MODELING APPROACHES FOR CALCULATING COST-EFFECTIVENESS OF DEDICATED OUTSIDE AIR SYSTEMS

Experience and Results from a study funded by NEEA

12/11/2019

Made possible by:

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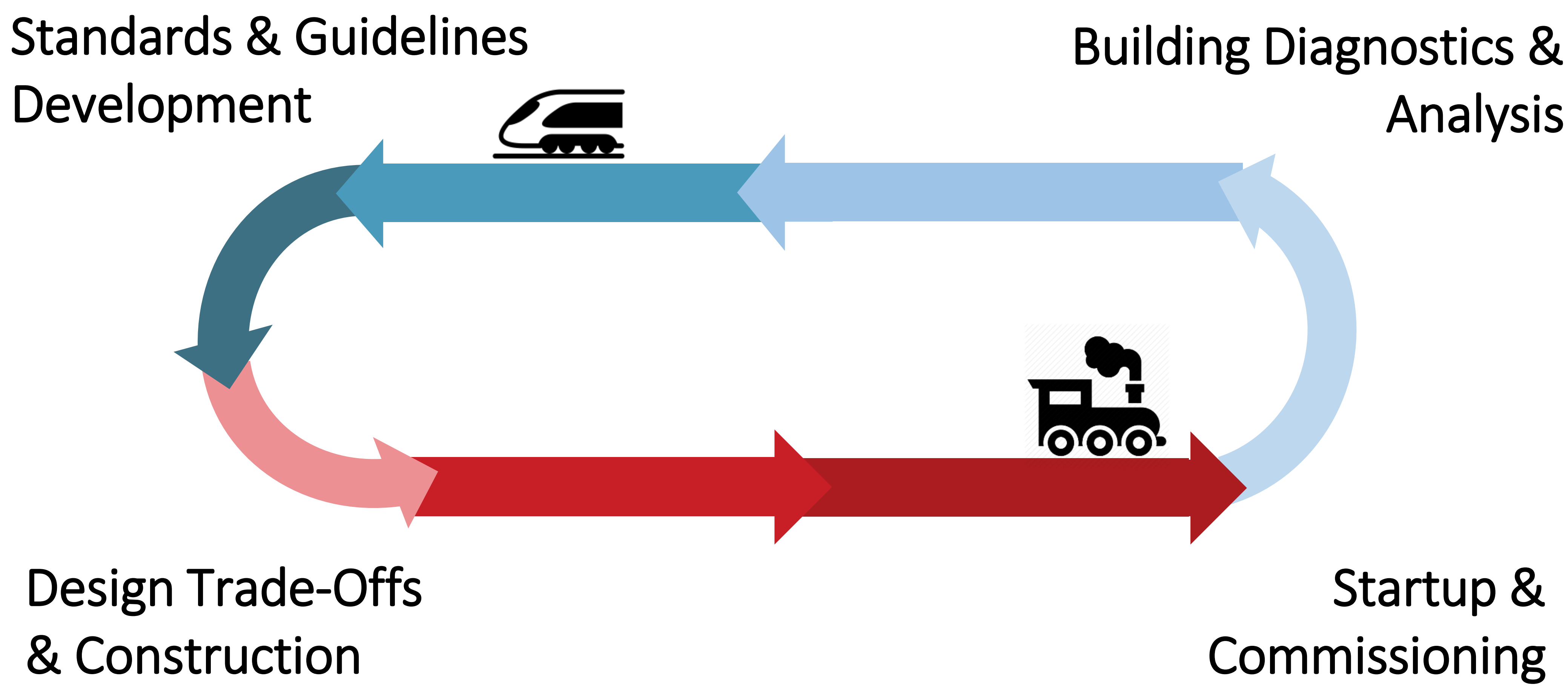
Red Car Analytics

Purpose + Passion + Performance



Agenda for Today

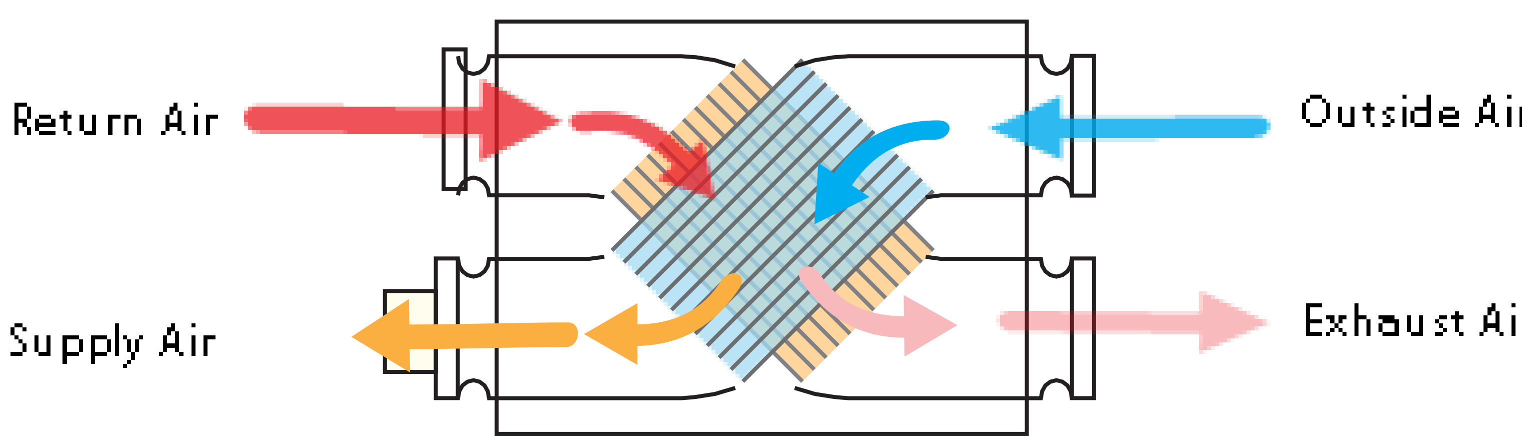
1. Review of DOAS Types
2. Status of DOAS Research Effort, What We Are Analyzing
3. Tools & Approach of Analysis
4. High Level Results
5. Modeling DOAS
    1. *Minimum Criteria*
    2. *Best Practices*
    3. *Advanced Configurations*

Types of Dedicated Outside Air Systems

Ventilation Only

Heat Recovery Ventilation

Energy Recovery Ventilation

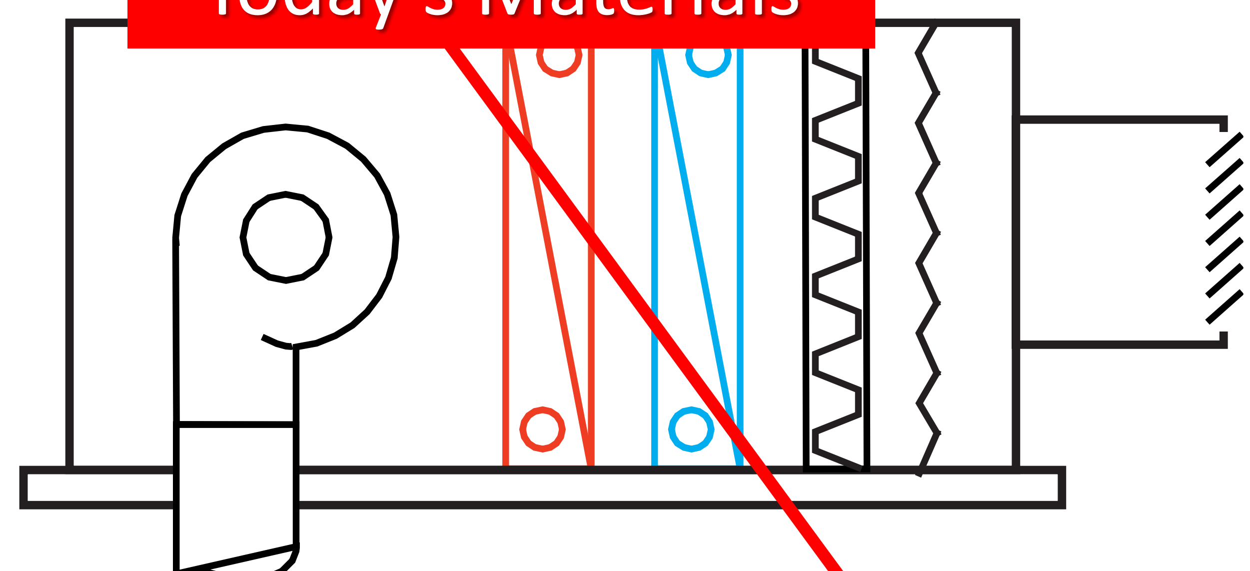


Ventilation with Active Conditioning

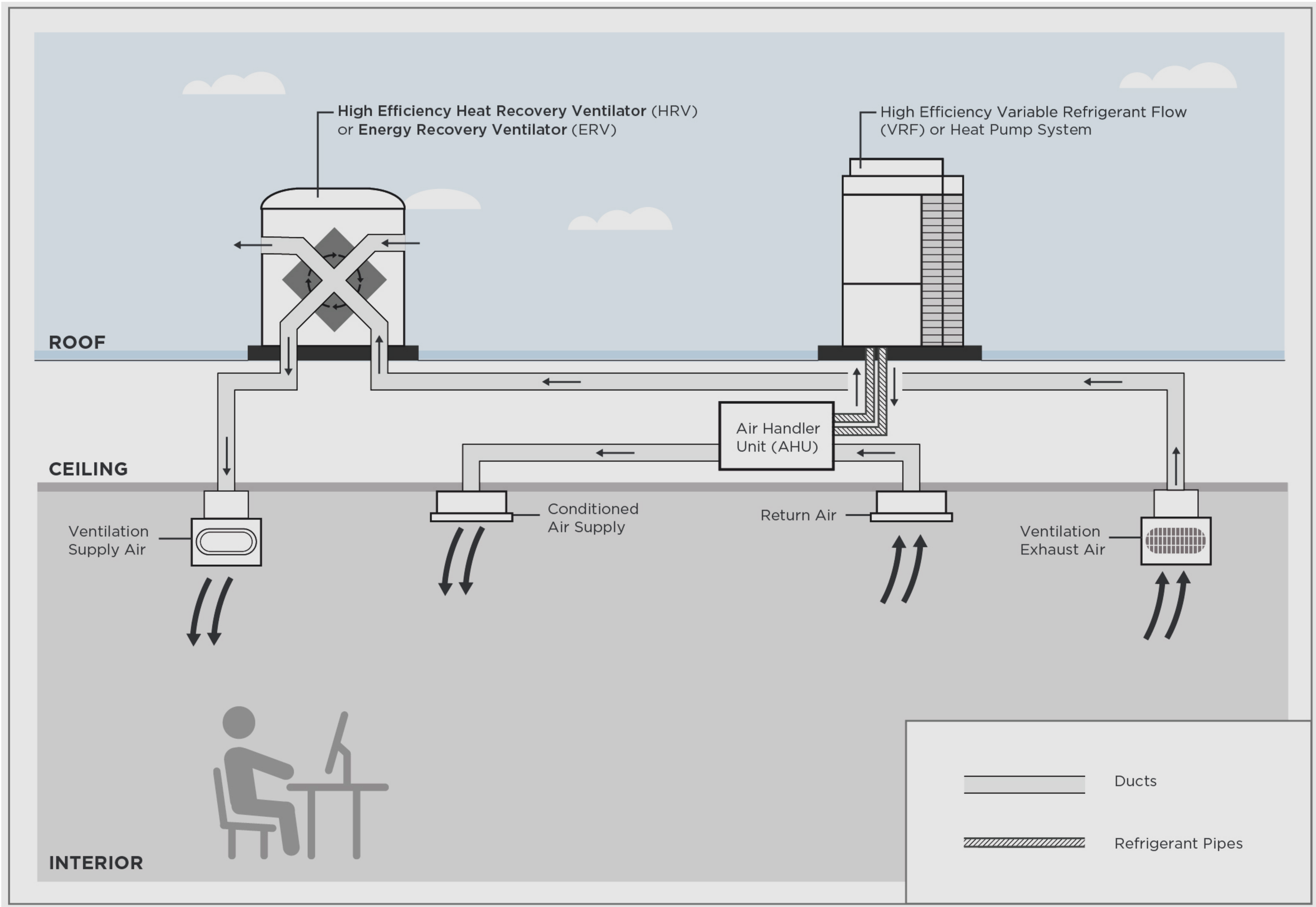
DX DOAS

Custom DOAS

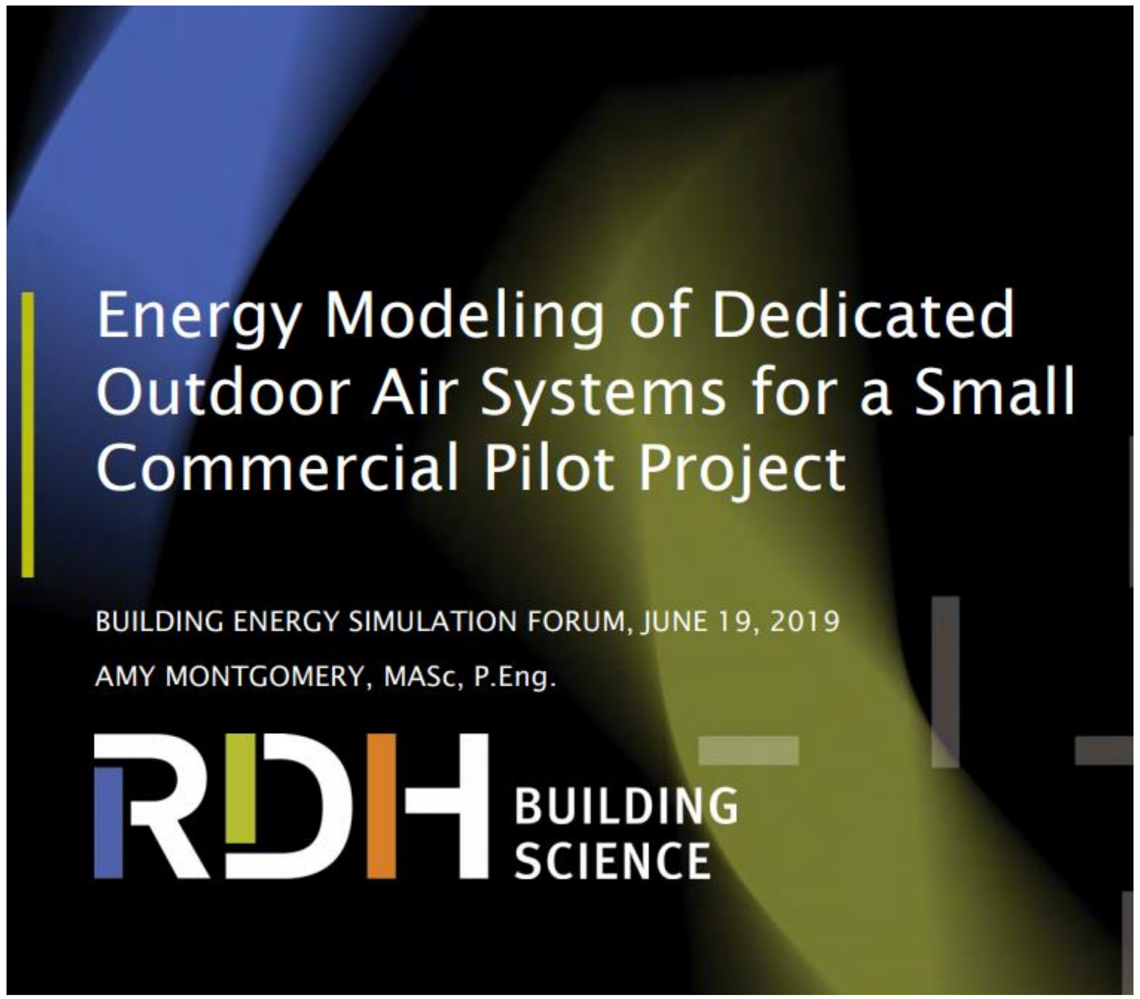
Not Included in Today's Materials



Dedicated Outside Air Systems Efficiency



DOAS Energy Analysis Reports



Economic Analysis of Heat Recovery Equipment in Commercial Dedicated Outside Air Systems

Three System Configurations

- Code Efficiency
- Mid Tier Efficiency
- Very High Efficiency

05/12/2019

REDCAR ANALYTICS

Dedicated Outside Air Capacity Analysis

Updated Economic Analysis
Updated Efficiency Analysis

Very High Efficiency

Pending end 2019

REDCAR ANALYTICS

1. https://www.energytrust.org/wp-content/uploads/2019/06/BESF_Presentation_190619.pdf
2. https://betterbricks.com/solutions/hvac/dedicated-outside-air-system-doas

neea

Economic Analysis of DOAS Tiers

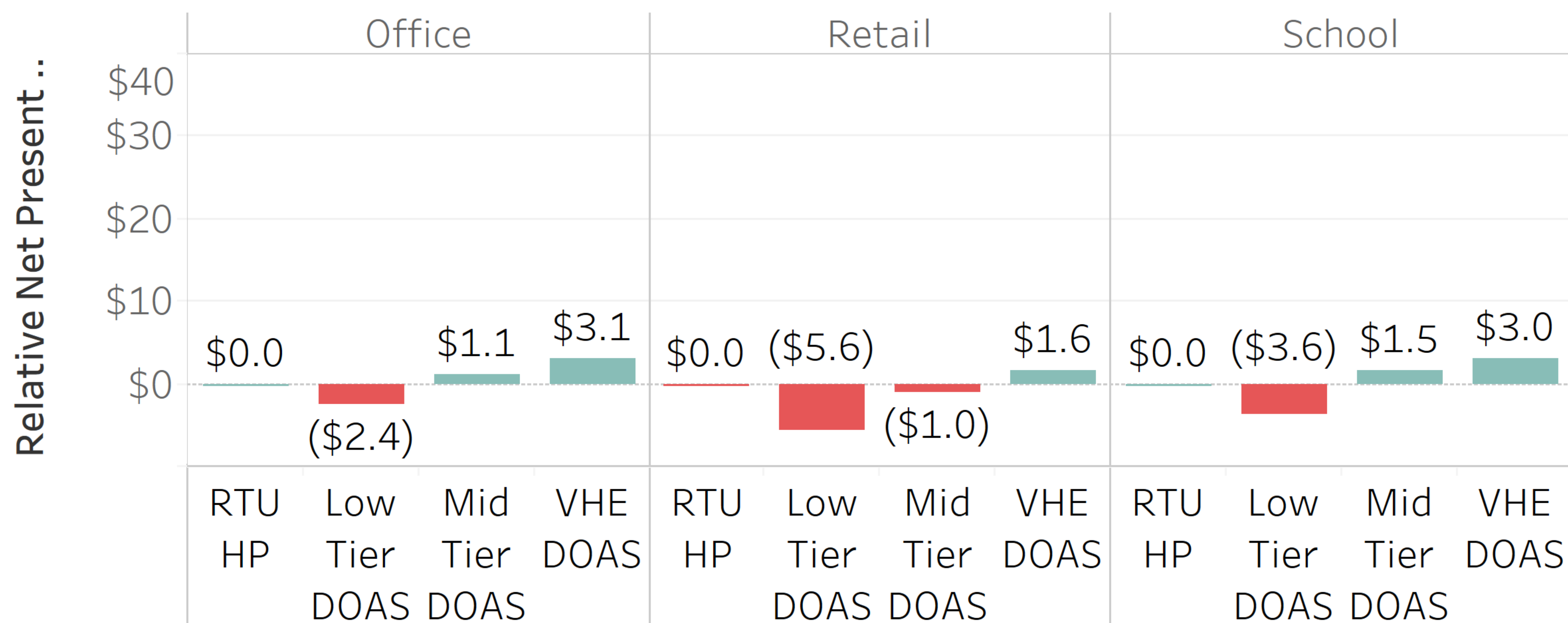
RTU Heat Pump	Low Tier DOAS With VRF	Mid Tier DOAS With VRF	VHE Tier DOAS With VRF
			
