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NET ZERO FELLOWSHIP 2019

Multifamily Energy Use and Construction Cost Reference Guide

Presented by Glumac

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1 INTRODUCTION

This guide is intended for use by architects, engineers, and energy modelers during the concept and schematic design phases of a new construction multifamily project.

1.1 HOW TO USE THE ENERGY MODELING ESTIMATES

The energy modeling results in this document are intended to reflect real world usage for multifamily projects. The energy use intensities (EUI, in kBtu/sf-yr) reflect a residential floorplate with an interior corridor, and do not include ground floor retail, restaurants, or underground parking. This is to avoid confusion and divergence based on building height and footprint.

The results in this guide are contained in a series of tables, corresponding to different occupant densities and geographic locations in Oregon. To determine which occupant density corresponds best to your project, calculate the occupant density as follows:

Occupant Density = Occupants/Residential-Unit-Area

Once calculated, compare the project's occupant densities to these definitions:

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

If you occupant density falls between one of the above, some interpolation can be performed.

1.2 HOW TO USE THE CONSTRUCTION COST ESTIMATES

Like the energy results, the cost information reflects an all-residential floorplate with internal corridors. Adding a large parking structure, for example, will decrease the $/GSF because it increases the GSF and requires less cost add per area than the residential part of the building. Again, this was done to avoid confusion and divergence based on building height and footprint. The cost estimate information is likely to be most useful in estimating incremental cost differences to upgrade various energy-related systems.

For each cost estimate provided, there is a $/GSF cost based on a 6-story, half block geometry. However, other cost units are often provided to allow tailoring to a specific project. For example, the envelope pricing is all provided in $/SF-of-surface units as well, so that the team can estimate pricing specific to their project.

1.3 OTHER QUESTIONS?

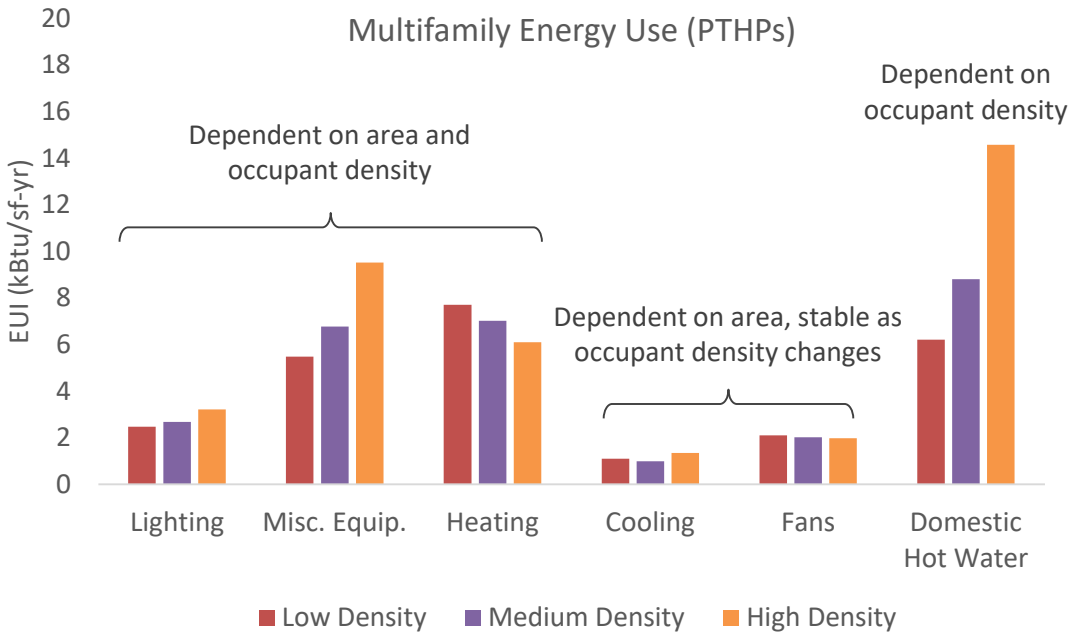
A detailed methodology for the information presented in this Reference Guide is contained in the associated research paper, published on the Energy Trust of Oregon website.

2 TYPICAL MULTIFAMILY ENERGY USE

Residential energy use is driven by two factors:

1. **Building size (floor area, volume, geometry)**
2. **Occupant density**

Traditional Energy Use Intensity (EUI) benchmarking uses energy-use-per-area (kBtu/sf-yr) to estimate energy use by building type, but this breaks down at different occupant densities in multifamily buildings.



Takeaways

- **Cooling and fan** energy use is primarily **driven by area**,
- **Heating, equipment** (appliances, plug loads) and **lighting** energy use are impacted by both **area and occupant density**, and
- **Domestic hot water** energy use is driven **entirely by occupant density** and can increase total EUI by 20-30% depending on density.
- **In Portland, typical PTHP multifamily EUI can range from 25 – 37 kBtu/sf.**

3 Low Cost Best Practices

The following design elements are included in the benchmarking results shown in the previous section due to their low cost and energy savings potential.

Moderate glazing ratio (30%)

A 25-30% glazing ratio is high enough to allow access to daylighting and low enough to keep heat transfer and construction costs low. Remember that typical dual pane **windows allow 5 times more heat transfer than walls** by area!

Non-metal framed windows

Typical dual pane **metal framed windows allow 20-30% more heat transfer** than their vinyl or fiberglass counterparts.

Heat pumps for space heating

Heat pumps use the refrigeration cycle to move heat where it's needed and are 3+ times more efficient than electric resistance or combustion.

LED lighting

Advances in LED technology have vastly expanded the design options and reduced the price to parity with fluorescent options.

