



Net Zero Fellowship 2019  
**The Cost of Multifamily Energy Efficiency  
in Oregon**



## Agenda

20 minutes - Multifamily Energy Use

20 minutes - Construction Costs

20 minutes - Integrating Costs and Energy

20 minutes - Q&A

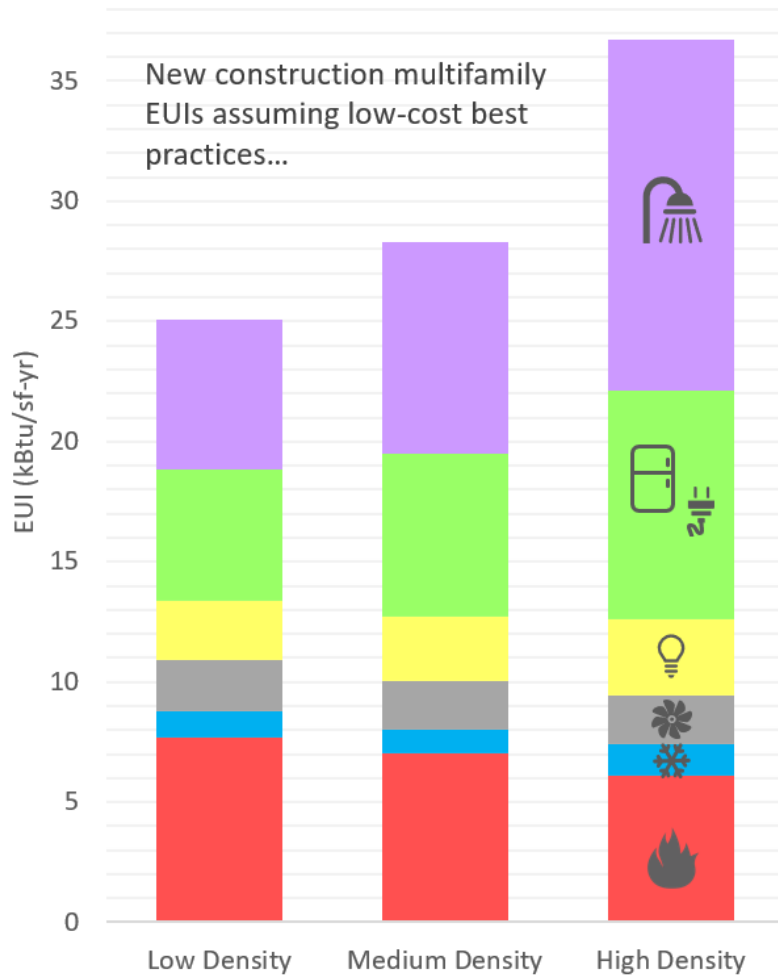


## Learning Objectives

1. Gain basic understanding of **multifamily building energy use**.
2. Explore common **energy efficiency strategies** for multifamily Net Zero Design.
3. Review **drivers of multifamily construction cost** and how they interact with energy efficiency.
4. Evaluate **effectiveness of strategies** based on cost impacts and energy saved.

# Multifamily Energy Use

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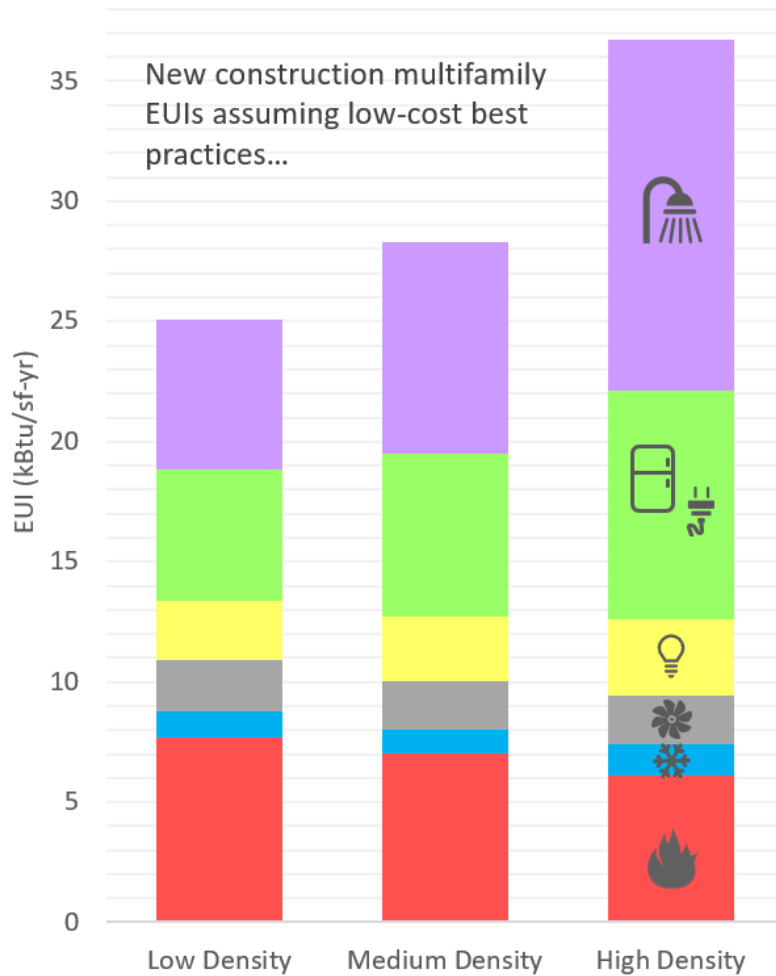


How does energy use vary?

Metrics: kBtu/sf or kBtu/person?

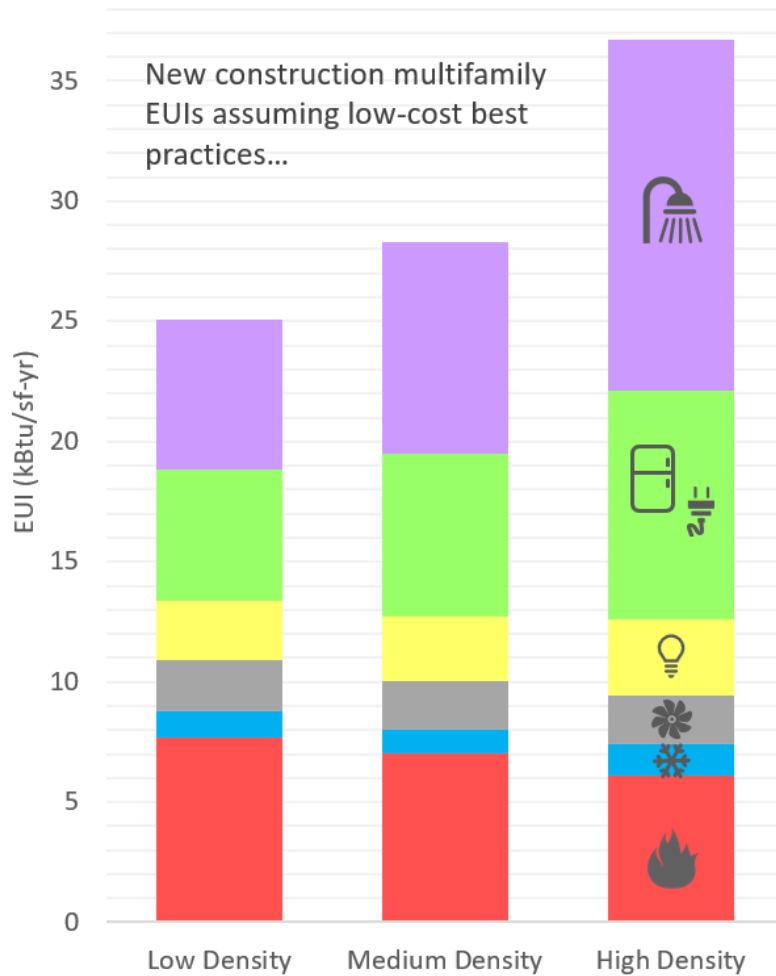
Net Zero Energy Strategies

# Multifamily Energy Use



**Domestic hot water is dependent on occupant density and behaviors, not area.** Low-flow fixtures, efficient washers and dishwashers are assumed as they are low cost and best practice.

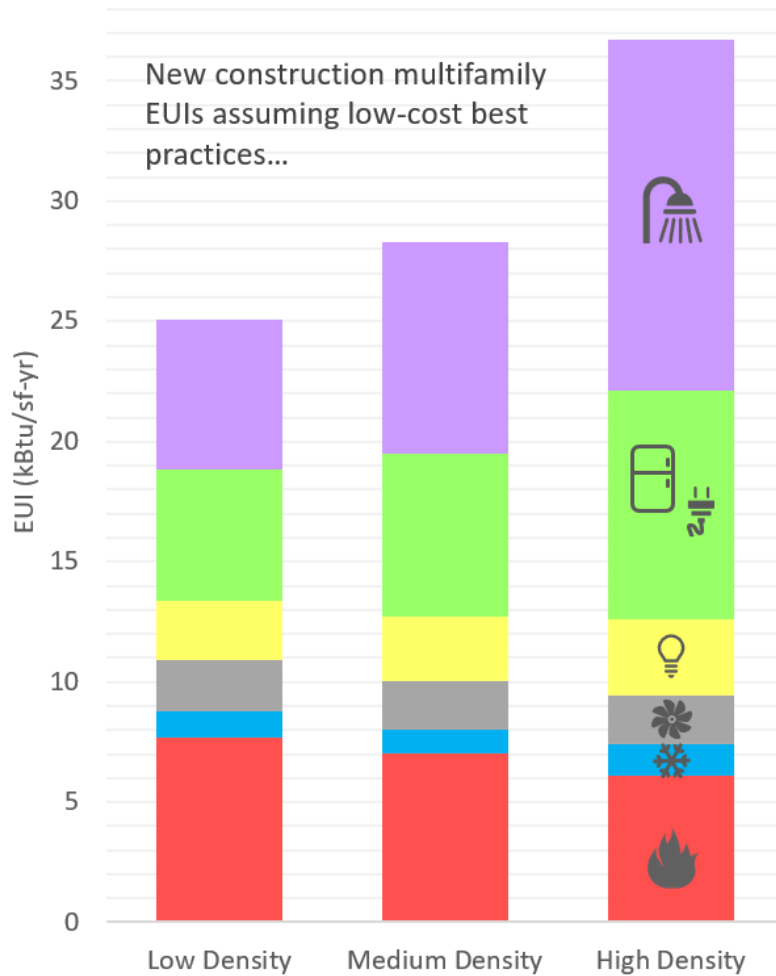
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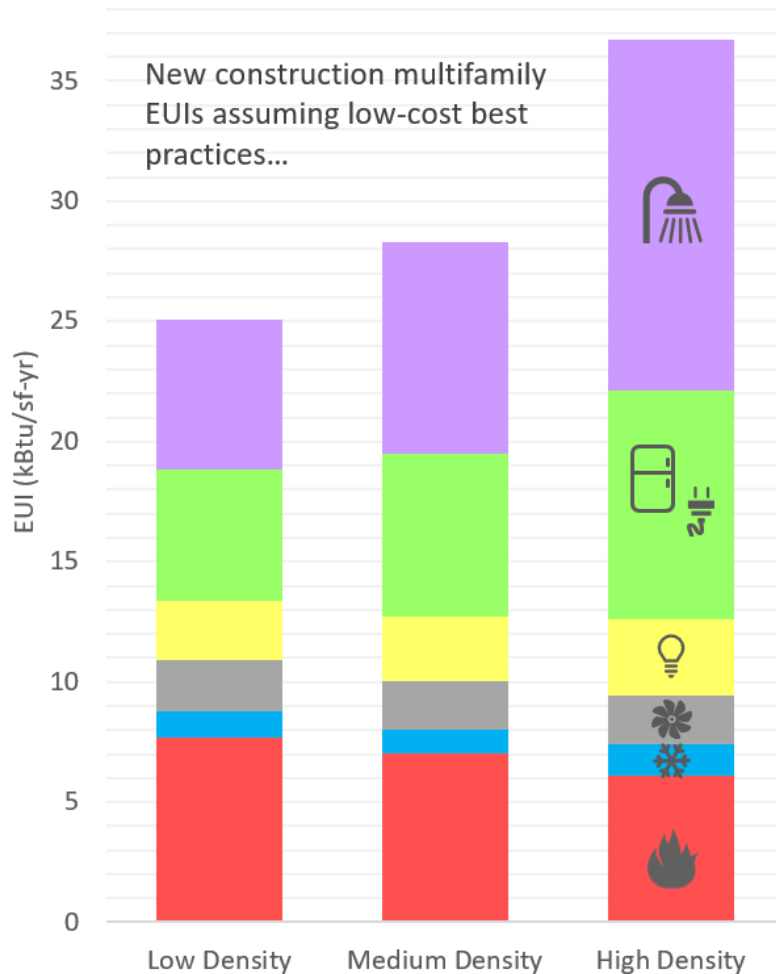
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**Lighting and plug loads are dependent on area *and* occupant density.** LEDs and efficient appliances are assumed.

