Getting the Most Out of DOAS: Energy Modeling Guidelines for Configuration and Verification

2.22.2023

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Agenda

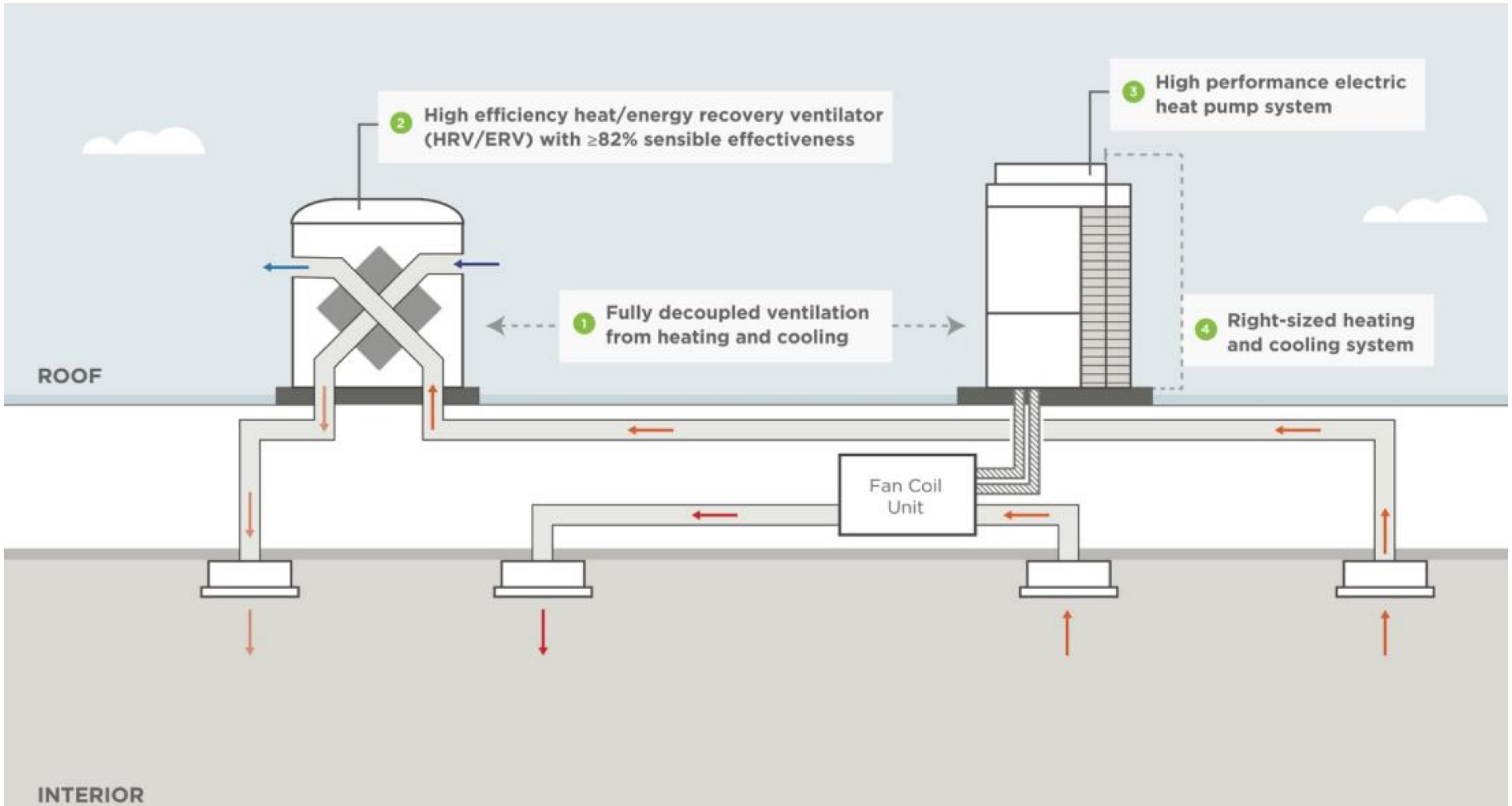
1. Review Goals of Webinar
2. About Very High Efficiency DOAS and efforts by NEEA
3. Creating a VHE DOAS Energy Model
    1. Configuring two systems serving one zone
    2. Ventilation fan power and control
    3. Bypass and supply air control
    4. HRV/ERV defrost
    5. DX-DOAS cooling
4. Lessons Learned in Modeling VHE DOAS
5. Steps to Verify and Self-Check a Model

Goal of Webinar

1. Provide a brief overview of what VHE DOAS is and where to find more information
2. Provide energy modeling techniques to configure a VHE DOAS systems.
3. Share lessons learned from calibrated models of VHE DOAS buildings.

About VHE DOAS

Very High Efficiency Dedicated Outside Air Systems



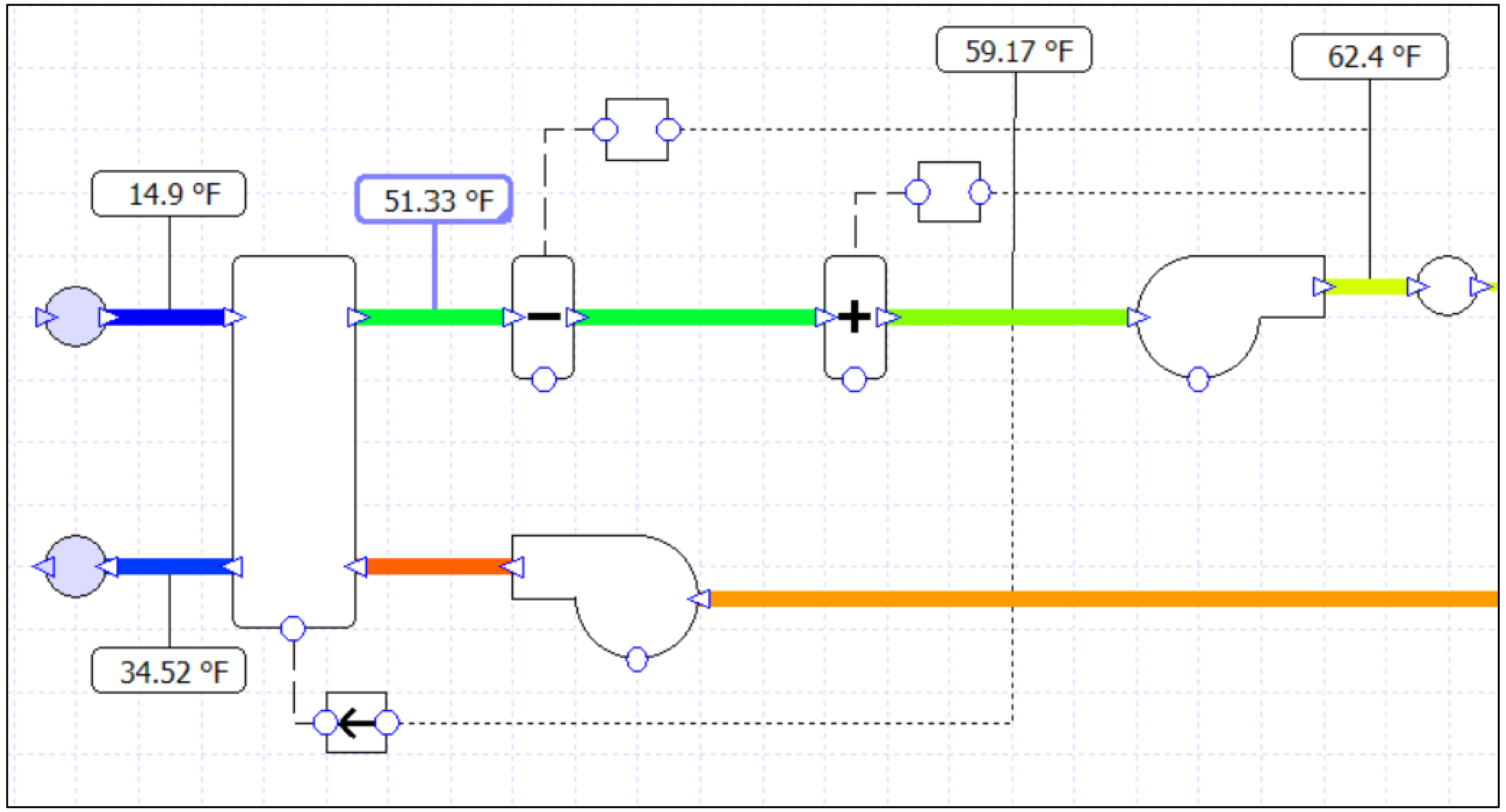
https://betterbricks.com/solutions/very-high-efficiency-doas

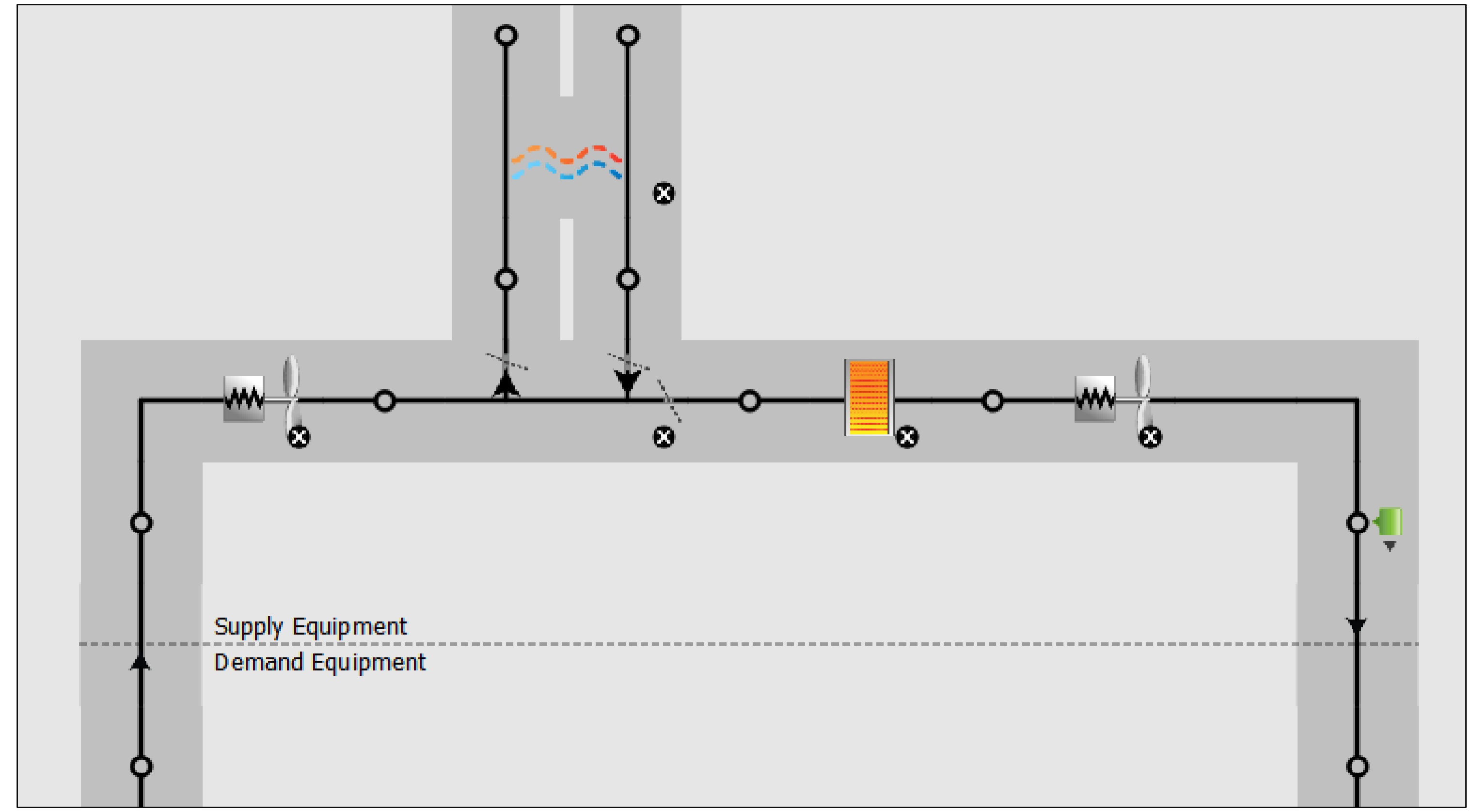
Relation to WA Code and ASHRAE 90.1

- **VHE DOAS, in efficiency criteria to WA Code**
  - sits above the WA 2018 base code and
  - has some aspects which are better than or worse than the WA 2018 Advanced DOAS Package
  - requires higher sensible recovery effectiveness and provides a prescriptive or design condition requirement.
  - Currently requires electric heat pump systems while WSEC allows a wider range of technologies.

- **VHE DOAS, in efficiency criteria to ASHRAE 90.1 2019**
  - Chapter 6 Considerations:
    - Ventilation Zone Isolation (6.4.3.3.4) may require multiple DOAS units in buildings > 25,000 sf to avoid active ventilation zone damper control (VAV boxes) to save cost
    - With Exhaust air heat recovery (6.5.6.1) systems can avoid demand control ventilation in units >3,000 cfm
    - To maintain ventilation only-duct work without a full economizer requires cooling fan coils < 54,000 Btu/hr or, higher efficiency rated cooling unit (exception 11 to 6.5.1)

