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NET ZERO FELLOWSHIP 2019

The Cost of Multifamily Energy Efficiency in Oregon

Presented by Glumac

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1 INTRODUCTION

1.1 MOTIVATION

Design teams require both energy savings and cost estimates early in the design process to optimize energy efficiency within project budgetary constraints. Energy modelers usually have a formal engineering background, well suited for energy consumption and savings estimates but insufficient to provide cost estimates based on more than anecdotal project experience. This knowledge gap in the energy modeling industry suggests there is a need for basic cost estimation resources for energy modelers and design teams.

Without early access to cost estimates, design teams are less able to capitalize on "low hanging fruit," develop strategies for incorporating higher cost measures, and pursue designs realistically aligned with the project budget. Unfortunately, projects with goals like net zero often face late stage budget reckonings, including redesign costs that reduce the percentage of total funds going towards higher efficiency equipment, materials, and labor. This project's goal was to increase the energy modeling industry's knowledge of cost drivers and develop resources that design teams and energy modelers can use to independently estimate costs associated with proposed measures, which will improve the industry's ability to optimize energy savings per dollar invested.

1.2 PROJECT GOALS

1. Improve design teams' understanding of how multifamily buildings use energy.
2. Improve design teams' understanding of design and market elements that impact multifamily project cost, specifically with respect to energy efficiency.
3. Develop resources that teams can use during early design to prioritize energy efficiency measures that will meet project sustainability goals within budget.

2 BACKGROUND

2.1 EXISTING RESOURCES

Construction industry cost estimation tools exist including **RS Means** and **CBRE's Cost Lab** (previously Whitestone). These companies maintain libraries of cost information that can be purchased and used, but they are either difficult to use without experience and training or prohibitively expensive. This is particularly true for independent energy modelers who do not have the resources of a larger MEP or A/E firm. RS Means and Whitestone present the following barriers to cost estimation:

- Casual users of these tools have no way to check their work if their firms do not have professional cost estimators on staff.
- Estimating costs for efficiency upgrades often requires a level of detail not included in purchased data sets.

Building Component Cost Community (BC3) is a public database developed by PNNL that provides costs for primary building components including walls, fenestration, equipment, and energy efficiency measures. Its data has a lower level of detail than purchasable resources and is geared towards single-family residential projects.

National Residential Efficiency Measure Database (NREMD) is a "publicly available, centralized resource of residential building retrofit measures and costs for the U.S. building industry" developed by NREL. Like BC3, its data has a lower level of detail than purchasable resources and is geared towards residential projects. Latest public release: v3.1.0 on January 8, 2018.

2.2 RELEVANT LITERATURE

Studies have been conducted by various organizations on the incremental costs of net zero and high efficiency design.

- *The Economics of Zero-Energy Homes* (2018) by Rocky Mountain Institute studied incremental costs to achieve net zero and net zero ready construction in single family homes in four US climates.
- *Net-Zero Energy Residential Building Component Cost Estimates* report (2016) was published by the National Institute of Standards and Technology (NIST) and used to develop the "Building Industry Reporting and Design for Sustainability" (BIRDS) software tool.
- *National Cost-Effectiveness of the Residential Provisions of the 2015 IECC* (2015) was published by the Pacific Northwest National Laboratory.

2.3 REMAINING GAPS

Existing public resources contain data that lacks the necessary level of detail required by energy modelers evaluating energy efficiency measures for new construction projects. Purchasable resources have higher levels of detail but require further investigation as they are generally inaccessible to professionals whose jobs are not primarily dedicated to cost estimation. There is a need for accessible, system-specific cost data for energy efficiency measures.

3 METHODOLOGY

This section describes methods used to estimate building energy use and construction costs for a base building design and energy related alternates.

3.1 SCOPE

The resources produced with this research are intended to be accurate and applicable to most midrise (4-11 story) multifamily **new construction** buildings in Oregon. To that end, the following variables have been studied and included for each energy and cost estimate:

- Occupant density
- Location

The analysis focuses on residential floors with interior corridors; ground floor retail, lobbies, and amenity spaces are not included. Other elements that could not be included in the scope due to budget constraints are discussed where relevant.

3.1.1 Baseline Building Design

Total construction costs and baseline energy use were generated for a baseline building design with the following elements.

Substructure
- Standard foundations (4-11 story wood framed construction)
- Concrete slab on grade with R-15 perimeter insulation
- No basement or underground parking

Shell
- Concrete interior flooring
- Wood-framed walls (6” stud, batt insulation, no exterior insulation)
- Exterior wall cladding, molding, caulking sealing
- Dual pane vinyl windows (U-0.31), 25% operable, 30% window to wall ratio*
- Concrete slab roof on metal deck, R-32 insulation

* Window to wall ratio (WWR) impacts energy use and pricing, but a decreasing WWR decreases both cost and energy use. Since there is not a cost premium associated with the energy savings from a reduced WWR, WWR variance was not studied extensively. A 25-30% WWR is considered ideal when balancing heat loss and daylighting. Additionally, the WWR is frequently locked in during the pro-forma process and is not at the discretion of design teams.

Interiors
Low-cost multifamily interiors including:
- Partitions and interior doors
- Stair construction and finishes
- Wall, floor, and ceiling finishes

Conveying
- Non-regenerative traction elevators (first unit freight type, consequent units passenger type)

Plumbing

- Bathroom fixtures, low-flow
    - Toilet
    - Fiberglass insert baths/shower
    - Counter mounted sink
- Kitchen fixtures, low-flow
    - Double bowl sink with garbage disposal
- Dishwasher hook-up, per apartment
- Washer/dryer/ice-maker utility box, per apartment
- In-unit hot and cold water piping, with insulation
- Centralized hot and cold water distribution piping
- Centralized natural gas condensing boilers, 92% AFUE
- Sanitary waste systems
- Rain water drainage systems
- Allowance for plumbing general requirements, documentation, commissioning, supervision, pressure testing, and permits

HVAC

- **Continuous* bathroom** and **kitchen exhaust fans**, with occupancy-based boost, ducted to perimeter
- **Electric resistance heat** throughout residential units, **no in-unit cooling****
- Centralized corridor RTU, DX/gas, 0.2 CFM/sf of corridor, with ductwork
- 2,000-4,000 CFM of miscellaneous exhaust (trash, mech./elec. rooms)
- Fires Smoke Dampers
- Allowance for HVAC testing and balancing
- Allowance for HVAC BIM, permit, documentation, testing, and supervision

* Although continuous exhaust/ventilation systems increase total building energy compared to intermittent exhaust systems, they improve indoor air quality and preserve building value by reducing humidity damage.

** In-unit mechanical cooling is becoming more necessary as Oregon's climate changes. However, since many designs still choose electric resistance without cooling, that was chosen as the baseline.

Fire Protection

- Allowance for sprinklers, standpipes, etc.

Electrical

- Standard, mostly LED design
- Code minimum controls

Equipment and Furnishings

- Energy Star refrigerators, dishwashers, washer/dryers
- Electric stoves/ovens
- Ventless recirculation kitchen hoods
- Low-cost kitchen and bathroom cabinets, countertops

3.1.2 Energy-Related System Alternates for Analysis

The following systems were analyzed for energy use and cost impacts.

Shell

- 10% reduction in total shell conductivity
- 20% reduction in total shell conductivity
- 35% reduction in total shell conductivity

Plumbing

- In-unit electric resistance water heaters
- Centralized heat pump water heaters

HVAC

- In-unit heat recovery ventilators
- PTHP in main, electric heat in bedrooms
- PTHP in main and ducted to bedrooms
- Split system heat pumps in main, electric heat in bedrooms
- Split system heat pumps in main and ducted to bedrooms
- VRF in main, electric heat in bedrooms
- VRF in main and ducted to bedrooms

3.1.3 Approach to Generating Ranges

As discussed in section 3.1, the intention of this research is to be accurate and applicable to a variety of midrise multifamily projects in Oregon. However, it was necessary to balance broad applicability with the time constraints of the research scope; to that end, a limited selection of example projects were used to capture realistic (i.e. market proven) variation in building geometry and layout, and the resultant energy and cost impacts.

3.2 EXAMPLE PROJECT CHARACTERISTICS

To develop useful energy and price ranges, energy analysis and pricing were performed for three (3) real example projects completed within the past two (2) years. These example projects were chosen based on their differing residential unit mix and density, which affect energy use intensity and system pricing.

Characteristics of the example projects used to generate energy and cost ranges are summarized in the following tables; project names have been changed.

Table 1. Example Project Density Characteristics

Project	Density	Sqft/Occ	Occ/Apt	Sqft/Apt
Patmore	High	209	3.16	660
Barrow	Medium	347	1.78	617
Carson	Low	493	1.25	617

Table 2. Example Project Unit Mixture Characteristics

Project	Density	Studios	One Bed	Two Bed	Three Bed	Bath/Apt	Bath/Sqft
Patmore	High	16%	44%	22%	18%	1.4	0.00212
Barrow	Medium	61%	22%	17%	0%	1.0	0.00162
Carson	Low	66%	24%	7%	4%	1.1	0.00179

Occupant density and unit mixture are the example project characteristics captured in the energy modeling results, as they have a large impact on building energy use and cost and are not at the discretion of most design teams.

3.3 WEATHER FILES

For each system analyzed, energy model results were generated using three (3) different weather files:

1. TMY3 Portland International Airport
2. TMY3 Salem Municipal Airport McNary Field
3. TMY3 Medford Rogue Valley International Airport

3.4 ENERGY MODEL INPUTS FOR THE BASELINE AND ALTERNATES

A generic energy model was created in eQuest 3-65 based on the Barrow Project, a half block project in Portland, OR with a roughly 100' by 200' footprint. The geometry was simplified to remove first floor retail, the parking garage, and reduce the number of residential levels. A multipliers was applied to the second level to achieve the desired building height of six (6) floors, which was held constant for all simulations.

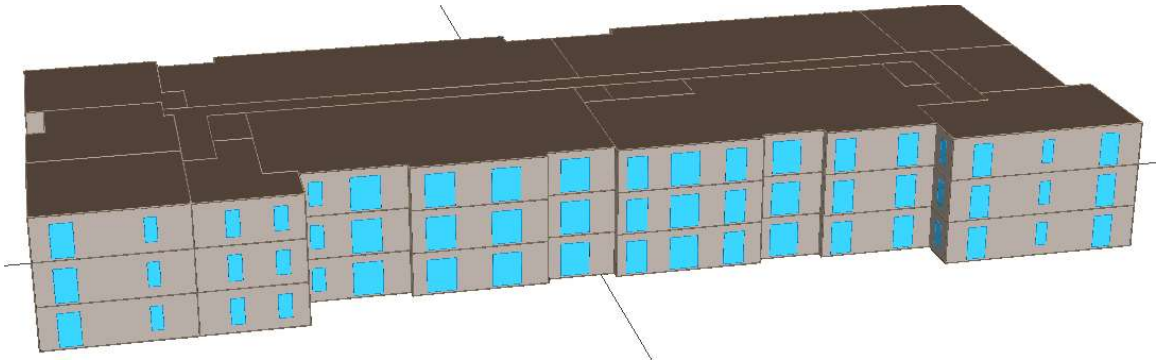

Figure 1. Glumac Gardens Generic Multifamily eQuest Model

3.4.1 Envelope

The baseline construction is modeled as wood-framed walls, a span deck roof with insulation above deck, and a 30% window-to-wall ratio (WWR) of dual pane non-metal framed punched windows. Window area was not varied for this study.

Envelope characteristics for the baseline building and several alternates are shown in the table below. Baseline characteristics are taken from ASHRAE 90.1-2016 for Climate Zone 4 (Table 5.5-4), residential requirements.

Table 3. Modeled Envelope Characteristics (1 of 2)

Envelope Characteristics		Baseline		10% UA Reduction	
Component	Area	U-Value	UA	U-Value	UA
Roof	20555	0.032	657.8	**0.027**	555.0
Walls (net)	30669	0.064	1962.8	0.064	1962.8
Windows	13144	0.31	4074.6	**0.27**	3548.8
Slab (area)	20555	0.0185	379.7	0.0185	379.7
Totals	84923	**0.083**	7074.9	**0.076**	6446.4

Table 4. Modeled Envelope Characteristics (2 of 2)

Envelope Characteristics		20% UA Reduction				35% UA Reduction	
Component	Area	U-Value	UA	U-Value	UA	U-Value	UA
Roof	20555	**0.027**	555.0	0.032	657.8	**0.027**	555.0
Walls (net)	30669	**0.04**	1226.8	0.064	1962.8	**0.04**	1226.8
Windows	13144	**0.27**	3548.8	**0.19**	2497.3	**0.19**	2497.3
Slab (area)	20555	0.0185	379.7	0.0185	379.7	0.0185	379.7
Totals	84923	**0.067**	5710.3	**0.065**	5497.6	**0.055**	4658.8

As can be seen in the tables above, overall building U-value reductions can be achieved through multiple combinations of insulation and window improvements; average building U-value was studied and the results can be generalized to other buildings with similar U-value.

3.4.2 Plug Loads and Appliances

Plug load and appliance energy use estimates were generated based on a combination of Energy Star data, Energy Star Multifamily Simulation Guidelines, and previous experience. In-unit kWh/sf loads vary based on occupant density and residential unit mix, so a summary is given for the three (3) project examples.

Table 5. Per Occupant Residential Equipment Loads

In-Unit Equipment	kW	Minutes/Wk-Occ	kWh/Yr-Occ	Sensible	Latent
Electric Cooktop (1 Burner)	0.9	70	55	0.4	0.3
Microwave	1.0	80.5	70	0.4	0.3
Laptop/tablet	0.03	450	12	1	0
0.5 kWh/day-occ misc. (TVs, small appliances, etc.)			183	1	0
Cleaning Appliances	kWh/Load	Loads/Wk-Occ	-		
Dishwasher, Energy Star	0.67	1	35	0.6	0.15
Clothes Washer, Energy Star	0.19	1.5	15	0.8	0
Dryer, Ventless, Compact	1.31	1.5	103	0.15	0.05
		Total kWh/Yr-Occ	**471**	0.62	0.10

Sensible and latent load fractions for each type of equipment are taken from the Multifamily Simulation Guidelines.

Cooktop and **microwave** use is estimated based on a combination of cooking from scratch and reheating frozen or purchased meals; an additional 0.5 kWh/day-occ is added based on 30 minutes per day use of more energy intensive small appliances like hairdryers, vacuums, electric kettles.

Dishwasher energy use is based on 164/year kWh for an Energy Star unit per the Multifamily Simulation Guidelines, which accounts for 245 loads according to Energy Star test procedures. While 245 loads/year, or 4.7 loads/week, may be appropriate for a family with young children, it is too high for many multifamily occupants like young professionals and retired couples. For this reason energy use has been normalized to 1 load/person/week. This does not include energy to heat hot water.

Clothes washing energy is based on 57 kWh/year for an Energy Star unit per the Multifamily Simulation Guidelines, which accounts for 295 loads according to Energy Star test procedures,

and has been normalized to 1.5 load/person/week. This does not include energy to heat hot water. **Clothes drying** energy is based on 372 kWh/year for a ventless, compact electric dryer, which accounts for 283 loads, and has been normalized to 1.5 load/person/week. Dryer information is from the *ENERGY STAR Market & Industry Scoping Report, Residential Clothes Dryers* published November 2011.

In addition to per-occupant loads, each apartment also contains a **refrigerator**, which is modeled as using 423 kWh per year per Energy Star Multifamily Simulation Guidelines, regardless of occupancy.

Table 6. Per Apartment Residential Equipment Loads

Refrigerator	kWh/Yr-Apt	Sensible	Latent
Mid Size, Energy Star	423	1	0

Table 7. Example Project In-Unit Equipment Loads

Project	kWh/sf	Sensible	Latent
Patmore	2.90	0.70	0.08
Barrow	2.04	0.75	0.07
Carson	1.64	0.78	0.06

Common area plug loads (corridor, stairwells, storage) are modeled at 15.7 kWh/sf per the Multifamily Simulation Guidelines.

3.4.3 Lighting

Installed lighting power was modeled based on recent project experience; LED lighting no longer has a cost premium compared to incandescent or fluorescent in new construction, so a mostly-LED design is assumed.

Table 8. Multifamily Lighting Power Density and Energy Use

Area	W/sf	Hrs/Day	kWh/sf
Residential Units	0.70	1.5+0.5/occ/apt	0.54-0.79
Corridors	0.35	24	3.0
Stairwells	0.50	1.2	0.2
Storage	0.60	1.2	0.3

Table 9. Example Project Residential Lighting Use

Project	kWh/sf	Hrs/Day
Patmore	0.79	3.1
Barrow	0.61	2.4
Carson	0.54	2.1

Full load hours are varied for in-unit lighting use based on number of occupants per apartment. This was done to capture per occupant lighting needs as well as per area lighting needs; an apartment occupied by two people will use more lighting energy than the same apartment occupied by only one person, but the difference will not be linearly occupant driven as there are lighting use efficiencies when multiple occupants use the same room.

3.4.4 Ventilation

Continuous ventilation has been modeled in all scenarios, owing to its occupant and building health advantages compared to intermittent ventilation. Humidity concerns, in particular, drive the desire for continuous exhaust and ventilation in multifamily buildings. **Bathroom and kitchen exhaust fans** have been modeled as operating continuously at a low flow, with a bump up for two (2) hours per day to a boost flow.

Table 10. Residential Exhaust Minimum and Boost Flows

Exhaust Flows	Oregon Min.	Min. Flow	Max Flow/Size
Per Bath	20 CFM	30 CFM	60 CFM
Per Kitchen	25 CFM	35 CFM	70 CFM
Per Person	15 CFM	20 CFM	20 CFM
Gen. Ventilation	0.053 CFM/SF	0.075 CFM/SF	0.075 CFM/SF

The modeled minimum flows slightly exceed the Oregon Mechanical Code minimums to ensure adequate minimum airflows will be delivered, regardless of variables like stack effect and pressure changes at the exhaust outlet.

Outdoor airflows were calculated for each of the example projects by unit type: studios, one-, two-, and three-bedroom. Minimum ventilation is calculated as the minimum of the following:

- Combined bathroom and kitchen exhaust flows.
- Combined occupant minimum flows (per Oregon Mechanical Code assume two (2) occupants in the first bedroom, add one (1) person per additional bedroom).
- General area minimum ventilation of 0.35 ACH.

Table 11. Studio Exhaust and Ventilation Calculations

Studio Ventilation	SF/Unit	Bath #	Min Vent (CFM)	Size Vent (CFM	Enrg Avg (CFM)
Patmore	416	1	65	130	70.4
Barrow	529	1	65	130	70.4
Carson	547	1	65	130	70.4

Table 12. One Bedroom Exhaust and Ventilation Calculations

One Bedroom Ventilation	SF/Unit	Bath #	Min Vent (CFM)	Size Vent (CFM	Enrg Avg (CFM)
Patmore	551	1	65	130	70.4
Barrow	634	1	65	130	70.4
Carson	638	1	65	130	70.4

Table 13. Two Bedroom Exhaust and Ventilation Calculations

Two Bedroom Ventilation	SF/Unit	Bath #	Min Vent (CFM)	Size Vent (CFM	Enrg Avg (CFM)
Patmore	767	1	65	130	70.4
Barrow	928	1	69.6	130	74.6
Carson	963	2	95	190	102.9

Table 14. Three Bedroom Exhaust and Ventilation Calculations

Three Bedroom Ventilation	SF/Unit	Bath #	Min Vent (CFM)	Size Vent (CFM	Enrg Avg (CFM)
Patmore	1014	2	95	190	102.9
Barrow	N/A				
Carson	1105	2	95	190	102.9

Average project ventilation rates are shown below.

Table 15. Example Project Residential Ventilation Rates

Project Ventilation	Design/Max (CFM/SF)	Energy Average (CFM/SF)
Patmore	0.182	0.116
Barrow	0.185	0.115
Carson	0.187	0.120

Overall ventilation rates is most closely correlated with a project's bathroom density.

Corridor ventilation was modeled at 0.2 CFM/sf.

3.4.5 Temperature Schedules

Heating and cooling schedules for the residential units and corridors are 24/7 and set at 70 F and 75 F respectively.

3.4.6 HVAC Systems

Ventilation delivery and conditioning systems were modeled with the following performance characteristics.

Table 16. Ventilation System Characteristics

Ventilation System	W/CFM
Baseline (bath fan, ducted to perimeter)	0.260
Heat Recovery Ventilator (70% effective)	0.730

Because of the variation in ventilation CFM/SF, energy from ventilation fans is varied with occupant density.

Four (4) residential conditioning systems were modeled explicitly, with the following characteristics. All in-unit fans are modeled as cycling with load.

Table 17. In-Unit Conditioning System Characteristics

Residential HVAC System	Fan W/CFM	Heating			Cooling	
		Type	COP	Min HP (F)	Type	EER
Baseline	0.24	Electric	1.0	N/A	N/A	-
PTHP	0.24	Heat Pump	3.3 - 3.6	24	Heat Pump	10.6 - 11.9
Split HPs	0.24	Heat Pump	3.5 - 3.6	17	Heat Pump	11.9 - 12.9
VRF	0.24	Heat Pump	3.5 - 3.6	0	Heat Pump	11.9 - 12.9

Table 18. Corridor Conditioning System Characteristics

Corridor HVAC System	Fan W/CFM	Heating			Cooling	
		Type	COP	Min HP (F)	Type	EER
Baseline	0.55	Electric	1.0	N/A	DX	11.0
PTHP	0.55	Electric	1.0	N/A	DX	11.0
Split HPs	0.55	Electric	1.0	N/A	DX	11.0
VRF	0.55	Heat Pump	3.5 - 3.6	0	Heat Pump	11.9 - 12.9

Note that the VRF systems are also modeled with PVVT curves to account for additional efficiencies gained by VRF heat recovery.

Results for the PTHP, split HP, and VRF systems with **electric heat in the bedrooms** were calculated via interpolation; the heating and cooling EUIs for the DX system and electric heat simulations were area weighted based on the ratio of bedroom and living/kitchen area in the example projects.

Table 19. Residential Unit Area Ratios

Area Ratios	Main	Bedroom
Patmore	77%	23%
Barrow	87%	13%
Carson	88%	12%

For example, the "PTHP with electric heat in bedrooms" (**PTHPwEH**) HVAC EUI for **Patmore** would be calculated as follows:

PTHPwEH Heat EUI = 77% x [PTHP Heat EUI] + 23% x [EH Heat EUI]

PTHPwEH Cool EUI = 77% x [PTHP Cool EUI] + 23% x [EH Cool EUI]

PTHPwEH Fan EUI = [PTHP Fan EUI]

3.4.7 Domestic Hot Water Loads

Domestic hot water loads are modeled based on Energy Star appliance data, previous project experience, and metered data. The following table assumes a water heater **supply temperature of 125 F.**

Table 20. Per Occupant Fixture Flow Calculations

Hot Water Use	Fixture Flows		Fixture Temp	% Hot Water	Minutes/ Day	Gallons Hot/Day
Showerheads	1.75	gpm	105	73%	8	10.3
Bathroom Faucets	0.5	gpm	105	73%	1.5	0.6
Kitchen Faucets	1.5	gpm	105	73%	1	1.1
Total Gallons of Fixture Hot Water/Day/Person						**11.9**

Table 21. Per Occupant Appliance Hot Water Calculations

Cleaning Appliances	Gallons Hot/Load	Loads/ Week	Gallons Hot/Week	Gallons Hot/Day
Dishwasher, Energy Star	3.5	1.0	3.5	0.5
Clothes Washer, Energy Star	2.9	1.5	4.3	0.6
Total Gallons of Appliance Hot Water/Day/Person				**1.1**

Per load hot wat water use for dishwashers is based on Energy Star maximums; clothes washer gallons of hot water per load is estimated to be 20% of total water use, where total water is based on Energy Star data. This daily estimate of **13 gallons/day/occupant of supply temperature hot water** aligns with recent studies of residential hot water use, including the 2015 paper "Estimating Daily Domestic Hot-Water Use in North American Homes" published by Florida Solar Energy Center.