**HVAC is dependent on area, and stable as occupant density changes.** Non-metal windows, wood framing, and heat pump conditioning are assumed.



# Multifamily Energy Use



Domestic hot water is dependent on occupant density and behaviors, not area.

**Heat pump water heaters**

Washers and dishwashers are assumed as they are low cost and best practice.

**Right-size fridges and heat pump dryers**

dependent on LEDs and med.

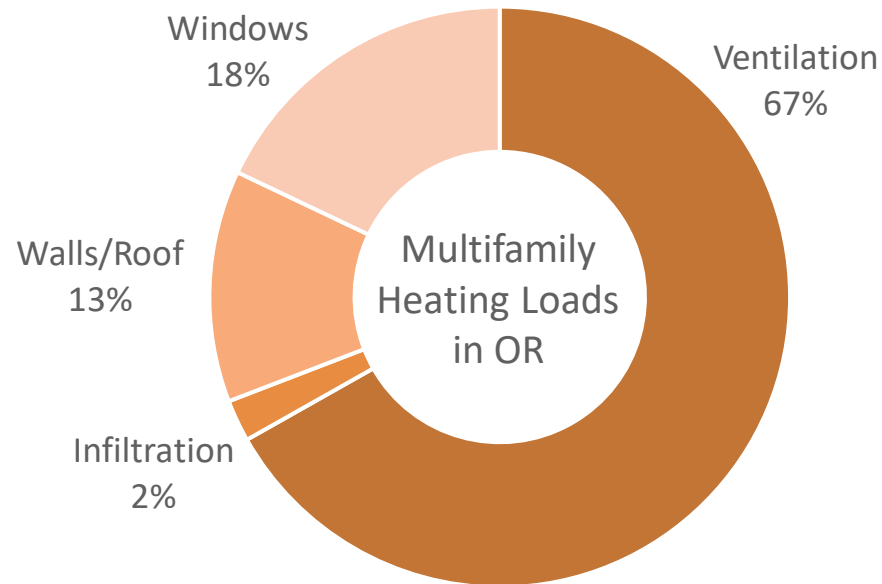
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**Right-size heat recovery ventilators, triple pane windows**

heat pump conditioning are assumed.

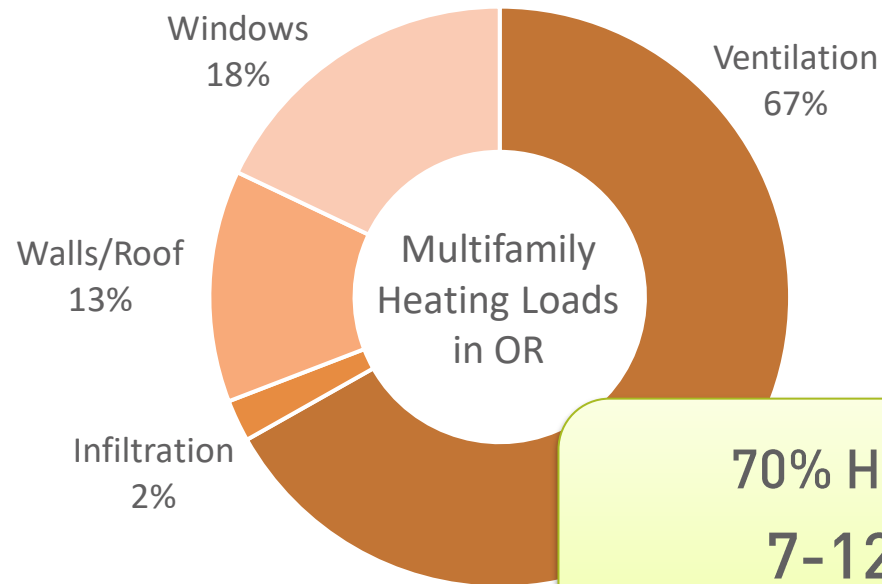
## Ventilation Loads

Energy used to condition ventilation air can account for 50-70% of multifamily HVAC energy use in Portland, if ventilated at code required levels. **Overventilation can double this and should be avoided.**



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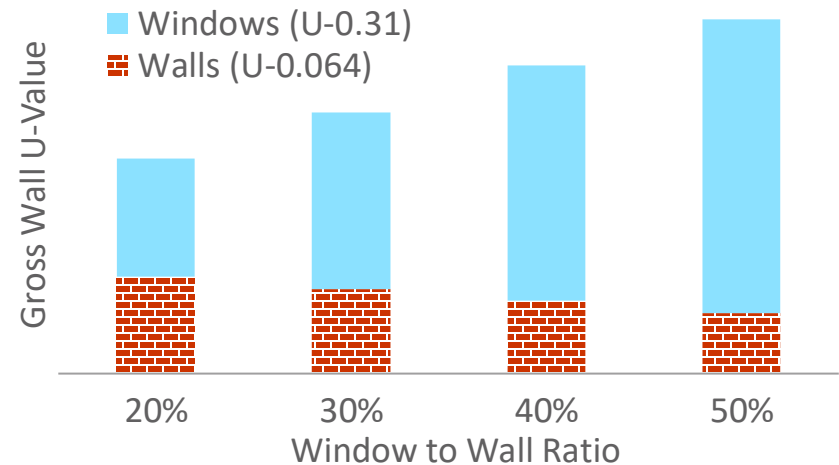


**70% Heat Recovery?  
7-12% savings  
vs PTHP system without**

## Envelope Loads

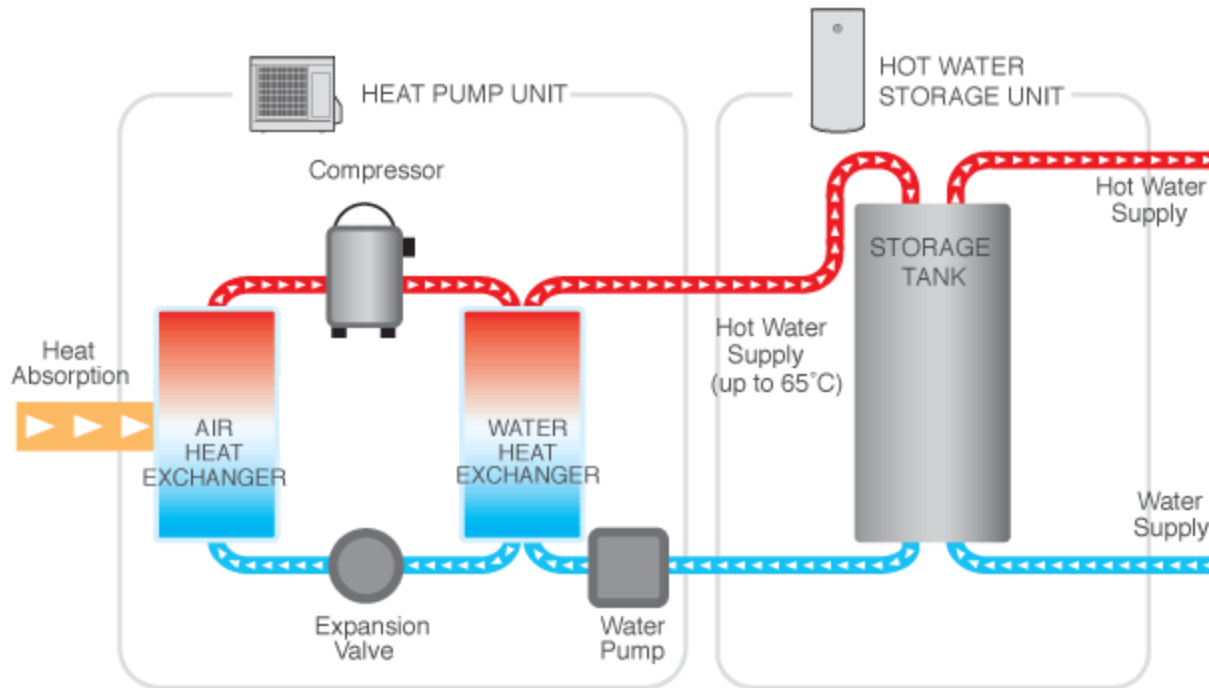
Increasing insulation and selecting high performance dual pane or **triple pane windows** will reduce HVAC loads from the envelope.

- A **25-30% glazing** ratio is high enough to allow access to daylighting and low enough to keep heat transfer and construction costs low.
- Non-metal framed dual-pane windows (U-0.26-0.31) allow 20-40% less heat transfer than metal-framed (U-0.38-0.42).

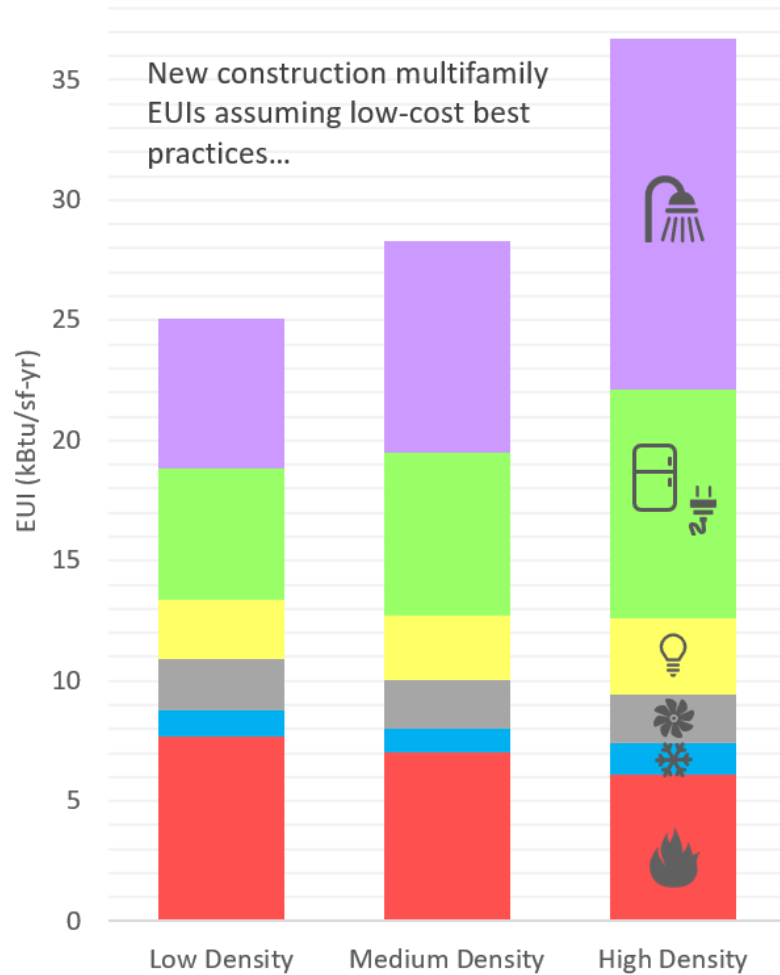


# Heat Pump Water Heaters

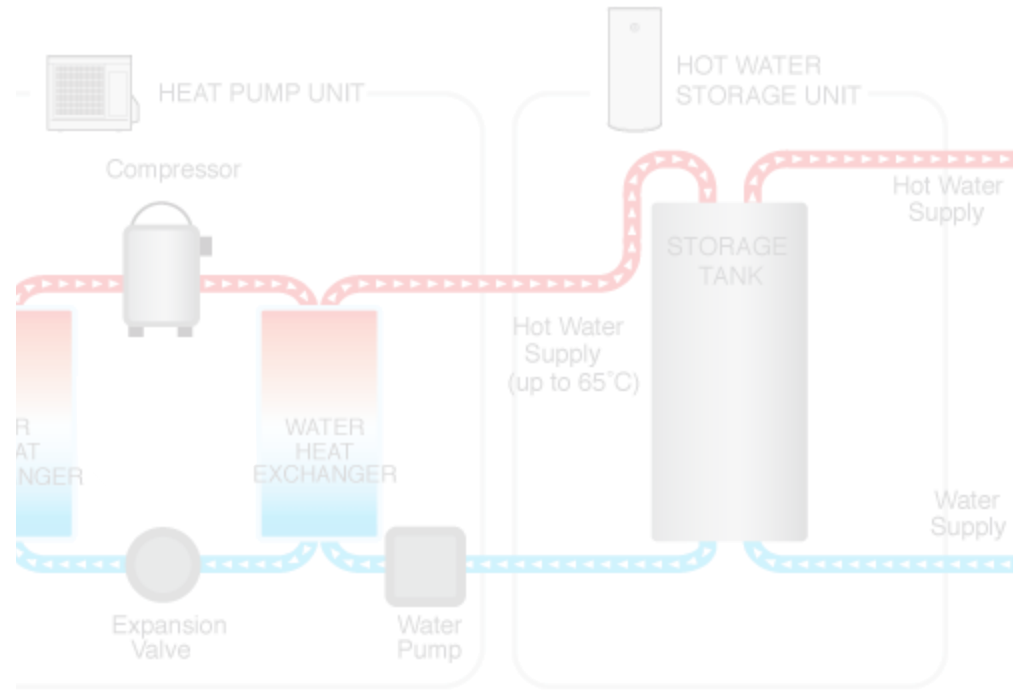
COP of 2 – 3  
(gas ~ 0.85)



