MEMORANDUM

Date:	**11/03/2022**
To:	**Stoyan Bumbalov**
From:	**Rob Salcido, Matt Tyler**
Subject:	**Updated Cost-Benefit Analysis of Select WSEC-R Proposals**

This memo summarizes PNNL's preliminary review of a subset of WSEC-R proposals. The objective was to review submitted data in proposals, supplement and revise the cost-benefit analyses as needed, and review life cycle cost analyses per state protocols or using alternative methods if necessary for providing better analysis. Due to tight timing, this memo mainly focuses on reviewing submitted data in proposals.

Analysis Methodology

The PNNL analysis for specific proposals followed the standard modeling and cost effectiveness methodology as detailed in the DOE established methodology published in 2015.[1] The analysis is conducted with two building types (single family and multifamily), four foundation types (slab, crawlspace, unheated basement and heated basement) and four system types (gas furnace, electric furnace, oil furnace and heat pump). The simulations are run using the 2018 Washington Energy Code as the baseline across the Washington climate zones (4C and 5B) to estimate energy use changes and energy cost changes based on the proposals. Single family prototypes were 2,376 sq ft and multifamily dwelling units were 1,200 sq ft. Each prototype was simulated with the 2018 Washington state residential energy code (2018 WSEC-R) as the baseline case. The updated prototype was simulated based on the language in each proposal analyzed. Proposals were not combined but analyzed individually for their cost effectiveness.

The baseline 2018 WSEC-R prototypes also included additional energy efficiency requirements as specified in the code. For the single family prototype at 2,376 sq ft, 6.0 credits were required while the multifamily dwelling unit at 1,200 sq ft required 3.0 credits. The additional efficiency measures selected for the analysis based on prototype are shown below. Note that for the electric heating proposal, another measure was added to overcome the fuel normalization table credits. These measures are shown in parentheses below.

Heat Pump Space Heating, Window U-factor and Infiltration Reduction Proposals

Single Family: 1.6: 40% UA Reduction, 6.1: 2.4 or 3.6 kW PV (Add 5.4: 2.8 HPWH)
Multifamily: 1.5: 30% UA Reduction, 6.1: 2.4 or 3.6 kW PV (Add 5.4: 2.8 HPWH)

Heat Pump Water Heater Proposal

Single Family: 1.6: 40% UA Reduction, 6.1: 2.4 or 3.6 kW PV (Add 2.2 HRV/2.0 ACH50)
Multifamily: 1.5: 30% UA Reduction, 6.1: 2.4 or 3.6 kW PV (Add 5.4: 2.8 HPWH)

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

The table below highlights the economic parameters and values used for the cost effectiveness analysis. As mentioned above, this analysis follows the DOE established methodology. There are slight differences in the DOE economic parameters and values compared with those in the original proposal submissions. A future version of this analysis will use the Washington values. The social cost of carbon (SCC) was not included in this analysis but will be considered for each proposal in the final report.

Economic Parameters Used in the Washington Proposals Analysis

Economic Parameters	Values Used in Analysis	Washington Values
Mortgage interest rate (fixed rate)	5%	5%
Loan fees	1% of mortgage amount	1% of mortgage amount
Loan term	30 years	30 years
Down payment	10% of home value	10% of home value
Nominal discount rate (equal to mortgage rate)	5%	5%
Inflation rate	1.6%	3.0%
Marginal federal income tax	15%	25%
Property tax	1.1%	1.1%
Electricity Rate	0.0975 $/kWh	0.0966 $/kWh
Natural Gas Rate	0.983 $/therm	1.062 $/therm

The cost effectiveness results for the four proposals analyzed are summarized below. These results are a statewide weighted average by building type, HVAC system, and foundation type as described earlier. More details on each analysis with assumptions and results are in each section below. For the life cycle cost savings, a positive number means the measure is cost effective.

Proposal	Life Cycle Cost Savings (LCC)	Energy Cost Savings ($)	Energy Savings (kBtu)	Simple Payback (yrs)
Heat Pump Space Heating	-$5,950	-$227	13,000	NA
Heat Pump Water Heater	-$1,524	$46	4,925	41.2
Window U-factor	$2	$7	548	15.1
Envelope Air Leakage	$322	$64	5,200	18.8

Proposal 21-GP2-065 – Heat Pump Space Heater

The code change requires all space heating to be heat pumps with exceptions for buildings with small heating loads. Allows gas heat pumps to meet the requirement. Shows a cost savings by removing gas infrastructure.

