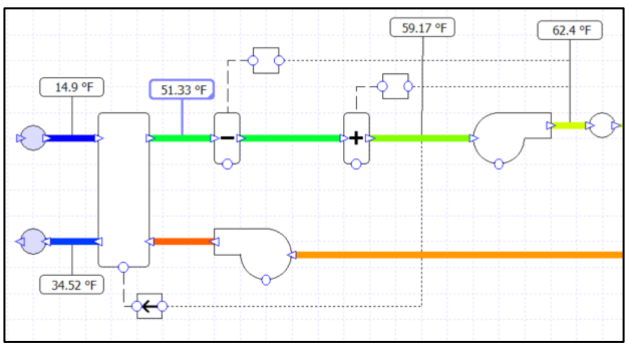
February 21, 2023

Energy Modeling Guide for Very High Efficiency DOAS



Final Report

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1. Introduction

The Very High Efficiency Dedicated Outdoor Air System (VHE DOAS) is a type of commercial building HVAC system with the potential to reduce HVAC energy costs by 30% to 50% for new and existing buildings in the Pacific Northwest. Developed and refined over several years of research, market analysis, and demonstration project installations, this system approach improves indoor-air quality and occupant comfort, and decreases energy use, compared to a conventional rooftop packaged HVAC equipment.

This guide addresses a resource gap for best representing VHE DOAS systems in annual energy modeling. It is designed to provide technical analysis support and recommendations using lessons learned and time-tested methods. The information has been developed based on findings from several prior evaluations of VHE DOAS and a series of calibrated building energy models.

This guide aims to enhance energy modelers' accuracy in predicting energy use and future savings for VHE DOAS in typical commercial building applications. The guide primarily focuses on VHE DOAS with heat recovery ventilators (HRVs) based on case studies in the Pacific Northwest though the VHE DOAS system can be implemented with energy recovery ventilators (ERVs). The guide is structured as a general energy modeling guide for energy analysts and design consultants who build and provide technical analysis support. Most modeling specific examples are referenced within the context of an EnergyPlus modeling platform, however, all of the recommended modeling approaches can be implemented in the most commonly used modeling software packages.

2. Objectives

The guide's objectives are to provide a consolidated resource for energy consultants evaluating VHE DOAS systems as they create representative building energy models. Specific objectives include:

1. Provide guidance on configuring and controlling a decoupled DOAS that meets the VHE DOAS requirements within a whole building energy model.
2. Provide lessons learned from calibrated energy modeling of VHE DOAS systems where common input assumptions under predicted building heating loads and under predicted energy savings.
3. Provide guidance on how to verify and check a VHE DOAS energy model.

3. Background, What is VHE DOAS

ASHRAE defines DOAS as, "An air system that uses separate equipment to condition all the outdoor air brought into a building for ventilation and delivers it to each occupied space, either directly or in conjunction with local or central heating/cooling units serving those same spaces. The local or central heating/cooling units are used to maintain space temperature". VHE DOAS improves the efficiency of the DOAS approach with the following key components:

1) The ventilation equipment is fully decoupled from primary heating/cooling equipment to provide optimal control of each critical function.
2) A heat or energy recovery ventilator (HRV/ERV) is specified with 82% or greater sensible effectiveness.
3) High-performance electric heating/cooling equipment.
4) Heating/cooling equipment is "right-sized" based on accurate calculations of building thermal needs.

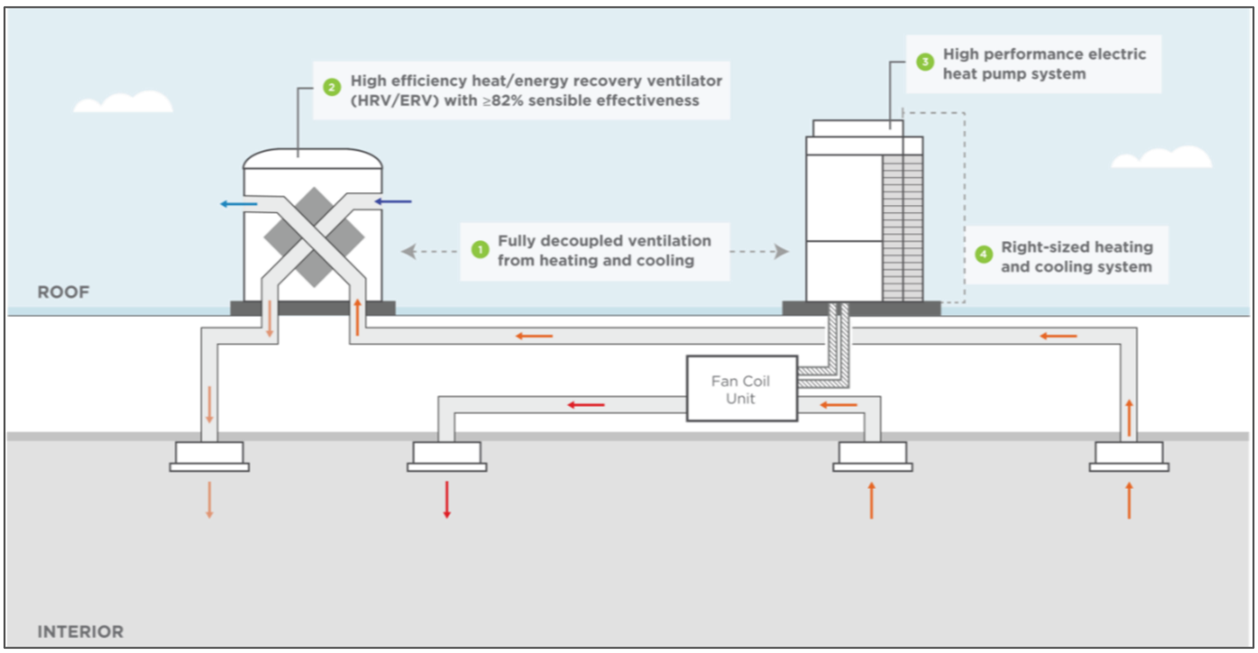

Figure 1: NEEA diagram of commercial building application of VHE DOAS

VHE DOAS goes beyond the requirements that are outlined in various codes, such as the Washington State Energy Code. The system can be broken down into two sub-systems: (1) ventilation and (2) zonal heating and cooling.

Ventilation

In the VHE DOAS approach, the HRV/ERV DOAS unit provides ventilation air to occupied spaces independently from the primary heating/cooling equipment. A high efficiency heat exchanger within the HRV/ERV passively pre-conditions incoming outside air by transferring heat to or from the outgoing airstream without mechanical heating or cooling coils. In many Northwest climates the ventilation air can often be delivered directly to indoor spaces without supplemental heating or cooling because of the high efficiency heat recovery.

Heating and Cooling

To maximize performance, it is critical to select high-efficiency electric heat pump heating/cooling equipment that is correctly sized for the space and or building loads. There are several types of heating/cooling equipment particularly well suited to this approach, including variable-refrigerant flow (VRF) systems, hydronic systems served by high efficiency air-to-water heat pump central plants, and systems utilizing ground-source or ground-water heat pumps. To optimize system efficiency and occupant thermal comfort, these systems can utilize variable speed compressors, variable speed fans, and variable refrigerant flow and modulation of the units operational pressures and temperatures.

For more information, including design guidelines, research findings, and case studies, visit: betterbricks.com/solutions/very-high-efficiency-doas.

4. Configuring VHE DOAS in an Energy Model

In developing an energy model of a VHE DOAS system several modeling challenges often arise that can result in either overprediction of HVAC energy use or incorrect estimates of energy use and energy savings. This section provides recommendations on ways to configure the energy model components and set up basic control inputs to best represent the documented and expected performance of VHE DOAS.

Recommended approaches address:

1. Configuring two systems serving one zone - one system for ventilation, and one for space conditioning.
2. Configuring system controls:
    a. Input of ventilation flow rates and DOAS size.
    b. Defining thermostatic control zones and unoccupied period space conditioning systems.
    c. Review of staging control consideration for HRV/ERVs and space conditioning systems.
    d. Ensuring that space conditioning systems are not delivering any ventilation air to the space.

4.1 Configuring Two Systems Serving One Thermal Zone

A fundamental principle of VHE DOAS is using two systems to serve each thermal zone, one dedicated to ventilation and one for heating and cooling. The VHE DOAS system diagram is shown below with the two systems annotated in dashed lines.

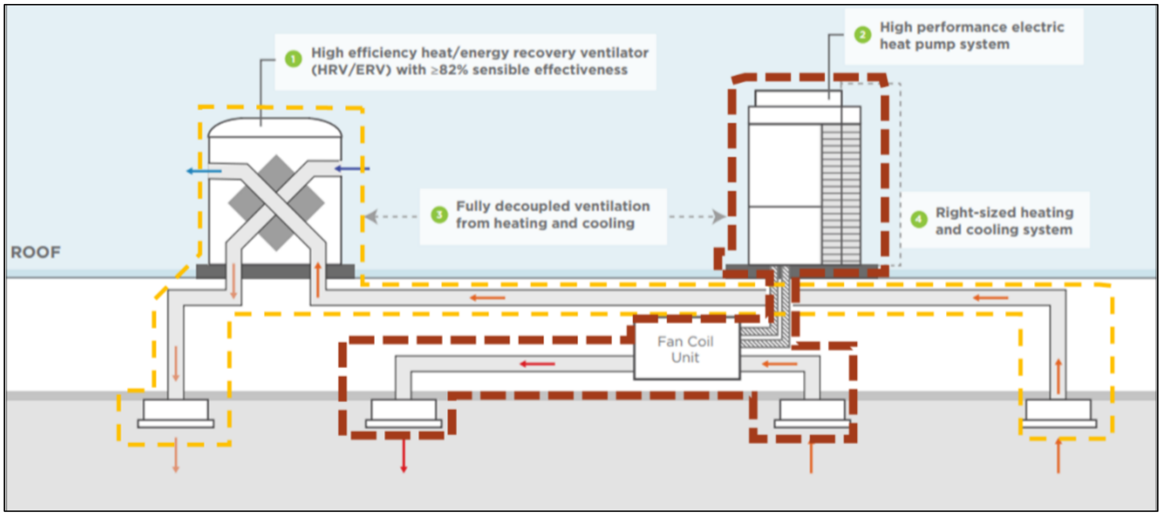

Figure 2: VHE DOAS with two systems highlighted, ventilation and space conditioning

In energy modeling, this can be challenging to implement properly in that most software is built on the idea of a single system serving each zone. Today, all of the commonly used energy modeling software platforms support explicit modeling approaches or tested work-around modeling approaches to effectively simulate the performance of VHE DOAS. In most energy modeling software, there will be three distinct components to specify:

1. the central DOAS unit,
2. the zone air terminal device delivering ventilation, and
3. the fan coil or other heating and cooling device.

In many software packages, setting up HVAC systems often requires specifying a bundled package of an outdoor air unit and a type of zone conditioning system all at once, such as four-pipe fan coils, chilled beams, VRF, or mini-splits. Explicit modeling approaches are discussed below for EnergyPlus, Virtual Environment IES, eQuest/DOE2.3, and EDSL-TAS,

EnergyPlus. In EnergyPlus, two discrete systems must be created, each assigned to a zone using a component which lists the equipment and the order in which they provide heating and cooling.

