

The PNNL analysis for the 2021 WSEC-R followed the standard modeling and cost-effectiveness methodology detailed in Taylor et al. (2015).[1] EnergyPlus simulations were run using the 2018 WSEC-R as the baseline across the Washington state climate zones (4C and 5B) to estimate energy use changes, energy cost changes, and carbon emissions based on the proposals. Single-family prototypes are 2,376 sq ft while multifamily dwelling units are 1,200 sq ft. The updated prototypes were simulated based on the new code language in each proposal.

The WSEC-R baseline and updated prototypes included additional energy efficiency credit requirements as required in Section R406. For the single-family prototype at 2,376 sq ft, 6.0 credits were required for the 2018 WSEC-R and 5.0 credits required for the 2021 WSEC-R. The multifamily dwelling unit at 1,200 sq ft required 4.5 credits for both the 2018 and 2021 WSEC-R. When a proposal required the addition of more efficiency, the energy credits in the updated prototype were adjusted to account for the additional efficiency. The energy credits selected in the baseline and updated prototypes are listed in Section 3.0 where the details on the analysis for each proposal are presented.

2.1 Methodology

This section provides an overview of the methodology used in evaluating the cost-effectiveness of the proposals for the 2021 WSEC-R compared to the 2018 WSEC-R. Cost-effectiveness results for life cycle cost (LCC) savings, simple payback, and cash flow are calculated for each building type in each climate zone. The results are weighted to aggregate results to the climate zone level. Weighting factors for each of the prototype buildings were developed for all U.S. climate zones using 2019 new residential construction starts and residential construction details from the U.S. Census (Census 2010), the Residential Energy Consumption Survey (RECS 2013), and the National Association of Home Builders (NAHB 2009). The weights were fine-tuned by the revised county-to-climate zone map based on the ASHRAE 169-2013 climate zone changes.

DOE's cost-effectiveness methodology evaluates 32 residential prototypes comprising two building types (single-family and low-rise multifamily), four foundation types (slab, crawl, unheated basement, and heated basement), and four heating system types (gas furnace, oil furnace, electric furnace, and heat pump). These prototypes are simulated with TMY3 weather data from locations in Washington representing the two climate zones and two moisture regimes in this analysis.

Construction cost differences between the 2018 WSEC-R and the 2021 WSEC-R for each proposal were taken directly from DOE/PNNL reports on the cost-effectiveness of new code editions, Home Depot and Lowes stores, as well as conversations with heat pump manufacturers and sales representatives. National cost estimates were adjusted by a Washington-specific construction cost multiplier[2] and appropriate Consumer Price Index (CPI) multipliers[3] to bring costs into 2022 dollars.

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[1] https://www.energycodes.gov/sites/default/files/2021-07/residential_methodology_2015.pdf

[2] https://www.energycodes.gov/sites/default/files/2021-11/Location_Factors_Report.pdf

[3] https://www.usinflationcalculator.com/inflation/consumer-price-index-and-annual-percent-changes-from-1913-to-2008/

Life Cycle Cost (LCC) savings is the primary measure used to assess the economic impact of building energy codes. LCC is the calculation of the present value of costs over a 30-year period including initial equipment and construction costs, energy savings, maintenance and replacement costs, and residual value of components at the end of the 30-year period. When the LCC of the updated code (e.g., the 2021 WSEC-R) is lower than that of the previous code (the 2018 WSEC-R), the updated code is considered cost-effective. In other words, when life cycle cost savings is positive, the proposal is considered cost-effective.

The energy savings from the simulation analysis are converted to energy cost savings using the electricity and gas prices established for analyzing Washington energy code proposals. In addition, the oil price is the most recent state-specific residential oil price from DOE's Energy Information Administration. Fuel prices used in this analysis can be found in Table 2. Fuel prices are escalated over the analysis period based on EIA's year-by-year projections in the 2021 Annual Energy Outlook,[1] Reference Case Table 3.[2]

Table 2. Fuel Prices Used in the Analysis

Electricity ($/kWh)	Gas ($/Therm)	Oil ($/MBtu)
0.0966	1.062	2.52

Per the established methodology, PNNL calculates three metrics from the perspective of the homeowner—LCC, simple payback, and cash flow. LCC is the primary metric used by DOE and Washington state for determining the cost-effectiveness of an overall code or individual code change. The economic parameters used in the current cost-effectiveness analysis are summarized in Table 3. The economic parameters are recently updated following the established methodology to account for changing economic conditions.

Table 3. Summary of Economic Parameters Used in Cost-Effectiveness Analysis

Parameter	Value
Mortgage Interest Rate	5%
Loan Term	30 years
Down-Payment Rate	10% of home price
Points and Loan Fees	1.0% of mortgage amount
Analysis Period	30 years
Property Tax Rate	1.1% of home price/value
Income Tax Rate	15% federal
Inflation Rate	3.0% annual
Home Price Escalation Rate	Equal to inflation rate

An additional analysis metric required for all Washington energy code proposals is the life cycle cost savings when including the social cost of carbon (SCC). Emission factors used in the calculation of carbon emissions and SCC are extracted from the Carbon Externality

[1] https://www.eia.gov/outlooks/aeo/

[2] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=3-AEO2021&sourcekey=0

spreadsheet as part of the Washington Life Cycle Cost Analysis Tool version 2020-A, provided by the Washington Office of Financial Management. Carbon emissions are based on annual fuel consumption based on the simulation of the baseline and updated prototypes. Carbon emission factors used in the analysis are shown in Table 4.

Table 4. Carbon Emission Factors by Fuel Type

Energy Source	Carbon Emission Factor[1]
Electricity	4.12×10^{-4} metric tons CO_2/kWh (0 after 2030)
Natural Gas	0.00531 metric tons CO_2/therm
Oil	9.62×10^{-3} metric tons CO_2/gallon

The life cycle savings of SCC is determined based on a net present value (NPV) calculation of annual savings in the SCC over a 30-year period. The social cost of carbon is based on estimates from the U.S. Government Interagency Working Group on SCC.[1] The annual social cost of carbon for the years 2010 to 2118 is contained in the Washington Life Cycle Cost Analysis Tool. The annual social cost of carbon is multiplied by the annual carbon emissions over a 30-year period to calculate the total dollar value of the carbon emissions. The NPV of SCC is calculated with a discount rate of 5% over the 30 years of carbon emissions. The difference in the NPV of SCC for the baseline case and updated case based on each proposal is the NPV savings for SCC.