A summary of each example project's domestic hot water loads is shown below.

Table 22. Example Project Domestic Hot Water Loads

Project	Gallons Hot/Day/SF	Gallons Hot/Yr/SF	Annual Heating Load	
Patmore	0.062	22.8	14.2	kBtu/sf
Barrow	0.038	13.7	8.6	kBtu/sf
Carson	0.026	9.7	6.0	kBtu/sf

Note that **these are loads, not energy use**, which will be determined based on the efficiency of the water heater.

3.4.8 Domestic Hot Water Systems

Domestic water heater systems were modeled with the following performance characteristics.

Table 23. Domestic Water Heater Performance

Water Heating System	Fuel	Rated Efficiency	Est. Seasonal Eff.
Centralized Condensing Natural Gas Boilers	Natural Gas	92%	85%
Centralized Heat Pump Water Heaters	Electricity	2-2.5 COP at 24 F	2.7 COP
In-Unit Electric Hot Water Heaters	Electricity	100%	97%

3.5 MATERIAL AND EQUIPMENT QUANTIFICATION

For the baseline building and each energy related system alternate, estimates were made for the quantities of materials and equipment required for construction. Normalized pricing for materials and equipment was supplied by a cost consultant, Rider Levett Bucknall (RLB).

3.5.1 Envelope Quantification

Substructure and shell quantities for $/GSF pricing were calculated based on the three (3) example project shell characteristics.

Table 24. Example Project Shell Characteristics

Shell	Footprint	Levels	Area/Floor	Perimeter	Wall Height	SF Wall/ SF Floor
Patmore	U	4	13998	636	12.4’	0.562
Barrow	I	7	18997	787	10.0’	0.414
Carson	L	8	19151	667	10.5’	0.366

Window $/GSF pricing is based on the SF Wall/SF Floor ratios, a 30% window to wall ratio, and 25% operable window area. Roofing $/GSF is based on a 6 floor, stacked geometry.

3.5.1 Conveying Quantification

Elevator type and quantity were taken from project examples.

3.5.2 Plumbing Quantification

Centralized natural gas condensing boilers were the designed domestic hot water heating system for Barrow and Carson, so system sizing for those two buildings is taken from design documents. Patmore’s natural gas boilers were sized theoretically with input from Glumac staff, primarily based on expected building occupancy.

Centralized heat pump hot water heater system elements were sized based on Ecotope’s “Ecosizer” tool, which can be found at:

https://ecosizer.ecotope.com/sizer/size/

The following table summarizes the heat pump equipment sizing.

Table 25. Heat Pump Water Heater Equipment Sizing

HP Water Heaters	Maintenance Temperature	Tank Volume	Swing Tank Volume	Heat Capacity	Swing Resist. Element
Patmore	140 F	934 gal	236 gal	171.0 kBtu/hr	5.7 kW
Barrow	140 F	1732 gal	300 gal	314.4 kBtu/hr	18.3 kW
Carson	140 F	1785 gal	300 gal	324.4 kBtu/hr	19.2 kW

In-unit electric hot water heaters were allocated based on number of bathrooms.

The following figure shows overall plumbing quantities for the baseline and alternates.

Figure 2. Plumbing Equipment Quantities

			Patmore	Barrow	Carson
All Plumbing System Options will include the following components…			**Qty**	**Qty**	**Qty**
Plumbing Fixtu	Bathroom Fixtures	per bathroom	70	162	188
Plumbing Fixtu	Kitchen Fixtures	per kitchen	50	162	170
Domestic Wate	Domestic Cold Water Distribution (applies to all designs)	SF of building	38768.5	113542	123717
Domestic Wate	Allowance for *centralized* Domestic Hot Water Distribution, w	SF of building	38768.5	113542	123717
Sanitary Waste	Sanitary Waste	SF of building	38768.5	113542	123717
Rain Water Dra	Rain Water Drainage	SF of building	38768.5	113542	123717
Other Plumbin	Other Plumbing Systems (below)	SF of building			
	Allowance for plumbing general requirements, documentation,	SF of building	38768.5	113542	123717
	Allowance for plumbing pressure testing	SF of building	38768.5	113542	123717
	Allowance for plumbing permits	SF of building	38768.5	113542	123717
The following are specific plumbing options, and their *additional* components					
Centralized Natural Gas Condensing Boilers					
Domestic Wate	Storage tank, 125 gal	EA	2	4	4
Domestic Wate	Condensing natural gas water heater, 200-600 MBH; AO Smith BT	MBH	1000	2000	2000
Centralized Heat Pump Hot Water Heaters					
Domestic Wate	Storage tank, 500 gal	EA		3.464	3.57
Domestic Wate	Storage tank, 300 gal	EA	3.113		
Domestic Wate	Storage tank, 300 gal	EA	1	1	1
Domestic Wate	CxA-20 - $40,900 ea. (125.9 kBtu/h)	EA	1	1	1
Domestic Wate	CxA-30 - $46,860 ea. (191.6 kBtu/h)	EA		1	1
Domestic Wate	Per-apartment electric domestic water heater - INSTALL (Katy w	EA	1	1	1
Domestic Wate	10 kW Instantaneous Electric Water Heater (for HPWH reheat)	EA	1		
Domestic Wate	20 kW Instantaneous Electric Water Heater (for HPWH reheat)	EA		1	1
In-Unit Electric Hot Water Heaters					
Domestic Wate	Allowance for *centralized* Domestic Hot Water Distribution, w	SF of building	-19384.3	-56771.1	-61858.5
Domestic Wate	In-Apt Electric Water Heater	EA	70	162	188
Domestic Wate	Per-apartment electric domestic water heater - INSTALL (Katy w	EA	50	162	170

3.5.3 HVAC Quantification

Material and equipment quantities and sizing are based on the example project's final designs and input from Glumac engineers.

Figure 3. HVAC Equipment Quantities

			Patmore	Barrow	Carson
All HVAC System Options will include the following components…			**Qty**	**Qty**	**Qty**
Systems Testin	Allowance for TAB--HVAC Testing and Balancing	SF	38768.5	113542	123717
Other HVAC Sy	Allowance for HVAC BIM, permit, documentation, testing and su	SF	38768.5	113542	123717
Other HVAC Sy	Exhaust fans and ductwork, all accessories included--allowance	CFM	3700	2790	1830
The following are specific HVAC options, and their *additional* components					
Electric Heat, Bathroom Exhaust Fans, Corridor RTU					
Heat Generatin	Electric cove heater - 400W	EA	71	90	82
Heat Generatin	Electric cove heater - 800W	EA	50	162	170
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608
PTHP in central room with Electric Heat in Bedrooms, Corridor RTU					
Terminal & Pac	PTHP - 7000 BTU (LG or Amana)	EA		18	0
Terminal & Pac	PTHP - 12000 BTU (LG or Amana)	EA	30	116	125
Terminal & Pac	PTHP - 15000 BTU (LG or Amana)	EA	20	28	45
Heat Generatin	Electric cove heater - 400W	EA	71	90	82
Heat Generatin	Electric cove heater - 800W	EA			
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608
PTHP in central room, ducted to bedrooms, Corridor RTU					
Terminal & Pac	PTHP - 7000 BTU (LG or Amana)	EA	0	18	0
Terminal & Pac	PTHP - 12000 BTU (LG or Amana)	EA	30	116	125
Terminal & Pac	PTHP - 15000 BTU (LG or Amana)	EA	20	28	45
Distribution Sy	Ductwork + transfer fan(s) to blow living room air into bedroom(s)	Each bedroom	71	90	82
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608

Split HPs in central room with Electric Heat in Bedrooms, Corridor RTU					
Terminal & Pac	Split Heat Pump - 9000 BTU (Daikin, Mitsubishi, or LG)	EA		18	0
Terminal & Pac	Split Heat Pump - 12000 BTU (Daikin, Mitsubishi, or LG)	EA	32	116	125
Terminal & Pac	Split Heat Pump - 18000 BTU (Daikin, Mitsubishi, or LG)	EA	18	28	45
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	0	0	0
Heat Generatin	Electric cove heater - 400W	EA	71	90	82
Heat Generatin	Electric cove heater - 800W	EA			
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608

Split HPs in central room, ducted to bedrooms, Corridor RTU					
Terminal & Pac	Split Heat Pump - 9000 BTU (Daikin, Mitsubishi, or LG)	EA	0	18	0
Terminal & Pac	Split Heat Pump - 12000 BTU (Daikin, Mitsubishi, or LG)	EA	32	116	125
Terminal & Pac	Split Heat Pump - 18000 BTU (Daikin, Mitsubishi, or LG)	EA	18	28	45
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	0	0	0
Distribution Sy	Ductwork + transfer fan(s) to blow living room air into bedroom(s)	Each bedroom	71	90	82
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608

VRF in central room with Electric Heat in Bedrooms, Corridor RTU					
Terminal & Pac	VRF Condenser Unit (include support platforms)	ton	77.5	227.1	247.4
Terminal & Pac	VRF Branch Controller	EA	6	18	21
Terminal & Pac	VRF Refrigerant Line (include pipe supports)	EA apartment	50	162	170
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	50	162	170
Heat Generatin	Electric cove heater - 400W	EA	71	90	82
Heat Generatin	Electric cove heater - 800W	EA			
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608
Controls & Inst	DDC Controls - General - Allowance	SF	38768.5	113542	123717

VRF in central room, ducted to bedrooms, Corridor RTU					
Terminal & Pac	VRF Condenser Unit (include support platforms)	ton	77.5	227.1	247.4
Terminal & Pac	VRF Branch Controller	EA	6	18	21
Terminal & Pac	VRF Refrigerant Line (include pipe supports)	EA apartment	50	162	170
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	50	162	170
Distribution Sy	Ductwork + transfer fan(s) to blow living room air into bedroom(s)	Each bedroom	71	90	82
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608
Controls & Inst	DDC Controls - General - Allowance	SF	38768.5	113542	123717
VRF in all rooms, Corridor RTU					
Terminal & Pac	VRF Condenser Unit (include support platforms)	ton	77.5	227.1	247.4
Terminal & Pac	VRF Branch Controller	EA	77.537	227.0844	247.434
Terminal & Pac	VRF Refrigerant Line (include pipe supports)	EA apartment	6	18	21
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	6	18	21
Terminal & Pac	DX Fan Coil (for split heat pumps or VRF) - Cassette	EA	71	90	82
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	70	162	188
Terminal & Pac	AHU, no heat recovery, DX+ gas furnace	CFM	1850	6400	9100
Distribution Sy	SA and RA Ductwork	Lb	4058	15188	12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	1924	5423	3198
Distribution Sy	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	38768.5	113542	123717
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	17	42	33
Distribution Sy	Fire Smoke Dampers (FSD)	Sq-in	1296	5904	4608
Controls & Inst	DDC Controls - General - Allowance	SF	38768.5	113542	123717
Add HRV - Electric Heat, Bathroom Exhaust Fans, Corridor RTU					
Terminal & Pac	Energy/Heat Recovery Unit (Small, Per Apartment - 90 CFM) - Lo	EA	20	0	18
Terminal & Pac	Energy/Heat Recovery Unit (Small, Per Apartment - 120 CFM) - Lo	EA	50	162	170
Terminal & Pac	Bathroom exhaust fan (like Panasonic) < 80 CFM	EA	-70	-162	-188
Distribution Sy	SA and RA Ductwork	Lb	-4058	-15188	-12627
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	-1924	-5423	-3198
Distribution Sy	SA and RA Ductwork	Lb	9985	40130	40123
Distribution Sy	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	8543	32288	32756
Distribution Sy	Duct Diffussers and Grills [QTY is Allowance]	EA	70	162	188

3.5.4 Electrical Quantification

Material and equipment quantities and sizing are based on the example project's final designs and input from Glumac engineers. Baseline electrical pricing was performed and additional calculations were done to determine impacts to electrical pricing from HVAC and plumbing design alternates. Electrical impacts to HVAC and plumbing costs are wrapped into the total HVAC and pluming cost summaries, rather than be shown on the electrical pricing summary.

Where element pricing is not broken out, for example with "PTHP in central room, ducted to bedrooms, Corridor RTU", the pricing impact is equal to the previous system, in this case "PTHP in central room with Electric Heat in Bedrooms, Corridor RTU."

Figure 4. Electrical Equipment Quantities

			Patmore	Barrow	Carson
All Electrical System Options will include the following components...			**Qty**	**Qty**	**Qty**
Lighting and Br	Common area light fixtures (low cost, mostly dimmable LED can	SF of common ar	5759.5	13655.3	18753
Lighting and Br	Conduit and wire to light fixtures and controls	SF of common ar	5759.5	13655.3	18753
Lighting and Br	In-Unit Lighting - Overhead Fixture (Bedrooms)	EA	71	90	82
Lighting and Br	In-Unit Lighting - Bathroom Vanity	EA	70	162	188
Lighting and Br	In-Unit Lighting - Three (3) Can Fixtures (Kitchens)	per kitchen	50	162	170
Electrical Servi	Feeders, cable trays, conduit, etc	SF	38768.5	113542	123717
Electrical Servi	Grounding	SF	38768.5	113542	123717
Electrical Servi	Outlets and other low voltage devices	SF	38768.5	113542	123717
Electrical Servi	Conduit and wire to outlets and low voltage devices	SF	38768.5	113542	123717
Electrical Servi	Permits/Bonds/Manuals &Testing	SF	38768.5	113542	123717
Communicatio	Communications & Security	SF	38768.5	113542	123717
Other Electrica	Emergency System Power	SF	38768.5	113542	123717
Electrical Servi	ATS	KVA	72	117	216
Electrical Servi	Emergency Generator	kW	100	150	200
Electric Heat, Bathroom Exhaust Fans, Corridor RTU, Nat Gas DHW					
Electrical Servi	100A - Distribution Panel	EA	50	162	170
Electrical Servi	Switchboards	Amps	2200	3800	4200
The following are specific HVAC/plumbing options, and their *additional* components					
PTHP in central room with Electric Heat in Bedrooms, Corridor RTU					
Electrical Servi	100A - Distribution Panel	EA	-50	-162	-170
Electrical Servi	125A - Distribution Panel	EA	50	162	170
Electrical Servi	Switchboards	Amps	1628	3917	4318
Electrical Servi	Switchboards	Amps	-1458	-3344	-3709
PTHP in central room, ducted to bedrooms, Corridor RTU					
Split HPs in central room with Electric Heat in Bedrooms, Corridor RTU					
Electrical Servi	100A - Distribution Panel	EA	-50	-162	-170
Electrical Servi	125A - Distribution Panel	EA	50	162	170
Electrical Servi	Switchboards	Amps	1502	3555	3938
Electrical Servi	Switchboards	Amps	-1458	-3344	-3709
Split HPs in central room, ducted to bedrooms, Corridor RTU					
VRF in central room with Electric Heat in Bedrooms, Corridor RTU					
Electrical Servi	Switchboards	Amps	1502	3555	3938
Electrical Servi	Switchboards	Amps	-1458	-3344	-3709
VRF in central room, ducted to bedrooms, Corridor RTU					
VRF in all rooms, Corridor RTU				0	0
Add HRV - Electric Heat, Bathroom Exhaust Fans, Corridor RTU					
Electrical Servi	Switchboards	Amps	1502	3555	3938
Electrical Servi	Switchboards	Amps	-1458	-3344	-3709
Add HP Domestic Water Heaters					
Electrical Servi	200A - Distribution Panel	EA	1	2.345	2.68
Electrical Servi	Switchboards	Amps	201	469	536

3.6 SYSTEM PRICING

To generate pricing estimates, materials and equipment quantities were multiplied by the normalized pricing provided by RLB and overhead of 28-34% was applied.

Table 26. Construction Overhead Costs

Overhead Costs	
Subguard Insurance	1% - 2%
General Conditions	6% - 10%
Bonding	1% - 1.5%
Overhead & Profit	3% - 5%
Design Contingency	12% - 15%

3.6.1 Normalized Pricing Request

Based on a review of several 100% Construction Documents pricing sets provided by RLB, Glumac developed a pricing request for the necessary materials and equipment necessary to build pricing estimates for the baseline building design and energy related alternates. The following figures show samples of the normalized pricing request from Glumac to RLB. The yellow highlights indicate information provided by RLB.

Figure 5. Excerpt from Shell Pricing Request

B - Shell				
L3		Description of Component	Unit	Price/Unit
B1010	Floor Construction	Concrete slab (SD-level pricing)	SF of floors	$ 12.00
B1020	Roof Construction	Concrete slab (SD-level pricing)	SF of roof	$ 20.00
B2010	Exterior Walls	Wood stud framing, 6"	SF of walls	$ 10.00
B2010	Exterior Walls	Mineral fiber insulation, 1", attached with metal z-furring	SF of walls	$ 2.75
B2010	Exterior Walls	Mineral fiber insulation, 1", attached with fiberglass clips	SF of walls	$ 5.00
B2010	Exterior Walls	Mineral fiber insulation, 2", attached with metal z-furring	SF of walls	$ 3.50
B2010	Exterior Walls	Mineral fiber insulation, 2", attached with fiberglass clips	SF of walls	$ 6.00
B2010	Exterior Walls	Mineral fiber insulation, 5", attached with metal z-furring	SF of walls	$ 6.50
B2010	Exterior Walls	Mineral fiber insulation, 5", attached with fiberglass clips	SF of walls	$ 8.00
B2010	Exterior Walls	Self-adhered air barrier	SF of walls	$ 4.50
B2010	Exterior Walls	Batt insulation, fill 6" cavity (~5.5" actual, R19-R21)	SF of walls	$ 2.50
B2010	Exterior Walls	Vapor retarder	SF of walls	$ 1.25
B2010	Exterior Walls	Everything else (cladding, molding, caulking/sealing for weatherproofi	SF of walls	$55 - $70
B2020	Exterior Windows	Dual pane vinyl windows, fixed - MATERIAL	SF of windows	$ 25.00
B2020	Exterior Windows	Dual pane vinyl windows, fixed - LABOR	SF of windows	$ 20.00
B2020	Exterior Windows	Dual pane vinyl windows, slider - MATERIAL	SF of windows	$ 40.00
B2020	Exterior Windows	Dual pane vinyl windows, slider - LABOR	SF of windows	$ 25.00
B2020	Exterior Windows	Dual pane vinyl windows, casement - MATERIAL	SF of windows	$ 42.00

Figure 6. Excerpt from Plumbing Pricing Request

D20 - Plumbing				
L3		Description of Component	Unit	Price/Unit
D2010	Plumbing Fixtures	Give SD-level $/fixture or $/bathroom for low-cost multifamly, no counts.		
	Plumbing Fixtures	Hot/Cold Piping, Venting in a typical unit	LS	$6,981.00
	Plumbing Fixtures	Bathroom Fixtures	per bathroom	$2,940.00
	Plumbing Fixtures	Kitchen Fixtures	per kitchen	$1,939.00
	Plumbing Fixtures	Water closet	EA	$710.00
	Plumbing Fixtures	Bath / shower fiberglass insert	EA	$1,361.00
	Plumbing Fixtures	Lavatory (counter mounted)	EA	$869.00
	Plumbing Fixtures	Double bowl kitchen sink with garbage disposal	EA	$1,524.00
	Plumbing Fixtures	Dishwasher hook-up	EA	$85.00
	Plumbing Fixtures	Washer/dryer/icemaker utility box	EA	$330.00
D2020	Domestic Water Distribution	Domestic Cold Water Distribution (applies to all designs)	SF of building	$1.35
D2020	Domestic Water Distribution	Domestic Hot Water distribution, with insulation, **inside apartments (applies to all designs)**	per Apt	$2,605.00
D2020	Domestic Water Distribution	Allowance for ***centralized*** Domestic Hot Water Distribution, with insulation (piping from central hot water heater to all apartment doors), and recirculation pump(s)	SF of building	$1.60
D2020	Domestic Water Distribution	Storage tank, 100 gal	EA	$9,644.00
D2020	Domestic Water Distribution	Storage tank, 200 gal	EA	$10,623.00
D2020	Domestic Water Distribution	Storage tank, 500 gal	EA	$14,950.00

Figure 7. Excerpt from HVAC Pricing Request

D30 - HVAC				
L3		Description of Component	Unit	Price/Unit
D3020	Heat Generating Systems	Electric cove heater - 400W	EA	$547.00
D3020	Heat Generating Systems	Electric cove heater - 800W	EA	$580.00
D3020	Heat Generating Systems	Electric cove heater - 1200W	EA	$590.00
D3040	Distribution Systems	SA and RA Ductwork	Lb	$9.53
D3040	Distribution Systems	SA and RA Ductwork Insulation [SF of ductwork area]	SF of ductwork	$4.50
D3040	Distribution Systems	Duct Specialties--duct silencers and sound/noise attenuation	SF of building	$0.55
D3040	Distribution Systems	Duct Diffussers and Grills [QTY is Allowance]	EA	$150.00
D3040	Distribution Systems	Hydronic piping for heating/cooling, 4-pipe (include pump allowance)	SF of building	$9.72
D3040	Distribution Systems	Hydronic piping for heating/cooling, 2-pipe (include pump allowance)	SF of building	$4.75
D3040	Distribution Systems	Condenser water piping (include pump allowance)	SF of building	$1.65
D3040	Distribution Systems	Ductwork + transfer fan(s) to blow living room air into bedroom(s)	Each bedroom	$1,594.00
D3050	Terminal & Package Units	PTHP - Install only	EA	$2,630.00
D3050	Terminal & Package Units	PTHP - 7000 BTU (LG or Amana)	EA	$3,419.00
D3050	Terminal & Package Units	PTHP - 12000 BTU (LG or Amana)	EA	$3,615.00
D3050	Terminal & Package Units	PTHP - 15000 BTU (LG or Amana)	EA	$3,695.00
D3050	Terminal & Package Units	Split Heat Pump - 9000 BTU (Daikin, Mitsubishi, or LG)	EA	$6,765.00
D3050	Terminal & Package Units	Split Heat Pump - 12000 BTU (Daikin, Mitsubishi, or LG)	EA	$7,005.00

Figure 8. Excerpt from Electrical Pricing Request

D50 - Electrical				
L3		**Description of Component**	**Unit**	**Price/Unit**
D5010	**Electrical Service & Distributior**	100A - Distribution Panel	EA	$1,700.00
D5010	**Electrical Service & Distributior**	125A - Distribution Panel	EA	$2,100.00
D5010	**Electrical Service & Distributior**	200A - Distribution Panel	EA	$3,200.00
D5010	**Electrical Service & Distributior**	Switchboards	Amps	$24.00
D5010	**Electrical Service & Distributior**	Transformers	KVA	$47.75
D5010	**Electrical Service & Distributior**	ATS	KVA	$50.00
D5010	**Electrical Service & Distributior**	Feeders, cable trays, conduit, etc	SF	$3.50
D5010	**Electrical Service & Distributior**	Grounding	SF	$1.80
D5010	**Electrical Service & Distributior**	Outlets and other low voltage devices	SF	$1.50
D5010	**Electrical Service & Distributior**	Conduit and wire to outlets and low voltage devices	SF	$1.50
D5010	**Electrical Service & Distributior**	Permits/Bonds/Manuals &Testing	SF	$2.30
D3090	**Other HVAC Systems & Equipm**	Allowance for Emergency Generator shroud/exhaust/sound attenuator	EA	$77,044
D5090	**Other Electrical Systems**	Emergency Generator 600 kW 3 phase diesel 277/480V c/w Brkrs. (B	EA	$233,804
D5090	**Other Electrical Systems**	Emergency Generator 500 kW 3 phase diesel 277/480V c/w Brkrs. (B	EA	$194,836
D5090	**Other Electrical Systems**	Emergency Generator 1000 kW 3 phase diesel 277/480V c/w Brkrs. (E	EA	$389,673
D5090	**Other Electrical Systems**	Emergency Generator	kW	$389.67
D5020	**Lighting and Branch Wiring**	Common area light fixtures (low cost, mostly dimmable LED can fixtur	SF of common are	$8.00
D5020	**Lighting and Branch Wiring**	Occupancy controls	SF of common are	$2.50
D5020	**Lighting and Branch Wiring**	Conduit and wire to light fixtures and controls	SF of common are	$2.00
D5020	**Lighting and Branch Wiring**	In-Unit Lighting - Fixtures, conduit, wiring, switches	LS	$3,980.00

4 RESULTS

This section summarizes the energy modeling and construction pricing results.

