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VERY HIGH EFFICIENCY DEDICATED OUTSIDE AIR SYSTEMS DESIGN GUIDE

UPDATED JANUARY 2023

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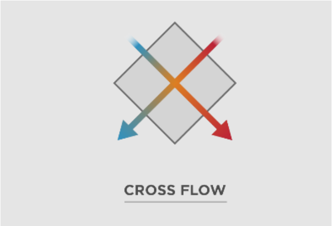
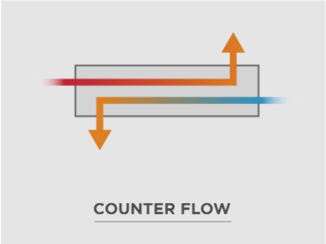
DEFINITIONS

TERM	DEFINITION
Air-to-air heat exchanger	An exchanger that transfers heat from an exhaust airstream to a separate supply airstream. The most common types are fixed plate, rotary wheels, heat pipes, runaround coil loops, and shell and tube.
Coefficient of Performance (COP)	(1) Ratio of the rate of net heat output to the total energy input expressed in consistent units and under designated rating conditions. (2) Ratio of the refrigerating capacity to the work absorbed by the compressor per unit time.
Counterflow heat exchanger	Heat exchanger in which fluids flow in opposite directions approximately parallel to each other; inlets for the two fluids are at opposite ends of the exchanger.
Crossflow flow heat exchanger	Heat exchanger in which fluids flow perpendicular to each other. Compare to counterflow heat exchanger. 
Crossflow leakage	Crossflow leakage occurs when air leaks from the exhaust airstream to the supply airstream of an energy recovery ventilator (ERV) through seals leakage, gaps in construction, or entrainment/carryover. 
Decoupled system design	An HVAC system whose ventilation and primary heating/cooling fans are controlled separately. A DOAS system is considered fully decoupled if the ventilation air is completely separate from the primary heating/cooling system. In contrast, a partially coupled system may have ventilation air ducted into the heating and cooling ductwork downstream of zone heating/cooling coils.
Dedicated outside air systems (DOAS)	ASHRAE defines DOAS systems as, "an air system that uses separate equipment to condition all of 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 HVAC units serving those same spaces. The local or central HVAC units are used to maintain space temperature."
Demand control ventilation (DCV)	DCV is a ventilation control strategy that provides automatic reduction of outdoor (ventilation)air below design rates when the actual occupancy of spaces served by the system is less than design occupancy.
Duct static pressure	The pressure reading in a duct, typically reported in gage pressure relative to atmospheric pressure. The total static pressure across a fan represents the amount of pressure required to overcome the resistance to airflow in a system's components and ductwork. If expressed as gage pressure, it may be negative or positive. In a dynamic system, static pressure is the difference between total and velocity pressures in H_2O (kPa).
Economizer function	The ability of an HRV to bypass heat recovery when outside air is cooler than inside air and cooling is needed in the building. This offsets some or all the need for mechanical cooling.

TERM	DEFINITION
Energy recovery ventilator (ERV)	An ERV provides both sensible (temperature) heat recovery and latent (moisture) heat recovery, while an HRV provides only sensible heat recovery.
Fan performance curve	Graphical or tabular representation of static or total pressure and power input over a range of air volume flow rate at a stated inlet density and fan speed(s). It may include static and mechanical efficiency curves.
Free cooling	An approach to passively provide cooling to a building by using cool outside air instead of mechanical cooling. Also referred to as economizing.
Heat pump	A reversible thermodynamic device that can provide either heating or cooling by transferring ("pumping") heat. The condenser and evaporator may change roles to transfer heat in either direction. Heat pumps may be air source (outdoor air used as heat source/sink), or water source (ground loop, evaporative cooler, cooling tower or domestic water used as heat source/sink). Heat pumps may also use air or water as the working fluid used to deliver heating or cooling to the space.
Heat recovery ventilator (HRV)	An air handling unit that provides ventilation and passively conditions the ventilation air with a heat exchanger. An HRV consists of two air streams: one that delivers fresh air to the building and one that exhausts stale air from the building. Both incoming and outgoing air pass through a heat exchanger, a device that allows heat to transfer from one airstream to the other without the two airstreams coming in contact with one another.
Hydronic systems	A thermal distribution system that uses water or a mixture of water and additives as the heating/cooling distribution medium in a building.
Indoor air quality	Attributes of the respirable air inside a building (indoor climate), including gaseous composition, humidity, temperature and contaminants.
Multi-zone system design	As opposed to single zone, multi-zone refers to multiple indoor units connected to a single outdoor heat pump unit. All VRF are multi-zone, while mini-split heat pumps can be either single zone or multi-zone. Both single zone and multi-zone heat pumps can be ducted or ductless.
Nominal Airflow	Nominal airflow is defined by manufacturer for determination of product compliance with Prescriptive HRV/ERV Requirements and should represent typical peak application airflow.
Non-ducted return path	When more air is supplied to a closed space (e.g., an office room), air must be transferred out of the room to avoid pressure buildup. If not done by a return duct, the air can be transferred to another room that has a return grille via a transfer grille/duct or under a door undercut.
Packaged rooftop unit (RTU)	A packaged rooftop unit, or RTU, is a type of HVAC system that contains all the components needed to provide conditioned air and ventilation in one concise unit.
Passive House Institute (PHI)	PHI is a non-profit 501(c)(3) organization committed to making high-performance passive buildings the mainstream market standard. Learn more at passivehouse.com.
Plate heat exchanger	Fixed plates that separate hot and cold air streams and maintain their separation but allow heat transfer.
Radiant heating/cooling system	ASHRAE defines radiant systems as temperature-controlled surfaces where 50% or more of the design heat transfer takes place by thermal radiation.
Rated Flow or Rated Unit Full Flow	The manufacturer's rating for the unit's full flow capacity.

TERM	DEFINITION
Sensible Effectiveness	The net sensible energy recovered by the supply airstream between the two airstreams as a percent of the potential sensible energy that could be recovered.
Step-function improvement in system efficiency	A discrete jump in performance or savings, similar to the math term.
Variable Air Volume (VAV) systems	A type of HVAC system that varies the airflow and temperature, unlike constant air volume (CAV) systems, which supply a constant airflow at a variable temperature.
Variable Defrost Control	Provides continuously variable power to provide only the needed amount of heat to prevent frost buildup in a heat exchanger.
Very high efficiency dedicated outside air systems (very high efficiency DOAS)	Very high efficiency DOAS is an HVAC approach that improves the overall efficiency of the DOAS concept by pairing a high-performance heating/cooling system with a very high efficiency heat recovery ventilator (HRV) or energy recovery ventilator (ERV), and optimized system design.
VRF heating/cooling systems	An engineered direct-expansion (DX) multi-split system incorporating at least one variable capacity compressor distributing refrigerant through a piping network to multiple indoor fan-coil units. Each unit is capable of individual zone temperature control through integral zone temperature control devices and common communications network.
Wheel-type rotary heat exchanger	A thermal wheel (aka, rotary heat exchanger, rotary air-to-air enthalpy wheel, or heat recovery wheel) is a type of energy recovery heat exchanger. The air-permeable wheel is designed to absorb heat and/or moisture. To recover the energy, the wheel is positioned within the supply and exhaust airstreams of an air-handling system, transferring energy between airstreams as it rotates.

Disclaimer: This document, along with the equipment list and any guidance and recommendations included herein, are intended to assist the recipient in evaluating energy efficient HVAC system options; it should not be used in place of professional design or engineering services. Moreover, this document and its contents are provided "as is" without any warranty or representation regarding quality, accuracy, non-infringement, or usefulness. Under no circumstances are NEEA or NEEA's funders liable for any direct, indirect, special, incidental, consequential or other damages.

INTRODUCTION

The following system definition and design recommendations provide guidance to manufacturers, designers and specifiers regarding the key components of a Very High Efficiency Dedicated Outside Air System (or VHE DOAS). 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. Beyond the system requirements to effectively design to VHE DOAS standards, this guide outlines additional design recommendations for optimal performance.

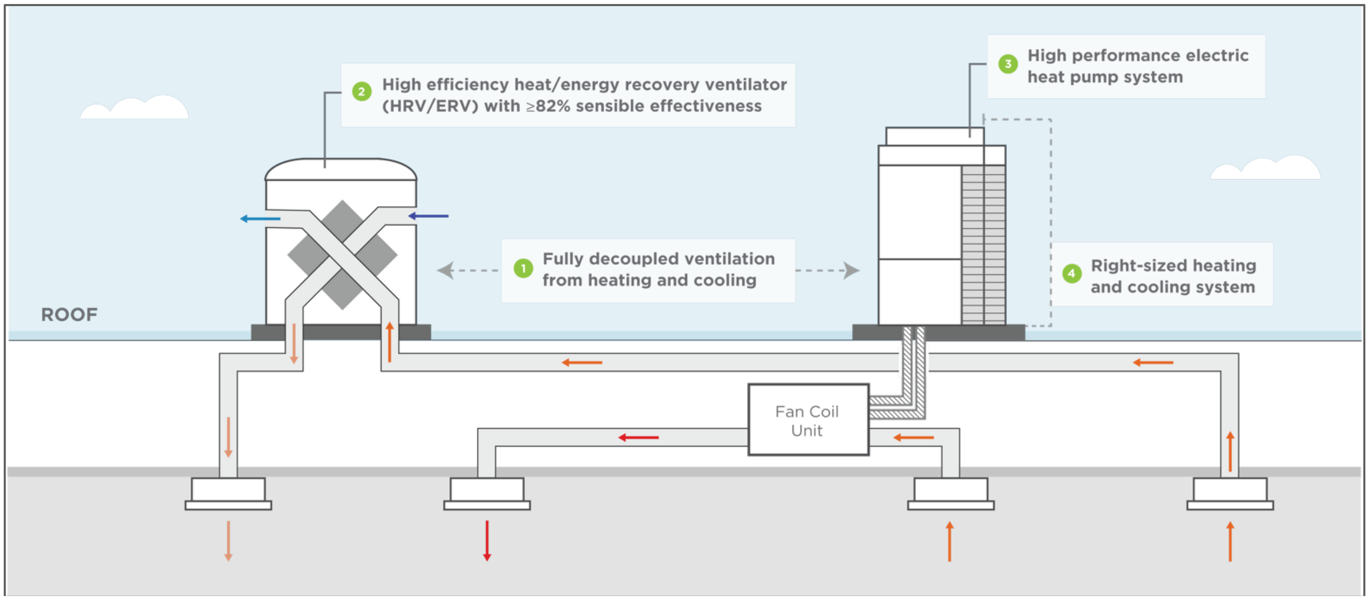
For more information, including research findings and case studies, visit: betterbricks.com/solutions/very-high-efficiency-doas.

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 fully decoupled from primary heating/cooling equipment to provide optimal control of each critical function*
2) *A heat or energy recovery ventilator (HRV/ERV) with 82% or greater sensible effectiveness*
3) *High-performance electric heating/cooling equipment*
4) *Right-sized heating/cooling equipment*

[FIGURE 1: KEY COMPONENTS OF VHE DOAS]



EQUIPMENT SUMMARY

Ventilation

In the VHE DOAS approach, the HRV/ERV 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. According to detailed analysis[1], an HRV/ERV with 82% sensible effectiveness can provide room-neutral air (within 3-7°F) over 99% of occupied hours in most of climate zone 4C.

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 building's load. There are several types of heating/cooling equipment particularly suited to this approach, including variable-refrigerant flow (VRF), 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 utilize variable speed compressors and fans.

VHE DOAS goes beyond the requirements that are outlined in various codes, such as the Washington State Energy Code. For details and comparisons, refer to Appendix C.

DEMONSTRATED RESULTS

VHE DOAS can reduce a building's total energy costs by using significantly less energy than most other HVAC systems. Analysis of several Northwest pilot installations of VHE DOAS, as benchmarked and monitored for energy performance before and after installation, demonstrates an average of 48% whole-building energy savings and a 69% reduction of HVAC energy use compared to a code-minimum replacement of existing equipment. These Northwest demonstration projects were carried out in collaboration with building owners, alliance partners and BetterBricks from 2015–2021. The projects were conducted to better understand the design, modeling, and installation process of VHE DOAS in small-to-medium commercial buildings, as well as validate energy savings.

Detailed project information and analysis on the initial eight projects can be found at betterbricks.com/resources/vhe-doas-pilot-project-summary-report, and case studies on all demonstration projects to-date can be viewed at betterbricks.com/solutions/very-high-efficiency-doas.