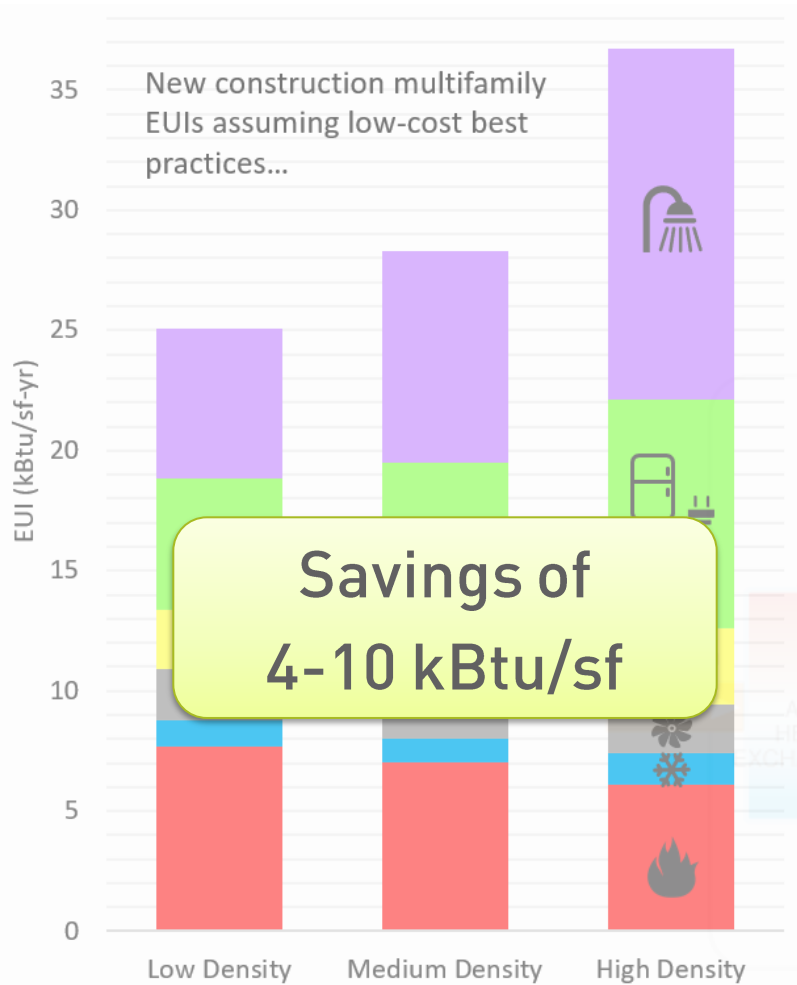
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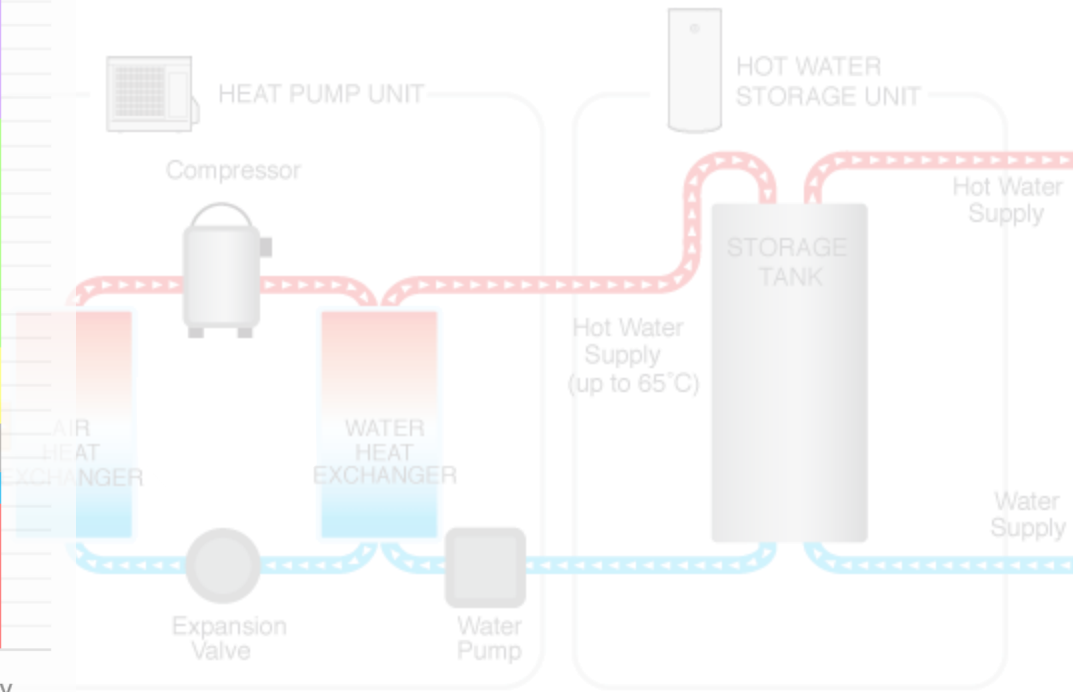
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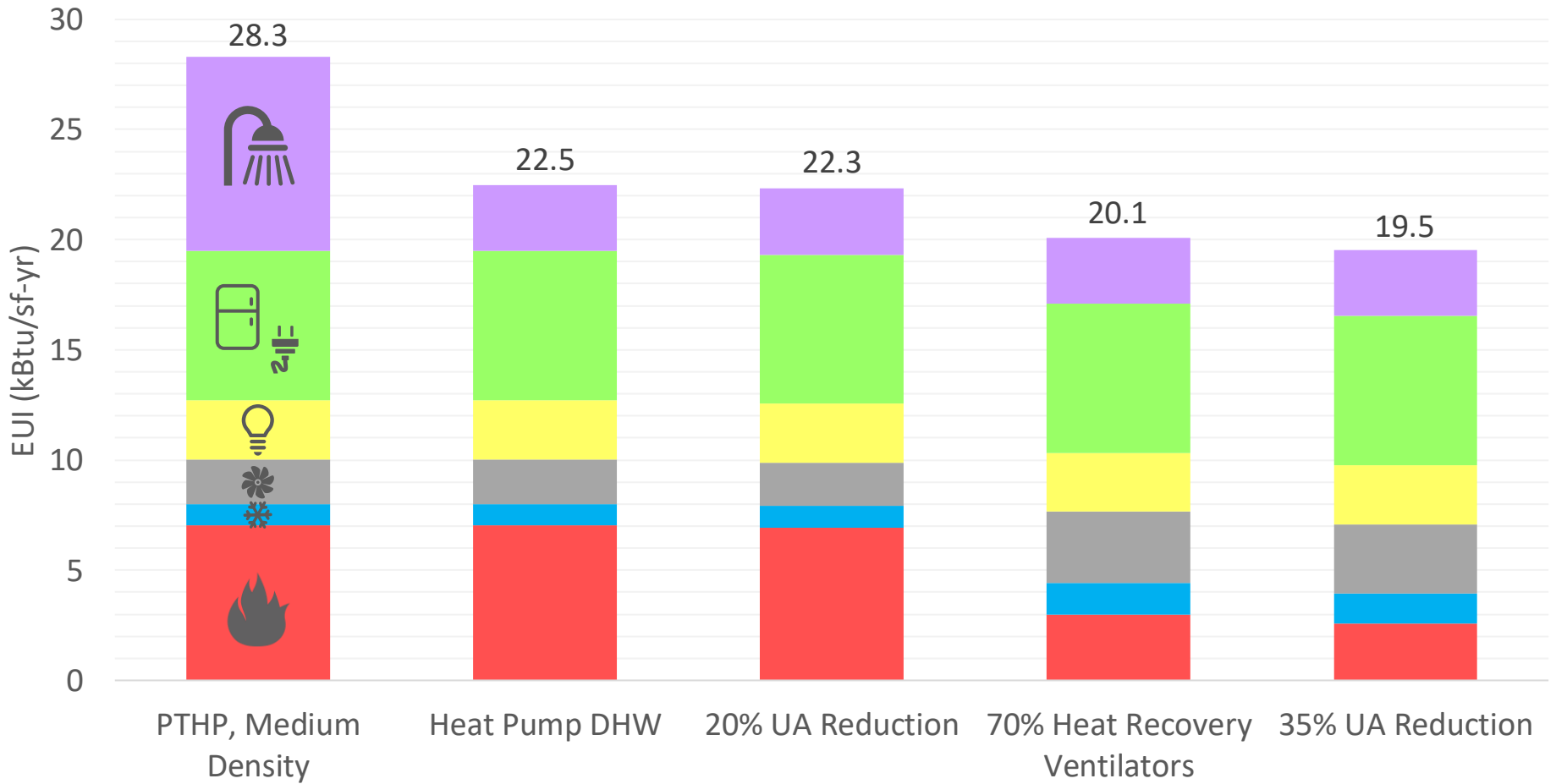
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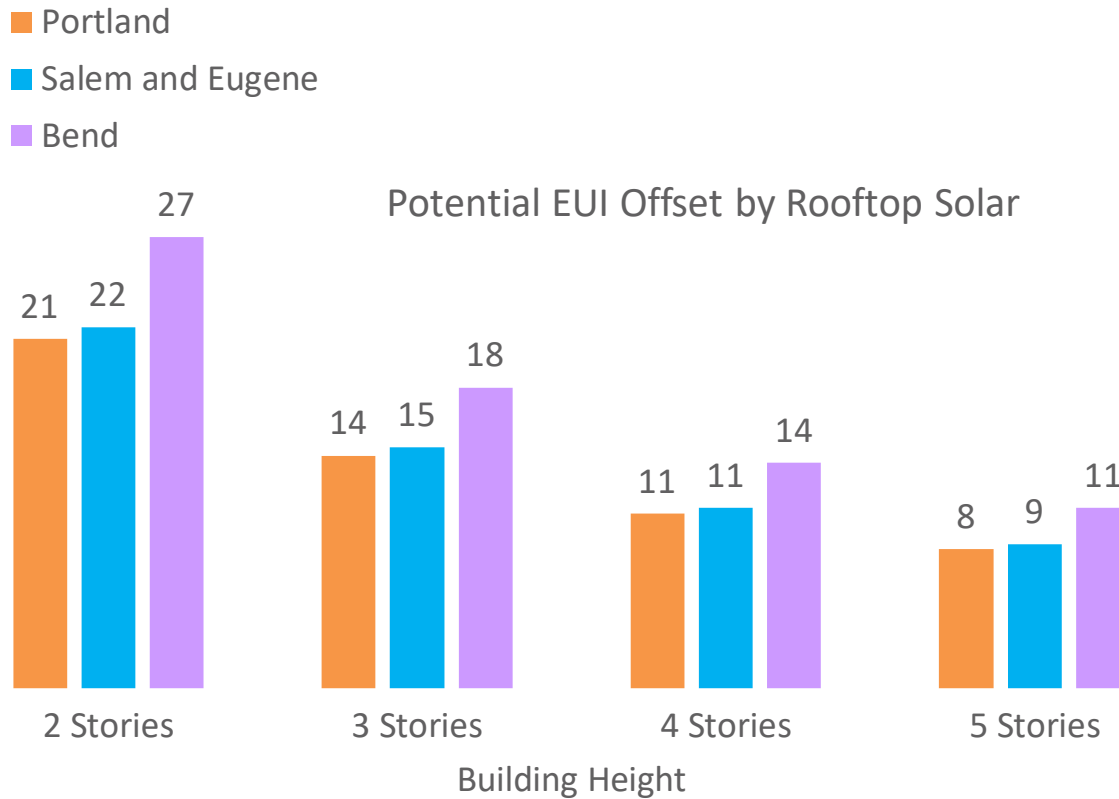
# Getting to Zero