4.1 ENERGY MODELING RESULTS

This section summarizes the energy modeling results for three (3) different cities in Oregon, for the baseline and a variety of plumbing, HVAC, and envelope alternates.

4.1.1 Portland

The following tables summarize the energy use intensity (EUI) end use results for Portland, Oregon. All results are in units of kBtu/sf-yr.

Figure 9. Total Baseline Energy Results, Portland

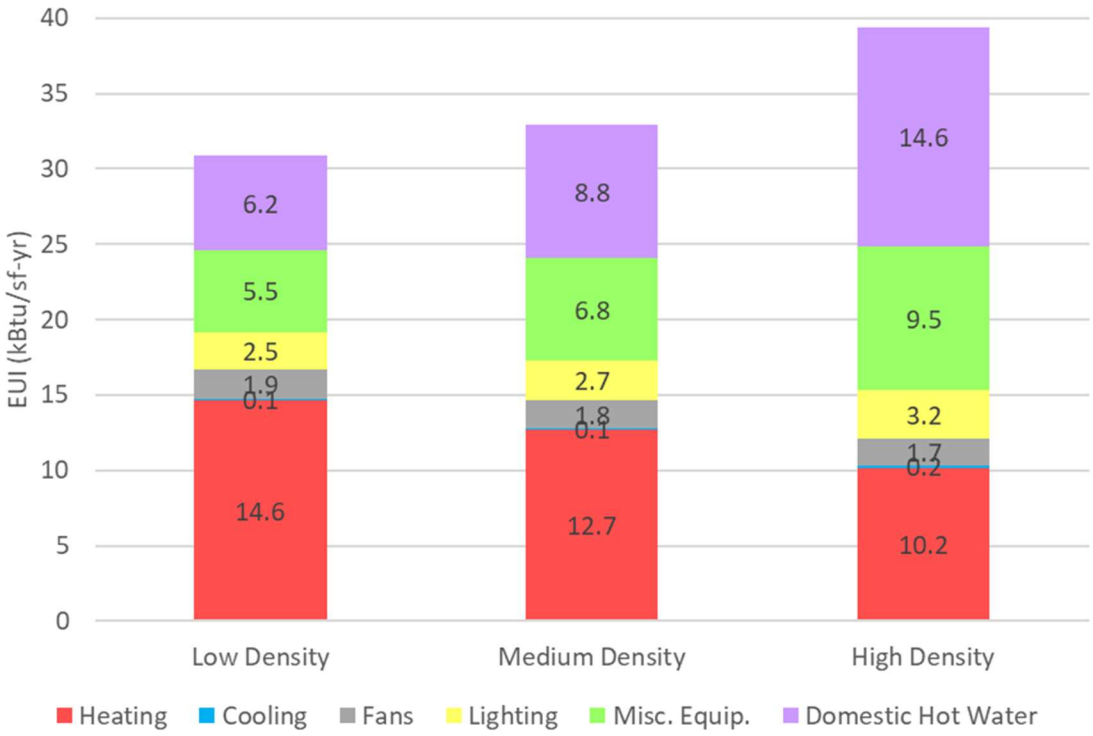

Table 27. Domestic Hot Water Heating Energy Results, Portland

Water Heating System	Dom. Hot Water EUI (kBtu/sf)		
	Low Density	Medium Density	High Density
Centralized Condensing Natural Gas Boilers (Baseline)	6.2	8.8	14.6
Centralized Heat Pump Water Heaters	2.0	2.8	4.6
In-Unit Electric Hot Water Heaters	5.4	7.7	12.8

Table 28. Low Density Baseline and Alternate HVAC Energy Results, Portland

Energy Results for Low Density Multifamily in Portland, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	14.6	0.1	1.9	16.7	
+ 10% UA Reduction	15.0	0.1	1.9	17.0	-1.0%
+ 20% UA Reduction	14.3	0.1	1.9	16.3	1.2%
+ 35% UA Reduction	13.4	0.1	1.9	15.3	4.4%
+ HRV (70% effect.)	4.7	0.3	3.1	8.1	27.9%
+ 10% UA Reduction	4.8	0.2	3.1	8.1	27.8%
+ 20% UA Reduction	4.2	0.3	3.1	7.5	29.6%
+ 35% UA Reduction	3.5	0.3	3.0	6.8	32.0%
PTHPs, Bedroom Electric Heat	8.5	1.0	2.1	11.6	16.4%
+ 10% UA Reduction	8.7	0.7	2.1	11.5	16.8%
+ 20% UA Reduction	8.4	0.7	2.0	11.2	17.8%
+ 35% UA Reduction	8.0	0.8	2.0	10.8	19.1%
+ HRV (70% effect.)	4.0	1.3	3.3	8.6	26.1%
+ 10% UA Reduction	4.0	1.1	3.3	8.3	27.1%
+ 20% UA Reduction	3.7	1.1	3.2	8.0	28.1%
+ 35% UA Reduction	3.3	1.1	3.2	7.6	29.3%
PTHPs, Ducted to Bedrooms	7.7	1.1	2.1	10.9	18.7%
+ 10% UA Reduction	7.8	0.8	2.1	10.7	19.3%
+ 20% UA Reduction	7.6	0.8	2.0	10.5	20.1%
+ 35% UA Reduction	7.3	0.8	2.0	10.2	21.2%
+ HRV (70% effect.)	3.9	1.5	3.3	8.7	26.0%
+ 10% UA Reduction	3.9	1.2	3.3	8.3	27.0%
+ 20% UA Reduction	3.6	1.2	3.2	8.1	27.9%
+ 35% UA Reduction	3.2	1.3	3.2	7.7	29.0%
Split System HPs, Bedroom Electric Heat	8.2	0.9	2.1	11.2	17.9%
+ 10% UA Reduction	8.3	0.7	2.1	11.1	18.2%
+ 20% UA Reduction	8.1	0.7	2.0	10.8	19.2%
+ 35% UA Reduction	7.7	0.7	2.0	10.4	20.5%
+ HRV (70% effect.)	3.8	1.2	3.3	8.3	27.2%
+ 10% UA Reduction	3.8	0.9	3.3	8.0	28.0%
+ 20% UA Reduction	3.5	1.0	3.2	7.7	29.0%
+ 35% UA Reduction	3.1	1.0	3.2	7.4	30.2%
Split System HPs, Ducted to Bedrooms	7.3	1.0	2.1	10.4	20.4%
+ 10% UA Reduction	7.4	0.7	2.1	10.2	20.9%
+ 20% UA Reduction	7.2	0.7	2.0	10.0	21.7%
+ 35% UA Reduction	6.9	0.8	2.0	9.7	22.7%
+ HRV (70% effect.)	3.7	1.3	3.3	8.3	27.2%
+ 10% UA Reduction	3.7	1.0	3.3	8.0	28.1%

+ 20% UA Reduction	3.4	1.0	3.2	7.7	29.0%
+ 35% UA Reduction	3.1	1.1	3.2	7.4	30.0%
VRF, Bedroom Electric Heat	7.2	0.9	2.1	10.2	21.0%
+ 10% UA Reduction	7.4	0.7	2.1	10.1	21.3%
+ 20% UA Reduction	7.1	0.7	2.0	9.8	22.3%
+ 35% UA Reduction	6.7	0.7	2.0	9.4	23.5%
+ HRV (70% effect.)	2.9	1.2	3.3	7.5	29.9%
+ 10% UA Reduction	3.0	0.9	3.3	7.2	30.8%
+ 20% UA Reduction	2.7	0.9	3.2	6.9	31.7%
+ 35% UA Reduction	2.3	1.0	3.2	6.6	32.8%
VRF, Ducted to Bedrooms	6.2	1.0	2.1	9.3	23.9%
+ 10% UA Reduction	6.3	0.7	2.1	9.2	24.4%
+ 20% UA Reduction	6.1	0.7	2.0	8.9	25.2%
+ 35% UA Reduction	5.8	0.7	2.0	8.6	26.2%
+ HRV (70% effect.)	2.7	1.3	3.3	7.3	30.3%
+ 10% UA Reduction	2.7	1.0	3.3	7.0	31.2%
+ 20% UA Reduction	2.5	1.0	3.2	6.8	32.1%
+ 35% UA Reduction	2.2	1.1	3.2	6.5	33.0%

Table 29. Medium Density Baseline and Alternate HVAC Energy Results, Portland

Energy Results for Medium Density Multifamily in Portland, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	12.7	0.1	1.8	14.7	
+ 10% UA Reduction	12.9	0.1	1.8	14.9	-0.7%
+ 20% UA Reduction	12.3	0.1	1.8	14.2	1.3%
+ 35% UA Reduction	11.4	0.1	1.8	13.3	4.1%
+ HRV (70% effect.)	3.7	0.3	2.9	7.0	23.4%
+ 10% UA Reduction	3.7	0.3	2.9	6.9	23.4%
+ 20% UA Reduction	3.2	0.3	2.9	6.4	25.0%
+ 35% UA Reduction	2.6	0.3	2.9	5.8	26.9%
PTHPs, Bedroom Electric Heat	7.7	1.1	2.0	10.9	11.5%
+ 10% UA Reduction	7.9	0.9	2.0	10.7	12.0%
+ 20% UA Reduction	7.6	0.9	2.0	10.4	12.9%
+ 35% UA Reduction	7.2	0.9	1.9	10.0	14.1%
+ HRV (70% effect.)	3.3	1.6	3.2	8.1	19.9%
+ 10% UA Reduction	3.3	1.3	3.2	7.8	20.9%
+ 20% UA Reduction	3.0	1.3	3.1	7.5	21.8%
+ 35% UA Reduction	2.6	1.4	3.1	7.1	22.9%
PTHPs, Ducted to Bedrooms	7.0	1.3	2.0	10.3	13.3%
+ 10% UA Reduction	7.1	1.0	2.0	10.1	13.9%
+ 20% UA Reduction	6.9	1.0	2.0	9.8	14.7%

+ 35% UA Reduction	6.6	1.0	1.9	9.5	15.6%
+ HRV (70% effect.)	3.3	1.8	3.2	8.2	19.5%
+ 10% UA Reduction	3.3	1.4	3.2	7.9	20.6%
+ 20% UA Reduction	3.0	1.4	3.1	7.6	21.5%
+ 35% UA Reduction	2.6	1.6	3.1	7.3	22.4%
Split System HPs, Bedroom Electric Heat	7.4	1.0	2.0	10.4	12.9%
+ 10% UA Reduction	7.5	0.8	2.0	10.3	13.3%
+ 20% UA Reduction	7.3	0.8	2.0	10.0	14.2%
+ 35% UA Reduction	6.9	0.8	1.9	9.6	15.3%
+ HRV (70% effect.)	3.2	1.4	3.2	7.8	20.8%
+ 10% UA Reduction	3.2	1.1	3.2	7.5	21.8%
+ 20% UA Reduction	2.9	1.2	3.1	7.2	22.7%
+ 35% UA Reduction	2.5	1.2	3.1	6.9	23.7%
Split System HPs, Ducted to Bedrooms	6.6	1.1	2.0	9.8	14.8%
+ 10% UA Reduction	6.7	0.9	2.0	9.6	15.4%
+ 20% UA Reduction	6.5	0.9	2.0	9.4	16.1%
+ 35% UA Reduction	6.2	0.9	1.9	9.0	17.0%
+ HRV (70% effect.)	3.1	1.6	3.2	7.9	20.6%
+ 10% UA Reduction	3.1	1.3	3.2	7.5	21.6%
+ 20% UA Reduction	2.8	1.3	3.1	7.3	22.4%
+ 35% UA Reduction	2.5	1.4	3.1	7.0	23.3%
VRF, Bedroom Electric Heat	6.5	1.0	2.0	9.5	15.7%
+ 10% UA Reduction	6.6	0.8	2.0	9.4	16.1%
+ 20% UA Reduction	6.3	0.8	2.0	9.1	17.0%
+ 35% UA Reduction	6.0	0.8	1.9	8.7	18.1%
+ HRV (70% effect.)	2.4	1.4	3.2	7.0	23.2%
+ 10% UA Reduction	2.4	1.1	3.2	6.7	24.2%
+ 20% UA Reduction	2.1	1.2	3.1	6.4	25.0%
+ 35% UA Reduction	1.7	1.2	3.1	6.1	25.9%
VRF, Ducted to Bedrooms	5.6	1.1	2.0	8.7	18.0%
+ 10% UA Reduction	5.7	0.9	2.0	8.5	18.6%
+ 20% UA Reduction	5.5	0.9	2.0	8.3	19.3%
+ 35% UA Reduction	5.2	0.9	1.9	8.0	20.2%
+ HRV (70% effect.)	2.2	1.6	3.2	7.0	23.3%
+ 10% UA Reduction	2.2	1.3	3.2	6.6	24.4%
+ 20% UA Reduction	2.0	1.3	3.1	6.4	25.1%
+ 35% UA Reduction	1.6	1.4	3.1	6.1	25.9%

Table 30. High Density Baseline and Alternate HVAC Energy Results, Portland

Energy Results for High Density Multifamily in Portland, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	10.2	0.2	1.7	12.1	
+ 10% UA Reduction	10.3	0.2	1.7	12.3	-0.4%
+ 20% UA Reduction	9.7	0.2	1.7	11.6	1.2%
+ 35% UA Reduction	8.9	0.2	1.7	10.7	3.5%
+ HRV (70% effect.)	2.2	0.4	2.9	5.5	16.8%
+ 10% UA Reduction	2.1	0.4	2.9	5.4	16.9%
+ 20% UA Reduction	1.7	0.4	2.9	5.1	17.9%
+ 35% UA Reduction	1.3	0.4	2.9	4.6	19.0%
PTHPs, Bedroom Electric Heat	7.0	1.3	2.0	10.3	4.6%
+ 10% UA Reduction	7.1	1.1	1.9	10.1	5.0%
+ 20% UA Reduction	6.8	1.1	1.9	9.8	5.9%
+ 35% UA Reduction	6.4	1.1	1.9	9.4	7.0%
+ HRV (70% effect.)	2.2	2.0	3.3	7.5	11.8%
+ 10% UA Reduction	2.2	1.7	3.2	7.1	12.7%
+ 20% UA Reduction	1.9	1.8	3.2	6.8	13.4%
+ 35% UA Reduction	1.5	1.9	3.2	6.6	14.0%
PTHPs, Ducted to Bedrooms	6.1	1.6	2.0	9.7	6.1%
+ 10% UA Reduction	6.2	1.3	1.9	9.4	6.8%
+ 20% UA Reduction	5.9	1.3	1.9	9.2	7.4%
+ 35% UA Reduction	5.6	1.4	1.9	8.9	8.2%
+ HRV (70% effect.)	2.2	2.4	3.3	8.0	10.5%
+ 10% UA Reduction	2.2	2.1	3.2	7.5	11.7%
+ 20% UA Reduction	1.9	2.2	3.2	7.3	12.3%
+ 35% UA Reduction	1.5	2.3	3.2	7.1	12.7%
Split System HPs, Bedroom Electric Heat	6.8	1.2	2.0	9.9	5.5%
+ 10% UA Reduction	6.9	1.0	1.9	9.8	6.0%
+ 20% UA Reduction	6.6	1.0	1.9	9.4	6.8%
+ 35% UA Reduction	6.1	1.0	1.9	9.0	7.9%
+ HRV (70% effect.)	2.1	1.8	3.3	7.2	12.5%
+ 10% UA Reduction	2.1	1.5	3.2	6.8	13.3%
+ 20% UA Reduction	1.8	1.6	3.2	6.6	14.0%
+ 35% UA Reduction	1.4	1.7	3.2	6.4	14.6%
Split System HPs, Ducted to Bedrooms	5.8	1.4	2.0	9.2	7.4%
+ 10% UA Reduction	5.8	1.2	1.9	8.9	8.0%
+ 20% UA Reduction	5.6	1.2	1.9	8.7	8.6%
+ 35% UA Reduction	5.3	1.2	1.9	8.4	9.3%
+ HRV (70% effect.)	2.1	2.2	3.3	7.6	11.5%
+ 10% UA Reduction	2.1	1.9	3.2	7.2	12.5%

+ 20% UA Reduction	1.8	1.9	3.2	7.0	13.1%
+ 35% UA Reduction	1.5	2.1	3.2	6.8	13.5%
VRF, Bedroom Electric Heat	6.0	1.2	2.0	9.1	7.5%
+ 10% UA Reduction	6.1	1.0	1.9	9.0	8.0%
+ 20% UA Reduction	5.8	0.9	1.9	8.6	8.8%
+ 35% UA Reduction	5.3	1.0	1.9	8.2	9.9%
+ HRV (70% effect.)	1.5	1.8	3.3	6.6	14.0%
+ 10% UA Reduction	1.5	1.5	3.2	6.2	14.9%
+ 20% UA Reduction	1.2	1.6	3.2	6.0	15.4%
+ 35% UA Reduction	0.9	1.7	3.2	5.8	15.9%
VRF, Ducted to Bedrooms	4.7	1.4	2.0	8.2	10.0%
+ 10% UA Reduction	4.8	1.2	1.9	7.9	10.6%
+ 20% UA Reduction	4.6	1.2	1.9	7.7	11.2%
+ 35% UA Reduction	4.3	1.2	1.9	7.4	11.9%
+ HRV (70% effect.)	1.4	2.2	3.3	6.8	13.5%
+ 10% UA Reduction	1.3	1.9	3.2	6.4	14.5%
+ 20% UA Reduction	1.1	1.9	3.2	6.2	15.0%
+ 35% UA Reduction	0.8	2.1	3.2	6.1	15.2%

4.1.2 Salem

The following tables summarize the energy use intensity (EUI) end use results for Salem, Oregon. All results are in units of kBtu/sf-yr.

Figure 10. Total Baseline Energy Results, Salem

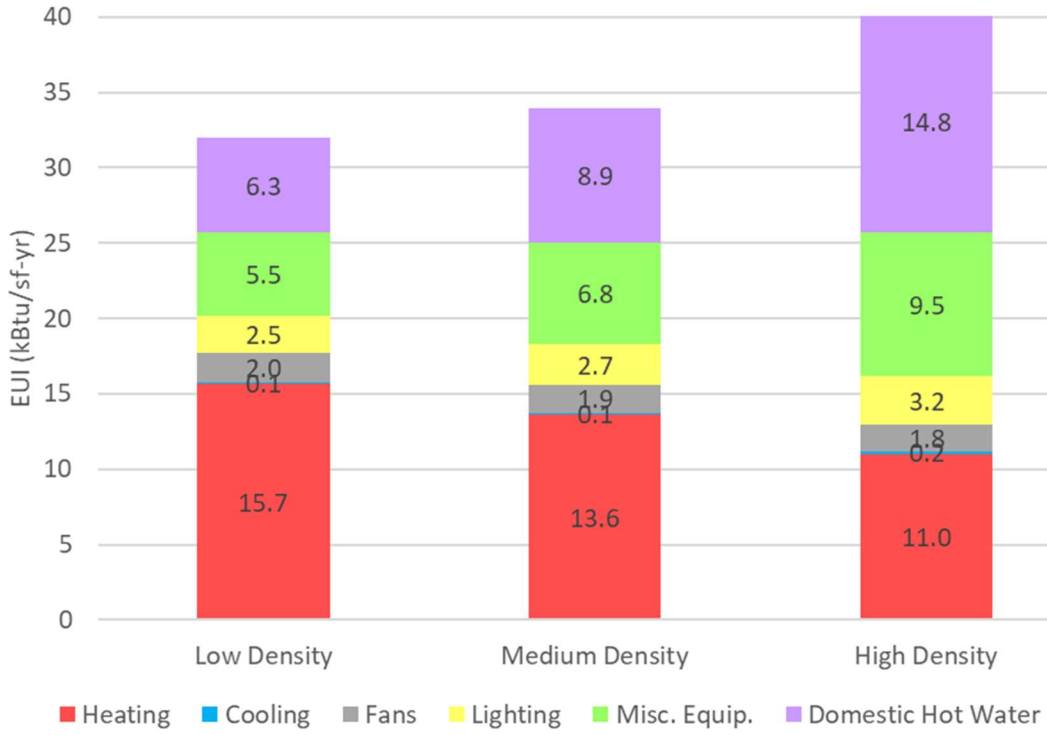

Table 31. Domestic Hot Water Heating Energy Results, Salem

Water Heating System	Dom. Hot Water EUI (kBtu/sf)		
	Low Density	Medium Density	High Density
Centralized Condensing Natural Gas Boilers (Baseline)	6.3	8.9	14.8
Centralized Heat Pump Water Heaters	2.0	2.8	4.6
In-Unit Electric Hot Water Heaters	5.5	7.8	12.9

Table 32. Low Density Baseline and Alternate HVAC Energy Results, Salem

Energy Results for Low Density Multifamily in Salem, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	15.7	0.1	2.0	17.7	
+ 10% UA Reduction	16.0	0.1	2.0	18.1	-1.1%
+ 20% UA Reduction	15.3	0.1	1.9	17.4	1.1%
+ 35% UA Reduction	14.3	0.1	1.9	16.3	4.4%
+ HRV (70% effect.)	5.1	0.3	3.1	8.5	29.0%
+ 10% UA Reduction	5.2	0.2	3.1	8.5	28.8%
+ 20% UA Reduction	4.6	0.2	3.1	7.9	30.7%

+ 35% UA Reduction	3.8	0.3	3.0	7.1	33.1%
PTHPs, Bedroom Electric Heat	9.8	1.0	2.2	13.0	14.7%
+ 10% UA Reduction	10.0	0.8	2.1	12.9	15.1%
+ 20% UA Reduction	9.7	0.8	2.1	12.6	16.1%
+ 35% UA Reduction	9.3	0.8	2.1	12.1	17.5%
+ HRV (70% effect.)	4.8	1.4	3.4	9.5	25.7%
+ 10% UA Reduction	4.8	1.1	3.3	9.2	26.6%
+ 20% UA Reduction	4.5	1.1	3.3	8.9	27.7%
+ 35% UA Reduction	4.0	1.2	3.3	8.5	29.0%
PTHPs, Ducted to Bedrooms	9.0	1.1	2.2	12.4	16.8%
+ 10% UA Reduction	9.2	0.9	2.1	12.2	17.4%
+ 20% UA Reduction	8.9	0.9	2.1	11.9	18.2%
+ 35% UA Reduction	8.6	0.9	2.1	11.5	19.4%
+ HRV (70% effect.)	4.7	1.5	3.4	9.6	25.4%
+ 10% UA Reduction	4.8	1.2	3.3	9.3	26.4%
+ 20% UA Reduction	4.5	1.2	3.3	9.0	27.4%
+ 35% UA Reduction	4.0	1.3	3.3	8.6	28.5%
Split System HPs, Bedroom Electric Heat	9.0	0.9	2.2	12.1	17.7%
+ 10% UA Reduction	9.1	0.7	2.1	12.0	18.0%
+ 20% UA Reduction	8.9	0.7	2.1	11.7	19.0%
+ 35% UA Reduction	8.4	0.7	2.1	11.2	20.4%
+ HRV (70% effect.)	4.2	1.2	3.3	8.8	28.0%
+ 10% UA Reduction	4.3	1.0	3.3	8.5	28.8%
+ 20% UA Reduction	4.0	1.0	3.3	8.2	29.8%
+ 35% UA Reduction	3.5	1.0	3.3	7.8	31.0%
Split System HPs, Ducted to Bedrooms	8.1	1.0	2.2	11.3	20.2%
+ 10% UA Reduction	8.2	0.8	2.1	11.1	20.7%
+ 20% UA Reduction	8.0	0.8	2.1	10.9	21.5%
+ 35% UA Reduction	7.6	0.8	2.1	10.5	22.6%
+ HRV (70% effect.)	4.1	1.4	3.3	8.8	27.9%
+ 10% UA Reduction	4.1	1.1	3.3	8.5	28.9%
+ 20% UA Reduction	3.9	1.1	3.3	8.2	29.8%
+ 35% UA Reduction	3.5	1.1	3.3	7.9	30.9%
VRF, Bedroom Electric Heat	7.9	0.9	2.2	11.0	21.1%
+ 10% UA Reduction	8.0	0.7	2.1	10.9	21.4%
+ 20% UA Reduction	7.8	0.7	2.1	10.6	22.4%
+ 35% UA Reduction	7.4	0.7	2.1	10.1	23.8%
+ HRV (70% effect.)	3.3	1.2	3.3	7.8	31.0%
+ 10% UA Reduction	3.3	1.0	3.3	7.5	31.9%
+ 20% UA Reduction	3.0	1.0	3.3	7.2	32.9%
+ 35% UA Reduction	2.6	1.0	3.2	6.8	34.0%