Further, an economic analysis of VHE DOAS conducted in 2019 show it's cost-effective in most applications, and, over time, costs will likely decrease due to more industry design experience, installation familiarity, and additional competing product lines. The report demonstrates VHE DOAS to have the highest net-present value across Northwest climate zones compared to two other HVAC strategies, RTU HP and WSEC DOAS, that were studied. To view the complete study, visit: betterbricks.com/uploads/resources/NEEA-DOAS-Analysis-Report_Red-Car_Final.pdf.

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[1] *Energy 350 Memo: "Annual HRV/ERV Supply Air Temperature Findings", 9/25/2022.*

SYSTEM REQUIREMENTS

The following System Requirements detail the key components of systems that qualify as VHE DOAS.

[TABLE 1: VHE DOAS SYSTEM REQUIREMENTS]

1) Decoupled Ventilation Design

Minimum Requirement: Ventilation and heating/cooling system fans must be controlled separately[2].

- Ventilation air from the HRV/ERV unit is supplied to each occupied space, either directly through a dedicated supply outlet or through heating/cooling ductwork when the ventilation supply air is delivered downstream of the terminal heating/cooling coils.

Best Practice: Fully decoupled system design

- Ventilation air is delivered directly to each occupied space. Separate ventilation supply outlets are provided for all spaces, as well as either a ducted return or a non-ducted return path with the free area sized so that air velocity does not exceed 300 FPM. Note that a plenum return is acceptable.
- Except where site conditions limit or restrict this approach, maintain at least half the length of the spacing between ventilation supply air outlet and exhaust/return grille should be at least half the length of the space to avoid short-circuiting.

2) High Efficiency Heat/Energy Recovery Ventilation (HRV/ERV)

- Prescriptive Requirements Path: Equipment listed on the Compliant Products Lists (CPL)*

OR

- Design Requirements Path: Demonstrate compliance with Design Requirements column of *HRV/ERV Minimum Requirements Table* in Appendix A with equipment selected at design conditions using AHRI 1060 certified software with HRV/ERV sensible effectiveness ≥ 82%*

*See *HRV/ERV Minimum Requirements Table* in Appendix A for detailed CPL requirements and current qualified equipment.

3) High-Performance Electric Heating/Cooling Equipment

Allowable Heating/Cooling Equipment Types
Multi-zone or single zone air-source split system heat pump (i.e., mini-split or ducted/ductless multi-zone), VRF air-source heat pump, air-to-water heat pump or heat pump chiller,[3] ground-source or ground-water source heat pumps.

Exception: Water-source heat pumps admissible only if existing in the building and not being replaced.[4]
Exception: Multi-family and lodging buildings may use the following alternate heating sources:

- Packaged terminal heat pumps that meet minimum efficiency requirements in Appendix B.
- Electric resistance heat in PHIUS certified buildings in spaces where no cooling is provided.

Exception for non-primary heating equipment:

- Semi-heated, unoccupied space: an enclosed space within a building that is heated by a heating system whose output capacity is less than 8 Btu/h-ft^2 of floor area and is not typically occupied (i.e., utility rooms, stairwells with fire risers, etc.) may be heated using an alternate equipment type (electric resistance, gas, etc.) controlled to a space temperature setpoint of 50°F or lower. All spaces heated by a heating system whose output capacity is greater than or equal to 8 Btu/h-ft^2 of floor area must meet the minimum system efficiency requirements of Appendix B.
- Secondary/backup heating equipment: heating equipment designed and controlled to come on only when outside air temperature falls below the ASHRAE 99.6% heating dry-bulb temperature for the location of the building may deviate from *allowable heating/cooling equipment types*.

Heating/Cooling System Efficiency
Heating/cooling equipment must meet minimum efficiency requirements as defined in the *Heating/Cooling Equipment Minimum Efficiency Requirements* detailed in Appendix B.

4) Right-Sized Heating/Cooling

Minimum Requirement: Right-sized heating/cooling system is supported by load calculations and uses no greater than 20% safety factors.

Best Practice: A right-sized heating/cooling system is supported by load calculations and uses no greater than 10% safety factors.

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[2] *Exception: Systems using active chilled beams.*

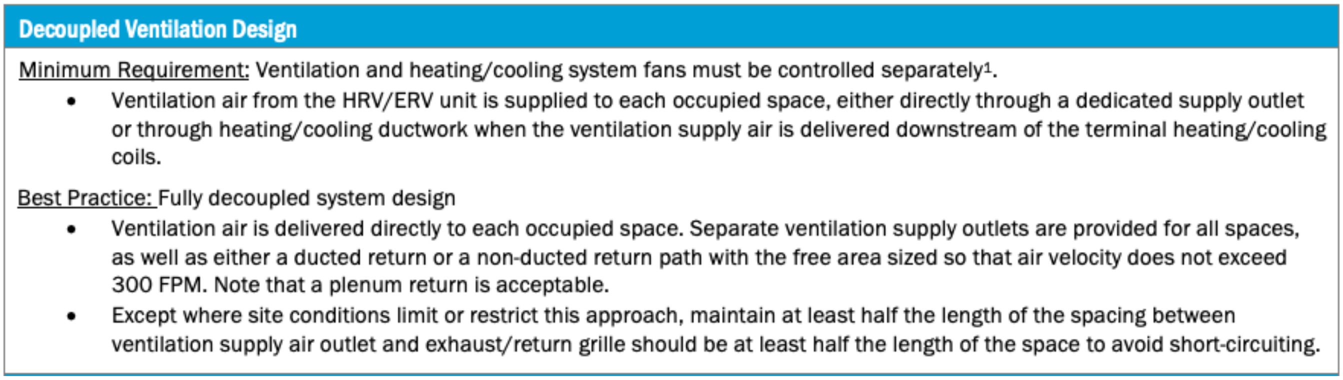
[3] *Air-to-water heat pump may be used with various downstream terminal units. Terminal unit options may include chilled beams, 4-pipe fan coil units with ECM fan motors, or radiant heating/cooling systems.*

[4] *Water-source heat pumps are excluded because they typically use a fossil-fuel boiler as a central heating source.*

BACKGROUND AND DESIGN CONSIDERATIONS

The following design considerations provide additional background and best practices for designing VHE DOAS to achieve optimal system performance:

DECOUPLED VENTILATION DESIGN



Decoupled Ventilation Design

Minimum Requirement: Ventilation and heating/cooling system fans must be controlled separately[1].

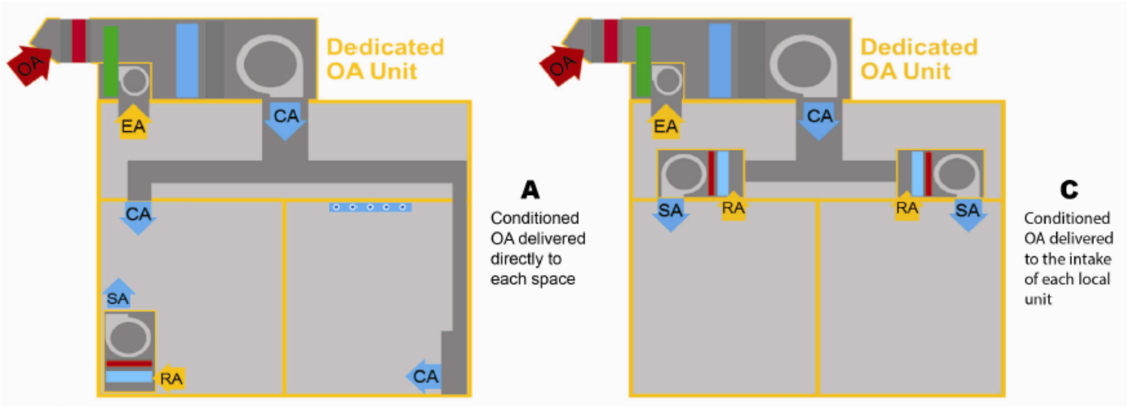
- Ventilation air from the HRV/ERV unit is supplied to each occupied space, either directly through a dedicated supply outlet or through heating/cooling ductwork when the ventilation supply air is delivered downstream of the terminal heating/cooling coils.

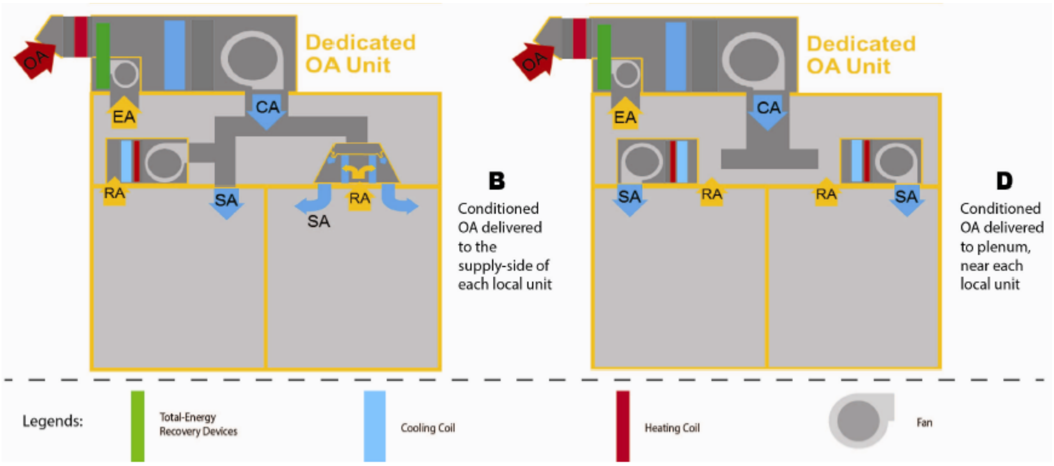
Best Practice: Fully decoupled system design

- Ventilation air is delivered directly to each occupied space. Separate ventilation supply outlets are provided for all spaces, as well as either a ducted return or a non-ducted return path with the free area sized so that air velocity does not exceed 300 FPM. Note that a plenum return is acceptable.
- Except where site conditions limit or restrict this approach, maintain at least half the length of the spacing between ventilation supply air outlet and exhaust/return grille should be at least half the length of the space to avoid short-circuiting.

VHE DOAS improves upon typical DOAS approaches by fully decoupling the ventilation and space conditioning systems, and then pairing high-efficiency heating/cooling equipment with a very high efficiency HRV/ERV to serve the ventilation load. Decoupled system design refers to complete separation of ventilation air from heating/cooling air. The benefits of separating the heating/cooling system from the ventilation system include reducing the capacity of heating/cooling systems, using smaller, more efficient fans in both the ventilation and the heating/cooling system, and being able to independently control the heating/cooling system from the ventilation system, to operate only when necessary. Separating the ventilation air from the heating/cooling equipment also leads to energy savings as the heating/cooling fans should cycle off when there is no call for heating or cooling. Air is a poor conduit of energy—decoupled system designs typically utilize water or refrigerant-based systems for transferring heat to, from and within the building, which is a more efficient strategy than traditional systems. Also, decoupled systems help alleviate the energy intensive practice of simultaneous heating and cooling that often occurs in traditional system design.

[FIGURE 2: ENERGY RECOVERY BENEFITS OF DIFFERENT DEDICATED OUTDOOR AIR (OA) SYSTEMS CONFIGURATIONS IN VARIOUS CLIMATES (SOURCE: DENG 2014)]





B Conditioned OA delivered to the supply-side of each local unit

D Conditioned OA delivered to plenum, near each local unit

Best Practice: Fully Decoupled System Design Considerations

- Ventilation air must be delivered directly to the occupied space,[5] with ventilation and heating/cooling system fans controlled independently.

  Decoupled system design is critical to the performance of the overall VHE DOAS system, as significant benefits and energy savings come from controlling these heating/cooling and ventilation independently. As a best practice, ventilation air should not be combined with heating/cooling air prior to entering the occupied space. In the most extreme climates where a slight tempering of the ventilation air is advised, this function must be provided separately from the heating/cooling air that provides comfort conditioning directly to the building zones and be limited to a maximum of 65°F for heating and a minimum of 80°F for cooling.