[1] https://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf

3.0 2021 WSEC-R Analysis Results

The following sections highlight the cost-effectiveness results and societal benefits of the combined proposals and updated R406 code language that make up the 2021 WSEC-R. The results consist of energy savings by fuel type, energy cost savings, construction costs, and life cycle savings, as well as the life cycle savings of SCC. Details on the simulations to determine the cost-effectiveness of each proposal can be found in the *Final Cost-Benefit Analysis of Select 2021 WSEC Residential Provisions* submitted to the SBCC before this report.

3.1 Analysis

PNNL merged proposals 1-8 together and incorporated the latest Washington code language into one model and analyzed them as one overall code change by EnergyPlus simulation for cost-effectiveness assessment. For the cost-effectiveness analysis of the proposals reflecting the 2021 WSEC-R, the energy credit options used in the simulations are detailed for the baseline case and the updated case. The PNNL single-family prototypes representing the 2021 WSEC-R have a total of 5.0 credits from section R406. The multifamily prototypes for the 2021 WSEC-R have 261 credits due to heat pump water heating which far exceeds the commercial credit requirements of 41 for R-2 buildings in Table C406.1 of the 2021 WSEC-C. The PNNL prototypes representing the 2018 WSEC-R baseline cases have a total of 6.0 credits and 4.5 credits for single-family and multifamily homes, respectively. The baseline 2018 WSEC-R prototypes use all four HVAC system types, while the 2021 WSEC-R prototypes use only heat pump systems (space heating and water heating). The energy credit options and corresponding credits values listed in the tables correspond to Table R406.3—Energy Credits in the 2021 WSEC-R, and Table C406.2—Efficiency Measure Credits in the 2021 Commercial Washington State Energy Code, (2021 WSEC-C). The additional efficiency options used for the 2018 and 2021 WSEC-R analyses for the baseline case and updated case are shown in Table 5 and Table 6.

Table 5. Baseline Model Descriptions for the 2018 WSEC-R

Credits	Single-Family Fossil Fuel	Single-Family Electric	Multifamily Fossil Fuel	Multifamily Electric
Fuel Normalization Table		1.0		1.0
1.2 (Window 0.20 U-factor)			1.0	1.0
1.6 (30% UA Reduction)	2.0	2.0		
2.1 (3.0 ACH50)	0.5	0.5		
3.1 (95 AFUE Furnace)	1.0		1.0	
5.5 (NEEA Tier III HPWH)	2.0	2.0	2.5	2.5
7.1 (ENERGY STAR Appliances)	0.5	0.5		
Total Credits	**6.0**	**6.0**	**4.5**	**4.5**

AFUE: annual fuel utilization efficiency. HPWH: heat pump water heater. NEEA: Northwest Energy Efficiency Alliance. UA: envelope UA value. UEF: uniform energy factor.

Table 6. Updated Model Descriptions for the 2021 WSEC-R/WSEC-C

Credits	Single-Family Electric	Multifamily Electric
Fuel Normalization Table		
1.4 (30% UA Reduction)	1.5	
2.1 2.0 ACH50 + HRV 65% SRE	0.5	
4.1 (Ducts in Conditioned Space)	0.5	
5.4 (NEEA Tier III HPWH)	2.0	
7.1 (ENERGY STAR Appliances)	0.5	
C406.2.6.3 (Heat Pump Water Heating)		261
Total Credits	**5.0**	**261**

3.2 2021 WSEC-R Overall Savings and Cost-Effectiveness

For this analysis, the incremental costs for installing the code change proposals include the avoided cost of installing the gas infrastructure in the fossil fuel prototypes. The prototypes with electric space heating and electric water heating are fully electric and do not have any gas infrastructure as part of the model. As a result, construction costs for the electric heating systems do not include the avoided cost of installing the gas infrastructure because the baseline is already fully electric. The $4,240 (single-family) and $3,151 (multifamily) incremental cost to install a heat pump applies only to the fossil fuel and electric furnace scenarios. It does not apply to the heat pump scenario because both the baseline and updated code models use a heat pump. The construction costs used for the complete 2021 WSEC-R analysis are shown below.

Single-Family Construction Costs:

- Install Heat Pump: $4,240
- Remove 95 AFUE Furnace: $(3,633)
- Remove Air Conditioner: $(1,133)
- Avoided Gas Infrastructure: $(2,300)[1]
- Upgrade Electric Service: $700[1]
- Reduce Air Leakage to 2.0 ACH50 $1,511
- Install HRV with 65% SRE $1,500
- Updated envelope efficiency $1,508
- **Fossil Fuel Prototype Construction Costs: $2,394**
- **Electric Furnace Prototype Construction Costs: $2,394**
- **Heat Pump Prototype Construction Costs: $2,919**

[1] https://www.swenergy.org/pubs/heat-pump-study-2022

Multifamily Construction Costs:

- Install Heat Pump: $3,151
- Remove 95 AFUE Furnace: $(1,891)
- Remove Air Conditioner: $(1,065)
- Avoided Gas Infrastructure: $(2,300)[1]
- Upgrade Electric Service: $700[1]
- Window Change (U-factor 0.2 to 0.26): $(100)
- Wood Frame Wall R-Value Change (R-21 to R-20+3.8): $(215)
- Below Grade Wall R-Value Change (R21+5 to R-20+3.8): $(160)
- Infiltration Change (5 ACH50 to 4 ACH50): $315
- Duct Leakage Change (4 CFM25/100 sq ft to 8 CFM25/100 sq ft): $(161)
- HRV with 60% Sensible Recovery Efficiency $1,040
- **Fossil Fuel Prototype Construction Costs: $106**
- **Electric Furnace Prototype Construction Costs: $1,485**
- **Heat Pump Prototype Construction Costs: $1,290**

This cost-effectiveness analysis shows that the 2021 WSEC-R amendments to the 2018 WSEC-R will yield substantial energy and LCC savings. The individual consumer impact of the 2021 WSEC-R is reduced annual energy costs of $170, resulting in $5,927 in additional life-cycle benefits from energy cost savings and SCC savings when compared to the 2018 WSEC-R. LCC savings are $4,568 and LCC savings of the SCC are $1,359. The 2021 WSEC-R does increase the energy use and cost of electricity due to the code provisions requiring space heating and SWH be electric. The life-cycle analysis results are shown in Table 7.