# Net Zero Energy and Solar in Oregon

Net Energy = Gross Energy Consumption – Renewables Offset



**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.



## Takeaways for Multifamily Energy Efficiency

Occupant Density and Behavior

Heat Pump Water Heaters

Ventilation Loads and Heat Recovery

# Construction Costs



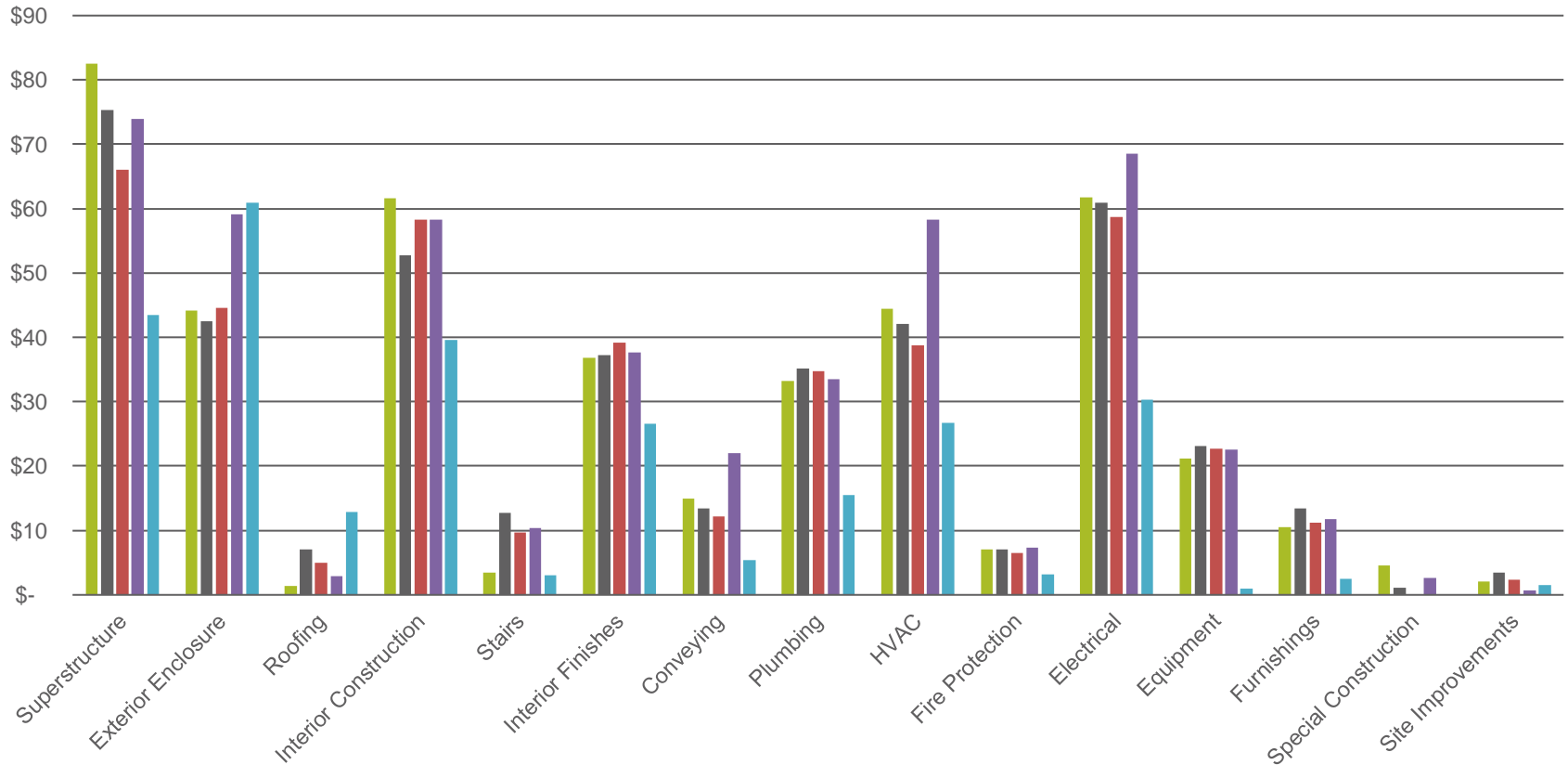
## How are cost estimates done?

### Top Down (Benchmarking)

- Based on extensive experience, adjusting for current market conditions
- Low level of detail → \$/sf, \$/unit
- What SD teams need!

# Cost Benchmarking (Uniformat II)

Sample L2 Construction Costs/Sf (Portland, 2020)





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### Bottom Up

- Based on itemized component data, bundled with labor and overhead costs

# Exploring detailed cost estimates

| C1 CORE & SHELL |   |  |      |        |          |              |
|-----------------|---|--|------|--------|----------|--------------|
|                 |   | Description  | Unit | Qty    | Rate     | Total        |
| B2010           | B | <b>B2010 Exterior Walls</b>                            |      |        |          |              |
| B2010           | B | 77 Type 1 - aluminum curtain wall                      | SF   | 23,483 | 75.00    | 1,761,225.00 |
| B2010           | B | 154 Type 1 - composite aluminum panel                  | SF   | 12,866 | 40.00    | 514,640.00   |
| B2010           | B | 156 Type 1 - GFRC panel                                | SF   | 31,131 | 50.00    | 1,556,550.00 |
| B2010           | B | 78 Type 2 - GFRC panel                                 | SF   | 4,984  | 50.00    | 249,200.00   |
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| B2010           | B | 157 Aluminum slab cover                                | SF   | 238    | 25.00    | 5,950.00     |
| B2010           | B | 83 Louvers   | SF   | 1,358  | 65.00    | 88,270.00    |
| B2010           | B | 581 6ft high privacy screens - metal frame with GFRC p | EA   | 10     | 2,150.00 | 21,500.00    |
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| B3010           | B | <b>B3010 Roof Coverings</b>                            |      |        |          |              |
| B3010           | B | 147 SBS two-ply modified bituminous membrane c/w ca    |      |        |          |              |
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|                                  |       |                |                 |                        |
|----------------------------------|-------|----------------|-----------------|------------------------|
| <b>ESTIMATED NET COST</b>        |       | <b>228,829</b> | <b>\$306.05</b> | <b>\$70,032,449.09</b> |
| <b>MARGINS &amp; ADJUSTMENTS</b> |       |                |                 |                        |
| Subguard Insurance               | 1.1%  |                |                 | \$770,356.94           |
| General Conditions               | 6.0%  |                |                 | \$4,248,168.36         |
| Bonding                          | 0.8%  |                |                 | \$600,407.81           |
| Overhead & Profit                | 2.7%  |                |                 | \$2,027,457.04         |
| Design Contingency               | 8.0%  |                |                 | \$6,214,307.14         |
| Art Allowance                    | 0.5%  |                |                 | \$419,465.75           |
| LEED Allowance                   | 1.0%  |                |                 | \$843,126.11           |
| Escalation to Q4 2019            | 13.3% |                |                 | \$11,323,304.13        |
| <b>ESTIMATED TOTAL COST</b>      |       | <b>228,829</b> | <b>\$421.62</b> | <b>\$96,479,042.37</b> |



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Quantification

Normalized Pricing

|                                  |       |  |         |          |                 |
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Normalized Pricing

Overhead



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- Requires in-depth knowledge of all components → architecture, MEP
- Overwhelming!  
...What we'd do if we had infinite time!

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### Middle Ground?

- Harvest data from project examples to build knowledge of required system components
- Request normalized pricing data from RLB
- Build “Typical” Bottom Up estimates with “constants”
  - E.g. Wooden frame, punched windows, no basement
  - Vary energy-specific systems, emphasis on studying mechanical systems

## What is “typical”?

Chose 3 recent projects to price → variations in layout and unit mix

| 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      |

Priced all systems with most emphasis on energy-related options

# What is “typical”?

Chose 3 recent projects to price → variations in layout and unit mix

|   |                     | Patmore |               |             | Barrow |               |             | Carson |               |             |
|---|---------------------|---------|---------------|-------------|--------|---------------|-------------|--------|---------------|-------------|
|   |                     | Qty     | Total         | \$/GSF      | Qty    | Total         | \$/GSF      | Qty    | Total         | \$/GSF      |
| <b>All HVAC System Options will include the following components...</b>           |                     |         |               |             |        |               |             |        |               |             |
| Allowance for TAB--HVAC Testing and Balancing                                     | 0.85 SF             | 38768.5 | 32953         | 0.85        | 113542 | 96511         | 0.85        | 123717 | 105159        | 0.85        |
| Allowance for HVAC BIM, permit, documentation, testing and su                     | 0.95 SF             | 38768.5 | 36830         | 0.95        | 113542 | 107865        | 0.95        | 123717 | 117531        | 0.95        |
| Exhaust fans and ductwork, all accessories included--allowance                    | 4.75 CFM            | 3700    | 17575         | 0.45        | 2790   | 13253         | 0.12        | 1830   | 8693          | 0.07        |
|   |                     |         | 87358         | 2.25        |        | 217628        | 1.92        |        | 231383        | 1.87        |
| <b>The following are specific HVAC options, and their *additional* components</b> |                     |         |               |             |        |               |             |        |               |             |
| <b>Electric Heat, Bathroom Exhaust Fans, Corridor RTU</b>                         |                     |         | <b>266733</b> | <b>6.88</b> |        | <b>719992</b> | <b>6.34</b> |        | <b>720417</b> | <b>5.82</b> |
| Electric cove heater - 400W   | 547.00 EA           | 71      | 38837         | 1.00        | 90     | 49230         | 0.43        | 82     | 44854         | 0.36        |
| Electric cove heater - 800W   | 580.00 EA           | 50      | 29000         | 0.75        | 162    | 93960         | 0.83        | 170    | 98600         | 0.80        |
| Bathroom exhaust fan (like Panasonic) < 80 CFM                                    | 325.00 EA           | 70      | 22750         | 0.59        | 162    | 52650         | 0.46        | 188    | 61100         | 0.49        |
| AHU, no heat recovery, DX+ gas furnace  | 5.65 CFM            | 1850    | 10453         | 0.27        | 6400   | 36160         | 0.32        | 9100   | 51415         | 0.42        |
| SA and RA Ductwork  | 9.53 Lb             | 4058    | 38676         | 1.00        | 15188  | 144741        | 1.27        | 12627  | 120335        | 0.97        |
| SA and RA Ductwork Insulation [SF of ductwork area]                               | 4.50 SF of ductwork | 1924    | 8659          | 0.22        | 5423   | 24402         | 0.21        | 3198   | 14391         | 0.12        |
| Duct Specialties--duct silencers and sound/noise attenuation                      | 0.55 SF of build    | 38768.5 | 21323         | 0.55        | 113542 | 62448         | 0.55        | 123717 | 68044         | 0.55        |
| Duct Diffusers and Grills [QTY is Allowance]                                      | 150.00 EA           | 17      | 2550          | 0.07        | 42     | 6300          | 0.06        | 33     | 4950          | 0.04        |
| Fire Smoke Dampers (FSD)  | 5.50 Sq-in          | 1296    | 7128          | 0.18        | 5904   | 32472         | 0.29        | 4608   | 25344         | 0.20        |
|   |                     |         | <b>179375</b> | <b>4.63</b> |        | <b>502364</b> | <b>4.42</b> |        | <b>489033</b> | <b>3.95</b> |