Low flow fixtures

1.75 gpm showerheads; this is the highest impact plumbing fixture and is an improvement compared to a 2.0 or 2.5 gpm conventional fixture.

1.5 gpm kitchen faucet, 0.5 bathroom faucet.

Energy Star appliances including all refrigerators (mid-size), dishwashers, washers and dryers

Refrigerators account for 30-50% of the total equipment energy use in each living unit. Choosing **appropriately sized refrigerators** based on occupant expectations is important for energy efficiency; for example, if the unit will only house 1-2 people and is located within walking distance to multiple restaurants, consider a **mini fridge**.

Dishwashers reduce hot water energy use by 50% compared to handwashing and should therefore be included in each living unit.

Access to clothes dryers is expected in Oregon's multifamily market and true heat pump solutions (that pull heat from outdoor air rather than ambient apartment air) are still rare in the US so the baseline assumes electric dryers.

A Note on Occupant Wellbeing

Certain building elements that significantly improve occupant wellbeing, like mechanical cooling and continuous ventilation, are sometimes removed from designs to save energy or reduce cost. However, as our climate changes and expectations for building capabilities increase, sacrificing occupant wellbeing for energy savings is discouraged.

4 Strategies for Net Zero Multifamily

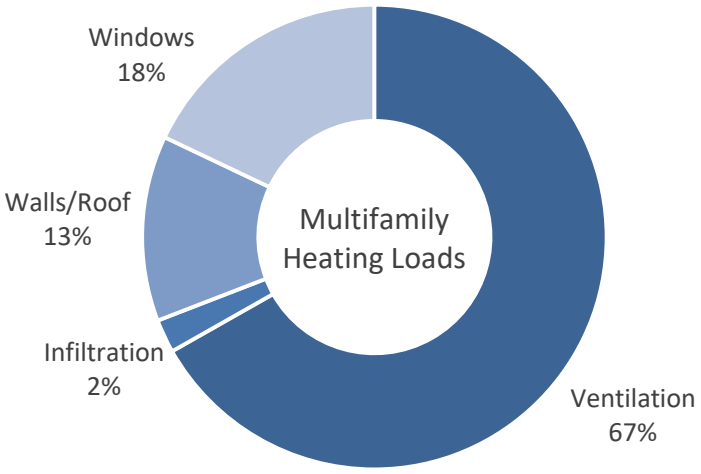
This section emphasizes some of the **highest impact design choices** for reducing multifamily energy use in Oregon, beyond low cost best practices.

HVAC: Reduce Loads, Recover Heat

Mechanical heating and cooling loads must be reduced by **improving the envelope** and **recovering heat for ventilation.**

Ventilation Loads

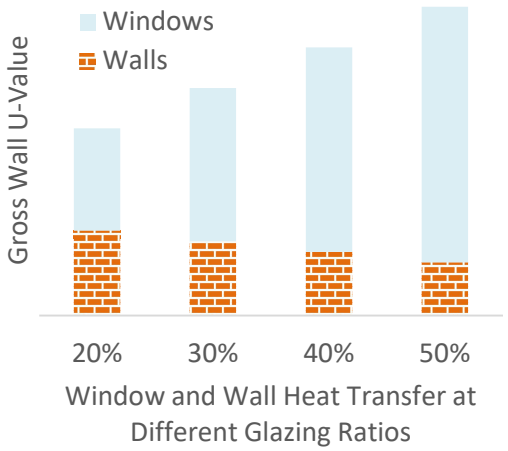
Energy used to condition continuous ventilation air can account for 50-70% of multifamily HVAC energy use in Oregon, if ventilated at code required levels. **Overventilation should be avoided**. Including **heat recovery** reduces ventilation loads by 50-90% and **can reduce HVAC energy use by 30-40%.**



- Using ventless dryers or opting for a **central laundry room** provides an opportunity to recover dryer exhaust heat in the winter and remove its waste heat from residential units in the summer.
- Heat recovery can be done unit-by-unit, floor-by-floor, or at a central Dedicated Outdoor Air System (DOAS) that serves the entire building.

Envelope Loads

Increasing insulation and selecting high performance dual pane or triple pane windows will reduce HVAC loads from the envelope. **Non-metal framed windows** and a moderate **window to wall ratio of 20-30%** are key to reduce heat transfer through the envelope.



Domestic Hot Water Heating: Use a Heat Pump

Domestic hot water is conventionally heated via electric resistance or natural gas and in most types of building this only represents 2-4% of total building energy. However, in multifamily buildings **domestic hot water heating uses 25-40% of total building energy** when heated this way.

Water Heating System	Dom. Hot Water EUI (kBtu/sf)		
	Low Density	Medium Density	High Density
Centralized Condensing Natural Gas Boilers	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

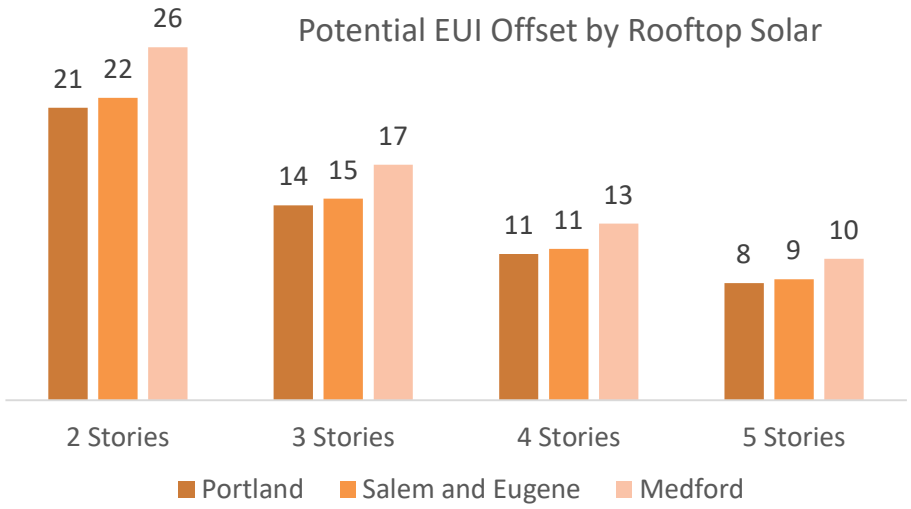
5 Net Zero in Oregon

There are various definitions of Net Zero Energy but one of the most popular is that total annual energy use for a building can be offset by total annual production by an on-site photovoltaic solar array, usually roof mounted.