Table 7. Consumer Impact of Combined Proposals for the 2021 WSEC-R

Metric	Compared to the 2018 WSEC-R
Annual (first year) energy cost savings ($)	$170
LCC savings ($)	$4,568
SCC LCC savings ($)	$1,359
Total LCC savings ($)	$5,927
Added construction cost ($)	$471
First year carbon emissions savings (tons)	30.5
Simple payback period (yrs)	2.8
Annual electric savings (kWh)	–915
Annual gas savings (therms)	243
Annual fuel oil savings (gallons)	0.47

[1] https://www.swenergy.org/pubs/heat-pump-study-2022

3.3 2021 WSEC-R Greenhouse Gas Emissions Reductions

The 2021 WSEC-R will result in statewide societal benefits such as cost savings, reduced greenhouse gas emissions, and job creation. Shown in Table 8, Washington residents could expect to save over $2 billion in energy costs and reduce statewide CO_2e emissions over 30 years by 17,050,000 metric tons, equivalent to the annual CO_2e emissions of 3,708,000 cars on the road (1 MMT CO_2 = 217,480 cars driven/year).

Table 8. 2021 WSEC-R Societal Benefits

Statewide Impact	First Year	30 Years Cumulative
Energy cost savings, $	5,739,000	2,005,000,000
CO_2e emission reduction, metric tons	36,900	17,050,000

3.4 2021 WSEC-R Jobs Impacts

Energy-efficient building codes impact job creation through two primary value streams:

1. Dollars returned to the economy through reduction in utility bills and resulting increase in disposable income, and;
2. An increase in construction-related activities associated with the incremental cost of construction that is required to produce a more energy efficient building.

When a building is built to a more stringent energy code, there is the long-term benefit of the ratepayer paying lower utility bills.

- This is partially offset by the increased cost of that efficiency, establishing a relationship between increased building energy efficiency and additional investments in construction activity.
- Since building codes are cost-effective, (i.e., the savings outweigh the investment), a real and permanent increase in wealth occurs that can be spent on other goods and services in the economy, just like any other income, generating economic benefits and creating additional employment opportunities.

Updating the Washington State energy code to the 2021 WSEC-R will also stimulate the creation of high-quality jobs across the state. As outlined in Table 9, the impact on utility bills and construction-related activities from adopting the 2021 WSEC-R will lead to over 10,000 jobs created in Washington over the next 30 years.

Table 9. Impact of the 2021 WSEC-R on Washington State Jobs

Statewide Impact	First Year	30 Years Cumulative
Jobs created due to construction-related activities and reduced utility bills	365	10,300

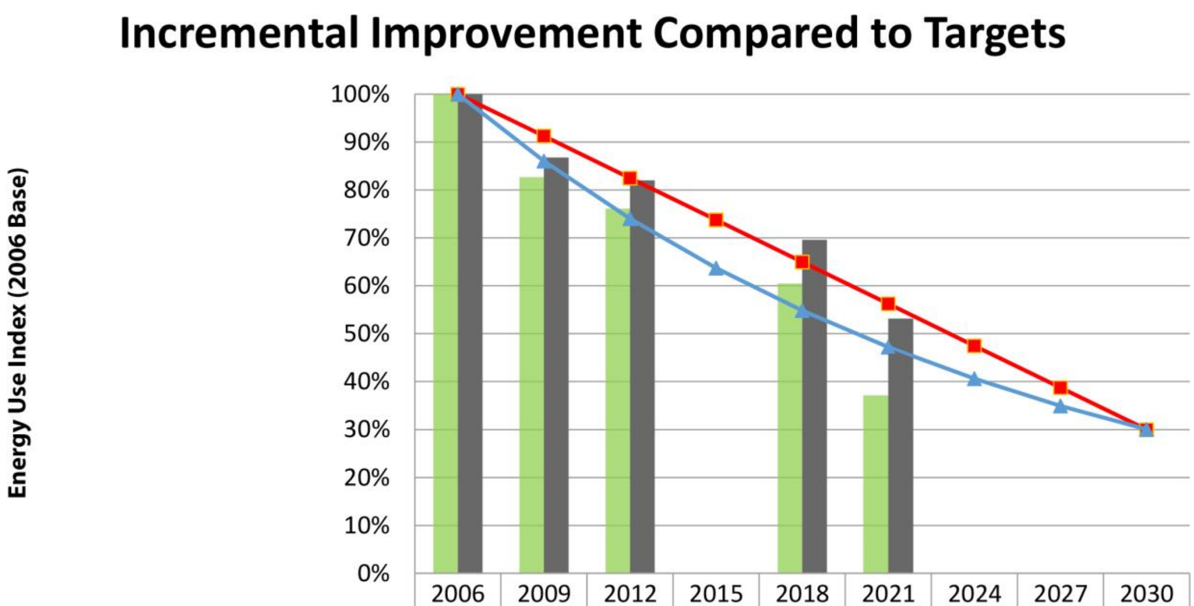
3.5 2021 WSEC-R Percent Reduction in Energy Use over 2006 WSEC-R

As shown in Table 10 on the following page, the simulated energy use index for the 2018 WSEC-R compared to the 2006 WSEC-R is 60.5%. The energy use index of 60.5% indicates that the 2018 WSEC-R is 39.5% more efficient than the 2006 WSEC-R. This data is based on prior analyses by Ecotope and O'Brien360.

Based on the current analysis conducted by PNNL comparing the 2021 WSEC-R to the 2018 WSEC-R, the statewide weighted average whole building energy savings of 2021 WSEC-R relative to 2018 WSEC-R is 38.5%. Multiplying the 60.5% energy use index (2018 WSEC-R compared to 2006 WSEC-R) with the 38.5% savings (2021 WSEC-R relative to 2018 WSEC-R) yields a 23.3% reduction over the 2018 WSEC-R energy use index. The 2018 WSEC-R energy use index of 60.5% minus the 23.3% reduction yields the new 2021 WSEC-R energy use index of 37.2% relative to the 2006 WSEC-R.

In other words, a newly constructed residential building that minimally complies with the 2021 WSEC-R is expected to have 37.2% energy use intensity compared to a building that minimally complies with the 2006 WSEC-R, assuming in this example the building's energy use matches the statewide weighted average energy use. This means that the new residential building will use 62.8% less energy than a home built to the provisions of the 2006 WSEC-R. Table 10 on the following page shows the current 2021 WSEC-R energy use index compared to previous editions of the WSEC.