Priced all systems with most emphasis on energy-related options

# What is “typical”?

Chose 3 recent projects to price → variations in layout and unit mix

| All HVAC System Options will include the following components... |                     | Patmore |               |             | Barrow |               |             | Carson |               |             |
|--|---------------------|---------|---------------|-------------|--------|---------------|-------------|--------|---------------|-------------|
|  |                     | Qty     | Total         | \$/GSF      | Qty    | Total         | \$/GSF      | Qty    | Total         | \$/GSF      |
| Allowance for TAB--HVAC Testing and Balancing                    | 0.85 SF             | 38768.5 | 32953         | 0.85        | 113542 | 96511         | 0.85        | 123717 | 105159        | 0.85        |
| Allowance for HVAC BIM, permit, documentation, testing and su    | 0.95 SF             | 38768.5 | 36830         | 0.95        | 113542 | 107865        | 0.95        | 123717 | 117531        | 0.95        |
| Exhaust fans and ductwork, all accessories included--allowance   | 4.75 CFM            | 3700    | 17575         | 0.45        | 2790   | 13253         | 0.12        | 1830   | 8693          | 0.07        |
|  |                     |         |               |             |        | 217628        | 1.92        |        | 231383        | 1.87        |
| <b>The following are specific HVAC options, and their *a</b>     |                     |         |               |             |        |               |             |        |               |             |
| <b>Electric Heat, Bathroom Exhaust Fans, Corridor RTU</b>        |                     |         |               |             |        | <b>719992</b> | <b>6.34</b> |        | <b>720417</b> | <b>5.82</b> |
| Electric cove heater - 400W                                      |                     |         |               |             | 0      | 49230         | 0.43        | 82     | 44854         | 0.36        |
| Electric cove heater - 800W                                      |                     |         |               |             | 2      | 93960         | 0.83        | 170    | 98600         | 0.80        |
| Bathroom exhaust fan (like Panasonic) < 80 CFM                   |                     |         |               |             | 62     | 52650         | 0.46        | 188    | 61100         | 0.49        |
| AHU, no heat recovery, DX+ gas furnace                           | 5.65 CFM            | 1850    | 10453         | 0.27        | 6400   | 36160         | 0.32        | 9100   | 51415         | 0.42        |
| SA and RA Ductwork   | 9.53 Lb             | 4058    | 38676         | 1.00        | 15188  | 144741        | 1.27        | 12627  | 120335        | 0.97        |
| SA and RA Ductwork Insulation [SF of ductwork area]              | 4.50 SF of ductwork | 1924    | 8659          | 0.22        | 5423   | 24402         | 0.21        | 3198   | 14391         | 0.12        |
| Duct Specialties--duct silencers and sound/noise attenuation     | 0.55 SF of build    | 38768.5 | 21323         | 0.55        | 113542 | 62448         | 0.55        | 123717 | 68044         | 0.55        |
| Duct Diffusers and Grills [QTY is Allowance]                     | 150.00 EA           | 17      | 2550          | 0.07        | 42     | 6300          | 0.06        | 33     | 4950          | 0.04        |
| Fire Smoke Dampers (FSD)   | 5.50 Sq-in          | 1296    | 7128          | 0.18        | 5904   | 32472         | 0.29        | 4608   | 25344         | 0.20        |
|  |                     |         | <b>179375</b> | <b>4.63</b> |        | 502364        | 4.42        |        | 489033        | 3.95        |

Other cost factors?

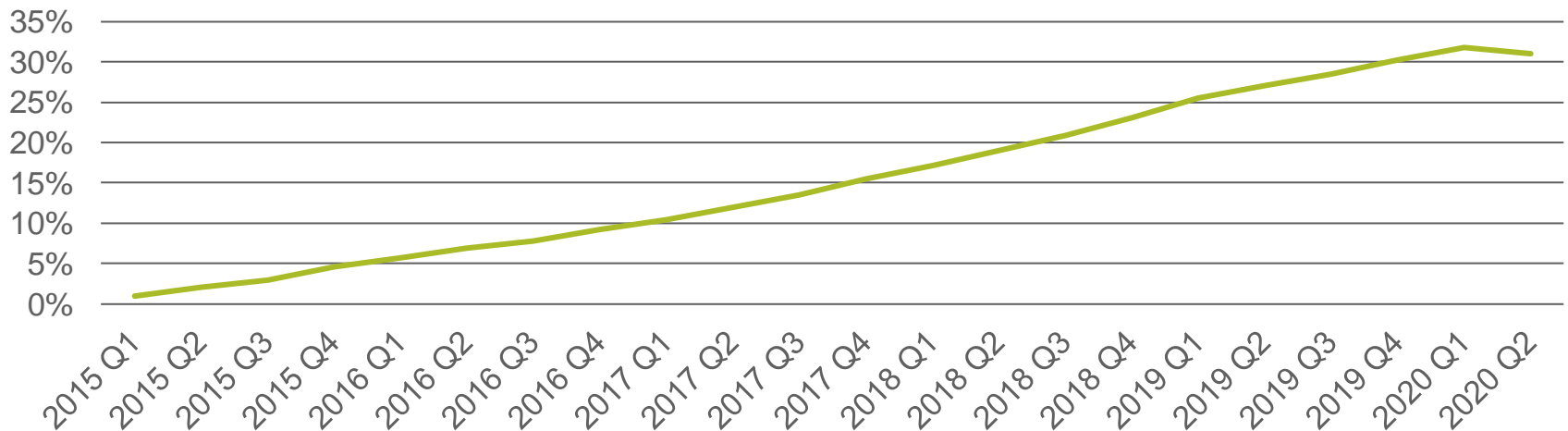
Priced all systems with most emphasis on energy-related options



## Identifying Cost Factors – Escalation

- 3-5%/year in Portland, largest factor in cost changes over time
- RLB publishes quarterly reports with escalation data, can be used to adjust cost estimates over time
- Can be used to adjust historical cost data to current dollars

Construction Cost Escalation (Portland)



## Identifying Cost Factors – Contractor Quality/Experience

- Primarily selected based on project size and system type
  - Reflected in \$/material and \$/capacity data
- Mid-size multifamily (i.e. 3+ stories) will mostly be handled by **mid-range contractors** from large cities
  - They have **minimum overheads** (insurance, bonds, etc.)
  - Lower costs are possible for smaller projects (2-4 stories) but are not the focus of this project



## Identifying Cost Factors – Location

- Assuming mid-range contractors based out of large metros, there are premiums associated with suburban and rural construction
  - Baseline → Portland
  - Other metros +0.5% → Salem, Eugene
  - Smaller/rural areas +2-3% → Corvallis, Pendleton, the coast, etc.
- Premiums are due to added travel/transport costs for workers and supplies to arrive on site





Let's look at some pricing results!

Used 3 Example Projects

Itemized Materials, Equipment, Labor

Added Overhead

# Envelope

## quantized costs

| Envelope System                                      | Cost         |   |              | Cost (Adjusted) |   |                 | Cost Unit              | System Life |
|--|--------------|---|--------------|-----------------|---|-----------------|------------------------|-------------|
| Standard foundations (concrete, 4-11 story wood      | 9.00         | - | 9.00         | \$ 11.50        | - | \$ 12.05        | GSF of building        | 50          |
| Slab on Grade w/ R-15 perimeter insulation           | 7.00         | - | 7.00         | \$ 8.95         | - | \$ 9.40         | SF of slab             | 50          |
| Concrete flooring (complete assembly)                | 12.00        | - | 12.00        | \$ 15.35        | - | \$ 16.10        | SF of floors           | 50          |
| Baseline wood-framed wall (6" stud, batt insul)      | 18.25        | - | 18.25        | \$ 23.35        | - | \$ 24.45        | SF of wall             | 50          |
| Ext. wall cladding, molding, caulking/sealing        | 55.00        | - | 70.00        | \$ 70.40        | - | \$ 93.80        | SF of wall             | 50          |
| <b>Base foundations, flooring, wood framed walls</b> | <b>46.95</b> | - | <b>69.77</b> | <b>\$ 60.10</b> | - | <b>\$ 93.50</b> | <b>GSF of building</b> | <b>50</b>   |
| Add 1" mineral fiber insul., metal z-furring         | 2.75         | - | 2.75         | \$ 3.50         | - | \$ 3.70         | SF of wall             | 50          |
| Add 1" mineral fiber insul., fiberglass clips        | 5.00         | - | 5.00         | \$ 6.40         | - | \$ 6.70         | SF of wall             | 50          |
| Add 2" mineral fiber insul., metal z-furring         | 3.50         | - | 3.50         | \$ 4.50         | - | \$ 4.70         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., metal z-furring</b>  | <b>0.38</b>  | - | <b>0.59</b>  | <b>\$ 0.50</b>  | - | <b>\$ 0.80</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 2" mineral fiber insul., fiberglass clips        | 6.00         | - | 6.00         | \$ 7.70         | - | \$ 8.05         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., fiberglass clips</b> | <b>0.66</b>  | - | <b>1.01</b>  | <b>\$ 0.85</b>  | - | <b>\$ 1.35</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 5" mineral fiber insul., metal z-furring         | 6.50         | - | 6.50         | \$ 8.30         | - | \$ 8.70         | SF of wall             | 50          |
| Add 5" mineral fiber insul., fiberglass clips        | 8.00         | - | 8.00         | \$ 10.25        | - | \$ 10.70        | SF of wall             | 50          |
| Typical dual pane vinyl windows (U-0.31)             | 50.63        | - | 50.63        | \$ 64.80        | - | \$ 67.85        | \$/ (SF of window)     | 25          |
| <b>Typical dual pane vinyl windows (U-0.31)</b>      | <b>5.55</b>  | - | <b>8.54</b>  | <b>\$ 7.10</b>  | - | <b>\$ 11.45</b> | <b>GSF of building</b> | <b>25</b>   |
| Typical dual pane fiberglass windows (U-0.31)        | 70.63        | - | 70.63        | \$ 90.45        | - | \$ 94.65        | \$/ (SF of window)     | 50          |
| <b>Typical dual pane fiberglass windows (U-0.31)</b> | <b>7.75</b>  | - | <b>11.91</b> | <b>\$ 9.90</b>  | - | <b>\$ 15.95</b> | <b>GSF of building</b> | <b>50</b>   |
| High perf. vinyl dual pane windows (U-0.27)          | 52.63        | - | 52.63        | \$ 67.40        | - | \$ 70.55        | \$/ (SF of window)     | 25          |
| <b>High perf. vinyl dual pane windows (U-0.27)</b>   | <b>5.77</b>  | - | <b>8.87</b>  | <b>\$ 7.40</b>  | - | <b>\$ 11.90</b> | <b>GSF of building</b> | <b>25</b>   |
| High perf. fiberglass dual pane windows (U-0.27)     | 72.63        | - | 72.63        | \$ 93.00        | - | \$ 97.35        | \$/ (SF of window)     | 50          |

# Envelope

28%-34%  
overhead

| Envelope System                                      | Cost         |   |              | Cost (Adjusted) |   |                 | Cost Unit              | System Life |
|--|--------------|---|--------------|-----------------|---|-----------------|------------------------|-------------|
| Standard foundations (concrete, 4-11 story wood      | 9.00         | - | 9.00         | \$ 11.50        | - | \$ 12.05        | GSF of building        | 50          |
| Slab on Grade w/ R-15 perimeter insulation           | 7.00         | - | 7.00         | \$ 8.95         | - | \$ 9.40         | SF of slab             | 50          |
| Concrete flooring (complete assembly)                | 12.00        | - | 12.00        | \$ 15.35        | - | \$ 16.10        | SF of floors           | 50          |
| Baseline wood-framed wall (6" stud, batt insul)      | 18.25        | - | 18.25        | \$ 23.35        | - | \$ 24.45        | SF of wall             | 50          |
| Ext. wall cladding, molding, caulking/sealing        | 55.00        | - | 70.00        | \$ 70.40        | - | \$ 93.80        | SF of wall             | 50          |
| <b>Base foundations, flooring, wood framed walls</b> | <b>46.95</b> | - | <b>69.77</b> | <b>\$ 60.10</b> | - | <b>\$ 93.50</b> | <b>GSF of building</b> | <b>50</b>   |
| Add 1" mineral fiber insul., metal z-furring         | 2.75         | - | 2.75         | \$ 3.50         | - | \$ 3.70         | SF of wall             | 50          |
| Add 1" mineral fiber insul., fiberglass clips        | 5.00         | - | 5.00         | \$ 6.40         | - | \$ 6.70         | SF of wall             | 50          |
| Add 2" mineral fiber insul., metal z-furring         | 3.50         | - | 3.50         | \$ 4.50         | - | \$ 4.70         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., metal z-furring</b>  | <b>0.38</b>  | - | <b>0.59</b>  | <b>\$ 0.50</b>  | - | <b>\$ 0.80</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 2" mineral fiber insul., fiberglass clips        | 6.00         | - | 6.00         | \$ 7.70         | - | \$ 8.05         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., fiberglass clips</b> | <b>0.66</b>  | - | <b>1.01</b>  | <b>\$ 0.85</b>  | - | <b>\$ 1.35</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 5" mineral fiber insul., metal z-furring         | 6.50         | - | 6.50         | \$ 8.30         | - | \$ 8.70         | SF of wall             | 50          |
| Add 5" mineral fiber insul., fiberglass clips        | 8.00         | - | 8.00         | \$ 10.25        | - | \$ 10.70        | SF of wall             | 50          |
| Typical dual pane vinyl windows (U-0.31)             | 50.63        | - | 50.63        | \$ 64.80        | - | \$ 67.85        | \$/ (SF of window)     | 25          |
| <b>Typical dual pane vinyl windows (U-0.31)</b>      | <b>5.55</b>  | - | <b>8.54</b>  | <b>\$ 7.10</b>  | - | <b>\$ 11.45</b> | <b>GSF of building</b> | <b>25</b>   |
| Typical dual pane fiberglass windows (U-0.31)        | 70.63        | - | 70.63        | \$ 90.45        | - | \$ 94.65        | \$/ (SF of window)     | 50          |
| <b>Typical dual pane fiberglass windows (U-0.31)</b> | <b>7.75</b>  | - | <b>11.91</b> | <b>\$ 9.90</b>  | - | <b>\$ 15.95</b> | <b>GSF of building</b> | <b>50</b>   |
| High perf. vinyl dual pane windows (U-0.27)          | 52.63        | - | 52.63        | \$ 67.40        | - | \$ 70.55        | \$/ (SF of window)     | 25          |
| <b>High perf. vinyl dual pane windows (U-0.27)</b>   | <b>5.77</b>  | - | <b>8.87</b>  | <b>\$ 7.40</b>  | - | <b>\$ 11.90</b> | <b>GSF of building</b> | <b>25</b>   |
| High perf. fiberglass dual pane windows (U-0.27)     | 72.63        | - | 72.63        | \$ 93.00        | - | \$ 97.35        | \$/ (SF of window)     | 50          |