  The primary reason for a fully decoupled design is to ensure the heating/cooling system fans can turn off whenever zone temperatures are satisfied. Setting up heat/cool fans to cycle on load maybe require special setup by the manufacturer’s rep or commissioning agent upon building startup and commissioning. When ventilation air is required to be delivered via the heating/cooling system indoor units, the system remains in operation and uses excess fan energy to deliver ventilation air. Heating and cooling airflows are almost always larger than ventilation airflows, so requiring an oversize heat/cool fan to run a part load to deliver minimal vent air wastes energy, Additionally, in some cases partially coupled systems that deliver ventilation air to the return side of heating/cooling fan coil units have been found to have issues effectively delivering ventilation air to all spaces, especially during low-load conditions. Heating/cooling fan coil units that cycle off when there is no active call for heating or cooling eliminate the energy penalty associated with constantly running the fan coil unit fans but can cause issues as the ventilation air may no longer be balanced. During these low load conditions there is very little airflow through the ductwork that was designed for both ventilation air and primary heating/cooling air, but now only carries the ventilation air. In these conditions the ventilation air rarely makes it to the terminal diffusers and causes the rooms farthest away from the fan coil units to be under-ventilated.

- Maintain at least half the length of the space between ventilation supply air outlet and exhaust/return grille to avoid short-circuiting (except where site conditions limit or restrict this approach).

  This best practice prioritizes ventilation effectiveness as the primary basis for air distribution design, rather than other factors such as minimization of duct runs. With a fully decoupled DOAS design, ventilation air sometimes enters the room at very low flows and velocities. Therefore, without careful consideration of diffuser location and selection, the ventilation air may be short-circuited without fully benefitting the room

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[5] *Exception: Systems using active chilled beams.*

occupants. Designers should select diffusers with acceptable performance characteristics at the expected airflows. In small rooms, the airflow may be as low as 15–20 cfm and require a specialty diffuser.

This best practice design helps ensure that adequate return-air paths are provided for both heating/cooling and ventilation air, even when doors are closed, by requiring dedicated return air inlets for heating and cooling air in all cases. For ventilation air, most larger rooms will require a ducted exhaust air path, but smaller airflows may use a non-ducted return path with free area sized so that velocity does not exceed 300 fpm.

- Supply and return outlets/inlets are required for ducted heating/cooling systems. For ventilation systems, separate supply outlets are required for all space, and they must include either a ducted return or a non-ducted return path with the free area sized so that velocity does not exceed 300 FPM. Note that a plenum return is acceptable.

  The Northwest pilot projects verified that in smaller spaces with doors that are often closed, a lack of return air grilles for heating/cooling air at flow rates above 25 cfm can pressurize the space by 10 Pa (.04” w.c.) or more. This results in unwanted increases in fan power for heating/cooling and ventilation. Because ventilation flow rates for smaller spaces are typically under 25 cfm, return grilles for ventilation air can be placed in common area spaces. Air transfer under doors generally works without excessive room pressurization for total flow rates under 25 cfm, as long as the design airflow velocity does not exceed 300 fpm.

Good Practice: Partially Decoupled System Design Considerations

- Ventilation air from the HRV/ERV unit is provided to each occupied indoor space and may be supplied either directly or downstream of the terminal heating/cooling coils.

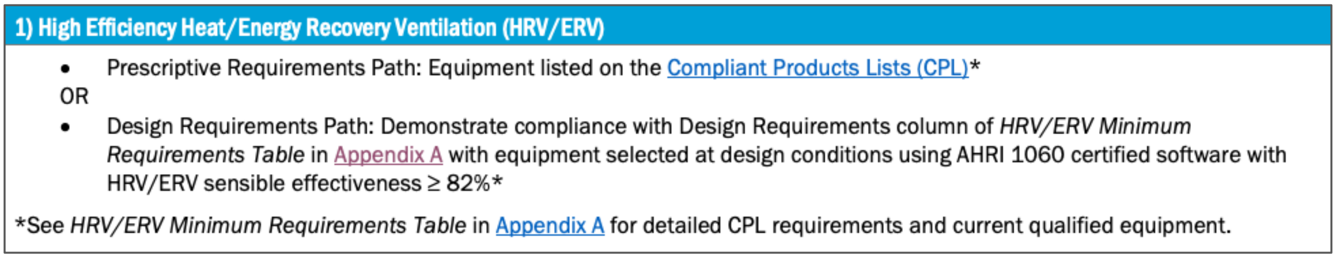
  While not encouraged, in some cases, designers may consider delivering ventilation air downstream of the heating/cooling fan coil units in the supply ductwork. This decision reduces the number of supply diffusers in the conditioned space and can limit the amount of ventilation ductwork. Careful consideration should still be given to balancing the ventilation air in conditions when the fan coil unit fans are cycled off as the same ventilation air imbalance issues that occur in a system where ventilation air is delivered to the return side of the heating/cooling fan coil units can occur where these units serve multiple spaces. Delivering ventilation air to the return side of the heating/cooling fan coil units is not recommended as ventilation air can travel through return ductwork and not reach all of the spaces when the heating/cooling fan coil units cycle off in low load situations.

Further Design Considerations:

Ventilation system design is important. Careful design that follows basic ventilation design principles is imperative to project success. This includes appropriate sizing of ductwork, diffusers, grilles and HRVs, and, when feasible, bringing fresh supply-air in on one side of an occupied space and out the other to avoid short-circuiting which can contribute to poor indoor air quality.

VERY HIGH EFFICIENCY HRV/ERV

This section outlines the basis for the High Efficiency HRV/ERV equipment requirements and expands on the requirement, providing design considerations for each component. VHE DOAS performance relies on HRV/ERVs employed with several key minimum performance specifications and capabilities. Utilizing the prescriptive requirements, the Certified Products List (CPL), or following the Design Requirements will result in optimal system performance.



1) High Efficiency Heat/Energy Recovery Ventilation (HRV/ERV)

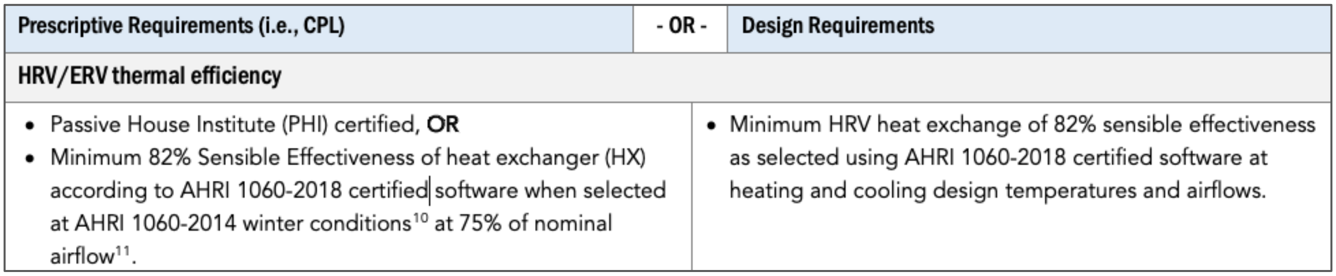
- Prescriptive Requirements Path: Equipment listed on the Compliant Products Lists (CPL)*

OR

- Design Requirements Path: Demonstrate compliance with Design Requirements column of *HRV/ERV Minimum Requirements Table* in Appendix A with equipment selected at design conditions using AHRI 1060 certified software with HRV/ERV sensible effectiveness ≥ 82%*

*See *HRV/ERV Minimum Requirements Table* in Appendix A for detailed CPL requirements and current qualified equipment.

HRV/ERV Thermal Efficiency



Prescriptive Requirements (i.e., CPL)	**- OR -**	**Design Requirements**
HRV/ERV thermal efficiency		
• Passive House Institute (PHI) certified, **OR** • Minimum 82% Sensible Effectiveness of heat exchanger (HX) according to AHRI 1060-2018 certified software when selected at AHRI 1060-2014 winter conditions[10] at 75% of nominal airflow[11].		• Minimum HRV heat exchange of 82% sensible effectiveness as selected using AHRI 1060-2018 certified software at heating and cooling design temperatures and airflows.

An HRV/ERV with 82% sensible effectiveness has been demonstrated to eliminate the need for supplemental heating/cooling of the ventilation air in climate zone 4c, which covers coastal areas in Northwest. This lack of post-conditioning is achieved by incoming air being pre-heated or pre-cooled to within 7°F of the conditioned space temperature 99% of occupied hours[6]. This ultimately decreases the run time and energy consumption of the heating/cooling system.

Most HRV/ERV products used for recovering energy from ventilation air, including most crossflow plate heat exchangers, feature sensible effectiveness ratings between 50 and 70% even though products with higher effectiveness are becoming more widely available. There are a growing number of wheel and plate type products available that offer sensible effectiveness ratings into the low to mid-80% range. the popular

The heat recovery effectiveness is only one aspect of how efficiently an HRV/ERV reclaims energy from exhaust air. Other important factors that impact HRV/ERV efficiency include fan/motor losses, crossflow air leakage, and defrost energy, among others. The VHE DOAS High Efficiency HRV/ERV Requirements aim to integrate these energy-intensive components of the system into a very efficient whole-box solution designed to temper ventilation air to comfortable distribution temperatures.

DESIGN CONSIDERATIONS

Minimum sensible heat recovery efficiency must be satisfied in conditions with AHRI 1060-2018 certified software. The key reason for the heat recovery effectiveness minimum of 82% is to require systems to minimize or eliminate the need for tempering the ventilation airstream before delivery to the building spaces for the vast majority of

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[6] *Assuming 8am – 5pm schedule, a typical weather year for Portland, OR (CZ 4c), an HRV with 82% sensible effectiveness, and a winter space temperature setpoint of 70°F.*

operating hours in Climate Zones 4–6. This not only reduces the heating and cooling system energy consumption (and energy costs) but can also enable a reduction in heating and cooling system size, reducing first cost. It also eliminates the cost and control complexity imposed by the need to manage system components for conditioning the ventilation air that is delivered in typical HVAC systems.

The 82% sensible recovery requires the use of either a counterflow plate, dual-core reciprocating, or enthalpy wheel-type heat exchanger. (See Figures 5, 6 and 7 on page 19 for visual reference).

Designers should specify an HRV/ERV that is PHI Certified or with at least an 82% sensible effectiveness in order to eliminate (or significantly reduce) the need for tempering of ventilation air before delivering to the building spaces. Many of the currently available HRV/ERVs that meet this level of efficiency are outdoor-rated units intended to be roof- or pad-mounted. However, low-profile units are becoming available that are intended to be mounted on or hung above ceilings.

- Applicability Across Climates

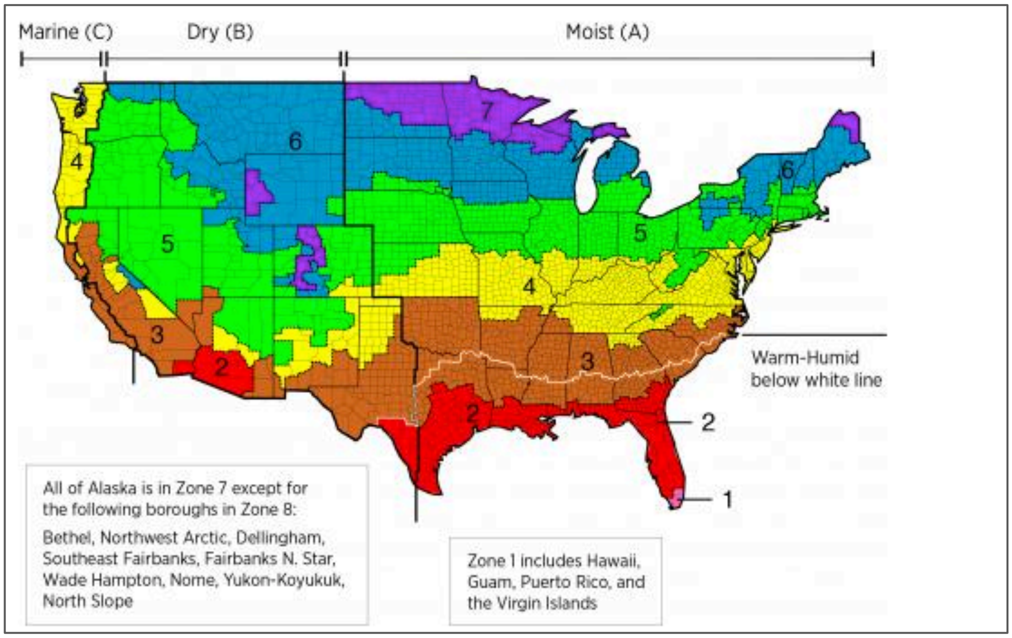
  The Northwest climate is not uniform, but it is mostly limited to the three primary zones of 4C (Mixed Marine; Seattle, WA, Portland, OR), 5B (Cool Dry; Spokane, WA, Boise, ID), and 6B (Cold Dry; all Montana), as shown below. The coastal areas west of the Cascade Mountains, with generally milder temperatures and relatively low humidity, have little need for frost protection or dehumidification. These areas often don't require supplemental heating and cooling of the ventilation air. Inland marine areas can experience wintertime extreme conditions, sometimes for extended periods, where frost control is needed. East of the Cascades, however, conditions are colder and drier. While an HRV is typically a suitable choice, some supplemental heating of ventilation air may be required east of the Cascades. The following table lists the percent of occupied hours that an HRV with 82% sensible effectiveness will deliver ventilation air within 7°F in a representative city in each of the Northwest's 3 climate zones.