Table 10. 2021 WSEC-R Energy Use Index



	2006	2009	2012	2015	2018	2021	2024	2027	2030
Residential	100%	82.7%	76.1%		60.5%	37.2%			
Commercial	100%	86.8%	82.0%		69.6%	53.0%			
Target: 8.75 % savings compared to the 2006 WSEC	100%	91%	83%	74%	65%	56%	48%	39%	30%
Target: 14% savings compared to each previous code	100%	86%	74%	64%	55%	47%	41%	35%	30%

4.0 Individual Proposal Analyses (Qualitative)

In this section, the cost-effectiveness analyses conducted for 2021 WSEC-R code change proposals 9 through 18 by the proponents are reviewed to determine if the quantification of energy and cost savings are plausible. This qualitative review is for the 2021 WSEC-R code change proposals that cannot be analyzed by simulation because they fit outside the normal functions of the PNNL prototype buildings and infrastructure. The reviews take a qualitative look at the cost-benefit analysis provided by the code change proponents and provide feedback if any necessary changes are required.

4.1 Proposal 9: Additions (21-GP2-073 – review only)

Proposal 21-GP2-073 for home additions adds an exemption that could be used by the authority having jurisdiction (AHJ) when a small addition has an undue burden (cost incurred by structural hindrances, real-life practicality of install, or overly costly requirements with little to no benefit) trying to achieve the R406.2 or R406.3 credit requirements.

4.1.1 Proposed Code Language for Additions

R502.1 General. Additions to an existing building, building system, or portion thereof shall conform to the provisions of this code because those provisions relate to new construction without requiring the unaltered portion of the existing building or building system to comply with this code except as specified in this chapter. Additions shall not create unsafe or hazardous conditions or overload existing building systems. An addition shall be deemed compliant with this code when the addition alone complies, when the existing building and addition comply with this code as a single building, or when the building with the addition uses no more energy than the existing building. Additions shall be in accordance with Section R502.1.1 or R502.1.2.

> **R502.1.1 Small additions.** Additions not greater than 150 square feet (13.9 m^2) shall not be required to comply with Section R406.

R502.3 Prescriptive compliance. *Additions* shall comply with Sections R502.3.1 through R502.3.4.

> **R502.3.1 Building envelope.** New building envelope assemblies that are part of the *addition* shall comply with Sections R402.1, R402.2, R402.3.1 through R402.3.5, and R402.4.
>
> > **R502.3.1.1 Existing ceilings with attic spaces.** Where an *addition* greater than 150 square feet (13.9 m^2) adjoins existing ceilings with attic spaces, the existing attic spaces shall comply with Section R402.
>
> **R502.3.2 Heating and cooling systems.** HVAC ducts newly installed as part of an *addition* shall comply with Section R403.

Exception: The following need not comply with the testing requirements of Section R403.3.3:

1. Additions of less than 150 square feet.
2. Duct systems that are documented to have been previously sealed as confirmed through field verification and diagnostic testing in accordance with procedures in WSU RS-33.
3. Existing duct systems constructed, insulated, or sealed with asbestos.

4.1.2 Review

The code change proposal mentions that there would be no cost impact to exempt additions less than or equal to 150 sq ft (13.9 m^2) from the additional credit requirements. The purpose of the exemption is to alleviate cost burdens of Section R406 additional efficiency credits for very small additions. For very small projects (additions) with minimal impact on energy use, requiring additional efficiency items would prove an undue financial burden on the homeowners. The potential costs of the additional efficiency requirements could potentially be much larger than the cost of the addition itself. In effect, this proposal would result in overall cost savings without the requirement of the additional R406 efficiency credits.

For the 2021 WSEC-R, an addition between 100 and 500 sq ft would require 2 credits of additional efficiency built in for the entire home.

The following are energy credit examples from Table R406.3 and associated potential construction costs:

- Option 1.6: 30% UA reduction in the envelope insulation ($5,000)
- Option 2.3: Reduced air leakage to 0.6 ACH50 ($3,600)
- Option 3.6: Ductless minisplit system ($3,060)
- Option 5.4: NEEA Tier III hot water heating system ($1,900)

Each of the above examples would result in a significant cost for a small (150 sq ft or less) addition to a home. The cost savings of not requiring additional efficiency would be substantial. The proposal to add an exemption from the additional efficiency requirements for small additions appears valid because those costs could overshadow the costs of the addition itself. An additional benefit of this code change proposal is less inspection time and permitting requirements for the AHJ. To run a cost-effectiveness analysis of residential additions to a home is outside the scope of the PNNL residential infrastructure and was not analyzed through simulation.

4.2 Proposal 10: Testing Agency Certification (21-GP2-088 – review only)

In the 2018 WSEC-R, any code official may require that air leakage testing be conducted by a third-party testing agency. Code change proposal 21-GP2-088 for testing agency certification improves the quality and consistency of the third-party testing agency by specifying the minimum credentials that testing agencies must have. To improve accuracy and accountability, this proposal also requires that the testing report include location verification and a time stamp of the date of the air leakage test.

4.2.1 Testing Agency Certification Proposed Code Language

R402.4.1.2 Testing. The building or dwelling unit shall be tested for air leakage. The maximum air leakage rate for any building or dwelling unit under any compliance path shall not exceed 5.0 air changes per hour. Testing shall be conducted with a blower door at a pressure of 0.2 inches w.g. (50 pascals). For this test only, the volume of the home shall be the conditioned floor area in ft^2 (m^2) multiplied by 8.5 feet (2.6 m). Where required by the *code official*, air leakage testing shall be conducted by an approved third party. A written report of the test results, including verified location and time stamp of the date of the test, shall be signed by the testing agency and provided to the building owner and *code official*. Testing shall be performed at any time after creation of all penetrations of the building thermal envelope. Once visual inspection has confirmed that air sealing has been conducted in accordance with Table R402.4.1.1, operable windows and doors manufactured by a *small business* are permitted to be sealed off at the frame before the test.

Testing of single-family dwellings and townhouses shall be conducted in accordance with RESNET/ICC 380. The test pressure and leakage rate shall comply with Section R402.4.1.3.

For Group R-2 occupancies, testing shall be conducted in accordance with ASTM E779, ASTM E1827, or ASTM E3158. The individual performing the air leakage test shall be trained and certified by a certification body that is, at the time of permit application, an ISO 17024 accredited certification body, including but not limited to the Air Barrier Association of America.