# Envelope

28%-34%  
overhead

| Envelope System                                      | Overhead Costs |   |              |                 |   |                 | System Life            |    |
|--|----------------|---|--------------|-----------------|---|-----------------|------------------------|----|
|  |                |   |              |                 |   |                 |                        |    |
| Standard foundations (concrete, 4-11 story wood      | 9.0            |   |              |                 |   |                 | 50                     |    |
| Slab on Grade w/ R-15 perimeter insulation           | 7.0            |   |              |                 |   |                 | 50                     |    |
| Concrete flooring (complete assembly)                | 12.0           |   |              |                 |   |                 | 50                     |    |
| Baseline wood-framed wall (6" stud, batt insul)      | 18.2           |   |              |                 |   |                 | 50                     |    |
| Ext. wall cladding, molding, caulking/sealing        | 55.0           |   |              |                 |   |                 | 50                     |    |
| <b>Base foundations, flooring, wood framed walls</b> | <b>46.95</b>   |   | <b>69.77</b> | <b>\$ 80.10</b> |   | <b>\$ 95.50</b> | <b>GSF of building</b> | 50 |
| Add 1" mineral fiber insul., metal z-furring         | 2.75           | - | 2.75         | \$ 3.50         | - | \$ 3.70         | SF of wall             | 50 |
| Add 1" mineral fiber insul., fiberglass clips        | 5.00           | - | 5.00         | \$ 6.40         | - | \$ 6.70         | SF of wall             | 50 |
| Add 2" mineral fiber insul., metal z-furring         | 3.50           | - | 3.50         | \$ 4.50         | - | \$ 4.70         | SF of wall             | 50 |
| <b>Add 2" mineral fiber insul., metal z-furring</b>  | <b>0.38</b>    | - | <b>0.59</b>  | <b>\$ 0.50</b>  | - | <b>\$ 0.80</b>  | <b>GSF of building</b> | 50 |
| Add 2" mineral fiber insul., fiberglass clips        | 6.00           | - | 6.00         | \$ 7.70         | - | \$ 8.05         | SF of wall             | 50 |
| <b>Add 2" mineral fiber insul., fiberglass clips</b> | <b>0.66</b>    | - | <b>1.01</b>  | <b>\$ 0.85</b>  | - | <b>\$ 1.35</b>  | <b>GSF of building</b> | 50 |
| Add 5" mineral fiber insul., metal z-furring         | 6.50           | - | 6.50         | \$ 8.30         | - | \$ 8.70         | SF of wall             | 50 |
| Add 5" mineral fiber insul., fiberglass clips        | 8.00           | - | 8.00         | \$ 10.25        | - | \$ 10.70        | SF of wall             | 50 |
| Typical dual pane vinyl windows (U-0.31)             | 50.63          | - | 50.63        | \$ 64.80        | - | \$ 67.85        | \$(SF of window)       | 25 |
| <b>Typical dual pane vinyl windows (U-0.31)</b>      | <b>5.55</b>    | - | <b>8.54</b>  | <b>\$ 7.10</b>  | - | <b>\$ 11.45</b> | <b>GSF of building</b> | 25 |
| Typical dual pane fiberglass windows (U-0.31)        | 70.63          | - | 70.63        | \$ 90.45        | - | \$ 94.65        | \$(SF of window)       | 50 |
| <b>Typical dual pane fiberglass windows (U-0.31)</b> | <b>7.75</b>    | - | <b>11.91</b> | <b>\$ 9.90</b>  | - | <b>\$ 15.95</b> | <b>GSF of building</b> | 50 |
| High perf. vinyl dual pane windows (U-0.27)          | 52.63          | - | 52.63        | \$ 67.40        | - | \$ 70.55        | \$(SF of window)       | 25 |
| <b>High perf. vinyl dual pane windows (U-0.27)</b>   | <b>5.77</b>    | - | <b>8.87</b>  | <b>\$ 7.40</b>  | - | <b>\$ 11.90</b> | <b>GSF of building</b> | 25 |
| High perf. fiberglass dual pane windows (U-0.27)     | 72.63          | - | 72.63        | \$ 93.00        | - | \$ 97.35        | \$(SF of window)       | 50 |

# Envelope

Included multiple units

| Envelope System                                      | Cost         |   |              | Cost (Adjusted) |   |                 | Cost Unit              | System Life |
|--|--------------|---|--------------|-----------------|---|-----------------|------------------------|-------------|
| Standard foundations (concrete, 4-11 story wood      | 9.00         | - | 9.00         | \$ 11.50        | - | \$ 12.05        | GSF of building        | 50          |
| Slab on Grade w/ R-15 perimeter insulation           | 7.00         | - | 7.00         | \$ 8.95         | - | \$ 9.40         | SF of slab             | 50          |
| Concrete flooring (complete assembly)                | 12.00        | - | 12.00        | \$ 15.35        | - | \$ 16.10        | SF of floors           | 50          |
| Baseline wood-framed wall (6" stud, batt insul)      | 18.25        | - | 18.25        | \$ 23.35        | - | \$ 24.45        | SF of wall             | 50          |
| Ext. wall cladding, molding, caulking/sealing        | 55.00        | - | 70.00        | \$ 70.40        | - | \$ 93.80        | SF of wall             | 50          |
| <b>Base foundations, flooring, wood framed walls</b> | <b>46.95</b> | - | <b>69.77</b> | <b>\$ 60.10</b> | - | <b>\$ 93.50</b> | <b>GSF of building</b> | <b>50</b>   |
| Add 1" mineral fiber insul., metal z-furring         | 2.75         | - | 2.75         | \$ 3.50         | - | \$ 3.70         | SF of wall             | 50          |
| Add 1" mineral fiber insul., fiberglass clips        | 5.00         | - | 5.00         | \$ 6.40         | - | \$ 6.70         | SF of wall             | 50          |
| Add 2" mineral fiber insul., metal z-furring         | 3.50         | - | 3.50         | \$ 4.50         | - | \$ 4.70         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., metal z-furring</b>  | <b>0.38</b>  | - | <b>0.59</b>  | <b>\$ 0.50</b>  | - | <b>\$ 0.80</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 2" mineral fiber insul., fiberglass clips        | 6.00         | - | 6.00         | \$ 7.70         | - | \$ 8.05         | SF of wall             | 50          |
| <b>Add 2" mineral fiber insul., fiberglass clips</b> | <b>0.66</b>  | - | <b>1.01</b>  | <b>\$ 0.85</b>  | - | <b>\$ 1.35</b>  | <b>GSF of building</b> | <b>50</b>   |
| Add 5" mineral fiber insul., metal z-furring         | 6.50         | - | 6.50         | \$ 8.30         | - | \$ 8.70         | SF of wall             | 50          |
| Add 5" mineral fiber insul., fiberglass clips        | 8.00         | - | 8.00         | \$ 10.25        | - | \$ 10.70        | SF of wall             | 50          |
| Typical dual pane vinyl windows (U-0.31)             | 50.63        | - | 50.63        | \$ 64.80        | - | \$ 67.85        | \$/ (SF of window)     | 25          |
| <b>Typical dual pane vinyl windows (U-0.31)</b>      | <b>5.55</b>  | - | <b>8.54</b>  | <b>\$ 7.10</b>  | - | <b>\$ 11.45</b> | <b>GSF of building</b> | <b>25</b>   |
| Typical dual pane fiberglass windows (U-0.31)        | 70.63        | - | 70.63        | \$ 90.45        | - | \$ 94.65        | \$/ (SF of window)     | 50          |
| <b>Typical dual pane fiberglass windows (U-0.31)</b> | <b>7.75</b>  | - | <b>11.91</b> | <b>\$ 9.90</b>  | - | <b>\$ 15.95</b> | <b>GSF of building</b> | <b>50</b>   |
| High perf. vinyl dual pane windows (U-0.27)          | 52.63        | - | 52.63        | \$ 67.40        | - | \$ 70.55        | \$/ (SF of window)     | 25          |
| <b>High perf. vinyl dual pane windows (U-0.27)</b>   | <b>5.77</b>  | - | <b>8.87</b>  | <b>\$ 7.40</b>  | - | <b>\$ 11.90</b> | <b>GSF of building</b> | <b>25</b>   |
| High perf. fiberglass dual pane windows (U-0.27)     | 72.63        | - | 72.63        | \$ 93.00        | - | \$ 97.35        | \$/ (SF of window)     | 50          |



# HVAC Systems

| 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 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          |

## HVAC Systems

| 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 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          |

## HVAC Systems

| 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 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          |

# Domestic Hot Water Heating

## In-unit and centralized options

| 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          |

## What about electrical infrastructure impacts?

Electrical impacts are included in the relevant system costs.

| Energy Saving Strategy   | Cost (Adjusted)            | Cost Unit              |
|--|----------------------------|------------------------|
| <b>Electric Heat, Bathroom Exhaust Fans, Corridor RTU, Nat Gas DHW</b> | <b>\$ 34.28 - \$ 38.61</b> | <b>GSF of building</b> |
| PTHP in central room with Electric Heat in 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 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        |