Heat Recovery Effectiveness			
n/a	**50%**	**70%**	**83%**
Efficient Fans			
Code Minimum	Code Minimum	✓	✓✓
Advanced Ventilation Controls			
Code Minimum	Code Minimum	✓✓	✓✓✓
System Right Sizing			
n/a	n/a	✓	✓

Economic Analysis of DOAS Tiers

Annual Energy Savings Relative to the RTU HP System

Climate	Office			Retail			School		
	Low Tier DOAS	Mid Tier DOAS	VHE DOAS	Low Tier DOAS	Mid Tier DOAS	VHE DOAS	Low Tier DOAS	Mid Tier DOAS	VHE DOAS
(CZ4c) Mixed Marine	22%	24%	31%	17%	22%	27%	24%	26%	30%
(CZ5b) Cool Dry	25%	27%	33%	18%	23%	28%	27%	29%	33%
(CZ6b) Cold Dry	27%	31%	36%	19%	24%	30%	32%	34%	39%

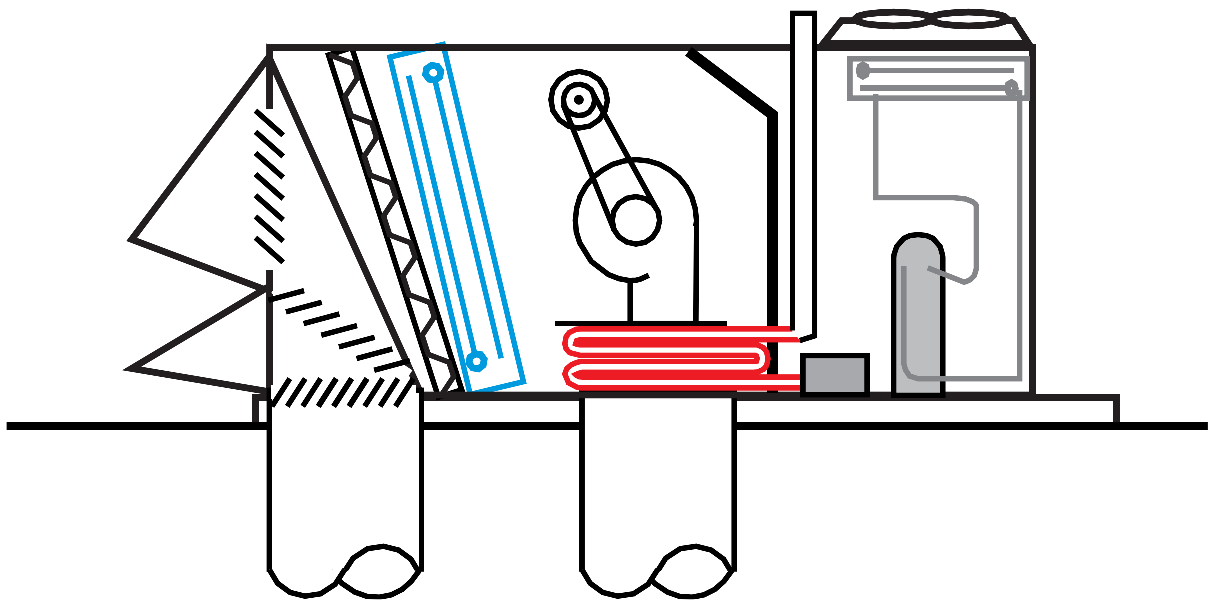
Relative Net Present Value ($/sf), 20 Yr -(CZ4c) Mixed Marine



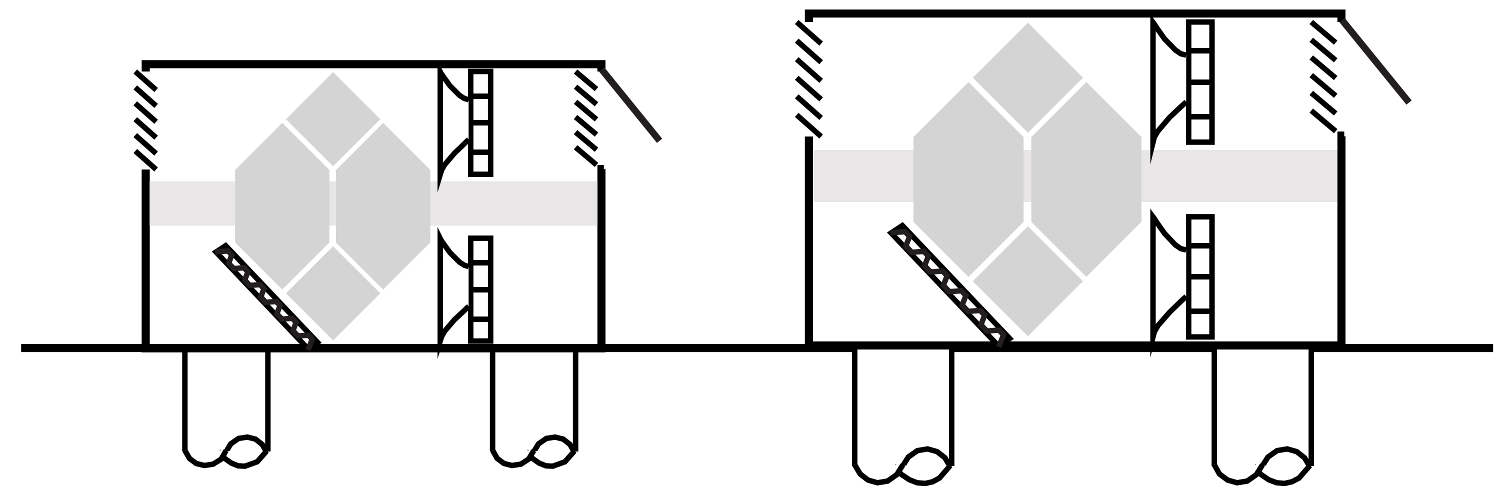
REDCAR ANALYTICS

Dedicated Outside Air Capacity Analysis

Roof Top Unit



Dedicated Outside Air
(Heat Recovery Ventilator)



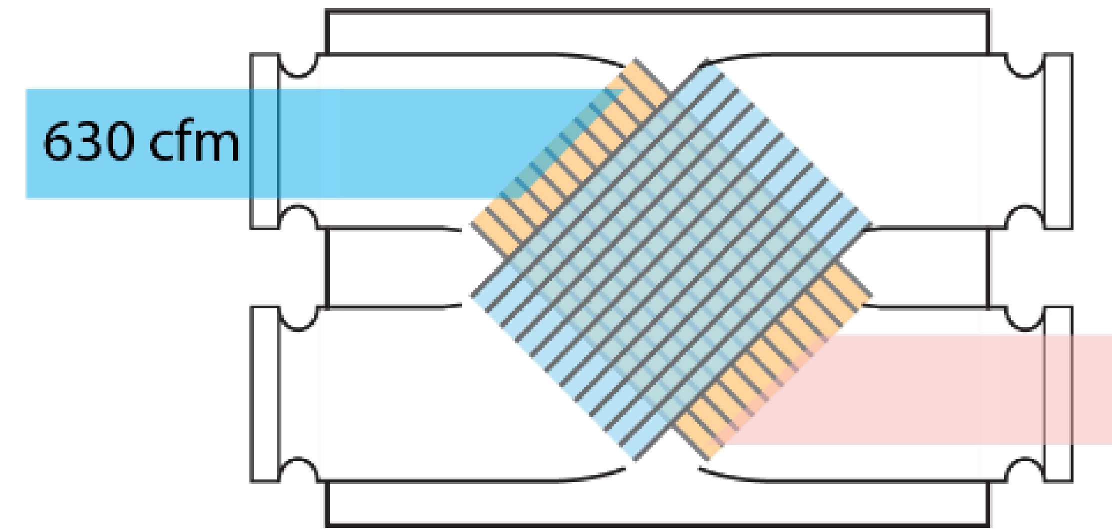
What is the energy use sensitivity to sizing a VHE DOAS system if sized for 50% nominal capacity compared with a system sized for 100% nominal capacity?

1. In depth efficiency performance criteria for VHE DOAS.
2. Revised bottom up, cost model by component for HVAC systems.
3. Revised efficiency criteria for Low Tier, Mid Tier for comparison.

Modeling Systems at 50% Capacity

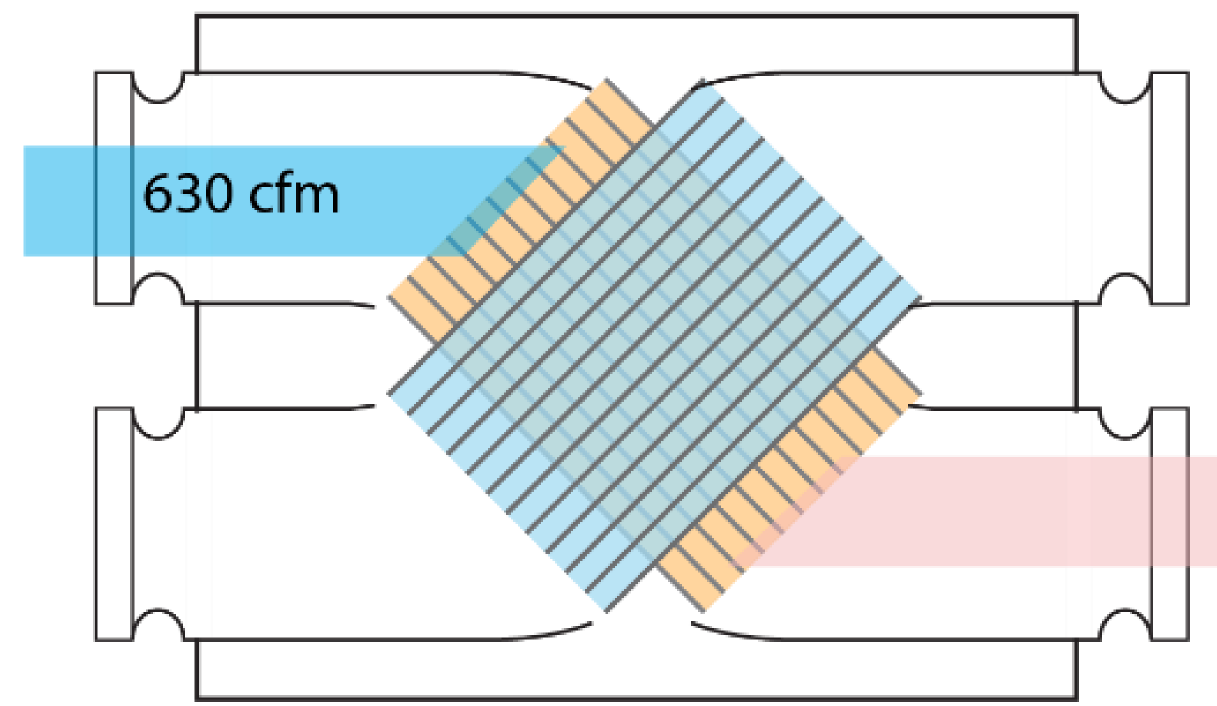
- Heat Recovery Ventilator Selected at half the rated capacity of a product.
- Overall system provides the same airflow for a project.

100% Capacity



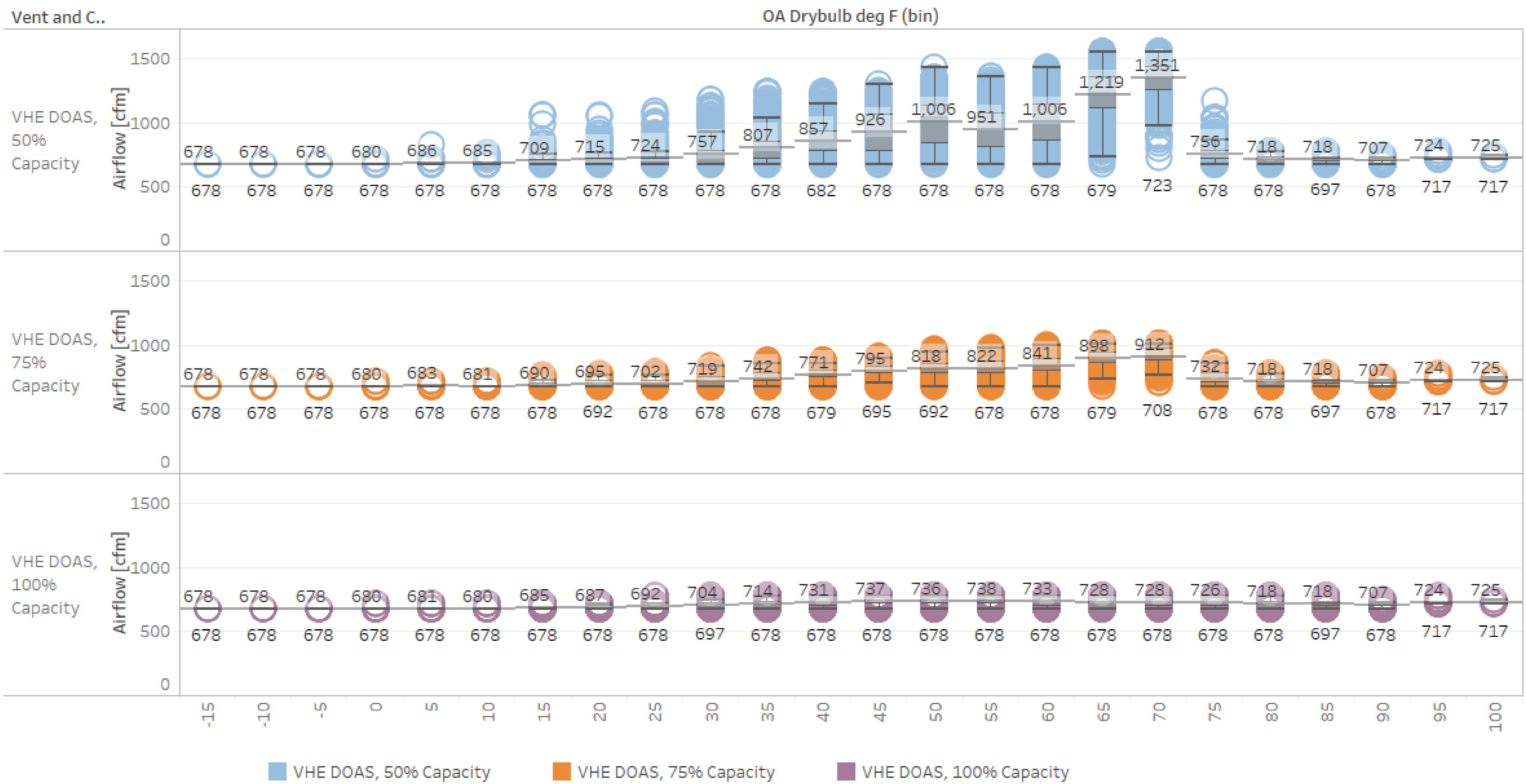
- Benefits:
  1. Provides future flexibility & growth.
  2. Can downsize HVAC on larger buildings from increased HRV effectiveness.
  3. Increased energy efficiency:
     - Reduced fan static pressure
     - Increased heat recovery effectiveness
     - Reduced air velocity reduces noise