4.2.2 Review

Proposal 21-GP2-088 for air leakage testing agency certification is primarily editorial in nature to improve the quality and consistency of the third-party testing agency's credentials. No assumption is made that clarifying the third-party testing qualifications would improve the air tightness of the home or the accuracy of the testing results. Simulation analysis would assume that the home meets the air sealing and testing requirements of Section R402.4.1.2 and that as a result, no energy or cost impacts would occur. This proposal would have no simulated energy impact.

4.3 Proposal 11: Service Water Heating Circulation Control (21-GP2-071 – review only)

Code change proposal 21-GP2-071 for service water heating (SWH) circulation control aims to reduce the amount of energy required to maintain prompt delivery of service hot water to plumbing fixtures by optimizing the circulation system pump controls. The purpose of an SWH circulation system is to reduce the amount of time required to provide hot water to the furthest fixture. However, controls are needed to minimize circulation pump operation when there is no demand for hot water. This is particularly important in buildings with a central SWH system.

This proposal requires electronically commutated motors (ECMs) for SWH circulation pumps in Group R-2 buildings where a central SWH system serves multiple dwelling units. Circulation pumps with ECMs offer improved energy savings compared to circulation pumps with standard induction motors. The ECM motor requirement aligns with the 2021 WSEC-C requirements. In addition, this proposal requires that the system return pipe in a circulation system be a dedicated return pipe rather than a cold-water pipe to reduce heat energy loss in the system.

4.3.1 Service Water Heating Circulation Control Proposed Code Language

R403.5.1 Heated water circulation and temperature maintenance systems. Heated water circulation systems shall be in accordance with Section R403.5.1.1. Heat trace temperature maintenance systems shall be in accordance with Section R403.5.1.2. Automatic controls, temperature sensors, and pumps shall be in an accessible location. Manual controls shall be in a readily accessible location.

R403.5.1.1 Circulation systems. Heated water circulation systems shall be provided with a circulation pump. The system return pipe shall be a dedicated return pipe. Gravity and thermosiphon circulation systems are prohibited. Controls shall automatically turn off the circulation pump when the water in the circulation loop is at the desired temperature and when there is no demand for hot water.

R403.5.1.1.1 Demand recirculation water systems serving an individual dwelling unit. Where installed, *demand recirculation water systems* shall have controls that start the pump upon receiving a signal from the action of a fixture or appliance user, sensing the presence of a fixture user, or sensing the flow of hot or tempered water to a fixture fitting or appliance.

4.3.2 Review

The proponent of the SWH circulation control proposal states that one of the purposes of the proposed code language is to require ECMs in circulation pumps in Group R-2 buildings. However, the code change proposal contains no language toward requiring ECMs for the circulation pumps. The only significant code change with this proposal is removing the allowance of the cold-water supply pipe as an option for a return pipe. The remainder of the code change proposal was editorial. The proponent claims that having ECM motors in the circulation pumps will save 120 kWh/year due to the increased motor efficiency with an estimated 4,000 hours of operation. While the circulation pump motor energy savings based on the hours of pump operation is correct, the hours of operation seem excessive given the level of control required in the energy code. This assumption would mean the pumps run 11 hours per day every day of the year. Without any control, a circulation pump will run 8,760 hours per year. While there is no standard or measure of average circulation pump operational time, better circulation controls will reduce circulation pump and water heating time.

The proponent claims that the incremental first cost for a circulation pump with an ECM motor is $250, which appears to be a correct assumption. There are many circulation pumps for residential hot water circulation on the market in the $300 range. It is not clear if the ECM requirement was overlooked in the code proposal or removed accidentally. Given the claim that ECM motors save 20% over a standard induction motor, the energy savings generated would be higher if the motor had a longer operational time, which the circulation controls will work to reduce. Given the small pump energy savings of the ECM motor for the circulation pump and improved circulation control, there will be energy savings compared to a standard induction motor without circulation control. However, there appears to be no ECM motor requirement in the code change proposal, so savings will only occur from circulation control.

Per consultation with members of the PNNL Appliance Standards team, the claim that a dedicated hot water return pipe in a circulation system can reduce heat energy loss versus allowing a cold-water pipe to be used as the return is true. The heat loss reduction would be small and may not make a sufficient difference in energy use for service hot water. Calculating the savings could be complicated because there are many variables to consider in a residential setting, such as hot water demand profiles, fixture flow rates, and pipe length to the furthest fixture. Finally, allowing tepid water to flow into the domestic cold-water supply pipes could contribute to Legionella growth and introduction of dissolved metals from the hot water heater into the cold-water supply distribution piping.

4.4 Proposal 12: Energy Credit Options 3.1 and 3.2 (21-GP2-034 – review only)

Code change proposal 21-GP2-034 provides a new connected thermostat credit option (Option 3.7) for Table R406.3—Energy Credits in the 2021 WSEC-R. Option 3.7 of the High Efficiency HVAC Equipment Options section rewards a connected thermostat with 0.5 energy credits. Connected thermostat credit savings apply to gas furnaces (natural gas or propane) and central hydronic boiler systems (Option 3.1), as well as central ducted forced air heat pumps (Option 3.2). The connected thermostat must be on the ENERGY STAR Certified Smart Thermostats list.[1]

The proponent of this code change proposal makes the following claims:

- Provides additional options for saving energy that are cost-effective (4-year simple payback)
- Provides builder and occupant flexibility to meet energy credits.
- Improves HVAC contractor compliance with R403.1 controls.
- Reduces AHJ workload.

The proponent provides additional benefits for occupant, utility, and climate goals related to the following:

- Utility demand response.
- HVAC fault detection.
- Occupant and/or service technician maintenance and operation.
- IoT platform for saving additional energy from:
  - Miscellaneous electric loads, ground fault interrupters, garage doors, smart plugs.
  - Lighting.
  - Appliances.
  - Smart ventilation.
  - Shutting off equipment besides HVAC when not needed (daily, weekly, or vacation modes).