PNNL modeled all space heating with a heat pump meeting minimum federal efficiency requirement combined with electric supplemental heat. PNNL will review the proponent's incremental costs associated with the heat pumps and the corresponding cost-effectiveness analysis.

PNNL Cost Effectiveness Analysis

The PNNL analysis for the heat pump heating proposal shows that installing an 8.2/14 SEER electric heat pump over an electric resistant furnace (COP = 1) combined with a 13 SEER air conditioner will show aggregated annual energy cost savings of $344 based on Washington utility rates. The electric heat pump saves almost 6,000 kBtu in energy over the electric resistance furnace for multifamily and over 21,000 kBtuh in energy for the single family home. This represents 24% and 37% energy savings respectively.

Installing the same efficiency electric heat pump over a gas furnace of 80 AFUE combined with a 13 SEER AC showed average aggregated annual energy costs increase by $360. For the single family homes, the aggregated increase in electricity costs was $944 while the reduction in gas costs was only $553 for a net increase in annual energy costs of $360. Replacing the gas furnace with an electric heat pump reduces energy use by 9,400 kBtu (26%) for a multifamily dwelling unit and by 28,000 kBtu (34%) for a single family home. Overall estimated annual energy savings for all prototypes averaged 13,000 kBtu. The space heating heat pump proposal does reduce overall energy consumption, but the fuel prices make the switch more expensive on an energy cost basis. For homes with electric resistant heating, it makes sense to replace this system with a heat pump as the average aggregated annual savings were $344.

PNNL estimated that replacing a federal minimum efficiency gas furnace and air conditioner with a minimum federal efficiency heat pump would cost an additional $600 on average. Given that this proposal was a decarbonization proposal, PNNL did not price out the cost of removing the gas infrastructure from the home. If proposals were combined to remove all gas equipment from the home, taking credit for the removal of the gas infrastructure would be warranted. If there is a significant cost reduction of the gas infrastructure, the heat pump proposal could be cost effective overall. As it stands now, replacing a gas furnace/AC with a heat pump shows higher annual energy costs. PNNL will update the analysis for this proposal with updated utility rates as well as economic parameters for the final report. There is a possibility of combining this proposal with the heat pump water heater proposal and combine the costs with the removal of the gas infrastructure to be part of this analysis.

PNNL Cost Effectiveness Findings: *Overall this proposal is not cost effective due to the gas furnace increased costs but would prove cost effective for electric resistance heating systems to be replaced with heat pumps. PNNL will update this analysis with new utility rates and economic parameters as well as the potential for combining the heat pump and heat pump water heater proposals.*

Proposal 21-GP2-066 – Heat Pump Water Heater

Removes the requirement for a heat pump water heater (HPWH) for low-rise multifamily buildings due to concerns over space constraints in smaller residential units. The cost-effectiveness analysis shows upfront cost savings and shows life cycle cost savings when the social cost of carbon is included.

PNNL simulated multifamily buildings with fossil fuel water heaters and compare with HPWH to show the change in energy use between the two systems.

PNNL Cost Effectiveness Analysis

The PNNL analysis for heat pump water heaters replaced all water heaters in the prototypes with heat pump water heaters (2.8 UEF) in single family homes only. The PNNL prototypes use the same fuel for space heating and water heating. As a result, the electric systems use an electric resistance storage water heater, the gas and oil use the same fuel respectively for storage water heaters. Instantaneous water heaters were not analyzed as part of this proposal. The prototype water heaters were all at the federal minimum efficiency level by fuel type. For the EnergyPlus simulations, heat pump water heaters were installed in conditioned space without venting so the chilled exhaust air was delivered to the conditioned space.

The result was that heating energy increased while cooling energy decreased. In order to determine the energy and energy cost saving for each system type, the results from the simulations were aggregated together over all foundation types and climate zones for Washington based on construction weights. Thus, for the electric furnace/electric water heater combination, replacing the water heater with a heat pump water heater saved $71 (aggregated over all foundation types and climate zones) and reduced energy consumption by 2,944 kBtu. The same methodology was used for all system types.