Net Energy = Consumption – Renewables Offset

Solar Availability in Oregon

Solar availability, or the amount of energy that can be harvested from a building's site, will vary by geographic location and site constraints. Site constraints might include shading from trees, topography, or other buildings.



Understanding the potential solar offset for a project is an important step in determining the annual energy consumption a building is targeting to meet its energy efficiency goals.

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

6 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.

6.1 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.

6.2 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.

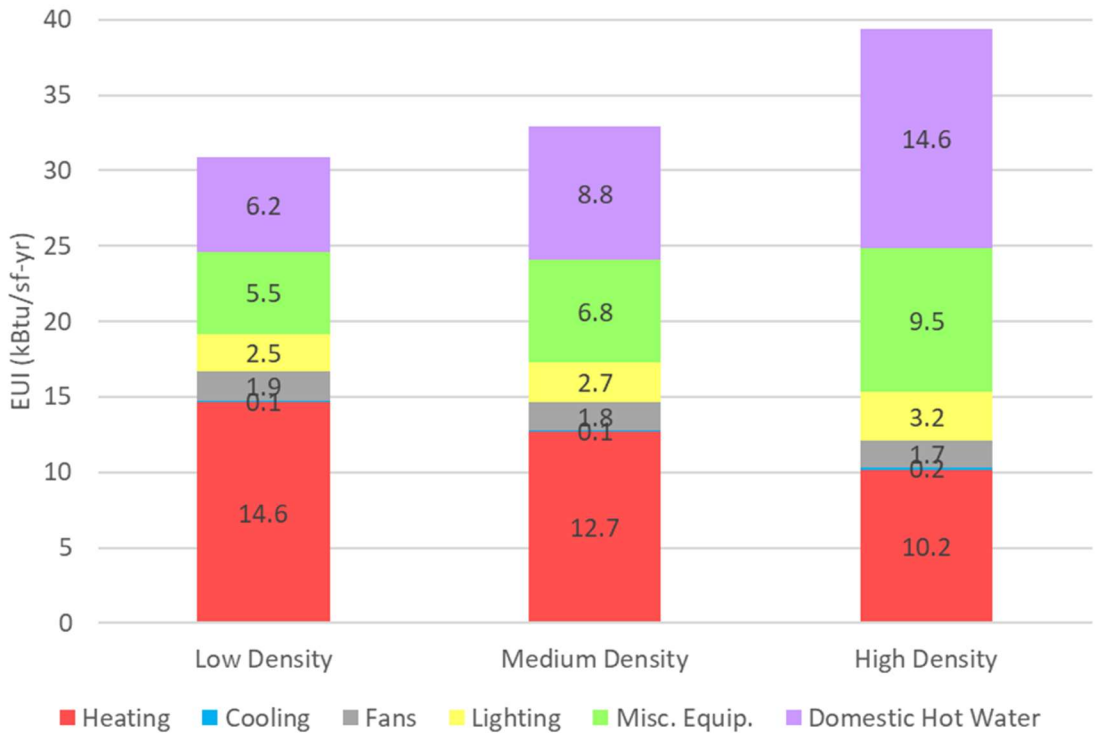
6.3 RENEWABLES

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.

7 PORTLAND ENERGY ESTIMATES

The following tables summarize the energy use intensity (EUI) end use results for Portland, Oregon. The **baseline HVAC system is electric resistance heating without in-unit cooling.** All results are in units of kBtu/sf-yr.