[TABLE 2: APPLICABILITY ACROSS NORTHWEST CLIMATE ZONES]

Climate Zone	Representative City	ASHRAE 99.6% heating dry-bulb temperature	Percent of occupied hours supply air is delivered within 7°F of room temperature without supplemental heating	Hours outside of 7°F	Sensible Recovery Required to meet 99% of hours within 7°F
4C	Portland, OR	25.9°F	99.2%	18	82%
5B	Boise, ID	11.4°F	91.5%	199	86%
6B	Missoula, MT	-1.7°F	81.3%	438	88%

In colder climates, heat recovery systems will also need to protect against frost on the heat exchanger when outside ambient temperatures approach and go below freezing. High efficiency HRVs/ERVs, such as those in the VHE DOAS design, require defrost control to ensure high efficiency operation in cold conditions and have built-in frost protection within the unit. ERVs tend to have a lower threshold for frost protection due to the transfer of moisture across the heat exchanger. According to one manufacturer, an ERV may require frost protection at around 5F, while an HRV would likely require it at 25F. For these reasons, frost prevention systems are required for VHE DOAS systems when winter design conditions fall within the anticipated frost threshold. Refer to the Defrost Control Capabilities section below for additional defrost strategies and considerations.

[FIGURE 3: IECC CLIMATE ZONES MAP]



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:

Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Source: 2012 IECC – International Energy Conservation Code; International Code Council (ICC)

- <u>HRV vs. ERV (sensible recovery vs. total enthalpy recovery)</u>

  The minimum HRV/ERV efficiency requirement for VHE DOAS in the Northwest is focused on sensible energy recovery, as latent energy recovery or rejection is seldom a priority in this climate as indoor humidity tends to remain low in both the winter and summer. Additionally, HVAC systems in small-to-medium commercial buildings in the Northwest are rarely actively controlled to maintain indoor relatively humidity so there tends to be very little energy savings associated with latent heat recovery/rejection. However, other parts of the country that have significant latent cooling loads and would benefit from using a high-efficiency ERV instead of an HRV and might wish to add a minimum latent recovery requirement (around 55% at 75% of system nominal full airflow rate).

  The Northwest is a heating dominant climate and in most commercial applications active dehumidification is not required. For this reason, designers should select an HRV or ERV with the highest sensible recovery and fan efficiency that meets the other requirements of a design. ERVs can provide additional thermal comfort benefits by recovering some moisture in the winter when the indoor environment is often very dry and by rejecting moisture in high occupancy periods when the indoor environment is more humid than the outdoor air entering the building. However, most commercial HVAC systems in the Northwest do not actively humidify or dehumidify and therefore there is typically not a significant energy benefit to total energy recovery.

<u>HRV/ERV Fan Efficiency</u>

Prescriptive Requirements (i.e., CPL)	**- OR -**	**Design Requirements**
HRV/ERV fan efficacy		
• PHI certified, **OR** • Minimum 1.3 cfm/Watt at 0.5" w.g. external static pressure at 75% of rated air flow[10]. Variable speed supply and exhaust fans are required.		• Minimum 1.3 cfm/Watt at design operating conditions[11]. Variable speed supply and exhaust fans are required.

The majority of HRV/ERV products sold in the North America used for recovering ventilation airflow losses feature fan efficiencies much lower than this requirement with typical fan efficacies between 0.5 and 1 cfm/watt (1 to 2 watts/cfm). This level of performance is such that if the heating/cooling system is very efficient (e.g., a VRF/VRV-type heat pump system), using these fans to recover ventilation energy will often consume more energy in fan power than is recovered from the ventilation air exhaust stream, counteracting the investment of high efficiency HRV/ERV systems.

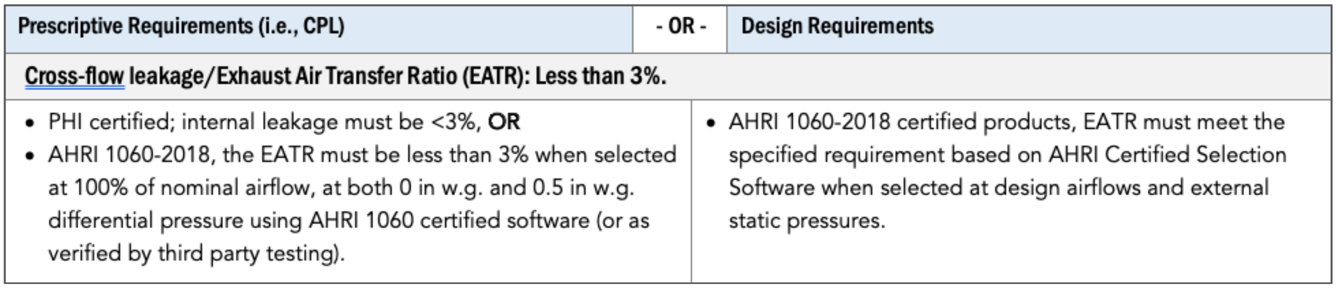
The specification set at 1.3 cfm/watt ensures that the energy balance between energy recovered and energy expended is always positive. This results in a COP of about 20 in the cooling mode and 30 in the heating mode at design conditions, or about 10 times the efficiency of a typical heat pump system (COPs for HRVs/ERVs is the ratio of energy recovered to energy used to recover it). As in the case of heat exchange efficiency, using the most efficient fans tends to deliver a step-function improvement in system efficiency.

DESIGN CONSIDERATIONS

- To meet the VHE DOAS requirements, the HRV/ERV units must use variable speed fans, which is often achieved with ECMs in the smaller sizes and variable frequency direct-drive motors in larger sizes. Detailed fan and fan motor data is often presented as a curve or in table form with performance shown at different airflow rates and static pressure conditions. The VHE DOAS requirement is set to a specific point on the fan curve (at 75% of rated unit full flow and 0.5” w.g. external static pressure). There is also a “design” path that allows a designer to select an HRV/ERV not on the compliant product list as long as it meets the required fan efficiency of 1.3 cfm/watt

- Designers should specify an HRV/ERV with efficient fans that, at a minimum, have a total unit performance of 1.3 cfm/watt at balanced supply and exhaust flow at 75% of rated full flow and 0.5” ESP. For example, a unit with a rated airflow of 1,000 cfm should have a maximum total fan power (both supply and exhaust fans) of 575 watts when supplying 750 cfm of supply air at 0.5” ESP (750 cfm supply / 575 watts supply and exhaust fan power = 1.3 cfm/watt).

Cross-flow Leakage/Exhaust Air Transfer Ratio (EATR)



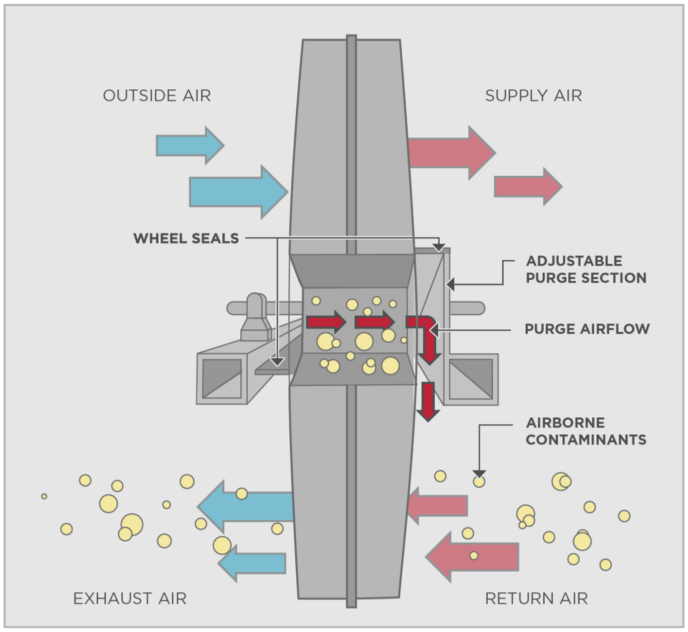
Prescriptive Requirements (i.e., CPL)	**- OR -**	**Design Requirements**
Cross-flow leakage/Exhaust Air Transfer Ratio (EATR): Less than 3%.		
• PHI certified; internal leakage must be <3%, **OR** • AHRI 1060-2018, the EATR must be less than 3% when selected at 100% of nominal airflow, at both 0 in w.g. and 0.5 in w.g. differential pressure using AHRI 1060 certified software (or as verified by third party testing).		• AHRI 1060-2018 certified products, EATR must meet the specified requirement based on AHRI Certified Selection Software when selected at design airflows and external static pressures.

Cross-flow leakage compromises the efficiency of the heat exchange process, sometimes significantly.

Additionally, depending on the level of contaminants in the exhaust air stream, many occupancy types make it unacceptable to have inadvertent recirculation of contaminated exhaust air across the heat exchanger to the fresh supply air. In all cases, minimizing recirculation of environmental air back into the building is a best practice for maintaining healthy indoor air quality.

Limiting crossflow leakage to less than 3% under specific test conditions, or using AHRI 1060-2018 certified products, eliminates poor performance issues as much as possible. Crossflow leakage is defined as the percentage of exhaust air that leaks to the incoming airstream, noted as a percentage of the average airflow in an HRV/ERV unit’s operating range. (AHRI refers to this as EATR.)

[FIGURE 4: CROSSFLOW WHEEL SYSTEM LEAKAGE]



DESIGN CONSIDERATIONS

- Some designers are hesitant to exhaust rest rooms or janitor closets through the HRV/ERV due to concerns with cross flow leakage. According to ASHRAE 62.1, Class 2 air (which includes rest rooms) can safely be used for energy recovery as long as EATR is less than 10%. With all compliant HRV/ERVs having EATR less than 3% designers should be confident in including rest room exhaust air in the energy recovery air stream. Adding dedicated rest room exhaust fans adds unnecessary first cost, wastes energy, and can lead to unbalanced air stream challenges that can reduce HRV/ERV heat recovery efficiency.
- Rotary heat recovery devices ("wheels") are often considered to have higher crossflow leakage than plate-type heat exchangers. This is due to potential leakage around seals at the wheel and the possibility for entrained air to be released into the supply airstream ("carryover"). Designers should follow best practice to reduce both modes of wheel leakage as much as possible.
    - **Seal leakage** can be reduced by controlling differential pressures between adjacent airstreams within an air-to-air ERV. Additionally, if a wheel is designed so that differential pressure between the supply airstream and the exhaust airstream is positive, it will naturally push any leakage into the exhaust airstream rather than recirculating into the ventilation supply. This can be controlled with proper fan placement, or by applying control dampers in the return airstream. This is also noted as a best practice in ASHRAE's guidance for endemic operation of ERVs.[7]
    - **Carryover leakage** can be reduced by including a purge section in the rotary energy recovery device. A purge section is a section of the wheel that directs outdoor air through the wheel and into the exhaust air outlet to remove any entrained exhaust air before rotating back into the supply airstream. All VHE DOAS compliant HRV/ERV products that use wheels for energy recovery are required to include purge to minimize crossflow leakage.
- PHI and AHRI certified HRV/ERVs have tested/rated leakage rates at range of airstream differential pressure conditions. If an HRV/ERV is selected to operate at an airflow and/or differential pressure outside of the conditions which the unit was tested, designers should ensure that the leakage rate at design conditions are still acceptable. This is particularly important in applications in which the differential pressure between the

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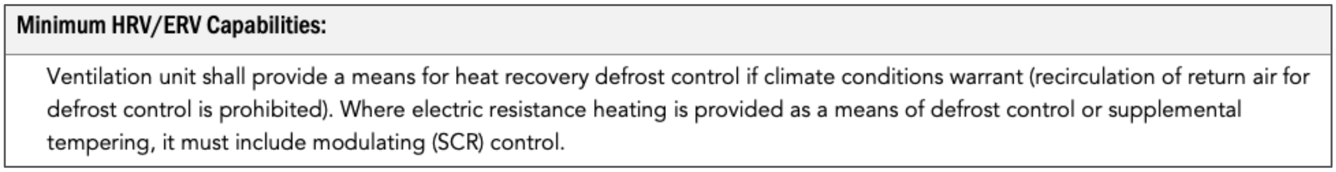
[7] https://www.ashrae.org/file%20library/technical%20resources/covid-19/practical-guidance-for-epidemic-operation-of-ervs.pdf

outside air entering and the exhaust air leaving the HRV/ERV is expected to be significant, such as an indoor installation with long duct runs to the exterior.