https://betterbricks.com/resources/doas-comparison



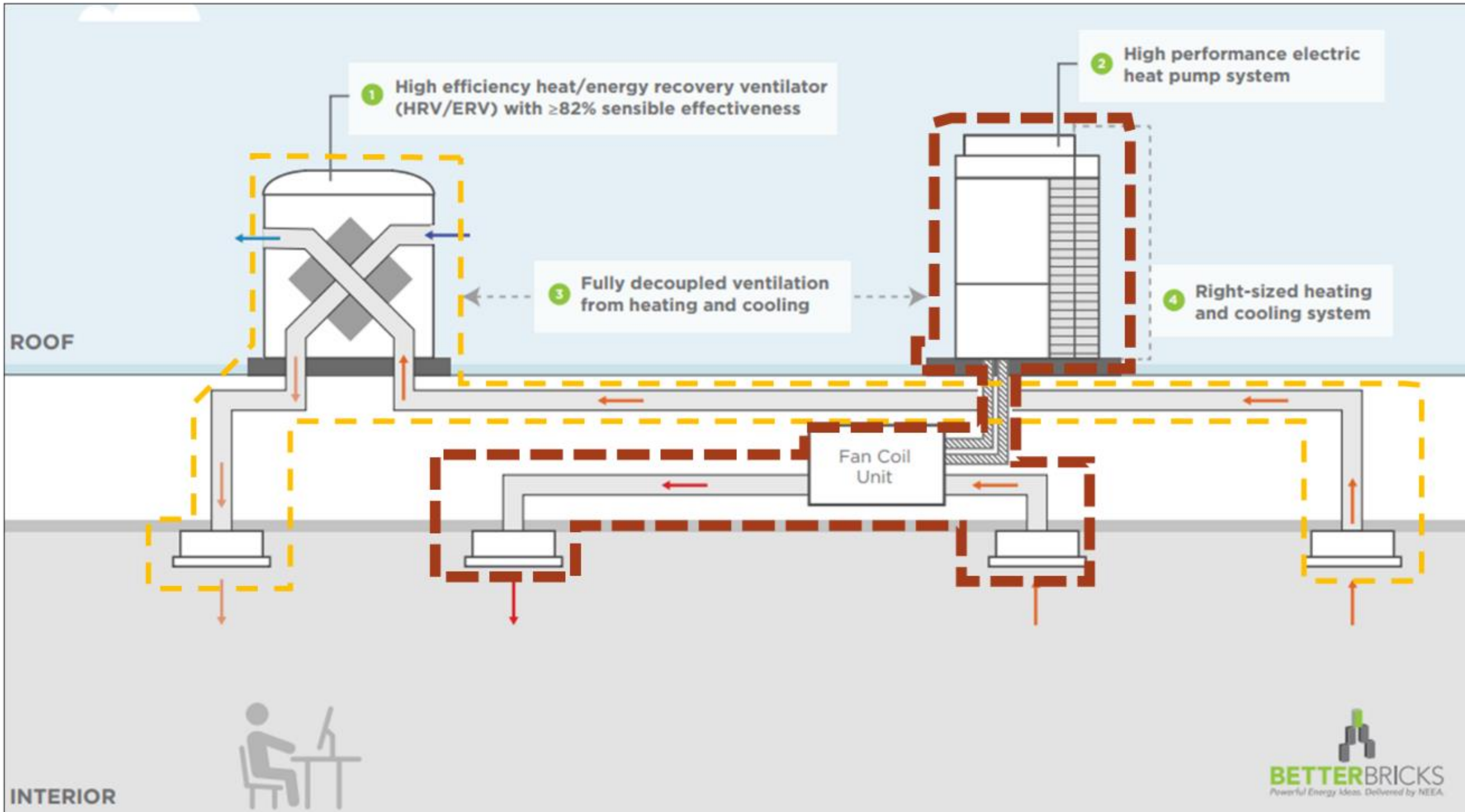


VHE DOAS Configuration

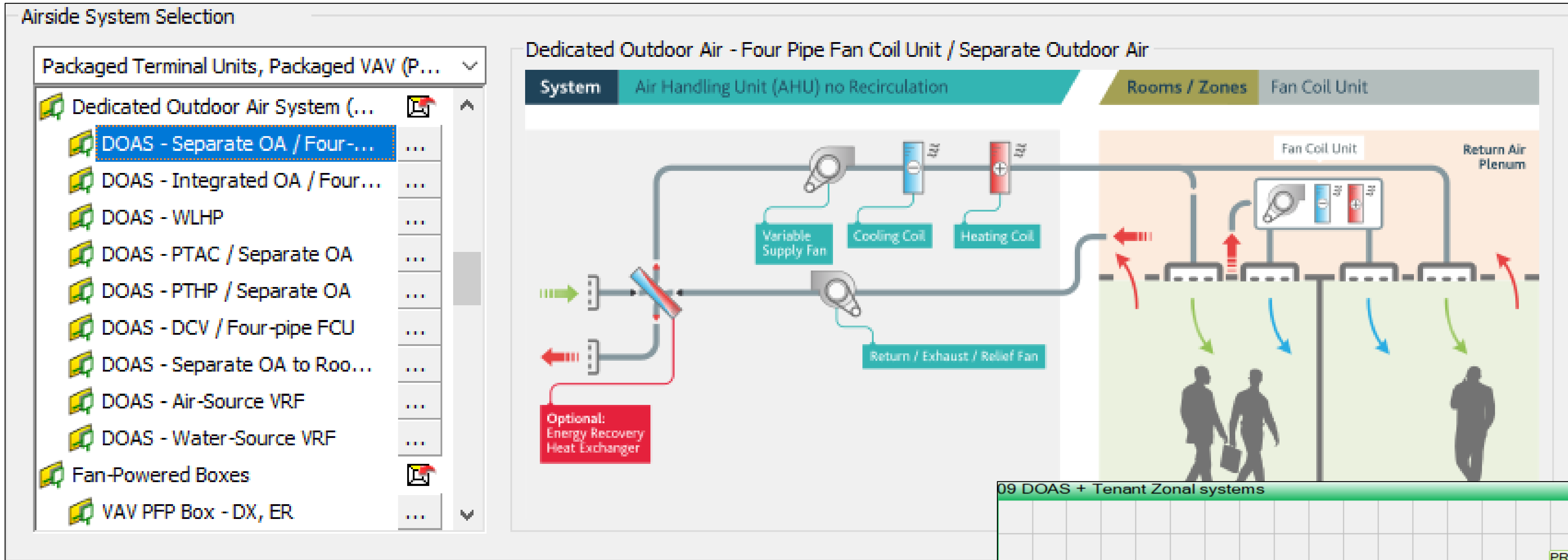
In Energy Modeling Software

1. Configuring two systems serving one zone
2. Ventilation fan power and control
3. Bypass and supply air control
4. HRV/ERV defrost
5. DX-DOAS cooling

Configuring Ventilation and Space Conditioning Systems

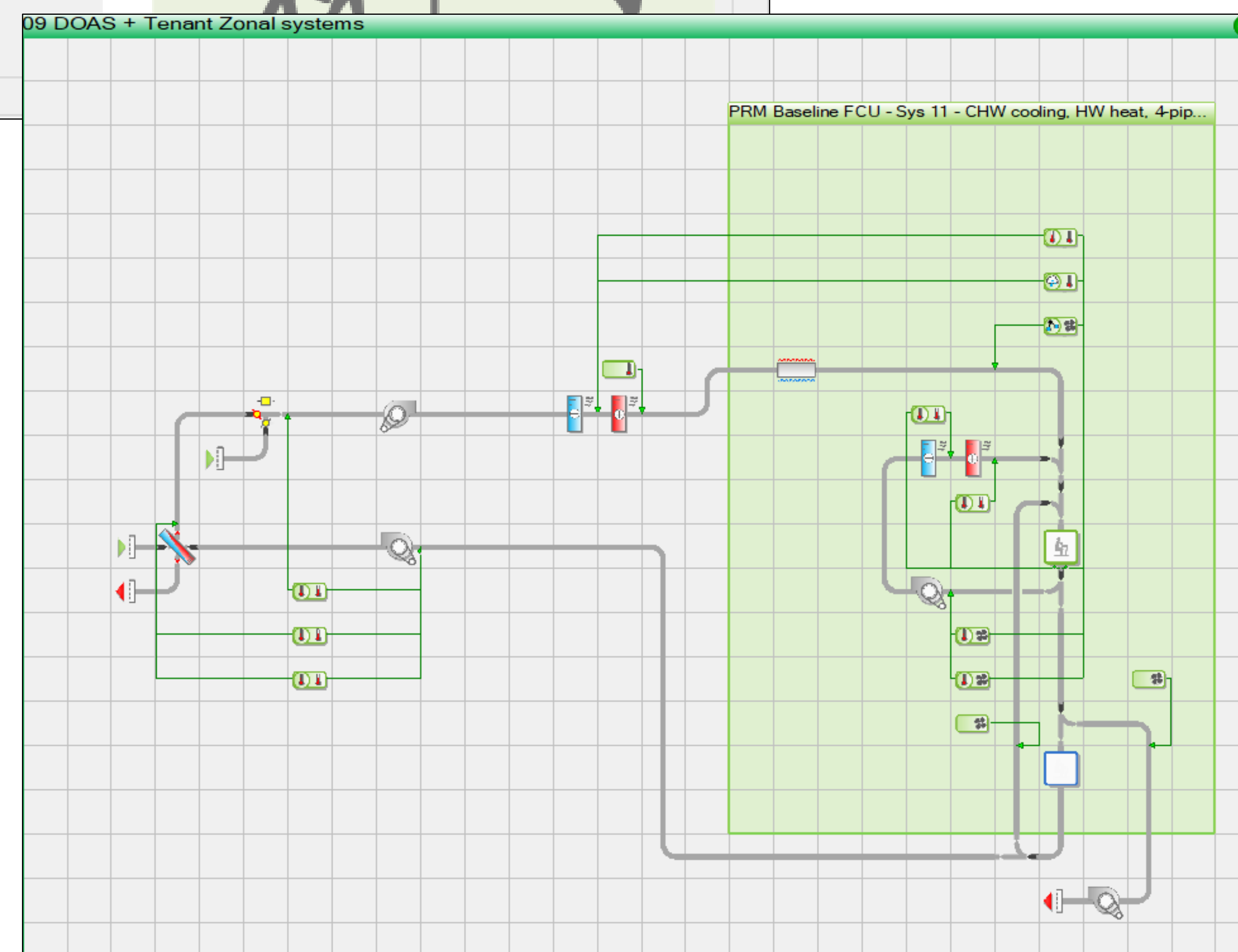


Example of Two Systems Serving One Zone, VE-IES

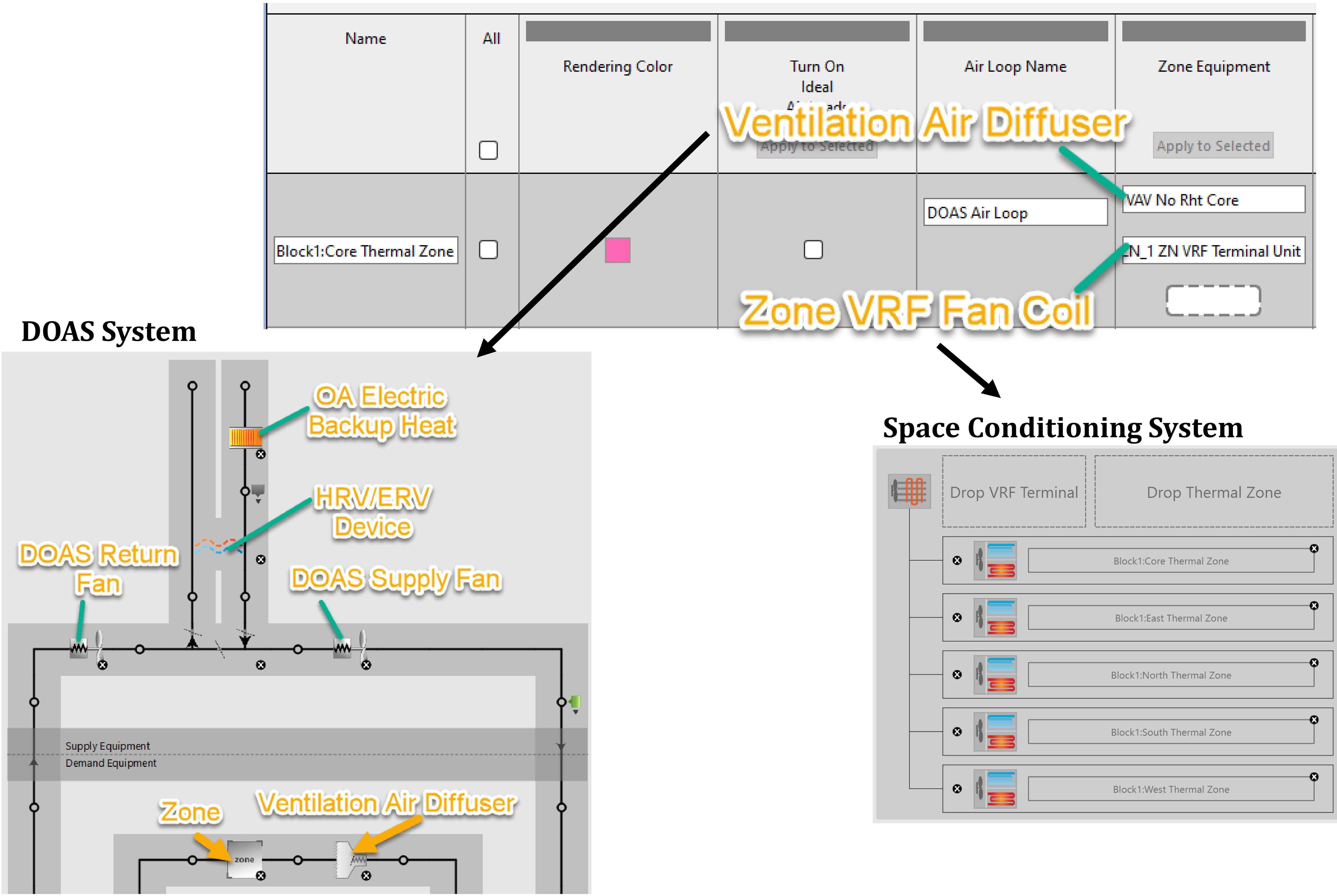


Wizard systems builder showing the two systems serving one zone.

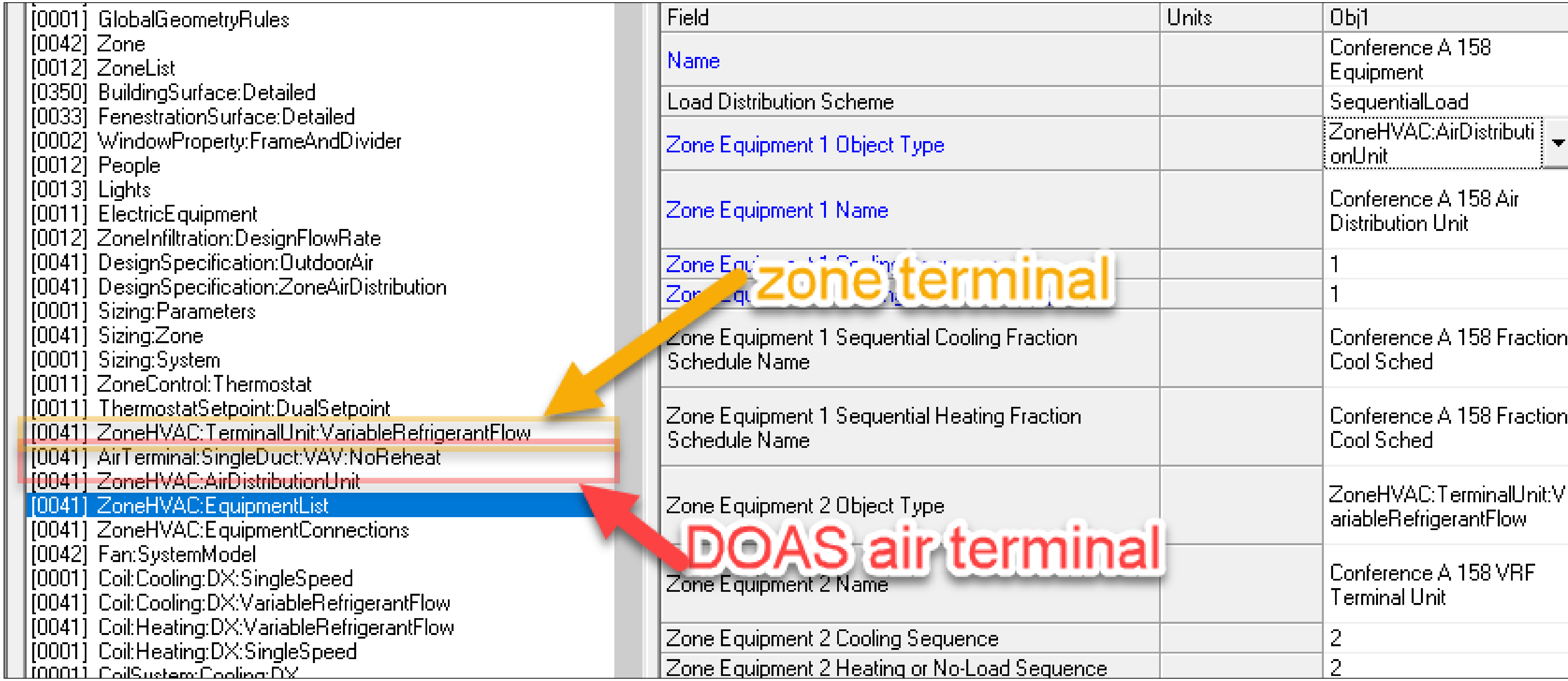
Active system diagram for system components, showing the system in one box and the sub-zone-system in the green box.