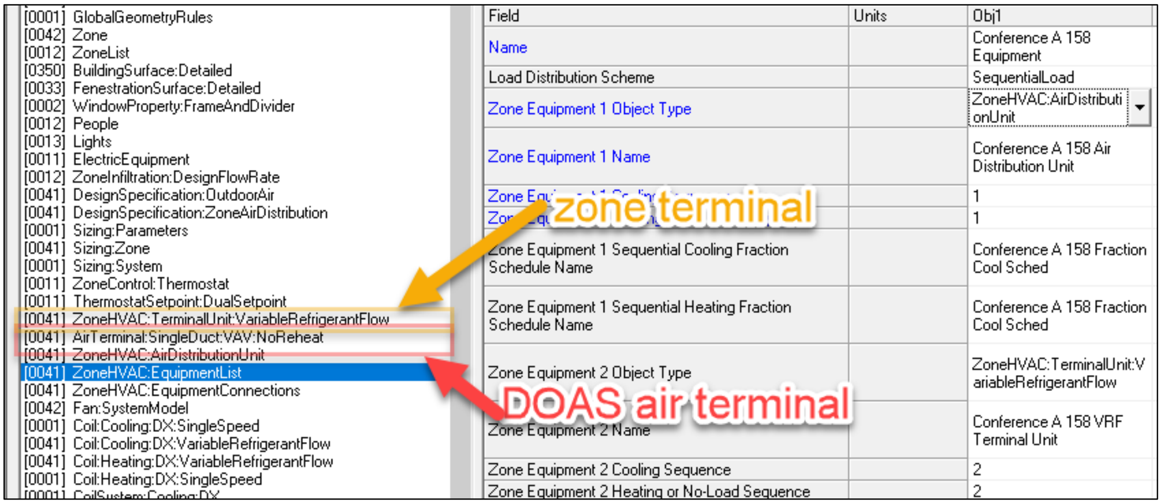

Figure 3: DOAS Configuration Example of EnergyPlus 9.4

Error! Reference source not found. shows the zone terminal unit element, shown in yellow, and the ventilation air terminal unit, highlighted in red. Both are cross-referenced and sequenced in EnergyPlus using the ZoneHVAC:EquipmentList object.

The same components can be visually seen in a software like OpenStudio, which is built on EnergyPlus components. The shared link is shown in Figure 4 for the zone terminal unit and the ventilation air loop, along with a diagram showing components in the DOAS unit.

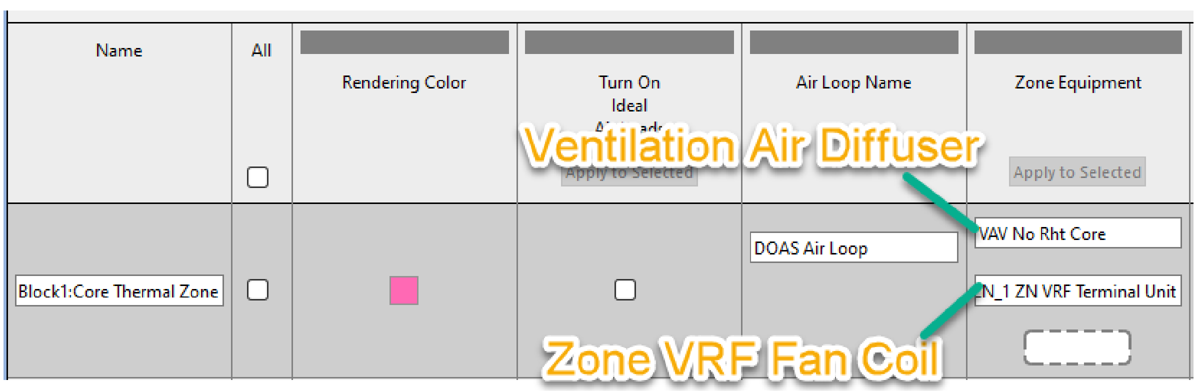

Figure 4: DOAS Configuration Example of OpenStudio 3.4.0, Zone Components

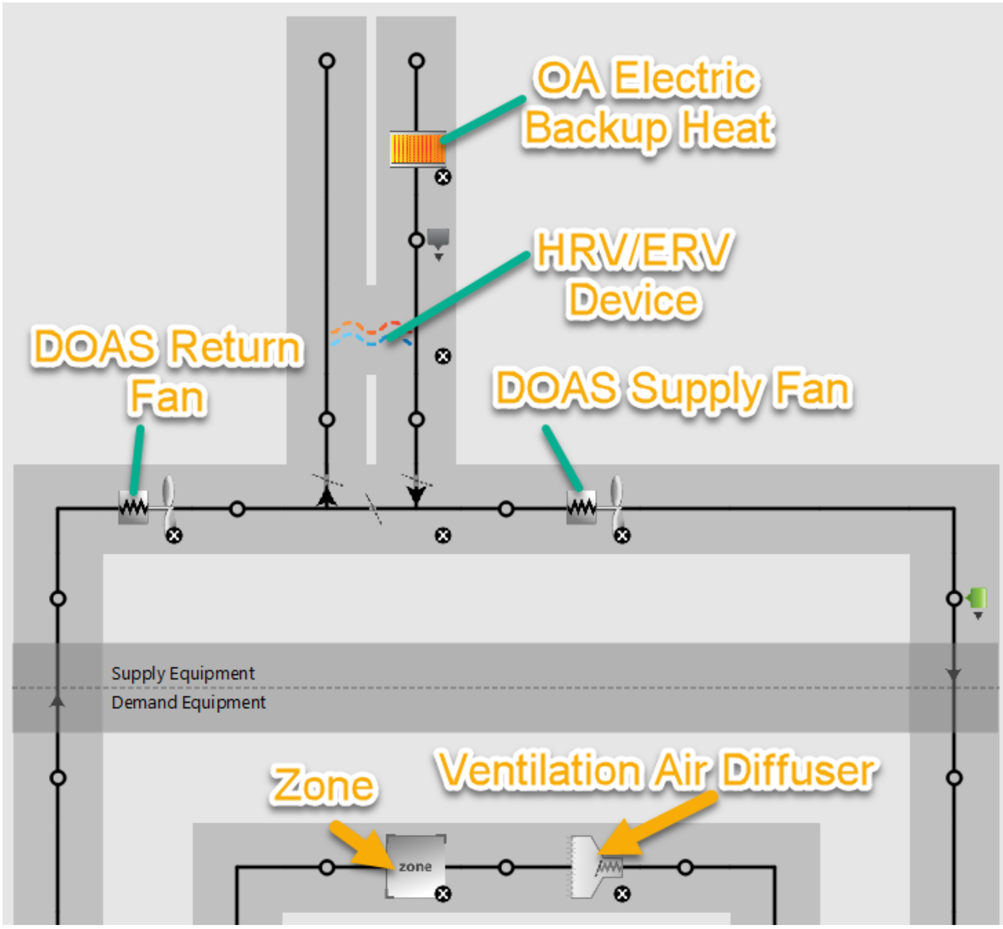

Figure 5: DOAS Configuration Example of OpenStudio 3.4.0, DOAS Unit

Figure 5 shows two screenshots from OpenStudio, one specific to the thermal zone where you can see two systems at the zone equipment level, the ventilation air diffuser and the Zone VRF Fan Coil. The other screenshot shows just the DOAS ventilation system, where components can be configured visually.

VE-IES. In Virtual Environment's Integrated Environmental Solutions (VE-IES), the system wizard and system diagrams (Figures 5 and 6) show distinct zone and system level components which can be manipulated independently.

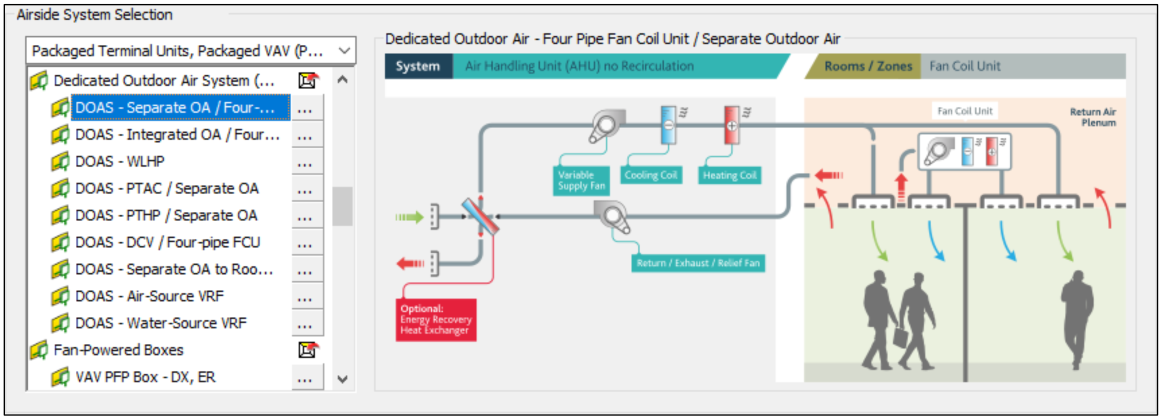

Figure 6: DOAS Configuration Example of VE-IES Configuration Wizard

Figure 6 shows how IES allows a user to pick from a library of pre-built HVAC system configurations if so desired and includes a diagram of how ventilation air and zone conditioning is achieved. In the diagram, the use of System shows components that would be specific to the DOAS unit and the use of the term Room/Zone shows the zone fan coil as well as the ventilation diffusers both serving one zone.