50% Capacity



Detailed Results of VHE DOAS Airflow

Airflow by Outside Air Bin

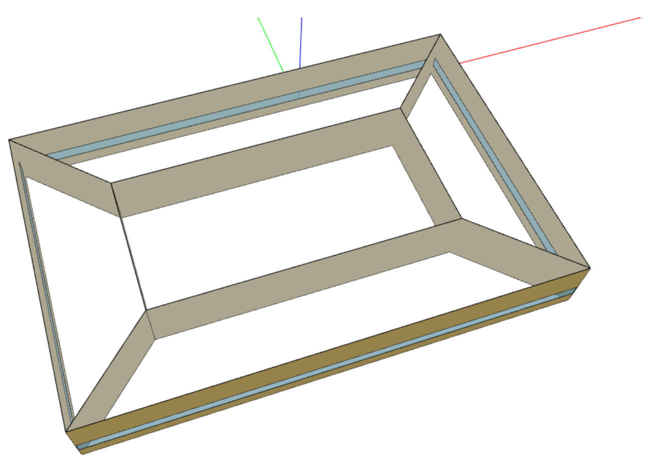


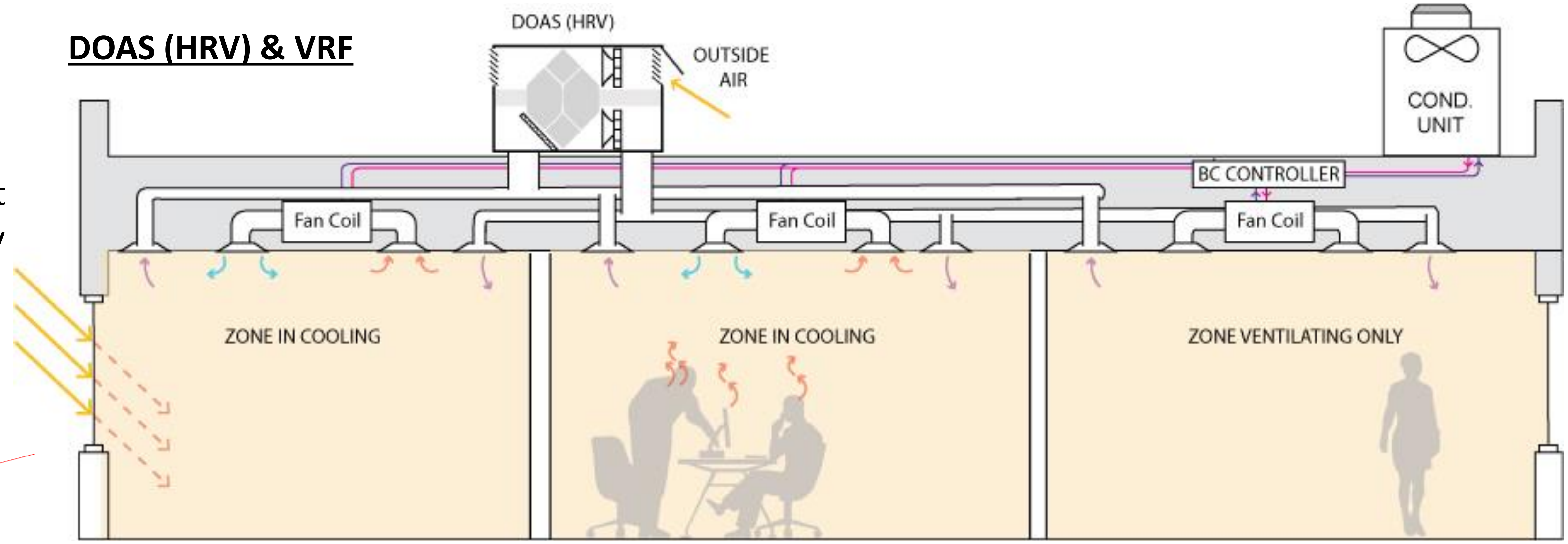
Tools & Approach

HVAC Configurations

DOAS (HRV) & VRF

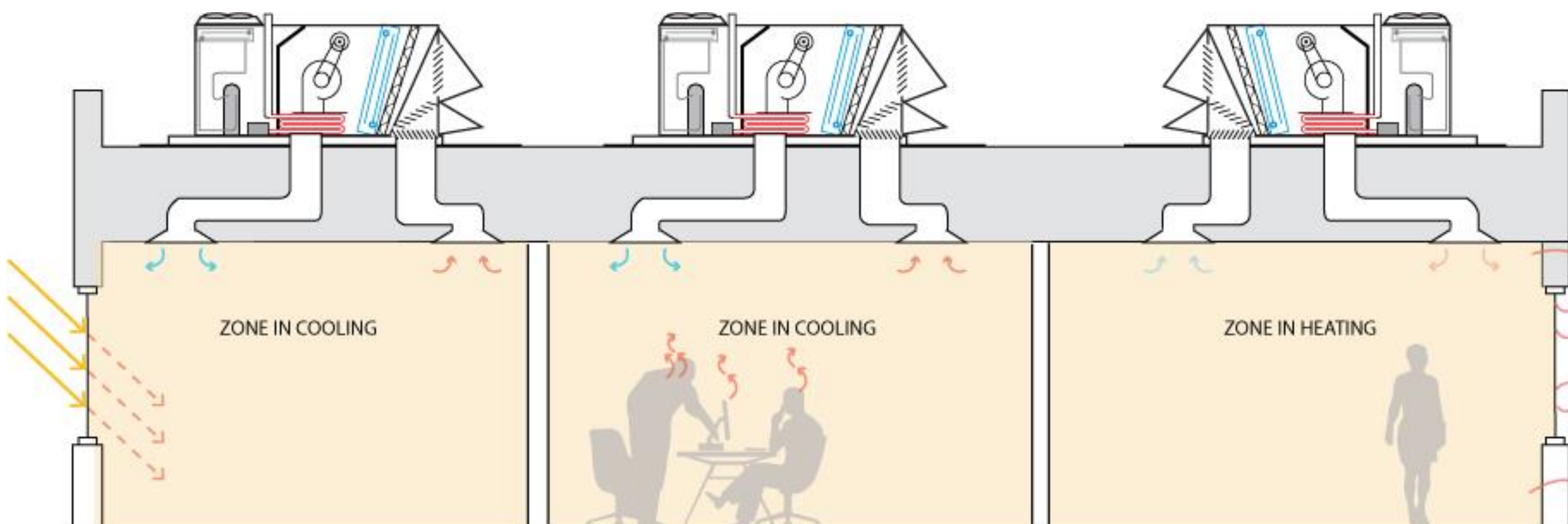
- 5 Zone Models
- Individual Zone T-Stat
- VRF, no heat recovery
- HRV, sensible only
- OA electric freeze control





Rooftop Units (Heat Pumps)

- RTU CV Fans
- Heat Pump Heating



Economic Analysis Report 1

- Small Office, School, Retail Building (DOE)
- Climate Zones 4C, 5B, 6B
- Cities: Portland OR, Boise ID, Helena MT
- Pre-1980s constructions
- RTU Heat Pumps (all elec)
- HRV Efficiency Tiers

- OpenStudio for HVAC Configurations
- EnergyPlus for Detailed Inputs

OpenStudio 2.7

EnergyPlus 9.1

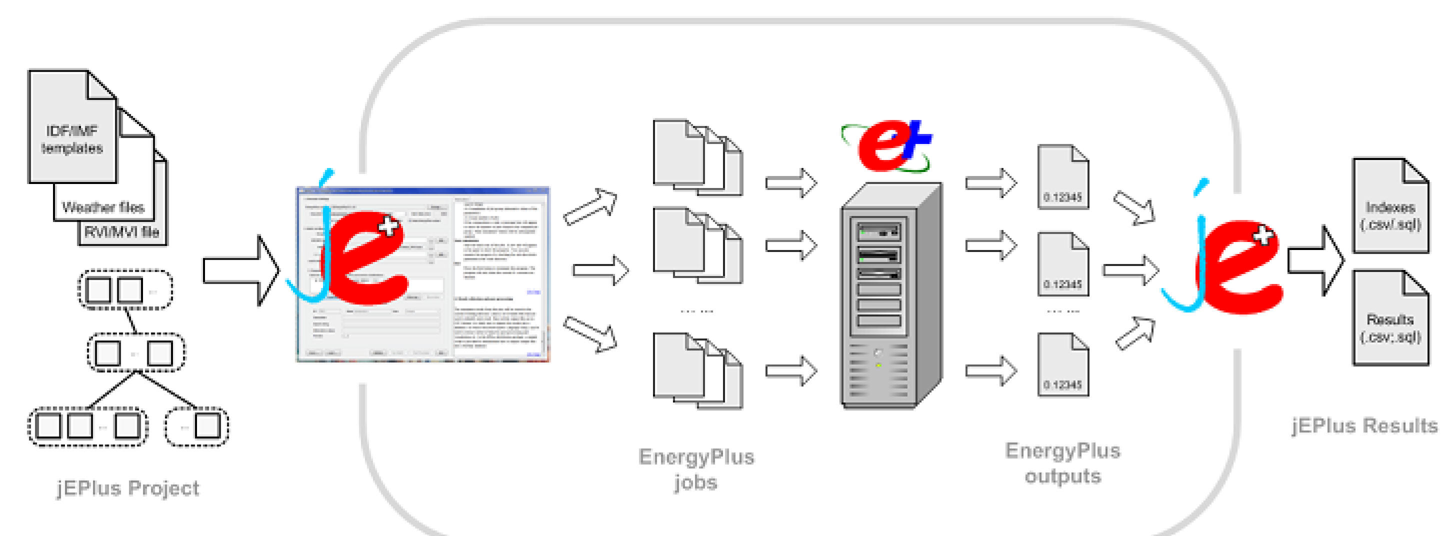
DOAS Capacity Analysis Report 2

- Small Office Building (DOE)
- Climate Zones 4C, 5B, 6B
- Cities: Portland OR, Boise ID, Helena MT
- Pre-1980s & ASHRAE 90.1 2013 constructions
- RTU Heat Pumps (all elec)
- HRV Advanced Control

- OpenStudio for HVAC Configurations
- EnergyPlus for Detailed Inputs
- JEPlus for Parametric Analysis

OpenStudio 2.7

EnergyPlus 9.1



JEPlus 2.7

Efficiency Inputs and Assumptions

1. Equipment Cut Sheets for Engineering Performance
   HRV effectiveness
   Fan power per airflow

2. Code Minimum Efficiencies for HVAC
   RTU EER, COP (heat pump)
   VRF COP

3. Physics & Engineering Calculations & Assumptions
   Component Based TSP for Systems
   Heat Recovery Effectiveness at capacity ratios

REDCAR ANALYTICS

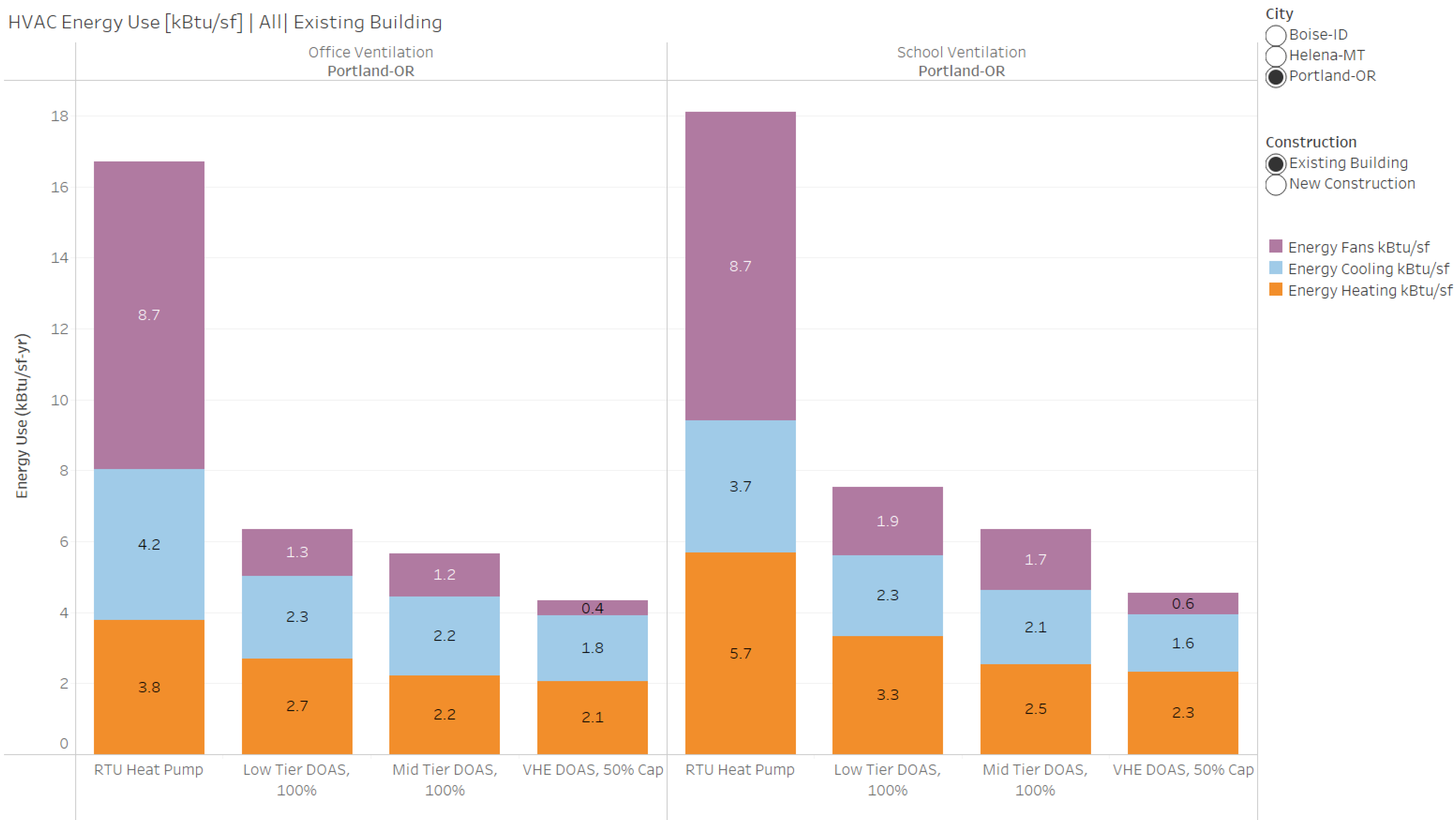
Economic Analysis Modeling

- Sourced information from:
  - Projects with itemized HVAC
  - Interviews with PNW General Contractors
  - Cost estimates of components from Equipment Reps / Manufactures

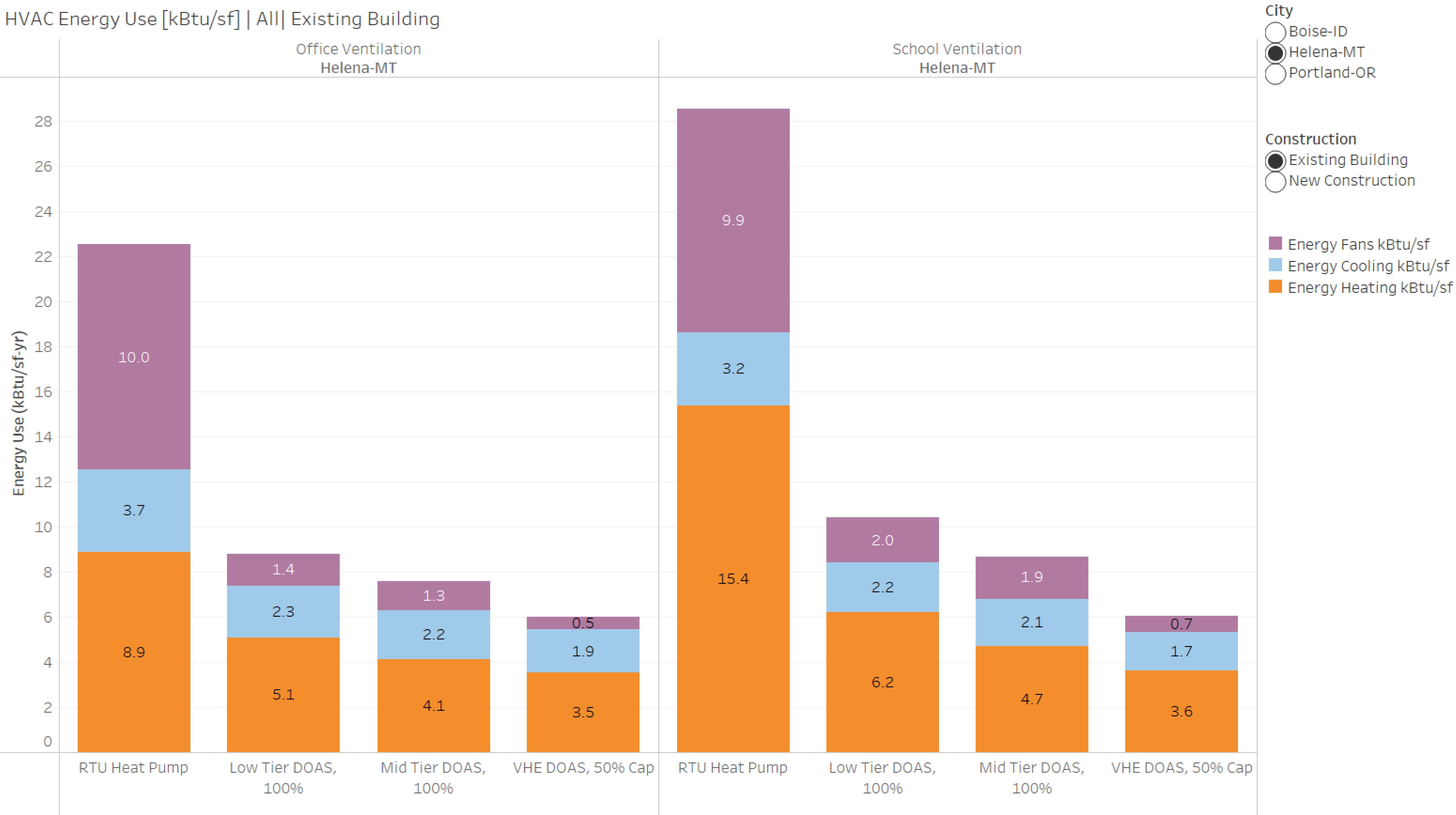
- Normalized Data to Unit Costs and Building Floor Area.
- Sized Equipment needs based on climate, peak demand, and building area of prototype models.
- Flat $0.10/kWh and a 3% energy escalation rate.