Example of Two Systems Serving One Zone, OpenStudio

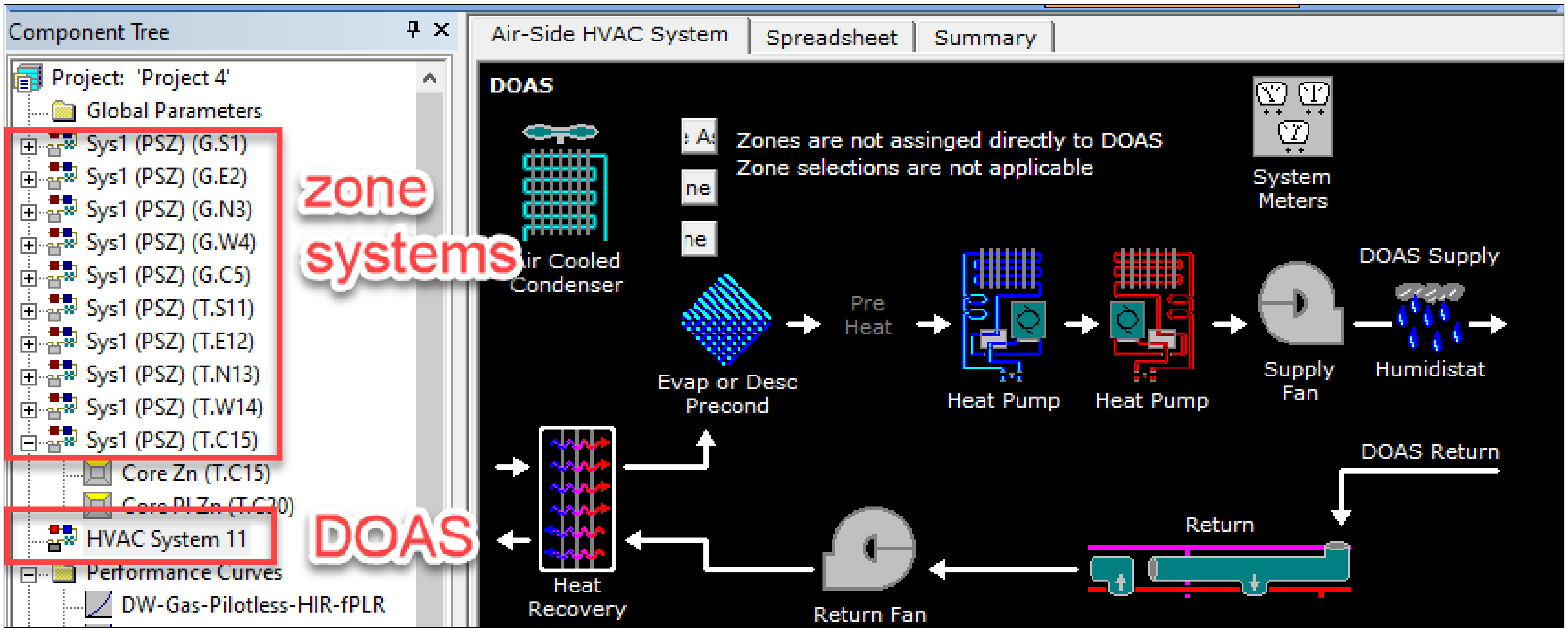


Example of Two Systems Serving One Zone, EnergyPlus



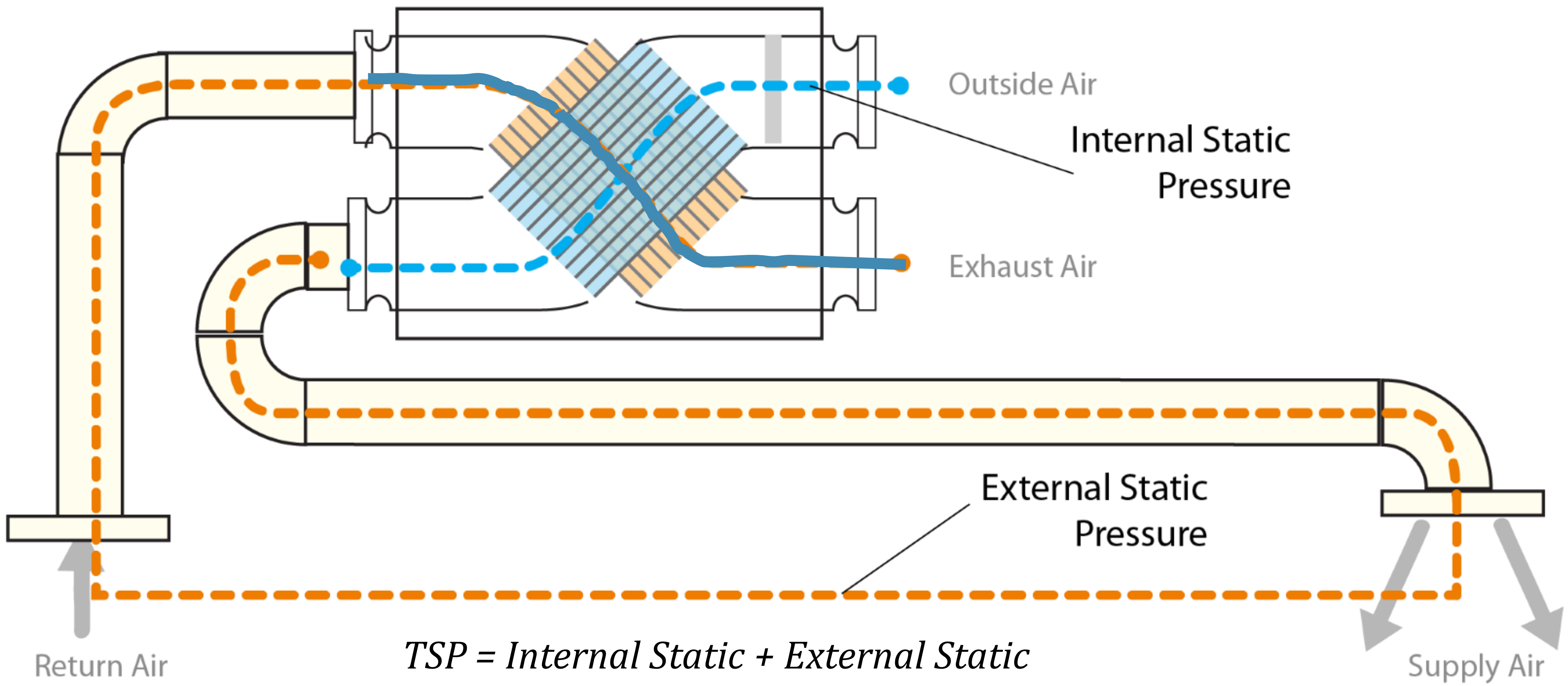
The order of sequencing is important specifically in EnergyPlus to ensure proper thermostat control. Ventilation must go first to introduce outdoor air and space conditioning systems second to fully condition all loads.

Example of Two Systems Serving One Zone, eQuest



DOAS Ventilation Fan Power

- The total power of the supply and exhaust fans providing ventilation.
- Not all drawings will list all information needed, typical will only give external static.
- Where information is lacking, estimating the operational fan power can greatly increase energy estimate vs assuming full power.

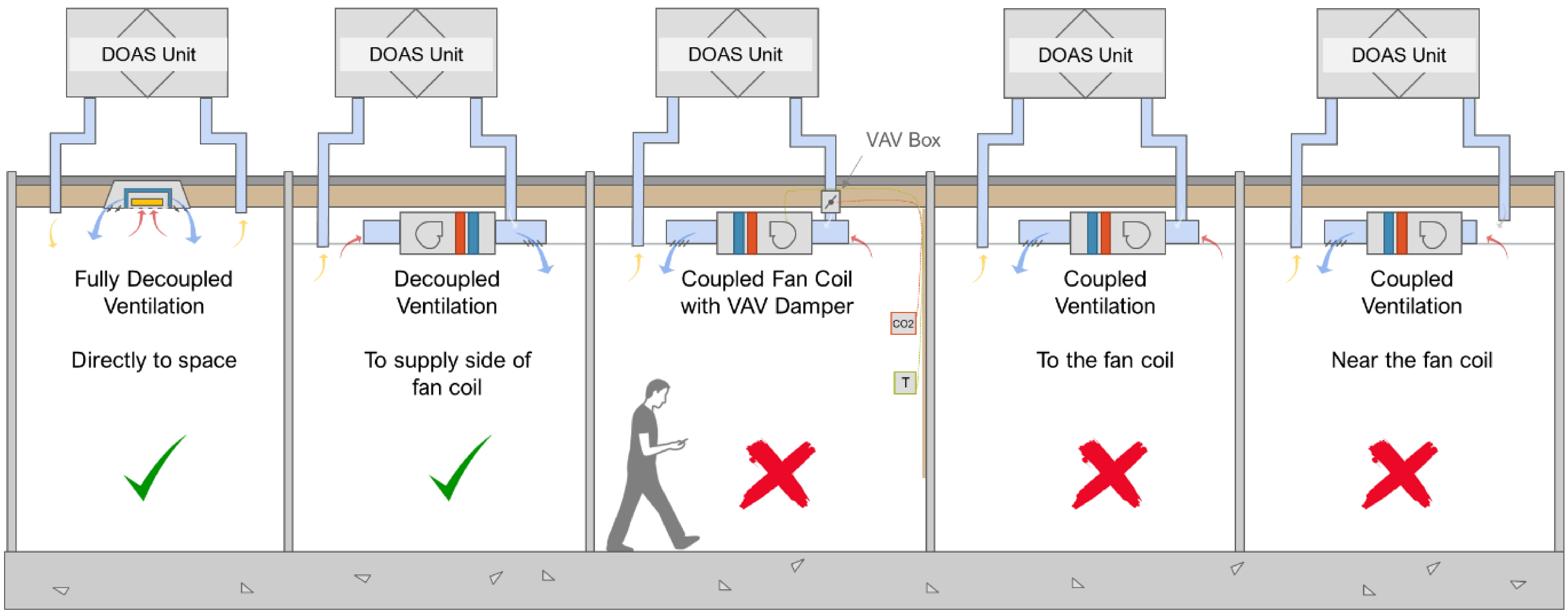


TSP = Internal Static + External Static

$$\text{Fan power (Watts)} = \frac{746 * TSP\ (total\ static\ pressure) * cfm}{6345 * \text{fan efficiency} * \text{fan motor efficiency}}$$

• Design fan power for the supply and exhaust	2.0 cfm/watt to 1.3 cfm/watt.
• Field measured with VHE DOAS	2.7 cfm/watt to 1.3 cfm/watt.

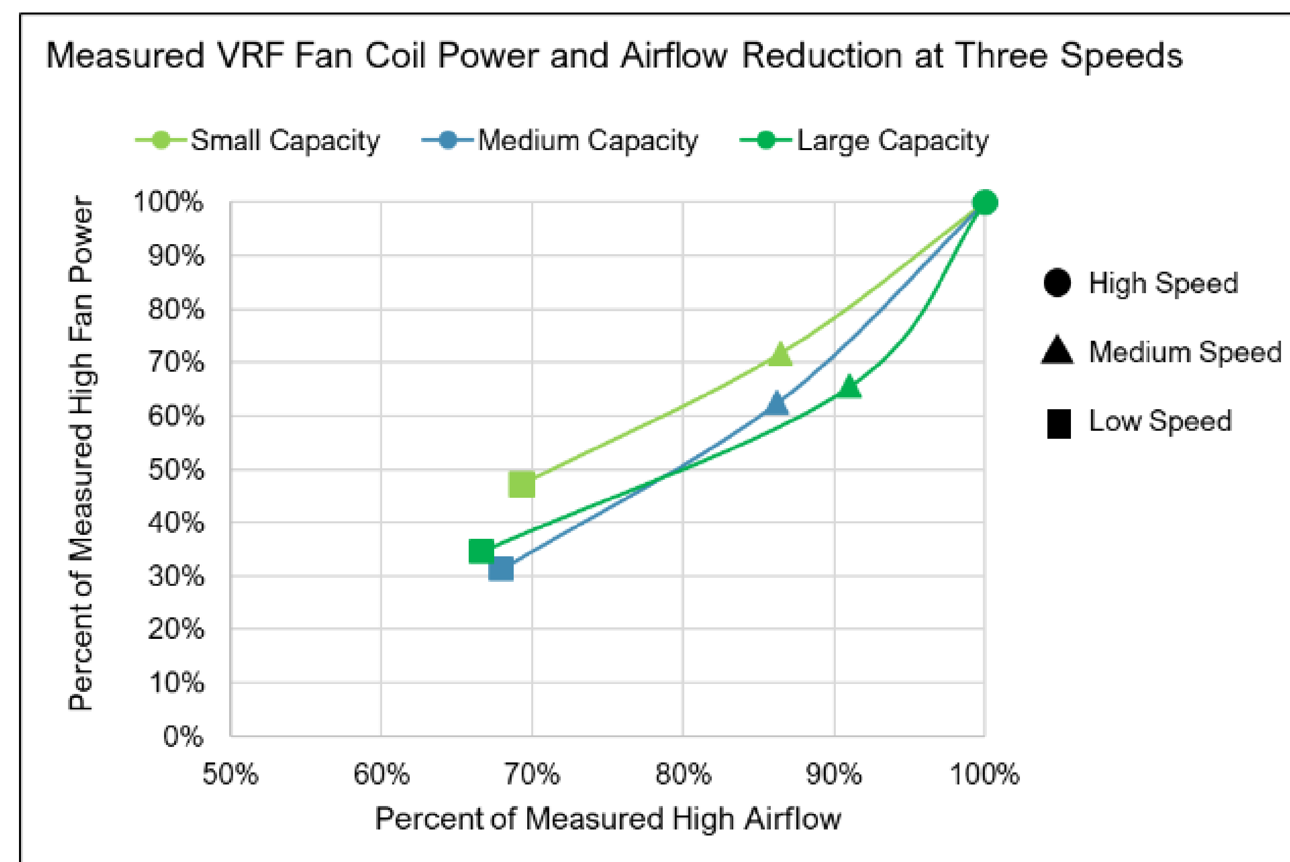
Zone Fan Controls and Ventilation Configuration



Ensuring fans cycle fully off in an energy model.

Zone Fan Power: Fan Coils, Fan Cassettes

- The greatest energy savings and criterion of VHE DOAS is the ability to fully cycle fans off when not in use.
- Often non-ducted systems will be 0.75 inches or less of total pressure, ducted will be 1.5 inches or less.
- Peak fan power should be within the range of 0.3 to 0.65 watt/cfm.
- Most fan cassettes or fan coils operate at 75% or less of rated motor capacity.



EnergyPlus Zone Fan Control Examples

[0041] Sizing:Zone
[0001] Sizing:System
[0011] ZoneControl:Thermostat
[0011] ThermostatSetpoint:Dual!
[0041] ZoneHVAC:TerminalUnit:'
[0041] AirTerminal:SingleDuct:V/
[0041] ZoneHVAC:AirDistributior
[0041] ZoneHVAC:EquipmentLis
[0041] ZoneHVAC:EquipmentCo
[0042] Fan:SystemModel
[0001] Coil:Cooling:DX:SingleSp
[0041] Coil:Cooling:DX:VariableF
[0041] Coil:Heating:DX:VariableF
[0001] Coil:Heating:DX:SingleSp
[0001] CoilSystem:Cooling:DX
[0001] CoilSystem:Heating:DX
[0001] HeatExchanger:AirToAir:!
[0002] AirConditioner:VariableRe
[0002] ZoneTerminalUnitList
[0001] Controller:OutdoorAir
[0001] Controller:MechanicalVer
[0001] AirLoopHVAC:ControllerLi
[0001] AirLoopHVAC
[0001] AirLoopHVAC:OutdoorAir!
[0001] AirLoopHVAC:OutdoorAir!
[0001] OutdoorAir:Mixer
[0001] AirLoopHVAC:ZoneSplitte
[0001] AirLoopHVAC:SupplyPath
[0001] AirLoopHVAC:ZoneMixer
[0001] AirLoopHVAC:ReturnPath
[0001] Branch
[0001] BranchList
[0083] NodeList
[0003] OutdoorAir:Node
[0017] EnergyManagementSyste
[0001] EnergyManagementSyste
[0013] EnergyManagementSyste

Field	Units	Obj1
Name		Conference A 158 VRF Fan
Availability Schedule Name		OfficeHVACAvail
Air Inlet Node Name		Conference A 158 VRF DX HCoil Outlet Node
Air Outlet Node Name		Conference A 158 VRF Terminal Outlet Node
Design Maximum Air Flow Rate	ft3/min	autosize
Speed Control Method		Continuous
Electric Power Minimum Flow Rate		0.6
Design Pressure Rise	inH2O	1.61789589
Motor Efficiency		0.9
Motor In Air Stream Fraction		1
Design Electric Power Consumption	Btu/h	autosize
Design Power Sizing Method		TotalEfficiencyAnd Pressure
Electric Power Per Unit Flow Rate	W/(ft3/min)	
Electric Power Per Unit Flow Rate Per Unit Pressure	W/((ft3/min)-inH2O)	
Fan Total Efficiency		0.45
Electric Power Function of Flow Fraction Curve Name		Conference A 158 VRF_Fan Curve
Night Ventilation Mode Pressure Rise	inH2O	
Night Ventilation Mode Flow Fraction		
Motor Loss Zone Name		
Motor Loss Radiative Fraction		
End-Use Subcategory		Zone Fan Energy

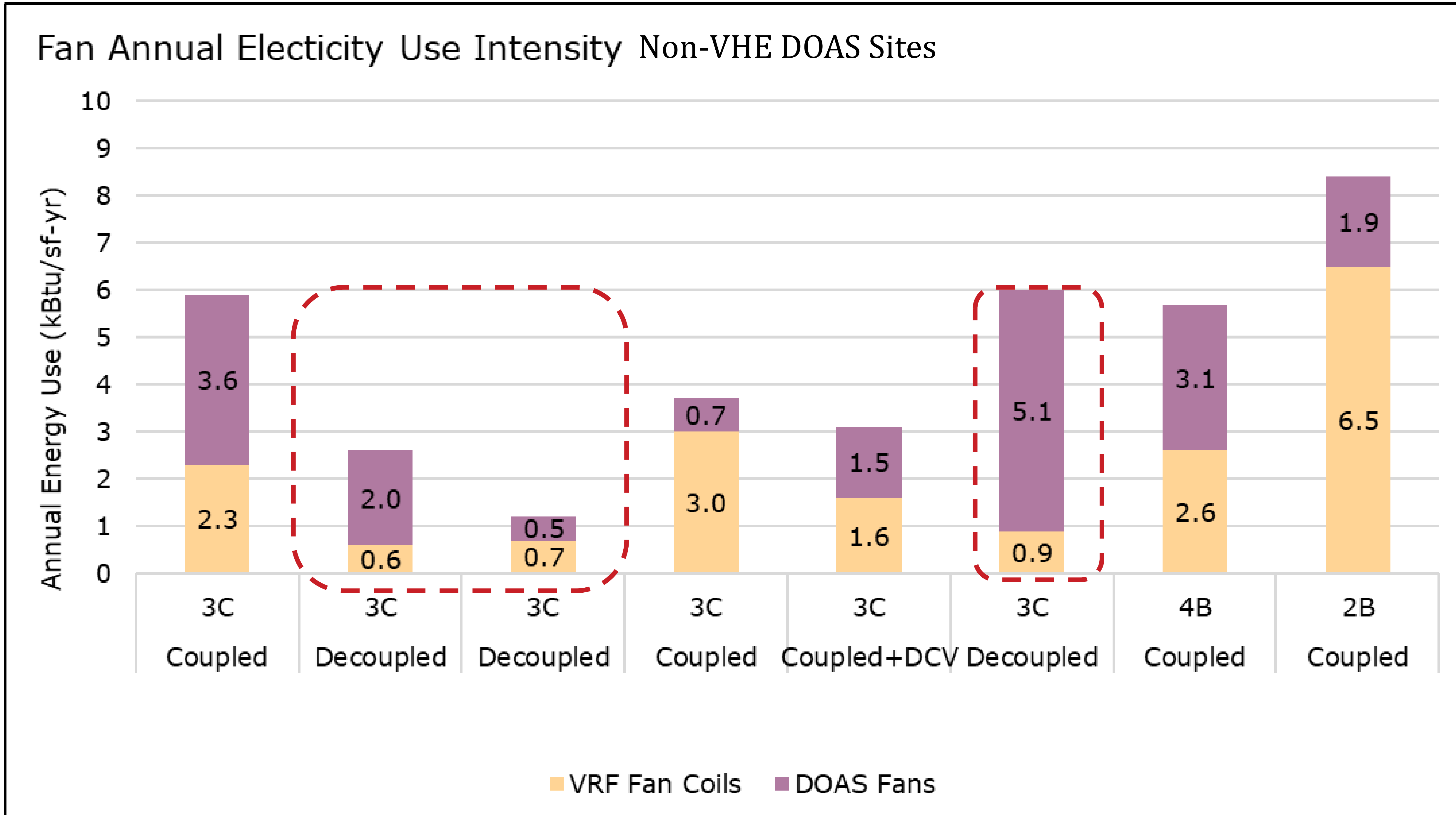
Decoupled Fan, Able to Turn-Down to 0% Flow