4.4.1 Energy Credit Options 3.1 and 3.2 Proposed Code Language

New Definition:
<u>CONNECTED THERMOSTAT. An internet-enabled device that automatically adjusts heating and cooling temperature settings.</u>

[1] https://www.energystar.gov/productfinder/product/certified-connected-thermostats/results

OPTION	DESCRIPTION	CREDIT(S)	
		All Other	Group R-2
3. HIGH EFFICIENCY HVAC EQUIPMENT OPTIONS Only one option from Items 3.1 through 3.6 may be selected in this category.			
3.1[a]	Energy Star rated (U.S. North) Gas or propane furnace with minimum AFUE of 95% **or** Energy Star rated (U.S. North) Gas or propane boiler with minimum AFUE of 90%. To qualify to claim this credit, the building permit drawings shall specify the option being selected and shall specify the heating equipment type and the minimum equipment efficiency.	1.0	1.0
3.2[a]	Air-source centrally ducted heat pump with minimum HSPF of 9.5. To qualify to claim this credit, the building permit drawings shall specify the option being selected and shall specify the heating equipment type and the minimum equipment efficiency.	1.0	N/A

3.7[b] Connected thermostat meeting ENERGY STAR Certified Smart Thermostats | EPA ENERGY STAR specifications 0.5 0.5

Footnote b: Option 3.7 can only be taken with Options 3.1 and 3.2.

4.4.2 Review

The proponent stated that ENERGY STAR connected thermostats cost about $200 (after 35% markup from the contractor to the owner) which matches cost estimates from a PNNL technical brief: *Demand Response in Residential Energy Code*.[1] ENERGY STAR claims that connected thermostats will save 8% on heating and cooling bills or $50 per year.[2] According to the ENERGY STAR page for connected thermostats:

> "Savings from ENERGY STAR smart thermostats and the test method used to determine these savings are closely tied together. Together with interested stakeholders, EPA created a repeatable test procedure that determines whether or not a smart thermostat meets a minimum threshold of HVAC savings (e.g., percent runtime reductions) compared to the installed base of all other thermostats in the United States. The test method defines an auditable process to select a sample of homes spread across the country. It also specifies how to use EPA-provided software to analyze a year of data from each sample home and to aggregate the data from all homes. The results are submitted to a third-party certification body. This process ensures that savings aren't simply the effects of regional over-representation. ENERGY STAR smart thermostats save energy – regardless of climate zone."

According to the proponent, consumer annual savings are expected to be roughly $30–$60/year, giving a simple payback between 4 to 8 years over a 15-year useful life. Based on ENERGY STAR expected savings with a connected thermostat, these results are plausible.

Additional heat pump savings from connected thermostats can be realized from improved supplemental electric resistance heat lockout controls above 35 °F. AHJ field verifications

[1] https://www.energycodes.gov/sites/default/files/2021-10/TechBrief_GEB_Oct2021.pdf

[2] https://www.energystar.gov/products/heating_cooling/smart_thermostats/smart_thermostat_faq

typically do not include the scope of verifying the control settings. In addition, many HVAC contractors do not adjust from non-lockout electric resistance mode to lockout controls above 35 °F mode. The lockout control algorithms in many EPA connected thermostats will result in more realized savings for single-speed heat pumps with 10–15 kW of strip heat. There will be no time impact for the AHJs, who typically do not have time to verify if a connected thermostat is in place.

4.5 Proposal 13: Cold Climate Heat Pump – Table R406.3 Option 3.2 (21-GP2-023)

Code change proposal 21-GP2-023 requires the installation of a cold climate heat pump in areas where the winter design temperature is less than 23 °F to claim credit for R406.3 Option 3.2 for centrally ducted heat pumps. If the home is constructed in a colder climate zone, it must install a Northeast Energy Efficiency Partnership (NEEP) qualified cold climate heat pump. Using cold climate heat pumps can significantly reduce electric consumption over standard heat pumps with strip heat supplemental systems. This change will encourage the use of cold climate heat pumps and reduce the need for large supplemental heat systems with heat pumps.

4.5.1 Cold Climate Heat Pump Option 3.2 Proposed Code Language

3.2[a] Air-source centrally ducted heat pump with a minimum HSPF of 9.5. In areas where the winter design temperature as specified in WAC 51-11C-80100 is 23 °F or below, a cold climate heat pump found on the NEEP code climate ASHP qualified product list shall be used. NEEP cold climate heat pump list can be found here: https://neep.org/heatingelectrification/ccashp-specification-product-list.

To qualify to claim this credit, the building permit drawings shall specify the option being selected and shall specify the heating equipment type, and the minimum equipment efficiency.

a. An alternative heating source sized at a maximum of 0.5 watts/ft^2 (equivalent) of heated floor area or 500 watts, whichever is bigger, may be installed in the dwelling unit.

4.5.2 Review

The original code change proposal allowed a 9.0 HSPF cold climate heat pump to qualify for the Option 3.2 credit, which requires a 9.5 HSPF standard heat pump. The final version of the proposal requires a 9.5 HSPF cold climate heat pump in regions where the winter design temperature is less than 23 °F. According to NEEPs Cold Climate Air Source Heat Pump Specification (Version 4.0),[1] a central air-conditioning heat pump must have a COP greater than or equal to 1.75 at 5 °F during maximum capacity operation. A cold climate heat pump will serve space heating from the compressor at lower temperatures than the standard heat pump and thus use less electric backup resistance heat.

The proponent claimed that the incremental cost of switching from a 9.5 HSPF standard heat pump to a cold climate heat pump at 9.0 HSPF would be less than $1,000. The proponent also claimed that cold climate heat pumps do not need electric resistance backup heat (estimated cost: $550 for material and labor), an electrical connection for strip heat (estimated cost: $200 for material and labor), or a strip heat lock out kit (estimated cost: $250 for material and labor).

[1] https://neep.org/sites/default/files/media-files/cold_climate_air_source_heat_pump_specification_-_version_4.0_final.pdf

Total estimated savings from avoided accessories with a cold climate heat pump total $1,000. The net cost increase to go from a standard heat pump plus supplemental accessories to a cold climate heat pump that does not require these accessories is estimated at less than $1,000 per dwelling (≤ $2,000 increased cost for cold climate heat pump minus $1,000 avoided accessory cost for supplemental heat accessories). The proponent is not clear on whether the incremental cost is due to switching from a 9.5 HSPF to a 9.0 HSPF cold climate heat pump or switching to an equal-efficiency cold climate heat pump. Even though a cold climate heat pump will have higher capacities at lower air temperatures than a standard heat pump, there will be insufficient heating capacity to meet the heating load. Thus, completely removing the backup heating system would be inadvisable. The incremental construction costs seem plausible, but it is advisable to estimate the incremental cost at $2000 to cover the electric backup resistance heating.