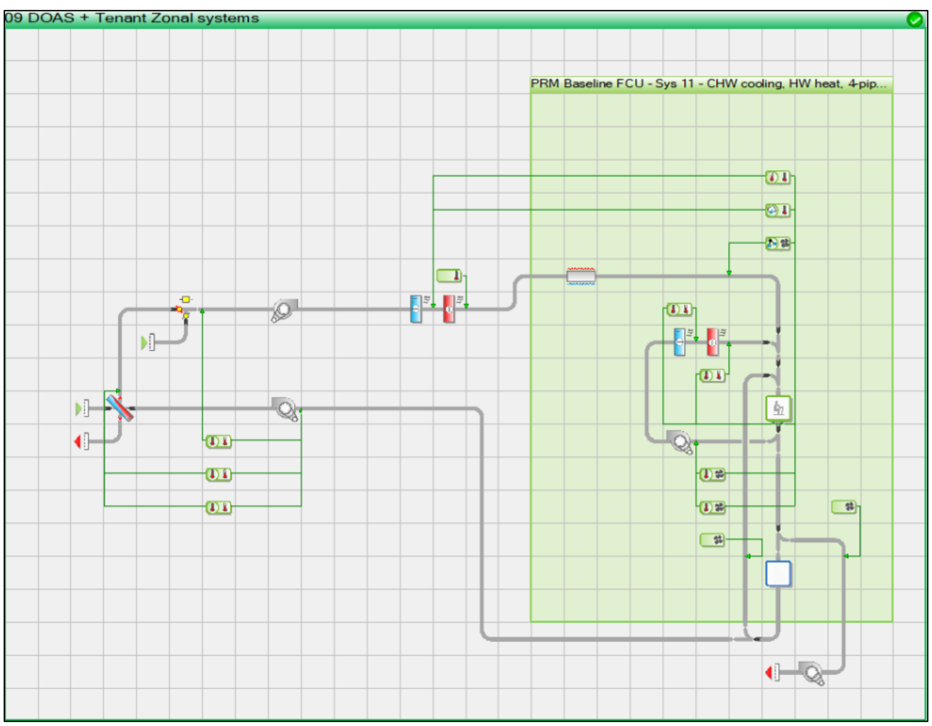

Figure 7: DOAS Configuration Example of VE-IES Software 2022.1.1.0

Figure 7 shows the result of this system in IES components, where objects can be individually enhanced to best represent the efficiency and controls of a system. IES allows for groups of zones to be represented here as a lite green box, where each zone has it's own individual elements which are all based on the configuration shown.

eQuest/DOE2.3. In eQuest, running DOE2.3, the wizard building tool does have a feature for configuring DOAS and will create a zone level system that can operate independently from the dedicated ventilation only unit or be integrated on the mixed air side. The linkage between systems is less obvious and relies on selections in each system discretely. This linkage is made as part of the outside air input for each space conditioning unit, or zone systems as illustrated in Figure 7. DOAS systems can directly serve the conditioned space served by a zone system, or can be linked to the mixed air input of a zone system. For VHE DOAS models, DOAS systems should be directly linked to the conditioned space, and will influence the return air temperature and humidity associated with the zone system serving that space.

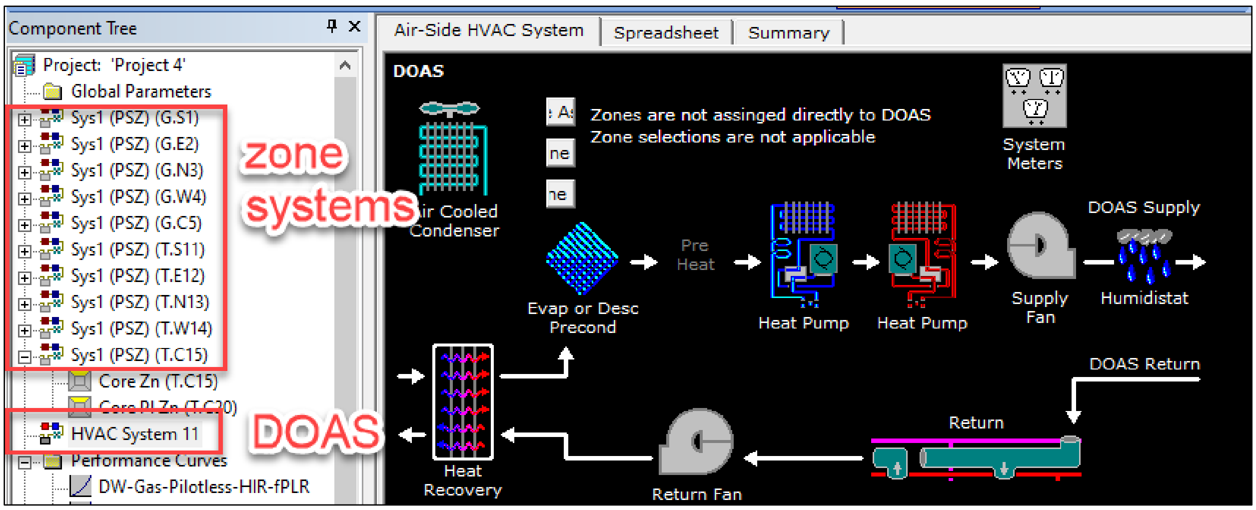

Figure 8: DOAS Configuration Example of eQuest 3.6.5 Software

EDSL-TAS. EDSL-TAS has a similar structure to VE-IES in providing users with a wizard and component based diagram to develop the DOAS system model input. TAS uses the term Grouped Mechanical Ventilation to refer to a common DOAS unit serving multiple zone elements.

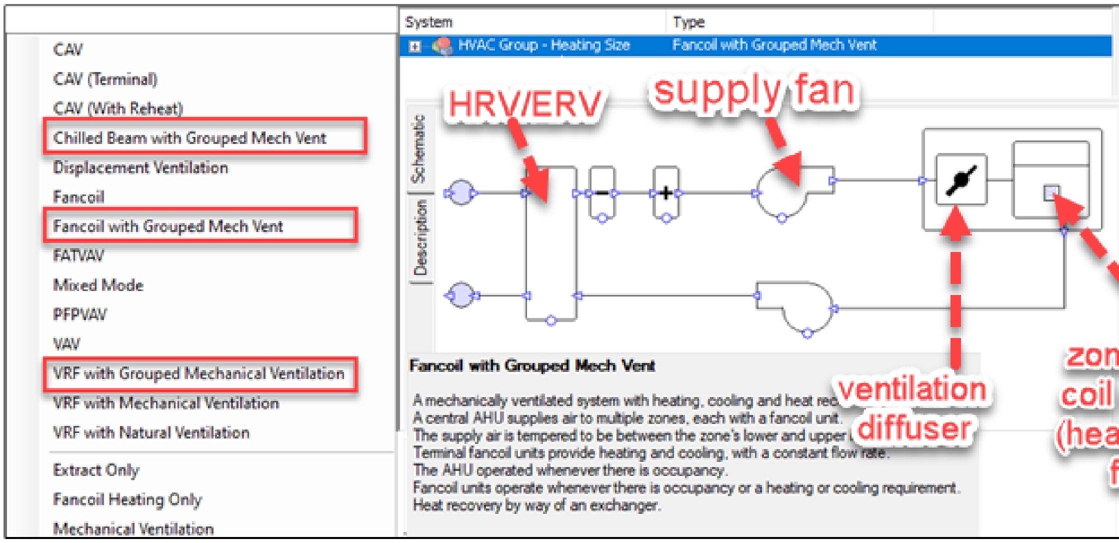

Figure 9: DOAS Configuration Example of EDSL-TAS Configuration Wizard

Figure 9 shows how a user can pick from a library of pre-built HVAC system configurations if so desired, similar to VE-IES.

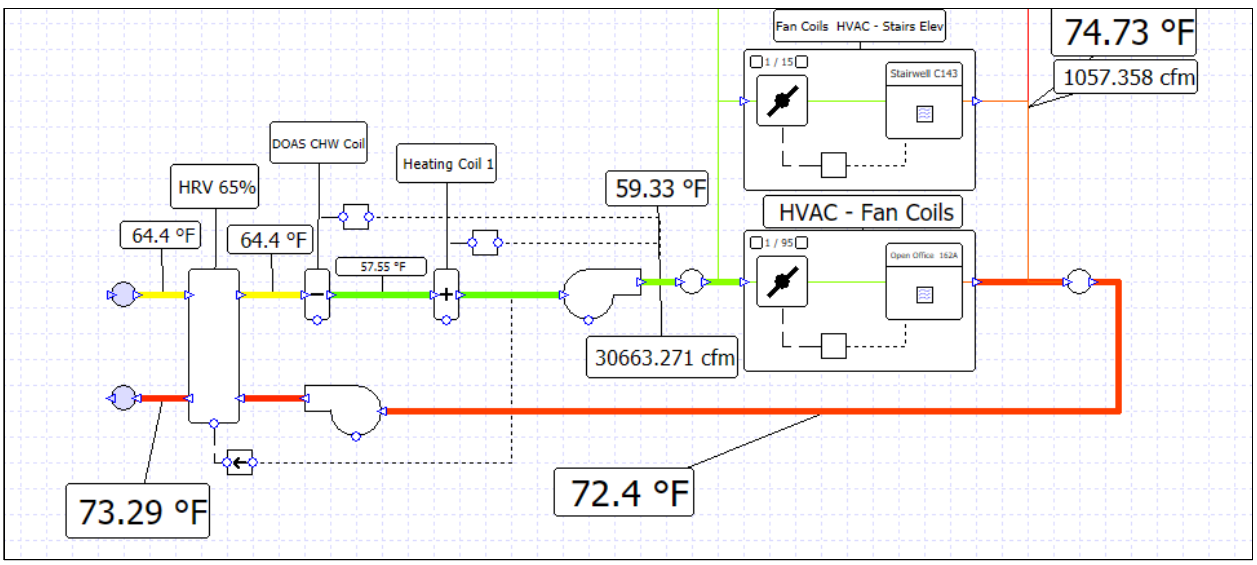

Figure 10: DOAS Configuration Example of EDSL-TAS Software version 9.5.2

Figure 10 show the final TAS HVAC interface, where system components can be further refined for efficiency and controls to match a system's design. Similar to VE-IES, zone components are able to be grouped together as shown in the figure above for visual simplicity in the diagram.

4.2 Key Items for System Configuration

Within each energy modeling software package, there are a few key things to verify when setting up the components. These are discussed below.

Verify ventilation rates and size of DOAS unit.

Ensure the DOAS air loop is sized just for ventilation flow rates versus air flow rates required for full cooling. In some software and early design, it is common to use auto-sizing to simulate energy modeling components. In several simulation software defaults, such as EnergyPlus, air loops initially set up will default to full cooling (see Figure 10) when sizing and result in much larger systems than are being installed. Ventilation air flow rates are most often determined by code requirements, not heating or cooling loads. Modelers should take control of the ventilation air flow requirements directly, on a zone-by-zone basis. Air flow can by input in several ways.

- Ventilation air flow per zone, in cfm: The modeler will need to execute external code calculations, or obtain this information from the ventilation schedule in a completed design.
- Ventilation air flow per zone, in cfm/person: This approach can use an input directly from a relevant code document, such as ASHRAE Standard 62 but will also rely on an appropriate input for peak occupancy. Care should be taken that the appropriate air flow rate is ultimately being used by the model.
- Ventilation air flow per zone, in cfm/sq.ft.: This approach can use an input directly from a relevant code document, such as ASHRAE Standard 62 but may still need external calculations to confirm total zone level ventilation air flow rates.

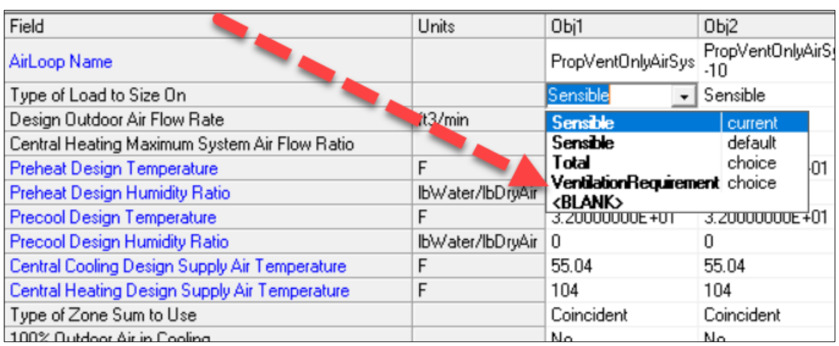

Figure 11: EnergyPlus example for sizing air loops to ventilation only

Control zone heating and cooling systems for off-hours temperature control and keep ventilation off.