Results from Capacity Study

Portland Energy Results (Draft in progress)



Helena Montana Energy Results (draft in progress)



Modeling DOAS

Energy Modeling, Levels of Detail

OpenStudio 2.7

EnergyPlus 9.1

01

MINIMUM CRITERIA
Basic Energy Modeling Components

02

BEST PRACTICE
DOAS (HRV) Efficient Controls

03

ADVANCED CONFIGURATIONS
DOAS (HRV) Custom Controls

Layers to Energy Modeling HVAC

Air Systems

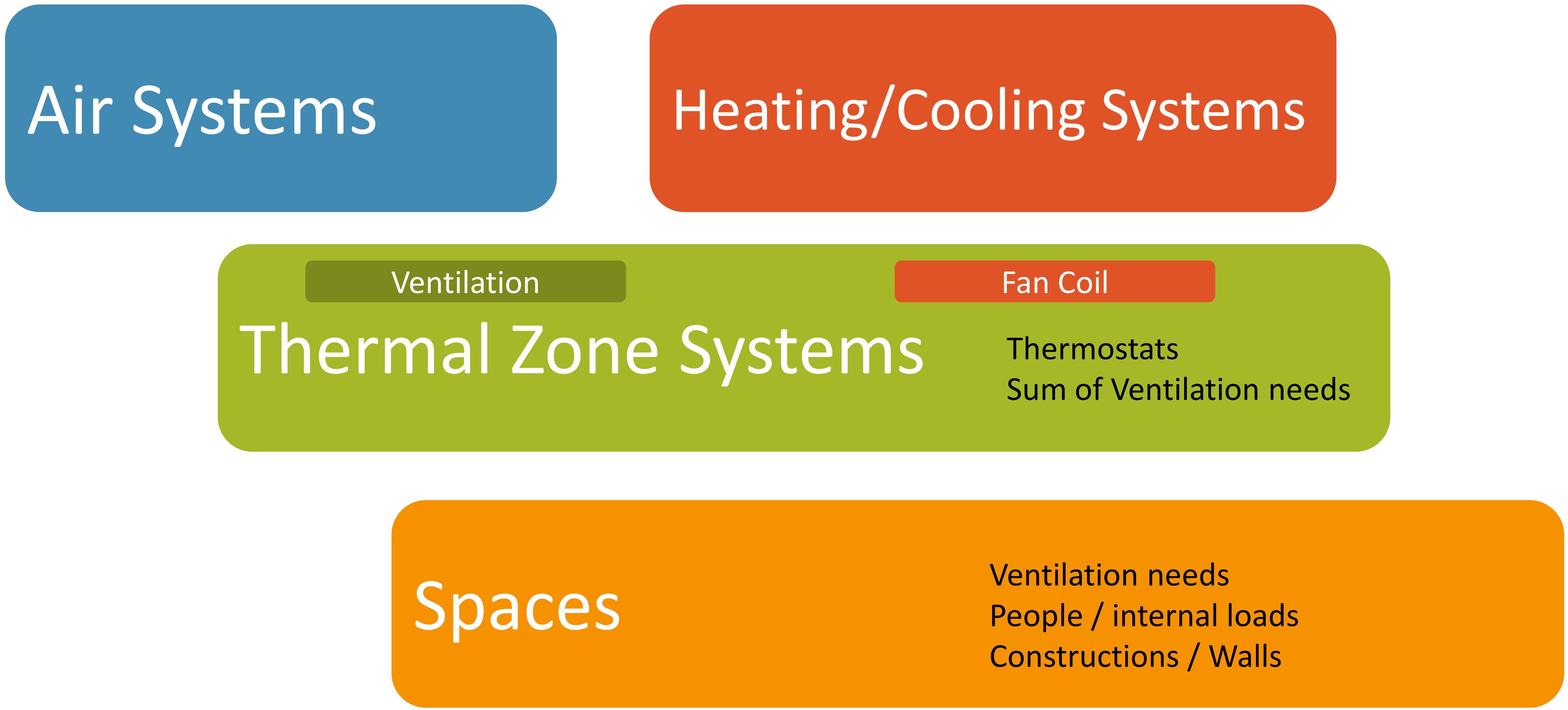
Thermal Zone Systems

Thermostats
Sum of Ventilation needs

Spaces

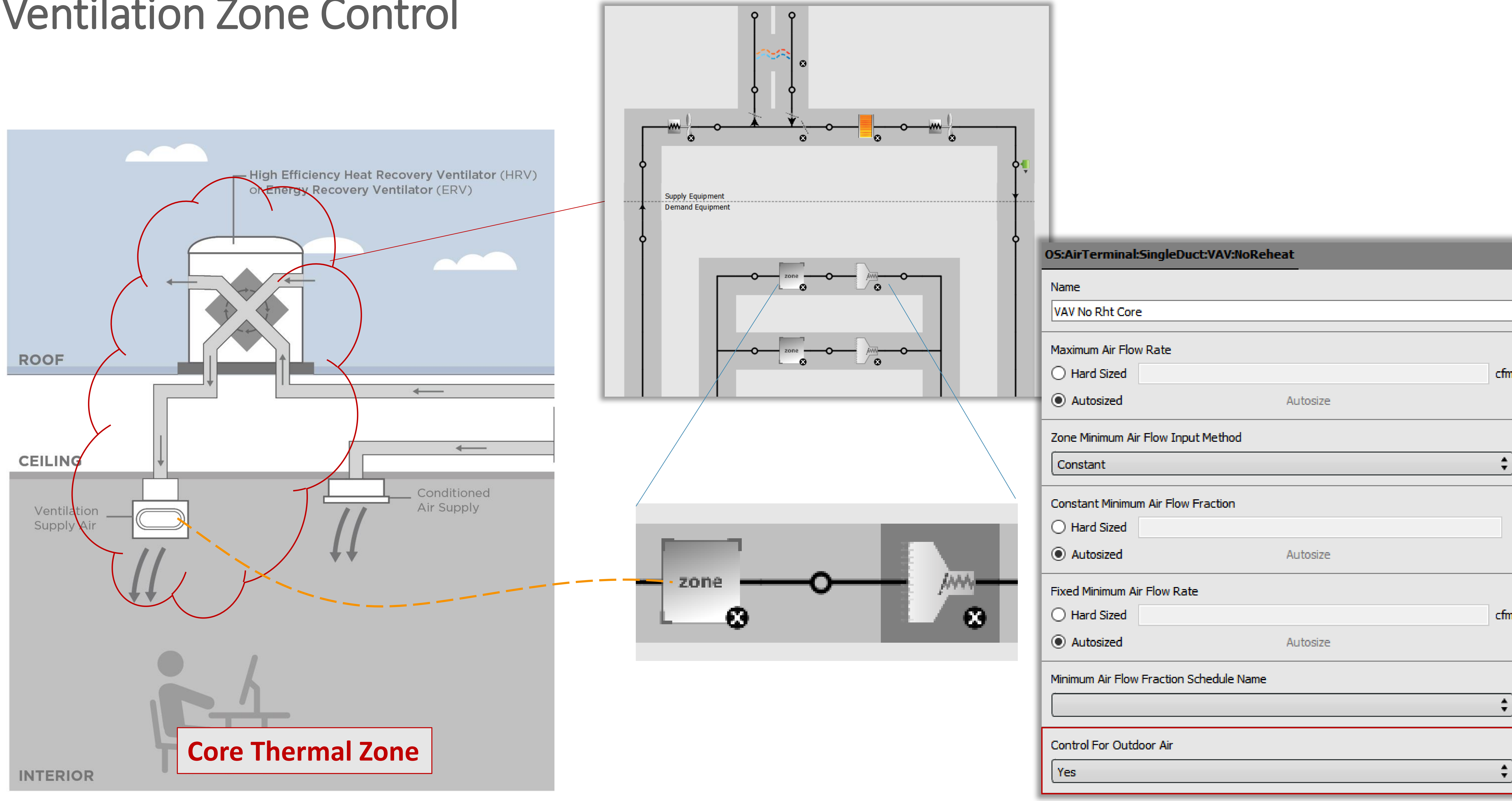
Ventilation needs
People / internal loads
Constructions / Walls

Layers to Energy Modeling HVAC, DOAS



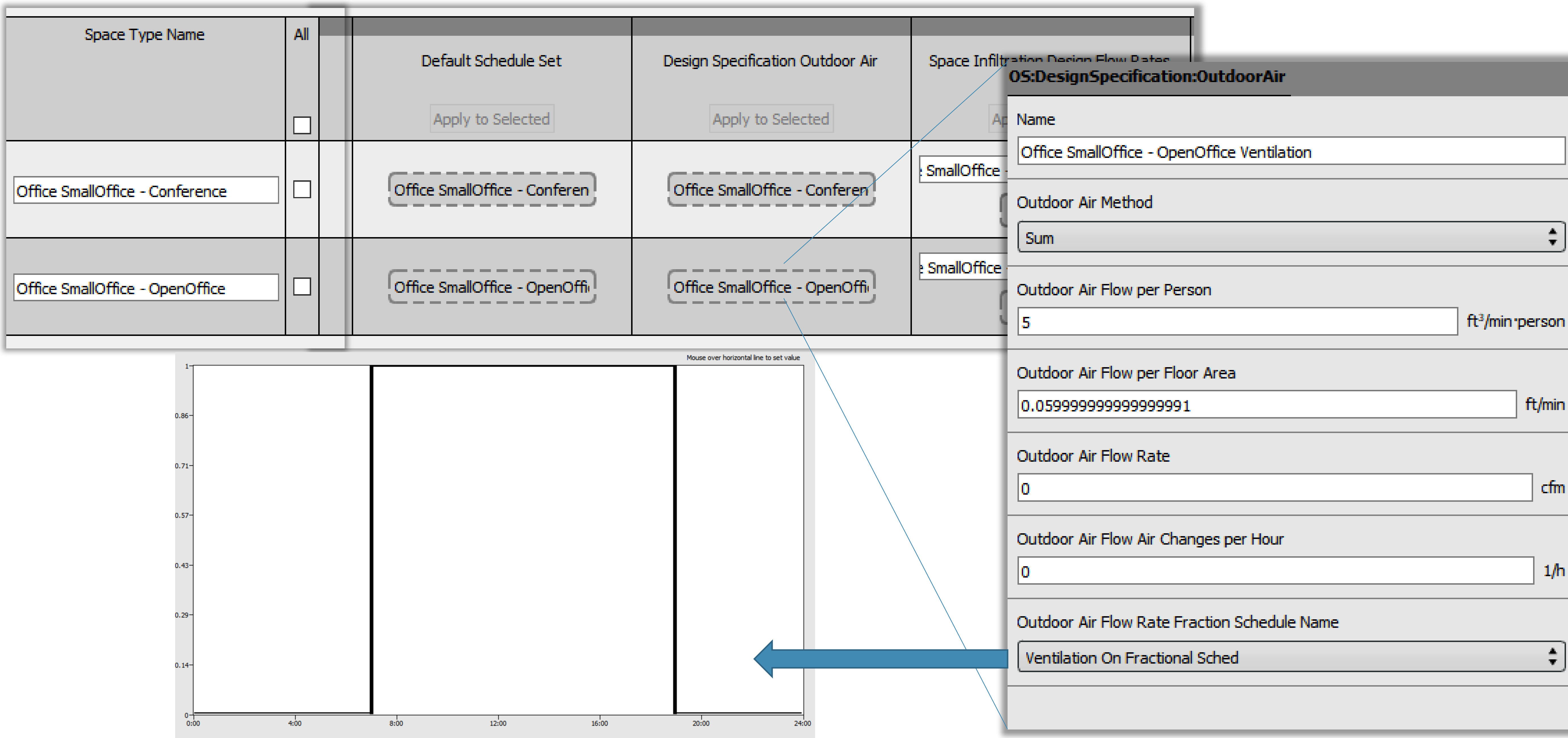
Ventilation Zone Control

HVAC Ventilation System (DOAS)



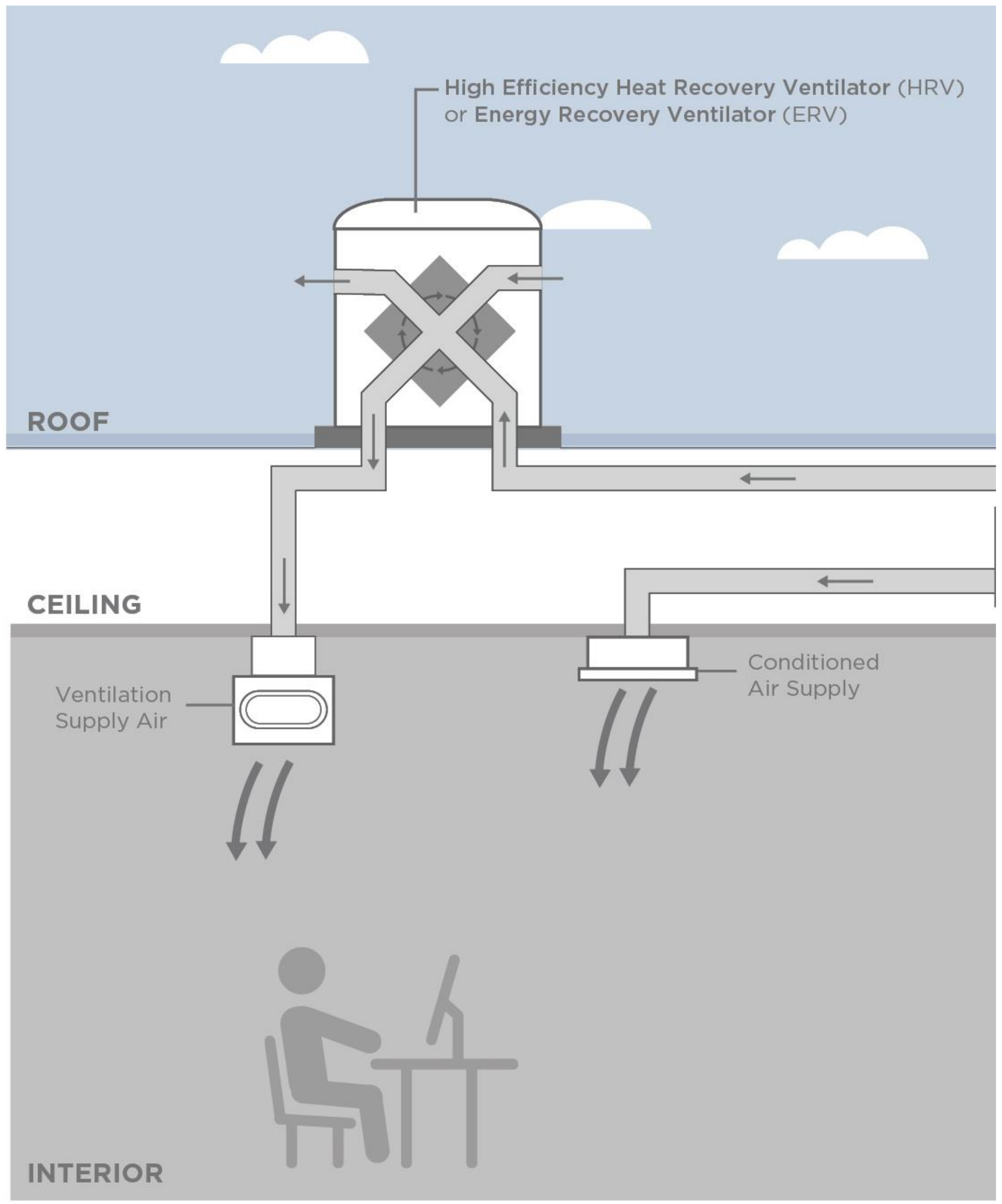
- Recommended to use VAV zone object even if constant volume.
- Specify ‘Control For Outdoor Air’ on the VAV box object.
- Assign a constant ventilation schedule to the space (see next slide).

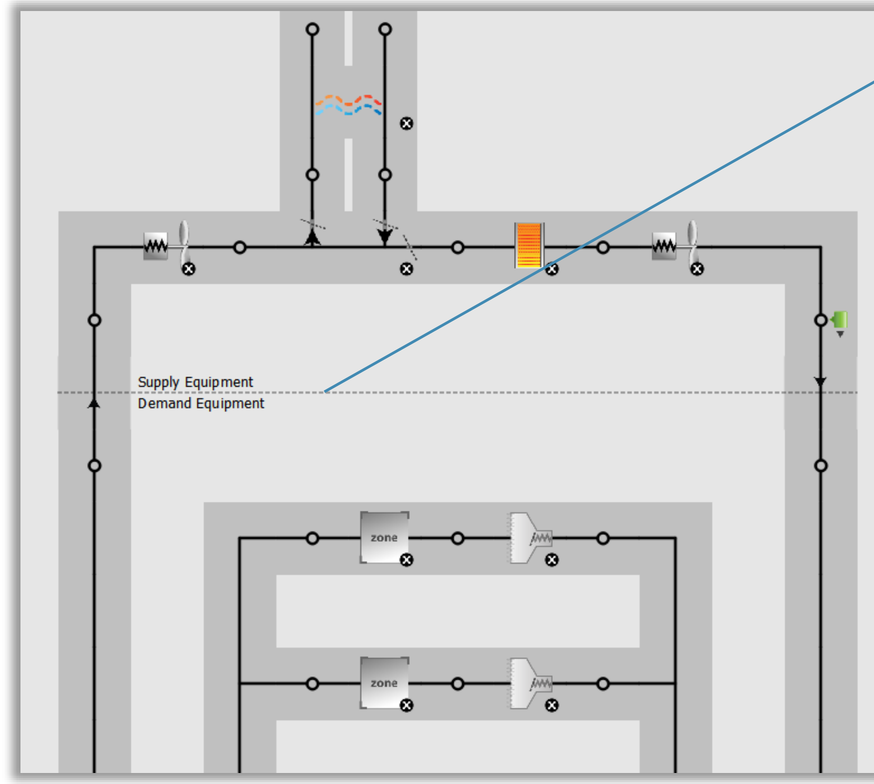
Ventilation Zone Control

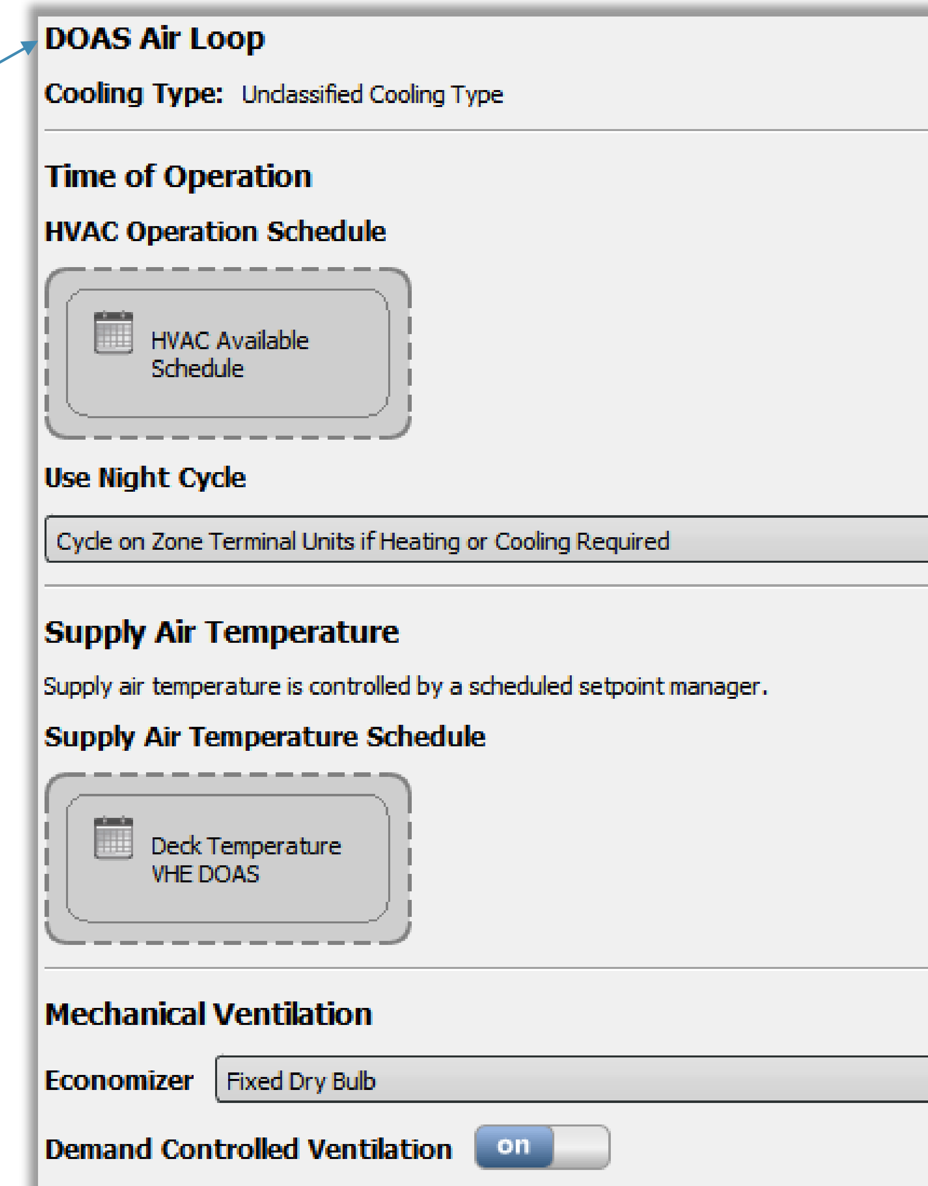


- For each space type or every definition of ventilation air, assign an ‘Outdoor Air Flow Rate Fraction Schedule’ which matches the operational times for the building.
- Fractional schedule, set to 1.0 during occupied hours.
- Enables model to always ventilation proper amount as space types change.