VRF, Ducted to Bedrooms	6.9	1.0	2.2	10.1	24.0%
+ 10% UA Reduction	7.0	0.8	2.1	9.9	24.5%
+ 20% UA Reduction	6.8	0.8	2.1	9.6	25.3%
+ 35% UA Reduction	6.4	0.8	2.1	9.3	26.4%
+ HRV (70% effect.)	3.0	1.4	3.3	7.7	31.4%
+ 10% UA Reduction	3.0	1.1	3.3	7.4	32.4%
+ 20% UA Reduction	2.8	1.1	3.3	7.1	33.2%
+ 35% UA Reduction	2.4	1.1	3.2	6.8	34.3%

Table 33. Medium Density Baseline and Alternate HVAC Energy Results, Salem

Energy Results for Medium Density Multifamily in Salem, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	13.6	0.1	1.9	15.6	
+ 10% UA Reduction	13.9	0.1	1.9	15.9	-0.8%
+ 20% UA Reduction	13.3	0.1	1.8	15.2	1.2%
+ 35% UA Reduction	12.3	0.1	1.8	14.2	4.2%
+ HRV (70% effect.)	4.0	0.3	3.0	7.3	24.5%
+ 10% UA Reduction	4.1	0.3	3.0	7.3	24.4%
+ 20% UA Reduction	3.6	0.3	2.9	6.8	26.0%
+ 35% UA Reduction	2.8	0.3	2.9	6.1	28.1%
PTHPs, Bedroom Electric Heat	9.0	1.1	2.1	12.2	10.0%
+ 10% UA Reduction	9.1	0.9	2.1	12.0	10.5%
+ 20% UA Reduction	8.8	0.9	2.0	11.7	11.5%
+ 35% UA Reduction	8.4	0.9	2.0	11.3	12.8%
+ HRV (70% effect.)	4.1	1.6	3.3	9.0	19.6%
+ 10% UA Reduction	4.1	1.3	3.2	8.6	20.6%
+ 20% UA Reduction	3.8	1.3	3.2	8.3	21.6%
+ 35% UA Reduction	3.3	1.4	3.2	7.9	22.8%
PTHPs, Ducted to Bedrooms	8.3	1.3	2.1	11.7	11.6%
+ 10% UA Reduction	8.4	1.0	2.1	11.4	12.3%
+ 20% UA Reduction	8.2	1.0	2.0	11.2	13.1%
+ 35% UA Reduction	7.8	1.0	2.0	10.8	14.1%
+ HRV (70% effect.)	4.1	1.8	3.3	9.1	19.0%
+ 10% UA Reduction	4.1	1.4	3.2	8.8	20.2%
+ 20% UA Reduction	3.8	1.5	3.2	8.5	21.1%
+ 35% UA Reduction	3.4	1.6	3.2	8.1	22.1%
Split System HPs, Bedroom Electric Heat	8.2	1.0	2.1	11.3	12.7%
+ 10% UA Reduction	8.3	0.8	2.0	11.1	13.2%
+ 20% UA Reduction	8.0	0.8	2.0	10.8	14.1%
+ 35% UA Reduction	7.6	0.8	2.0	10.4	15.4%
+ HRV (70% effect.)	3.6	1.4	3.2	8.3	21.7%

+ 10% UA Reduction	3.6	1.2	3.2	7.9	22.6%
+ 20% UA Reduction	3.3	1.2	3.2	7.6	23.5%
+ 35% UA Reduction	2.8	1.2	3.2	7.3	24.6%
Split System HPs, Ducted to Bedrooms	7.4	1.1	2.1	10.6	14.7%
+ 10% UA Reduction	7.5	0.9	2.0	10.4	15.3%
+ 20% UA Reduction	7.3	0.9	2.0	10.2	16.0%
+ 35% UA Reduction	6.9	0.9	2.0	9.8	17.0%
+ HRV (70% effect.)	3.5	1.6	3.2	8.4	21.4%
+ 10% UA Reduction	3.5	1.3	3.2	8.0	22.4%
+ 20% UA Reduction	3.3	1.3	3.2	7.7	23.3%
+ 35% UA Reduction	2.8	1.4	3.2	7.4	24.2%
VRF, Bedroom Electric Heat	7.1	1.0	2.1	10.2	15.9%
+ 10% UA Reduction	7.2	0.8	2.0	10.1	16.3%
+ 20% UA Reduction	7.0	0.8	2.0	9.8	17.2%
+ 35% UA Reduction	6.5	0.8	2.0	9.3	18.5%
+ HRV (70% effect.)	2.7	1.4	3.2	7.3	24.4%
+ 10% UA Reduction	2.7	1.1	3.2	7.0	25.3%
+ 20% UA Reduction	2.4	1.2	3.2	6.7	26.2%
+ 35% UA Reduction	2.0	1.2	3.2	6.4	27.3%
VRF, Ducted to Bedrooms	6.2	1.1	2.1	9.4	18.3%
+ 10% UA Reduction	6.3	0.9	2.0	9.2	18.9%
+ 20% UA Reduction	6.1	0.9	2.0	8.9	19.6%
+ 35% UA Reduction	5.7	0.9	2.0	8.6	20.6%
+ HRV (70% effect.)	2.5	1.6	3.2	7.3	24.5%
+ 10% UA Reduction	2.5	1.3	3.2	6.9	25.6%
+ 20% UA Reduction	2.2	1.3	3.2	6.7	26.4%
+ 35% UA Reduction	1.8	1.4	3.2	6.4	27.2%

Table 34. High Density Baseline and Alternate HVAC Energy Results, Salem

Energy Results for High Density Multifamily in Salem, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	11.0	0.2	1.8	13.0	
+ 10% UA Reduction	11.2	0.2	1.8	13.2	-0.4%
+ 20% UA Reduction	10.6	0.2	1.7	12.5	1.2%
+ 35% UA Reduction	9.7	0.2	1.7	11.5	3.5%
+ HRV (70% effect.)	2.5	0.4	2.9	5.8	17.8%
+ 10% UA Reduction	2.4	0.4	2.9	5.7	17.9%
+ 20% UA Reduction	2.0	0.4	2.9	5.3	19.0%
+ 35% UA Reduction	1.5	0.4	2.9	4.8	20.2%
PTHPs, Bedroom Electric Heat	8.2	1.3	2.0	11.5	3.6%
+ 10% UA Reduction	8.2	1.1	2.0	11.3	4.1%

+ 20% UA Reduction	7.9	1.1	2.0	11.0	5.0%
+ 35% UA Reduction	7.4	1.1	2.0	10.5	6.2%
+ HRV (70% effect.)	2.9	2.0	3.3	8.2	11.9%
+ 10% UA Reduction	2.8	1.7	3.3	7.8	12.9%
+ 20% UA Reduction	2.5	1.7	3.3	7.5	13.6%
+ 35% UA Reduction	2.0	1.9	3.3	7.2	14.4%
PTHPs, Ducted to Bedrooms	7.3	1.6	2.0	11.0	4.9%
+ 10% UA Reduction	7.4	1.3	2.0	10.7	5.6%
+ 20% UA Reduction	7.1	1.3	2.0	10.4	6.3%
+ 35% UA Reduction	6.8	1.4	2.0	10.1	7.1%
+ HRV (70% effect.)	3.0	2.4	3.3	8.8	10.4%
+ 10% UA Reduction	2.9	2.1	3.3	8.3	11.6%
+ 20% UA Reduction	2.6	2.1	3.3	8.0	12.3%
+ 35% UA Reduction	2.2	2.3	3.3	7.8	12.9%
Split System HPs, Bedroom Electric Heat	7.5	1.2	2.0	10.7	5.6%
+ 10% UA Reduction	7.6	1.0	2.0	10.5	6.0%
+ 20% UA Reduction	7.3	0.9	2.0	10.2	6.9%
+ 35% UA Reduction	6.8	1.0	1.9	9.7	8.0%
+ HRV (70% effect.)	2.5	1.8	3.3	7.6	13.4%
+ 10% UA Reduction	2.4	1.5	3.2	7.2	14.3%
+ 20% UA Reduction	2.1	1.5	3.2	6.9	15.0%
+ 35% UA Reduction	1.7	1.7	3.2	6.7	15.6%
Split System HPs, Ducted to Bedrooms	6.5	1.5	2.0	10.0	7.5%
+ 10% UA Reduction	6.5	1.2	2.0	9.7	8.1%
+ 20% UA Reduction	6.3	1.2	2.0	9.4	8.7%
+ 35% UA Reduction	5.9	1.2	1.9	9.1	9.5%
+ HRV (70% effect.)	2.5	2.2	3.3	8.0	12.3%
+ 10% UA Reduction	2.5	1.9	3.2	7.6	13.4%
+ 20% UA Reduction	2.2	1.9	3.2	7.3	14.0%
+ 35% UA Reduction	1.8	2.0	3.2	7.1	14.5%
VRF, Bedroom Electric Heat	6.6	1.2	2.0	9.8	7.9%
+ 10% UA Reduction	6.7	1.0	2.0	9.6	8.3%
+ 20% UA Reduction	6.4	0.9	2.0	9.3	9.2%
+ 35% UA Reduction	5.9	1.0	1.9	8.8	10.3%
+ HRV (70% effect.)	1.8	1.8	3.3	6.8	15.2%
+ 10% UA Reduction	1.7	1.5	3.2	6.5	16.1%
+ 20% UA Reduction	1.4	1.5	3.2	6.2	16.7%
+ 35% UA Reduction	1.1	1.7	3.2	6.0	17.2%
VRF, Ducted to Bedrooms	5.3	1.5	2.0	8.8	10.4%
+ 10% UA Reduction	5.3	1.2	2.0	8.5	11.0%
+ 20% UA Reduction	5.1	1.2	2.0	8.3	11.7%

+ 35% UA Reduction	4.8	1.2	1.9	7.9	12.5%
+ HRV (70% effect.)	1.6	2.2	3.3	7.0	14.7%
+ 10% UA Reduction	1.5	1.9	3.2	6.6	15.7%
+ 20% UA Reduction	1.3	1.9	3.2	6.4	16.3%
+ 35% UA Reduction	1.0	2.0	3.2	6.3	16.6%

4.1.1 Medford

The following tables summarize the energy use intensity (EUI) end use results for Medford, Oregon. All results are in units of kBtu/sf-yr.

Table 35. Total Baseline Energy Results, Medford

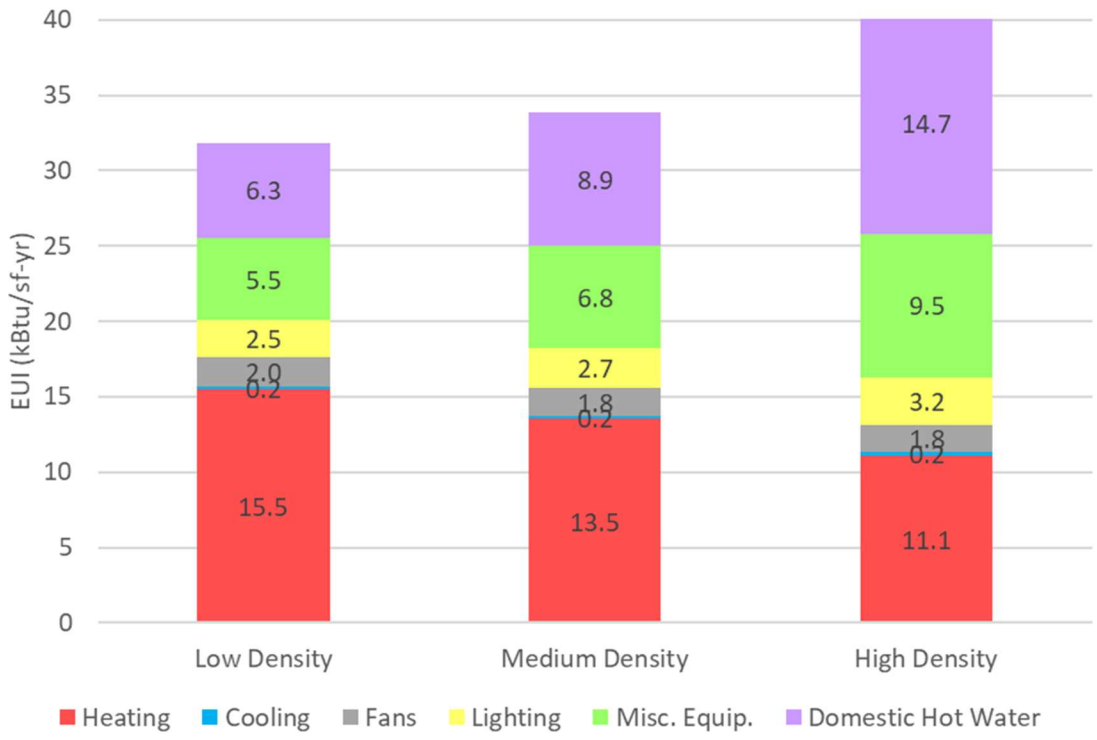

Table 36. Domestic Hot Water Heating Energy Results, Medford

Water Heating System	Dom. Hot Water EUI (kBtu/sf)		
	Low Density	Medium Density	High Density
Centralized Condensing Natural Gas Boilers (Baseline)	6.3	8.9	14.7
Centralized Heat Pump Water Heaters	2.0	2.8	4.6
In-Unit Electric Hot Water Heaters	5.5	7.8	12.9

Table 37. Low Density Baseline and Alternate HVAC Energy Results, Medford

Energy Results for Low Density Multifamily in Medford, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	15.5	0.2	2.0	17.6	
+ 10% UA Reduction	15.9	0.2	2.0	18.0	-1.3%
+ 20% UA Reduction	15.3	0.2	1.9	17.4	0.7%
+ 35% UA Reduction	14.3	0.2	1.9	16.4	3.7%
+ HRV (70% effect.)	4.8	0.3	3.1	8.3	29.4%
+ 10% UA Reduction	5.0	0.3	3.1	8.4	28.9%
+ 20% UA Reduction	4.5	0.3	3.1	7.8	30.7%
+ 35% UA Reduction	3.7	0.3	3.0	7.1	33.0%
PTHPs, Bedroom Electric Heat	9.5	1.5	2.2	13.2	13.8%
+ 10% UA Reduction	9.7	1.2	2.2	13.0	14.4%
+ 20% UA Reduction	9.4	1.1	2.2	12.7	15.4%
+ 35% UA Reduction	9.0	1.1	2.1	12.3	16.7%
+ HRV (70% effect.)	4.5	1.8	3.4	9.7	24.9%
+ 10% UA Reduction	4.5	1.4	3.4	9.3	26.0%
+ 20% UA Reduction	4.2	1.4	3.3	9.0	27.1%
+ 35% UA Reduction	3.8	1.5	3.3	8.6	28.3%
PTHPs, Ducted to Bedrooms	8.7	1.6	2.2	12.6	15.8%
+ 10% UA Reduction	8.8	1.3	2.2	12.3	16.6%
+ 20% UA Reduction	8.6	1.3	2.2	12.1	17.4%
+ 35% UA Reduction	8.3	1.3	2.1	11.7	18.5%
+ HRV (70% effect.)	4.4	2.0	3.4	9.8	24.4%
+ 10% UA Reduction	4.5	1.6	3.4	9.4	25.7%
+ 20% UA Reduction	4.2	1.6	3.3	9.1	26.7%
+ 35% UA Reduction	3.8	1.6	3.3	8.8	27.8%
Split System HPs, Bedroom Electric Heat	8.9	1.3	2.3	12.4	16.2%
+ 10% UA Reduction	9.0	1.0	2.2	12.3	16.7%
+ 20% UA Reduction	8.8	1.0	2.2	12.0	17.7%
+ 35% UA Reduction	8.4	1.0	2.1	11.6	19.0%
+ HRV (70% effect.)	4.0	1.6	3.4	9.1	26.9%
+ 10% UA Reduction	4.1	1.3	3.3	8.7	27.9%
+ 20% UA Reduction	3.8	1.3	3.3	8.4	28.9%
+ 35% UA Reduction	3.4	1.3	3.3	8.0	30.1%
Split System HPs, Ducted to Bedrooms	8.0	1.5	2.3	11.7	18.6%
+ 10% UA Reduction	8.1	1.2	2.2	11.5	19.3%
+ 20% UA Reduction	7.9	1.1	2.2	11.2	20.1%
+ 35% UA Reduction	7.6	1.1	2.1	10.9	21.1%
+ HRV (70% effect.)	3.9	1.8	3.4	9.1	26.7%
+ 10% UA Reduction	4.0	1.4	3.3	8.8	27.8%

+ 20% UA Reduction	3.7	1.4	3.3	8.5	28.8%
+ 35% UA Reduction	3.4	1.5	3.3	8.1	29.8%
VRF, Bedroom Electric Heat	7.9	1.3	2.3	11.4	19.4%
+ 10% UA Reduction	8.1	1.0	2.2	11.3	19.8%
+ 20% UA Reduction	7.8	1.0	2.2	11.0	20.8%
+ 35% UA Reduction	7.4	1.0	2.1	10.6	22.1%
+ HRV (70% effect.)	3.2	1.6	3.4	8.2	29.7%
+ 10% UA Reduction	3.2	1.3	3.3	7.8	30.7%
+ 20% UA Reduction	2.9	1.3	3.3	7.5	31.7%
+ 35% UA Reduction	2.5	1.3	3.3	7.2	32.8%
VRF, Ducted to Bedrooms	6.9	1.4	2.3	10.6	22.1%
+ 10% UA Reduction	7.0	1.1	2.2	10.3	22.8%
+ 20% UA Reduction	6.8	1.1	2.2	10.1	23.6%
+ 35% UA Reduction	6.5	1.1	2.1	9.8	24.7%
+ HRV (70% effect.)	2.9	1.8	3.4	8.1	29.8%
+ 10% UA Reduction	3.0	1.4	3.3	7.7	31.0%
+ 20% UA Reduction	2.7	1.4	3.3	7.4	31.9%
+ 35% UA Reduction	2.4	1.5	3.3	7.1	32.9%

Table 38. Medium Density Baseline and Alternate HVAC Energy Results, Medford

Energy Results for Medium Density Multifamily in Medford, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	13.5	0.2	1.8	15.6	
+ 10% UA Reduction	13.9	0.2	1.9	16.0	-1.1%
+ 20% UA Reduction	13.3	0.2	1.8	15.3	0.8%
+ 35% UA Reduction	12.4	0.2	1.8	14.4	3.6%
+ HRV (70% effect.)	3.8	0.4	2.9	7.1	24.9%
+ 10% UA Reduction	3.9	0.3	2.9	7.2	24.7%
+ 20% UA Reduction	3.4	0.4	2.9	6.7	26.2%
+ 35% UA Reduction	2.8	0.4	2.9	6.1	28.1%
PTHPs, Bedroom Electric Heat	8.7	1.6	2.2	12.5	9.2%
+ 10% UA Reduction	8.9	1.3	2.1	12.3	9.8%
+ 20% UA Reduction	8.6	1.3	2.1	11.9	10.8%
+ 35% UA Reduction	8.2	1.3	2.1	11.5	12.0%
+ HRV (70% effect.)	3.8	2.0	3.3	9.2	18.9%
+ 10% UA Reduction	3.9	1.7	3.3	8.8	20.1%
+ 20% UA Reduction	3.5	1.7	3.2	8.5	21.1%
+ 35% UA Reduction	3.1	1.7	3.2	8.1	22.1%
PTHPs, Ducted to Bedrooms	8.0	1.8	2.2	12.0	10.7%
+ 10% UA Reduction	8.1	1.5	2.1	11.7	11.5%

+ 20% UA Reduction	7.9	1.4	2.1	11.4	12.4%
+ 35% UA Reduction	7.6	1.4	2.1	11.1	13.3%
+ HRV (70% effect.)	3.8	2.3	3.3	9.4	18.2%
+ 10% UA Reduction	3.8	1.9	3.3	9.0	19.5%
+ 20% UA Reduction	3.6	1.9	3.2	8.7	20.4%
+ 35% UA Reduction	3.2	1.9	3.2	8.3	21.4%
Split System HPs, Bedroom Electric Heat	8.1	1.4	2.2	11.7	11.5%
+ 10% UA Reduction	8.3	1.2	2.1	11.5	12.0%
+ 20% UA Reduction	8.0	1.1	2.1	11.2	12.9%
+ 35% UA Reduction	7.6	1.2	2.1	10.8	14.1%
+ HRV (70% effect.)	3.4	1.8	3.3	8.6	20.7%
+ 10% UA Reduction	3.5	1.5	3.2	8.2	21.8%
+ 20% UA Reduction	3.2	1.5	3.2	7.9	22.7%
+ 35% UA Reduction	2.8	1.6	3.2	7.5	23.7%
Split System HPs, Ducted to Bedrooms	7.3	1.6	2.2	11.1	13.3%
+ 10% UA Reduction	7.4	1.3	2.1	10.8	14.0%
+ 20% UA Reduction	7.2	1.3	2.1	10.6	14.8%
+ 35% UA Reduction	6.9	1.3	2.1	10.2	15.8%
+ HRV (70% effect.)	3.4	2.0	3.3	8.7	20.2%
+ 10% UA Reduction	3.4	1.7	3.2	8.3	21.5%
+ 20% UA Reduction	3.1	1.6	3.2	8.0	22.3%
+ 35% UA Reduction	2.8	1.7	3.2	7.7	23.2%
VRF, Bedroom Electric Heat	7.1	1.4	2.2	10.7	14.3%
+ 10% UA Reduction	7.3	1.1	2.1	10.5	14.9%
+ 20% UA Reduction	7.0	1.1	2.1	10.2	15.8%
+ 35% UA Reduction	6.6	1.1	2.1	9.8	17.0%
+ HRV (70% effect.)	2.6	1.8	3.3	7.7	23.2%
+ 10% UA Reduction	2.6	1.5	3.2	7.4	24.3%
+ 20% UA Reduction	2.3	1.5	3.2	7.0	25.2%
+ 35% UA Reduction	2.0	1.6	3.2	6.7	26.1%
VRF, Ducted to Bedrooms	6.2	1.6	2.2	10.0	16.6%
+ 10% UA Reduction	6.3	1.3	2.1	9.7	17.3%
+ 20% UA Reduction	6.1	1.3	2.1	9.5	18.1%
+ 35% UA Reduction	5.8	1.3	2.1	9.1	19.0%
+ HRV (70% effect.)	2.4	2.0	3.3	7.8	23.1%
+ 10% UA Reduction	2.4	1.6	3.2	7.3	24.4%
+ 20% UA Reduction	2.2	1.6	3.2	7.0	25.2%
+ 35% UA Reduction	1.8	1.7	3.2	6.8	26.0%