The original cost-effectiveness analysis conducted by the proponent showed that a 9.0 HSPF cold climate heat pump would save $410 in electric costs from removing electric resistance backup heating alone. No simulated or estimated operational cost savings from the heat pump compressors were submitted. While it may be possible to reduce the electric resistance backup heating for a cold climate heat pump, it would not be advisable to remove it completely. As a result, cost savings from a smaller-capacity electric resistance system would be lower than the estimated $410. PNNL conducted a simulation analysis comparing a 9.5 HSPF standard heat pump to a 9.5 HSPF cold climate heat pump in climate zone 5B. The cold climate heat pump utilized performance curves developed by Oak Ridge National Laboratory (ORNL) based on performance data from market-available heat pumps. The results (aggregated over all foundation types) showed the cold climate heat pump reduced total energy use in a single-family home by 14.1% and in a multifamily dwelling unit by 5.5%. This equates to electric annual energy savings of 2,377 kWh and annual energy cost savings of $230 for a single-family home, and annual energy savings of 484 kWh and cost savings of $48 for a multifamily dwelling unit. The cold climate heat pump saved over 37% of heating energy in the single-family home because more heating was served by the compressor than by the electric resistance backup heating. The multifamily dwelling unit showed annual heating energy reduction of 24% with a cold climate heat pump. The residential simulation infrastructure does not have the ability to aggregate electric backup heating consumption, but one case showed that the standard heat pump used 5,200 kWh of backup heating while the cold climate heat pump backup heat consumed only 51 kWh in a single-family home.

The electric resistance heating capacity in the simulation models were auto-sized by EnergyPlus based on climate and compressor capacity. As a result, both heat pumps had the same size electric backup heating capacity due to similar sized heat pumps and the same climate. Because the cold climate heat pump could supply more heating capacity at lower air temperatures, it ran the electric resistance heating less frequently than the standard heat pump. Cold climate heat pump savings will occur from more efficient compressor operation at lower temperatures as well as reduced backup resistance heating consumption.

4.6 Proposal 14: Cold Climate Heat Pump – Table R406.3 Option 3.5 (21-GP2-024)

Code change proposal 21-GP2-024 requires the installation of a NEEP-listed cold climate heat pump rated at 10.0 HSPF to obtain additional efficiency credits for Option 3.5 in areas with a heating design temperature below 23 °F. Option 3.5 of Table R406.3 mandates a standard centrally ducted air-source heat pump with an HSPF of 11.0. The use of cold climate heat pumps can significantly reduce electric consumption over standard heat pumps with strip heat supplemental systems. Cold climate heat pumps have slightly lower HSPF ratings due to defrost cycles and base pan heaters. This change will encourage the use of cold climate heat pumps and reduce the need for large supplemental heat systems with standard centrally ducted air-source heat pumps.

4.6.1 Cold Climate Heat Pump Option 3.5 Proposed Code Language

Option 3.5[a]: Air-source centrally ducted heat pump with minimum HSPF of 11.0. <u>In areas where the winter design temperature as specified in WAC 51-11C-80100 is 23 °F or below, an air-source heat pump serving a centrally ducted system shall be a cold climate variable capacity heat pump as defined in the NEEP cold climate heat pump list, with a minimum HSPF of 10.0.</u>

To qualify to claim this credit, the building permit drawings shall specify the option being selected and shall specify the heating equipment type and the minimum equipment efficiency.

a. An alternative heating source sized at a maximum of 0.5 watts/ft^2 (equivalent) of heated floor area or 500 watts, whichever is bigger, may be installed in the dwelling unit.

4.6.2 Review

This review shows similar results to those for code change proposal 21-GP2-023 for a 9.5 HSPF cold climate heat pump. For this case, the proponent claims that the incremental cost of switching from an 11.0 HSPF standard air-source heat pump to a cold climate heat pump of 10.0 HSPF is less than $2,500. The proponent also claimed that cold climate heat pumps do not require electric resistance backup heat (estimated cost: $550 for material and labor), electrical connections for strip heat (estimated cost: $200 material and labor), or strip heat lock out kits (estimated cost: $250 material and labor). Total estimated savings from avoided electric backup heating accessories with a cold climate heat pump are $1,000. Net cost increase to go from a standard heat pump plus supplemental accessories to a cold climate heat pump that does not require these accessories is estimated to be less than $1,500 per dwelling unit (≤ $2,500 increased cost for a cold climate heat pump minus $1,000 avoided accessory cost for supplemental heat accessories). The incremental costs seem plausible, but it is better to estimate the incremental cost of a cold climate heat pump at $2,500 to cover the electric backup resistance heating.

The cost-benefit analysis conducted by the proponent showed that a 10.0 HSPF cold climate heat pump would save $410 in annual electric costs by removing electric resistance backup heat. While it may be feasible to reduce the electric resistance backup heating for a cold climate heat pump, it would not be advisable to remove it completely. Based on the PNNL cold climate heat pump simulations described below, annual energy cost savings from the reduced use of the backup heating system are significant.

PNNL conducted a simulation analysis comparing an 11.0 HSPF standard heat pump to a 10.0 HSPF cold climate heat pump in climate zone 5B. The cold climate heat pumps utilized performance curves developed by ORNL based on performance data from market-available heat pumps. The results (aggregated over all foundation types) showed the cold climate heat pump reduced total energy use in a single-family home by 14.0% and a multifamily dwelling unit by 5.5%. This equates to annual electric energy savings of 2,365 kWh and annual energy cost savings of $228 for a single-family home, and annual energy savings of 475 kWh and cost savings of $46 for a multifamily dwelling unit. The cold climate heat pump saved over 38% of annual heating energy in the single-family home because more space heating was served by the compressor than by the electric resistance backup heat. The multifamily dwelling unit showed annual heating energy reduction of 24.1% with a cold climate heat pump.

The residential simulation infrastructure does not have the ability to aggregate electric backup heating consumption. However, one case showed the standard heat pump used 5,199 kWh of backup heating while the cold climate heat pump backup consumed only 51 kWh in a single-family home. These results matched up closely with those from proposal 13 because they had the same electric resistance backup heat and compressor capacities but different seasonal efficiencies.