Figure 1. Total Baseline Energy Results, Portland



7.1 DOMESTIC HOT WATER HEATING ENERGY RESULTS

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

7.2 LOW DENSITY HVAC ENERGY RESULTS

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%

7.3 MEDIUM DENSITY HVAC ENERGY RESULTS

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%

7.4 HIGH DENSITY HVAC ENERGY RESULTS

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%

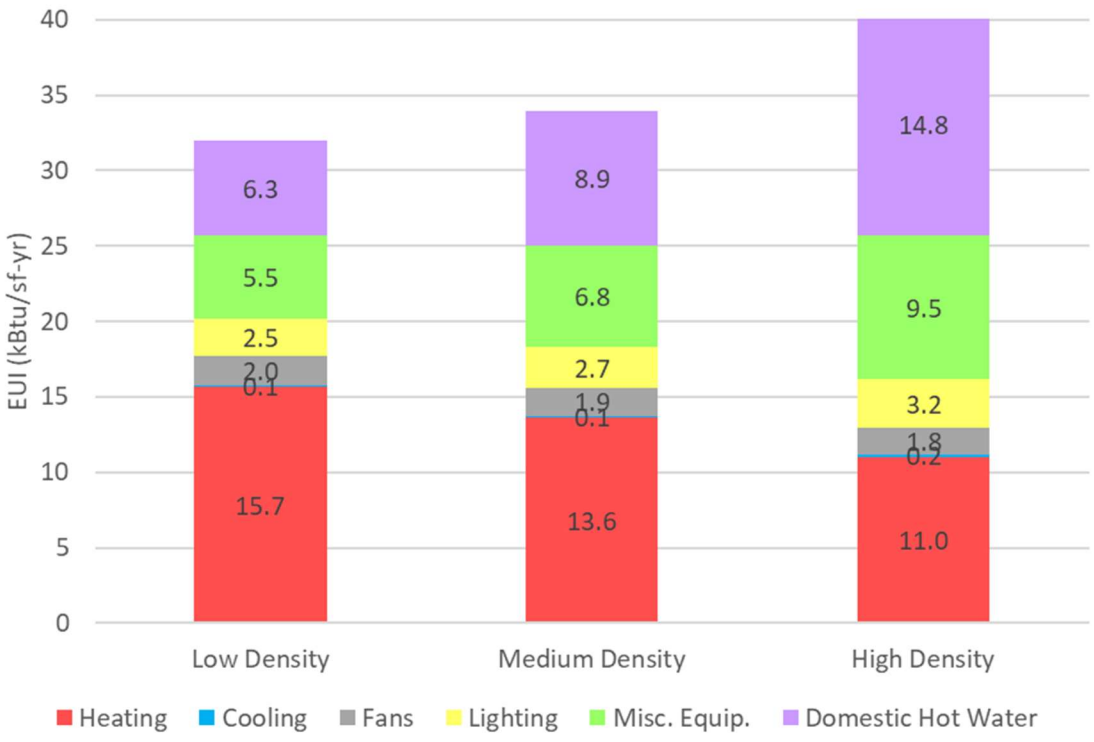
PTHPs, Bedroom Electric Heat	7.0	1.3	2.0	10.3	4.6%
+ 10% UA Reduction	7.1	1.1	1.9	10.1	5.0%
+ 20% UA Reduction	6.8	1.1	1.9	9.8	5.9%
+ 35% UA Reduction	6.4	1.1	1.9	9.4	7.0%
+ HRV (70% effect.)	2.2	2.0	3.3	7.5	11.8%
+ 10% UA Reduction	2.2	1.7	3.2	7.1	12.7%
+ 20% UA Reduction	1.9	1.8	3.2	6.8	13.4%
+ 35% 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%

8 SALEM ENERGY ESTIMATES

The following tables summarize the energy use intensity (EUI) end use results for Salem, Oregon. The **baseline HVAC system is electric resistance heating without in-unit cooling.** All results are in units of kBtu/sf-yr.

Figure 2. Total Baseline Energy Results, Salem



8.1 DOMESTIC HOT WATER HEATING ENERGY RESULTS

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

8.2 LOW DENSITY HVAC ENERGY RESULTS

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%

8.3 MEDIUM DENSITY HVAC ENERGY RESULTS

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%

8.4 HIGH DENSITY HVAC ENERGY RESULTS

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%

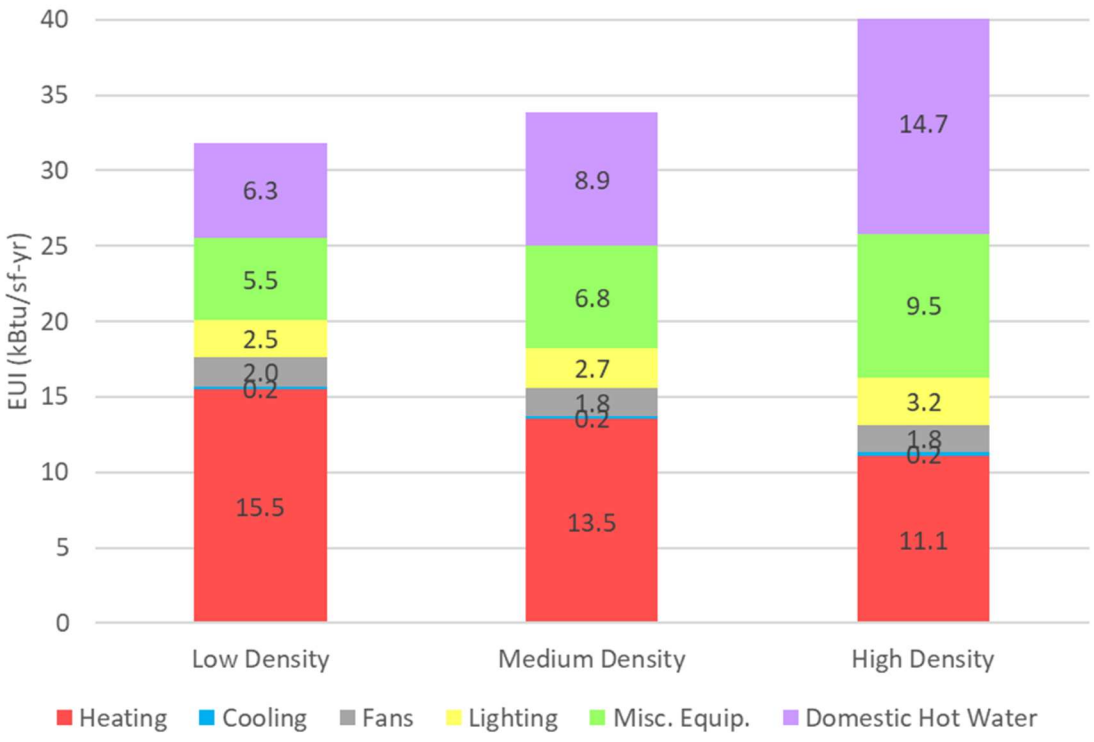
PTHPs, Bedroom Electric Heat	8.2	1.3	2.0	11.5	3.6%
+ 10% UA Reduction	8.2	1.1	2.0	11.3	4.1%
+ 20% UA Reduction	7.9	1.1	2.0	11.0	5.0%
+ 35% UA Reduction	7.4	1.1	2.0	10.5	6.2%
+ HRV (70% effect.)	2.9	2.0	3.3	8.2	11.9%
+ 10% UA Reduction	2.8	1.7	3.3	7.8	12.9%
+ 20% UA Reduction	2.5	1.7	3.3	7.5	13.6%
+ 35% 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%

9 MEDFORD ENERGY ESTIMATES

The following tables summarize the energy use intensity (EUI) end use results for Medford, Oregon. The **baseline HVAC system is electric resistance heating without in-unit cooling.** All results are in units of kBtu/sf-yr.