When a building is unoccupied, it is common to enable the HVAC system to still be able to operate and maintain the zone temperature setpoint, as defined in a thermostatic schedule. In an energy model, enabling the HVAC system to turn on when the temperature of a zone drifts outside of the unoccupied period thermostat setpoints is often referred to as night cycling, since the majority of the time this occurs is at night. This can, however, occur during the day, such as on weekends, and can occur in cooling mode as well as heating mode.

Different input approaches are used to allow an energy modeler to configure and control this function in combination with a separately controlled DOAS. Irrespective of the modeling platform, the general principles are the same.

The following principles are recommended.

- Input zone heating/cooling systems separate from the DOAS unit.
- Schedule the operation of the DOAS on a separate unique schedule from the zone heating/cooling systems. In general, the DOAS should operate continuously during the occupied periods, and be de-energized completely during unoccupied periods.
- Control zone heating/cooling system fans using a separate schedule that aligns with the thermostat schedules and defines the occupied period.
- Control zone heating/cooling systems based on a thermostat schedule that includes unoccupied period setback/set-up of temperature setpoints.
    - Allow fans to cycle on and off during the occupied period. (Note that the DOAS will be operating continuously during the occupied period.)
    - Allow the heating/cooling systems (in their entirety) to cycle on during unoccupied period to maintain unoccupied period thermostat setpoints.
    - This may require specifying the temperature drift allowed before cycling a system on.
    - This may require defining how long a system should then operate, either until the setpoint is maintained or for a set duration of time, such at 15 minutes in software that allows for sub hourly calculations.

In general, the energy model should be defined to match the control design intent, if known at the time of developing the model.

Ensure any zone fan coil systems do not introduce ventilation air directly.

While this can be a rare occurrence, some energy modeling software and system components can, by default, be configured to introduce outdoor air even if a DOAS unit is included in the model. This option is not applicable for all modeling software, though in EnergyPlus, specifically seen in VRF fan coil systems, these devices can be configured with ventilation air directly pulled into each unit. In OpenStudio (which utilizes EnergyPlus), the default VRF fan coil sets the ventilation air input to autosize instead of being set to zero, which will result in the unit auto-sizing for the ventilation airflow. This can result in duplication of ventilation air and incorrect thermal loads.

As with any modeling inputs, the output verification by the modeler should be undertaken to confirm that input intent is being modeled.

Proper staging of zone ventilation and conditioning systems.

Not all energy modeling software allows the user to see or change the order of conditioning that occurs between the two systems serving one zone at each timestep of the analysis. However, EnergyPlus allows for this functionality. As shown in the configuration section above, the equipment can be defined in a specific order of priority with regards to what system provides cooling or heating first.

As a default, it is recommended to stage the ventilation first in an energy model to avoid unmet thermostat hours or un-conditioned loads. If configured incorrectly, and a space conditioning system is the first system at each time-step of the analysis, the model may result in significant unmet thermostat hours from ventilation air, and ventilation load, being introduced second and either over cooling or overheating a space. Setting the ventilation DOAS unit, via a terminal air diffuser, to act in the first position ensures the thermal load is maintained. Note, this sequencing can get more complicated for DOAS units with active cooling or heating, which will be discussed in configuring controls later in this guide related to controlling DX-DOAS units.

5. System Efficiency Inputs for VHE DOAS in an Energy Model

While the referenced document for VHE DOAS requirements outlines the minimum efficiencies for a system, this section provides additional guidance and default assumptions for an energy modeler to consider.

5.1 Ventilation system fan power

In a DOAS, ventilation system fan power includes the power of both the supply and exhaust fans, typically within an HRV/ERV unit. This does not include small, dedicated exhaust fans such as those for restrooms which would otherwise be used regardless of the type of HVAC system.

In DOAS systems, ventilation fan power input and associated energy use is often over-estimated. One of the reasons for this is the use of peak design power, rather than anticipated operating power to guide model inputs. While most small and medium non-residential buildings use near constant volume systems, most operate at very low fan pressure, resulting in low energy use. For larger systems, variable speed motor considerations also need to be addressed for both peak and average operating conditions.

Engineering design documentation can be difficult to interpret at times, as a modeler is attempting to determine appropriate fan operating power input. A design may be trying to envision the worst-case-scenario or in some instances provide flexibility in an HVAC system, by providing a ventilation system with enough power to handle worst-case or future conditions. In smaller systems, not all design documentation will even include design operating power information and only define the nominal size of a fan motor, which will almost always result in an excessive fan power input if not appropriately adjusted by the modeler.

The following steps are recommended to determine reasonable operational fan power:

1. The total fan power for the supply and exhaust fans will be in the range of 2 cfm/watt to 1.3 cfm/watt.[1]
2. 0.5 to 1.0 W per cubic feet per minute of supply air (cfm). Fan power inputs outside of this range should have specific design and/or operating documentation to support the inputs.
    a. Review design documents, or equipment submittals, for specified system operational power. This is often listed as brake horsepower, for supply and exhaust fans. Ideally, this information will also include air flow rate, in cfm, and total static pressure (TSP) at the design air flow rate.
    b. In some mechanical designs, it can be common to only list the motor size, in horsepower, and the external static pressure (ESP) for system balancing. In this instance, it is recommended to calculate an estimated operational power, making the necessary assumptions to use the fan shaft power formula below or, requesting information from the DOAS unit submittal.

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

    This formula will require an assumption for the fan efficiency, motor efficiency, and the units internal static pressure (ISP), where:

    TSP = ESP + ISP

    Fan efficiency highly depends on the fan type and design, though will range from 40% to 60% in most applications. Motor efficiency is dependent on size and type, and ranges from 85% to 93%. As a starting point, projects can assume an ISP of 3.6 inches for both the supply and exhaust fan together, which is based on an assumption of the unit meeting the VHE DOAS requirements for the unit and having a fan at 60% efficiency and 92% efficient fan motor[2].

[1] Airflow in cfm includes supply air only. Power in watts represents he power of the supply and exhaust fans.

[2] VHE DOAS requirements require units be capable of 1.3 cfm/watt when operating at 0.5” of ESP.

c. Based on evaluation of field sites that have implemented VHE DOAS, a range of fan power between 1.3 to 2.7 cfm/watt is achievable (0.77 W/cfm to 0.35 W/cfm).

d. If a VHE DOAS unit is being installed in Washington State to the 2018 or later standard, units must at least meet a requirement of 1.0 W/cfm and for projects following the DOAS efficiency package in section 406, total fan power must achieve 0.5 W/cfm (2.0 cfm/W) based on the standard.

5.2 Ventilation heat recovery efficiency

Proper modeling of heat recovery efficiency depends on an understanding of how the energy modeling software package is using the term, and if the value provided by a design or equipment submittal is in alignment with a particular modeling package. In most energy modeling software, the required heat exchanger input is the effectiveness of the device, assuming balanced air flow. Different modeling packages have differing input requirements and structure, such as:

- 1 value, for both cooling and heating effectiveness.
- 2 values, 1 for cooling, 1 for heating effectiveness.
- 4 values, 2 at full flow and 2 at 75% flow to match the older test procedure of these units.

While the air flow balance between the supply and exhaust sides of a unit can impact effectiveness, it is recommended that modelers carefully consider whether to input imbalanced flows into the model or to take air flow imbalances into consideration outside the energy model via manually calculated adjustments to the modeled results. Some modeling software packages do allow for unbalanced airflow to be input, but it can add a level of complexity which may create more errors than improvements in accuracy, and will clearly require more output verification effort to insure that the modeled effectiveness and fan power is accurate.

5.3 Zone system fan power

Similar to small DOAS units, it can be very common for a design of zone fan systems to only list the nominal motor size and provide no information on the operational fan power or fan pressure. In the case of limited information, the following recommendations for how to estimate fan power input are provided:

1. Peak fan power should be within the range of 0.3 to 0.65 watt/cfm, based on and subject to the criteria listed below. Fan power inputs outside of this range should have specific design and/or operating documentation to support the inputs.

   a. Most fan cassettes or fan coils operate at 75% or less of rated motor capacity

   b. Fan power can always be estimated based on an average total-static-pressure for a system and then verified with the design engineer if numbers seem reasonable. Often non-ducted systems will be 0.75 inches or less of total pressure, ducted will be 1.5 inches or less.

c. Several energy codes, including ASHRAE 90.1 and California's Title 24, include criteria with regards to fan-coils and fan powered terminal units to be designed for no more than 0.35 W/cfm. This can be another source of an assumption and is equivalent to estimating a total pressure of 1.2 inches with a 45% efficient fan and 92% efficient motor.

d. In most modern fan cassettes or fan coils, airflow can be varied and, at times, completely turned off. Most fans will restrict the lowest airflow to no less than 60% based on field observations from three-speed fan cassettes. This can still enable fans to use less fan power than no part-load control, yet the turn down capabilities are not as great as other fan systems. The greatest energy savings and criterion of VHE DOAS is the ability to fully cycle fans off when not in use. This is addressed in subsequent sections.

6. Controlling VHE DOAS in an Energy Model

The following sections describe the primary control sequences for the ventilation components of a VHE DOAS system. While each can be represented in an energy model, they should be discussed with the design or construction team to verify they can be implemented with the equipment being installed.

6.1 Ventilation Bypass and Supply Air Temperatures

Background

With HRV/ERV DOAS units, the ability to bypass the heat/energy recovery device can be used to provide some degree of outside air economizer (or free cooling) functionality during mild outdoor conditions and/or as a means of maintaining a supply air temperature setpoint. Figure 11 conceptually illustrates an exhaust air bypass configuration.

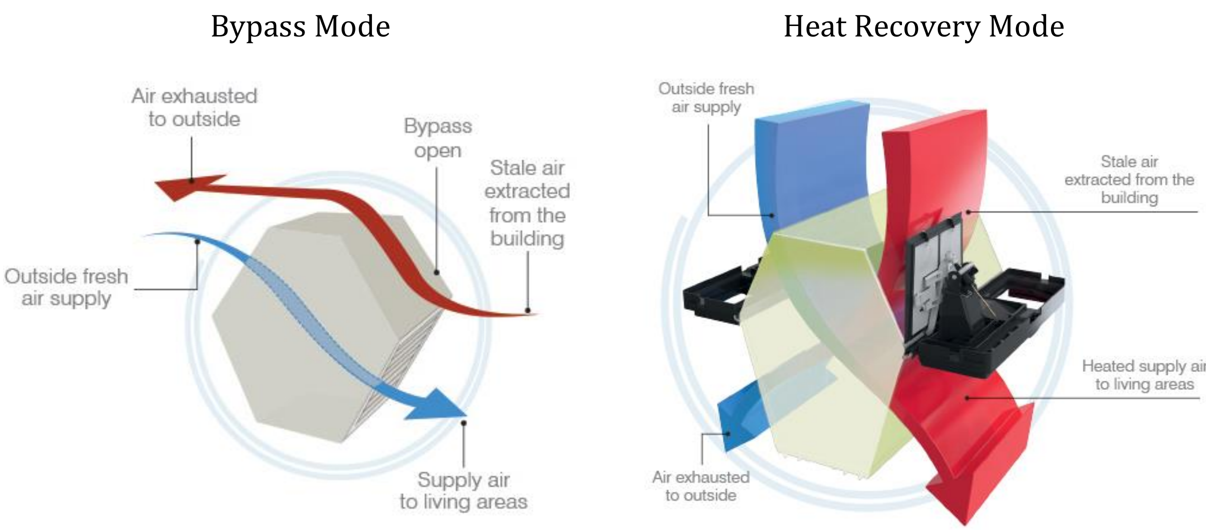

Figure 12: Bypass airflow pathway of HRV/ERV Core (image from: energyrecovery.com)

Bypass capabilities include two forms of functionality – non-integrated and integrated. With non-integrated bypass, the heat recovery device operate with full flow through the exchanger or full bypass of the exchanger depending upon control parameters. With integrated bypass, air flow is modulated from partial bypass to full, often controlling the amount of air that is bypassed to achieve a set supply air temperature. Integrated bypass expands the free cooling benefit the device can achieve and, as a result, can save more energy. As one example of how bypass capability can be configured, the Washington State 2021 energy code provides language on a DOAS economizer bypass component in section 406, requiring the unit be capable of bypass within a set range of temperature (see below).