Defrost Control Capabilities



Minimum HRV/ERV Capabilities:

Ventilation unit shall provide a means for heat recovery defrost control if climate conditions warrant (recirculation of return air for defrost control is prohibited). Where electric resistance heating is provided as a means of defrost control or supplemental tempering, it must include modulating (SCR) control.

In colder climates, heat recovery systems will require defrosting of the heat exchange core or wheel when outside ambient temperatures approach and fall below freezing. In the most efficient systems, moist indoor-air cools to near freezing temperatures on the exhaust side of the HX as heat transfers to the fresh outdoor airstream. This rarely occurs in less efficient HRVs/ERVs because these units recover so little energy that the exhaust airstream rarely reaches freezing temperatures. VHE DOAS compliant HRV/ERVs can be more susceptible to frost due to their high energy recovery effectiveness and low winter exhaust temperatures, so defrost should be considered during HRV/ERV selection and design.

Frost prevention systems typically either 1) pre-heat air entering a plate heat exchanger with a built-in core defrost electric-resistance heater, 2) decrease the amount of heat transfer by slowing down the wheel in a rotary HRV/ERV, or 3) mix incoming air with return air to increase the temperature of the air upstream of the heat exchanger core. The VHE DOAS requirements prohibit the use of recirculation as a means for frost protection. Additionally, a VHE DOAS compliant system should use defrost control efficiently and effectively. The VHE DOAS System Requirements prohibits recirculation of exhaust air and require some form of variable defrost.

Adaptive electric defrost is a frost-prevention strategy that applies a variable amount of electric heat energy to the incoming airstream to keep the exhaust side of the core frost-free when outside ambient temperatures are near or below freezing. The use of a variable capacity defrost system (with modulating SCR control) maximizes system efficiency by applying only as much defrost energy as is required by outside ambient conditions. Applying more heat than is required is wasting energy as it effectively exchanges "free" heat recovery with unneeded electric resistance heating. All HRV/ERVs on the compliant product list have internal components that protect the heat exchanger from building up frost. It is not recommended to ever add an additional pre-heater before the HRV/ERV heat exchanger.

For wheel-type HRV/ERVs, the most common and cost-effective frost prevention strategy is varying the wheel speed. If this strategy is used, the wheel speed should be able to be continuously slowed down to low speeds (typically 1–2 rpm) to avoid frosting. Partial or full recirculation of exhaust air to the incoming fresh airstream is prohibited for any HX type. This precludes the recirculation of exhaust air contaminants back into the building and reduces the amount of exhaust air available for heat exchange, even if during a limited number of hours per year.

DESIGN CONSIDERATIONS

- Designers should select an HRV/ERV that can operate with high efficiency heat recovery year-round. If frost protection is required given the winter design conditions (for both outside air and exhaust air), the HRV/ERV should be able to recover heat with minimal energy input. For example, if an HRV/ERV provides frost protection with an electric-resistance element sized for a 10F temperature rise at design conditions and ventilation airflow, the element input power should also be able to provide a 2F temperature rise at a different condition if sufficient to prevent frost build up.
- Designers should seek to minimize defrost as much as possible. Analysis has shown that ERVs are less susceptible to frost, with defrost activation temperatures in the 5°F to 10°F range (dependent upon indoor and outdoor humidity conditions). In regions with design temperatures in this range, ERVs can provide additional energy savings by allowing heat recovery without defrosting for a greater number of hours per

year. Also consider how defrost is activated. Some manufacturers enable defrost at a certain temperature, while some measure the differential pressure across the heat exchanger to determine when frost actually begins to form. Minimizing time and energy spent in defrost mode helps to ensure the most energy savings from the VHE DOAS system.

ADDITIONAL HRV/ERV DESIGN RECOMMENDATIONS

In addition to the VHE DOAS requirements for HRV/ERV units outlined above, Northwest-based pilot projects have demonstrated several best practices around HRV/ERV design. When fully implemented, the following additional design recommendations yield a best-in-class HVAC system. Designers are encouraged to consider whether each design recommendation below may be beneficial to your project.

Variable Speed HRV/ERV Fan Controls

Additional Recommendation	Added Value
HRV/ERVs with variable speed fans and inputs capable of controlling fan speed based on time-of-day scheduling, and inputs for CO2, relative humidity, VOCs and/or duct static pressure can enable additional energy savings through control strategies such as demand control ventilation.[8] Most of the HRV/ERV units on the compliant product list have integral controls that can implement all of these control strategies without a full building control system.	Variable fans allow for more efficient fan operation, easier startup and commissioning, and allows for varying ventilation levels when appropriate.

Variable speed HRV/ERV fans are part of the VHE DOAS system requirements – utilizing the variable speed fans for ventilation control is recommended and should be considered. Demand Control Ventilation (DCV), for example, is an energy code requirement for many commercial building occupancy categories that experience high occupant densities, such as conference rooms. Reducing ventilation airflow when occupancy levels are low saves both HRV/ERV fan energy and heating/cooling energy required to condition the outside air (although this is less important with a very high efficiency HRV/ERV). When DCV is enabled, it can automatically reflect occupancy patterns and rely less on pre-programmed schedules, which can result in significant energy reductions and an increase in occupant comfort. Education about proper use of controls for building occupants and operators is needed to fully maximize these benefits.

DESIGN CONSIDERATIONS

- Controlling ventilation rate in response to occupancy requires a suite of control capabilities and sensors that have to do with occupancy and level of occupancy. The most basic capability requirement is time-of-day scheduling where the HRV can be scheduled to operate only when the spaces served are occupied. A more sophisticated approach is varying fan speed in response to an air quality metric such as CO_2 level, concentration of volatile organic compounds (VOCs), or relative humidity.

  To allow for zone-level DCV, and to allow for reliable airflow balancing, the HRV should be able to control fan speed to a fixed duct static pressure setpoint. This requires a pressure sensor located in the duct system with a setpoint corresponding to the required pressure to move design airflow through the downstream air distribution elements and into the spaces. Typically, this setpoint would not be more than 1" w.g., but this depends upon the location of the pressure sensor. Variable fan speed is also required for this strategy either

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[8] Input for CO_2 and duct static pressure may be accomplished with integral sensors, auxiliary third-party sensors, or capability to receive 0-10 mV (or similar) signal from BMS, and respond accordingly.

through EC motors or variable frequency drives (VFDs). By locating modulating dampers controlled to CO_2 level (or two-position dampers controlled to occupancy sensor signals) in high occupancy zones, this feature allows DCV to be implemented in the critical zones.

- DCV at the zone or building level may not be an acceptable method depending on the application. The intent of this recommendation is to ensure the HRV has the capability to provide this functionality, not that the designer must use DCV in all applications. Many of the HRV/ERVs on the compliant product list have their own integral controller than can manage DCV when desired.
- It is not necessary in all applications to require zone-level DCV or varying fan speeds based on external sensors. If a single HRV serves a number of spaces with varying occupancies, the total ventilation airflow may be a fixed amount during occupied hours unless zone dampers are utilized. When serving a single large zone, such as an open office space, the HRV airflow may vary based on CO2 level in the return airstream, as this is a reasonable proxy for average zone conditions and this type of space can be assumed to have a relatively uniform indoor air pollutant profile unless there is a significant pollutant source (i.e., large printers, combustion appliances, etc.).

Heat Recovery Bypass Control Capabilities

Additional Recommendation	Added Value
Include through use of variable damper control, or wheel speed control.[9]	Allows for free cooling or night purges to offset mechanical cooling when outside air temperature is suitable.

Energy code typically requires this function, referred to as an economizer, for any system larger than 4 tons of cooling capacity. For many system configurations, code requires integrated economizer capability, where the outside air dampers can bring in cool air at the same time that the mechanical cooling can operate. The integrated capability can reduce the cooling load on a mechanical system during hours when the outside air temperature may not be sufficient to meet the whole-building cooling load alone.

DESIGN CONSIDERATIONS

- When separating ventilation from the primary heating and cooling system, the outside air is not provided by the heating/cooling system, so any economizer functionality must be provided through the HRV/ERV.

- Depending on technology type, there are multiple strategies to provide economizing when conditions allow, with little or no heat exchange occurring. For counterflow heat exchangers, the HRV must be equipped with variable bypass dampers that allow the outside air to bypass the heat exchanger core and be introduced to the space without tempering of the air. For wheel-type heat exchangers, the most common strategy is to vary the wheel speed to maintain a minimum supply-air temperature and then stop the wheel to limit heat exchange. For dual-core (reciprocating airflow) HRVs, the cycle period can be increased to reduce heat transfer.

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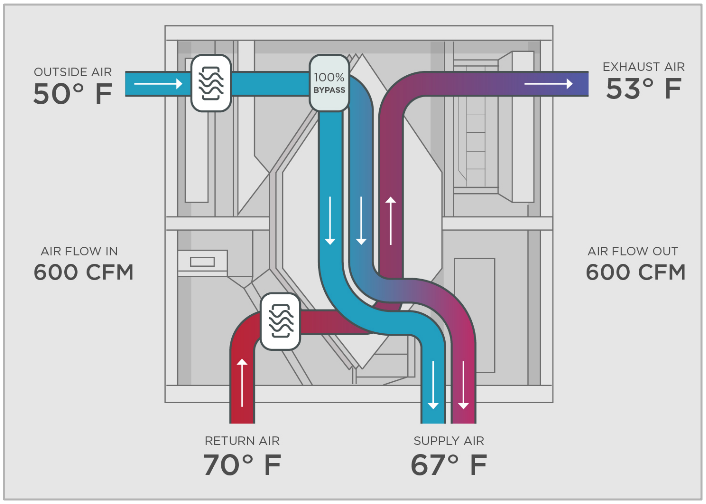
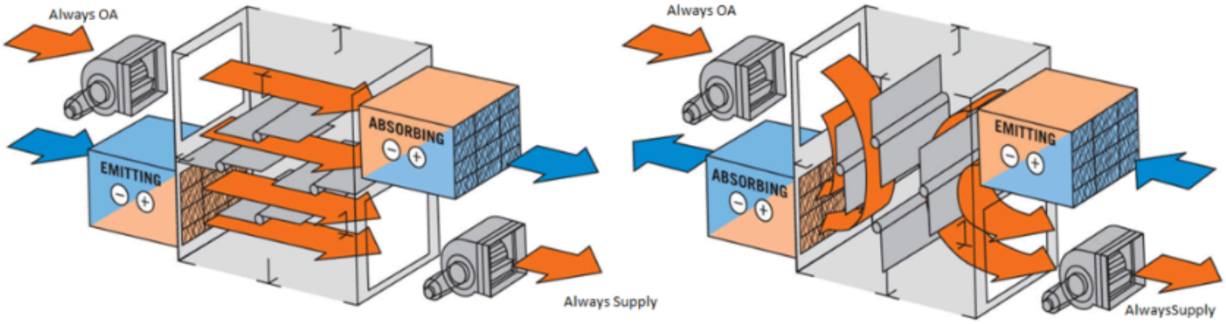
[9] Heat recovery bypass control allows for variable operation that avoids heat exchange when desirable.

[FIGURE 5: COUNTERFLOW, PLATE-STYLE HRV EXAMPLE]



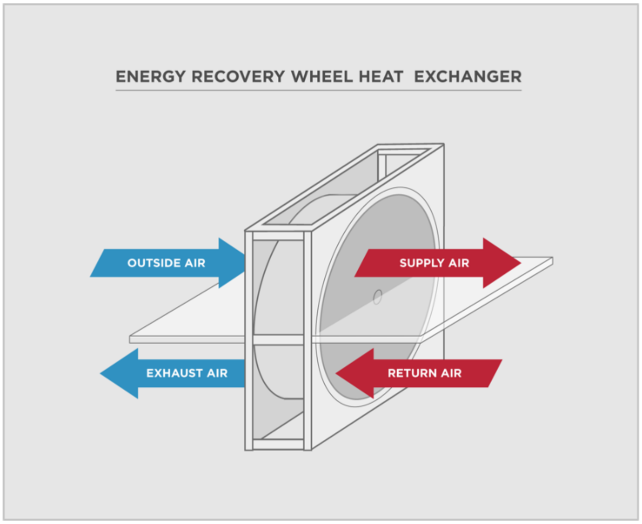
(Note: The illustration above is based on Ventacity Systems' product configuration. Other manufacturer product configurations may vary.)