Table 1. Total Baseline Energy Results, Medford



9.1 DOMESTIC HOT WATER HEATING ENERGY RESULTS

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

9.2 LOW DENSITY HVAC ENERGY RESULTS

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%

9.3 MEDIUM DENSITY HVAC ENERGY RESULTS

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%

9.4 HIGH DENSITY HVAC ENERGY RESULTS

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%

10 CONSTRUCTION PRICING ESTIMATES

10.1.1 Non-Energy Related

The following table summarizes non-energy related pricing results.

Table 2. 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

10.1.2 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 3. 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

10.1.3 Conveying

The following table summarizes the conveying system pricing results.

Table 4. 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

10.1.4 Plumbing

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

Table 5. 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

10.1.5 HVAC

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

Table 6. 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

10.1.6 Electrical

The following table summarizes the baseline electrical system pricing results.

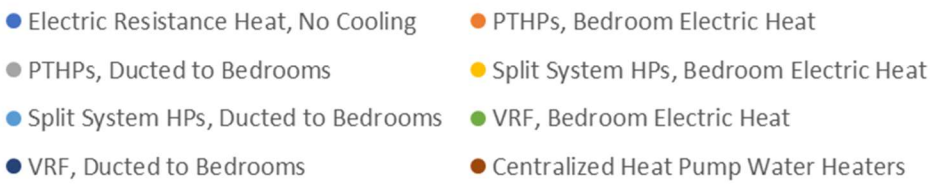
Table 7. Electrical Pricing Results

Energy Saving Strategy	Cost (Adjusted)	Cost Unit
Electric Heat, Bathroom Exhaust Fans, Corridor RTU, Nat Gas DHW	$ 34.28 - $ 38.61	GSF of building

11 BANG FOR BUCK GRAPHS

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. **Dots appearing in the bottom right of the graph have the best bang for buck.**

Figure 3. Graph Legend



Why are there so many dots of the same color?

Multiple (8x) dots of the same color appear on each graph, and are for the following results:

- 4x HVAC System without HRV
  - Baseline envelope (ASHRAE 90.1-2016)
  - 10% conductivity reduction
  - 20% conductivity reduction
  - 35% conductivity reduction
- 4x HVAC System with HRV
  - Baseline envelope (ASHRAE 90.1-2016)
  - 10% conductivity reduction
  - 20% conductivity reduction
  - 35% conductivity reduction