> 2. Where design outdoor airflow is greater than 500 cfm (250 L/s), the DOAS shall be equipped with an economizer bypass, damper control, or wheel speed control that is active between 55°F (13°C) and 75°F (24°C) and minimizes energy recovery or maintains an appropriate DOAS leaving air temperature when the building is generally in cooling, based either on outdoor air temperature or a DDC zone-based cooling system reset.

While this language provides guidance for engineers, it leaves the interpretation of full integrated or non-integrated bypass un-answered. Based on field testing and system operations, integrated bypass systems, where bypass starts at 55F and is fully enabled at 60F or 65F can be the most advantageous control for minimizing heating and cooling energy.

How to Implement in Energy Modeling Software

Bypass capability for supply air temperature and economizer cooling functionality is supported in varying degrees of complexity in the commonly used energy modeling software packages. For the detailed discussion below, EnergyPlus and EDSL-TAS capabilities are referenced.

In EnergyPlus, Figure 13 shows two different lock outs which can be specified in the Air to Air Heat Exchanger object. The Economizer Lockout field enables the unit to operate in a non-integrated model, either full bypass or full heat exchange. The second way to control the unit for bypass utilizes the feature of 'Supply Air Outlet Temperature Control' in the Air to Air Heat Exchanger object will allow for full integrated bypass control.

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

Figure 13: Heat Recovery bypass example from EnergyPlus

Either lockout controller can be used independently of the other. In EnergyPlus, the bypass toggle for the heat recovery device (Figure 12) works together with the outdoor air controller economizer inputs for upper and lower limits (Figure 13). It can be common practice to only define an upper limit of an economizer lockout and the lower limit is left blank. If configured this way, the software may unintentionally maintain bypass mode to well below the desired cutoff, often down to 45F. Not specifying this input can result in very low heat recovery.

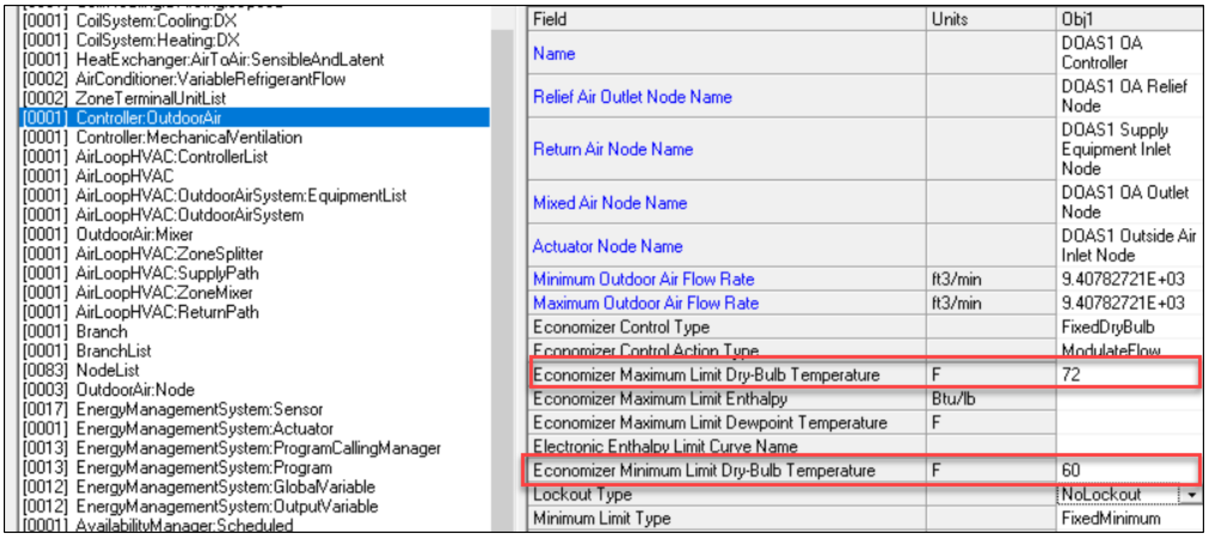

Figure 14: EnergyPlus Economizer Limit Controls

When using the supply air outlet control, a supply air setpoint manager must be utilized.

The EDSL-TAS and other software, such as VE-IES, allow for a more visual representation of bypass control of an air to air heat exchanger in an energy model and can enable 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 the outdoor air dry-bulb, bypassing when the outdoor air is above 42F until it is 65F and fully open.

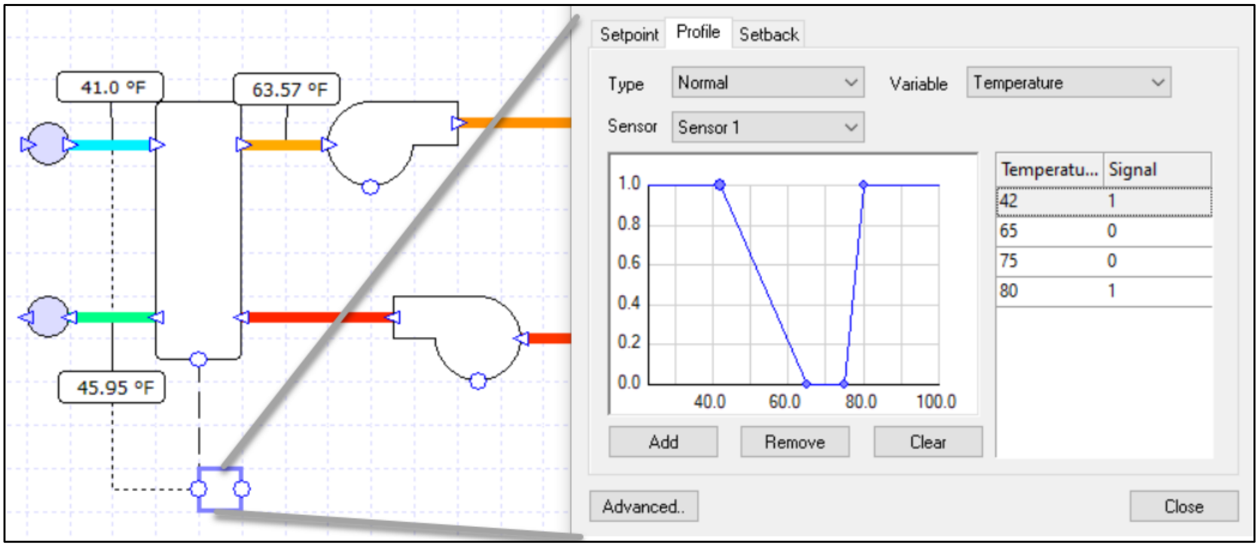

Figure 15: Heat recovery bypass example from EDSL-TAS

From Figure 15, between 42F and 65F, the unit operates in partial bypass with some air bypassing the heat exchanger, between 65 and 75F, the unit is in full bypass, and between 75F and 80F, the unit is in partial bypass again.

While more dynamic signals can be simulated with an energy model, such as resetting the setpoint based on outdoor air or based on whether each zone needs either heating or cooling, these functionalities are not commonly seen in packaged HRV/ERV DOAS controllers. Some units will implement a seasonal setpoint reset, shifting the setpoint from 60F in summer to 70F in winter. However, in evaluating this level of control, it is important first to verify that the units in consideration for a project are capable of such functionalities, and then to verify that the energy modeling software package can appropriately model such control sequences. This includes an honest assessment of the energy modelers understanding and experience in applying those modeling features. In the case of custom controls, a requirement and specification should be defined and provided for a unique control functionality, and modeling time reserved for iterative runs with output verification to document that the unique control sequences are being modeled appropriately

6.2 Zone system Unit Controls for Fan Cycling

Background

In a VHE DOAS system, ventilation air is required to be decoupled from space conditioning, and delivered directly to each zone or downstream of any zone system cooling and heating element. A visual of several ventilation configurations is shown in the diagram below, with two examples on the left being configurations that would be considered decoupled.

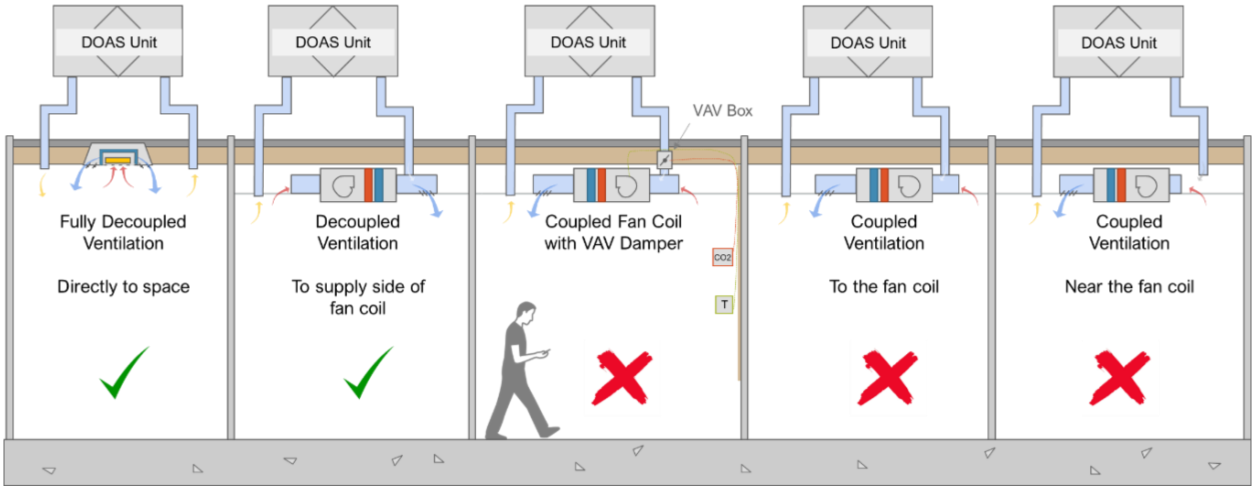

Figure 16: Illustrations of Ventilation Ducting Configurations in DOAS Systems

In both decoupled configurations, the zone fan cassette, fan coil, or other zonal system is decoupled from the ventilation pathway. This enables the unit to be able to modulate airflow to fully off when there is no need for heating or cooling. While zone fans can represent small power consumption on an individual basis, the sum of all of these fans running at low speed can significantly increase fan energy use if they are unable to cycle off.