Demand Control Ventilation Configurations

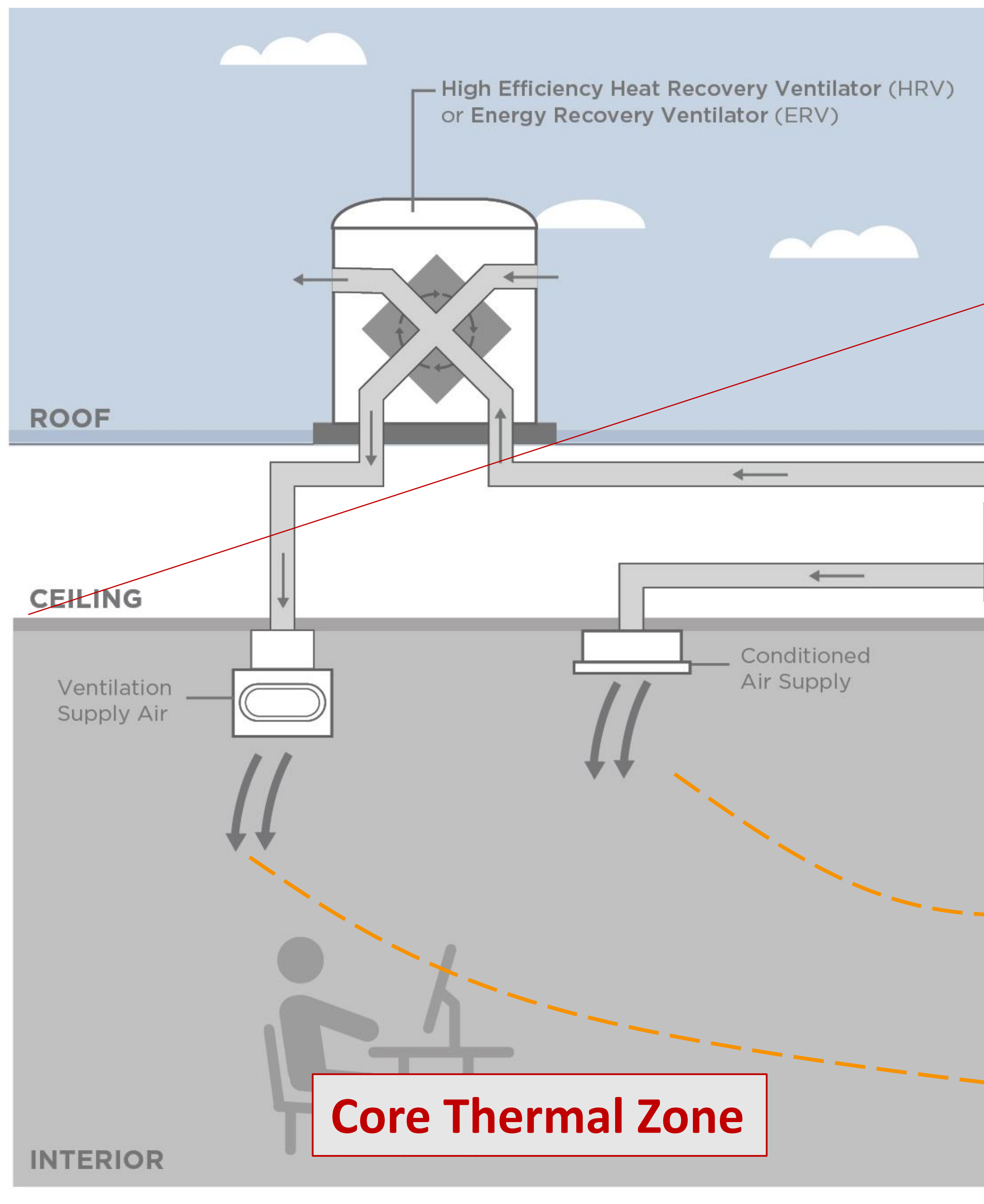


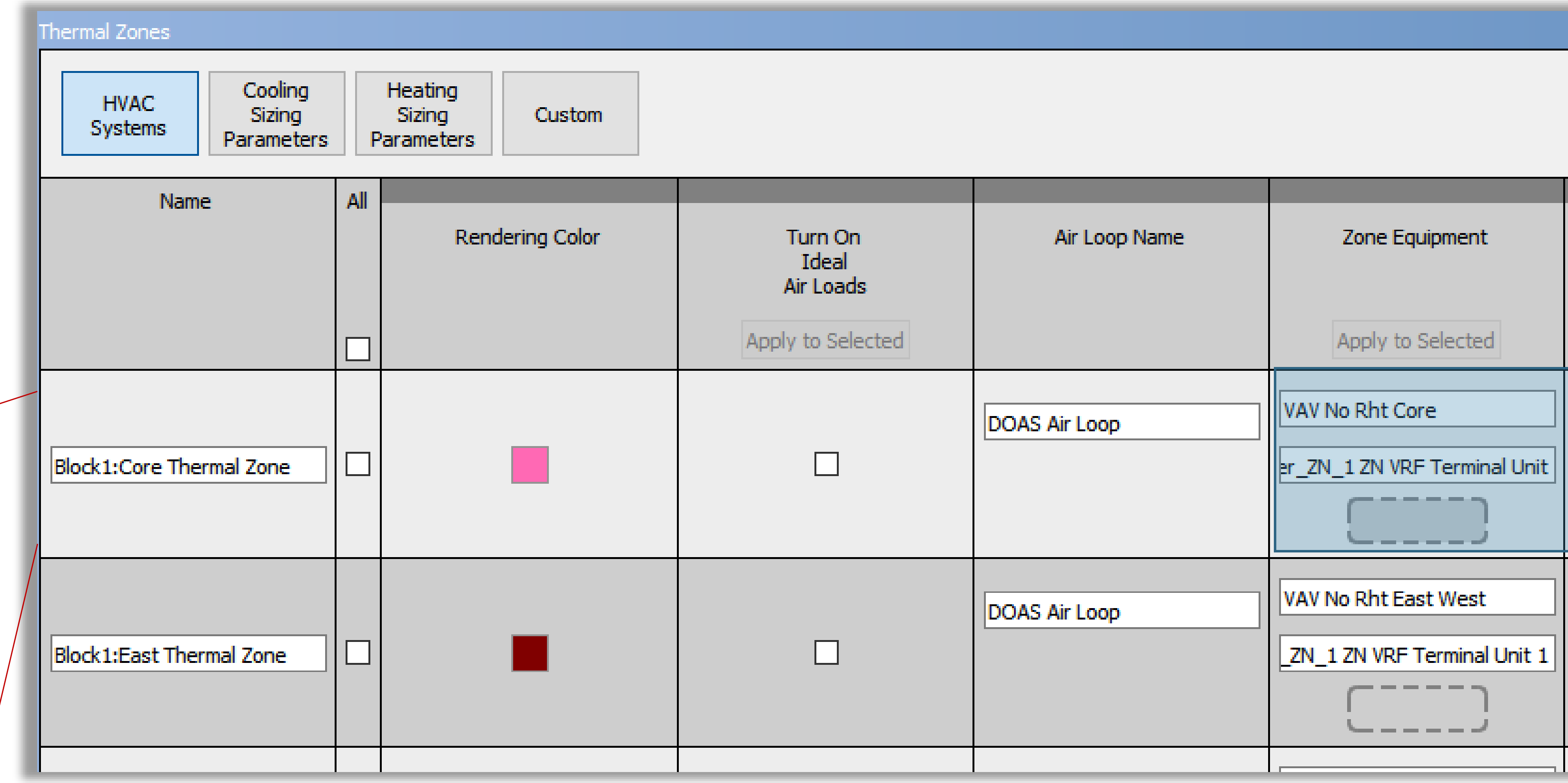




- For Demand Control Ventilation, create profiles for each space type to reflect when people will be in the space.
- Enable DCV at the HVAC System level to ON.

Zone System Sequencing






```
ZoneHVAC:EquipmentList,
  Block1:Core Thermal Zone Equipment List, !- Name
  SequentialLoad,                         !- Load Distribution Scheme
  ZoneHVAC:TerminalUnit:VariableRefrigerantFlow, !- Zone Equipment Object Type 1
  Perimeter_ZN_1 ZN VRF Terminal Unit,    !- Zone Equipment Name 1
  2,                                      !- Zone Equipment Cooling Sequence 1
  2,                                      !- Zone Equipment Heating or No-Load Sequence 1
  1,                                      !- Zone Equipment Sequential Cooling Fraction 1
  1,                                      !- Zone Equipment Sequential Heating Fraction 1
  ZoneHVAC:AirDistributionUnit,           !- Zone Equipment Object Type 2
  ADU VAV No Rht Core,                    !- Zone Equipment Name 2
  1,                                      !- Zone Equipment Cooling Sequence 2
  1,                                      !- Zone Equipment Heating or No-Load Sequence 2
  1,                                      !- Zone Equipment Sequential Cooling Fraction 2
  1;                                      !- Zone Equipment Sequential Heating Fraction 2
```

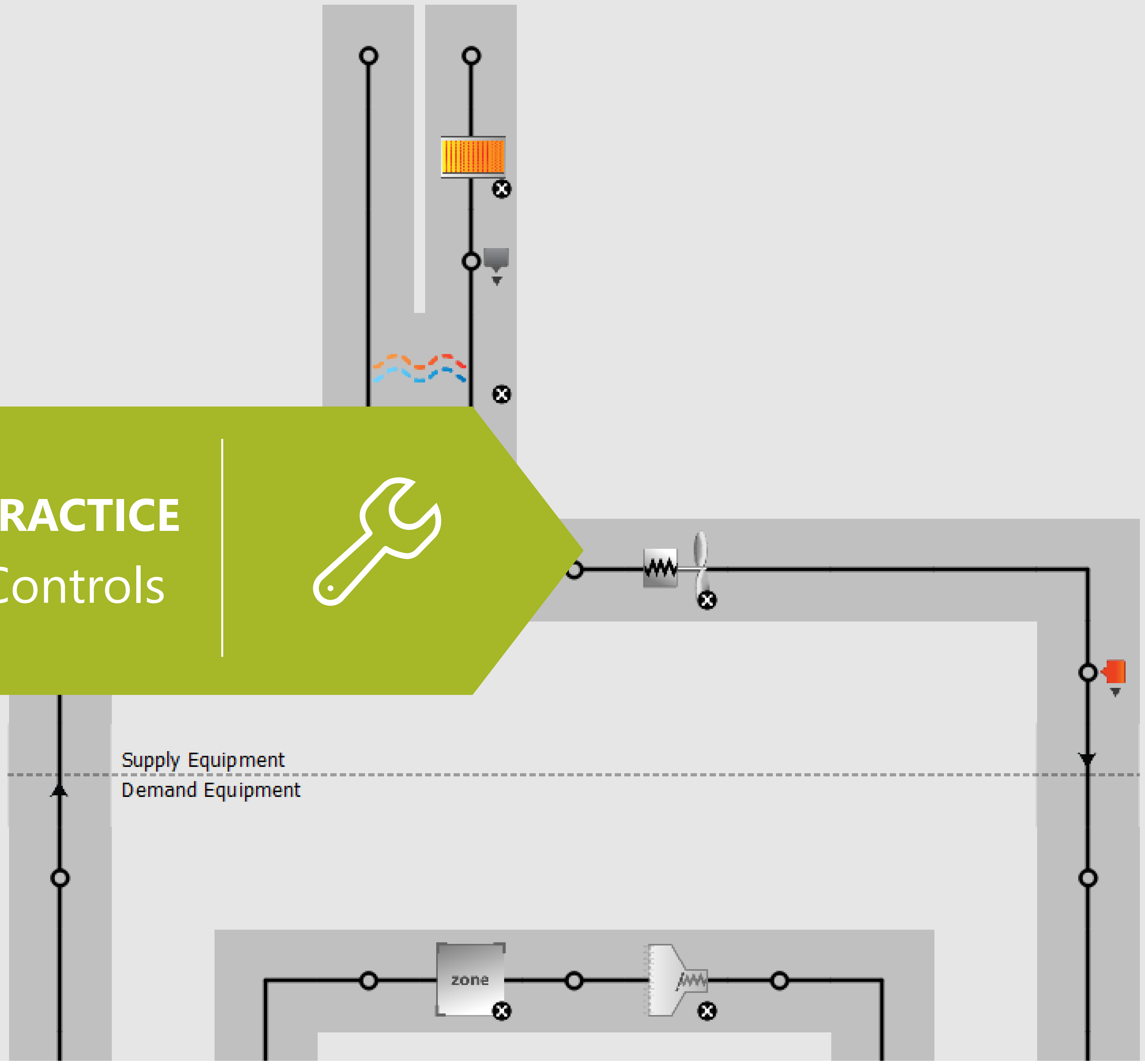
- Always sequence the ventilation first before the zone heating / cooling object.
- If sequenced second, the ventilation load will be added after heating and cooling is provided, resulting in unmet hours.

Energy Modeling Levels of Detail

02

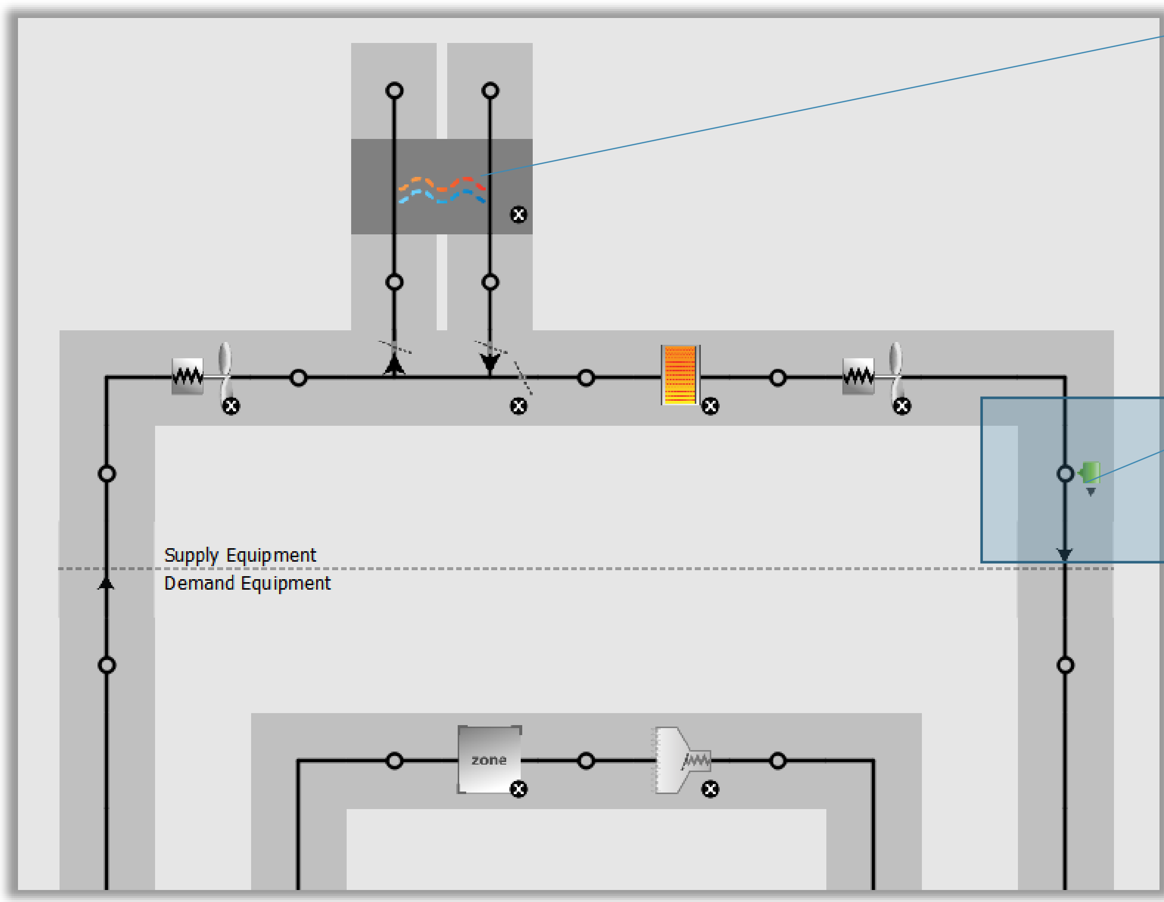
BEST PRACTICE

DOAS (HRV) Efficient Controls



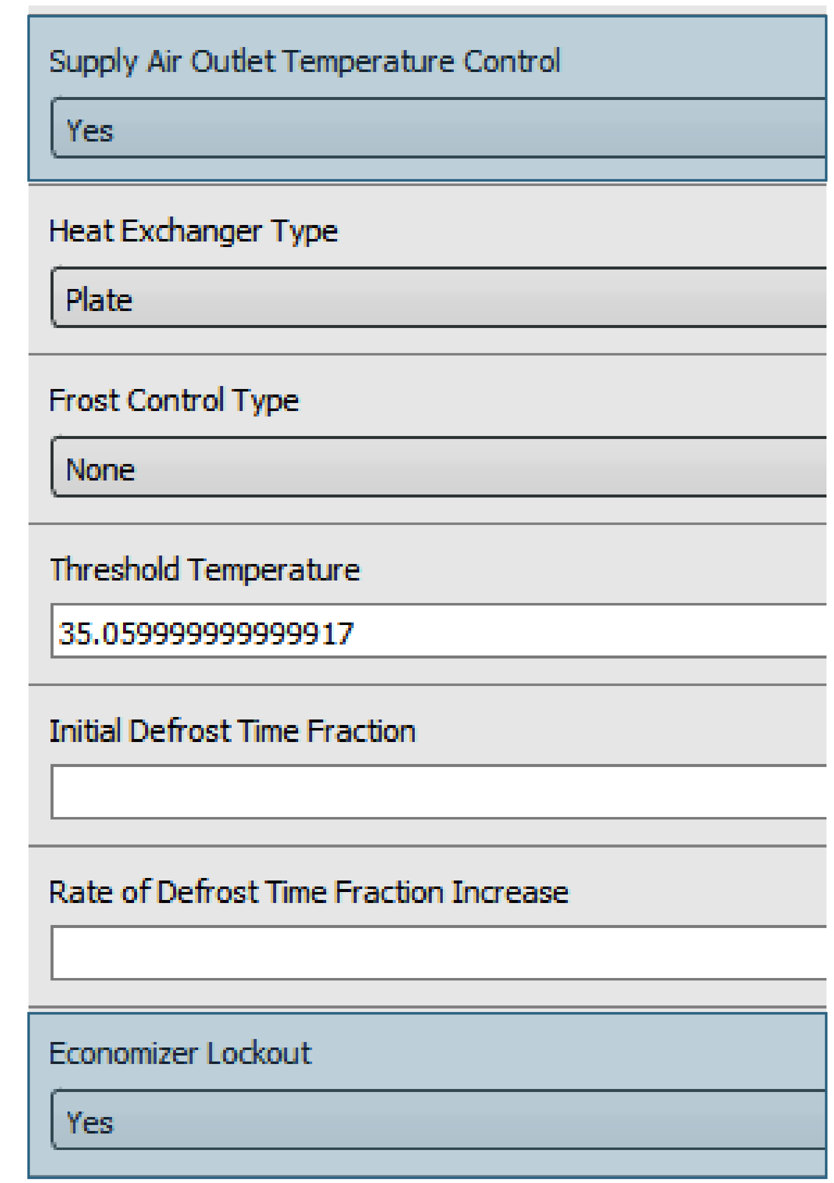
Core Bypass Control & Economizing

HVAC Ventilation System (DOAS)