11.1 PORTLAND, OREGON

Figure 4. Low Density Energy + Cost Results, Portland

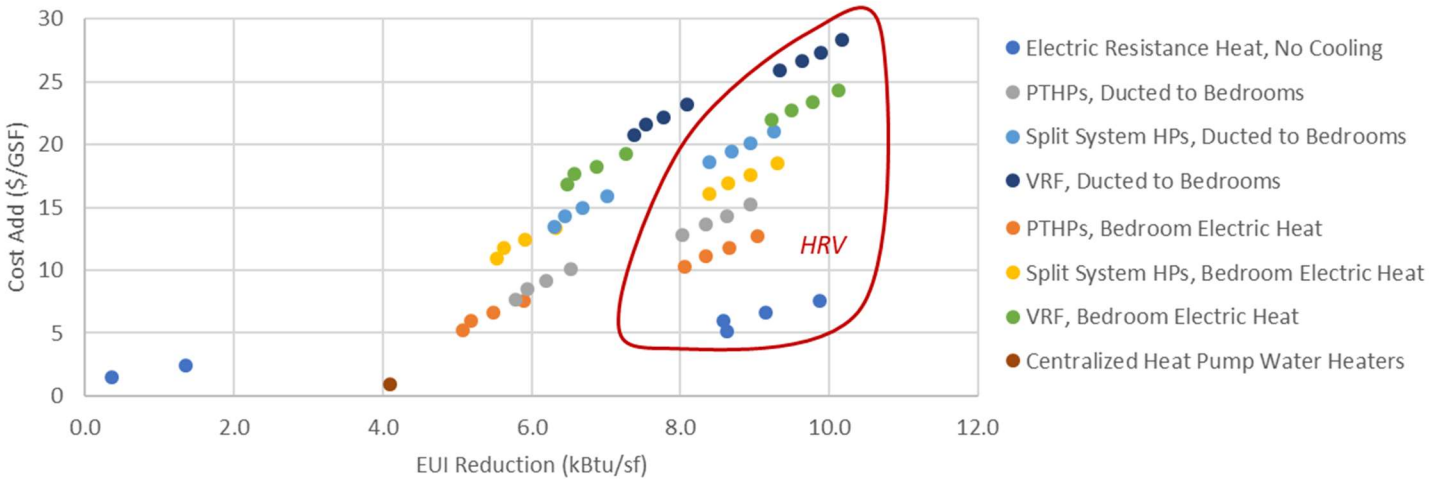


Figure 5. Medium Density Energy + Cost Results, Portland

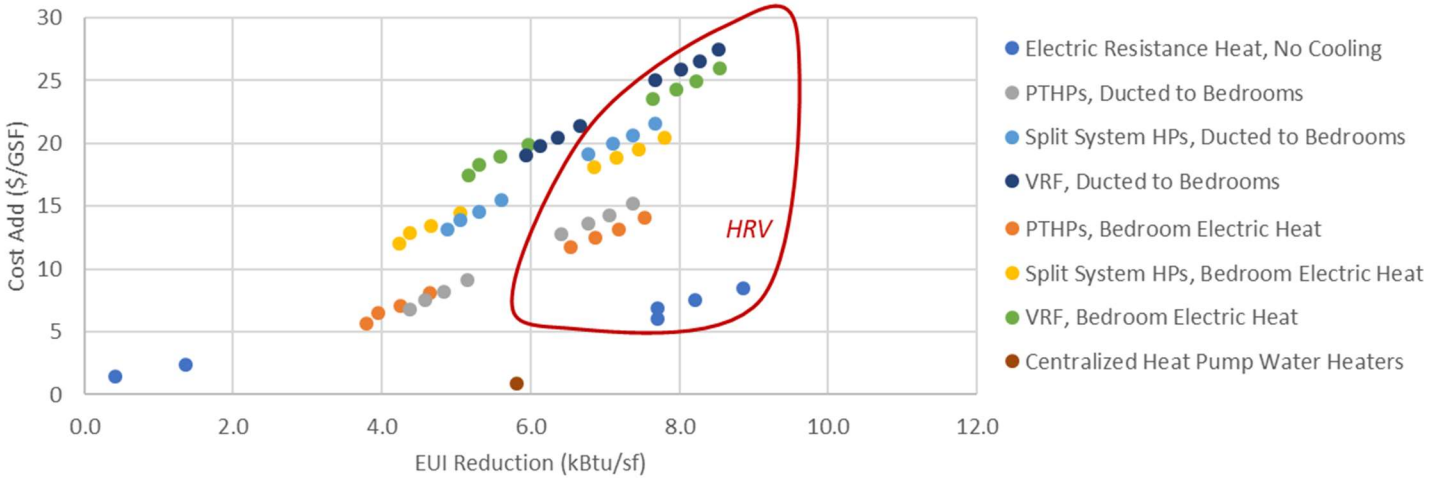
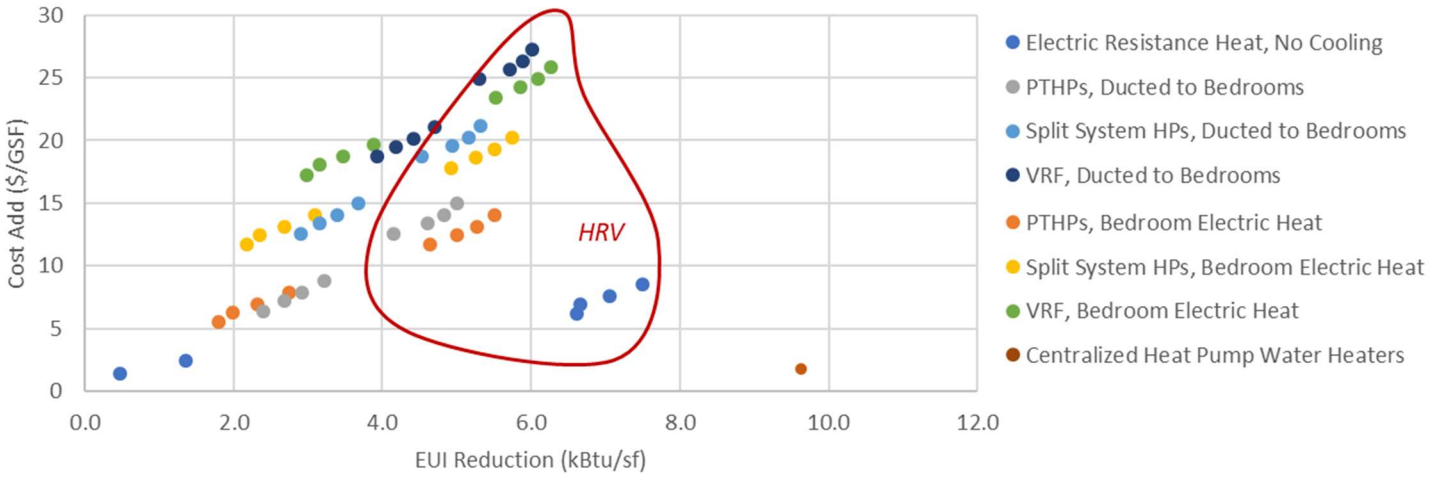