How to Implement in Energy Modeling Software

In configuring an energy model, it is important to choose a zone system type that has the capability to cycle fully off, and then be configured within the system input to enable this capability throughout the operating period of the unit.

In some software, zone fans can also be specified to operate at multiple speeds or with a fan curve. Representing multiple speeds at reduced power is also important if it can be simulated, although cycling fully off is ultimately the most important fan control feature. Simulating cycling zone fans in most energy modeling software will capture the majority of the fan energy savings of the zone fans if multi-speed capabilities cannot be simulated or are beyond the time available to implement.

As an example, in EnergyPlus, the FanSystemModel component can be used to best represent zone fans in small fan coils or fan cassettes. The object allows for multiple ways to set and control fan speed and power, allowing set speeds at set power ratios as a function of the total power or, utilizing a fan curve. In Figure 16 below, a fan curve is defined and referenced that sets a minimum fan power limit of 60%. With the Speed control Method set to continuous, this input will not allow cycling and will run continuously when occupied. To enable full cycling the fan curve would need to be revised and have a minimum limit of 0%.

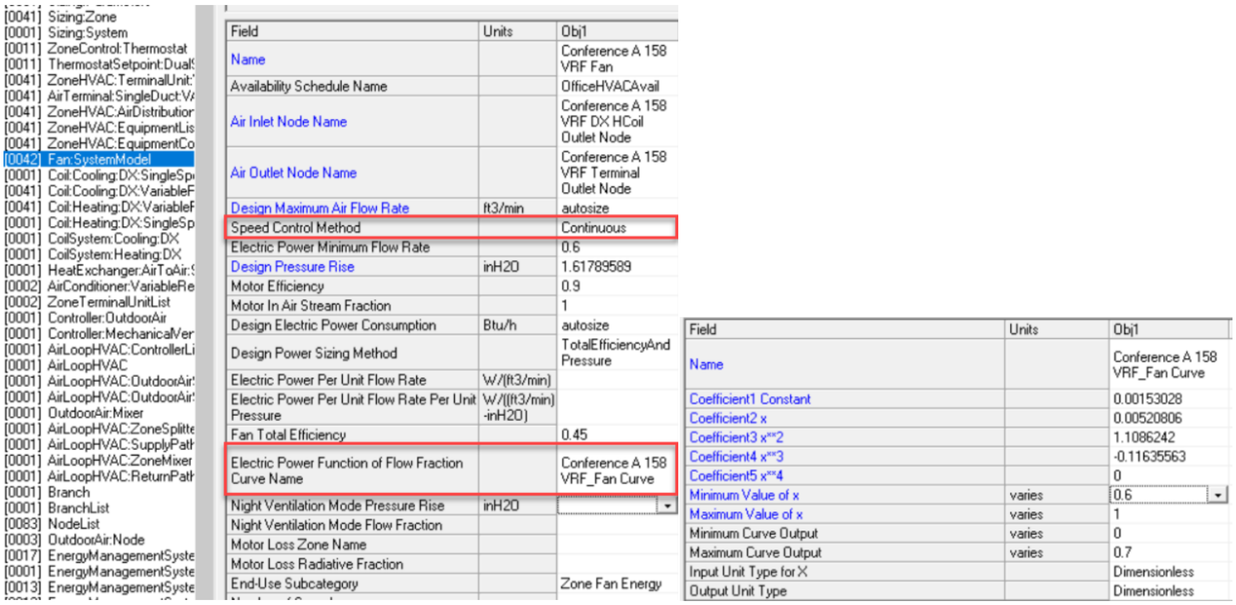

Figure 17: Zone fan element in EnergyPlus with fan controls

The figure above shows the fan curve used to control the power as a function of airflow and thermal load. As the load in the zone is decreased, the fan power is reduced. In this example, fan power can only be reduced to 60% and is a coupled ventilation configuration. If zone fans are unable to be set with capabilities to very speed to fully off, it is recommended to select fans which cycle on and off. Cycling fully off accounts for the majority of fan savings in these systems based on field observations and energy models.

6.3 Active Ventilation Cooling and Dehumidification

Background

Active cooling or dehumidification in DOAS units is sometimes required for buildings with high latent loads and a potential indoor moisture concern. While active cooling can be utilized in a DOAS unit, it is first and always recommended to evaluate if the outdoor air and ventilation rates in West Coast climates truly need dehumidification capabilities or if indoor moisture levels can be maintained with dry, outdoor air only. As an example, for a conference room with 33 sf/person, 155 Btu/person of latent heat and 0.5 cfm/sf of ventilation, the supply air dewpoint would need to be between 55F and 60F to maintain an acceptable range of moisture.

For system designs that implement DOAS units with active cooling, it is important to configure an energy model to properly control the DOAS cooling device and the zone cooling device to properly represent the quantity of air conditioning each system provides.

From field observations, two different buildings with a DX-DOAS unit only enabled at warmer outdoor air temperatures was greater than 65F, when outdoor dewpoint was high. At both sites, the DX-DOAS unit did provide some conditioning though was less than 20% of the total thermal conditioning.

How to Implement in Energy Modeling Software

In the energy model, recall the recommended configuration for a DOAS and zone fan coil system is to enable the DOAS unit to act as the first stage of zone conditioning. While this eliminates any unmet hours, using EnergyPlus as an example again, without a special set of controls, configuring a DOAS unit to provide the first stage of cooling and heating when there is an active cooling element will result in the majority of the cooling coming from the DOAS cooling coil versus from the zone fan coil system, which does not align with as observed operations. In most system configurations, the DOAS cooling component is less efficient than the space cooling units due to dehumidification requirements. If an energy model assigns most of the cooling load to the DOAS unit, cooling energy estimates will likely be higher than actual empirical data suggests.

It is recommended, therefore, to ensure any energy model with a DOAS cooling coil implements a limitation to only utilize the cooling element during conditions where it is intended to be enabled. In EnergyPlus, an Energy Management System (EMS) script was developed and included in the appendix to enable or disable the DX DOAS coil based on the outdoor air temperature for the site. This simple control allowed the cooling energy to best reflect field observations of installed systems.

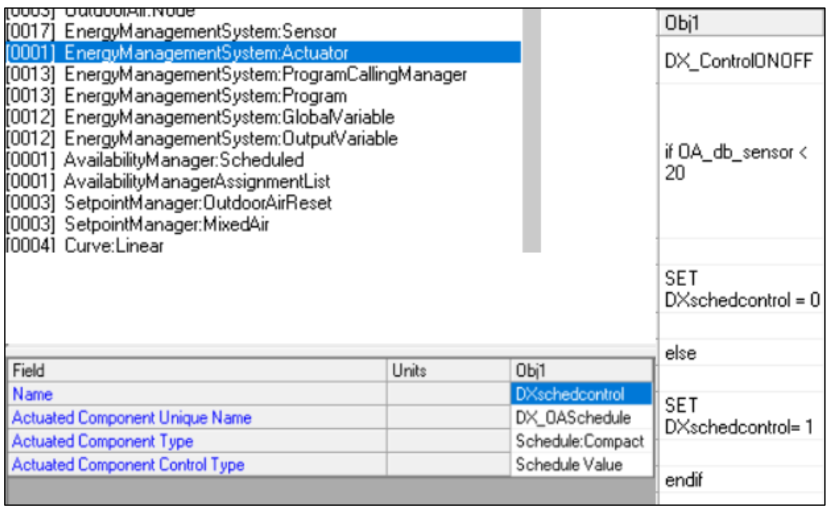

Figure 18: EnergyPlus EMS script to limit active ventilation cooling

Figure 18 shows a few of the EMS components in EnergyPlus, where the script creates a schedule used to operate the DOAS cooling component.

Other energy modeling software packages and energy modelers will have their own approaches to limiting the cooling energy used by a DOAS with mechanical cooling capability. As always, the modeler should develop informed inputs, and iterative verify input intent with output review.

6.4 Demand Control Ventilation

Background

Though not all buildings with a VHE DOAS system will have demand control ventilation (DCV), where DCV is used, it will typically only be enabled in some of the rooms in a building, such as conference rooms. This is typically implemented with occupancy based damper controls that close off air flow to certain rooms when they are unoccupied or experiencing significantly less than peak occupancy conditions. Configuring DCV will primarily reduce fan energy since fan power is reduced by the cube of the airflow reduction. Assuming fan speed controls are optimized, a 10% reduction in airflow will translate to a 27% reduction in fan power.

How to Implement in Energy Modeling Software

To represent DCV, most energy modeling software will approximate the benefit by using a fractional airflow profile which tracks with occupancy profiles and reduces the zone ventilation when occupancy reduces. In most energy models, ventilation requirements are specified in each space or thermal zone and defined as a peak ventilation rate and can include a fractional airflow profile. Most modeling software will not automatically modulate ventilation to specific zones without further input definition and options selected at air terminal units and/or at the DOAS air system itself consistent with the anticipated functionality of the DCV controls for a given system.

As an example, in EnergyPlus, air system input includes a toggle for enabling DCV. To fully enable DCV in EnergyPlus also requires specifying that zone terminal units actively track ventilation criteria during the simulation. The zone components required to be enabled are shown in Figure 18 below.

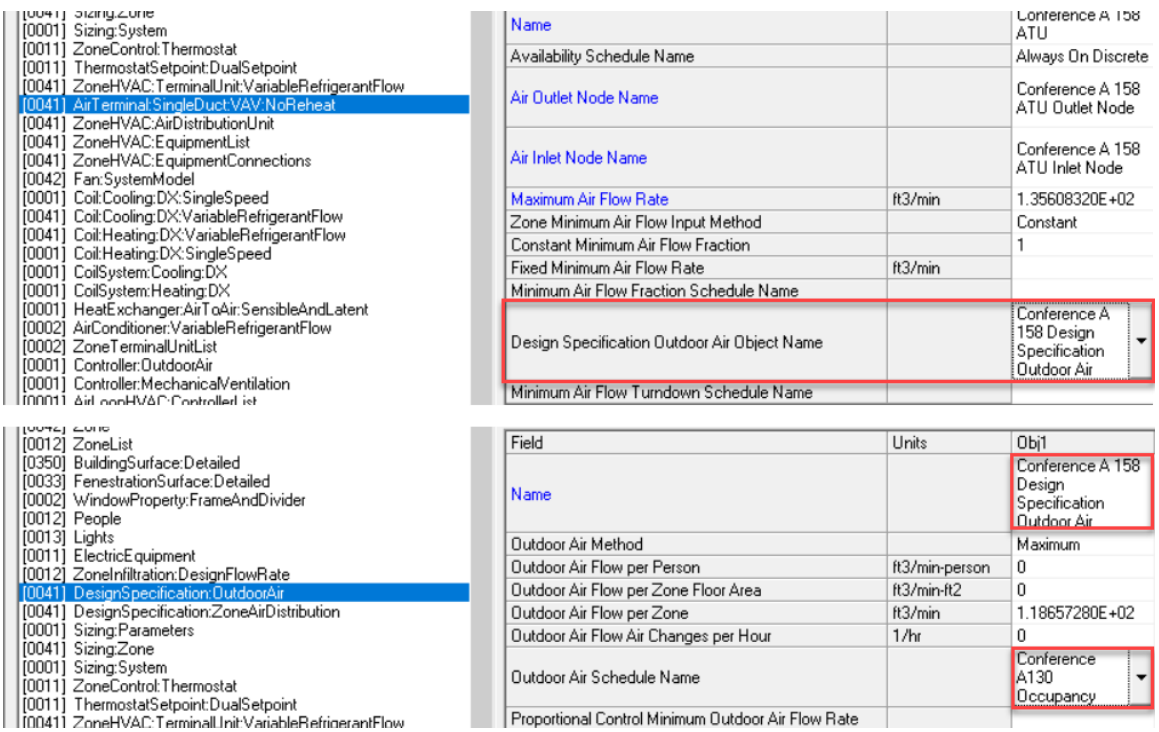

Figure 19: EnergyPlus example of zone inputs required for DCV

In EDSL-TAS, air system flows default to the peak zone ventilation rate though this can be adjusted to actively track and update ventilation requirements for each timestep. The zone air terminal requires a controller to actively review the ventilation needs and each zone group requires the fresh air rate method be set to an hourly option. In this case illustrated in Figure 19 below, it is set to Hourly Internal Conditions, and results in air flow rates tracking occupancy schedule.