## Takeaways for Construction Cost Drivers

Itemized Materials, Equipment, Labor

Overhead

Escalation, Contractor, Location

# Integrating Costs and Energy

## Low Density Results

| 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   |



# Low Density Results

## Incremental Cost

| 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          |

# Low Density Results

## Incremental Cost      Bang for Buck!

| 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          |

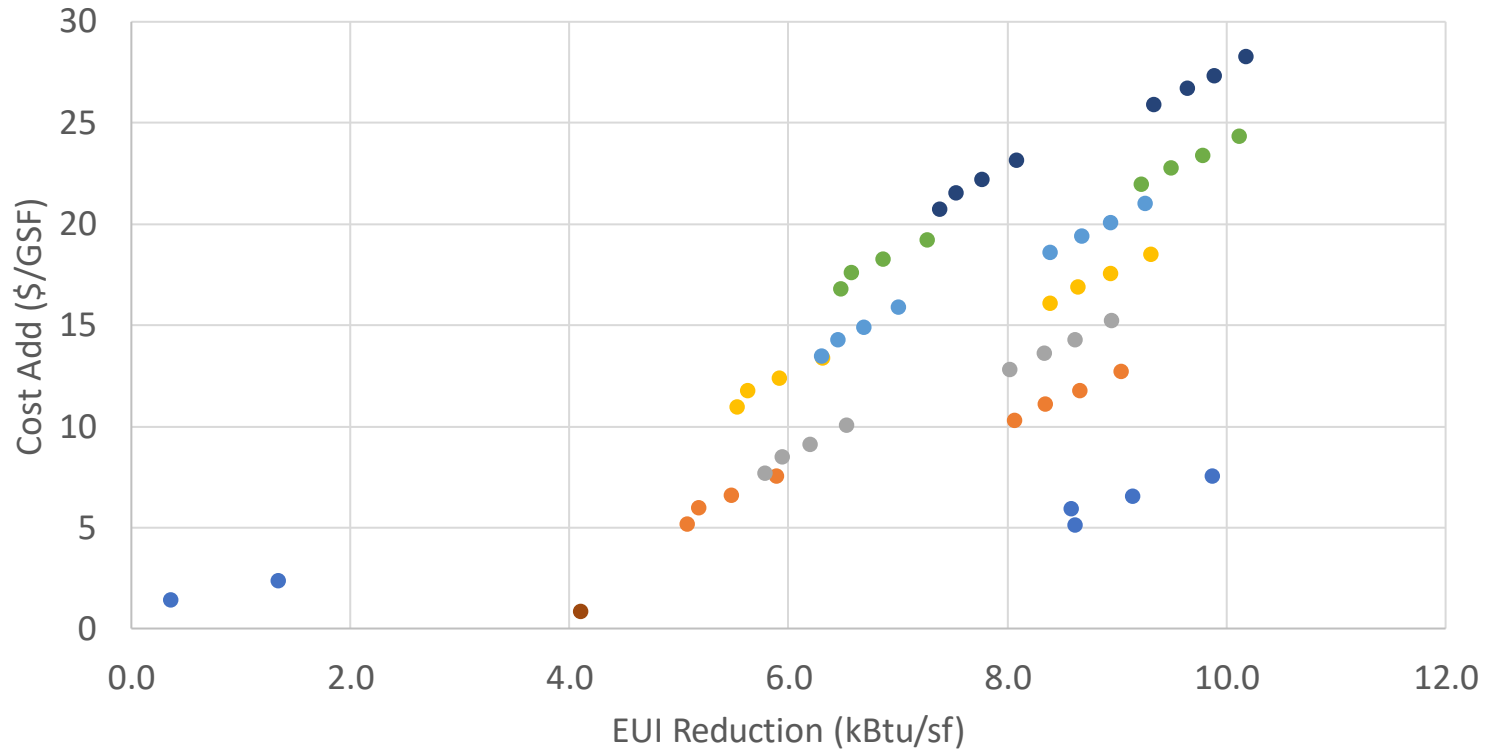
## Medium Density Results

| Energy + Cost Results for Low 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   |

## High Density Results

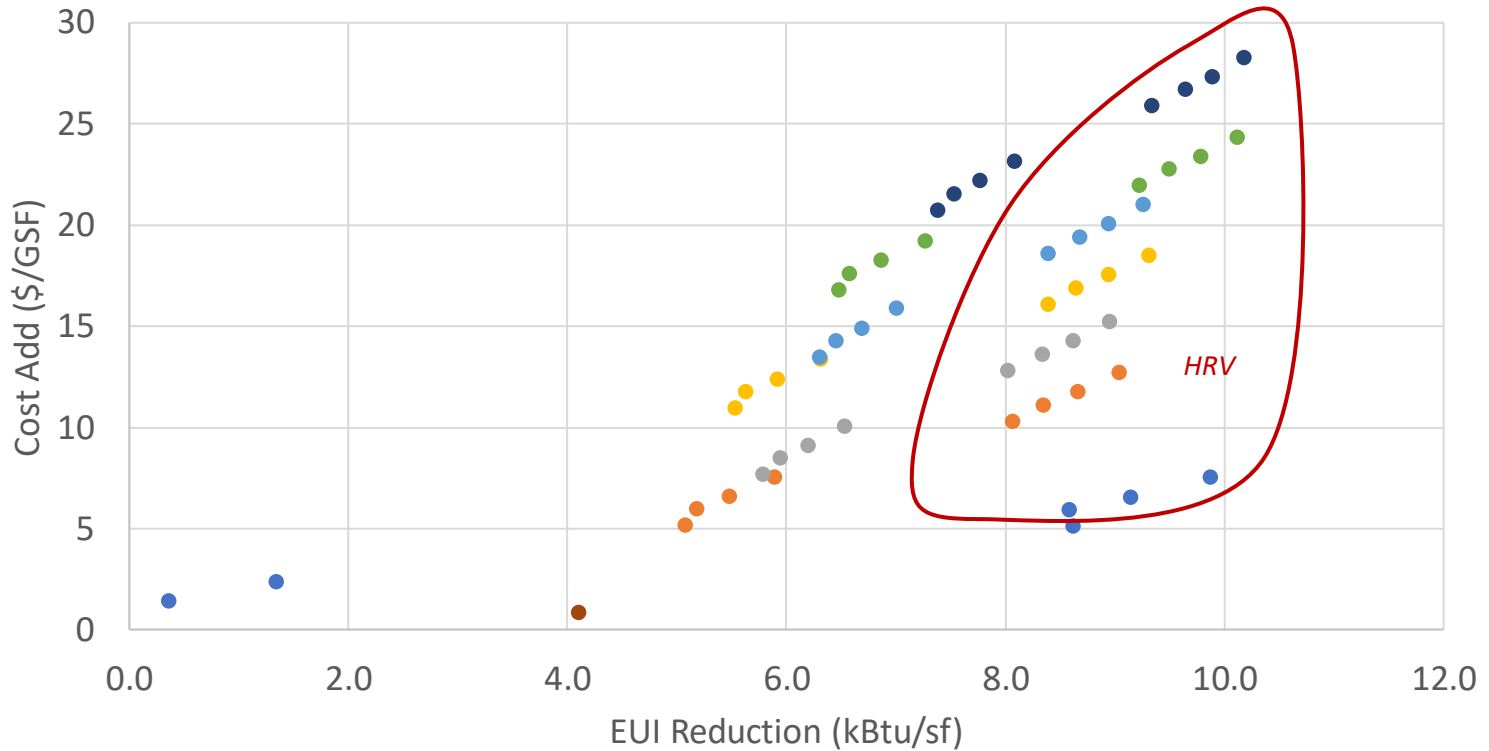
| Energy + Cost Results for Low Density Multifamily in Portland, OR | Adjusted Cost Add (\$/GSF) |            | Cost Per Savings (\$/kBtu) |             |
|---|----------------------------|------------|----------------------------|-------------|
| Centralized Heat Pump Water Heaters                               | \$ 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   |

## Low Density Cost vs Energy Saved



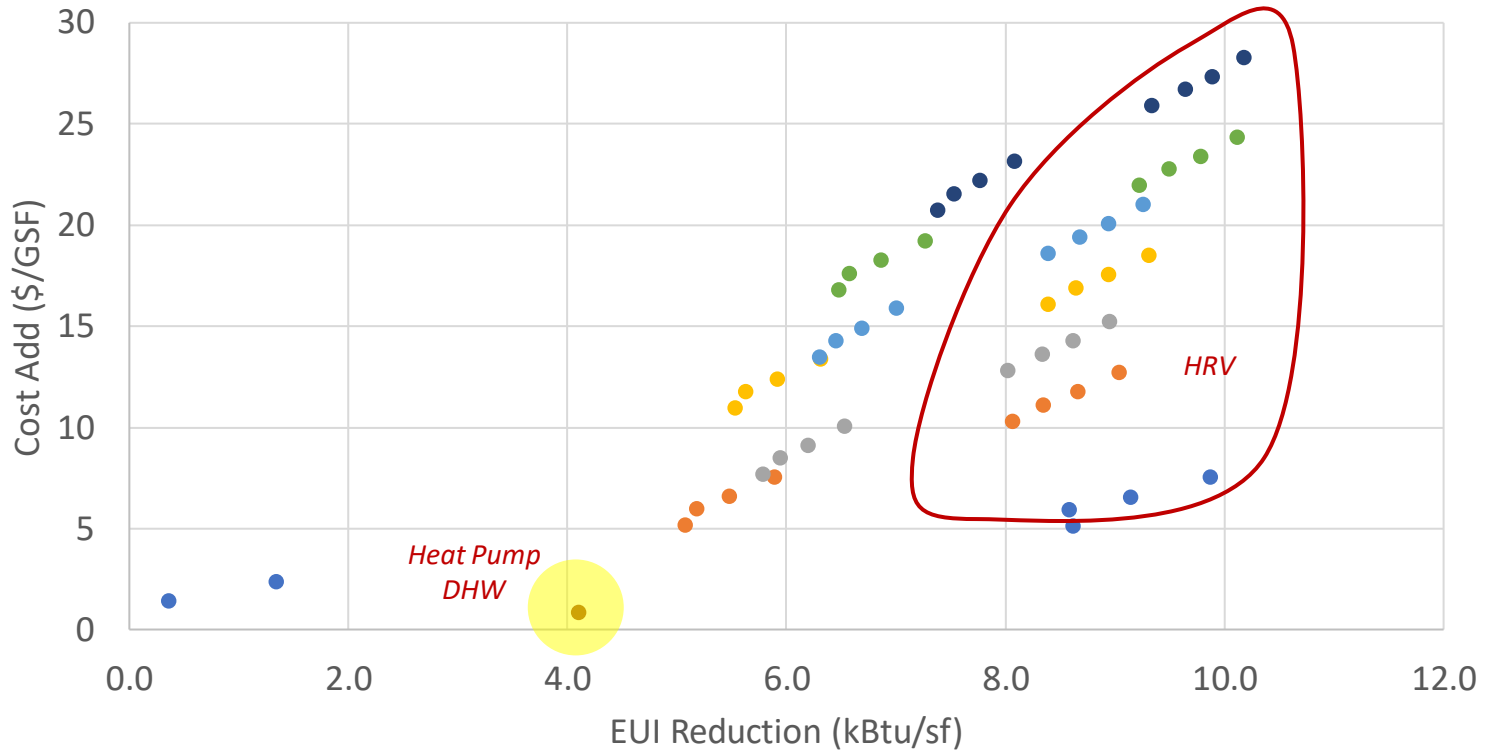
- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

## Low Density Cost vs Energy Saved



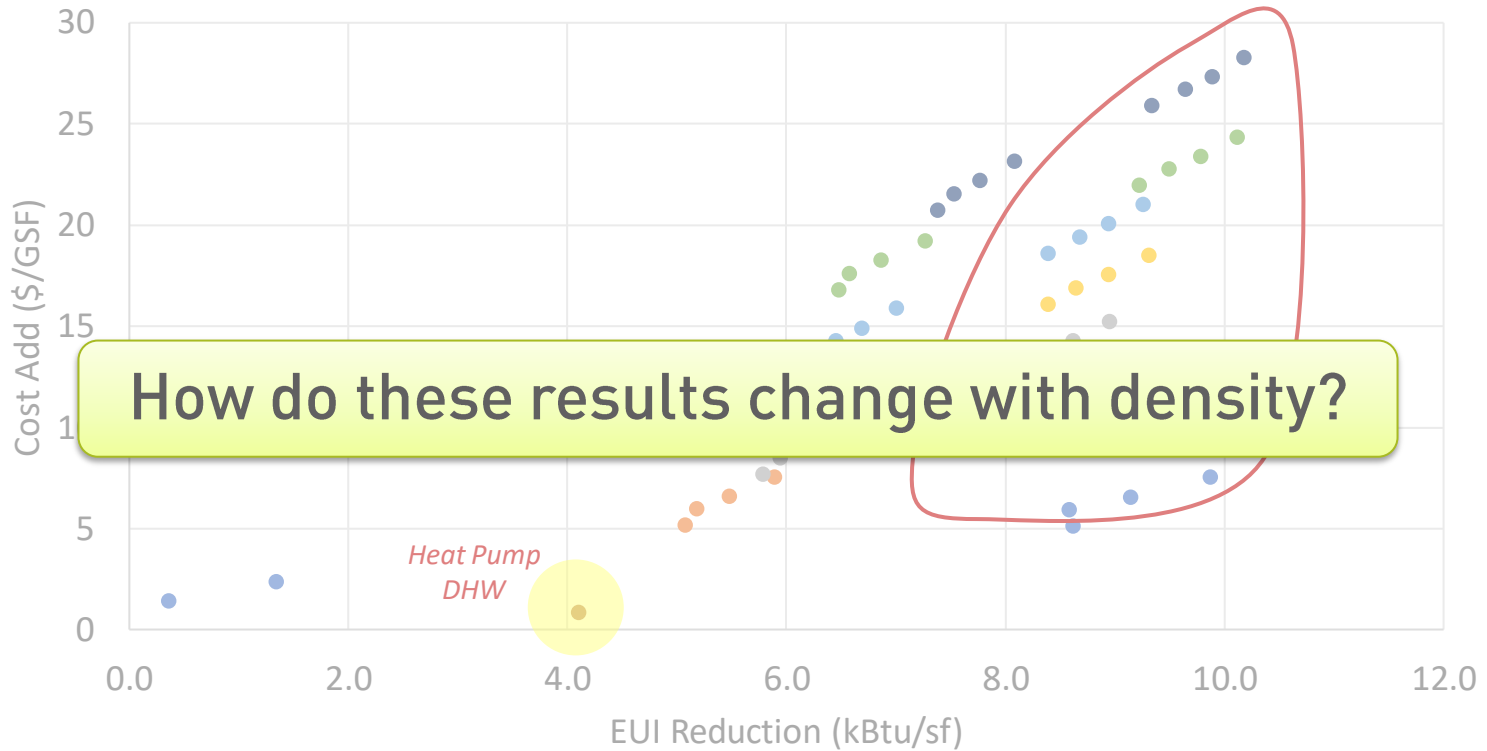
- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