Figure 6. High Density Energy + Cost Results, Portland



11.2 SALEM, OREGON

Figure 7. Low Density Energy + Cost Results, Salem

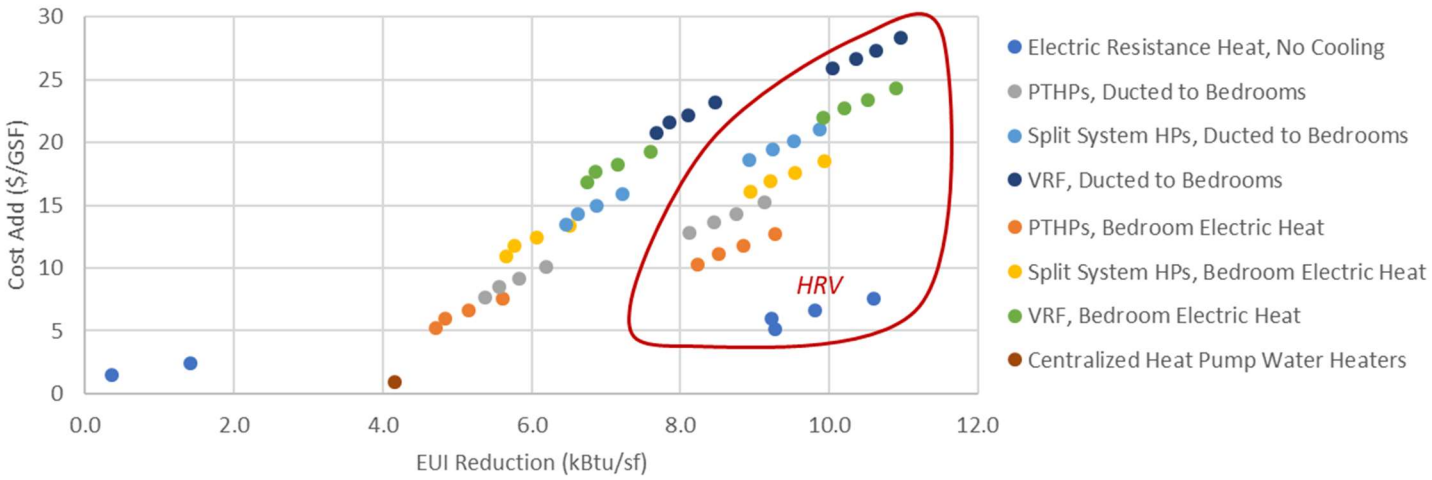


Figure 8. Medium Density Energy + Cost Results, Salem

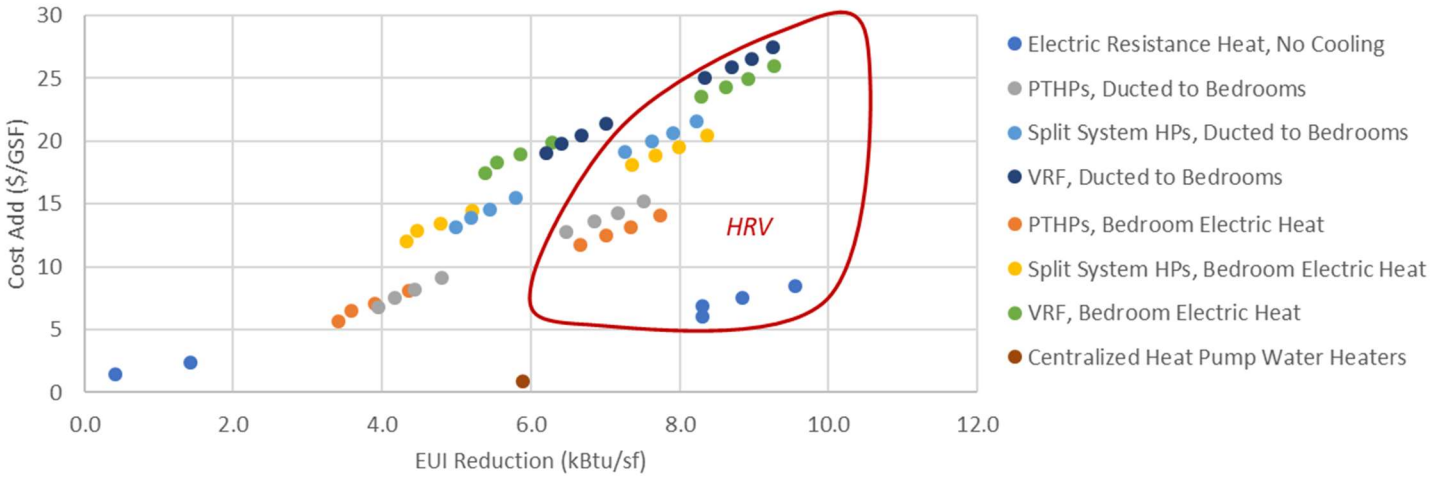
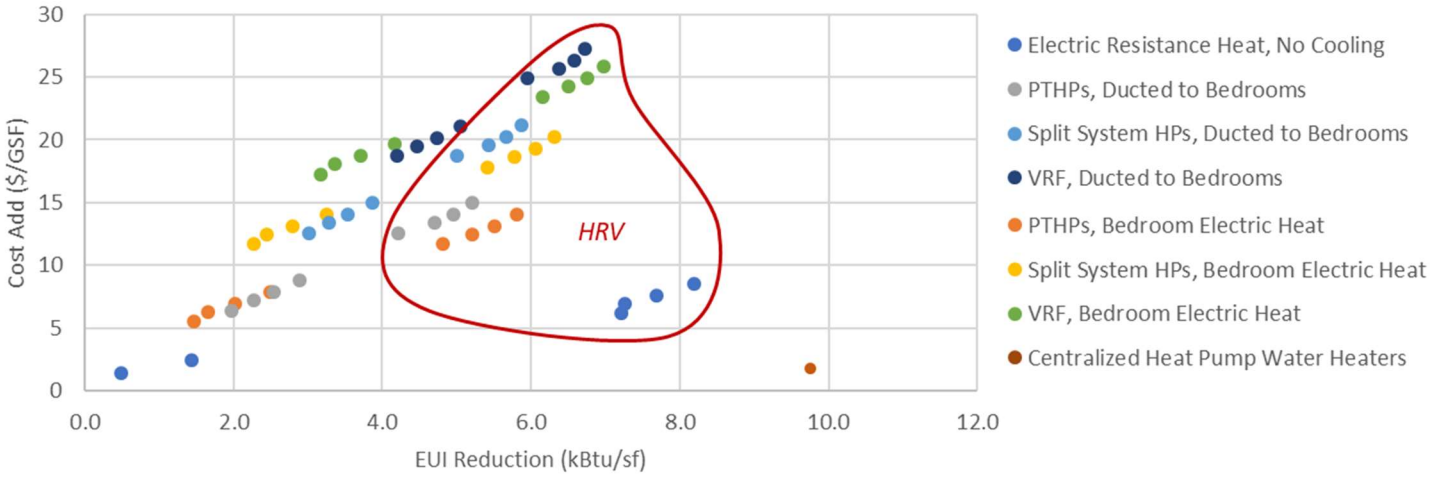