Table 39. High Density Baseline and Alternate HVAC Energy Results, Medford

Energy Results for High Density Multifamily in Medford, OR	Heating	Cooling	Fans	HVAC Total	Baseline Savings
Electric Resistance Heat, No Cooling	11.1	0.3	1.8	13.1	
+ 10% UA Reduction	11.4	0.2	1.8	13.4	-0.7%
+ 20% UA Reduction	10.8	0.2	1.8	12.8	0.9%
+ 35% UA Reduction	9.9	0.2	1.7	11.9	3.1%
+ HRV (70% effect.)	2.3	0.4	2.9	5.7	18.4%
+ 10% UA Reduction	2.4	0.4	2.9	5.7	18.3%
+ 20% UA Reduction	1.9	0.4	2.9	5.3	19.4%
+ 35% UA Reduction	1.4	0.4	2.9	4.8	20.6%
PTHPs, Bedroom Electric Heat	8.0	1.8	2.1	11.9	3.0%
+ 10% UA Reduction	8.1	1.5	2.1	11.7	3.5%
+ 20% UA Reduction	7.8	1.4	2.1	11.3	4.4%
+ 35% UA Reduction	7.4	1.5	2.0	10.9	5.5%
+ HRV (70% effect.)	2.7	2.4	3.4	8.5	11.4%
+ 10% UA Reduction	2.7	2.1	3.3	8.0	12.5%
+ 20% UA Reduction	2.3	2.1	3.3	7.7	13.3%
+ 35% UA Reduction	1.9	2.2	3.3	7.4	14.0%
PTHPs, Ducted to Bedrooms	7.1	2.2	2.1	11.4	4.2%
+ 10% UA Reduction	7.2	1.8	2.1	11.1	5.0%
+ 20% UA Reduction	6.9	1.8	2.1	10.8	5.7%
+ 35% UA Reduction	6.6	1.8	2.0	10.5	6.5%
+ HRV (70% effect.)	2.8	3.0	3.4	9.2	9.7%
+ 10% UA Reduction	2.7	2.5	3.3	8.6	11.1%
+ 20% UA Reduction	2.4	2.6	3.3	8.3	11.8%
+ 35% UA Reduction	2.0	2.7	3.3	8.1	12.4%
Split System HPs, Bedroom Electric Heat	7.5	1.6	2.1	11.2	4.7%
+ 10% UA Reduction	7.6	1.3	2.1	11.0	5.1%
+ 20% UA Reduction	7.3	1.3	2.0	10.7	6.0%
+ 35% UA Reduction	6.9	1.3	2.0	10.2	7.1%
+ HRV (70% effect.)	2.4	2.1	3.4	7.9	12.8%
+ 10% UA Reduction	2.4	1.8	3.3	7.5	13.7%
+ 20% UA Reduction	2.1	1.9	3.3	7.2	14.5%
+ 35% UA Reduction	1.7	2.0	3.3	7.0	15.1%
Split System HPs, Ducted to Bedrooms	6.4	2.0	2.1	10.5	6.3%
+ 10% UA Reduction	6.5	1.6	2.1	10.2	7.1%
+ 20% UA Reduction	6.3	1.6	2.0	10.0	7.8%
+ 35% UA Reduction	6.0	1.6	2.0	9.7	8.5%
+ HRV (70% effect.)	2.4	2.6	3.4	8.5	11.5%
+ 10% UA Reduction	2.4	2.3	3.3	8.0	12.7%

+ 20% UA Reduction	2.1	2.3	3.3	7.7	13.3%
+ 35% UA Reduction	1.8	2.4	3.3	7.5	13.8%
VRF, Bedroom Electric Heat	6.7	1.6	2.1	10.4	6.8%
+ 10% UA Reduction	6.8	1.3	2.1	10.2	7.2%
+ 20% UA Reduction	6.5	1.3	2.0	9.8	8.1%
+ 35% UA Reduction	6.1	1.3	2.0	9.4	9.2%
+ HRV (70% effect.)	1.7	2.1	3.4	7.3	14.4%
+ 10% UA Reduction	1.7	1.8	3.3	6.9	15.4%
+ 20% UA Reduction	1.4	1.9	3.3	6.6	16.1%
+ 35% UA Reduction	1.1	2.0	3.3	6.4	16.6%
VRF, Ducted to Bedrooms	5.4	2.0	2.1	9.4	9.0%
+ 10% UA Reduction	5.4	1.6	2.1	9.1	9.8%
+ 20% UA Reduction	5.2	1.6	2.0	8.9	10.5%
+ 35% UA Reduction	4.9	1.6	2.0	8.6	11.2%
+ HRV (70% effect.)	1.6	2.6	3.4	7.6	13.6%
+ 10% UA Reduction	1.5	2.3	3.3	7.1	14.8%
+ 20% UA Reduction	1.3	2.3	3.3	6.9	15.4%
+ 35% UA Reduction	1.0	2.4	3.3	6.7	15.7%

4.2 CONSTRUCTION PRICING RESULTS

4.2.1 Non-Energy Related

The following table summarizes non-energy related pricing results.

Table 40. Non-Energy Related Component Pricing Results

Building Component	Cost (Adjusted)	Cost Unit
Interior Construction + Finishes	$ 96.05 - $ 113.90	GSF of building
Fire Protection (sprinklers)	$ 6.40 - $ 6.70	GSF of building
Low-cost electric appliances + installation	$ 2.95 - $ 4.80	GSF of building
Low-cost kitchen/ bathroom cabinets, counters	$ 14.85 - $ 21.05	GSF of building

4.2.2 Envelope

The following table summarizes the envelope pricing results. **Bolded rows** indicate a price normalized to **building area. Yellow, bolded** rows are the components included in the baseline building.

Table 41. Envelope Pricing Results

Envelope System	Cost (Adjusted)	Cost Unit	System Life
Standard foundations (concrete, 4-11 story wood framed construction)	$ 11.50 - $ 12.05	GSF of building	50

Slab on Grade w/ R-15 perimeter insulation	$	8.95	-	$	9.40	SF of slab	50
Concrete flooring (complete assembly)	$	15.35	-	$	16.10	SF of floors	50
Baseline wood-framed wall (6" stud, batt insul)	$	23.35	-	$	24.45	SF of wall	50
Ext. wall cladding, molding, caulking/sealing	$	70.40	-	$	93.80	SF of wall	50
Base foundations, flooring, wood framed walls	**$**	**60.10**	**-**	**$**	**93.50**	**GSF of building**	50
Add 1" mineral fiber insul., metal z-furring	$	3.50	-	$	3.70	SF of wall	50
Add 1" mineral fiber insul., fiberglass clips	$	6.40	-	$	6.70	SF of wall	50
Add 2" mineral fiber insul., metal z-furring	$	4.50	-	$	4.70	SF of wall	50
Add 2" mineral fiber insul., fiberglass clips	$	7.70	-	$	8.05	SF of wall	50
Add 5" mineral fiber insul., metal z-furring	$	8.30	-	$	8.70	SF of wall	50
Add 5" mineral fiber insul., fiberglass clips	$	10.25	-	$	10.70	SF of wall	50
Typical dual pane vinyl windows (U-0.31)	$	64.80	-	$	67.85	$/(SF of window)	25
Typical dual pane vinyl windows (U-0.31)	**$**	**7.10**	**-**	**$**	**11.45**	**GSF of building**	25
Typical dual pane fiberglass windows (U-0.31)	$	90.45	-	$	94.65	$/(SF of window)	50
Typical dual pane fiberglass windows (U-0.31)	**$**	**9.90**	**-**	**$**	**15.95**	**GSF of building**	50
High perf. vinyl dual pane windows (U-0.27)	$	67.40	-	$	70.55	$/(SF of window)	25
High perf. vinyl dual pane windows (U-0.27)	**$**	**7.40**	**-**	**$**	**11.90**	**GSF of building**	25
High perf. fiberglass dual pane windows (U-0.27)	$	93.00	-	$	97.35	$/(SF of window)	50
High perf. fiberglass dual pane windows (U-0.27)	**$**	**10.20**	**-**	**$**	**16.40**	**GSF of building**	50
Triple pane vinyl punched windows (U-0.19)	$	74.10	-	$	77.55	$/(SF of window)	25
Triple pane vinyl punched windows (U-0.19)	**$**	**8.15**	**-**	**$**	**13.10**	**GSF of building**	25
Triple pane fiberglass punched windows (U-0.19)	$	106.25	-	$	111.20	$/(SF of window)	50
Triple pane fiberglass punched windows (U-0.19)	**$**	**11.65**	**-**	**$**	**18.75**	**GSF of building**	50
Roof Construction - Concrete slab (SD-level pricing)	$	25.60	-	$	26.80	SF of roof	50
Roof Coverings - Rigid polyiso, 4"	$	5.75	-	$	6.05	SF of roof	50
Roof Coverings - Rigid polyiso, 6"	$	7.05	-	$	7.35	SF of roof	50
Roof Coverings - Rigid polyiso, 8"	$	9.60	-	$	10.05	SF of roof	50
Roof Coverings - Everything else (SD-level allowance for total minus insulation)	$	28.15	-	$	34.85	SF of roof	50
Concrete roof (R-30, complete assembly)	$	60.80	-	$	69.00	SF of roof	50
Concrete roof (R-40, complete assembly)	$	63.40	-	$	71.70	SF of roof	50
Concrete roof (R-30, complete assembly)	**$**	**10.15**	**-**	**$**	**11.50**	**GSF of building**	50
Concrete roof (R-40, complete assembly)	**$**	**10.55**	**-**	**$**	**11.95**	**GSF of building**	50

4.2.3 Conveying

The following table summarizes the conveying system pricing results.

Table 42. Conveying Pricing Results

Conveying System	Cost (Adjusted)	Cost Unit	System Life
Traction passenger, non-regenerative drive	$ 57,617 - $ 64,330	per stop	25
Traction passenger, regenerative drive	$ 61,458 - $ 67,010	per stop	25
Traction freight, non-regenerative drive	$ 64,019 - $ 73,711	per stop	25
Traction freight, regenerative drive	$ 64,019 - $ 80,412	per stop	25
Non-Regenerative Elevators	$ 5.20 - $ 7.50	GSF of building	25
Regenerative Elevators	$ 5.45 - $ 7.90	GSF of building	25

4.2.4 Plumbing

The following table summarizes the plumbing system pricing results. Results include electrical infrastructure cost impacts beyond the baseline.

Table 43. Plumbing Pricing Results

Plumbing System	Cost (Adjusted)	Cost Unit	System Life
Base Plumbing (fixtures, piping, insulation)	$ 21.65 - $ 23.80	GSF of building	50
Centralized Natural Gas Condensing Boilers	$ 1.20 - $ 2.00	GSF of building	25
Centralized Heat Pump Hot Water Heaters	$ 2.05 - $ 3.85	GSF of building	20
In-Unit Electric Hot Water Heaters	$ 0.95 - $ 1.00	GSF of building	15

4.2.5 HVAC

The following table summarizes the HVAC system pricing results. Results include electrical infrastructure cost impacts beyond the baseline.

Table 44. HVAC Pricing Results

Energy Saving Strategy	Cost (Adjusted)	Cost Unit	System Life
Electric Heat, Bathroom Exhaust Fans, Corridor RTU	$ 7.45 - $ 9.20	GSF of building	13
PTHP in central room with Electric Heat in Bedrooms, Corridor RTU	$ 13.65 - $ 15.45	GSF of building	15
PTHP in central room, ducted to bedrooms, Corridor RTU	$ 14.50 - $ 18.00	GSF of building	15
Split HPs in central room with Electric Heat in Bedrooms, Corridor RTU	$ 19.55 - $ 21.60	GSF of building	20
Split HPs in central room, ducted to bedrooms, Corridor RTU	$ 20.45 - $ 23.85	GSF of building	20

VRF in central room with Electric Heat in Bedrooms, Corridor RTU	$	24.35	-	$	26.50	GSF of building	20
VRF in central room, ducted to bedrooms, Corridor RTU	$	25.25	-	$	29.05	GSF of building	20
VRF in all rooms, Corridor RTU	$	26.25	-	$	31.95	GSF of building	20
Add HRV to any listed HVAC system	$	5.05	-	$	6.35	GSF of building	18

4.2.6 Electrical

The following table summarizes the baseline electrical system pricing results. The **bolded baseline results** include baseline electrical infrastructure. The rest of the results are additional costs incurred to the electrical infrastructure based on the design alternates; these **are already included in the results shown in sections 4.2.4 and 4.2.5,** and are broken out here for reference.

Table 45. Electrical Pricing Results

Energy Saving Strategy	Cost (Adjusted)			Cost Unit
Electric Heat, Bathroom Exhaust Fans, Corridor RTU, Nat Gas DHW	**$ 34.28**	**-**	**$ 38.61**	**GSF of building**
PTHP in central room with Electric Heat in Bedrooms, Corridor RTU	$ 0.80	-	$ 0.93	GSF of building
PTHP in central room, ducted to bedrooms, Corridor RTU	$ 0.80	-	$ 0.93	GSF of building
Split HPs in central room with Electric Heat in Bedrooms, Corridor RTU	$ 0.70	-	$ 0.82	GSF of building
Split HPs in central room, ducted to bedrooms, Corridor RTU	$ 0.70	-	$ 0.82	GSF of building
VRF in central room with Electric Heat in Bedrooms, Corridor RTU	$ 0.03	-	$ 0.06	GSF of building
VRF in central room, ducted to bedrooms, Corridor RTU	$ 0.03	-	$ 0.06	GSF of building
VRF in all rooms, Corridor RTU	$ 0.03	-	$ 0.06	GSF of building
Add HRV to any listed HVAC system	$ 0.03	-	$ 0.06	GSF of building
HP Domestic Water Heaters	$ 0.21	-	$ 0.28	GSF of building
In-Unit Electric Domestic Water Heaters	$ 0.00	-	$ 0.00	GSF of building

4.3 ENERGY SAVINGS VS CONSTRUCTION ADD COSTS

This section summarizes the results of analysis done to examine incremental additions to first cost and energy savings from various envelope, HVAC, and plumbing alternates.

4.3.1 Portland

The following figure and tables summarize the estimated cost additions and energy saved for alternates in Portland, Oregon.

Figure 11. Low Density Energy + Cost Results, Portland

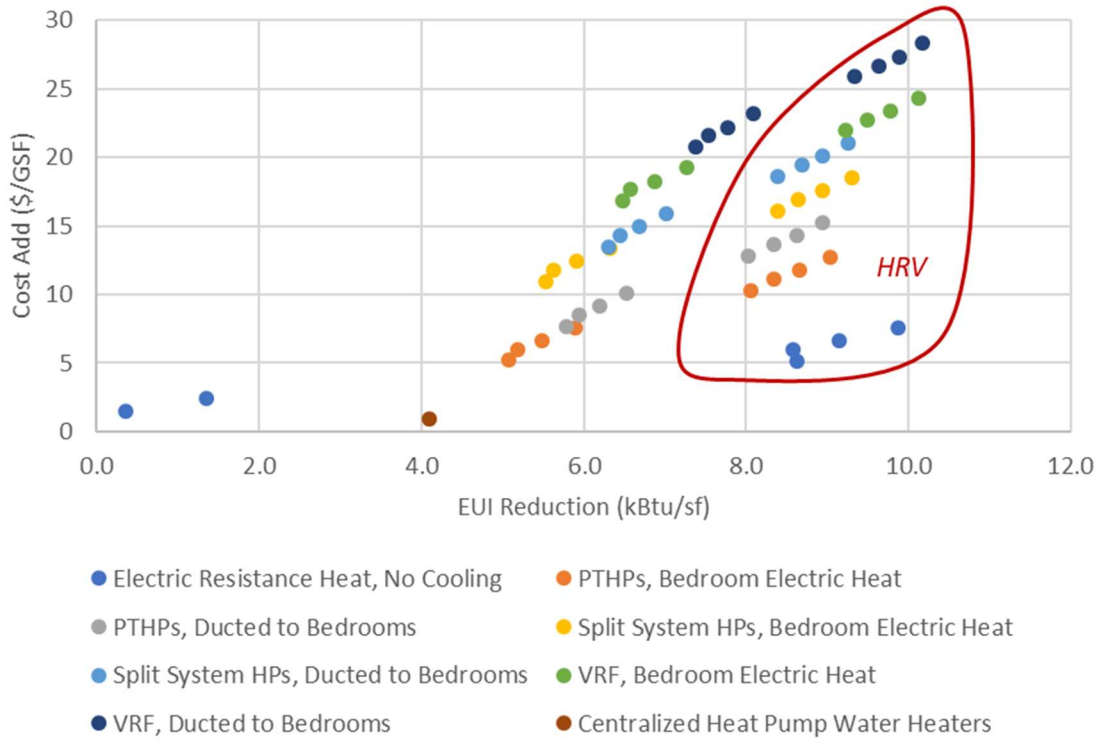

Table 46. Low Density Energy + Cost Results, Portland

Energy + Cost Results for Low Density Multifamily in Portland, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 0.87 - $ 0.91	$ 0.21 - $ 0.22
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (2.59) - $ (2.71)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 3.91 - $ 4.09
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.74 - $ 1.83
+ HRV (70% effect.)	$ 5.02 - $ 5.26	$ 0.58 - $ 0.61
+ 10% UA Reduction	$ 5.80 - $ 6.07	$ 0.68 - $ 0.71
+ 20% UA Reduction	$ 6.43 - $ 6.73	$ 0.70 - $ 0.74
+ 35% UA Reduction	$ 7.36 - $ 7.71	$ 0.75 - $ 0.78
PTHPs, Bedroom Electric Heat	$ 5.06 - $ 5.30	$ 1.00 - $ 1.04
+ 10% UA Reduction	$ 5.85 - $ 6.12	$ 1.13 - $ 1.18

+ 20% UA Reduction	$ 6.47 - $ 6.77	$ 1.18 - $ 1.24
+ 35% UA Reduction	$ 7.41 - $ 7.75	$ 1.26 - $ 1.32
+ HRV (70% effect.)	$ 10.09 - $ 10.56	$ 1.25 - $ 1.31
+ 10% UA Reduction	$ 10.87 - $ 11.38	$ 1.30 - $ 1.36
+ 20% UA Reduction	$ 11.49 - $ 12.03	$ 1.33 - $ 1.39
+ 35% UA Reduction	$ 12.43 - $ 13.01	$ 1.38 - $ 1.44
PTHPs, Ducted to Bedrooms	$ 7.52 - $ 7.87	$ 1.30 - $ 1.36
+ 10% UA Reduction	$ 8.30 - $ 8.69	$ 1.40 - $ 1.46
+ 20% UA Reduction	$ 8.93 - $ 9.34	$ 1.44 - $ 1.51
+ 35% UA Reduction	$ 9.86 - $ 10.32	$ 1.51 - $ 1.58
+ HRV (70% effect.)	$ 12.54 - $ 13.13	$ 1.56 - $ 1.64
+ 10% UA Reduction	$ 13.32 - $ 13.95	$ 1.60 - $ 1.67
+ 20% UA Reduction	$ 13.95 - $ 14.60	$ 1.62 - $ 1.69
+ 35% UA Reduction	$ 14.88 - $ 15.58	$ 1.66 - $ 1.74
Split System HPs, Bedroom Electric Heat	$ 10.73 - $ 11.23	$ 1.94 - $ 2.03
+ 10% UA Reduction	$ 11.51 - $ 12.05	$ 2.05 - $ 2.14
+ 20% UA Reduction	$ 12.13 - $ 12.70	$ 2.05 - $ 2.15
+ 35% UA Reduction	$ 13.07 - $ 13.68	$ 2.07 - $ 2.17
+ HRV (70% effect.)	$ 15.75 - $ 16.48	$ 1.88 - $ 1.97
+ 10% UA Reduction	$ 16.53 - $ 17.30	$ 1.91 - $ 2.00
+ 20% UA Reduction	$ 17.15 - $ 17.95	$ 1.92 - $ 2.01
+ 35% UA Reduction	$ 18.09 - $ 18.93	$ 1.94 - $ 2.03
Split System HPs, Ducted to Bedrooms	$ 13.18 - $ 13.80	$ 2.09 - $ 2.19
+ 10% UA Reduction	$ 13.96 - $ 14.62	$ 2.17 - $ 2.27
+ 20% UA Reduction	$ 14.59 - $ 15.27	$ 2.18 - $ 2.28
+ 35% UA Reduction	$ 15.52 - $ 16.25	$ 2.22 - $ 2.32
+ HRV (70% effect.)	$ 18.20 - $ 19.05	$ 2.17 - $ 2.27
+ 10% UA Reduction	$ 18.98 - $ 19.87	$ 2.19 - $ 2.29
+ 20% UA Reduction	$ 19.61 - $ 20.52	$ 2.19 - $ 2.29
+ 35% UA Reduction	$ 20.54 - $ 21.50	$ 2.22 - $ 2.32
VRF, Bedroom Electric Heat	$ 16.44 - $ 17.21	$ 2.54 - $ 2.66
+ 10% UA Reduction	$ 17.23 - $ 18.03	$ 2.62 - $ 2.74
+ 20% UA Reduction	$ 17.85 - $ 18.68	$ 2.60 - $ 2.72
+ 35% UA Reduction	$ 18.79 - $ 19.66	$ 2.59 - $ 2.71
+ HRV (70% effect.)	$ 21.46 - $ 22.47	$ 2.33 - $ 2.44
+ 10% UA Reduction	$ 22.25 - $ 23.29	$ 2.34 - $ 2.45
+ 20% UA Reduction	$ 22.87 - $ 23.94	$ 2.34 - $ 2.45
+ 35% UA Reduction	$ 23.81 - $ 24.92	$ 2.35 - $ 2.46
VRF, Ducted to Bedrooms	$ 20.29 - $ 21.24	$ 2.75 - $ 2.88
+ 10% UA Reduction	$ 21.07 - $ 22.06	$ 2.80 - $ 2.93
+ 20% UA Reduction	$ 21.70 - $ 22.71	$ 2.79 - $ 2.92

+ 35% UA Reduction	$	22.63	-	$	23.69	$	2.80	-	$	2.93
+ HRV (70% effect.)	$	25.31	-	$	26.49	$	2.71	-	$	2.84
+ 10% UA Reduction	$	26.09	-	$	27.31	$	2.71	-	$	2.83
+ 20% UA Reduction	$	26.72	-	$	27.97	$	2.70	-	$	2.83
+ 35% UA Reduction	$	27.65	-	$	28.94	$	2.72	-	$	2.84