Based on the system type and water heater type, the aggregated annual energy and energy cost savings from the simulations are shown below:

- Elec Furnace/Elec WH-> HPWH: $71 (2,944 kBtu decrease in energy)
- Gas System/Gas WH -> HPWH: $-9 (4,785 kBtu decrease in energy)
- Heat Pump/Elec WH -> HPWH: $144 (5,370 kBtu decrease in energy)
- Oil Furnace/Oil WH -> HPWH: $33 (3,746 kBtu decrease in energy)

Based on the construction weights in Washington, the overall aggregated annual energy cost savings across all single family homes was $46. The average energy use decrease from installing heat pump water heaters across all prototypes was 4,925 kBtu (6.8%). Based on the incremental cost to install an 80-gal heat pump water heater in a single family home at $1900, the estimated mortgage payment increase would be $105 based on the economic parameters shown above for DOE. As a result, the energy cost savings do not cover the increased cost of the mortgage, thus this proposal would not be cost effective overall. Having said that, observing the cost savings for an electric resistance water heater to a heat pump water heater would prove cost effective. The PNNL cost effectiveness analysis is conducted with the entirety of all system types.

For electric resistant hot water systems, replacing with heat pump water heaters would be cost effective. If the HPWH can be shown to have an incremental first cost less than $1900, this proposal might show cost effective as well. As mentioned in the previous section, PNNL will update the cost analysis with the latest Washington utility rates and economic parameters. There is a possibility of analyzing the heat pump proposals as one and combining with the cost credit of not having any gas infrastructure in place.

PNNL Findings: *This proposal is not cost effective overall but looking at a more granular level might prove cost effective for electric systems being replaced with a heat pump water heater. If the incremental cost of a HPWH is lower than $1900, this might be a cost-effective proposal overall.*

Proposal 21-GP2-084 – Definitions and Scope

This proposal changes R-2 buildings (three stories or less) with dwelling units accessed from interior spaces or corridors to follow the commercial energy code. If individual water heaters serve the units and the building is 3 stories or less, this building can use the residential code. The benefit is a single set of energy requirements for all multifamily buildings.

The original proposal focused on the fact that there would not be much energy differential between the commercial and residential energy codes and the cost impacts would be less for commercial. Cost comparison information for the modified proposal states that moving R-2 buildings (entry through interior) from residential code to the commercial code will cost very little extra, however the R406 options for residential adds extra costs.

The proposal states the commercial C406 costs will be much less than the R406 costs. The proposal shows that extra credits for commercial code can be low ($558) compared to the residential extra credits ($6,300).

The costs for the PV in the commercial energy credits appear slightly low due to the size of the PV system. The commercial code requirements state that for the reward of credits, the size of the system must be double the C411.1.1 requirements, which would be 1.0 W/sq ft or 820 watts costing $2,050.

The costs of moving to the commercial prescriptive requirements (envelope, air leakage & ventilation) appear to be similar but appear that they would increase costs for the windows, air leakage and ERV efficiency. The proponent states that extra costs would be covered by the extra credit options cost savings.

To fully understand the energy cost and first cost differences, PNNL could model the residential and commercial provisions of the codes in the PNNL prototype models to determine the energy budgets of the residential and commercial codes. It appears that there was a study conducted by Ecotope that shows similar energy usage for the base codes and energy credit packages.

For those provisions that change, PNNL would estimate incremental first costs to use in the cost-effectiveness analysis. If the overall cost of moving R-2 buildings to the commercial code indeed prove to show small energy savings, then no cost-effectiveness analysis would be required.

Proposal 21-GP2-079 – U-factor Replacements

This proposal improves residential window requirements through modifications to the U-factor.

The weighted average U-factor is proposed to change from 0.30 to 0.28. It is said that this proposal should be fairly noncontentious because U-0.28 windows were unanimously recommended for approval to be included in the 2024 IECC and Oregon has already adopted U-0.27 windows in their base energy code.

The motivation of the proposal is that windows are responsible for 45% to 49% of the total envelope heat loss although it represents only 6-8% of the envelope area. There is a shift from ~R3 code compliant / ENERGY STAR v6 double glazing windows to ~R4.6 to 5.3 / ENERGY STAR v7.0 (to be adopted for 2023) triple glazed windows. This proposal aligns the 4C/5B prescriptive requirements with the existing ENERGY STAR v6.0 program and makes use of the technology already in the marketplace.

The building types impacted by this proposal include single family and low rise multifamily.

The cost-effectiveness analysis shows that the proposed window improvement will payoff within roughly 23-31 years.