[FIGURE 6: DUAL CORE RECIPROCATING HEAT EXCHANGER EXAMPLE]



Source: Tempeff

[FIGURE 7: ENTHALPY WHEEL HRV EXAMPLE]



When selecting an HRV/ERV, designers should understand how and when economizing should take place, and then select a product that can maximize the amount of cooling load offset from the heating/cooling system. In order to do this, the selected HRV must be able to operate with full or partial heat recovery, or full economizing to maintain a minimum supply temperature. For example, if cooling is beneficial on a spring morning when the outside air temperature is 57F, partial heat recovery may be used to deliver 60F to avoid comfort issues while still providing partial economizing. To accomplish economizing in this way, temperature sensors in all four airstreams (outside, supply, return, exhaust) are typically required.

Filters

Additional Recommendation	Added Value
MERV 13 filters on outside air intake and MERV 8 filters on exhaust/return airstreams prior to the heat exchange medium. Filters on the exhaust airstream helps protect the heat exchanger from clogging which can reduce heat transfer.	Improved filtering capabilities can help to optimize indoor air quality by reducing outdoor air contaminates such as pollen, large particulates, and other pollutants. Higher efficiency filters are required to mitigate other pollutants such as smoke.

Without proper filtration of both the outside and return airstreams before entering the heat exchanger, heat transfer effectiveness can degrade over time. Additionally, with increasingly poor local air quality and high pollution levels in urban areas, it is important to filter outside air at a high efficiency to maintain a high indoor-air quality. As an additional measure, it is also recommended that some filtration (with lower MERV) be used on the return air entering the HRV/ERV to help keep the plates and media clean, especially if no filtration (or low-efficiency filtration) is present on the heating/cooling system.

DESIGN CONSIDERATIONS

- Filtration of the outside airstream is required by code and the MERV 13 recommendation helps provide a high level of indoor air quality. Some reciprocating technologies may not require filtration on the return/exhaust airstream but providing a filter on the return airstream will protect most heat exchangers from damage and buildup and help to ensure efficient operation. Designers should be sure to account for filter pressure drop (both clean and dirty) in external static pressure calculations.

  Note: Packaged HRV manufacturers sometimes include clean filter pressure drops as a part of their internal static pressures.

HRV/ERV Sizing

Additional Recommendation	Added Value
Consider selecting HRV/ERV units at 30% below peak airflow capacity of the equipment to allow for increased airflow during high-occupancy periods and future increased occupancy.	Oversizing the HRV/ERV increases energy recovery effectiveness and improves fan efficacy.

Designers should consider selecting the HRV/ERV to be sized so that the unit(s) run at around 30% less than the design ventilation airflow when meeting ASHRAE 62.1 ventilation rates (fully occupied, non-boosted). Supply ducting should be sized for maximum flow at an average friction loss of 0.08” w.g. per 100 ft. of straight-length duct.

Whether the reason is first cost or available space for equipment installation, many HVAC designers will look at the maximum required ventilation airflow for a system and choose the smallest HRV equipment that can meet the design condition. This sizing approach can significantly limit the system's performance. HRV system efficiency varies inversely with flow rate, both in recovery efficiency (i.e., lower flow means higher heat exchange rate) and fan efficacy. Sizing the HRV/ERV to run at lower than its peak airflow increases the heat recovery and fan efficiency. It also provides room for higher outside air flow for instances of high occupancy densities and when economizing is beneficial.

DESIGN CONSIDERATIONS

- This guideline attempts to ensure that the HRV/ERVs are properly sized for ventilation efficiency to maximize savings, and to minimize noise. It also attempts to ensure that the ventilation ducting is sized for full-flow economizing. Ventilation codes, such as the applicable mechanical code or ASHRAE Standard 62, should be used to determine the maximum required ventilation airflow rate for a system (or group of zones). To allow flexibility, designers should consider selecting an HRV/ERV to run at around 30% less airflow than its peak capacity when delivering design ventilation rates. This conservative sizing approach allows for very efficient fan and HX performance and allows the system to operate at a higher airflow to provide increased economizer benefit or to provide additional ventilation during increased occupancy conditions.

Ventilation Ductwork Design

Additional Recommendation	Added Value
Consider slightly oversizing ventilation supply and return ductwork and at a minimum size ventilation ductwork to no more than 0.08 inches water gauge pressure loss per 100 feet of straight duct. Doing so allows for periodic increases in ventilation supply air. Increasing ventilation air allows for more effective free cooling during night purges, and can be beneficial in a variety of circumstance, including temporary spikes in occupancy or in planning for future expansion. Larger ductwork also results in lower system static pressure to reduce the system's overall fan power. An additional strategy for minimizing duct length and therefore fan power is to incorporate localized ventilation units in larger buildings instead of a single large unit with long duct runs.	As demonstrated by a recent study,[10] increased ventilation flexibility is a very effective way of mitigating the risk of viral transmission in buildings, which can be achieved with a relatively small upfront cost of increased ductwork sizing. Additionally, energy modeling shows that reducing system fan power by 54% can yield up to 17% annual HVAC energy savings in climate zone 4C.

DESIGN CONSIDERATIONS

- When sizing ducts, simple friction-loss calculations can be used with an average friction loss of 0.08” w.g. per 100 ft. of straight-length duct at the maximum ventilation airflow at which the system is expected to operate (i.e., economizing or high-ventilation mode). If flexible duct is used, friction-loss calculations should be adjusted accordingly. In general, flexible duct will require larger diameters than rigid ducts for the same friction loss. Where possible, use round rigid? ducts. If rectangular ductwork is specified, be sure to use turning vanes in all elbow fittings and limit aspect ratio to 4:1.

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[10] *COVID-19 Risk Reduction Strategies and HVAC System Energy Impact,* Northwest Energy Efficiency Alliance, et. al., https://betterbricks.com/resources/covid-19-hvac-risk-reduction-strategies.

Ventilation Ductwork Insulation and Sealing

Additional Recommendation	Added Value
Insulation of ventilation ductwork should follow these guidelines: o Tempered air ducts (HRV/ERV supply/return) installed exterior to the building: R-12. o Tempered air ducts (HRV/ERV supply/return) installed in unconditioned spaces: R-8. o Tempered air ducts (HRV/ERV supply/return) installed in conditioned spaces: none. o Outside air (entering HRV/ERV) and exhaust air (leaving HRV/ERV) ducts installed in conditioned spaces: R-16. o Consider sealing existing ductwork used as ventilation supply or return/exhaust to SMACNA Seal Class B standards where accessible, or if delivering greater than 500 CFM at design conditions. Then insulate ventilation supply and exhaust as per relevant code requirements for heating and cooling ductwork.	Duct insulation prevents condensation in conditioned spaces and energy losses in unconditioned spaces. It is often overlooked by contractors and engineers that HRV/ERV exhaust air ductwork leaving HRV/ERV carries air that becomes very cold in the winter and condensation can occur. Sealing contributes to indoor air quality by ensuring that adequate ventilation air is delivered to all spaces.

The Northwest pilot projects uncovered serious system performance compromises due to the intake of outside air (or air at outside ambient temperatures in unconditioned spaces) into ventilation exhaust airstreams. Both efficiency and comfort were compromised in these cases. Especially in older buildings where ducting is being re-used or re-purposed, it is critical to verify and control the air leakage rates to minimize adverse system performance impacts. Also, where ventilation ducting is in unconditioned space, insulation is required to maintain comfortable fresh-air delivery temperatures. Any fresh-air intake or exhaust air ducts between the HRV/ERV and the outdoors that are inside the building also need to be insulated. When outdoor ambient conditions are very cold, both the fresh-air intake duct and exhaust duct will be at, or very close to, the outdoor ambient condition. Frost and condensation (and subsequent moisture damage) are likely unless the ducting is adequately insulated.

DESIGN CONSIDERATIONS

- Designers should carefully consider the temperature of each of the four air streams and what conditions all ductwork will experience. Selecting the recommended duct insulation levels will help maintain efficient system performance and comfortable supply air and prevent moisture damage to the building. By limiting duct leakage and insulating to the levels specified, the retrofit will exceed energy-code requirements, and will experience longer service life with fewer operational problems.

- Joints between flexible and rigid ducts should be fastened with a stainless-steel screw gear collar and sealed with non-toxic liquid sealant. Do not use duct tape.

- Duct insulation should be installed on the exterior of ductwork wherever possible. For outside ductwork, an insulation jacket should be installed to protect the insulation from rain and UV radiation, and to provide protection from damage due to rooftop maintenance work and regular wear and tear.

- R-16 insulation can be accomplished using 3”-thick board-type (rigid) polyisocyanurate (polyiso) thermal insulation or similar. It is more common to see 1–2”-thick insulation (R-6 to R-12) installed, but the incremental cost of 3”-thick polyiso insulation is minimal, especially because the HRV-entering outside air and leaving exhaust air ductwork will typically be very short or nonexistent in rooftop installations.

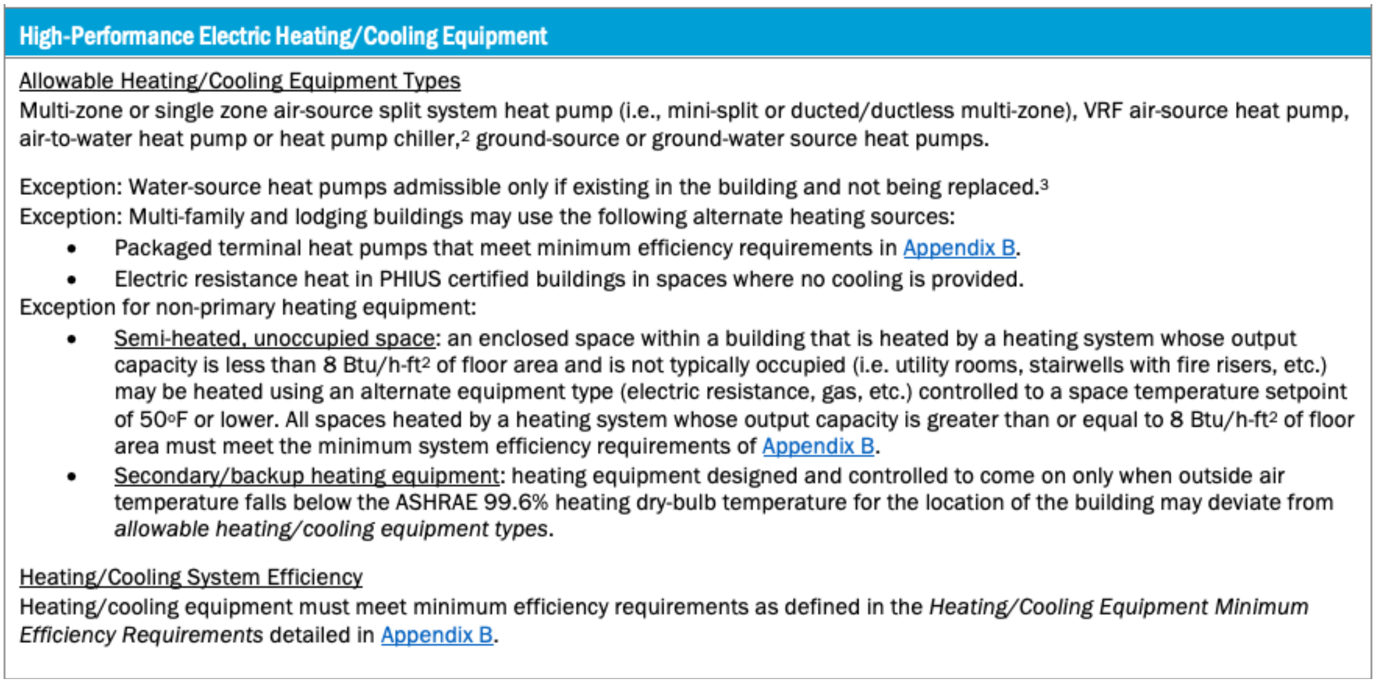
[FIGURE 8: EXAMPLE EXTERIOR DUCT SEALING]

- Properly sealed ductwork is a critical component to ensure VHE DOAS is operating as efficiently as possible. In multiple Northwest pilot projects, air leaks in the ventilation ducting and ductwork in the unconditioned attic spaces resulted in compromised system performance. HVAC complications and lessons from the pilots included:
  - Leaks in ventilation ducting causes deficiencies in air supply to spaces downstream. It is a misconception that lower airflows and the more-or-less room temperature air of ventilation systems decreases the importance of duct integrity compared to those of heating/cooling systems. This is particularly important with fully decoupled DOAS where ventilation air is delivered directly into the space, as deviations is air temperature can result in comfort issues.
  - Holes in ducting found in unconditioned attic space leads to significant amounts of unconditioned air being drawn into exhaust ducting. This causes a blending of conditioned and unconditioned air that compromises the performance of the HRV and changes the temperature of the delivered fresh-air supply.
  - VHE DOAS designers must ensure ducting is well-insulated between the HRV and the outdoors, regardless of whether it's in conditioned or unconditioned building volumes. For example, if the outside air is below freezing, the air moving in the ducts at the point of entry/exit (incoming supply and outgoing exhaust) will be near freezing. This can lead to condensation, freezing, and moisture damage without properly insulated ducting. Buildings with the highest risk of this issue have ducting routed through conditioned or semi-conditioned spaces where the relative humidity can provide the moisture necessary for condensation.
  - Minimize or avoid installing ventilation ducting above the roof as it can seriously compromise the performance of the system during cold or hot weather.
  - Make sure ducts are clean and free of mold or other allergens—particularly if the ducting has exposed insulation on the inner surfaces.