Supply Air Temperature Schedule

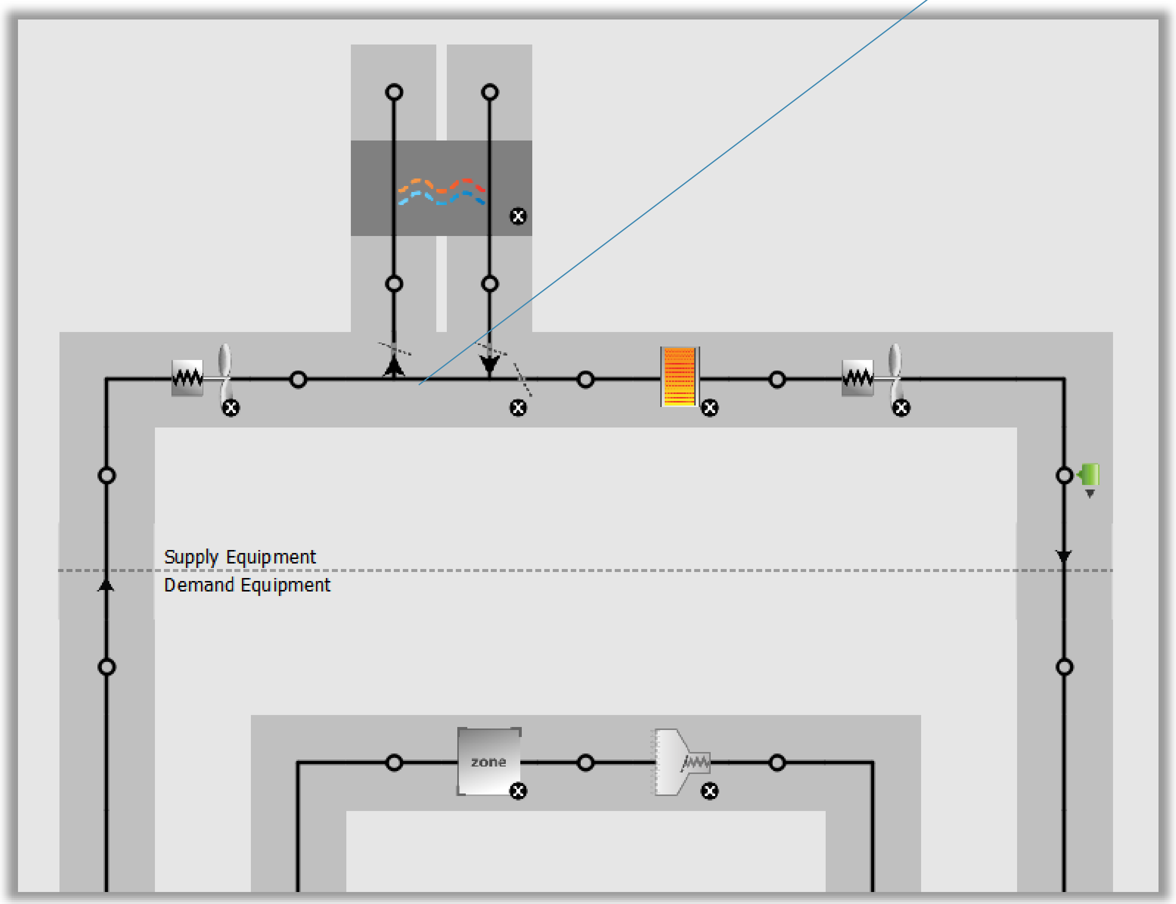
HeatExchanger:AirToAir:SensibleAndLatent,

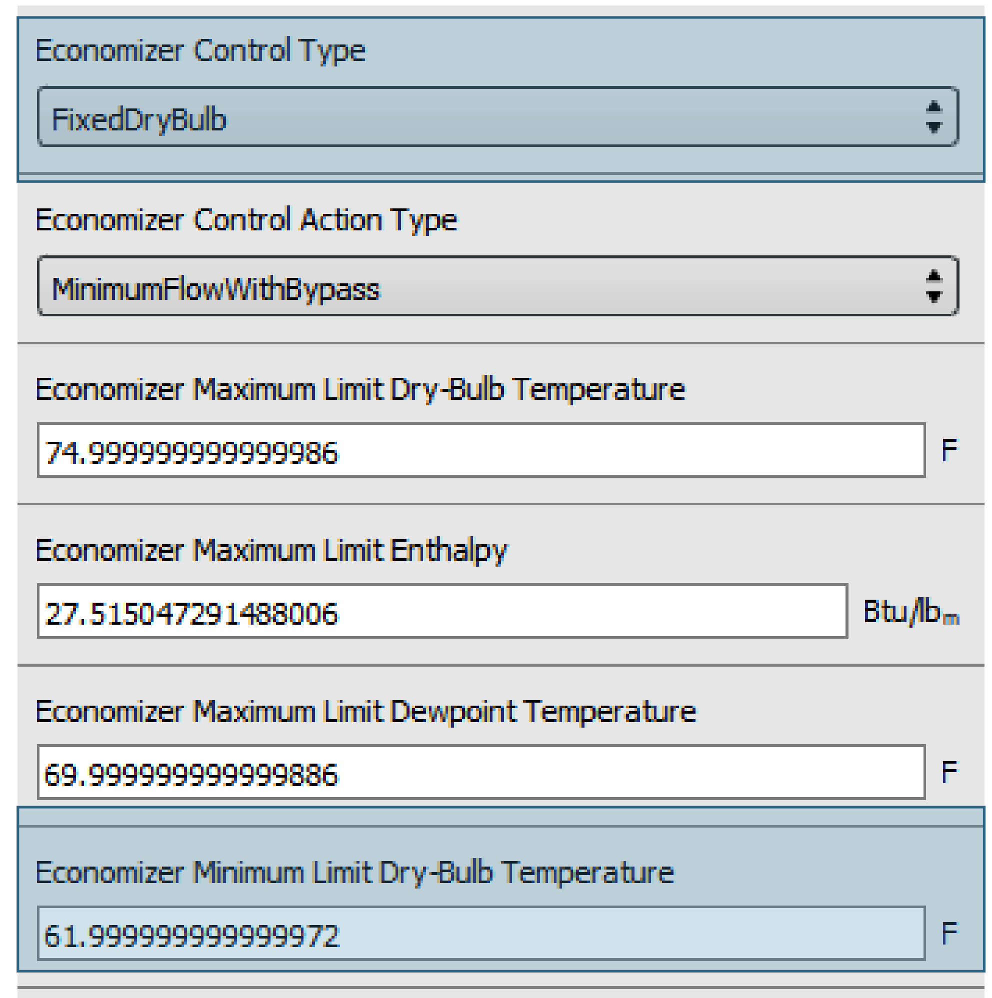


1. 'Supply Air Outlet Temperature Control' controls for partial bypass capabilities. Use if DOAS/HRV is able to partially bypass the core to maintain a supply air temperature.
2. Set the supply air temperature setpoint to properly reflect control capabilities. Typical is to have a seasonal setpoint, maintaining 60F in summer, 70F in winter.
3. 'Economizer Lockout' only controls non-integrated bypass functionalities and requires configurations of the Outside Air Controller (see next slide).

Core Bypass Control & Economizing

Controller:OutdoorAir,

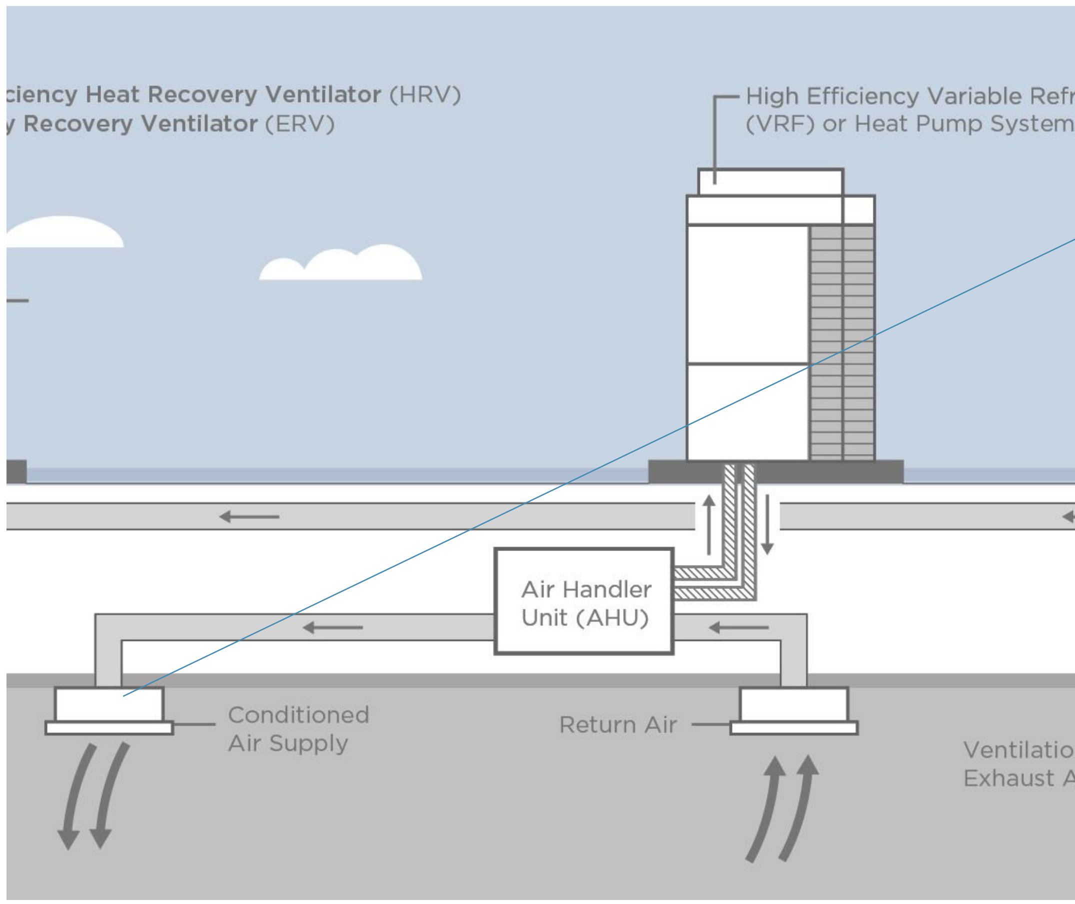


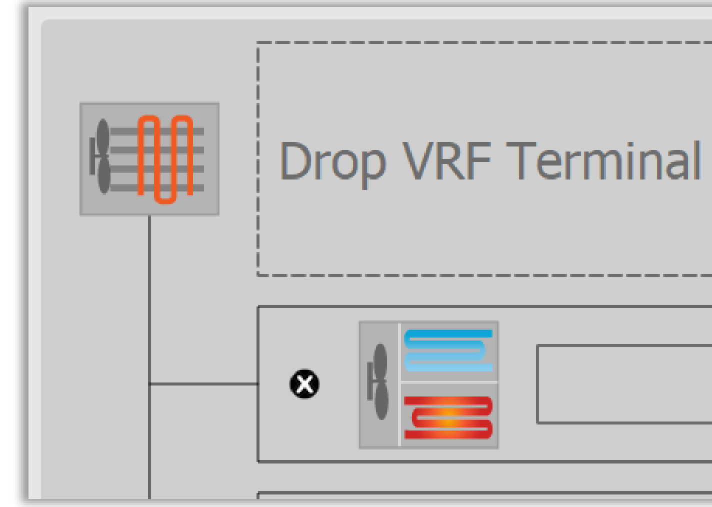


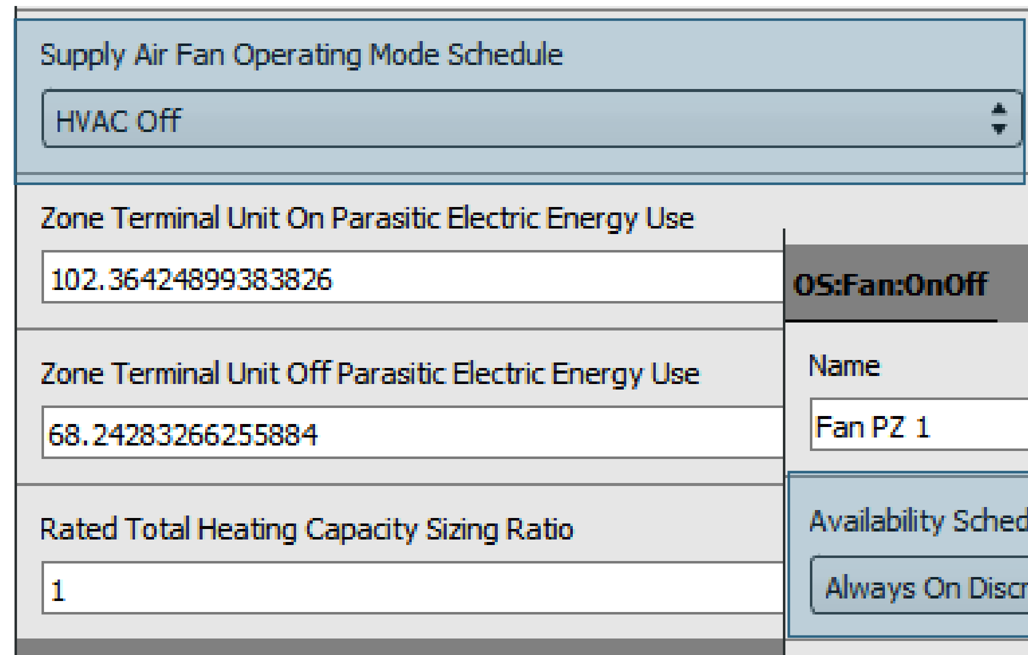
1. If using the ‘Economizer Lockout’ for full bypass capabilities, ensure to configure the Outdoor Air Controller.
2. Specify a type of control, typically Fixed Drybulb.
3. Ensure to specify a Minimum Drybulb limit. The default is to leave this blank which effectively will assume the building can economize well below 55F and cause excessive heating.
4. **Often it is recommended to NOT** use the Economizer Lockout and ONLY use the Supply Air Temperature control. This integrated bypass control will always result in energy benefits and does not require a detailed input on both Supply Air Temperature setpoints and Economizer limits which can change based on building type and location.