The cost for the window upgrades from U-0.30 to U-0.28 was estimated using builder interviews and ENERGY STAR v7.0 window specification analysis. An average of $1.22 / ft2 was estimated based on the average cost of $1.85 /ft2 from 4 builders ($2.00, $1.10, $2.45 and $1.85 / ft2), the ENERGY STAR estimates of $1.57 ($1.21 with 130% inflation to $1.57) and the cost of $0.25 / ft 2 as used in the ICF-2021 IECC cost-effectiveness analysis for upgrade of U-factor from 0.32 to 0.30 ($0.19/ft2 with 130% inflation to $0.25 / ft2) (1) this average is questionable and probably under-estimated due to the fact that the low end of $0.25 in the ICF analysis is from upgrading from U-0.32 to U-0.30; (2) On the other hand, the window upgrade may be over-pricing. ENERGY STAR analysis shows a simple payback of 6 years for lower U-0.30 to 0.28. and PNNL's costs for lower U-0.30 to 0.24 is only $0.41/ft2.

The cost analysis also assumed 0.177 kBtu/ft2 of energy saving from the window upgrade. In PNNL's 2021 IECC analysis, the overall EUI changes are 3.8 and 3.9 kBtu/ft2, respectively at CZ 4 and 5. However, this is the total change as the effects were not isolated for each efficiency measure to estimate the change only from the window upgrade from U-0.32 to U-0.30 in CZ 4.

The cost-effectiveness analysis was based on the use of the LCCA tool from the Office of Financial Management. The analysis was on CZ 4C and 5B with the consideration of two heating system types (gas furnace and heat pump) and only one foundation type, i.e., vented crawlspace.

PNNL conducted the energy and cost-effectiveness analysis with the following changes:

- Estimate the cost from lower U factor 0.30 to 0.28
- Use four foundation types and four heating system types in the analysis.

PNNL Cost Effectiveness Analysis

The PNNL analysis for the window U-factor proposal simply installed windows with a U-factor of 0.28 in place of the baseline window U-factor of 0.30. The simulations utilized a Solar Heat Gain Coefficient (SHGC) of 0.40 for all windows.

PNNL simulations estimated that upgrading the windows from a U-factor of 0.30 to 0.28 would have an incremental cost of $148 for single family homes and $50 for multifamily dwelling units. The aggregated energy and energy cost savings by building type are shown below:

- Single Family: $2.23 (867 kBtu energy savings)
- Multifamily: $10.80 (198 kBtu energy savings)

The PNNL analysis shows aggregated annual energy cost savings of $7 (548 kBtu) for all prototypes with a mortgage and tax payment increase of $6.6. The overall life cycle cost is $2.5 showing that this measure is just over the limit of being cost effective. The simple payback is calculated to be 15.1 years.

PNNL Cost Effectiveness Findings: Cost Effective

Proposal 21-GP2-073 – Update Section R406 Additional Efficiency Credits

This proposal updates the credit requirements based on size of home and building type. Credits are updated for primary heating source measures, envelope measures, HVAC, service water heating (SWH), renewable energy measures, and appliances.

To determine cost-effectiveness of this proposal, PNNL would determine what measures could be cost-effective for both single family and multifamily prototypes that meet the minimum credit requirements. First costs for those specific measures would be obtained and combined with the annual energy cost savings to determine the life cycle costs. It would likely take various attempts to find appropriate combinations of measures that would achieve cost-effectiveness while meeting the credit requirements. However, there is likely more than one cost-effective path.

The cost-effectiveness analysis conducted for this proposal was quite extensive and appeared to show all cases to be cost-effective except the small gas home. The energy savings and measure first costs associated with this proposal seemed appropriate. The PNNL analysis would most likely show similar results. The life cycle costs would only be for single family and multifamily buildings.

Proposal 21-GP2-089 – Allowed Leakage Rates

Proposal changes tested air leakage requirement from 5.0 ACH50 to 3.0 ACH50. For dwelling units, the requirement drops from 0.4 to 0.25 CFM50/sq ft of enclosure area. Group R-2 buildings where dwelling units are accessed from an internal corridor or common area must comply with the commercial leakage requirements to align with the commercial proposal.

The original proposal does not include any simulation analysis or cost-effectiveness analysis. This is a straightforward analysis to run in the PNNL prototype models with the differing air leakages and the estimate of the incremental cost to achieve those levels.