Field	Units	Obj1
Name		Creative Work Area 152 VRF_Fan Curve
Coefficient1 Constant		0.00153028
Coefficient2 x		0.00520806
Coefficient3 x**2		1.1086242
Coefficient4 x**3		-0.11635563
Coefficient5 x**4		0
Minimum Value of x	varies	0
Maximum Value of x	varies	1
Minimum Curve Output	varies	0
Maximum Curve Output	varies	.7
Input Unit Type for X		Dimensionless
Output Unit Type		Dimensionless

Coupled Fan, Always On at 60% Minimum Flow

Field	Units	Obj1
Name		Conference A 158 VRF_Fan Curve
Coefficient1 Constant		0.00153028
Coefficient2 x		0.00520806
Coefficient3 x**2		1.1086242
Coefficient4 x**3		-0.11635563
Coefficient5 x**4		0
Minimum Value of x	varies	0.6
Maximum Value of x	varies	1
Minimum Curve Output	varies	0
Maximum Curve Output	varies	0.7
Input Unit Type for X		Dimensionless
Output Unit Type		Dimensionless

Field Measurements of DOAS + Zone Fans (Non-VHE DOAS)



Office buildings and higher-education/office buildings.

Major observation between sites is the zone fan units configured in a decoupled configuration used less than 50% versus sites with coupled configurations.

REDCAR ANALYTICS

Heat Recovery, Bypass, Supply Air Controls

Common Control Capabilities of VHE DOAS Units:

1. Supply air setpoint. Controller will modulate bypass to meet the setpoint.

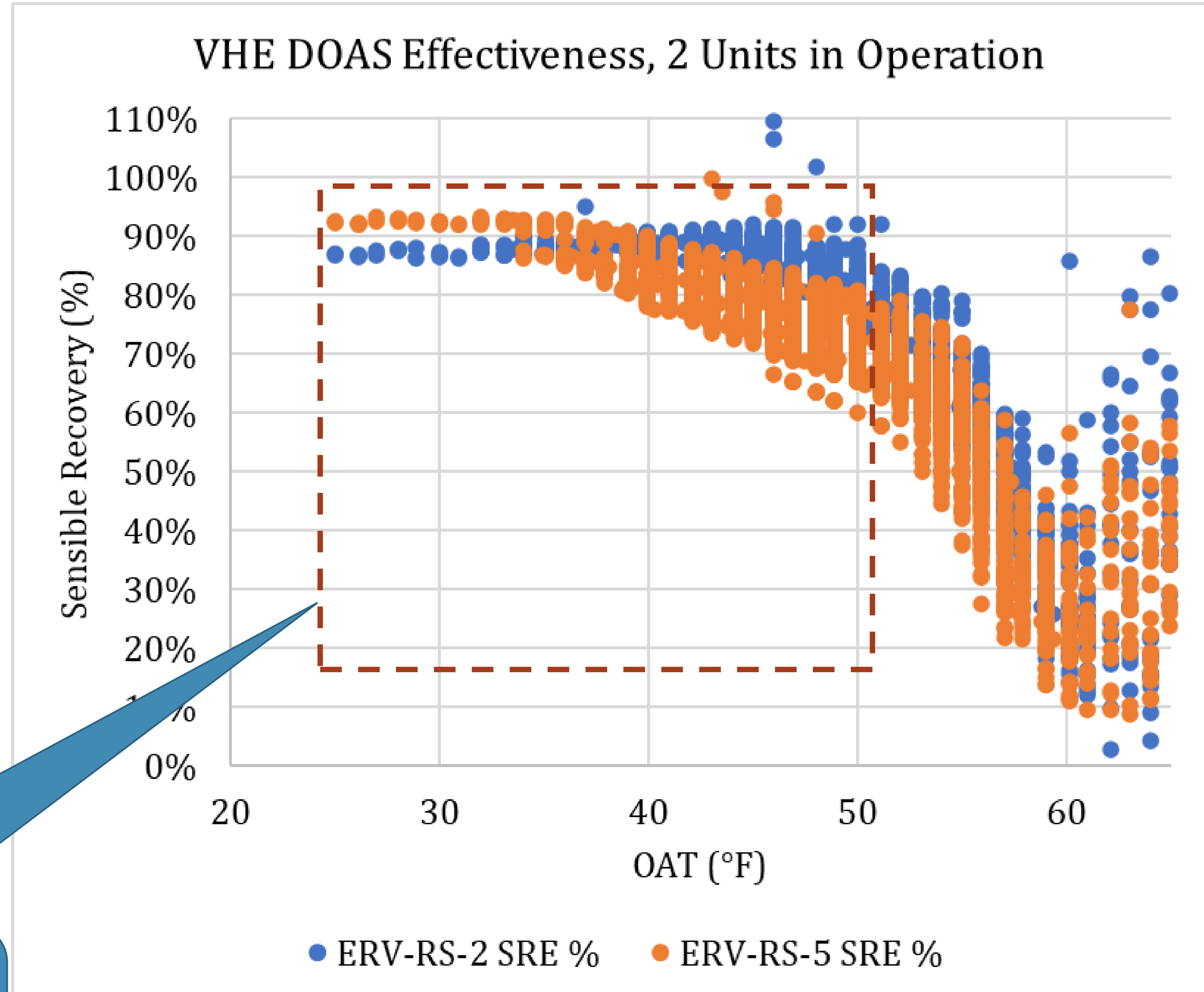
2. Ventilation economizing, bypass limits to modulate free cooling.

3. CO2 control, where the controller will modulate the volume of OA within limits, based on return CO2 signal.

Ventilation Heat Recovery (HRV)

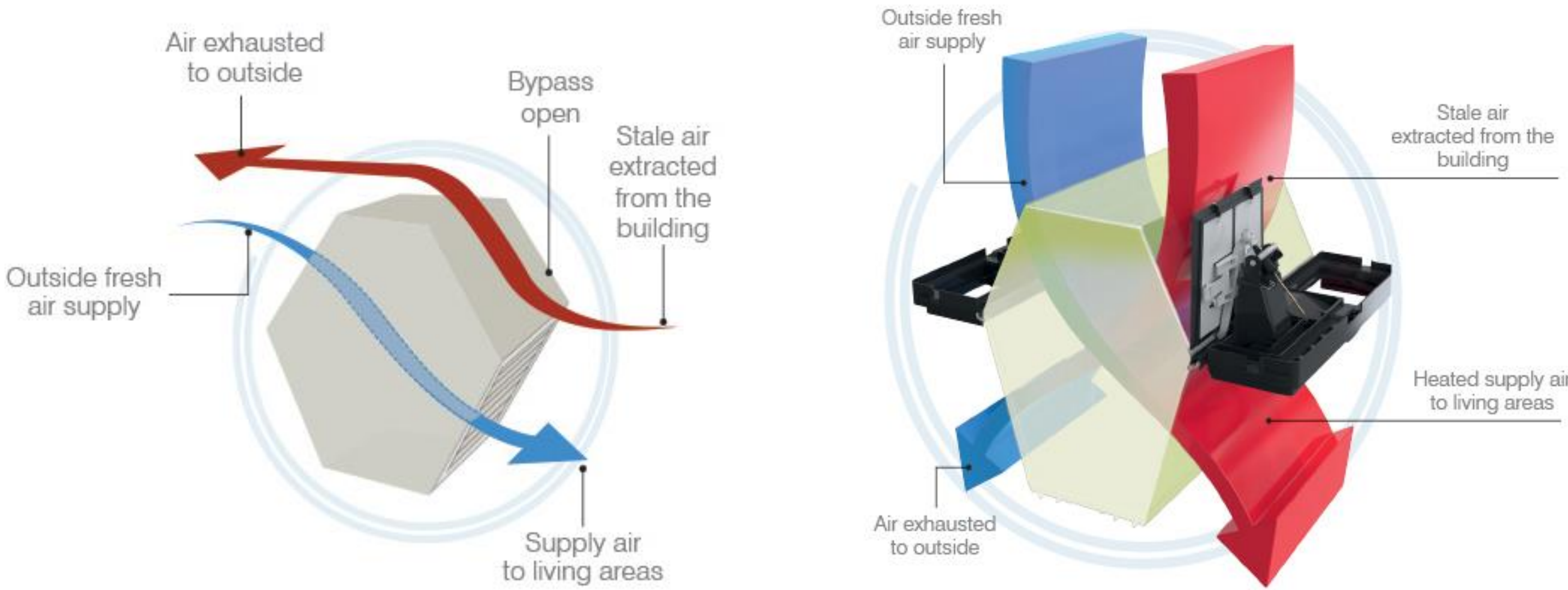
VHE DOAS Requires units be able to achieve a sensible heat recovery threshold in one of many ways:

- Passive House Institute (PHI) certified or,
- Minimum 82% Sensible Effectiveness of HX per AHRI 1060-2018 software at winter conditions and 75% nominal airflow and winter condition
- Minimum HRV HX of 82% sensible effectiveness at winter and summer design temperatures and airflows.



Full heat recovery mode

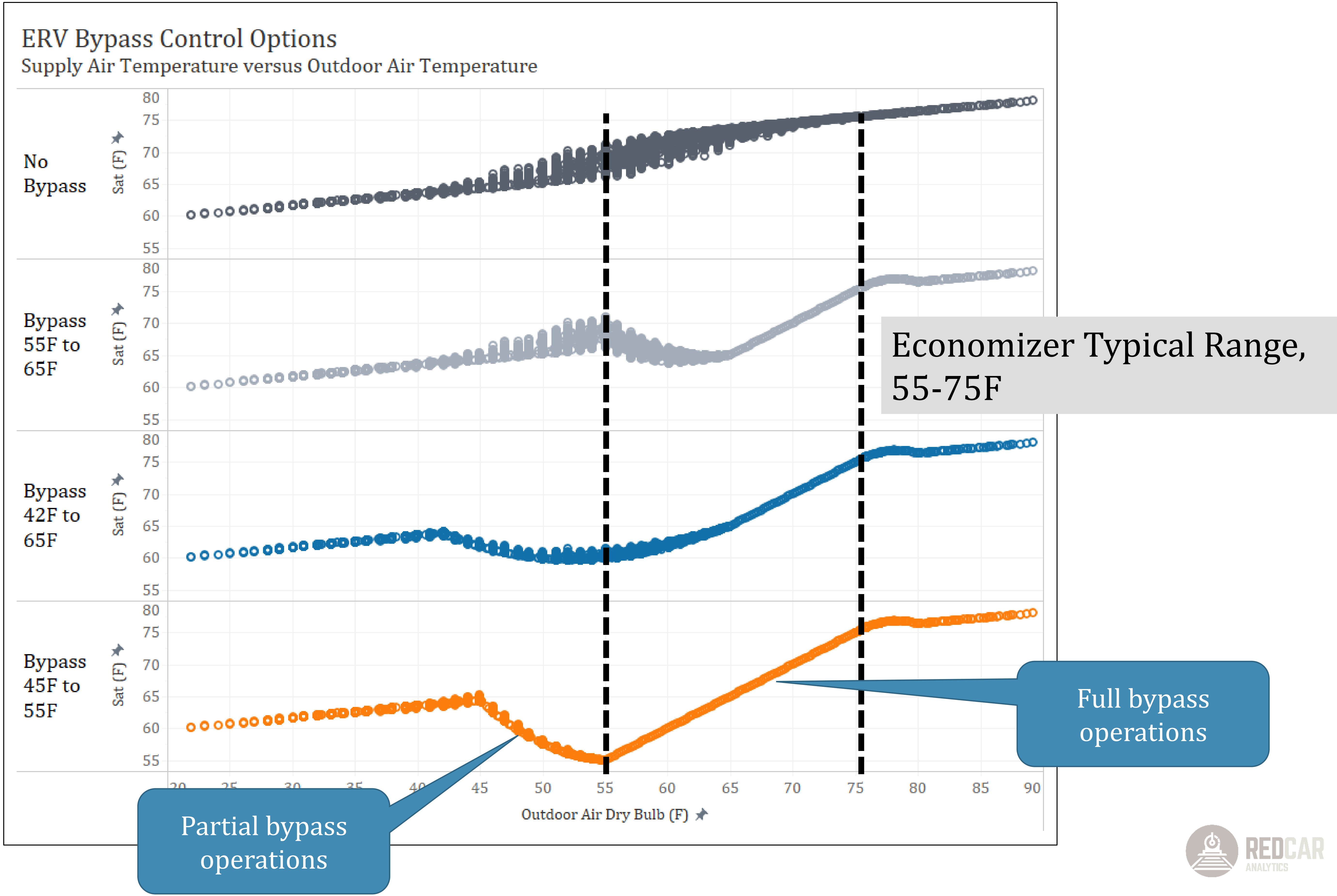
HRV/ERV Bypass and Supply Air Control



Bypass airflow pathway of HRV/ERV Core (image from: energyrecovery.com)

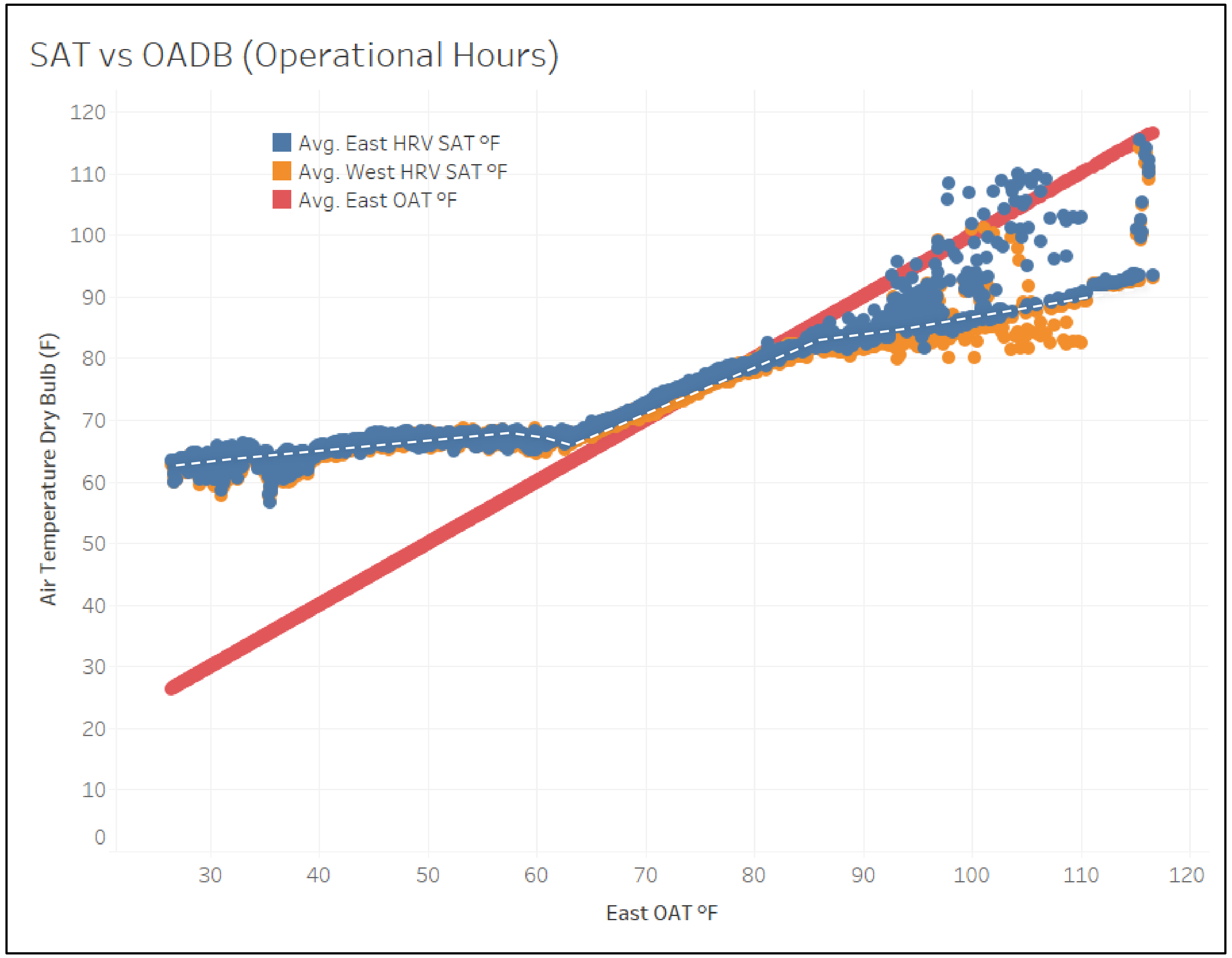
- **Non-Integrated bypass** – Bypasses the heat recovery device fully when conditions are satisfied
- **Integrated bypass** - modulate the bypassed airflow from partial bypass to full, often controlling the amount of air that is bypassed to achieve a set supply air temperature.