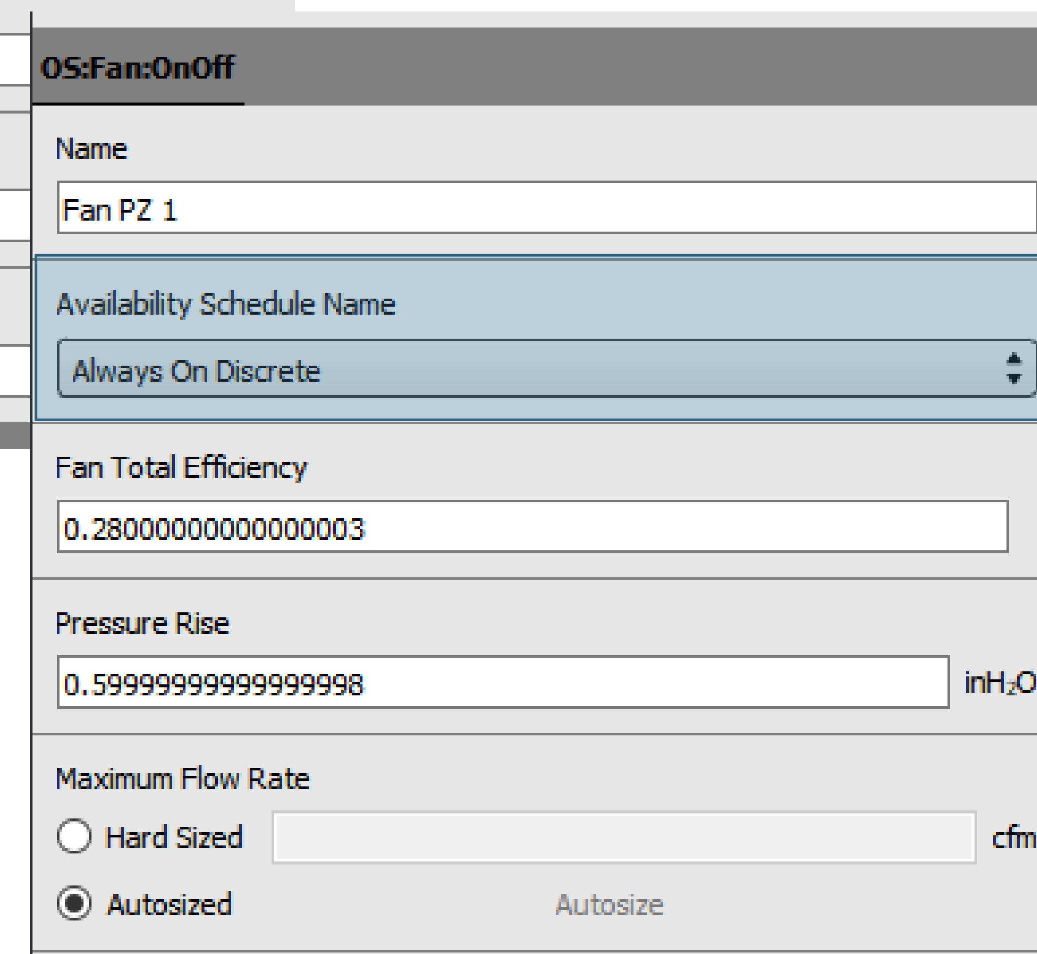
Heating and Cooling Zone Fan Cycling

HVAC Terminal Unit: Variable Refrigerant Flow







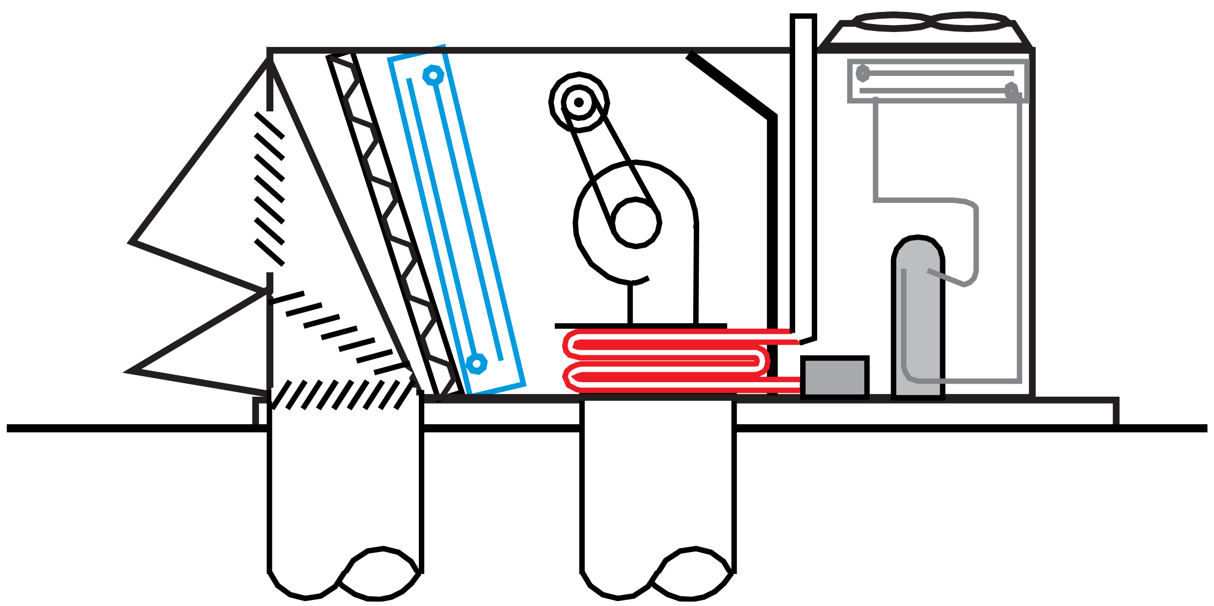


- To ensure that zone fan coils cycle on and off to only maintain thermostat needs, change the default schedules for the system.
- Set the ‘Supply Fan Operating Model Schedule’ to be an On/Off schedule set fully to 0. This ensures the fan is off by default.
- Keep the default ‘Availability Schedule’ to ‘Always On’. This allows the fan to be enabled when desired based on a thermostat call.

Heating and Cooling Zone Fan Cycling

Cycling Fans in RTU
Fan:SystemModel

Roof Top Unit

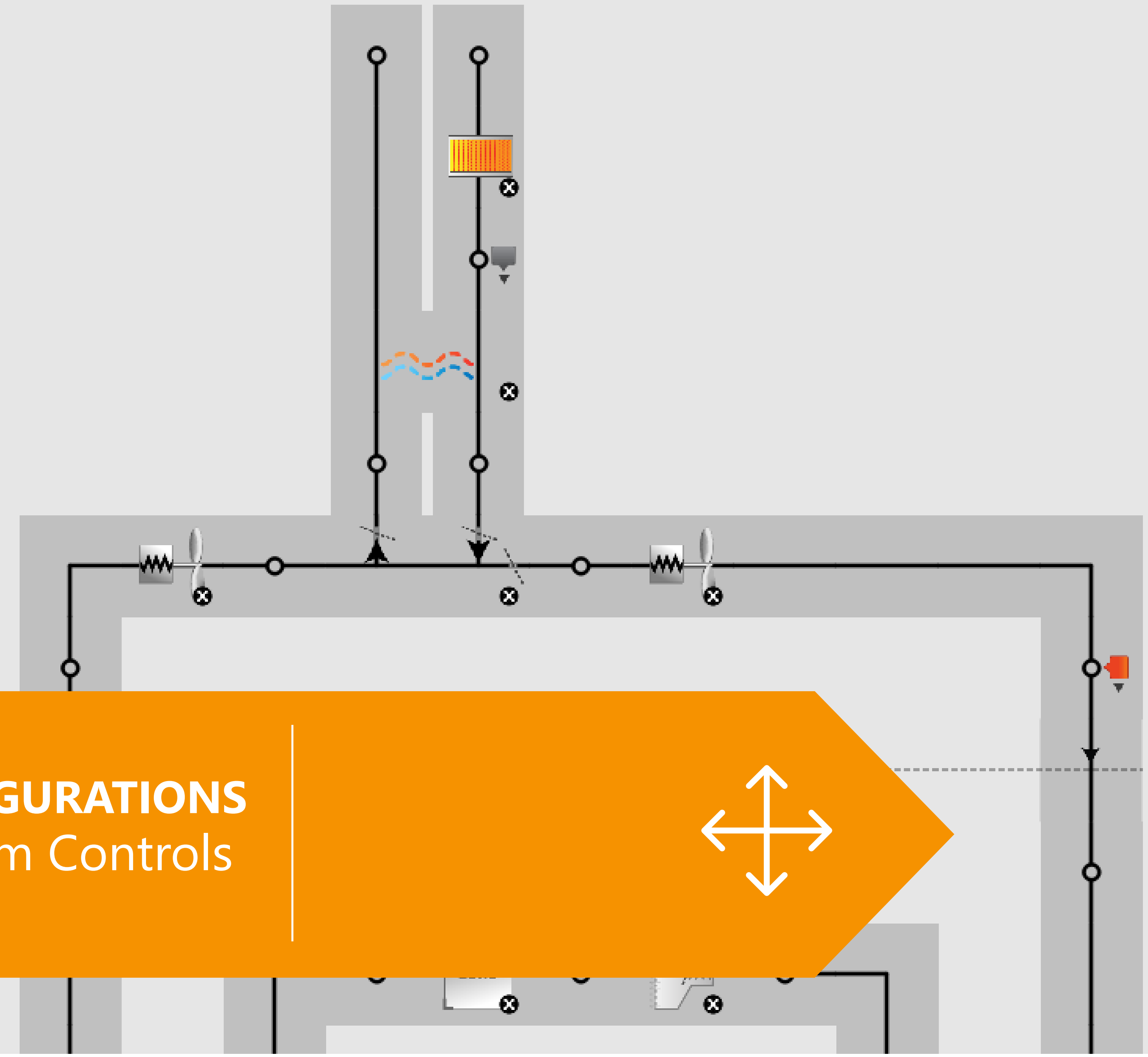


```
Fan:SystemModel,
    Var Spd Fan,          !- Name
    HVAC Available Schedule, !- Availability Schedule Name
    Node 19,                 !- Air Inlet Node Name
    Node Loop Airflow,       !- Air Outlet Node Name
    autosize,                !- Design Maximum Air Flow Rate {m3/s}
    Discrete,                !- Speed Control Method
    0.5,                     !- Electric Power Minimum Flow Rate Fraction
    688,                     !- Design Pressure Rise {Pa}
    0.75,                    !- Motor Efficiency
    0.5,                       !- Motor In Air Stream Fraction
    autosize,                        !- Design Electric Power Consumption {W}
    TotalEfficiencyAndPressure, !- Design Power Sizing Method
    ,                        !- Electric Power Per Unit Flow Rate {W/(m3/s)}
    1.66667,                 !- Electric Power Per Unit Flow Rate Per Unit Pre
    0.4,                     !- Fan Total Efficiency
    ,                        !- Electric Power Function of Flow Fraction Curve
    ,                        !- Night Ventilation Mode Pressure Rise {Pa}
    ,                        !- Night Ventilation Mode Flow Fraction
    ,                        !- Motor Loss Zone Name
    ,                        !- Motor Loss Radiative Fraction
    General,                 !- End-Use Subcategory
    2,                       !- Number of Speeds
    0.5,                     !- Speed 1 Flow Fraction
    0.556,                     !- Speed 1 Electric Power Fraction
    1,                       !- Speed 2 Flow Fraction
    1;                       !- Speed 2 Electric Power Fraction
```

- To model fans cycling off with RTUs when combined with DOAS fans must be changed to be either ON/OFF or the Fan SystemModel object which allows for multi-staged fan control.
- Enable the same System Operations Schedule to be set to a default schedule of 0s.
- Create New Fan Objects with multi speed function (shown here)
- Replace definition of fan object for each Packaged Unit and location in EnergyPlus text file.

Energy Modeling Levels of Detail

- Three levels of detail which could be used at different stages of design



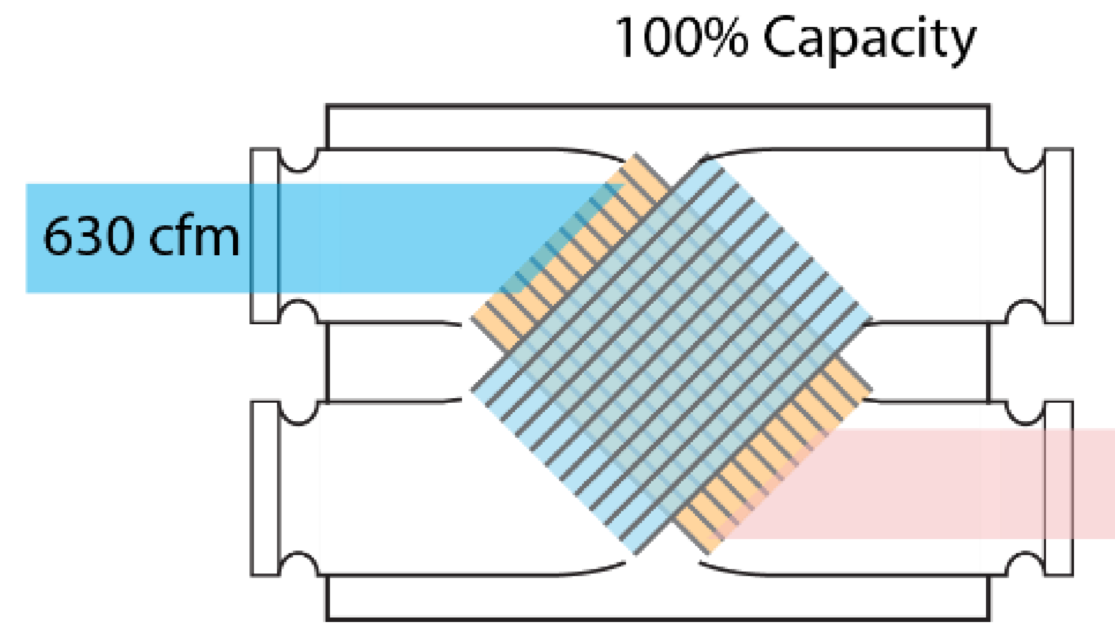
03

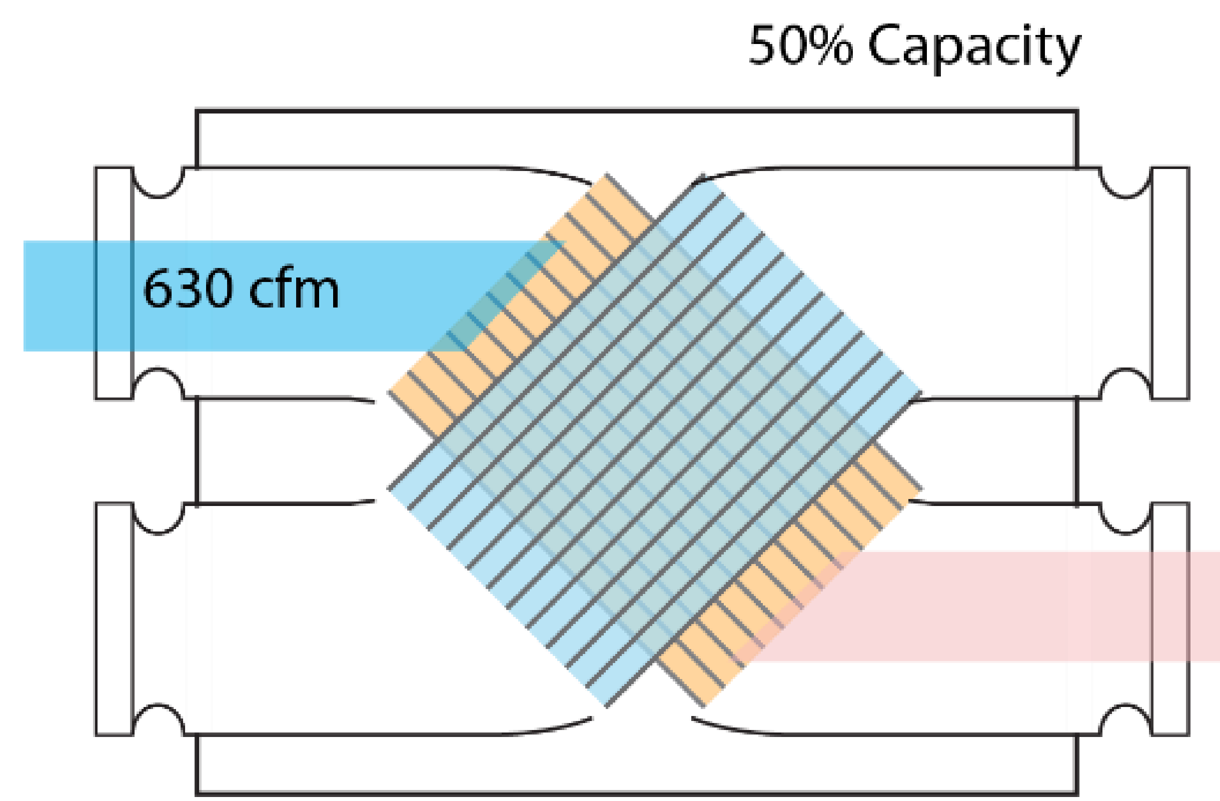
ADVANCED CONFIGURATIONS
DOAS (HRV) Custom Controls

Modeling Systems at 50% Capacity

- Heat Recovery Ventilator Selected at half the rated capacity of a product.
- Overall system provides the same airflow for a project.

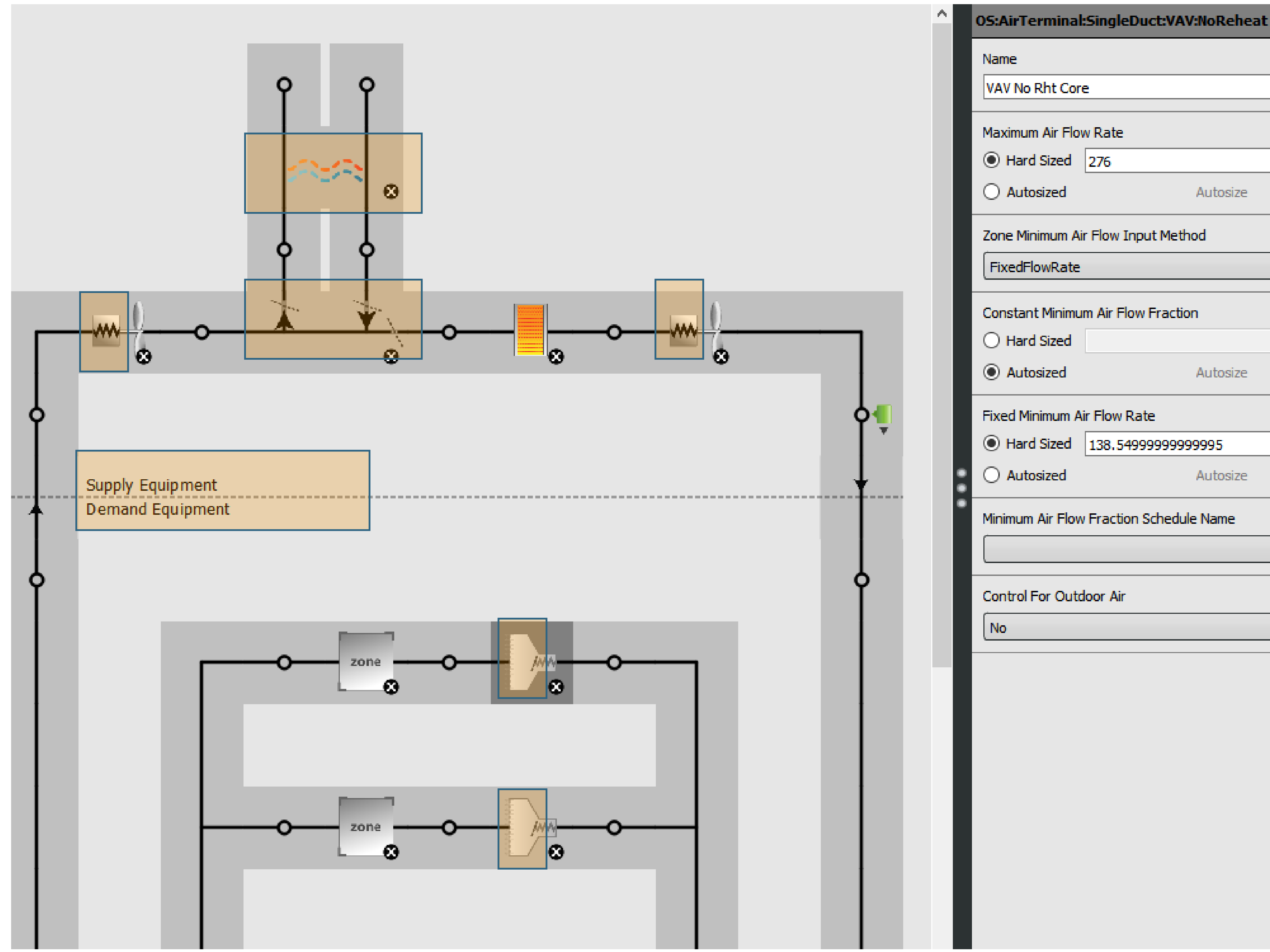
- Benefits:
  1. Provides future flexibility & growth.
  2. Can downsize HVAC on larger buildings from increased HRV effectiveness.
  3. Increased energy efficiency:
     - Reduced fan static pressure
     - Increased heat recovery effectiveness
     - Reduced air velocity reduces noise