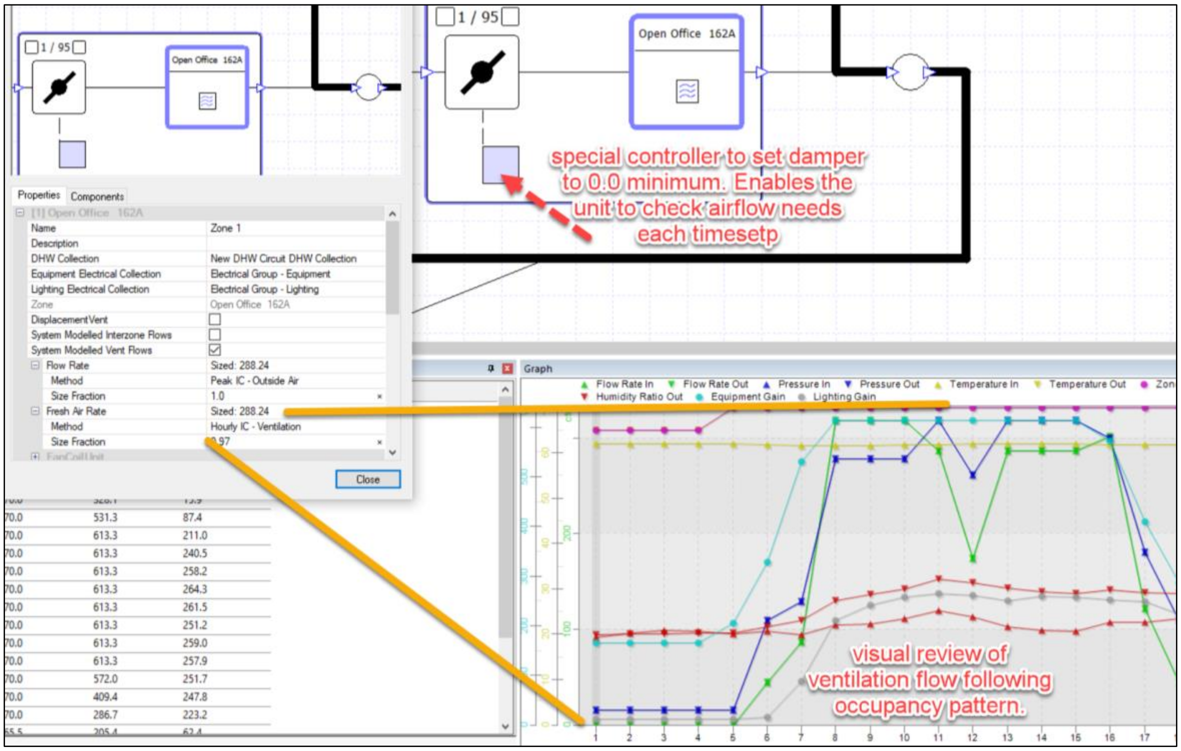

Figure 20: EDSL-TAS Example of zone components to enable DCV

Regardless of the degree of explicit modeling capability within a particular energy modeling software package, it is incumbent on the modeler to undertake external calculations to develop reasonable air flow profile data, and to make sure that those profiles are represented in the model, both for air flow and for fan power. Careful and logical consideration of inputs and iterative verification of outputs is required.

6.5 Defrost Control of HRV/ERV DOAS

Background

In many HRV/ERV DOAS units, the heat recovery device includes an electric resistance heating coil that is used to prevent frost build-up on the heat exchanger device during cold outdoor conditions. This component is not always included in an energy model, especially for climate zones where colder temperatures are rare, and the use of this element is not anticipated to occur either when the building is occupied or in a typical weather year. When it is utilized, the area where frost can build up is on the discharge or exhaust portion of the heat exchanger.

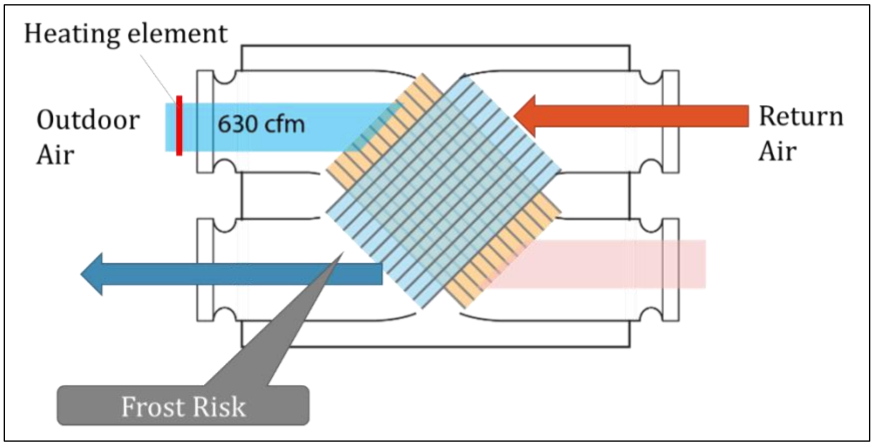

Figure 21: HRV/ERV DOAS unit frost risk diagram of location on the unit

For climates or regions where defrost control is being considered, the most common configuration utilizes an electric heating element on the incoming outdoor air (Figure 20) to ensure the exhaust air leaving the heat recovery device is maintained above a temperature that prevents frost.

How to Implement in Energy Modeling Software

In most energy modeling software, this configuration can be complex to implement and control. However, it can be explicitly modeled, and in cold climates, climate zone 5 and 6, can result in a more accurate energy estimate. As with any energy modeling comparison of two systems, if defrost control is simulated in a VHE DOAS system it should also be explicitly included in other standard systems.

A defrost control example, using EDSL-TAS is shown in Figure 21 The diagram shows a heating element pre-heating the outdoor air and controlled to only enable the heating coil when the air leaving the building drops below 41F. In the example, the air leaving is at 40.3 F and the heating coil is activated, pre-heating the outdoor air from 28.0 to 34.1 F. The example figure shows the dialog box for the coil controller.

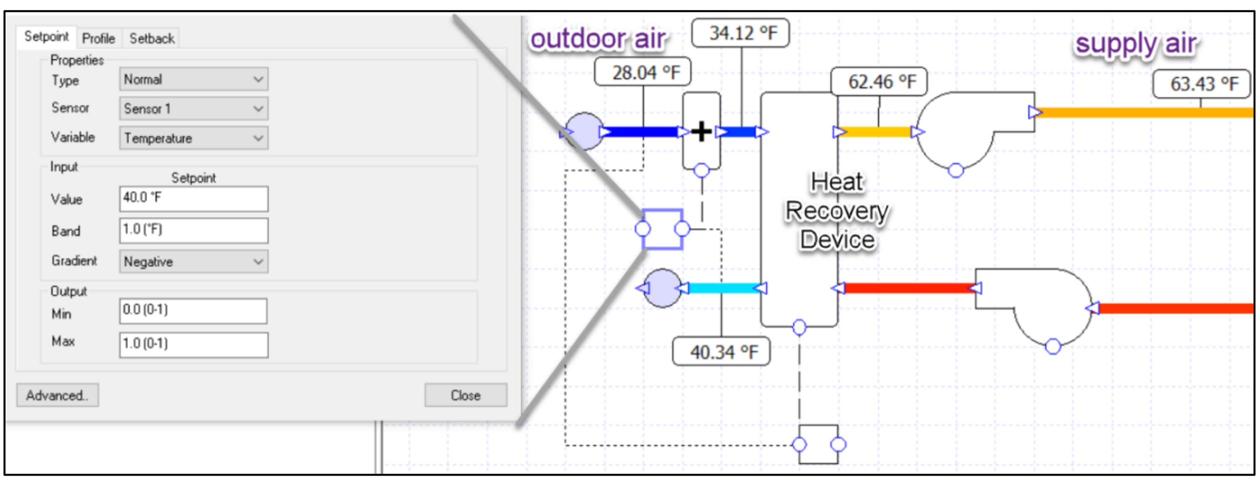

Figure 22: EDSL-TAS example of how to model defrost heating element

Figure 22 shows an example of simulating defrost in the same way in OpenStudio / EnergyPlus. The outdoor air path, shown at the top of the figure, includes a heating element as shown, and is controlled to ensure the discharge exhaust air node to a set setpoint. Thee heating element is only used when the control object detects the exhaust discharge air node is dropping below a set setpoint.

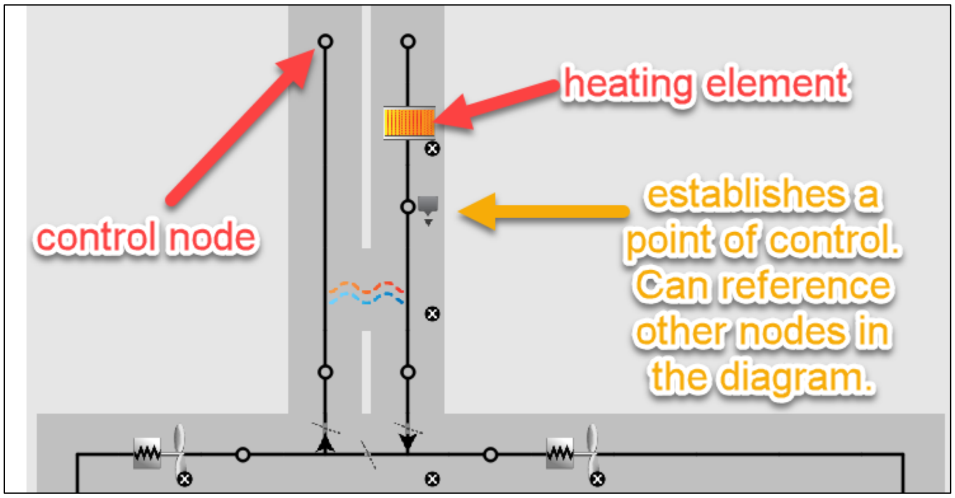

Figure 23: OpenStudio example of how to model defrost heating element

Active defrost control is also being researched, such as being able to change the setpoint and how sensitive the system is to operation. Other energy modeling software packages, such as eQuest, allow specification of preheat to maintain either fixed or optionally reset setpoints.