# Low Density Cost vs Energy Saved



- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

## Low Density Cost vs Energy Saved

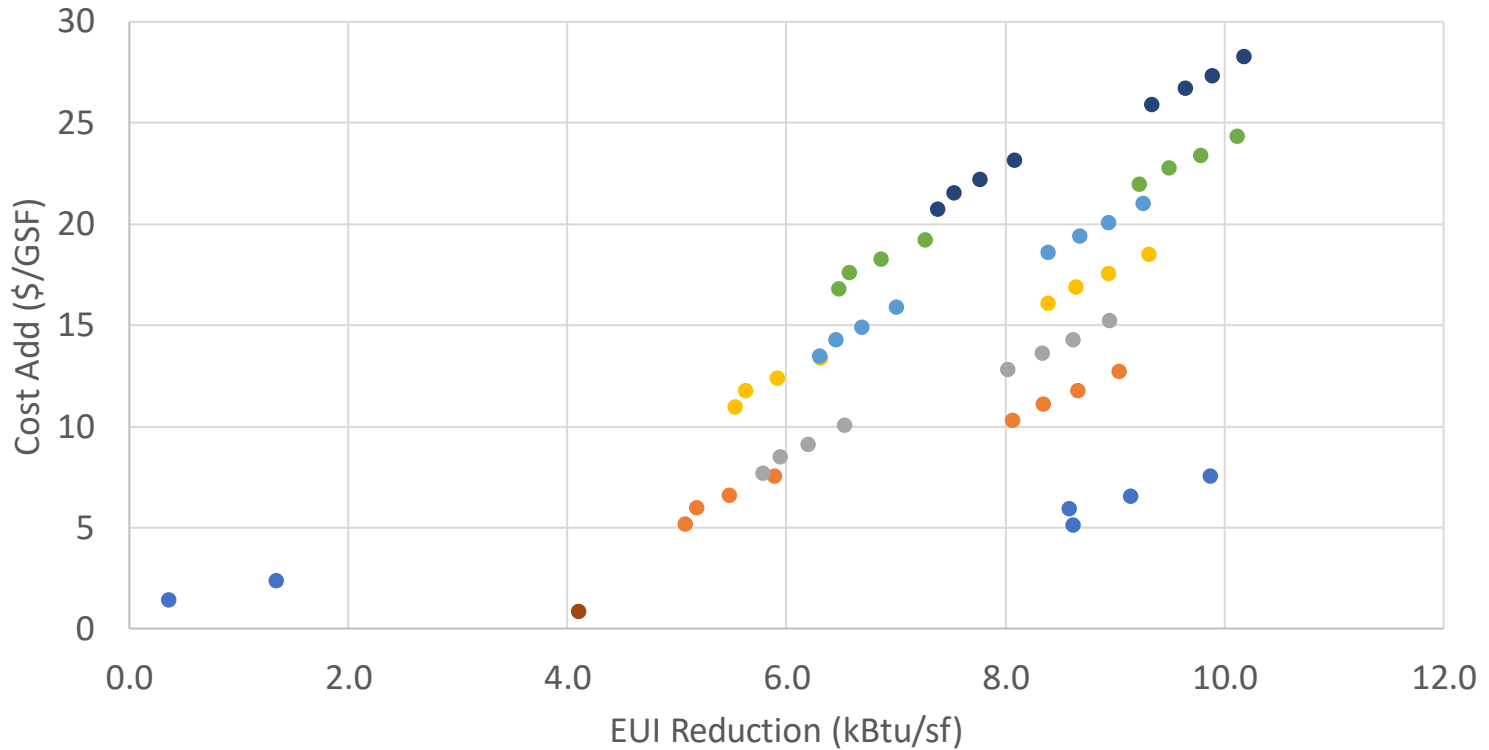


How do these results change with density?

- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

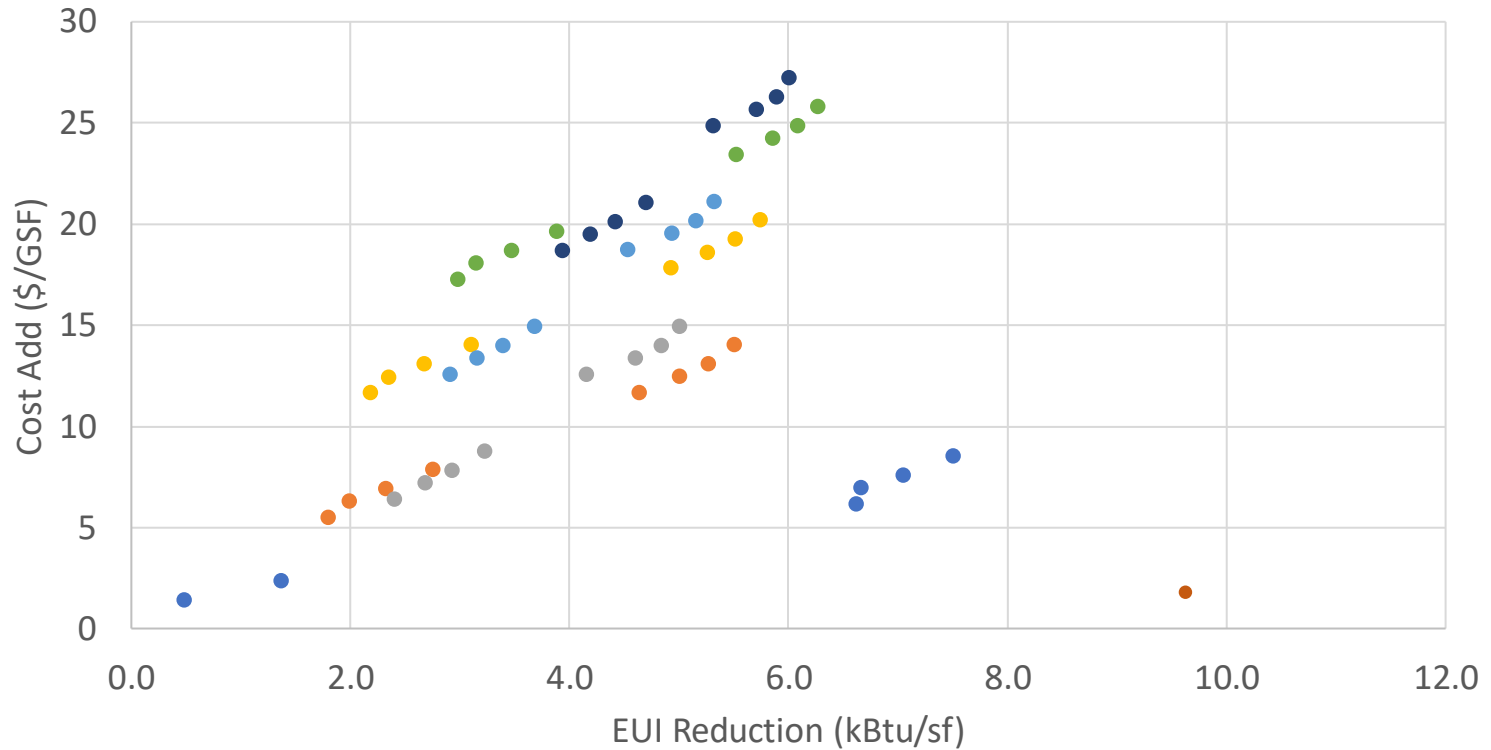


## Low Density vs High Density



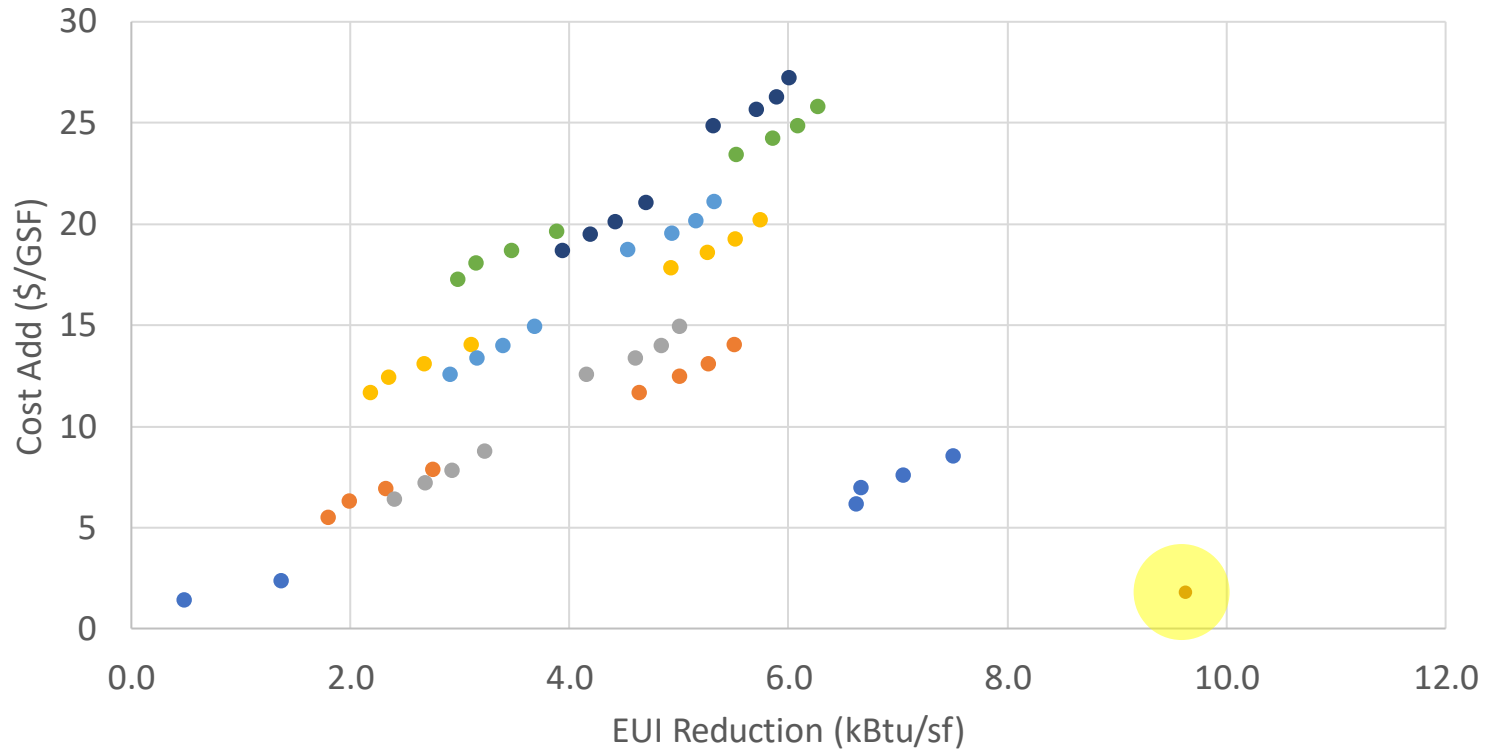
- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

## Low Density vs High Density



- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

## Low Density vs High Density



- Electric Resistance Heat, No Cooling
- PTHPs, Bedroom Electric Heat
- PTHPs, Ducted to Bedrooms
- Split System HPs, Bedroom Electric Heat
- Split System HPs, Ducted to Bedrooms
- VRF, Bedroom Electric Heat
- VRF, Ducted to Bedrooms
- Centralized Heat Pump Water Heaters

## Takeaways for Integrating Energy Savings and Cost Impacts

Heat Pump Water Heating Opportunities

Overhead

Escalation, Contractor, Location



**QUESTIONS?**