Figure 12. Medium Density Energy + Cost Results, Portland

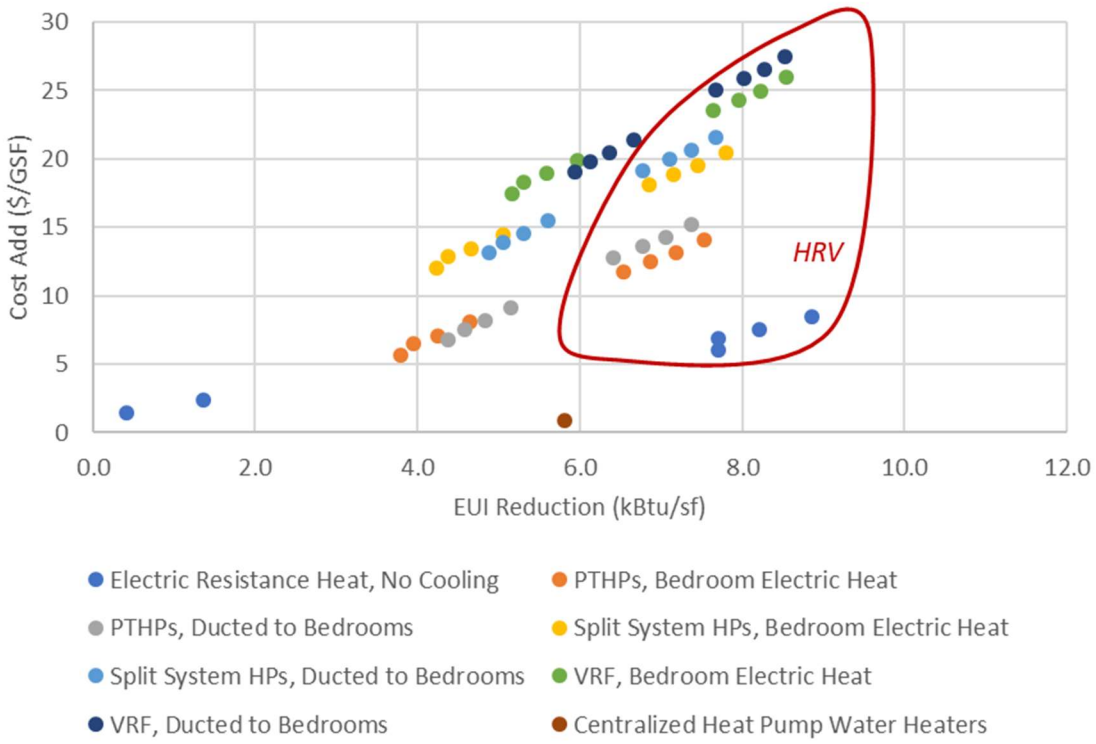

Table 47. Medium Density Energy + Cost Results, Portland

Energy + Cost Results for Medium Density Multifamily in Portland, OR	Adjusted Cost Add ($/GSF)				Cost Per Savings ($/kBtu)			
Centralized Heat Pump Water Heaters	$	0.90	- $	0.94	$	0.16	- $	0.16
Electric Resistance Heat, No Cooling								
+ 10% UA Reduction	$	0.78	- $	0.82	$	(3.30)	- $	(3.45)
+ 20% UA Reduction	$	1.41	- $	1.47	$	3.39	- $	3.55
+ 35% UA Reduction	$	2.34	- $	2.45	$	1.72	- $	1.80
+ HRV (70% effect.)	$	5.92	- $	6.19	$	0.77	- $	0.80
+ 10% UA Reduction	$	6.70	- $	7.01	$	0.87	- $	0.91
+ 20% UA Reduction	$	7.32	- $	7.67	$	0.89	- $	0.93
+ 35% UA Reduction	$	8.26	- $	8.64	$	0.93	- $	0.98
PTHPs, Bedroom Electric Heat	$	5.53	- $	5.79	$	1.46	- $	1.53
+ 10% UA Reduction	$	6.31	- $	6.61	$	1.60	- $	1.67
+ 20% UA Reduction	$	6.94	- $	7.26	$	1.63	- $	1.71

+ 35% UA Reduction	$ 7.87 - $ 8.24	$ 1.69 - $ 1.77
+ HRV (70% effect.)	$ 11.45 - $ 11.98	$ 1.75 - $ 1.83
+ 10% UA Reduction	$ 12.23 - $ 12.80	$ 1.78 - $ 1.86
+ 20% UA Reduction	$ 12.85 - $ 13.45	$ 1.79 - $ 1.87
+ 35% UA Reduction	$ 13.79 - $ 14.43	$ 1.83 - $ 1.92
PTHPs, Ducted to Bedrooms	$ 6.59 - $ 6.90	$ 1.51 - $ 1.58
+ 10% UA Reduction	$ 7.38 - $ 7.72	$ 1.61 - $ 1.69
+ 20% UA Reduction	$ 8.00 - $ 8.37	$ 1.66 - $ 1.74
+ 35% UA Reduction	$ 8.93 - $ 9.35	$ 1.74 - $ 1.82
+ HRV (70% effect.)	$ 12.51 - $ 13.09	$ 1.95 - $ 2.04
+ 10% UA Reduction	$ 13.29 - $ 13.91	$ 1.96 - $ 2.05
+ 20% UA Reduction	$ 13.92 - $ 14.57	$ 1.97 - $ 2.06
+ 35% UA Reduction	$ 14.85 - $ 15.54	$ 2.01 - $ 2.11
Split System HPs, Bedroom Electric Heat	$ 11.75 - $ 12.30	$ 2.78 - $ 2.91
+ 10% UA Reduction	$ 12.53 - $ 13.12	$ 2.87 - $ 3.00
+ 20% UA Reduction	$ 13.16 - $ 13.77	$ 2.82 - $ 2.95
+ 35% UA Reduction	$ 14.09 - $ 14.75	$ 2.79 - $ 2.92
+ HRV (70% effect.)	$ 17.67 - $ 18.49	$ 2.58 - $ 2.70
+ 10% UA Reduction	$ 18.45 - $ 19.31	$ 2.58 - $ 2.70
+ 20% UA Reduction	$ 19.07 - $ 19.96	$ 2.56 - $ 2.68
+ 35% UA Reduction	$ 20.01 - $ 20.94	$ 2.57 - $ 2.69
Split System HPs, Ducted to Bedrooms	$ 12.81 - $ 13.41	$ 2.63 - $ 2.75
+ 10% UA Reduction	$ 13.60 - $ 14.23	$ 2.69 - $ 2.81
+ 20% UA Reduction	$ 14.22 - $ 14.88	$ 2.68 - $ 2.81
+ 35% UA Reduction	$ 15.16 - $ 15.86	$ 2.70 - $ 2.83
+ HRV (70% effect.)	$ 18.73 - $ 19.60	$ 2.76 - $ 2.89
+ 10% UA Reduction	$ 19.51 - $ 20.42	$ 2.74 - $ 2.87
+ 20% UA Reduction	$ 20.14 - $ 21.08	$ 2.73 - $ 2.86
+ 35% UA Reduction	$ 21.07 - $ 22.06	$ 2.75 - $ 2.87
VRF, Bedroom Electric Heat	$ 17.08 - $ 17.87	$ 3.31 - $ 3.46
+ 10% UA Reduction	$ 17.86 - $ 18.69	$ 3.37 - $ 3.53
+ 20% UA Reduction	$ 18.48 - $ 19.35	$ 3.31 - $ 3.46
+ 35% UA Reduction	$ 19.42 - $ 20.32	$ 3.25 - $ 3.40
+ HRV (70% effect.)	$ 22.99 - $ 24.07	$ 3.01 - $ 3.15
+ 10% UA Reduction	$ 23.77 - $ 24.89	$ 2.99 - $ 3.13
+ 20% UA Reduction	$ 24.40 - $ 25.54	$ 2.96 - $ 3.10
+ 35% UA Reduction	$ 25.33 - $ 26.52	$ 2.97 - $ 3.11
VRF, Ducted to Bedrooms	$ 18.57 - $ 19.44	$ 3.13 - $ 3.27
+ 10% UA Reduction	$ 19.35 - $ 20.26	$ 3.16 - $ 3.31
+ 20% UA Reduction	$ 19.98 - $ 20.91	$ 3.14 - $ 3.29
+ 35% UA Reduction	$ 20.91 - $ 21.89	$ 3.14 - $ 3.28

+ HRV (70% effect.)	$ 24.49 - $ 25.63	$ 3.19 - $ 3.34
+ 10% UA Reduction	$ 25.27 - $ 26.45	$ 3.15 - $ 3.30
+ 20% UA Reduction	$ 25.89 - $ 27.10	$ 3.13 - $ 3.28
+ 35% UA Reduction	$ 26.83 - $ 28.08	$ 3.15 - $ 3.29

Figure 13. High Density Energy + Cost Results, Portland

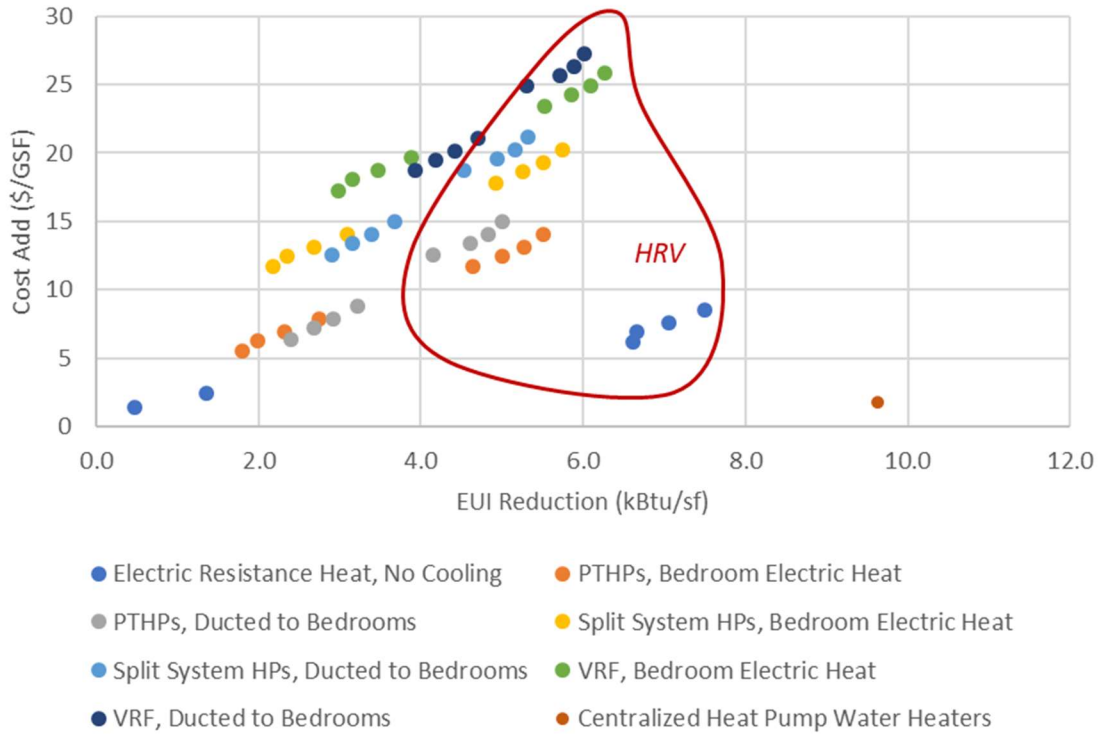

Table 48. High Density Energy + Cost Results, Portland

Energy + Cost Results for High Density Multifamily in Portland, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 1.77 - $ 1.85	$ 0.18 - $ 0.19
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (5.26) - $ (5.50)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 2.94 - $ 3.08
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.72 - $ 1.80
+ HRV (70% effect.)	$ 6.03 - $ 6.31	$ 0.91 - $ 0.95
+ 10% UA Reduction	$ 6.81 - $ 7.13	$ 1.02 - $ 1.07
+ 20% UA Reduction	$ 7.43 - $ 7.78	$ 1.05 - $ 1.10
+ 35% UA Reduction	$ 8.37 - $ 8.76	$ 1.12 - $ 1.17
PTHPs, Bedroom Electric Heat	$ 5.38 - $ 5.63	$ 2.99 - $ 3.13
+ 10% UA Reduction	$ 6.16 - $ 6.45	$ 3.10 - $ 3.25
+ 20% UA Reduction	$ 6.78 - $ 7.10	$ 2.93 - $ 3.06
+ 35% UA Reduction	$ 7.72 - $ 8.08	$ 2.81 - $ 2.94

+ HRV (70% effect.)	$ 11.40 - $ 11.94	$ 2.46 - $ 2.58
+ 10% UA Reduction	$ 12.19 - $ 12.76	$ 2.44 - $ 2.55
+ 20% UA Reduction	$ 12.81 - $ 13.41	$ 2.43 - $ 2.55
+ 35% UA Reduction	$ 13.75 - $ 14.39	$ 2.50 - $ 2.62
PTHPs, Ducted to Bedrooms	$ 6.27 - $ 6.56	$ 2.61 - $ 2.73
+ 10% UA Reduction	$ 7.05 - $ 7.38	$ 2.63 - $ 2.76
+ 20% UA Reduction	$ 7.67 - $ 8.03	$ 2.62 - $ 2.75
+ 35% UA Reduction	$ 8.61 - $ 9.01	$ 2.67 - $ 2.80
+ HRV (70% effect.)	$ 12.29 - $ 12.87	$ 2.96 - $ 3.10
+ 10% UA Reduction	$ 13.08 - $ 13.69	$ 2.84 - $ 2.97
+ 20% UA Reduction	$ 13.70 - $ 14.34	$ 2.83 - $ 2.97
+ 35% UA Reduction	$ 14.63 - $ 15.32	$ 2.92 - $ 3.06
Split System HPs, Bedroom Electric Heat	$ 11.39 - $ 11.93	$ 5.21 - $ 5.46
+ 10% UA Reduction	$ 12.18 - $ 12.75	$ 5.18 - $ 5.42
+ 20% UA Reduction	$ 12.80 - $ 13.40	$ 4.78 - $ 5.00
+ 35% UA Reduction	$ 13.74 - $ 14.38	$ 4.43 - $ 4.64
+ HRV (70% effect.)	$ 17.42 - $ 18.24	$ 3.54 - $ 3.70
+ 10% UA Reduction	$ 18.20 - $ 19.06	$ 3.46 - $ 3.62
+ 20% UA Reduction	$ 18.83 - $ 19.71	$ 3.41 - $ 3.57
+ 35% UA Reduction	$ 19.76 - $ 20.69	$ 3.44 - $ 3.60
Split System HPs, Ducted to Bedrooms	$ 12.28 - $ 12.86	$ 4.22 - $ 4.42
+ 10% UA Reduction	$ 13.07 - $ 13.68	$ 4.14 - $ 4.34
+ 20% UA Reduction	$ 13.69 - $ 14.33	$ 4.04 - $ 4.23
+ 35% UA Reduction	$ 14.63 - $ 15.31	$ 3.98 - $ 4.16
+ HRV (70% effect.)	$ 18.31 - $ 19.17	$ 4.04 - $ 4.23
+ 10% UA Reduction	$ 19.09 - $ 19.99	$ 3.87 - $ 4.05
+ 20% UA Reduction	$ 19.72 - $ 20.64	$ 3.83 - $ 4.00
+ 35% UA Reduction	$ 20.65 - $ 21.62	$ 3.88 - $ 4.06
VRF, Bedroom Electric Heat	$ 16.88 - $ 17.67	$ 5.67 - $ 5.93
+ 10% UA Reduction	$ 17.66 - $ 18.49	$ 5.61 - $ 5.87
+ 20% UA Reduction	$ 18.28 - $ 19.14	$ 5.27 - $ 5.51
+ 35% UA Reduction	$ 19.22 - $ 20.12	$ 4.95 - $ 5.18
+ HRV (70% effect.)	$ 22.91 - $ 23.98	$ 4.15 - $ 4.34
+ 10% UA Reduction	$ 23.69 - $ 24.80	$ 4.04 - $ 4.23
+ 20% UA Reduction	$ 24.31 - $ 25.45	$ 4.00 - $ 4.18
+ 35% UA Reduction	$ 25.25 - $ 26.43	$ 4.03 - $ 4.21
VRF, Ducted to Bedrooms	$ 18.27 - $ 19.12	$ 4.64 - $ 4.86
+ 10% UA Reduction	$ 19.05 - $ 19.94	$ 4.55 - $ 4.76
+ 20% UA Reduction	$ 19.68 - $ 20.60	$ 4.45 - $ 4.66
+ 35% UA Reduction	$ 20.61 - $ 21.58	$ 4.39 - $ 4.59
+ HRV (70% effect.)	$ 24.30 - $ 25.43	$ 4.58 - $ 4.79

+ 10% UA Reduction	$ 25.08 - $ 26.25	$ 4.39 - $ 4.60
+ 20% UA Reduction	$ 25.70 - $ 26.91	$ 4.36 - $ 4.56
+ 35% UA Reduction	$ 26.64 - $ 27.88	$ 4.43 - $ 4.64

4.3.2 Salem

The following figure and tables summarize the estimated cost additions and energy saved for alternates in Salem, Oregon.

Figure 14. Low Density Energy + Cost Results, Salem

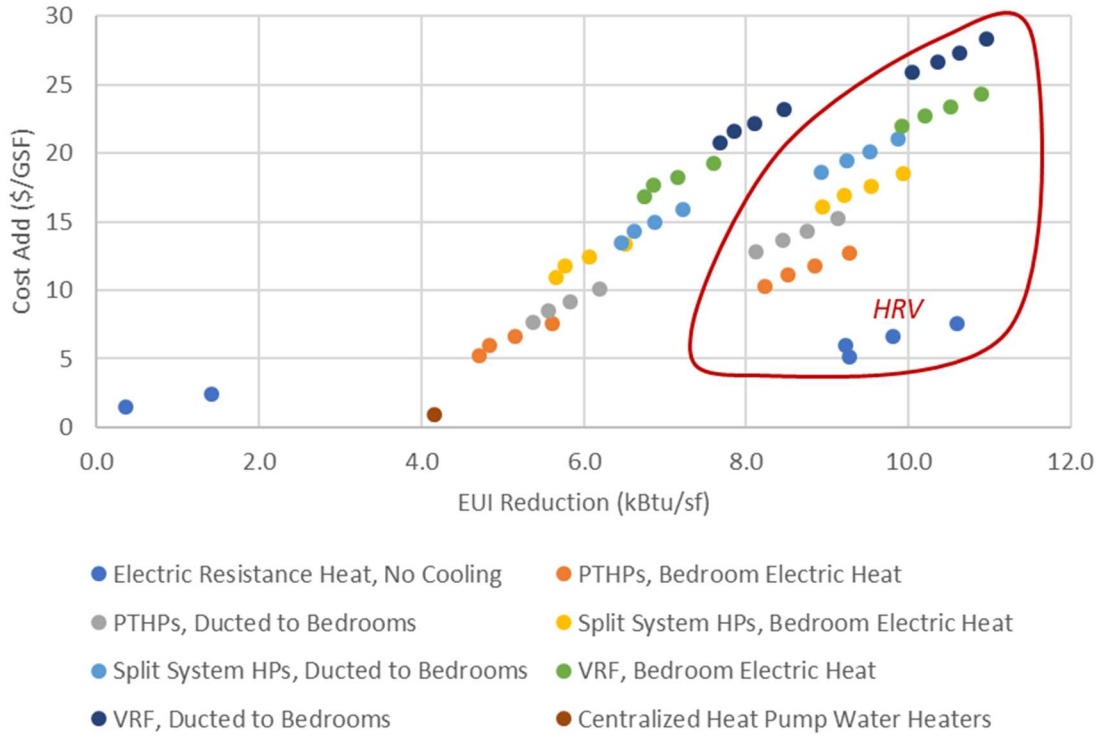

Table 49. Low Density Energy + Cost Results, Salem

Energy + Cost Results for Low Density Multifamily in Salem, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 0.87 - $ 0.91	$ 0.21 - $ 0.22
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (2.30) - $ (2.41)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 4.00 - $ 4.19
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.67 - $ 1.75
+ HRV (70% effect.)	$ 5.02 - $ 5.26	$ 0.54 - $ 0.57
+ 10% UA Reduction	$ 5.80 - $ 6.07	$ 0.63 - $ 0.66
+ 20% UA Reduction	$ 6.43 - $ 6.73	$ 0.66 - $ 0.69
+ 35% UA Reduction	$ 7.36 - $ 7.71	$ 0.69 - $ 0.73
PTHPs, Bedroom Electric Heat	$ 5.06 - $ 5.30	$ 1.08 - $ 1.13

+ 10% UA Reduction	$ 5.85 - $ 6.12	$ 1.21 - $ 1.27	
+ 20% UA Reduction	$ 6.47 - $ 6.77	$ 1.26 - $ 1.32	
+ 35% UA Reduction	$ 7.41 - $ 7.75	$ 1.32 - $ 1.38	
+ HRV (70% effect.)	$ 10.09 - $ 10.56	$ 1.23 - $ 1.28	
+ 10% UA Reduction	$ 10.87 - $ 11.38	$ 1.28 - $ 1.34	
+ 20% UA Reduction	$ 11.49 - $ 12.03	$ 1.30 - $ 1.36	
+ 35% UA Reduction	$ 12.43 - $ 13.01	$ 1.34 - $ 1.40	
PTHPs, Ducted to Bedrooms	$ 7.52 - $ 7.87	$ 1.40 - $ 1.46	
+ 10% UA Reduction	$ 8.30 - $ 8.69	$ 1.49 - $ 1.56	
+ 20% UA Reduction	$ 8.93 - $ 9.34	$ 1.53 - $ 1.60	
+ 35% UA Reduction	$ 9.86 - $ 10.32	$ 1.59 - $ 1.67	
+ HRV (70% effect.)	$ 12.54 - $ 13.13	$ 1.54 - $ 1.62	
+ 10% UA Reduction	$ 13.32 - $ 13.95	$ 1.58 - $ 1.65	
+ 20% UA Reduction	$ 13.95 - $ 14.60	$ 1.59 - $ 1.67	
+ 35% UA Reduction	$ 14.88 - $ 15.58	$ 1.63 - $ 1.71	
Split System HPs, Bedroom Electric Heat	$ 10.73 - $ 11.23	$ 1.90 - $ 1.98	
+ 10% UA Reduction	$ 11.51 - $ 12.05	$ 2.00 - $ 2.09	
+ 20% UA Reduction	$ 12.13 - $ 12.70	$ 2.00 - $ 2.09	
+ 35% UA Reduction	$ 13.07 - $ 13.68	$ 2.01 - $ 2.10	
+ HRV (70% effect.)	$ 15.75 - $ 16.48	$ 1.76 - $ 1.84	
+ 10% UA Reduction	$ 16.53 - $ 17.30	$ 1.79 - $ 1.88	
+ 20% UA Reduction	$ 17.15 - $ 17.95	$ 1.80 - $ 1.88	
+ 35% UA Reduction	$ 18.09 - $ 18.93	$ 1.82 - $ 1.91	
Split System HPs, Ducted to Bedrooms	$ 13.18 - $ 13.80	$ 2.04 - $ 2.14	
+ 10% UA Reduction	$ 13.96 - $ 14.62	$ 2.11 - $ 2.21	
+ 20% UA Reduction	$ 14.59 - $ 15.27	$ 2.12 - $ 2.22	
+ 35% UA Reduction	$ 15.52 - $ 16.25	$ 2.15 - $ 2.25	
+ HRV (70% effect.)	$ 18.20 - $ 19.05	$ 2.04 - $ 2.13	
+ 10% UA Reduction	$ 18.98 - $ 19.87	$ 2.05 - $ 2.15	
+ 20% UA Reduction	$ 19.61 - $ 20.52	$ 2.06 - $ 2.16	
+ 35% UA Reduction	$ 20.54 - $ 21.50	$ 2.08 - $ 2.18	
VRF, Bedroom Electric Heat	$ 16.44 - $ 17.21	$ 2.44 - $ 2.55	
+ 10% UA Reduction	$ 17.23 - $ 18.03	$ 2.51 - $ 2.63	
+ 20% UA Reduction	$ 17.85 - $ 18.68	$ 2.49 - $ 2.61	
+ 35% UA Reduction	$ 18.79 - $ 19.66	$ 2.47 - $ 2.59	
+ HRV (70% effect.)	$ 21.46 - $ 22.47	$ 2.16 - $ 2.26	
+ 10% UA Reduction	$ 22.25 - $ 23.29	$ 2.18 - $ 2.28	
+ 20% UA Reduction	$ 22.87 - $ 23.94	$ 2.18 - $ 2.28	
+ 35% UA Reduction	$ 23.81 - $ 24.92	$ 2.19 - $ 2.29	
VRF, Ducted to Bedrooms	$ 20.29 - $ 21.24	$ 2.64 - $ 2.76	
+ 10% UA Reduction	$ 21.07 - $ 22.06	$ 2.68 - $ 2.81	