4.7 Proposal 15: Cold Climate Heat Pump – Table R406.3 Option 3.6 (21-GP2-025 – review only)

Code change proposal 21-GP2-025 provides an exception to Table R406.3 Option 3.6 for ductless minisplit systems to allow smaller multi-zone minisplit systems to be installed for dwelling units with a design heat load less than 24 kBtuh nominal. The current language for Option 3.6 requires a ductless minisplit system heat pump with no electric resistance and a minimum HSPF rating of 10. The code change proposal adds an exception for a home with a heating load of 24,000 Btuh, which can use a multi-zone minisplit system with a 9.0 HSPF for full credit.

4.7.1 Multi-Zone Minisplit Heat Pump Option 3.6 Proposed Code Language

Option 3.6[a]: Ductless split system heat pumps with no electric resistance in the primary living areas. A ductless heat pump system with a minimum HSPF of 10 shall be sized and installed to provide heat to the entire dwelling unit at the design outdoor air temperature.

Exception: In homes with total heating loads of 24,000 Btuh or less using multi-zone minisplit systems with nominal ratings of 24,000 Btuh or less, the minimum HSPF to claim this credit shall be 9 HSPF.

a. An alternative heating source sized at a maximum of 0.5 watts/ft^2 (equivalent) of heated floor area or 500 watts, whichever is bigger, may be installed in the dwelling unit.

4.7.2 Review

In the reason statement for this code change proposal, the proponent claims that in the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) database of multi-zone heat pump systems, all manufacturers have lower HSPF ratings for smaller-size multi-zone systems. Because smaller multi-zone minisplit systems have lower HSPF ratings, builders of small homes may consider using multiple single-zone systems to meet the 10 HSPF requirement. In many of these homes, small multi-zone systems are a better choice for cost-effective HVAC design. Some of these small homes with a design load under 24 kBtuh may not have adequate room to install multiple outdoor compressors. Installing multiple outdoor compressors will create a more expensive heat pump system due to increased material and labor costs. This code change will encourage small sustainable homes and cost-effective HVAC design with properly sized multi-zone minisplit systems.

The proponent claims that material and labor costs for multi-zone minisplit installations on smaller homes may be lower than those for installing 2–4 single-zone minisplit systems. Each additional outdoor unit installation has an approximate cost of $1,000 in material and labor (exclusive of the compressor costs). In this scenario, there would typically be 1–2 additional heat pump compressor installations avoided per small home by installing an appropriately sized multi-zone minisplit system. The avoided cost estimate would typically be $1,500 (1.5 × $1,000) in cost savings per average home.

When comparing a multi-zone minisplit system at 9 HSPF to two single-zone minisplit systems, there is a negligible difference in energy use. However, in homes where there are three single-zone minisplit systems at 10 HSPF rather than a multi-zone minisplit system at 9 HSPF, there can be significant energy use advantages of using the multi-zone system. The energy use difference depends on where on the performance curves these systems operate during the year. Both systems might perform equally well given they are inverter-driven compressor systems that match the load of the building. Without direct energy simulation of each of these scenarios, it is difficult to prove the energy savings of the multi-zone system over the single-zone systems. The PNNL residential infrastructure is not capable of simulating multi-zone systems at this time. However, the argument that a multi-zone system would have a lower construction cost than multiple single-zone minisplit systems is plausible. It is possible that the multi-zone system would have more piping costs, but having one compressor is a cost saver. A home with a total design heating load of 24 kBtuh will not consume much heating energy, so savings might be minimal no matter how many single-zone minisplit systems are considered or installed.

4.8 Proposal 16: R406 Option 3.7 (21-GP2-050 – review only)

Code change proposal 21-GP2-050 adds a new additional efficiency option for air-to-water heat pumps rated with a COP. The code change proposal creates a new Table R406.3 Option 3.7 for an air-to-water heat pump with a minimum COP of 3.2 at 47 °F in accordance with AHRI Standard 550/590. The purpose behind the code change is to remove the current barrier for high-efficiency cold climate air-to-water heat pumps in residential sizes. These units are currently excluded from achieving Option 3 credits despite their high efficiency because they are only rated using COP. The COP efficiency allows credit for air-to-water heat pumps that are not rated with an HSPF. The new Option 3.7 rewards 1.5 credits for an air-to-water heat pump that meets the minimum COP requirement.

4.8.1 R406 Option 3.6 Proposed Code Language

Option 3.: Air-to-water heat pump with a minimum COP of <u>3.2 at 47 °F, rated in accordance with AHRI 550/590 by an accredited or certified testing lab. 1.5 credits.</u>

4.8.2 Review

The proponent claims energy savings could be achieved regionally by removing the current barrier to high-efficiency cold climate air-to-water heat pumps (reverse chillers) in residential sizes. These units are currently excluded from achieving Option 3 credits despite their high efficiency because of the requirement for an HSPF rating. This provides a high-efficiency electric option for homeowners wanting a hydronic, radiant system when natural gas is not available.

The proponent provided unit costs for various sizes of cold climate air-to-water heat pumps per the Arctic Energy website, which shows first costs between $4,000 and $6,000.[1] The standard electric resistance boiler used as a baseline can be in the range of $2,000–3,000 for similar sizes. This gives an incremental cost for the air-to-water heat pump of roughly $2,500. Given that the air-to-water heat pump would also cover cooling, construction costs would be reduced for the installation of an air conditioner.

The proponent utilized an hourly UA load analysis (Q = UA x (Tin – Tout)) to estimate an energy savings of 5.8 kWh per square foot of floor area. For a 2,376 square foot home, this would equate to 13,780 kWh of energy savings. The PNNL prototype models do not include air-to-water heat pump hydronic systems. However, the electric resistance furnace prototype (fully electric), which operates with a COP of 1.0 (similar to an electric boiler), consumes an average of 15,360 kWh annually in Washington climate zones. The space heating electric consumption is 4,034 kWh—switching to an air-to-water heat pump system with a COP of 3.2 would thus save approximately 2,700 kWh per year. This is far from the proponent's estimate of 13,780 kWh in savings for a single-family prototype. The 2,700 kWh energy savings equates to $261 of annual energy cost savings.

While the electric savings claimed by the proponent might be overstated, the energy savings of 2,700 kWh and corresponding annual energy cost savings of $261 over an electric boiler are substantial. Any air-to-water heat pump with a COP greater than 3.2 would generate additional energy savings. This proposal makes economic sense and removes a barrier to allowing air-to-water heat pumps with efficiencies rated using COP.

[1] https://www.arcticheatpumps.com/buy-cold-climate-heat-pump/heat-pumps-evi-low-temp.html

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