Modeling Systems at 50% Capacity

- Change in how airflow is controlled.
- Airflow is now controlled by cooling requests and economizer functionality.
- Requires all ventilation components on an air-loop be manually sized for increased capacity.
  - Air to Air HX
  - Outside Air Controller
  - Fans (supply return)
  - Air Loop
  - VAV boxes

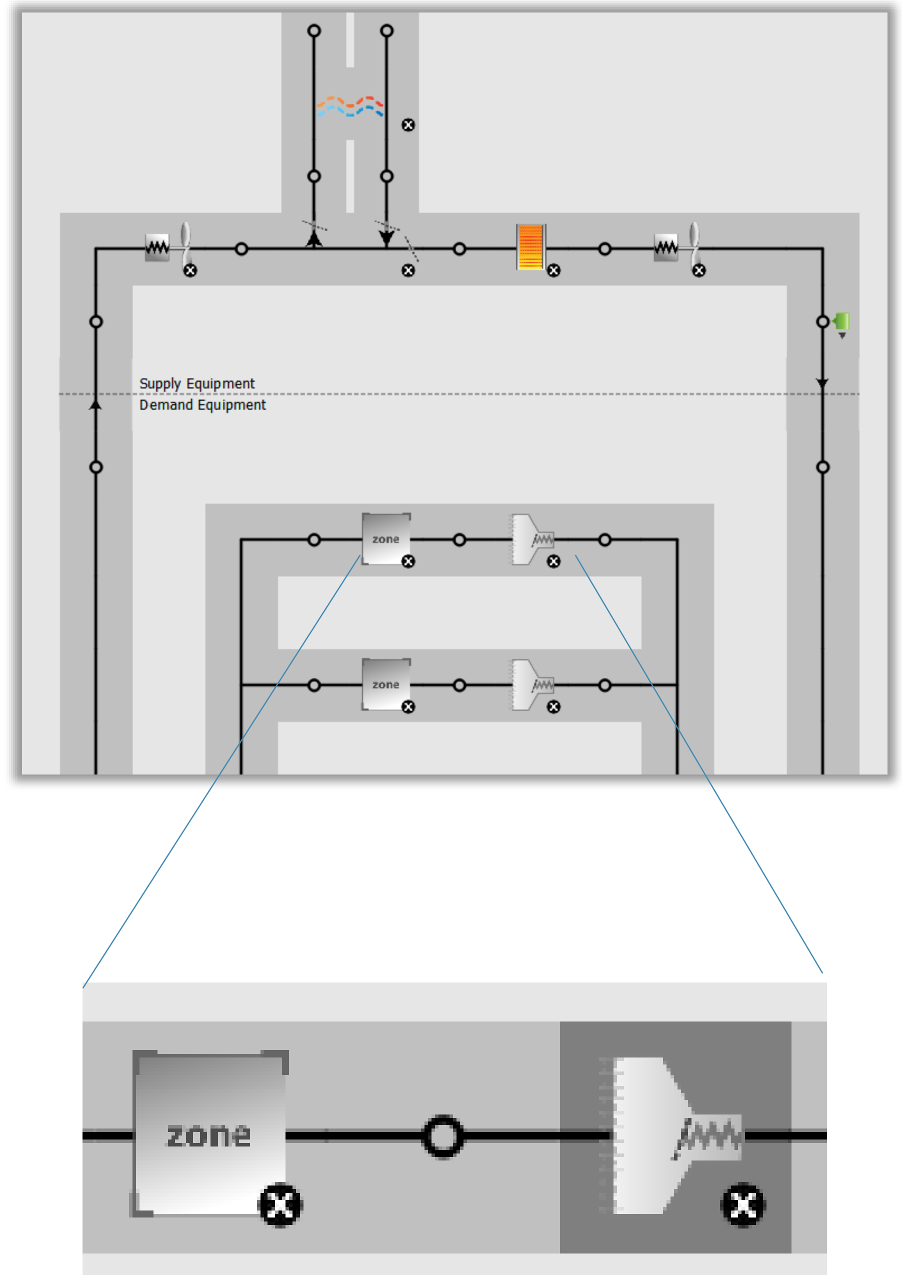


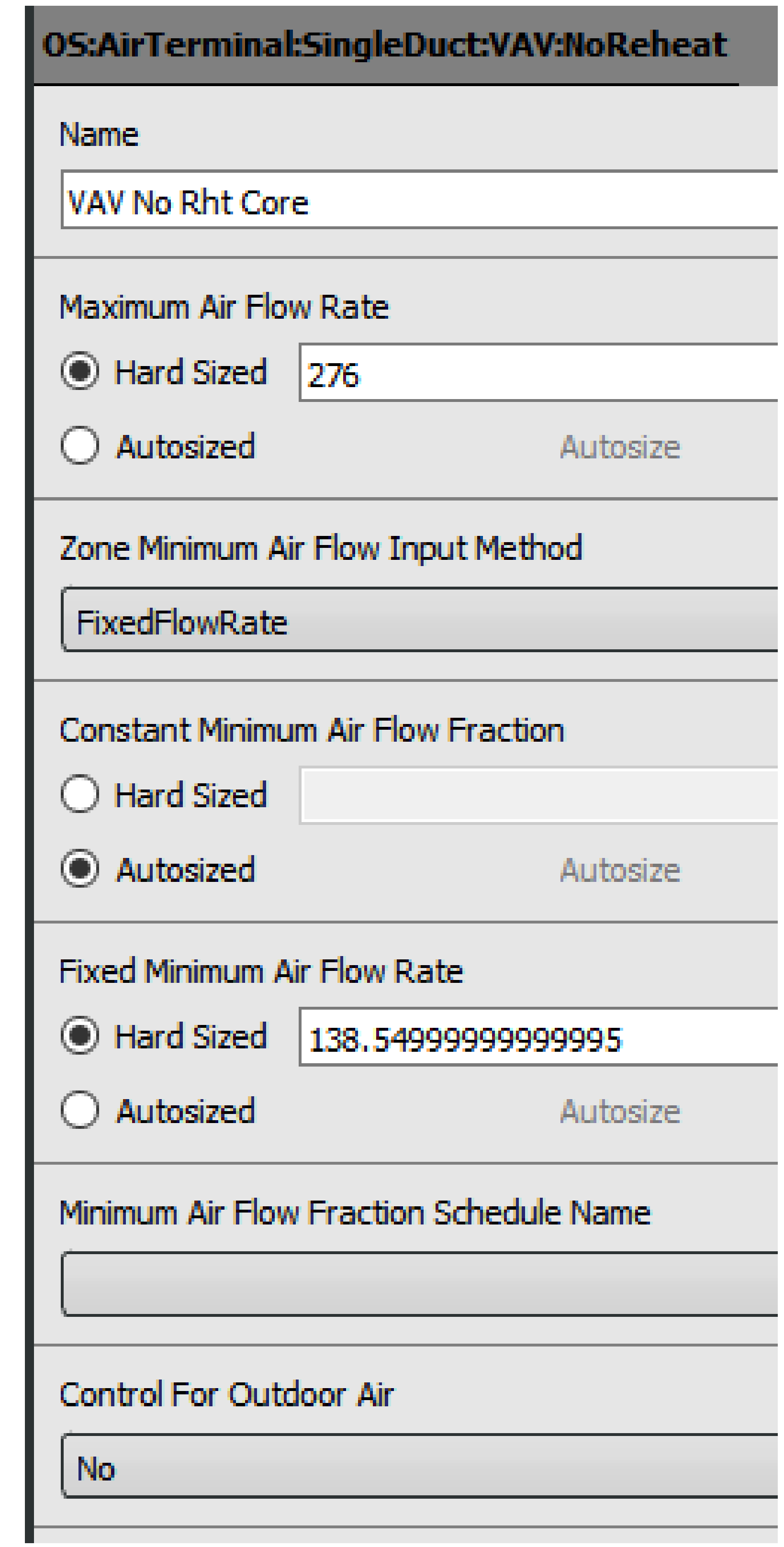
Modeling Systems at 50% Capacity

- VAV Box limits are critical:
  - Minimum airflow = ventilation
  - Maximum airflow = system maximum capacity

  - Remove the ‘Control for Outdoor Air’ to No.

HVAC Ventilation System (DOAS)

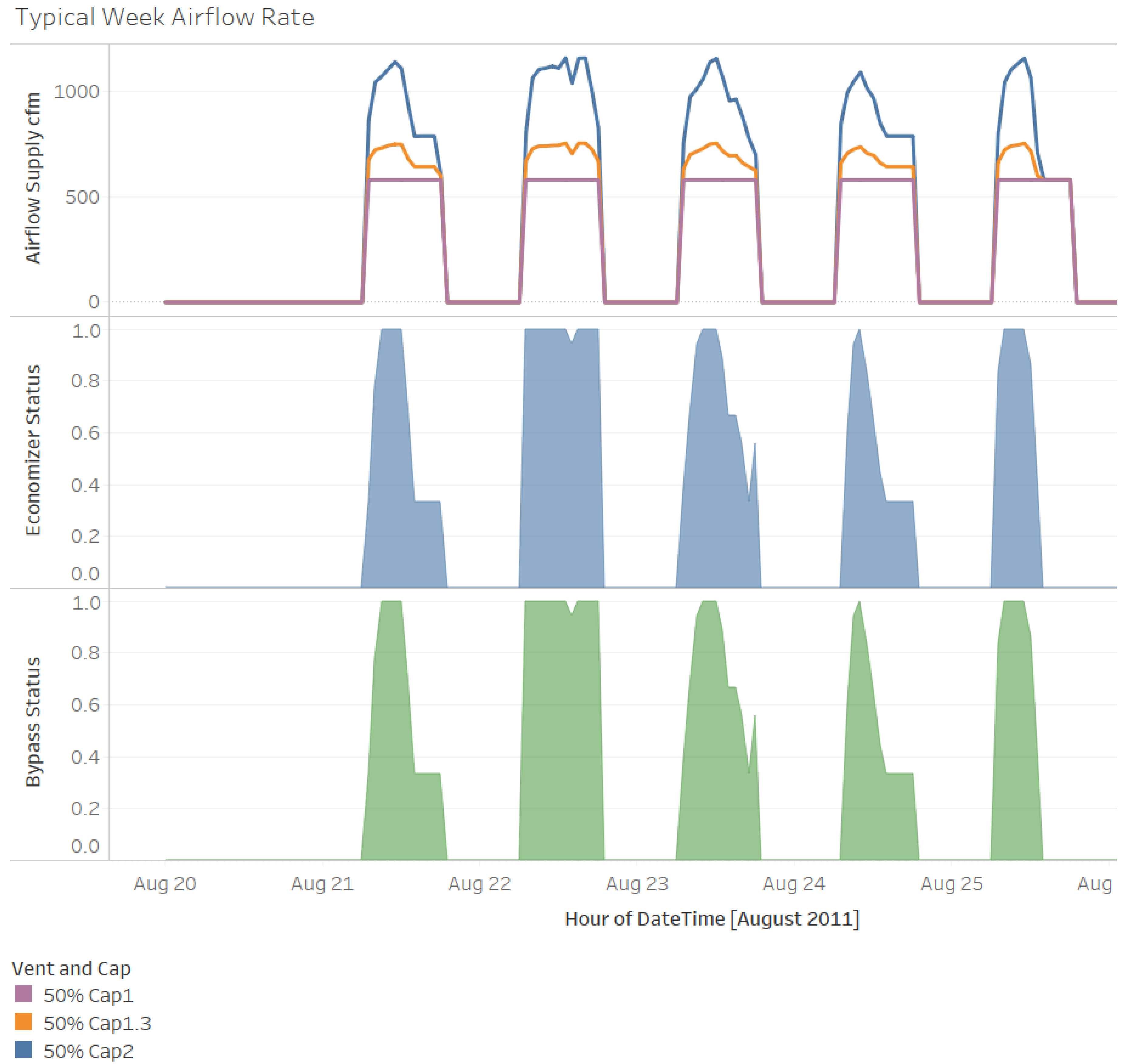




Modeling Systems at 50% Capacity

- Where the system can now provide more cooling with ventilation, the airflow will increase.

- This implies the DOAS (HRV) actively knows to provide cooling and can boost airflow. Ensure this type of control exists on the selected product.



Future Features in EnergyPlus

EnergyPlus New Features Planning for FY19

Each year, the EnergyPlus development team seeks input and feedback regarding new feature development for the upcoming year. Features are selected based on impact, demand, effort, and available developer expertise. Input from stakeholders is a crucial component of this process, and selected stakeholders were polled for their priorities. The stakeholders were asked to specify up to five new features for consideration for FY19.

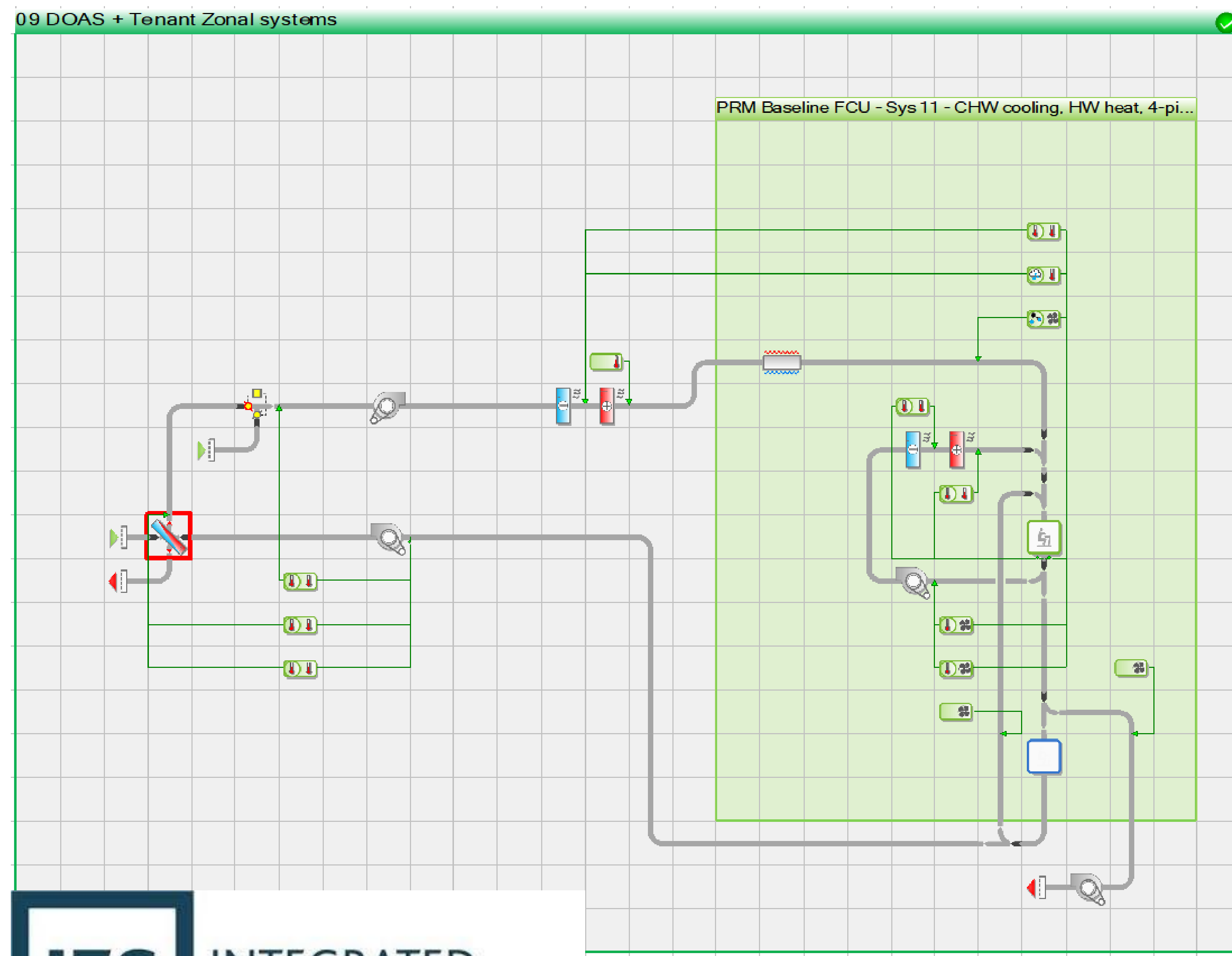
High Priority Feature Requests

#	Title	Description	Requester	Assigned Lab
3	Model DOAS supplying air to inlets of multiple AHUs	This feature develops the modeling and simulation approach for a dedicated outdoor air system (DOAS) connected to multiple air handling units (AHUs). Many buildings have a separate DOAS system that feeds outdoor air directly to individual AHUs on each building floor. Currently EnergyPlus can only model a DOAS delivering outdoor air directly to zones or to the inlet or outlet of zone equipment acting as terminal units. This feature will allow a single DOAS to supply air to the outdoor air inlet of multiple air systems.	LBNL, Carrier, University of Colorado	NREL
	Ability to attach DOAS to multiple rooftop units	Ability to attach one DOAS to multiple AirLoopHVAC objects would be helpful to model: DOAS connected to multiple rooftop units (or) multiple SZVAV/SZCV units	Trane	NREL

REDCAR ANALYTICS

DOAS to AHU, VE-IES

For projects with one central DOAS serving several air handling units or other systems, consider functionalities in VE-IES.



Summary of DOAS (HRV) Modeling Best Practices

1. Verify HRV control functionality. Many units only do on/off bypass.
2. Set Economizer Limits carefully.
3. Verify HRV flow control, if any.
4. Configure model with VAV boxes set to 'Control for Outdoor Air' YES as safe default.

Made possible by:

Northwest Energy Efficiency Alliance

Thank You & Questions

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