+ 20% UA Reduction	$ 21.70 - $ 22.71	$ 2.68 - $ 2.80
+ 35% UA Reduction	$ 22.63 - $ 23.69	$ 2.68 - $ 2.80
+ HRV (70% effect.)	$ 25.31 - $ 26.49	$ 2.52 - $ 2.64
+ 10% UA Reduction	$ 26.09 - $ 27.31	$ 2.52 - $ 2.64
+ 20% UA Reduction	$ 26.72 - $ 27.97	$ 2.51 - $ 2.63
+ 35% UA Reduction	$ 27.65 - $ 28.94	$ 2.52 - $ 2.64

Figure 15. Medium Density Energy + Cost Results, Salem

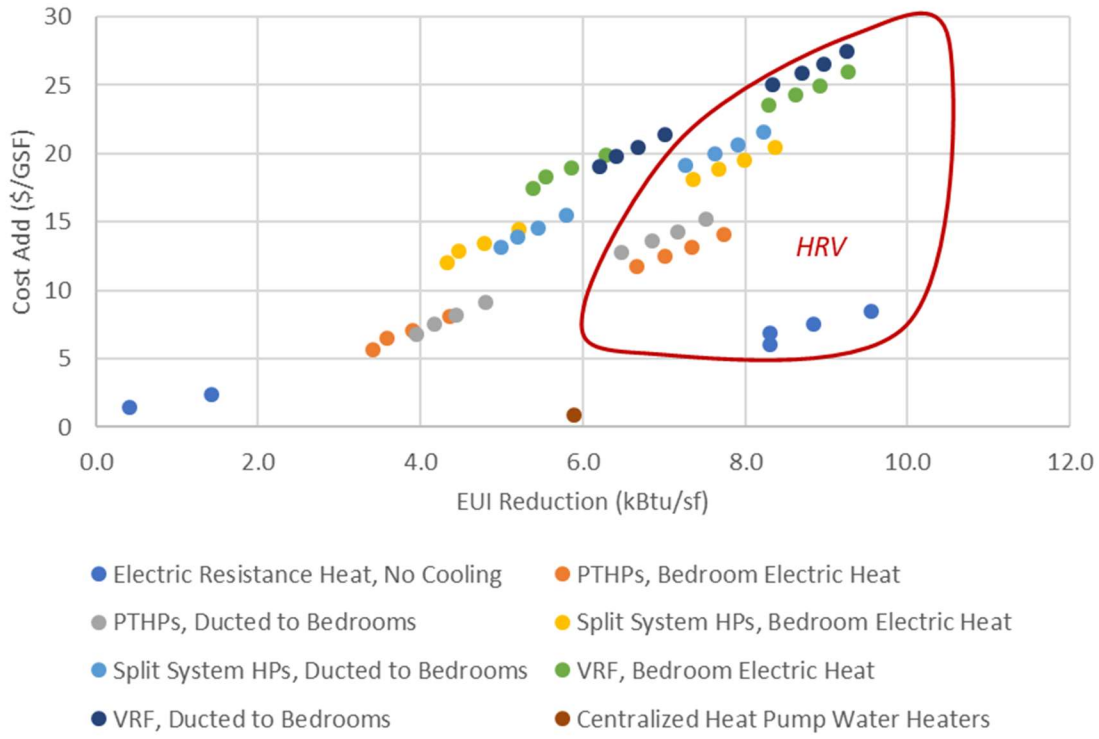

Table 50. Medium Density Energy + Cost Results, Salem

Energy + Cost Results for Medium Density Multifamily in Salem, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 0.90 - $ 0.94	$ 0.15 - $ 0.16
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (2.90) - $ (3.03)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 3.42 - $ 3.58
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.64 - $ 1.72
+ HRV (70% effect.)	$ 5.92 - $ 6.19	$ 0.71 - $ 0.75
+ 10% UA Reduction	$ 6.70 - $ 7.01	$ 0.81 - $ 0.84
+ 20% UA Reduction	$ 7.32 - $ 7.67	$ 0.83 - $ 0.87
+ 35% UA Reduction	$ 8.26 - $ 8.64	$ 0.86 - $ 0.90
PTHPs, Bedroom Electric Heat	$ 5.53 - $ 5.79	$ 1.62 - $ 1.69
+ 10% UA Reduction	$ 6.31 - $ 6.61	$ 1.76 - $ 1.84

+ 20% UA Reduction	$ 6.94 - $ 7.26	$ 1.78 - $ 1.86
+ 35% UA Reduction	$ 7.87 - $ 8.24	$ 1.81 - $ 1.89
+ HRV (70% effect.)	$ 11.45 - $ 11.98	$ 1.72 - $ 1.80
+ 10% UA Reduction	$ 12.23 - $ 12.80	$ 1.75 - $ 1.83
+ 20% UA Reduction	$ 12.85 - $ 13.45	$ 1.75 - $ 1.83
+ 35% UA Reduction	$ 13.79 - $ 14.43	$ 1.78 - $ 1.87
PTHPs, Ducted to Bedrooms	$ 6.59 - $ 6.90	$ 1.67 - $ 1.75
+ 10% UA Reduction	$ 7.38 - $ 7.72	$ 1.77 - $ 1.85
+ 20% UA Reduction	$ 8.00 - $ 8.37	$ 1.80 - $ 1.88
+ 35% UA Reduction	$ 8.93 - $ 9.35	$ 1.86 - $ 1.94
+ HRV (70% effect.)	$ 12.51 - $ 13.09	$ 1.93 - $ 2.02
+ 10% UA Reduction	$ 13.29 - $ 13.91	$ 1.94 - $ 2.03
+ 20% UA Reduction	$ 13.92 - $ 14.57	$ 1.94 - $ 2.03
+ 35% UA Reduction	$ 14.85 - $ 15.54	$ 1.98 - $ 2.07
Split System HPs, Bedroom Electric Heat	$ 11.75 - $ 12.30	$ 2.71 - $ 2.84
+ 10% UA Reduction	$ 12.53 - $ 13.12	$ 2.80 - $ 2.93
+ 20% UA Reduction	$ 13.16 - $ 13.77	$ 2.75 - $ 2.88
+ 35% UA Reduction	$ 14.09 - $ 14.75	$ 2.70 - $ 2.83
+ HRV (70% effect.)	$ 17.67 - $ 18.49	$ 2.40 - $ 2.51
+ 10% UA Reduction	$ 18.45 - $ 19.31	$ 2.40 - $ 2.52
+ 20% UA Reduction	$ 19.07 - $ 19.96	$ 2.39 - $ 2.50
+ 35% UA Reduction	$ 20.01 - $ 20.94	$ 2.39 - $ 2.50
Split System HPs, Ducted to Bedrooms	$ 12.81 - $ 13.41	$ 2.57 - $ 2.69
+ 10% UA Reduction	$ 13.60 - $ 14.23	$ 2.62 - $ 2.74
+ 20% UA Reduction	$ 14.22 - $ 14.88	$ 2.61 - $ 2.73
+ 35% UA Reduction	$ 15.16 - $ 15.86	$ 2.61 - $ 2.74
+ HRV (70% effect.)	$ 18.73 - $ 19.60	$ 2.58 - $ 2.70
+ 10% UA Reduction	$ 19.51 - $ 20.42	$ 2.56 - $ 2.68
+ 20% UA Reduction	$ 20.14 - $ 21.08	$ 2.55 - $ 2.67
+ 35% UA Reduction	$ 21.07 - $ 22.06	$ 2.56 - $ 2.68
VRF, Bedroom Electric Heat	$ 17.08 - $ 17.87	$ 3.17 - $ 3.31
+ 10% UA Reduction	$ 17.86 - $ 18.69	$ 3.22 - $ 3.37
+ 20% UA Reduction	$ 18.48 - $ 19.35	$ 3.16 - $ 3.30
+ 35% UA Reduction	$ 19.42 - $ 20.32	$ 3.09 - $ 3.23
+ HRV (70% effect.)	$ 22.99 - $ 24.07	$ 2.77 - $ 2.90
+ 10% UA Reduction	$ 23.77 - $ 24.89	$ 2.76 - $ 2.89
+ 20% UA Reduction	$ 24.40 - $ 25.54	$ 2.74 - $ 2.86
+ 35% UA Reduction	$ 25.33 - $ 26.52	$ 2.73 - $ 2.86
VRF, Ducted to Bedrooms	$ 18.57 - $ 19.44	$ 2.99 - $ 3.13
+ 10% UA Reduction	$ 19.35 - $ 20.26	$ 3.02 - $ 3.16
+ 20% UA Reduction	$ 19.98 - $ 20.91	$ 2.99 - $ 3.13

+ 35% UA Reduction	$ 20.91 - $ 21.89	$ 2.98 - $ 3.12
+ HRV (70% effect.)	$ 24.49 - $ 25.63	$ 2.94 - $ 3.08
+ 10% UA Reduction	$ 25.27 - $ 26.45	$ 2.91 - $ 3.04
+ 20% UA Reduction	$ 25.89 - $ 27.10	$ 2.89 - $ 3.02
+ 35% UA Reduction	$ 26.83 - $ 28.08	$ 2.90 - $ 3.03

Figure 16. High Density Energy + Cost Results, Salem

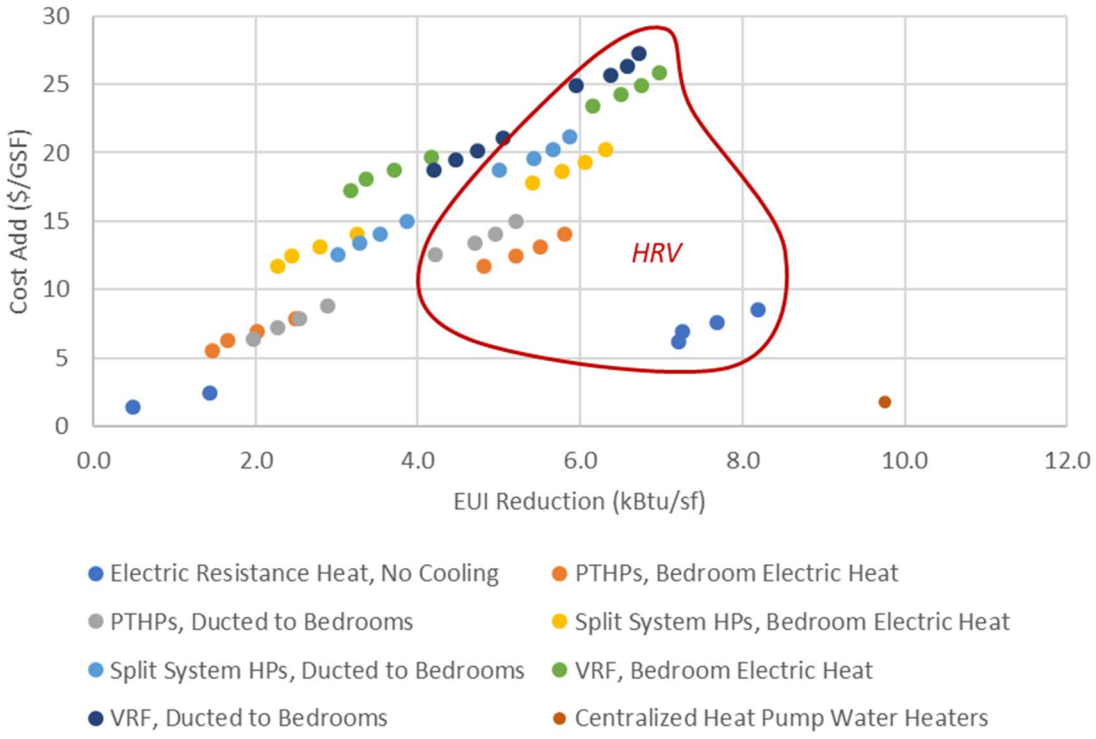

Table 51. High Density Energy + Cost Results, Salem

Energy + Cost Results for High Density Multifamily in Salem, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 1.77 - $ 1.85	$ 0.18 - $ 0.19
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (4.49) - $ (4.70)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 2.90 - $ 3.03
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.63 - $ 1.71
+ HRV (70% effect.)	$ 6.03 - $ 6.31	$ 0.84 - $ 0.87
+ 10% UA Reduction	$ 6.81 - $ 7.13	$ 0.94 - $ 0.98
+ 20% UA Reduction	$ 7.43 - $ 7.78	$ 0.97 - $ 1.01
+ 35% UA Reduction	$ 8.37 - $ 8.76	$ 1.02 - $ 1.07
PTHPs, Bedroom Electric Heat	$ 5.38 - $ 5.63	$ 3.68 - $ 3.85
+ 10% UA Reduction	$ 6.16 - $ 6.45	$ 3.72 - $ 3.89
+ 20% UA Reduction	$ 6.78 - $ 7.10	$ 3.37 - $ 3.53

+ 35% UA Reduction	$	7.72	-	$	8.08	$	3.09	-	$	3.24
+ HRV (70% effect.)	$	11.40	-	$	11.94	$	2.37	-	$	2.48
+ 10% UA Reduction	$	12.19	-	$	12.76	$	2.34	-	$	2.45
+ 20% UA Reduction	$	12.81	-	$	13.41	$	2.33	-	$	2.44
+ 35% UA Reduction	$	13.75	-	$	14.39	$	2.37	-	$	2.48
PTHPs, Ducted to Bedrooms	$	6.27	-	$	6.56	$	3.17	-	$	3.31
+ 10% UA Reduction	$	7.05	-	$	7.38	$	3.10	-	$	3.25
+ 20% UA Reduction	$	7.67	-	$	8.03	$	3.02	-	$	3.17
+ 35% UA Reduction	$	8.61	-	$	9.01	$	2.99	-	$	3.13
+ HRV (70% effect.)	$	12.29	-	$	12.87	$	2.92	-	$	3.05
+ 10% UA Reduction	$	13.08	-	$	13.69	$	2.78	-	$	2.92
+ 20% UA Reduction	$	13.70	-	$	14.34	$	2.76	-	$	2.89
+ 35% UA Reduction	$	14.63	-	$	15.32	$	2.81	-	$	2.94
Split System HPs, Bedroom Electric Heat	$	11.39	-	$	11.93	$	5.03	-	$	5.27
+ 10% UA Reduction	$	12.18	-	$	12.75	$	4.99	-	$	5.23
+ 20% UA Reduction	$	12.80	-	$	13.40	$	4.59	-	$	4.81
+ 35% UA Reduction	$	13.74	-	$	14.38	$	4.22	-	$	4.41
+ HRV (70% effect.)	$	17.42	-	$	18.24	$	3.22	-	$	3.37
+ 10% UA Reduction	$	18.20	-	$	19.06	$	3.15	-	$	3.30
+ 20% UA Reduction	$	18.83	-	$	19.71	$	3.11	-	$	3.26
+ 35% UA Reduction	$	19.76	-	$	20.69	$	3.13	-	$	3.28
Split System HPs, Ducted to Bedrooms	$	12.28	-	$	12.86	$	4.07	-	$	4.26
+ 10% UA Reduction	$	13.07	-	$	13.68	$	3.98	-	$	4.17
+ 20% UA Reduction	$	13.69	-	$	14.33	$	3.87	-	$	4.05
+ 35% UA Reduction	$	14.63	-	$	15.31	$	3.78	-	$	3.96
+ HRV (70% effect.)	$	18.31	-	$	19.17	$	3.66	-	$	3.84
+ 10% UA Reduction	$	19.09	-	$	19.99	$	3.52	-	$	3.68
+ 20% UA Reduction	$	19.72	-	$	20.64	$	3.48	-	$	3.64
+ 35% UA Reduction	$	20.65	-	$	21.62	$	3.52	-	$	3.69
VRF, Bedroom Electric Heat	$	16.88	-	$	17.67	$	5.31	-	$	5.56
+ 10% UA Reduction	$	17.66	-	$	18.49	$	5.26	-	$	5.51
+ 20% UA Reduction	$	18.28	-	$	19.14	$	4.93	-	$	5.16
+ 35% UA Reduction	$	19.22	-	$	20.12	$	4.61	-	$	4.83
+ HRV (70% effect.)	$	22.91	-	$	23.98	$	3.72	-	$	3.90
+ 10% UA Reduction	$	23.69	-	$	24.80	$	3.64	-	$	3.81
+ 20% UA Reduction	$	24.31	-	$	25.45	$	3.60	-	$	3.76
+ 35% UA Reduction	$	25.25	-	$	26.43	$	3.62	-	$	3.79
VRF, Ducted to Bedrooms	$	18.27	-	$	19.12	$	4.35	-	$	4.55
+ 10% UA Reduction	$	19.05	-	$	19.94	$	4.26	-	$	4.46
+ 20% UA Reduction	$	19.68	-	$	20.60	$	4.16	-	$	4.36
+ 35% UA Reduction	$	20.61	-	$	21.58	$	4.09	-	$	4.28

+ HRV (70% effect.)	$ 24.30 - $ 25.43	$ 4.09 - $ 4.28
+ 10% UA Reduction	$ 25.08 - $ 26.25	$ 3.94 - $ 4.12
+ 20% UA Reduction	$ 25.70 - $ 26.91	$ 3.91 - $ 4.09
+ 35% UA Reduction	$ 26.64 - $ 27.88	$ 3.96 - $ 4.15

4.3.1 Medford

The following figure and tables summarize the estimated cost additions and energy saved for alternates in Medford, Oregon.

Figure 17. Low Density Energy + Cost Results, Medford

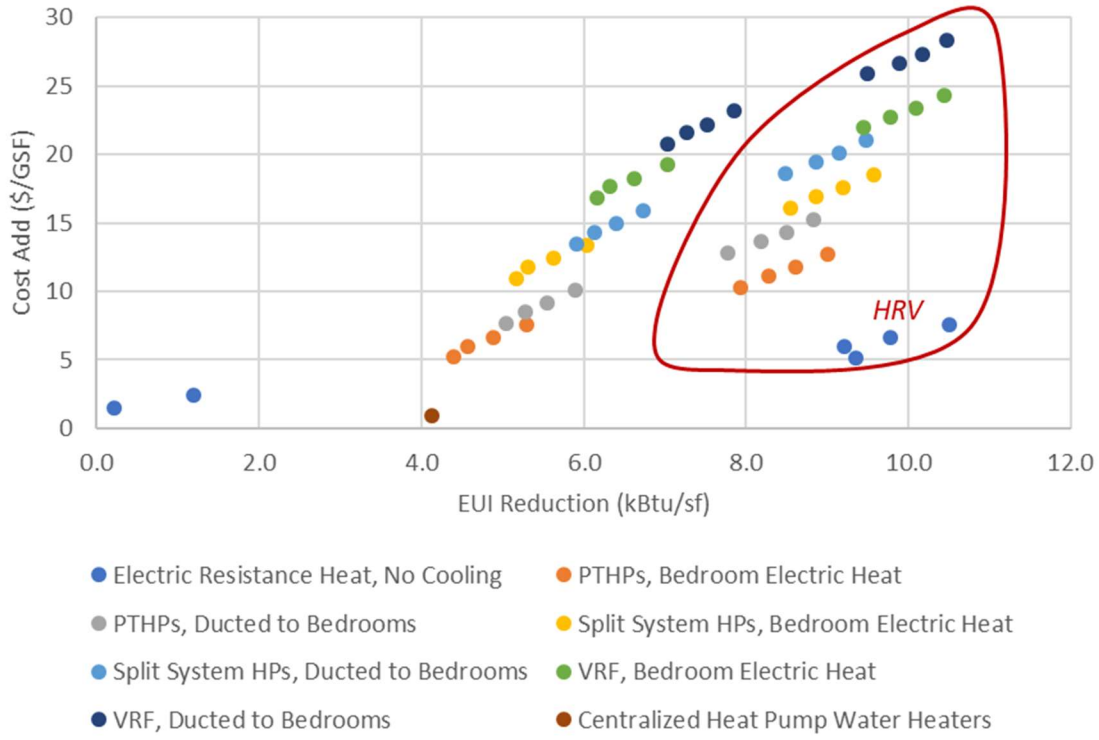

Table 52. Low Density Energy + Cost Results, Medford

Energy + Cost Results for Low Density Multifamily in Medford, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 0.87 - $ 0.91	$ 0.21 - $ 0.22
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (1.82) - $ (1.91)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 6.37 - $ 6.67
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.98 - $ 2.07
+ HRV (70% effect.)	$ 5.02 - $ 5.26	$ 0.54 - $ 0.56
+ 10% UA Reduction	$ 5.80 - $ 6.07	$ 0.63 - $ 0.66
+ 20% UA Reduction	$ 6.43 - $ 6.73	$ 0.66 - $ 0.69
+ 35% UA Reduction	$ 7.36 - $ 7.71	$ 0.70 - $ 0.73
PTHPs, Bedroom Electric Heat	$ 5.06 - $ 5.30	$ 1.15 - $ 1.20

+ 10% UA Reduction	$ 5.85 - $ 6.12	$ 1.28 - $ 1.34
+ 20% UA Reduction	$ 6.47 - $ 6.77	$ 1.32 - $ 1.39
+ 35% UA Reduction	$ 7.41 - $ 7.75	$ 1.40 - $ 1.46
+ HRV (70% effect.)	$ 10.09 - $ 10.56	$ 1.27 - $ 1.33
+ 10% UA Reduction	$ 10.87 - $ 11.38	$ 1.31 - $ 1.37
+ 20% UA Reduction	$ 11.49 - $ 12.03	$ 1.33 - $ 1.40
+ 35% UA Reduction	$ 12.43 - $ 13.01	$ 1.38 - $ 1.45
PTHPs, Ducted to Bedrooms	$ 7.52 - $ 7.87	$ 1.49 - $ 1.56
+ 10% UA Reduction	$ 8.30 - $ 8.69	$ 1.57 - $ 1.65
+ 20% UA Reduction	$ 8.93 - $ 9.34	$ 1.61 - $ 1.68
+ 35% UA Reduction	$ 9.86 - $ 10.32	$ 1.67 - $ 1.75
+ HRV (70% effect.)	$ 12.54 - $ 13.13	$ 1.61 - $ 1.69
+ 10% UA Reduction	$ 13.32 - $ 13.95	$ 1.63 - $ 1.70
+ 20% UA Reduction	$ 13.95 - $ 14.60	$ 1.64 - $ 1.72
+ 35% UA Reduction	$ 14.88 - $ 15.58	$ 1.69 - $ 1.76
Split System HPs, Bedroom Electric Heat	$ 10.73 - $ 11.23	$ 2.07 - $ 2.17
+ 10% UA Reduction	$ 11.51 - $ 12.05	$ 2.16 - $ 2.27
+ 20% UA Reduction	$ 12.13 - $ 12.70	$ 2.15 - $ 2.26
+ 35% UA Reduction	$ 13.07 - $ 13.68	$ 2.16 - $ 2.27
+ HRV (70% effect.)	$ 15.75 - $ 16.48	$ 1.84 - $ 1.93
+ 10% UA Reduction	$ 16.53 - $ 17.30	$ 1.86 - $ 1.95
+ 20% UA Reduction	$ 17.15 - $ 17.95	$ 1.87 - $ 1.95
+ 35% UA Reduction	$ 18.09 - $ 18.93	$ 1.89 - $ 1.98
Split System HPs, Ducted to Bedrooms	$ 13.18 - $ 13.80	$ 2.23 - $ 2.33
+ 10% UA Reduction	$ 13.96 - $ 14.62	$ 2.28 - $ 2.39
+ 20% UA Reduction	$ 14.59 - $ 15.27	$ 2.28 - $ 2.39
+ 35% UA Reduction	$ 15.52 - $ 16.25	$ 2.31 - $ 2.42
+ HRV (70% effect.)	$ 18.20 - $ 19.05	$ 2.14 - $ 2.25
+ 10% UA Reduction	$ 18.98 - $ 19.87	$ 2.14 - $ 2.24
+ 20% UA Reduction	$ 19.61 - $ 20.52	$ 2.14 - $ 2.24
+ 35% UA Reduction	$ 20.54 - $ 21.50	$ 2.17 - $ 2.27
VRF, Bedroom Electric Heat	$ 16.44 - $ 17.21	$ 2.67 - $ 2.79
+ 10% UA Reduction	$ 17.23 - $ 18.03	$ 2.73 - $ 2.86
+ 20% UA Reduction	$ 17.85 - $ 18.68	$ 2.69 - $ 2.82
+ 35% UA Reduction	$ 18.79 - $ 19.66	$ 2.67 - $ 2.80
+ HRV (70% effect.)	$ 21.46 - $ 22.47	$ 2.27 - $ 2.38
+ 10% UA Reduction	$ 22.25 - $ 23.29	$ 2.28 - $ 2.38
+ 20% UA Reduction	$ 22.87 - $ 23.94	$ 2.27 - $ 2.37
+ 35% UA Reduction	$ 23.81 - $ 24.92	$ 2.28 - $ 2.39
VRF, Ducted to Bedrooms	$ 20.29 - $ 21.24	$ 2.88 - $ 3.02
+ 10% UA Reduction	$ 21.07 - $ 22.06	$ 2.90 - $ 3.04