HIGH-PERFORMANCE ELECTRIC HEATING/COOLING EQUIPMENT AND SIZING

The heating/cooling system that provides comfort conditioning and operates with the HRV/ERV is critical to achieving overall energy performance associated with VHE DOAS. The following performance requirements address the heating/cooling system in a manner similar to the requirements provided for HRV/ERVs.

Heating/Cooling System Type



High-Performance Electric Heating/Cooling Equipment

Allowable Heating/Cooling Equipment Types

Multi-zone or single zone air-source split system heat pump (i.e., mini-split or ducted/ductless multi-zone), VRF air-source heat pump, air-to-water heat pump or heat pump chiller,[2] ground-source or ground-water source heat pumps.

Exception: Water-source heat pumps admissible only if existing in the building and not being replaced.[3]

Exception: Multi-family and lodging buildings may use the following alternate heating sources:

- Packaged terminal heat pumps that meet minimum efficiency requirements in Appendix B.
- Electric resistance heat in PHIUS certified buildings in spaces where no cooling is provided.

Exception for non-primary heating equipment:

- Semi-heated, unoccupied space: an enclosed space within a building that is heated by a heating system whose output capacity is less than 8 Btu/h-ft^2 of floor area and is not typically occupied (i.e. utility rooms, stairwells with fire risers, etc.) may be heated using an alternate equipment type (electric resistance, gas, etc.) controlled to a space temperature setpoint of 50°F or lower. All spaces heated by a heating system whose output capacity is greater than or equal to 8 Btu/h-ft^2 of floor area must meet the minimum system efficiency requirements of Appendix B.
- Secondary/backup heating equipment: heating equipment designed and controlled to come on only when outside air temperature falls below the ASHRAE 99.6% heating dry-bulb temperature for the location of the building may deviate from *allowable heating/cooling equipment types*.

Heating/Cooling System Efficiency

Heating/cooling equipment must meet minimum efficiency requirements as defined in the *Heating/Cooling Equipment Minimum Efficiency Requirements* detailed in Appendix B.

In commercial buildings, there are many heating/cooling system types that can provide comfort conditioning. Packaged RTUs are one of the most common existing system type targets for VHE DOAS retrofits. This is also the predominant system type for small commercial buildings across the Northwest. Also commonly installed in both retrofits and new construction are packaged heat pumps, and built-up air-handling systems of various configurations coupled with centralized hydronic systems.

For smaller systems (defined as having a nominal outdoor unit cooling capacity less than 65,000 Btu/hr.), the heating/cooling system is often a split-system heat pump. Systems can be either single-zone or multi-zone configurations. Multi-zone configurations should be carefully sized, as oversizing can result in performance significantly lower than stated by the manufacturer due to persistent part load operation. Indoor units can be ductless or ducted and typically are equipped with variable-speed fans. For large systems (≥ 65,000 Btu/hr.), system type shall be air-source VRF/VRV, air-to-water, groundwater-source, or ground-source multi-zone heat pump systems. To meet the minimum efficiency requirements outdoor units typically need to be equipped with variable speed inverter-driven compressors and variable speed condenser/evaporator fans. Efficiencies shall be as specified in Appendix B of the VHE DOAS System Requirements.

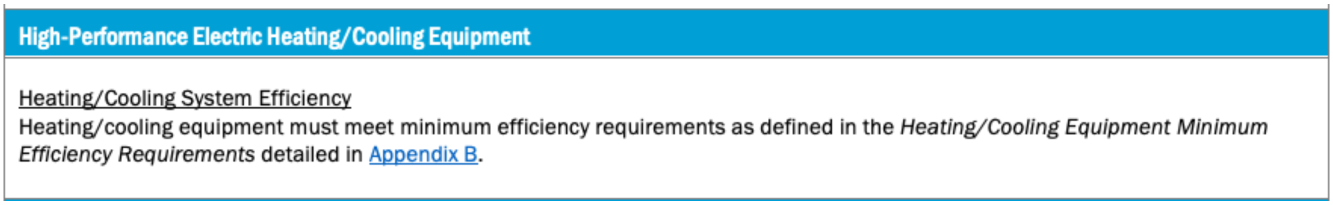
DESIGN CONSIDERATIONS

- Whenever multi-zone heat pump systems (i.e., multiple indoor units paired with a single outdoor unit) such as VRF or multi-zone split systems are considered, it is critical for system performance to correctly size the heating and cooling capacity. When indoor units are oversized, they will cycle too often. When multiple indoor units are oversized, the corresponding outdoor unit may rarely operate above its minimum capacity, causing it to consistently cycle on and off. These compounding issues can severely decrease the performance of the overall system. In both VRF and multi-zone split system air-source heat pump applications, small rooms with similar loads should be served by a common indoor unit with short, straight duct runs whenever possible. This approach not only prevents performance degradation, it simplifies system design, lowers equipment first cost and reduces ongoing maintenance costs.

- **Right sizing heating/cooling equipment** reduces energy use by reducing the amount of short-cycling during part-load conditions.
  The heating/cooling system can be downsized because the ventilation load is mostly eliminated from the equipment, sometimes as much as 10-30%. Additionally, equipment is traditionally oversized in current buildings so it is encouraged to complete load calculations for retrofits projects, instead of match the capacity of the existing equipment. Improvements in lighting power density, plug loads, envelope, and over-cautious safety factors represent areas where new systems can be downsized in addition to the high efficiency heat recovery reducing ventilation load. For example, in the Northwest pilot projects, many project sites were able to downsize the heating/cooling system by up to 50%. These savings are based on a one-to-one replacement where building occupancy, schedule, and use did not change in the renovation.

> ***In the past several years, new heat pump system configurations, typically referred to as a ductless split system, have gained some market penetration.***
>
> *These systems are available in single-zone and multi-zone configurations, as well as in air-source and groundwater-source applications. Like ductless split systems, larger versions of these systems are equipped with variable speed compressors and fans, and can achieve exceptional part-load efficiencies in both heating and cooling modes. These systems are typically referred to as VRF/VRV systems.*

Heating/Cooling System Efficiency



High-Performance Electric Heating/Cooling Equipment

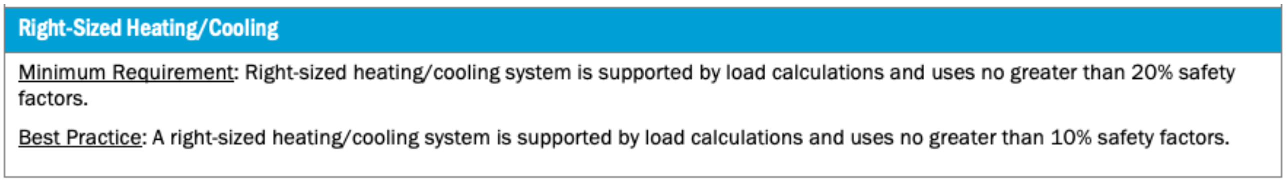
Heating/Cooling System Efficiency

Heating/cooling equipment must meet minimum efficiency requirements as defined in the *Heating/Cooling Equipment Minimum Efficiency Requirements* detailed in Appendix B.

DESIGN CONSIDERATIONS

- While nearly all VRF and mini-split heat pump manufacturers make equipment that exceeds these requirements, the largest systems (>240 kBtu/hr.) typically do not meet the minimum heating/cooling efficiency requirements. If the building peak/block load exceeds 240 kBtu/hr., the designer should consider dividing zones across multiple outdoor units so that system efficiency requirements are met or exceeded. This strategy may also be necessary to comply with refrigerant concentration limits (ASHRAE Standard 15) and stay within the maximum refrigerant line-lengths per equipment manufacturer instructions. For larger buildings, it is also critical for system performance to correctly size the indoor unit capacities based on accurate zone-level load calculations, combine rooms into similar zones using diversity where appropriate, avoid using ceiling cassettes for single spaces where capacity cannot be selected to match space load, and split up system zoning to provide a larger quantity of lower capacity outdoor units when practical.

Heating/Cooling Equipment Sizing



Right-Sized Heating/Cooling

Minimum Requirement: Right-sized heating/cooling system is supported by load calculations and uses no greater than 20% safety factors.

Best Practice: A right-sized heating/cooling system is supported by load calculations and uses no greater than 10% safety factors.

The Northwest pilot demonstration projects show that the efficiency of the VHE DOAS conversion makes it possible to significantly downsize the capacity of the heating/cooling system components. In fact, 6 of the 12 non-restaurant demonstration projects were able to downsize the heating/cooling system by 50% or more. This downsizing (right-sizing) can not only save first cost but also reduce both energy and demand savings whether an existing building conversion or new construction project. Even efficient heating/cooling systems do not always cycle efficiently under low-load conditions. Oversizing results from traditional rule-of-thumb sizing and seriously compromises energy savings while significantly increasing project costs.

DESIGN CONSIDERATIONS

- Careful load calculations should always be performed by designers, but experience from more than a dozen demonstration projects has shown that projects with office buildings converting to VHE DOAS designs often result in similar heating/cooling system sizes (normalized to conditioned floor area). These projects have demonstrated that the following sizing guidelines are achievable in typical office buildings in the Northwest region. In Climate Zone 4, the total nominal cooling capacity can often be sized at 750 sq. ft./ton. In Climate Zone 5 and 6, nominal total cooling capacity can often be sized at 600 sq. ft./ton. For example, in a 10,000 sq. ft. building in Portland (Climate Zone 4), the maximum nominal cooling capacity would be 13.3 tons, or 160,000 Btu/hr. (10,000 sq. ft. / 750 sq. ft./ton).

- The following are common issues that lead to oversizing heating/cooling systems in VHE DOAS projects: Note the design recommendation for heating/cooling system sizing for specific climate zone related guidance.
    - Using 400 sq. ft. per ton as a rule of thumb
    - Matching existing system capacity when significant improvements have been made to building envelope, lighting and plug load efficiency, and heat pump performance at low ambient temperatures
    - Failing to account for changes in occupant densities
    - Failing to account for very high efficiency heat recovery of HRV/ERV and including large ventilation loads in heating/cooling system load calculations
    - Using improper or overly conservative assumptions and safety factors, especially for occupant densities and internal lighting and equipment heat gains
    - Over-zoning small spaces with similar heating/cooling load profiles leading to oversizing indoor units (i.e., indoor VRF units in every 100 sq. ft. office building with 4,000 Btu/hr. peak-cooling loads, but needing to select smallest unit size of 6,000 Btu/hr.)

Further Design Considerations:

Right-sizing equipment and ducting. Standard heating/cooling systems are often oversized. The long-used conventional guideline of 400 sq. ft./ton of equipment capacity to design for office buildings can often be adjusted to 700–800 sq. ft./ton in Climate Zone 4, and at least 600 sq. ft./ton in Climate Zone 5. Sizing and integrity of ducting is important, especially with ventilation ducting.

ADDITIONAL HEATING/COOLING SYSTEM DESIGN CONSIDERATIONS

In addition to the VHE DOAS requirements for heating/cooling equipment outlined above, Northwest-based pilot projects have demonstrated several best practices around HVAC system design. When fully implemented, the following additional design recommendations yield a best-in-class HVAC system. Designers are encouraged to consider whether each design recommendation below may be beneficial to your project.

Heating/Cooling System Fan Operation

Additional Recommendation	Added Value
Cycle heating/cooling system fans off when there is no call for heating or cooling.[11]	Reduces energy consumption when the space is not being heated or cooled.