Analysis of Operational Bypass

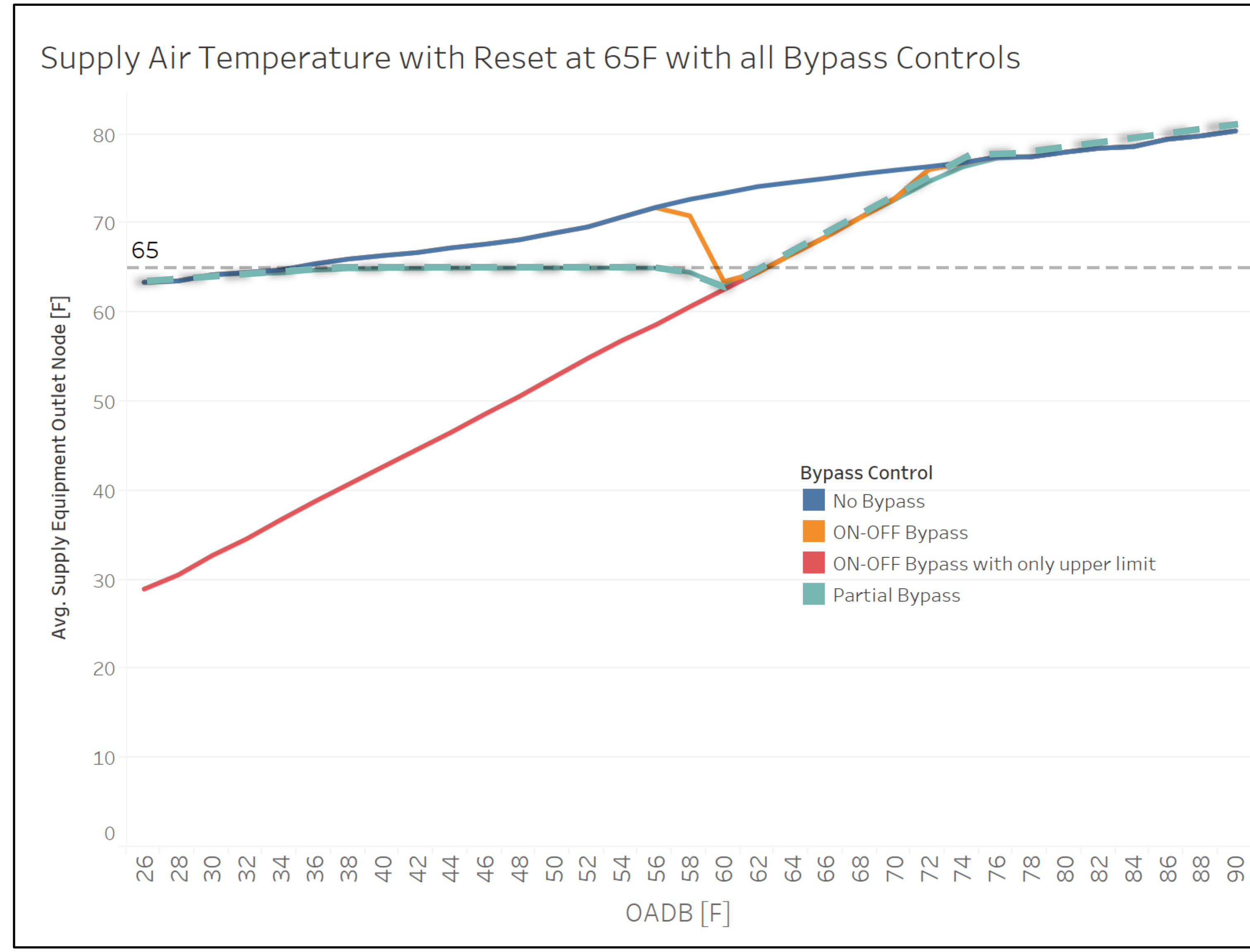


HRV Supply Air Temperature + Bypass

Observed control closest to Supply air control to a fixed setpoint (65) with partial bypass control



Energy 350 Office



EnergyPlus Sample HRV SAT Control Sequence

Implementing: EnergyPlus

The 'Economizer Lockout' effectively enables and disables the bypass when OA is within set limits. It is on or off.

The Supply Air Outlet Control modulates the bypass, allowing air to mix whenever it can achieve the set setpoint.

- **Integrated bypass** - modulate the bypassed airflow from partial bypass to full, often controlling the amount of air that is bypassed to achieve a set supply air temperature.

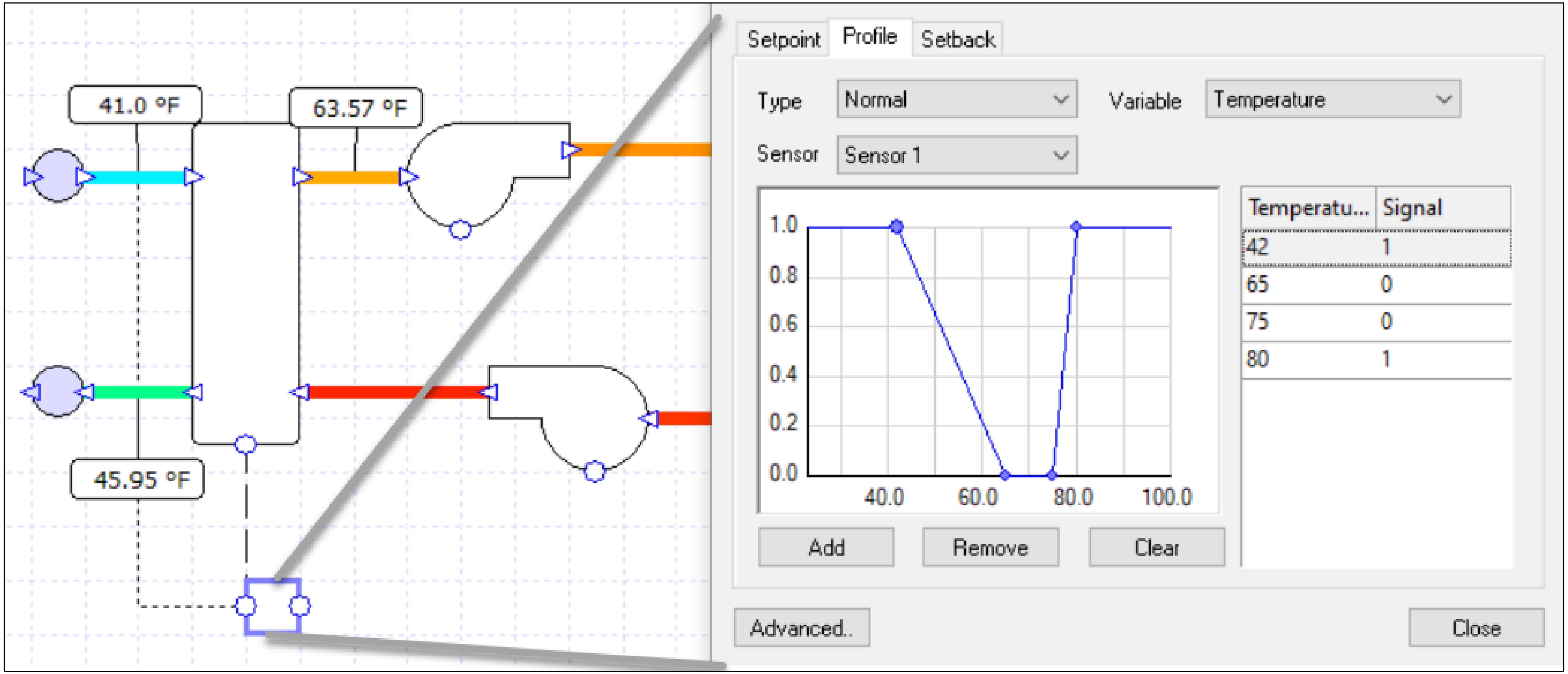
- **Non-Integrated bypass** – Bypasses the heat recovery device fully when conditions are satisfied

Field	Units	Obj1
Name		DOAS1 Energy Recovery Core
Availability Schedule Name		DOAS1 Always On Schedule
Nominal Supply Air Flow Rate	ft3/min	1.55949568E+03
Sensible Effectiveness at 100% Heating Air Flow	dimensionless	0.82
Latent Effectiveness at 100% Heating Air Flow	dimensionless	
Sensible Effectiveness at 75% Heating Air Flow	dimensionless	0.82
Latent Effectiveness at 75% Heating Air Flow	dimensionless	
Sensible Effectiveness at 100% Cooling Air Flow	dimensionless	0.82
Latent Effectiveness at 100% Cooling Air Flow	dimensionless	
Sensible Effectiveness at 75% Cooling Air Flow	dimensionless	0.82
Latent Effectiveness at 75% Cooling Air Flow	dimensionless	
Supply Air Inlet Node Name		DOAS1 Outside Air Inlet Node
Supply Air Outlet Node Name		DOAS1 ER Supply Outlet Node
Exhaust Air Inlet Node Name		DOAS1 OA Relief Node
Exhaust Air Outlet Node Name		DOAS1 ER Exhaust Outlet Node
Nominal Electric Power	W	0
Supply Air Outlet Temperature Control		Yes
Heat Exchanger Type		Rotary
Frost Control Type		None
Threshold Temperature	F	35.06
Initial Defrost Time Fraction	dimensionless	
Rate of Defrost Time Fraction Increase	1/F	
Economizer Lockout		Yes

Outdoor Air Controller Limits

Economizer Control Type		FixedDryBulb
Economizer Control Action Type		ModulateFlow
Economizer Maximum Limit Dry-Bulb Temperature	F	72
Economizer Maximum Limit Enthalpy	Btu/lb	
Economizer Maximum Limit Dewpoint Temperature	F	
Electronic Enthalpy Limit Curve Name		
Economizer Minimum Limit Dry-Bulb Temperature	F	60
Lockout Type		NoLockout
Minimum Limit Type		FixedMinimum

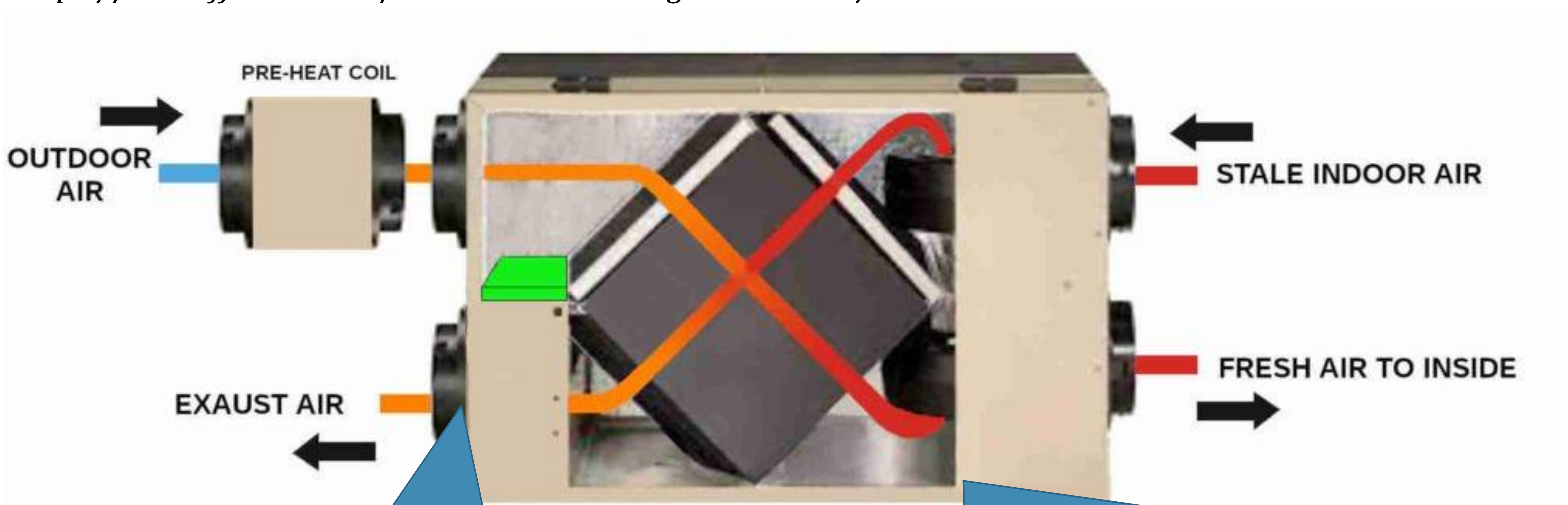
Implementing: EDSL-TAS



EDSL-TAS allows for a more visual representation of bypass control of an air to air heat exchanger in an energy model and can allow the system to bypass not just based on a supply air setpoint but any temperature in a system. In the example below, the bypass is controlled based on outdoor air dry-bulb, bypassing when the outdoor air is above 42F until it is 65F and fully open.

HRV/ERV Defrost Configuration and Controls

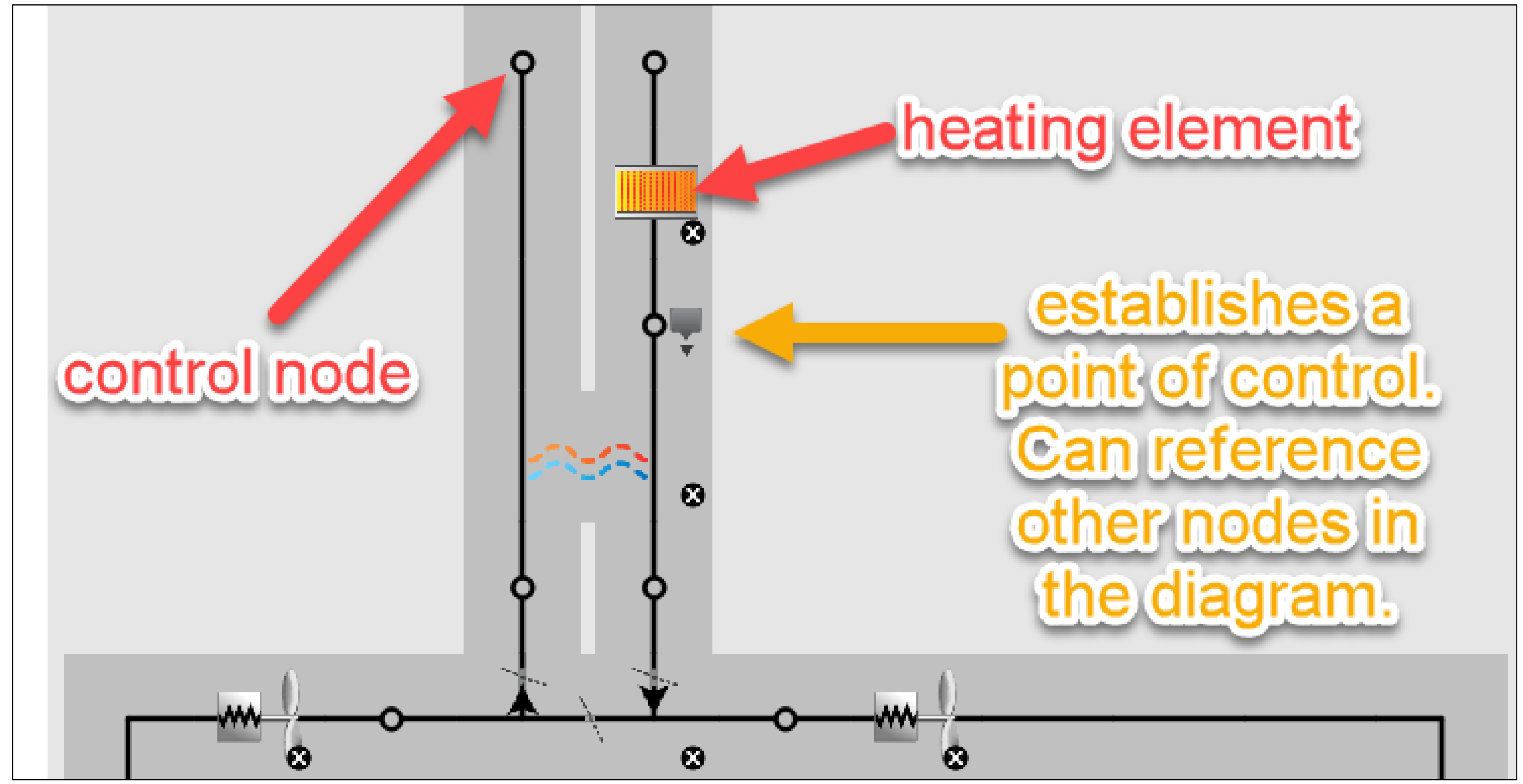
https://ohmefficient.com/residential-building-ventilation/