Figure 9. High Density Energy + Cost Results, Salem



11.3 MEDFORD, OREGON

Figure 10. Low Density Energy + Cost Results, Medford

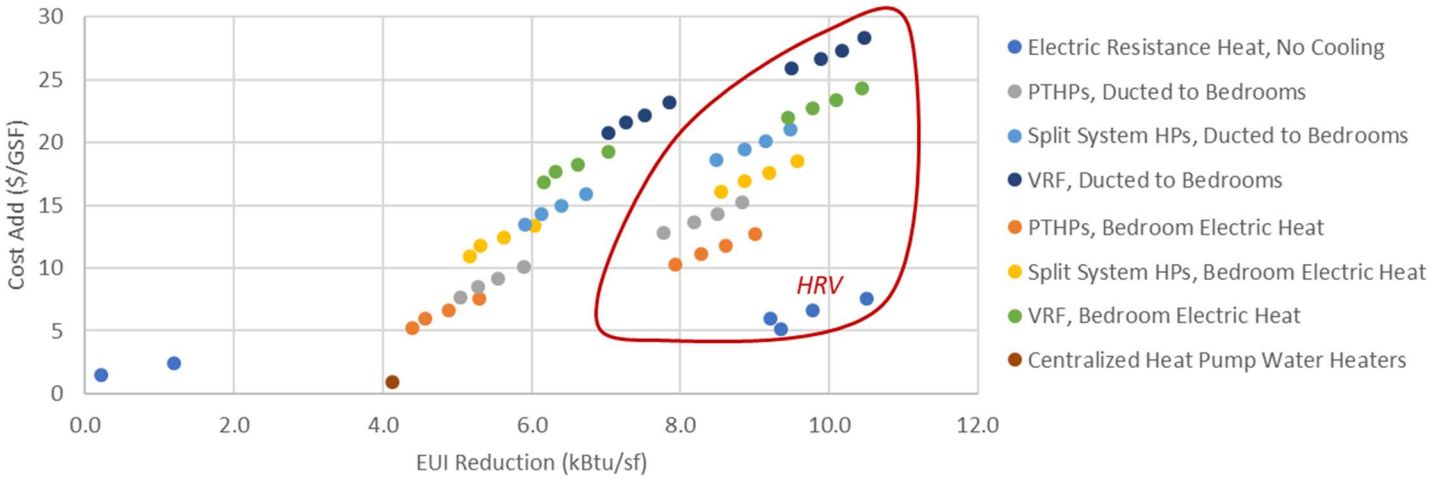


Figure 11. Medium Density Energy + Cost Results, Medford

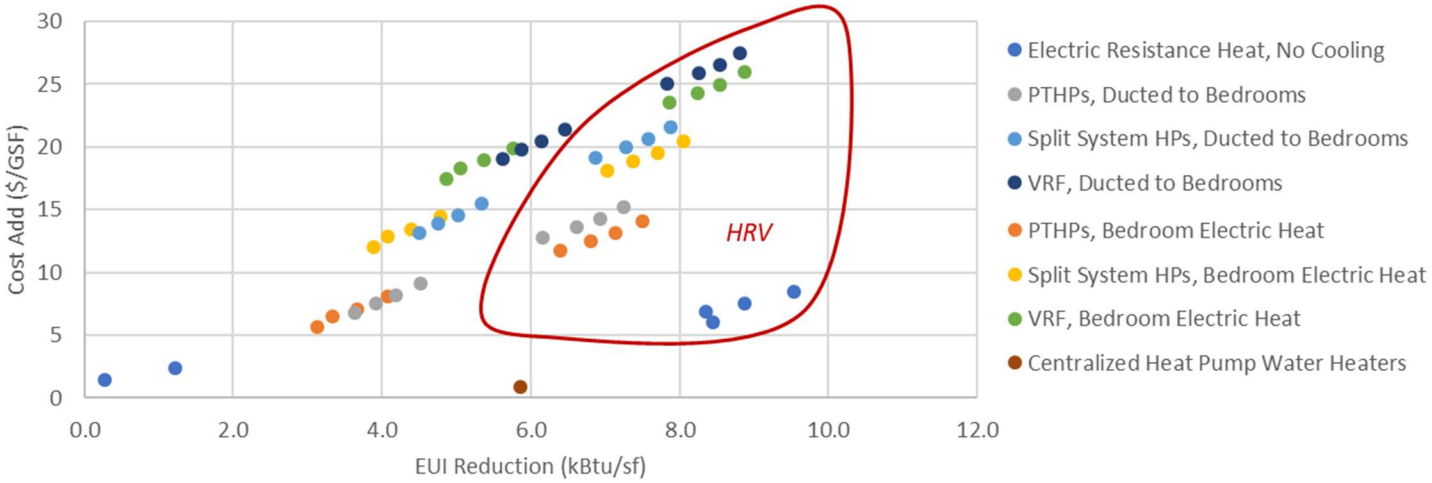


Figure 12. High Density Energy + Cost Results, Medford