+ 20% UA Reduction	$ 21.70 - $ 22.71	$ 2.88 - $ 3.02
+ 35% UA Reduction	$ 22.63 - $ 23.69	$ 2.88 - $ 3.02
+ HRV (70% effect.)	$ 25.31 - $ 26.49	$ 2.67 - $ 2.79
+ 10% UA Reduction	$ 26.09 - $ 27.31	$ 2.64 - $ 2.76
+ 20% UA Reduction	$ 26.72 - $ 27.97	$ 2.63 - $ 2.75
+ 35% UA Reduction	$ 27.65 - $ 28.94	$ 2.64 - $ 2.76

Figure 18. Medium Density Energy + Cost Results, Medford

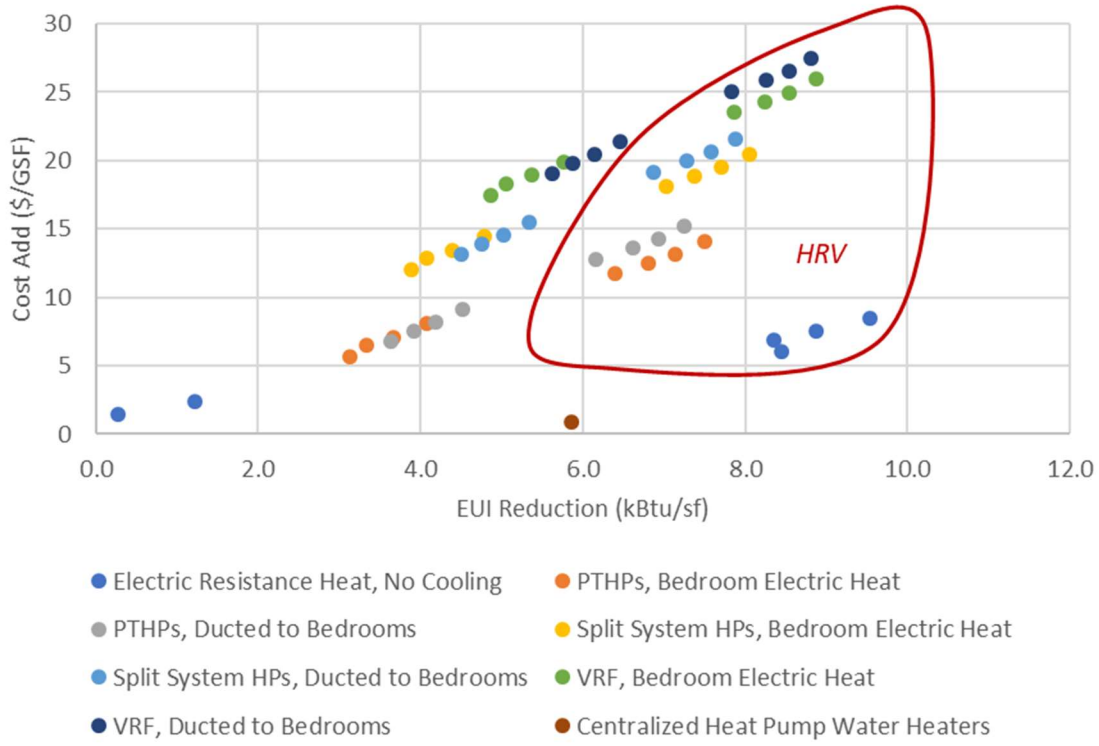

Table 53. Medium Density Energy + Cost Results, Medford

Energy + Cost Results for Medium Density Multifamily in Medford, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 0.90 - $ 0.94	$ 0.15 - $ 0.16
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (2.12) - $ (2.22)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 5.11 - $ 5.34
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.93 - $ 2.02
+ HRV (70% effect.)	$ 5.92 - $ 6.19	$ 0.70 - $ 0.73
+ 10% UA Reduction	$ 6.70 - $ 7.01	$ 0.80 - $ 0.84
+ 20% UA Reduction	$ 7.32 - $ 7.67	$ 0.82 - $ 0.86
+ 35% UA Reduction	$ 8.26 - $ 8.64	$ 0.87 - $ 0.91
PTHPs, Bedroom Electric Heat	$ 5.53 - $ 5.79	$ 1.77 - $ 1.85
+ 10% UA Reduction	$ 6.31 - $ 6.61	$ 1.89 - $ 1.98

+ 20% UA Reduction	$ 6.94 - $ 7.26	$ 1.89 - $ 1.98
+ 35% UA Reduction	$ 7.87 - $ 8.24	$ 1.93 - $ 2.02
+ HRV (70% effect.)	$ 11.45 - $ 11.98	$ 1.79 - $ 1.87
+ 10% UA Reduction	$ 12.23 - $ 12.80	$ 1.80 - $ 1.88
+ 20% UA Reduction	$ 12.85 - $ 13.45	$ 1.80 - $ 1.88
+ 35% UA Reduction	$ 13.79 - $ 14.43	$ 1.84 - $ 1.93
PTHPs, Ducted to Bedrooms	$ 6.59 - $ 6.90	$ 1.82 - $ 1.90
+ 10% UA Reduction	$ 7.38 - $ 7.72	$ 1.89 - $ 1.97
+ 20% UA Reduction	$ 8.00 - $ 8.37	$ 1.91 - $ 2.00
+ 35% UA Reduction	$ 8.93 - $ 9.35	$ 1.98 - $ 2.07
+ HRV (70% effect.)	$ 12.51 - $ 13.09	$ 2.03 - $ 2.13
+ 10% UA Reduction	$ 13.29 - $ 13.91	$ 2.01 - $ 2.10
+ 20% UA Reduction	$ 13.92 - $ 14.57	$ 2.01 - $ 2.10
+ 35% UA Reduction	$ 14.85 - $ 15.54	$ 2.05 - $ 2.15
Split System HPs, Bedroom Electric Heat	$ 11.75 - $ 12.30	$ 3.02 - $ 3.16
+ 10% UA Reduction	$ 12.53 - $ 13.12	$ 3.08 - $ 3.22
+ 20% UA Reduction	$ 13.16 - $ 13.77	$ 3.00 - $ 3.14
+ 35% UA Reduction	$ 14.09 - $ 14.75	$ 2.94 - $ 3.08
+ HRV (70% effect.)	$ 17.67 - $ 18.49	$ 2.52 - $ 2.63
+ 10% UA Reduction	$ 18.45 - $ 19.31	$ 2.50 - $ 2.62
+ 20% UA Reduction	$ 19.07 - $ 19.96	$ 2.48 - $ 2.59
+ 35% UA Reduction	$ 20.01 - $ 20.94	$ 2.49 - $ 2.60
Split System HPs, Ducted to Bedrooms	$ 12.81 - $ 13.41	$ 2.85 - $ 2.98
+ 10% UA Reduction	$ 13.60 - $ 14.23	$ 2.86 - $ 3.00
+ 20% UA Reduction	$ 14.22 - $ 14.88	$ 2.83 - $ 2.97
+ 35% UA Reduction	$ 15.16 - $ 15.86	$ 2.84 - $ 2.97
+ HRV (70% effect.)	$ 18.73 - $ 19.60	$ 2.73 - $ 2.86
+ 10% UA Reduction	$ 19.51 - $ 20.42	$ 2.68 - $ 2.80
+ 20% UA Reduction	$ 20.14 - $ 21.08	$ 2.66 - $ 2.78
+ 35% UA Reduction	$ 21.07 - $ 22.06	$ 2.67 - $ 2.80
VRF, Bedroom Electric Heat	$ 17.08 - $ 17.87	$ 3.51 - $ 3.68
+ 10% UA Reduction	$ 17.86 - $ 18.69	$ 3.54 - $ 3.70
+ 20% UA Reduction	$ 18.48 - $ 19.35	$ 3.44 - $ 3.61
+ 35% UA Reduction	$ 19.42 - $ 20.32	$ 3.37 - $ 3.53
+ HRV (70% effect.)	$ 22.99 - $ 24.07	$ 2.92 - $ 3.06
+ 10% UA Reduction	$ 23.77 - $ 24.89	$ 2.89 - $ 3.02
+ 20% UA Reduction	$ 24.40 - $ 25.54	$ 2.85 - $ 2.99
+ 35% UA Reduction	$ 25.33 - $ 26.52	$ 2.86 - $ 2.99
VRF, Ducted to Bedrooms	$ 18.57 - $ 19.44	$ 3.31 - $ 3.46
+ 10% UA Reduction	$ 19.35 - $ 20.26	$ 3.29 - $ 3.45
+ 20% UA Reduction	$ 19.98 - $ 20.91	$ 3.25 - $ 3.41

+ 35% UA Reduction	$ 20.91 - $ 21.89	$ 3.24 - $ 3.39
+ HRV (70% effect.)	$ 24.49 - $ 25.63	$ 3.13 - $ 3.27
+ 10% UA Reduction	$ 25.27 - $ 26.45	$ 3.06 - $ 3.20
+ 20% UA Reduction	$ 25.89 - $ 27.10	$ 3.03 - $ 3.17
+ 35% UA Reduction	$ 26.83 - $ 28.08	$ 3.04 - $ 3.19

Figure 19. High Density Energy + Cost Results, Medford

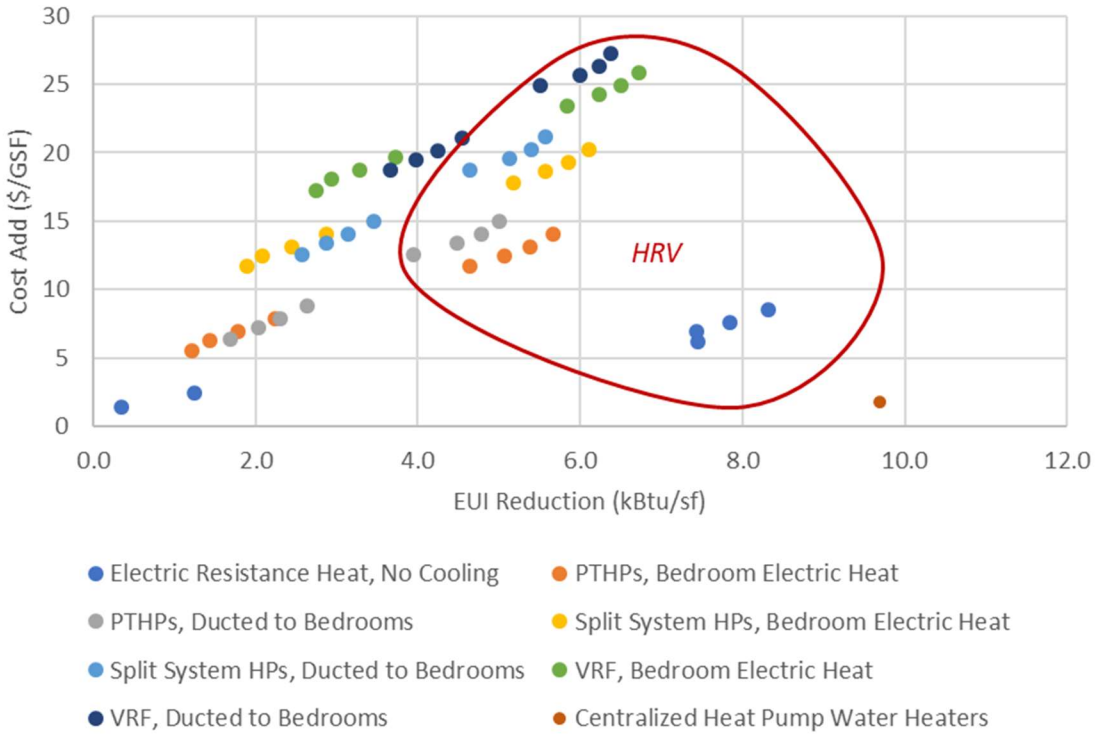

Table 54. High Density Energy + Cost Results, Medford

Energy + Cost Results for High Density Multifamily in Medford, OR	Adjusted Cost Add ($/GSF)	Cost Per Savings ($/kBtu)
Centralized Heat Pump Water Heaters	$ 1.77 - $ 1.85	$ 0.18 - $ 0.19
Electric Resistance Heat, No Cooling		
+ 10% UA Reduction	$ 0.78 - $ 0.82	$ (2.81) - $ (2.95)
+ 20% UA Reduction	$ 1.41 - $ 1.47	$ 3.97 - $ 4.16
+ 35% UA Reduction	$ 2.34 - $ 2.45	$ 1.88 - $ 1.97
+ HRV (70% effect.)	$ 6.03 - $ 6.31	$ 0.81 - $ 0.85
+ 10% UA Reduction	$ 6.81 - $ 7.13	$ 0.92 - $ 0.96
+ 20% UA Reduction	$ 7.43 - $ 7.78	$ 0.95 - $ 0.99
+ 35% UA Reduction	$ 8.37 - $ 8.76	$ 1.01 - $ 1.05
PTHPs, Bedroom Electric Heat	$ 5.38 - $ 5.63	$ 4.41 - $ 4.61
+ 10% UA Reduction	$ 6.16 - $ 6.45	$ 4.30 - $ 4.50
+ 20% UA Reduction	$ 6.78 - $ 7.10	$ 3.79 - $ 3.96

+ 35% UA Reduction	$ 7.72 - $ 8.08	$ 3.44 - $ 3.60
+ HRV (70% effect.)	$ 11.40 - $ 11.94	$ 2.46 - $ 2.58
+ 10% UA Reduction	$ 12.19 - $ 12.76	$ 2.41 - $ 2.52
+ 20% UA Reduction	$ 12.81 - $ 13.41	$ 2.38 - $ 2.49
+ 35% UA Reduction	$ 13.75 - $ 14.39	$ 2.43 - $ 2.54
PTHPs, Ducted to Bedrooms	$ 6.27 - $ 6.56	$ 3.70 - $ 3.88
+ 10% UA Reduction	$ 7.05 - $ 7.38	$ 3.47 - $ 3.63
+ 20% UA Reduction	$ 7.67 - $ 8.03	$ 3.33 - $ 3.48
+ 35% UA Reduction	$ 8.61 - $ 9.01	$ 3.27 - $ 3.42
+ HRV (70% effect.)	$ 12.29 - $ 12.87	$ 3.12 - $ 3.26
+ 10% UA Reduction	$ 13.08 - $ 13.69	$ 2.91 - $ 3.05
+ 20% UA Reduction	$ 13.70 - $ 14.34	$ 2.87 - $ 3.00
+ 35% UA Reduction	$ 14.63 - $ 15.32	$ 2.92 - $ 3.06
Split System HPs, Bedroom Electric Heat	$ 11.39 - $ 11.93	$ 5.99 - $ 6.27
+ 10% UA Reduction	$ 12.18 - $ 12.75	$ 5.84 - $ 6.11
+ 20% UA Reduction	$ 12.80 - $ 13.40	$ 5.25 - $ 5.49
+ 35% UA Reduction	$ 13.74 - $ 14.38	$ 4.77 - $ 4.99
+ HRV (70% effect.)	$ 17.42 - $ 18.24	$ 3.36 - $ 3.52
+ 10% UA Reduction	$ 18.20 - $ 19.06	$ 3.27 - $ 3.42
+ 20% UA Reduction	$ 18.83 - $ 19.71	$ 3.21 - $ 3.36
+ 35% UA Reduction	$ 19.76 - $ 20.69	$ 3.24 - $ 3.39
Split System HPs, Ducted to Bedrooms	$ 12.28 - $ 12.86	$ 4.77 - $ 5.00
+ 10% UA Reduction	$ 13.07 - $ 13.68	$ 4.54 - $ 4.75
+ 20% UA Reduction	$ 13.69 - $ 14.33	$ 4.35 - $ 4.56
+ 35% UA Reduction	$ 14.63 - $ 15.31	$ 4.23 - $ 4.43
+ HRV (70% effect.)	$ 18.31 - $ 19.17	$ 3.94 - $ 4.13
+ 10% UA Reduction	$ 19.09 - $ 19.99	$ 3.72 - $ 3.89
+ 20% UA Reduction	$ 19.72 - $ 20.64	$ 3.66 - $ 3.83
+ 35% UA Reduction	$ 20.65 - $ 21.62	$ 3.70 - $ 3.88
VRF, Bedroom Electric Heat	$ 16.88 - $ 17.67	$ 6.16 - $ 6.45
+ 10% UA Reduction	$ 17.66 - $ 18.49	$ 6.02 - $ 6.31
+ 20% UA Reduction	$ 18.28 - $ 19.14	$ 5.57 - $ 5.83
+ 35% UA Reduction	$ 19.22 - $ 20.12	$ 5.17 - $ 5.41
+ HRV (70% effect.)	$ 22.91 - $ 23.98	$ 3.92 - $ 4.10
+ 10% UA Reduction	$ 23.69 - $ 24.80	$ 3.80 - $ 3.97
+ 20% UA Reduction	$ 24.31 - $ 25.45	$ 3.73 - $ 3.91
+ 35% UA Reduction	$ 25.25 - $ 26.43	$ 3.76 - $ 3.93
VRF, Ducted to Bedrooms	$ 18.27 - $ 19.12	$ 4.99 - $ 5.22
+ 10% UA Reduction	$ 19.05 - $ 19.94	$ 4.80 - $ 5.02
+ 20% UA Reduction	$ 19.68 - $ 20.60	$ 4.64 - $ 4.86
+ 35% UA Reduction	$ 20.61 - $ 21.58	$ 4.54 - $ 4.75

+ HRV (70% effect.)	$ 24.30 - $ 25.43	$ 4.41 - $ 4.62
+ 10% UA Reduction	$ 25.08 - $ 26.25	$ 4.18 - $ 4.37
+ 20% UA Reduction	$ 25.70 - $ 26.91	$ 4.12 - $ 4.32
+ 35% UA Reduction	$ 26.64 - $ 27.88	$ 4.18 - $ 4.38

4.3.2 Photovoltaic Solar Panels

The following table summarizes rooftop solar panel production and installation cost in Oregon.

Table 55. Solar Panel Energy + Cost Results, Oregon

Photovoltaic Solar Panels	Production	Cost (Adjusted)	Cost Per Savings ($/kBtu)	System Life
Portland	3.85 kBtu/Watt	$ 3.20 - $ 4.70 per Watt	$ 0.83 - $ 1.22	25-30
Salem	3.97 kBtu/Watt		$ 0.81 - $ 1.18	
Medford	4.65 kBtu/Watt		$ 0.69 - $ 1.01	

5 DISCUSSION

This section contains a discussion of the results, including cost per savings, incremental cost in the context of total building cost, a recommendations for future work.

5.1 BEST BANG FOR BUCK

For all locations and densities studied, **centralized heat pump hot water heaters** are a clear cost-per-energy-savings winner, with a $0.16 - $0.22 per kBtu saved, whereas HVAC and envelope alternates start around $0.60 per kBtu saved for HRVs in a Low Density, Portland project. Within the envelope and HVAC alternates studied, $/kBtu saved trends upwards as total HVAC EUI reduction potential increases; in other words, energy savings are progressively more expensive as the building becomes more efficient.

5.1.1 Operational Costs for Hot Water, Electricity vs Natural Gas

The high energy savings potential and low $/kBtu results for heat pump hot water heaters suggest an opportunity for multifamily market transformation; this has been noted by groups like NEEA, and future iterations of the Washington and Seattle energy codes are planning to aggressively encourage heat pump water heating for multifamily projects. However, from a financial operations standpoint it is important to note that while heat pump water heaters will significantly reduce the **site** domestic hot water EUI compared to the natural gas condensing boiler baseline, they will have similar utility costs. This is due to the relative $/kBtu cost of natural gas and electricity in Oregon, with electricity being approximately 3 times more expensive than natural gas per site kBtu. This is also worth noting if the project is considering in-unit electric resistance water heaters: while they appear to save energy compared to natural gas boilers, they will be more expensive to operate.

5.1.2 Can we afford not to cool?

The electric resistance heating baseline was selected for this study as it is the lowest cost HVAC option for multifamily projects within Oregon and is still commonly seen in designs for low cost new construction. However, as our climate warms, and especially with the higher internal heat densities present in multifamily, **mechanical cooling is becoming a necessity**; for this reason, design teams should consider carefully whether to prioritize mechanical cooling or ventilation heat recovery more highly.

5.1.3 Renewables

Solar panel costs have decreased dramatically in the past decade and have impressive costs per savings of $0.69 - $1.22/kBtu depending on price and location in Oregon. This is at the lower end of $/kBtu for alternates evaluated in this study and suggests that solar panel investment should be compared to potential HVAC and envelope upgrades during design.

5.2 PROBLEMS AND SOURCES OF ERROR

To accommodate budget and time constraints, the following were not studied, which may have lead to errors in the results.

- Envelope footprint and orientation. The example project wall area to floor area ratios were used to calculate $/GSF pricing for exterior wall and window pricing, but this was not incorporated into the energy model results.
- The capacities used for HVAC pricing were not adjusted based on location or envelope interventions. Due to nominal sizing, this is unlikely to affect pricing more than density except in the case of VRF.
- Results have not been reviewed by contractors or developers, which may reveal errors.

5.3 RECOMMENDATIONS FOR FURTHER STUDY

This section explores areas for further study to improve design community understanding of high efficiency multifamily design.

5.3.1 Collaboration with Contractors and Developers

The pricing results presented in section 4.2 align with anecdotal pricing for recent projects completed by Glumac. However, review and feedback from contractors and developers could help reveal weaknesses in the analysis.

5.3.2 Cost Reductions for Common Efficiency Improvements

Pricing of system types changes over time. Further investigation of material and labor pricing for the alternates studied could reveal potential reductions in price point that would enable additional energy and cost savings.

5.3.3 Repetition with Additional Example Projects

Three (3) example projects were used for energy and cost analysis. Repetition of the methods with additional project examples could add value to the results.

5.3.4 Interactive Dashboard for Schematic Design Analysis

This study has provided broadly applicable energy and cost results for use on a wide range of multifamily projects in Oregon. However, the results are currently presented as a series of look up tables; use of these results would be more accessible if they were incorporated into a user-friendly, interactive dashboard. This could be achieved through the creation of a restricted spreadsheet or a Power BI file.

5.3.5 Use of Predicted Weather Files

The energy results of this study are based on TMY3 weather files. These files are from the early 2000s and do not reflect anticipated changes in our weather patterns due to climate change. Design teams attempting to make cost effective efficiency choices for buildings that will exist for 30-50 years would be aided by additional information about how relative savings may change over time.