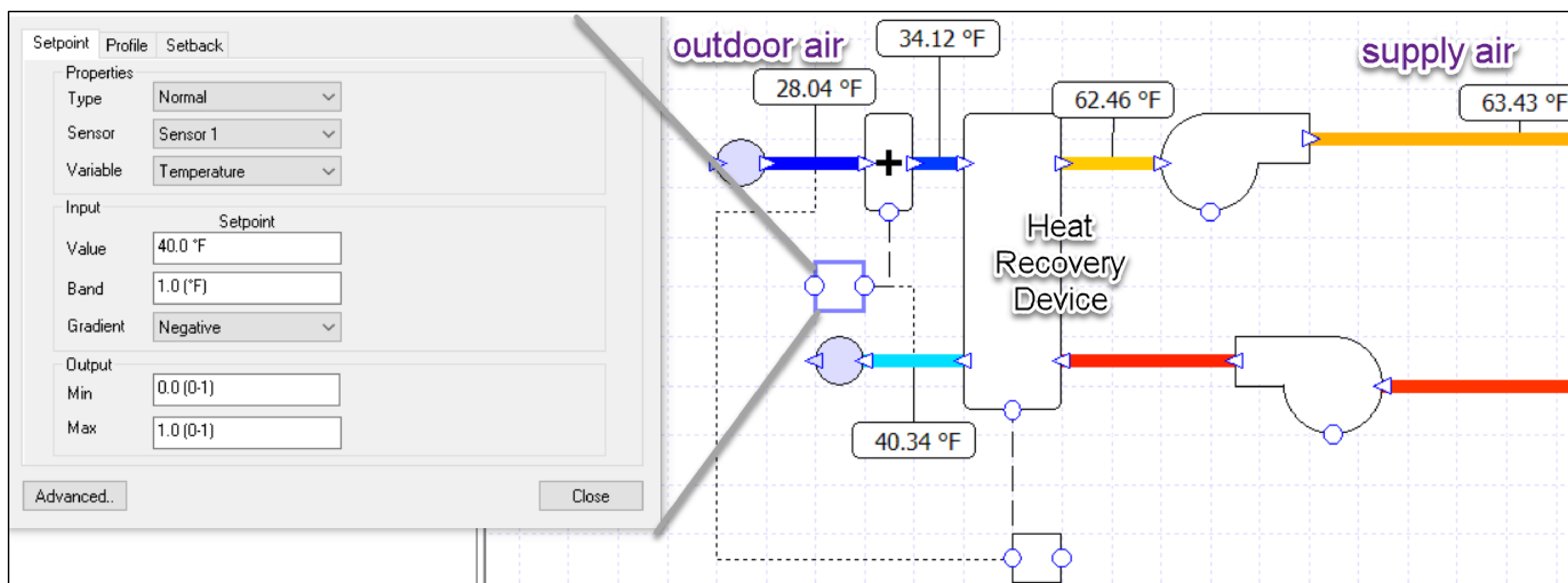


Ice can build-up at this point in the core

Typically, this will control to an exhaust air setpoint above freezing such as 40F or above to ensure the unit is protected.

Defrost Heat Control Examples



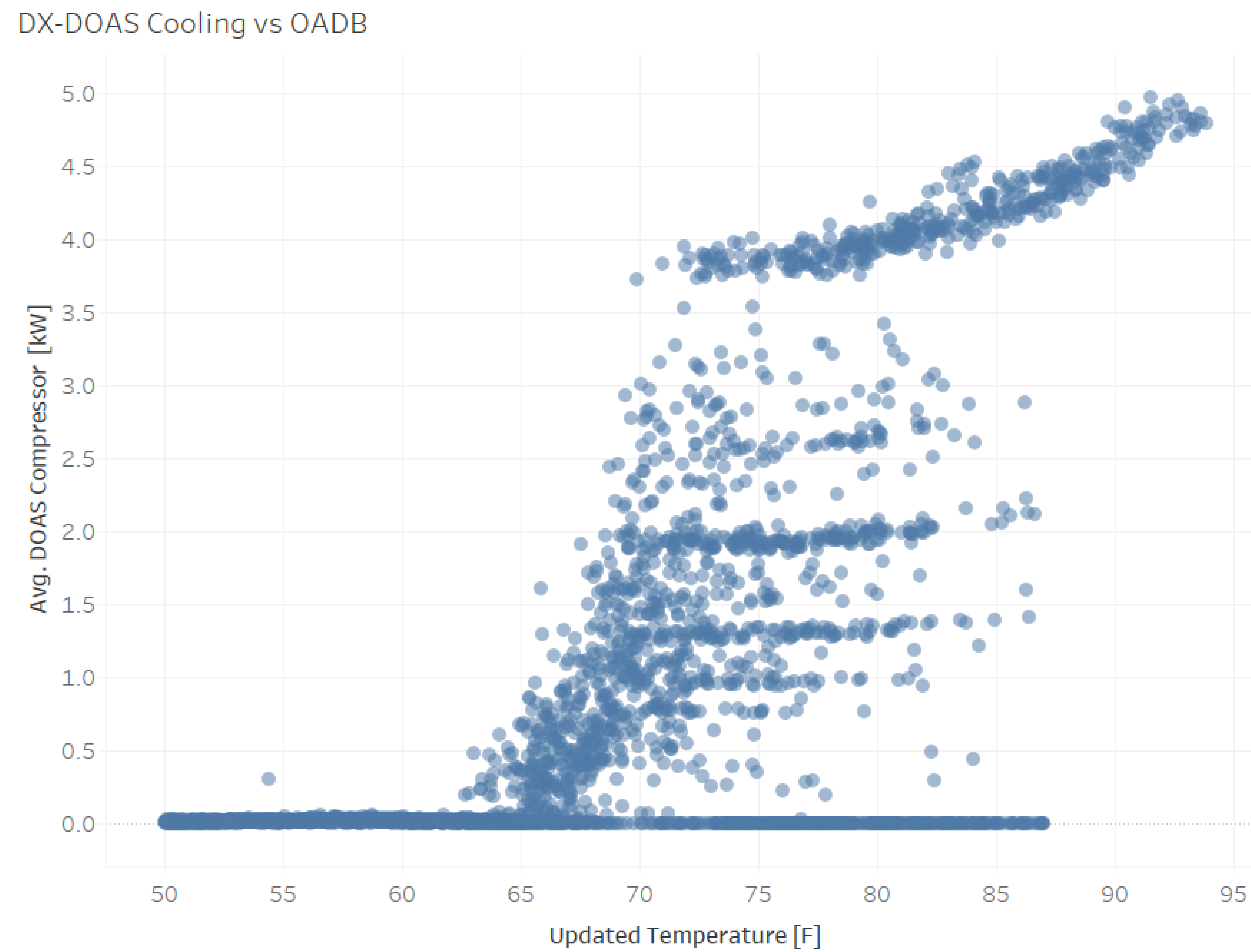


DX-DOAS Cooling Coil Controls

- DX-DOAS cooling systems are intended to be used for dehumidification and moisture control.

- Ensure the model controls the cooling unit as configured. Several units use a simple OA lockout, enabling cooling above a set dry bulb or measurable moisture threshold.

- Recommendation:
  - In Pacific Northwest, with relatively dry-air, limit the DX-DOAS cooling element to times when OADB exceeds 70F.

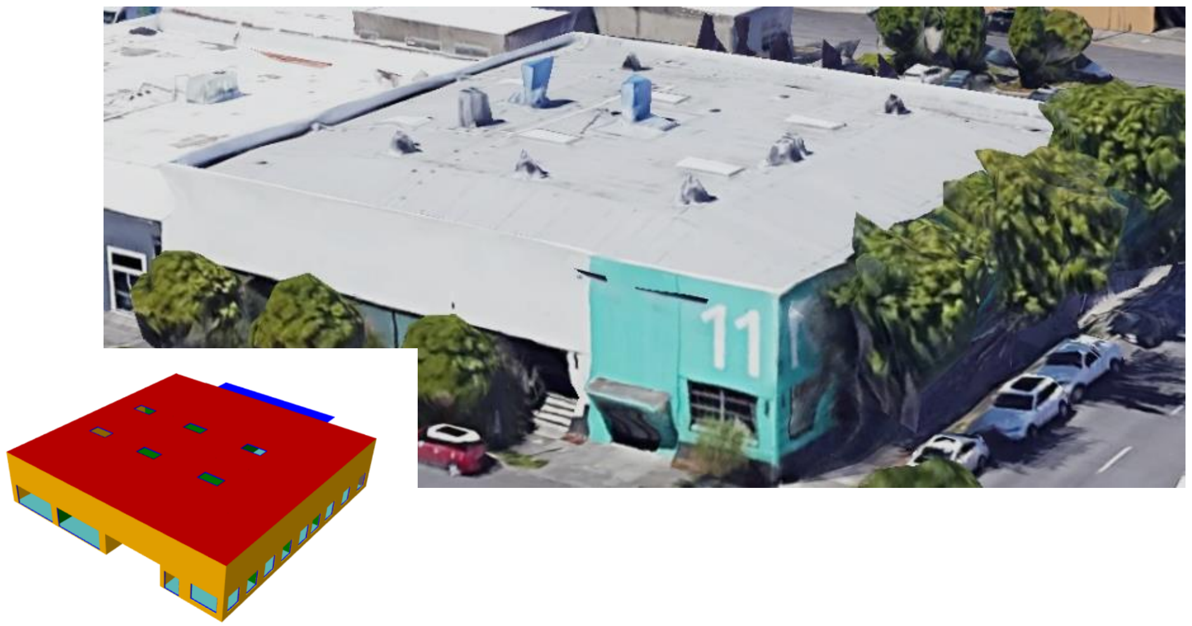


Report includes example Energy Management System (EMS) to only allow the cooling coil in the DOAS to be available

Lessons Learned in Modeling VHE DOAS

Calibrated Energy Model Field Studies

Single Story Existing Office, Portland OR



Multi-Family Housing, WA

Two Story New Office, Portland OR

Elementary School, WA

Building Data and Calibration Process

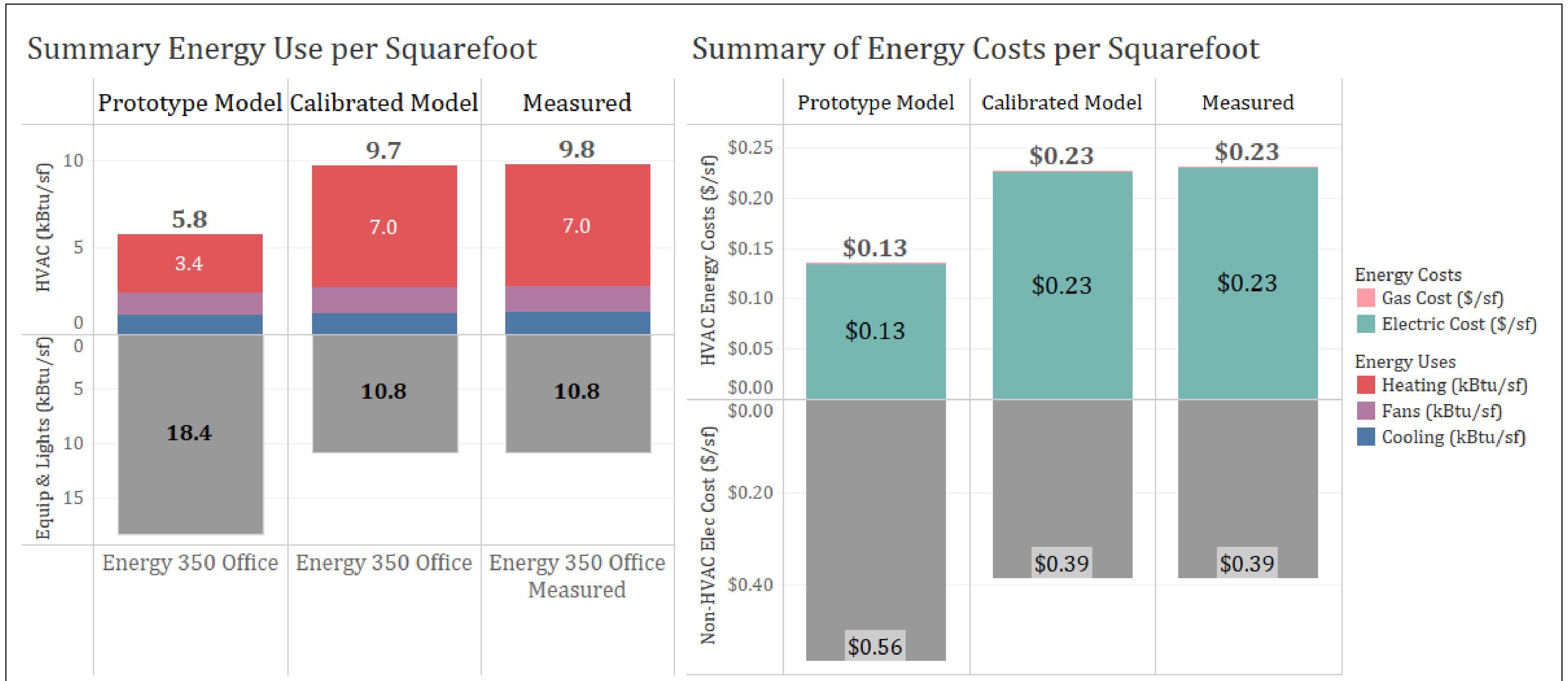
Building Data Available

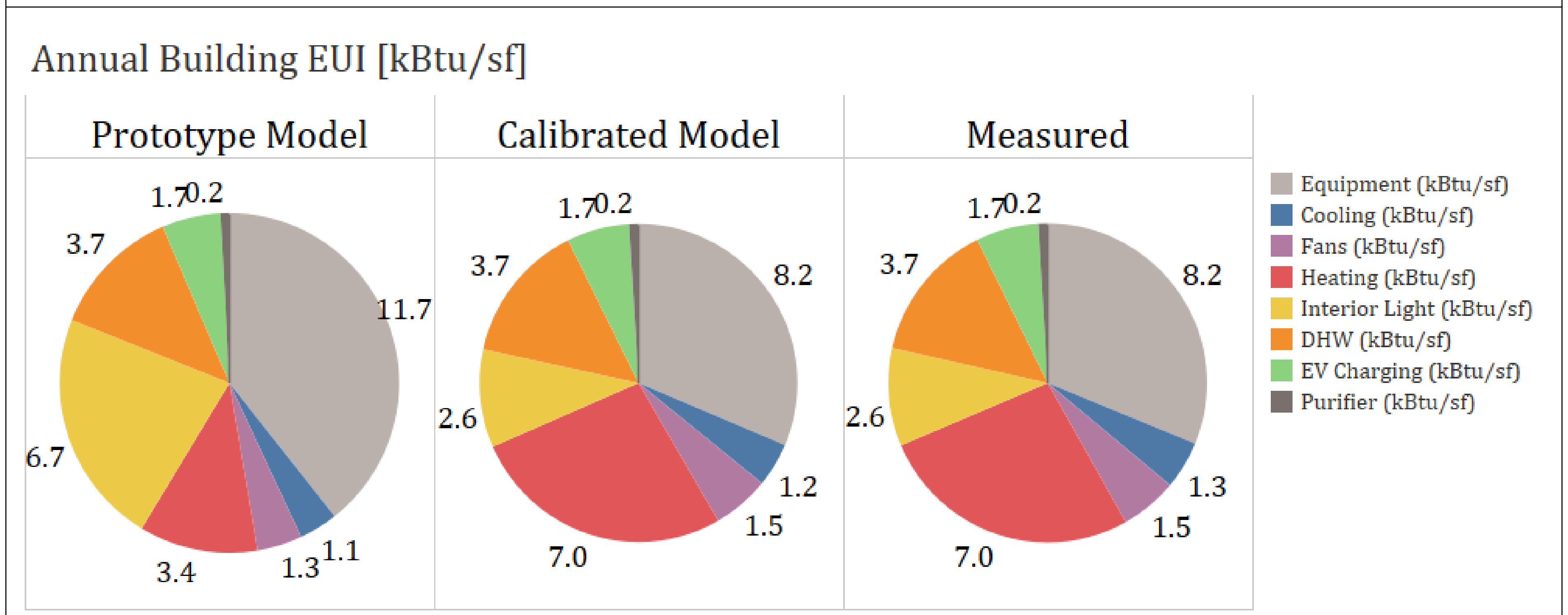
- Calibration of 8 to 10 months of data for two different office buildings
- Calibration of 7 to 15 months of data for multi-family building phases
- Calibration goal: within 5% to 10% of each HVAC end use measured, fans, heating, and cooling
- Data sets obtained:
  - Interval, 15-minute data, on HVAC end uses for power and ventilation temperatures to estimate heat recovery
  - Monthly data for other end uses, equipment, lighting, misc.
  - Outdoor weather at 15-minute data

Calibration Process:

1. Calibrate internal gains based on end-use monthly / annual data
2. Calibrate HVAC run time and thermostats
3. Calibrate operational fan power, DOAS and zone
4. Calibrate HRV effectiveness, bypass control, operational SAT setpoints
5. Calibrate as-built envelope leakage to heating and cooling power use, based on as-designed system efficiencies (COP, EER)
6. Simulated Alternate HVAC System Options

Existing Office Renovation, Portland Oregon





Building Component	Design
Building Floor Area	7,659 sf
Building Stories	2 stories
Window to Wall Ratio	N/S/E/W 28.3% / 27% / 10.2% / 0%
Skylight Area Ratio	2% of roof surface area
Building Structure	Existing half reinforced concrete mass walls. New half, CLT frame with window wall system
Wall Assembly	R-12 overall
Roof Assembly	R-36 overall
Window Assembly	Double pane low-e with AL frame. U-overall/SHGC/T-Vis 0.4 / 0.28 / 50% South 0.28 / 0.27/ 0.63 Other 0.29 / 0.39 / 0.70
Skylight Assembly	Double pane low-e with AL frame. U-overall/SHGC/T-Vis 0.4 / 0.28 / 60%
Foundation	Concrete Slab, Earth
Foundation U-factor	0.032

With calibrated internal gains, HVAC usage increased by 67%, primarily in heating, vs using standard assumptions.