7. Representative Building Thermal Needs

Normally in evaluating new HVAC efficiency measures, the focus of analysis is to ensure system efficiencies and controls are best represented in an energy model for relative energy savings assuming all other factors are reasonable and will not dramatically change the outcome. However, throughout the calibrated building modeling process of each VHE DOAS site, and within the review of operational data from pilot projects, a reoccurring theme in building energy use is observed: most commercial buildings used more heating and less cooling than anticipated. While these findings apply to any commercial buildings and HVAC systems, it can be specifically impactful to a VHE DOAS where heating efficiency and the ability to reduce extreme heating loads from ventilation are fundamental components. Without addressing the following items, an energy model will often under predict the energy savings potential of VHE DOAS and over predict the energy efficiency of standard systems, such as single zone rooftop or multi-zone variable air volume systems.

Several lessons learned deserve consideration when defining the assumptions used to characterize a building and predict its thermal needs.

7.1 Observations

1. **Whole building energy modeling often assumes ideal thermal envelope assemblies and does not consider thermal bridging impacts.**

In most building energy codes, the performance pathway for simulated energy modeling does not consider the impacts of thermal bridging, assuming new buildings are able to meet the wall, window, and roof insulation values. The reality is that few buildings perform at the levels of thermal performance stated (WA 2018, ASHRAE 90.1 2019, IECC 2021) due to thermal bridging of multiple assemblies and protrusions. In cold climates, this gap in over-estimation of a thermal assembly will under-predict heating needs, assuming less thermal loss, and over predict cooling needs, trapping heat in a building when it may be mild, and heat would otherwise be lost.

2. **Most of the projects evaluated were major renovations of existing buildings with old envelopes and new HVAC and lighting systems.**

The structure and thermal envelope were significantly dated in several buildings, although building systems would be fully replaced, and interior walls and features updated. This form of an existing building with new systems represents a hybrid use case currently not represented in a specific set of prototypical buildings. In many instances, envelope upgrades were not the primary focus of a renovation or were not considered by the building owner to be a priority. These hybrid buildings, with old envelopes and upgraded systems, represent a significant trend in construction renovation and an opportunity where very high efficiency systems for HVAC have shown a high potential for greater savings and better returns on investments than would otherwise exist in new construction.

3. **Building use was often lower for people, equipment, and lighting, than typical assumptions for the building and space type.**

In evaluating several small office buildings, the diversity of people fully utilizing each room or series of rooms was far less than is typically assumed in building energy modeling default assumptions. For example, conference rooms designed for 20 people and utilized for 2 or 3-person meetings. Further, several office buildings included larger multi-purpose areas for overflow workers or large functions, both of which occurred infrequently. Like people use patterns, equipment use of appliances or workstations was often far less than is assumed for office space types in energy models. Energy-consuming, heat-generating equipment such as servers were also consolidated quite frequently in small, dense closets and spaces such as conference rooms, closed offices, corridors, and workstations had fewer equipment gains locally or less frequently. Equipment estimations in energy models essentially serve two purposes, one based on quantifying the electrical needs directly and two the indirect heating loads this equipment generates.

For evaluating HVAC systems where the ability to re-capture heat and or produce heat from a heat pump efficiently are included, the proper estimation of internal gains can have dramatic impacts on the potential energy savings by influencing the size of the actual heating needs.

7.2 Recommendations

If internal condition assumptions for use and intensity can be defined by the energy modeler for the type of analysis being conducted, it is best to try and find as realistic assumptions and studies as possible.

Specific items for office buildings identified during this study include:

- Recommend setting corridors to little equipment gains, 0.1 W/sf
- IT/IDF computer room closets are often served by dedicated systems, either rooftop units or mini splits. In creating an energy model, a recommended value from field observations is 5 to 15 W/sf if no information is available. Many are designed for higher capacities yet operate below this limit.
- Open offices, closed offices, equipment electrical gains only, such as workstations, tend to be 0.7 W/sf at peak, depending on the density of seating. Seating density with a representative workstation of components should be developed based on the ASHRAE RP project from 2015 as a source of determining realistic W/sf.
- Conference rooms may be designed for high-capacity equipment needs yet should have schedules of diversity set to work-patterns for the building type. Few conference rooms function for all hours of a buildings operating hours, most tend to be used infrequently and at key times, early morning, and afternoons.
-

8. Verifying a VHE DOAS Energy Model

This section provides two sets of information for energy modelers to use when checking to verify that a VHE DOAS energy model is configured and controlled correctly in the absence of measured data or empirical experience with these systems.

8.1 Simple Validations

The following are simple checks of modeling inputs across the whole building or systems which can be done to verify that inputs are reasonable.

1. Check the ventilation total airflow rate. In many commercial buildings such as offices, ventilation may be between 0.1 cfm/sf and 0.2 cfm/sf. In buildings with more occupants per floor area, such as schools or assembly spaces, ventilation tends to be between 0.3 cfm/sf and 0.5 cfm/sf. In the case where a model is auto sizing or generating ventilation requirements between 1.0 cfm/sf or greater and the building is not a laboratory or other process-intensive space, the model is most likely not configured correctly.
2. Check the DOAS fan power. In some buildings, the exhaust fan is not necessarily located in the DOAS unit, so ensure you count the power of both supply and exhaust fans. The total power should be between 0.25 W/cfm and 1.0 W/cfm[3] in most commercially designed DOAS units. Several systems may have higher power thresholds and the operational power should be confirmed with any designer if indicated to be above 1.0 W/cfm.
3. Check the annual fan energy of the DOAS unit and the zone fan coils.
    - In a typical commercial building running 3,000 hrs to 4,000 hrs a year, the DOAS fan energy will be between 1.0 kBtu/sf to 3.0 kBtu/sf in office type buildings.
    - Zone fan energy in offices will tend to follow this same range of energy use, with 1.0 kBtu/sf reflective of decoupled zone fan coils and 3.0 kBtu/sf reflective of coupled fans running during all occupied hours.

8.2 Evaluate Seasonality of HVAC Energy Use

Another verification step can be to review the month-to-month energy use of the energy model's HVAC energy use for cooling, heating, and fans.

[3] Power in watts includes the supply and exhaust fans and airflow, in cubic feet per minute, is only the supply airflow rate.

1. Most buildings with VHE DOAS in the Pacific Northwest, which includes ventilation bypass, will use very little cooling in winter and little to no heating in summer.
2. Fan energy will be relatively constant in a VHE DOAS configuration in smaller buildings without DCV. Seasonal changes in fan energy will primarily be from zone fans running more frequently to heat or cool.

8.3 Parametric Verifications

Ideally, an energy model can be used to understand the sensitivity of key assumptions or details that may not be obvious to a decision maker. This guide recommends focusing on key assumptions that are most likely to change how energy is used and using very basic logic about heat transfer and building physics to identify the assumptions.

Why would a building need more or less heating or cooling?

Heating and cooling energy are needed by a building as changing temperature conditions require energy to maintain a comfortable indoor environment. In winter, heat losses from the envelope, air leakage, or from a need to bring in fresh air from outside can drive heating needs. In summer, solar gains and internal heat emitted from equipment, body heat and lighting all require cooling to keep the building temperature comfortable. Because VHE DOAS systems are able to nearly eliminate ventilation heat gains or losses it is important to understand how frequently internal gains are high, and ventilation air could decrease cooling energy, or when internal gains are low and envelope gains are high, and ventilation air would increase heating energy. Review the results and inputs to be able to answer the following verification questions can help interpret an energy model and understand how beneficial VHE DOAS is in this instance:

1. Are the input assumptions for internal gains reasonable? Would changing these be realistic and if so, what would be the increase in heating or cooling?
2. Are we confident the building's envelope is perfectly built and meeting a performance level of air tightness? Thermal bridging and air leakage can significantly vary if there is no plan to inspect the final assemblies. If these were worse than anticipated, how would this impact heating or cooling?

Why would a building use more or less fan energy?

In most modern HVAC systems, zone conditioning system fans or pumps, such as VRF, fan coils or hydronic radiant systems with pumps, can be configured with variable speed drives, though in small HVAC, components still tend to use multiple set speeds of operation or are at a constant speed, cycling on and off. Small, packaged rooftop units are not required to have fully variable speed fans and may be limited to only running the airflow to 50% of the flow at 30% of the rated full power. Packaged rooftop units are the common baseline system for many VHE DOAS small commercial buildings, so being able to represent this baseline accurately can have a significant impact on energy savings. Review the results and inputs to be able to answer the following verification questions:

1. How are the HVAC systems being sized in the model, and is it representative of what would be installed? Would an oversized system have a larger fan and higher part-load airflow?
2. How many systems would have been installed in this building? Is the model set up with several small rooftop units, one per thermal zone, and is this how a system would be built? If there were fewer, larger zones, would there be a different part load fan power?

Are there HVAC controls which could drastically change energy use?

Supply Air Temperature Significance

In a DOAS configuration, the supply air setpoint of the DOAS unit itself can be very sensitive to how much heat recovery (or cooling recovery) the system is capable of doing. In colder climates, the use of a setpoint that is too cold, like 55F, may result in more heating since any heat recovery device is simply not used unless it is below this temperature outdoors. Evaluating multiple setpoints can be an important step to understanding energy use in a VHE DOAS configuration.

Thermostat setpoints

Thermostat setpoint prediction is a common challenge of any energy model since it is highly dependent on human behavior as well as operations practices in a building. If a building may be at risk of high thermal envelope losses or highly glazed areas which could create comfort challenges, a tighter thermostat setpoint may end up being set. Evaluating energy use with different ranges of control can be a way to inform energy sensitivity of one HVAC system versus another.

9. References

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10. Appendix: EnergyPlus EMS Script

The script below is written in EnergyPlus and used to create to control a DOAS cooling coil. The primary goal of this script is to properly estimate energy use for air conditioning, where a DOAS unit with cooling will often have a lower efficiency component compared with a zone-conditioning system. In EnergyPlus, the sequencing of a DOAS unit as the primary cooling device will tend to over utilize a DOAS cooling element and under utilize a zone-conditioning system based on every field site observed with this configuration.

The script limits the coil's operations based on a threshold of outdoor air dry bulb. The dry bulb limit used is based on a building operating in the Pacific Northwest climate and buildings with latent load densities such as conference rooms or school classrooms. While this control is not a perfect solution to maintaining a set indoor moisture level it is a reasonable approximation of how these components will operate given empirical evidence from multiple field operations.

The script is published as part of the Appendix E in the report

Energy Efficiency Analysis of Commercial DX-DOAS and ERV/HRV DOAS

Located at betterbricks.com

https://betterbricks.com/resources/energy-efficiency-analysis-of-commercial-dx-doas-and-erv-hrv-doas