In the PNNL residential energy credits analysis, air leakage reductions of this magnitude will show total energy savings of 6-7% in climate zones 4, 5 and 6. PNNL also shows costs of $2,870 for a single family home to reduce from 5 ACH50 to 2 ACH50 and for multifamily it would be $1,500. Thus, the costs to reduce from 5 ACH50 to 3 ACH50 would be less. A rough estimate could be around $1,900 for single family and $1,000 for multifamily.

PNNL Cost Effectiveness Analysis

For the Washington climate zones, all prototype models were simulated at two infiltration levels: 5.0 ACH50 and 3.0 ACH50.

PNNL estimated the cost to tighten the dwelling unit from 5.0 to 3.0 ACH50 would cost $1914 for a single family home and $439 for a multifamily dwelling unit. There was discussion that achieving this level of building tightness requires Aero sealing of the building at the lowest possible cost of $3,000. PNNL will do more research and exploration of costs for tightening up the home to a 3.0 ACH50 level for an updated analysis in the final report. The aggregated energy cost savings for this reduced infiltration proposal based on simulation is $64 per year based with aggregated energy savings of 5,200 kBtu per year. The cost effectiveness analysis shows that reducing the infiltration is cost effective with lifetime present value savings of $322.

***PNNL Cost Effectiveness Findings**: Cost Effective*

Proposal 21-GP2-080 – Water Heater Install Location

Proposal changes the service hot water system requirement from no specification of the installation location to conditioned space for systems that use electric resistance heating elements as the primary heating source. The only exception for such installation location is when hot water efficiency is >= 2.0 UEF or less than 40 gal. This excludes the tankless water heater.

There was no simulation analysis or cost-effectiveness analysis conducted, and PNNL anticipates the energy impact would be relatively small. This would be a somewhat complex effort because the current residential prototype model does not have a garage or other unconditioned or semi- conditioned space. Due to this geometry limitation, the service hot water system has been modeled as installed in the conditioned space (as a baseline). To analyze the energy impact on this requirement, geometry enhancement will be needed to create the unconditioned garage.

Proposal 21-GP2-032 – Sealed Air Handler

This proposal adds a location requirement for air handlers. It proposes to change section R403.3.2.1 from “R403.3.2.1 Sealed air handler” to “R403.3.2.1 Sealed air handler and location” with the content change of “Air handlers shall be located in the conditioned space”.

The building types impacted by this proposal include single family and low rise multifamily (1-3 stories).

The proposal claims that locating the air handler inside the conditioned space will reduce labor and materials cost by right sizing the ducts. If the HVAC contractor uses ACCA manual D to size the thermal distribution system when using ACCA manual J and S to design load for sizing, a reduced linear footage of ductwork and smaller-size diameter of duct are derived. There is additional thermal comfort because the air handler does not need to reheat or re-cool between HVAC cycles with potential behavioral energy saving.

It assumes that relocating an air handler inside conditioned space is worth 0.5 energy credits (600 kWh/year). With the assumed $0.10/kWh fuel prices, it leads to $30 - $60 / year energy cost saving over the life of a 1,500 ft2 home. With a design cost for the air handler relocating of $100, the simple payback is 2 to 4 years.

The 600 kWh/year saving seems slightly high. Recall the savings of IECC 2021 over IECC 2018 are 3.8 kBtu/ft2 and 3.9 kBtu/ft2 at CZ 4 and 5, respectively, which are in the range of 1,000 kWh/year for a 2,400 ft2 single family home or 1,200 ft2 multifamily unit, the compound impact of all efficiency measures brought by IECC 2021.

PNNL may need to conduct a simulation to quantify the energy impact by relocating the air handler from unconditioned space to a conditioned space.

Currently there is no air handler modeled in the PNNL residential prototype models. In the EnergyPlus AirflowNetwork we have used, only duct objects can be assigned to a thermal zone but not the other distribution component including the air handler. Therefore, PNNL will add a duct object in the model that can have the rough size, shape and leakiness of the air handler to mimic the air handler, and this air-handler like duct object can then be located in either conditioned or unconditioned space.

Simulation will be conducted in two scenarios of the air handler location, i.e., inside or outside of the conditioned space, to estimate the energy impact of the relocation of the air handler. The $100 cost for re-design to put the air handler into conditioned space may be used as the estimate of the first cost if there is no better data on this. A cost-effectiveness analysis can be conducted to estimate the life-time cost.