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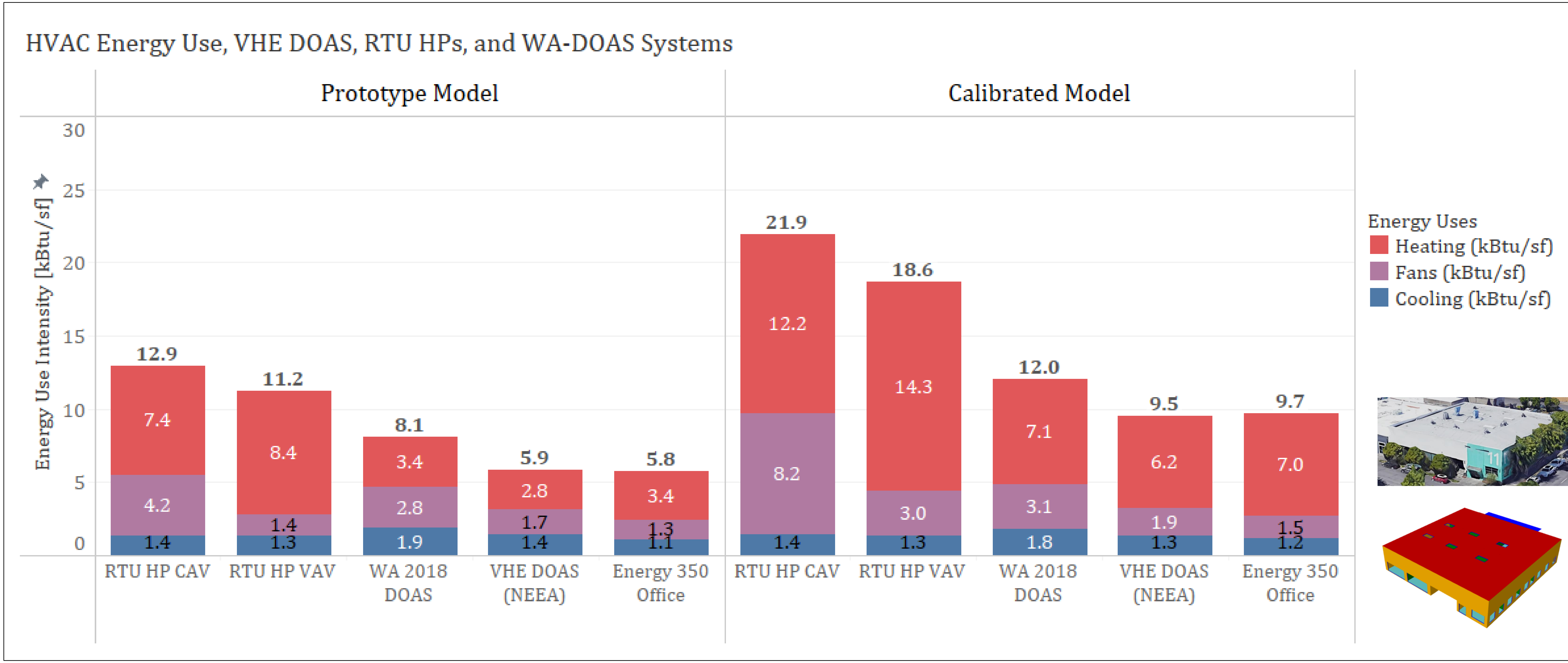
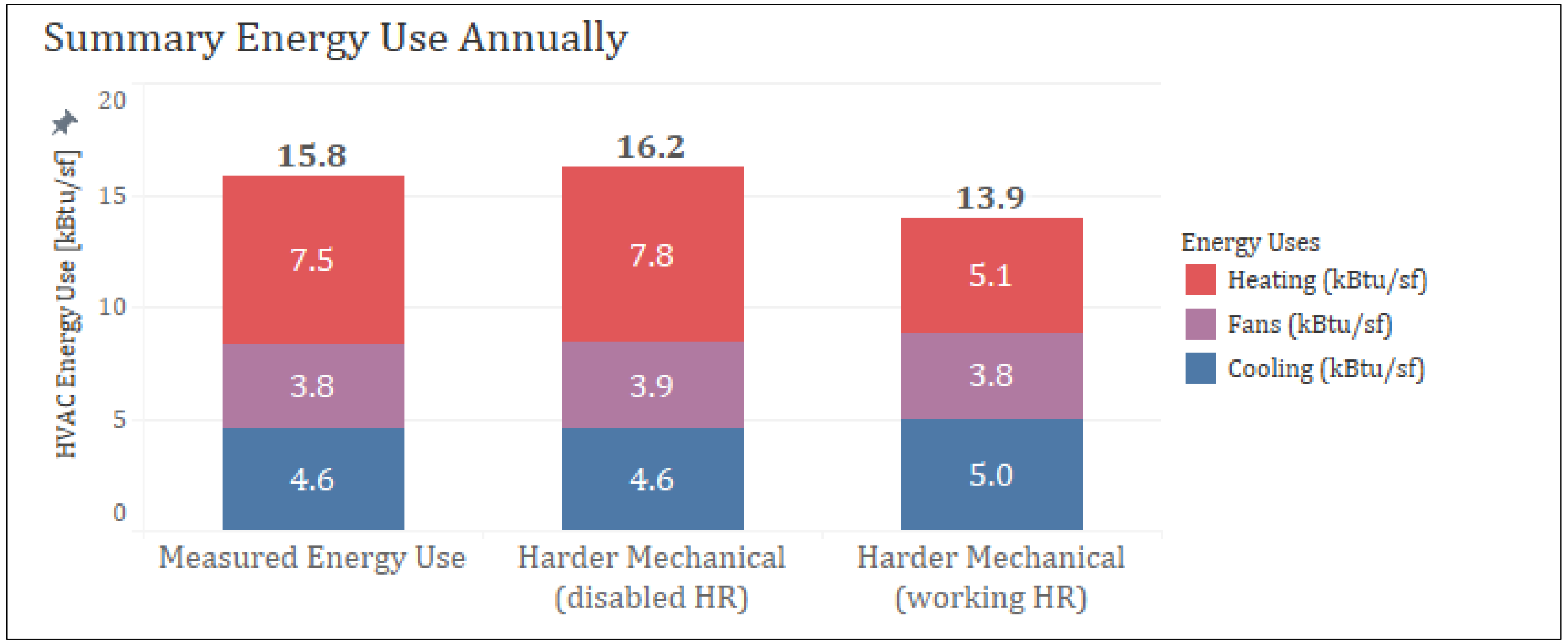
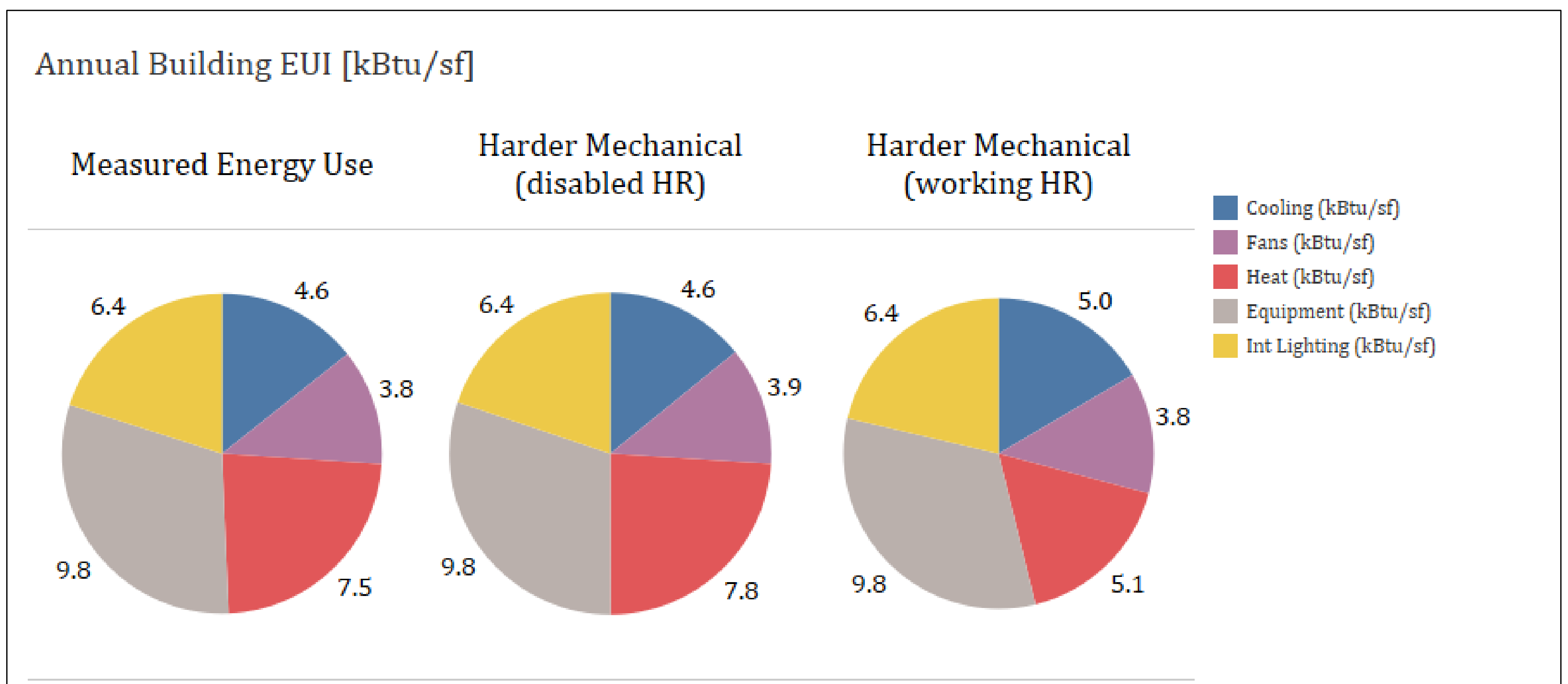
Existing Office Renovation, System- Comparison



- Comparison of HVAC systems with standard system efficiencies, evaluated with two sets of assumptions for internal gains and envelope leakage; Prototype and Calibrated.
- With Calibrated assumptions on gains, heating energy and fan power to move the heat increase in both types of RTU units, CAV and VAV.

New Construction Office, Portland Oregon



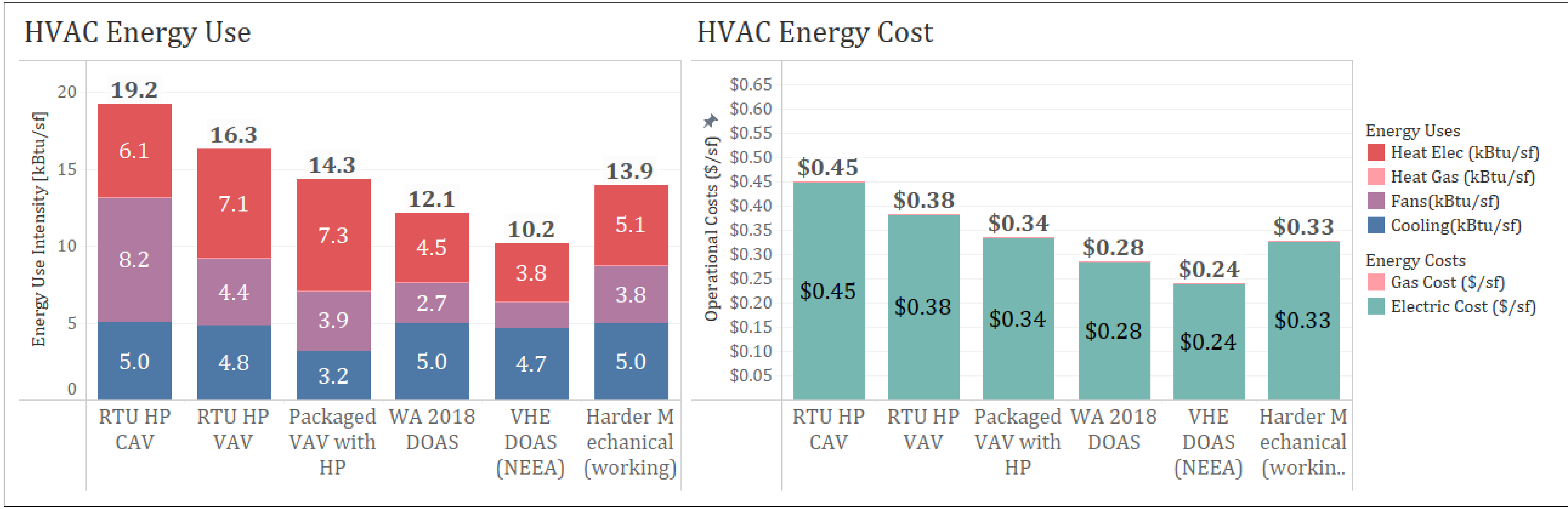


Building Component	Design
Building Floor Area	25,490 sf
Building Stories	2 stories
Window to Wall Ratio	N/S/E/W 36% / 34% / 26% / 32%
Skylight Area Ratio	5% of roof surface area
Building Structure	Metal wall assembly with brick veneer, Insulation on wood framed roof
Wall Assembly	R-12 overall
Roof Assembly	R-25 overall
Window Assembly	Double pane low-e with AL frame. U-COG/SHGC/T-Vis 0.28 / 0.27 / 63%
Skylight Assembly	Double pane low-e with AL frame. U-COG/SHGC/T-Vis 0.28 / 0.27 / 63%
Foundation	Concrete slab, Earth
Foundation U-factor	0.611

Not a full VHE DOAS system configuration:

- Use of coupled fan coils, remaining on when occupied
- DOAS fan power at 1 cfm/watt

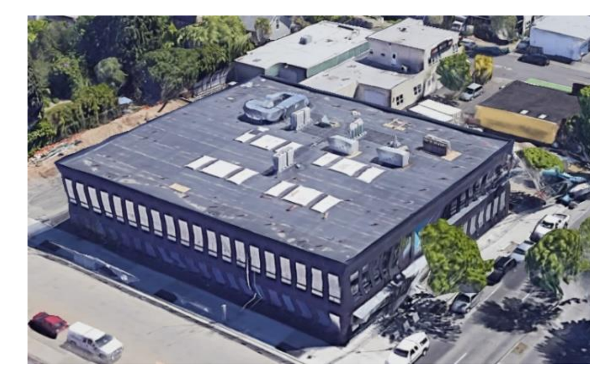
New Construction Office, Portland Oregon

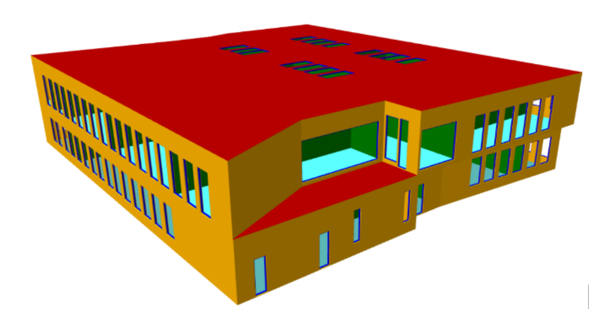


Coupled zone fan coils and a DOAS unit with ventilation fan power at 1 W/cfm.

With a full VHE DOAS configuration:

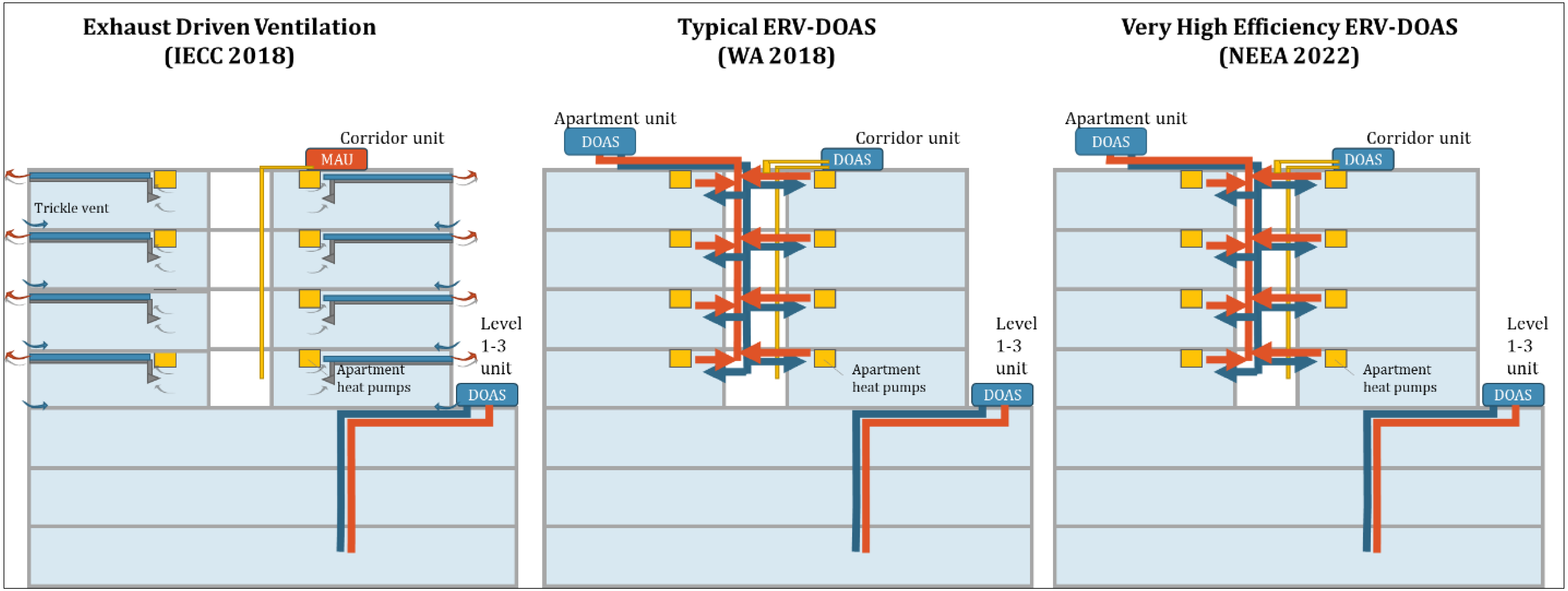
- The fan energy would have been reduced by 65%.
- Total HVAC costs could have been reduced by 27%





REDCAR ANALYTICS

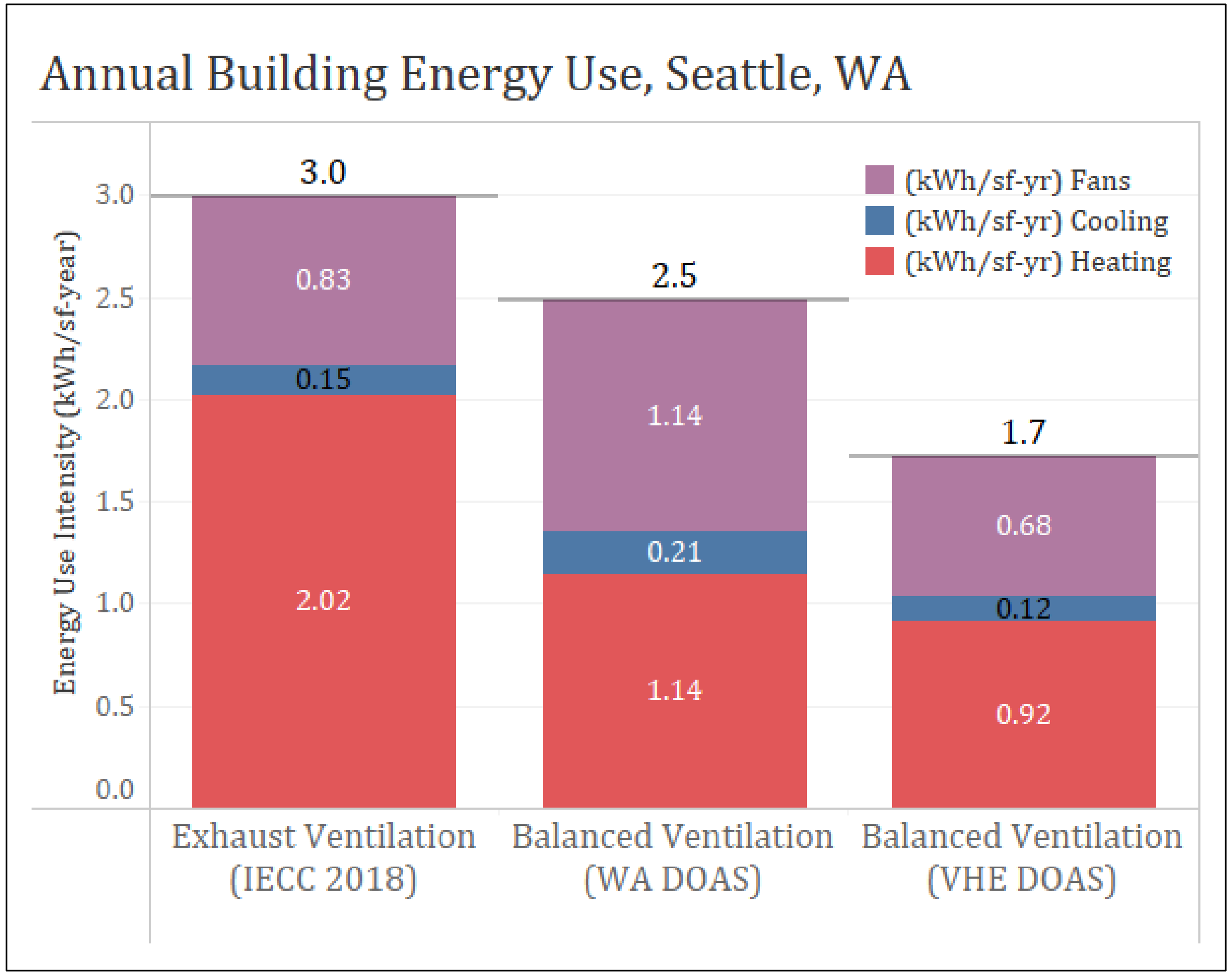
Multi-Family Building, Seattle WA



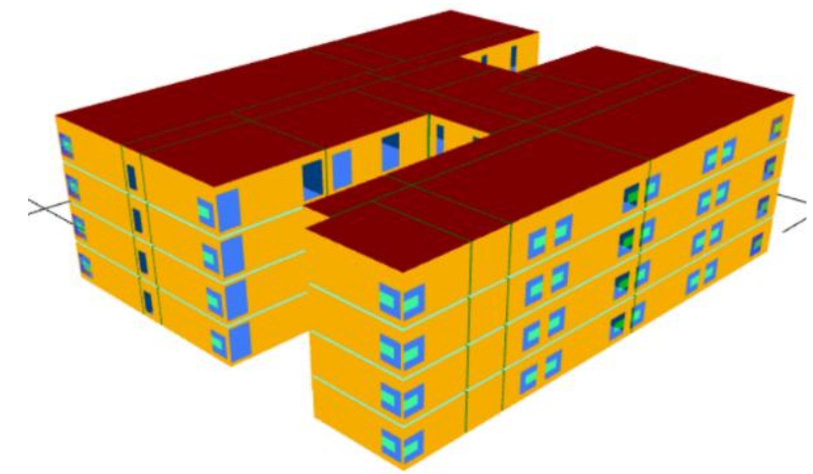
- Calibrated building envelope and internal gains from over 12 months of data on HVAC system trends, fan power, apartment heating.

- Developed a calibrated prototype buliding to then compare different HVAC system options:
  - Full VHE DOAS with apartment heat pumps
  - Exhaust Driven Ventilation with apartment heat pumps
  - WA DOAS with apartment heat pumps

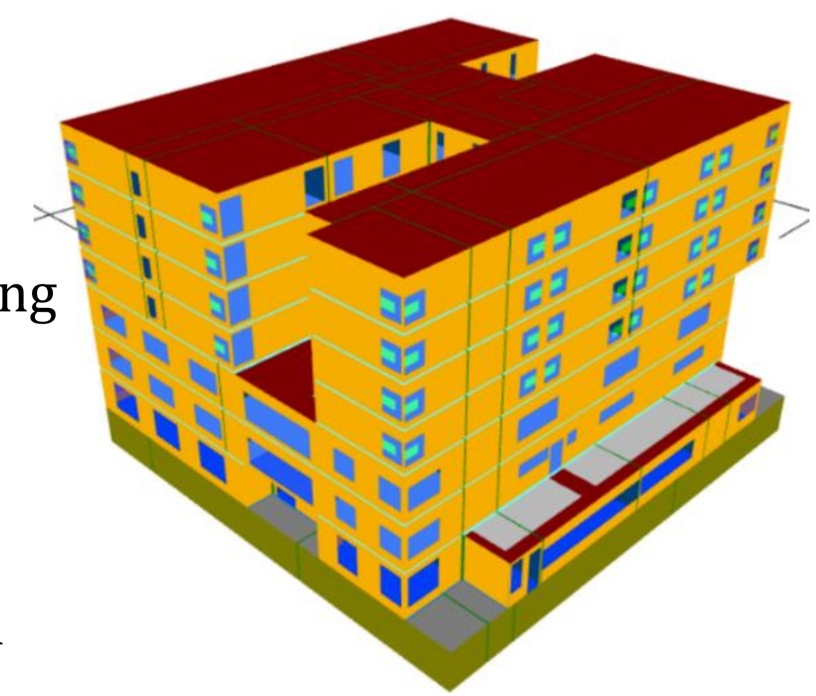
Annual Results of Simulated System Comparison



Apartment Levels-Only Evaluated



Whole Building Model



In multi-family apartments, HVAC can be reduced by 32% with a conventional balanced ventilation system and by 43% with exhaust driven ventilation.

Key Energy Targets for Modelers

These targets can provide an energy modeler with a way to quality-check their work is reasonable for a building type.

From these sites key observations about the energy use of each component can be made based on also knowing how the systems were configured relative to one another and were analyzed to develop general system performance indicators for this report and systems in general.

DOAS Unit Fans

DOAS ventilation fan energy when operating 24/7	3.6 kBtu/sf-year (8,760 hrs/yr).
Under normal hour (approx. 4,500 hrs/yr)	1.2 kBtu/sf-year (67% less energy)
HRV/ERV site energy use (approx. 4,500 hrs/yr)	0.8 kBtu/sf-year (78% less energy)
DX-DOAS +exhaust fan (approx. 4,500 hrs/yr)	1.8 kBtu/sf-year (50% less energy)

Zone Terminal Unit Fans

Coupled Fan Coils	2.8 kBtu/sf-year (4,500 hrs/yr)
Decoupled Fan Coils	0.8 kBtu/sf-year (71% savings)
Coupled Fan Coils + DCV Dampers	1.6 kBtu/sf-year (43% savings).

Cooling Energy in DX-DOAS

DX-DOAS cooling elements were observed to use 0.3 to 0.7 kBtu/sf-year, with the number of warm days being the largest difference between sites for increased energy.

REDCAR ANALYTICS

Key Findings of Calibrated VHE DOAS Process

Typical High Concerns with DOAS

1. DOAS fan energy will be high due to constant volume airflow
2. Cooling energy will be high due to no airside economizing and internal gains

Actual Areas of Concern Identified

1. Zone fans, if configured poorly, can use significant energy from being on all the time
2. Heating energy can be significant. Thermal bridging, old envelopes. High efficiency heat recovered extremely valuable

Typical Low Concerns

3. Zone fans are so small and are modular and likely use little energy
4. Commercial buildings use little heat, so basic heat recovery is good enough

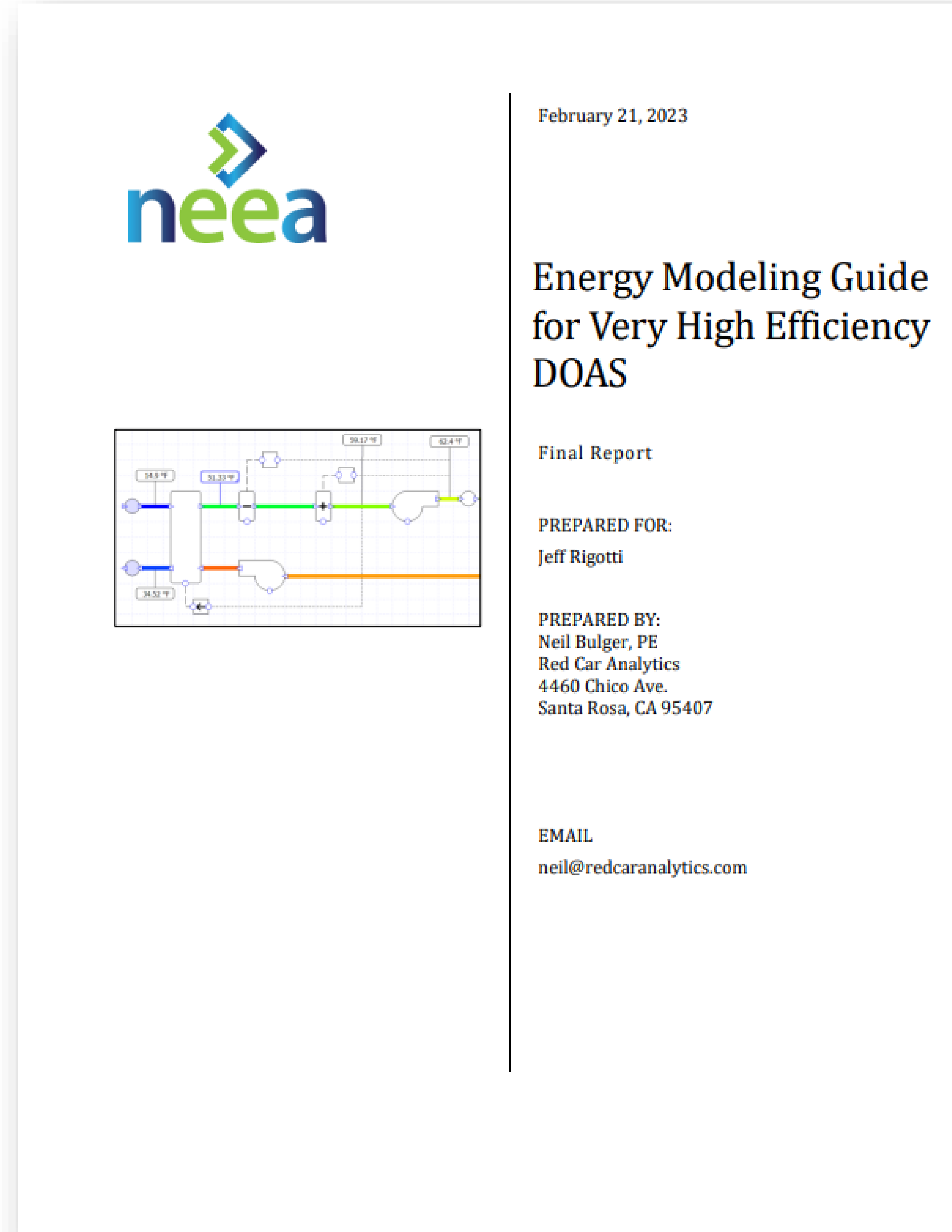
Actual Low Concerns

3. DOAS fans tend to be low pressure, low energy and are over engineered.
4. Cooling energy tends to be far less than predicted (lower actual building use)

Modeling Guide Publication Available Online

•Providing technical analysis support and recommendations using lessons learned and time-tested methods.

•Enhancing energy modelers’ accuracy in predicting energy use and future savings for very high efficiency DOAS in typical commercial building applications.


February 21, 2023

Energy Modeling Guide for Very High Efficiency DOAS

Final Report

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https://betterbricks.com/resources/energy-modeling-guide-for-very-high-efficiency-doas

Thank You & Questions

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