Though it is common in buildings with central control systems to schedule fans to turn off when there is no call for heating or cooling, it is less common for buildings without central controls to perform this function. As such, it is important that the heating/cooling system has the capability to turn fans off when the space is either unoccupied or has no call for heating or cooling.

DESIGN CONSIDERATIONS

- Heating/cooling system fans shall have the capability, and can be controlled, to turn off when there is no call for heating or cooling. This can be accomplished either through onboard logic on the heating/cooling system, or through a tie-in with a 3rd party central control system.
- This recommendation is most easily met in a fully decoupled design where ventilation air is delivered directly into the building spaces rather than through the primary heating/cooling system ductwork. It is important for total system efficiency that the heating/cooling system fans turn off when there is not a heating or cooling load, even during occupied hours when ventilation air continues to be delivered. If ventilation air is ducted to the heating/cooling system indoor units or return ducting, there may not be a clear path for the ventilation air to enter the building spaces.

Integral Refrigerant System Heat Recovery

Additional Recommendation	Added Value
Analysis of past projects show that integral refrigerant heat recovery is often not cost-effective. Designers are encouraged to be aware of this tendency when selecting a variable refrigerant flow (VRF) system and carefully consider zoning plans to ensure effective use of the VRF's heat recovery feature. If significant simultaneous heating and cooling is not expected than integral refrigerant heat recovery will not be effectively used.	This will help ensure the cost-effectiveness of the HVAC system.

For larger VRF systems, integral refrigerant heat recovery is available as an option. This type of heat recovery allows hot refrigerant gas to be diverted directly to indoor units calling for heat without the need for added compressor energy to be used.

A sophisticated refrigerant flow controller is integrated into the refrigerant distribution systems (often referred to as a "branch selector box") to support the heat recovery function. When zones on a single-flow controller experience significant operating hours with simultaneous demands for heating and cooling, integral heat recovery can be a

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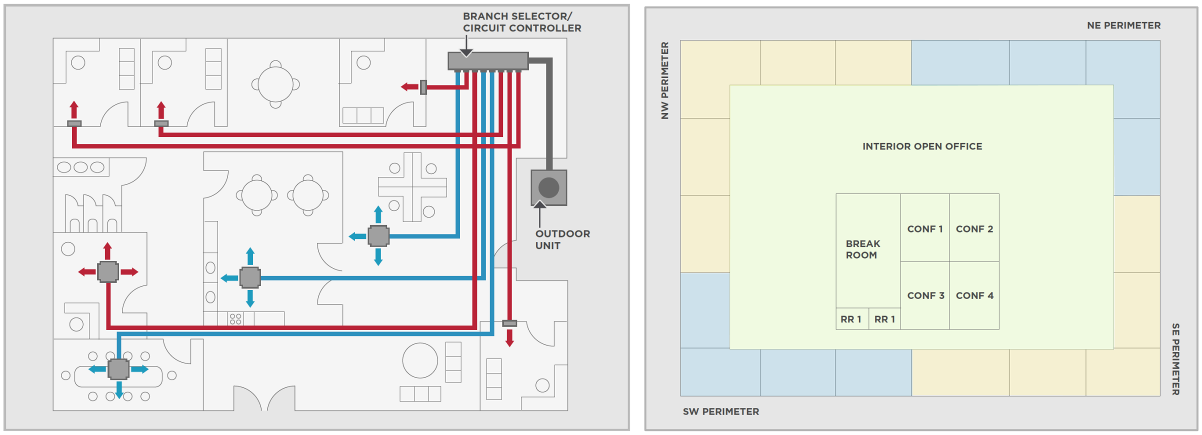
[11] Exception: Systems using active chilled beams or when space heating/cooling system fan power is less than 0.12 W/cfm.

useful feature to move heat where it is needed and save energy. Integral heat recovery is rarely a cost-effective choice for VHE DOAS installations and should be avoided unless significant simultaneous heating and cooling is expected.

DESIGN CONSIDERATIONS

- This recommendation is in place to eliminate the significant cost of integral refrigerant heat recovery of VRF systems, if such investment will not produce measurable additional energy savings or comfort benefit. It is recommended that if integral refrigerant heat recovery is included, an energy analysis is performed that demonstrates overall effectiveness, along with a zoning plan that documents the analyzed basis for applicable heating and cooling demands. The analysis should be based on the zones served by a single heat-recovery-capable refrigerant flow controller.

[FIGURE 9: EXAMPLE ZONING PLANS]



- Small, shallow buildings will rarely experience sustained simultaneous heating and cooling loads. Large, deep buildings with distinct core and perimeter zones may be able to effectively utilize integral refrigerant heat recovery, but only when zones that will experience simultaneous heating and cooling loads are balanced on a single refrigerant flow controller (served by a single outdoor unit and branch selector box). Even then, the magnitude of energy savings is very challenging to quantify and, even when using the most aggressive assumptions for energy savings, the incremental cost of adding refrigerant heat recovery to a VRF system is almost never cost-effective. Thus, the decision to specify refrigerant heat recovery on a VRF should be carefully considered by designers and owners.

CONSTRUCTION/INSTALLATION CONSIDERATIONS

Commissioning

Commissioning	Added Value
The commissioning agent should functionally test equipment installation, all dynamic control components and associated sequences of operation. The commissioning agent should also observe and verify ventilation system air balancing and duct leak testing. They should then make their report available to the system operator and building owner.	Ensures system operates as designed.

A Commissioning (Cx) agent should functionally test equipment installation and all dynamic control components and associated sequences of operation. If possible, the Cx agent should also observe and verify ventilation system air balancing and duct-leak testing. The Cx report shall be made available to system operator and building owner.

While system Cx is a well-known and often-used practice now in the HVAC industry, most Cx technicians do not yet have extensive experience with ventilation-only systems—especially those as sophisticated as the compliant HRV/ERV technologies. As for any HVAC system, adequate Cx is required to ensure that the system is performing in accordance with design intent and specification. This guideline minimizes the cost of Cx while assuring the necessary level of activity.

DESIGN CONSIDERATIONS

- System Cx should include functional performance testing of all control components and sequences of operation in the VHE DOAS. This includes vendor-provided controls, third-party control overlays, and control integration components. Functional performance tests should be supplemented with trend logs (via the control system), or portable data-logging, to confirm acceptable control sequence performance under actual conditions.

Startup and Testing, Adjusting, Balancing (TAB)

Startup and Testing, Adjusting, Balancing (TAB)	Added Value
The manufacturer (or a manufacturer approved technician) should provide startup of HRV. Consider requiring TAB of the entire HVAC system (including ventilation system airflow verification), with the following TAB conditions: o TAB should be completed after the fans have been set to design airflow rather than peak capacity. o Air at each diffuser and heating/cooling system air handler tested and balanced to within +/- 10% (or 5 CFM, whichever is greater) at design flow.[12] o HRV/ERV system airflow tested and balanced to within +/- 5% of design airflow at HRV unit.[13]	Ensures system is installed and operates as designed.

TAB is often included as a completion activity for major HVAC projects. At a minimum, the manufacturer, or representative, should provide startup of the HRV/ERV to ensure all components are operational and performing as specified. Additionally, it is important to run the HRV/ERV through its set of control sequences to ensure it operates as intended.

With VHE DOAS, traditional methods and tools used for measuring airflow may not be sufficient. Special flow hoods are required to measure very low flow rates (under 100 cfm) accurately, and the controls used in these systems are sometimes unfamiliar to designers and commissioning technicians. In addition, it is not often clear how to adjust airflow rates once initial testing has been executed in order to achieve the designed airflow intent.

DESIGN CONSIDERATIONS

- Startup and TAB should be executed on both the HRV/ERV and the heating/cooling system as part of the completion of a VHE DOAS project. Comprehensive TAB includes airflow measurement, adjustment, and

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[12] *TAB technician should use a flow hood measuring accurately down to 10 cfm, for both supply and exhaust airflows in a typical ventilation system.*

[13] *This is accomplished using reliable duct traverse at HRV unit discharge, or the manufacturer's on-board control output values.*

final verification of adequate airflow on the HRV/ERV (supply and exhaust), indoor heating and cooling units (ducted and unducted), and the ventilation air inlets and outlets. Adjustment should include use of volume balancing dampers in a ducted system, and software adjustment of fan speed ranges in unducted indoor units. Comprehensive TAB should also include duct leakage testing of all ducted systems.

ENERGY MODELING

Additional Recommendation	Added Value
Conventional energy modeling practices may misrepresent VHE DOAS energy performance. Most hourly simulation tools do not support explicit modeling of the system's components, making modeling workarounds necessary. Workarounds can include fan power adjustments, post-processing requirements and control system adjustments.	Models can be used to demonstrate life cycle savings associated with VHE DOAS.

Energy modeling can provide estimates of loads and annual energy performance to quantify the impacts of proposed design conditions on annual operating costs and equipment sizing. Energy modeling is a tool that can be used to drive both design decision-making and provide valuable information to the building owner, the authorities having jurisdiction, and/or the utilities for the purpose of efficiency incentive programs.

Current modeling tools require extra attention to more accurately model VHE DOAS systems. This design guideline recommends using non-standard energy modeling workarounds as needed. Here, descriptions of non-standard workarounds can be used by modelers to better calculate energy-savings potential.

Conventional modeling practices may misrepresent VHE DOAS energy performance. Many energy modelers are familiar with and use one of several common hourly energy simulation tools. While these are powerful tools that can be adapted for reasonably accurate modeling of VHE DOAS, many of the tools do not support explicit modeling of the system's components. As a result, modeling workarounds are generally required. The following solutions were developed while modeling the Northwest pilot projects, in addition to post-project analyses provided by expert modelers.

DESIGN CONSIDERATIONS

When evaluating the energy savings potential of VHE DOAS with energy modeling software such as EnergyPlus, VE-IES, eQuest, EDSL-TAS and others, how a system design is translated into representative energy modeling configurations is important to properly estimating energy use. The following key considerations are meant to give general guidance:

- Define the DOAS unit total fan power, supply and exhaust, to achieve the same cfm/watt for how the unit will operate. It is common for a design to use larger units with a design goal of operating them at 75% airflow. Low energy systems are between 1.3 cfm/watt and 2.0 cfm/watt.
- Utilize an HVAC system with zone fan coils or zone fan-refrigerant units which can cycle fans on and off, representing a decoupled DOAS configuration.
- Specify the heat recovery ventilation efficiency and configure the unit to bypass the heat recovery device. This may require using the systems economizer functionalities. Ensure to specify both an upper and lower outdoor dry bulb limit for proper operation. In DOAS configurations, this is often a lower limit of 60F and an upper limit of 70F or 75F depending on the system.
- Packaged rooftop cooling units will often have lower efficiencies at part load operations and are commonly oversized when installed. Ensure a proper part-load performance curve is used to capture energy use.
- Internal heat gains of lighting, people and equipment, can have dramatic impacts on an energy model's predicted heating and cooling needs of an HVAC system. In most commercial buildings, heat gains from

these sources tend to be far lower than air conditioning systems are sized with due to lighting often being LED operating at part-load, equipment continues to become more efficient with laptops, tablets, and monitors, and even body heat tends to be a mix of body types and activities, where most energy models will assume only one.

- Advanced DOAS control such as CO2 based on occupancy can have a dramatic benefit on energy savings if the unit is capable of varying at least 20% of the systems total airflow. Not all software may be capable of using variable DOAS fans which actively adjust airflow though where possible, use an airflow schedule which represents the hourly change in airflow, ensure the fans vary in speed, ensure the zone control units are selected to respond as well and vary the air delivery.

ENERGY MODELING REVIEW

Using the special considerations above, energy modeling programs can provide a reasonable means of approximating VHE DOAS energy consumption. The following modeling inputs should be reviewed when using EnergyPlus:

- HRV fan power: This will depend on the particular equipment, model, and configuration; however, fan power savings are typically significant between an electric RTU (i.e., fuel switching reference) and HRV DOAS.
- HRV control sophistication: If there are energy-efficient controls savings, ensure inputs and approaches are aligned with the proposed equipment and scope. For example, many compliant HRV/ERVs have built-in controls to enable economizing, respond to CO2 sensors (demand control), and optimize frost control cycle.
- Baseline RTU cooling part load performance degradation: Consider including current research published by NEEA on RTU cooling part load degradation in review of model inputs.

Further Design Considerations:

Systems are difficult to model using current software. VRFs and HRVs are difficult to model, especially when combining both systems into energy simulations. Built-in modeling assumptions in current software often over-estimate loads and baseline system performance. This requires recalibrations or supplemental calculations for the very high efficiency HRVs. In one of the Northwest pilot projects, it was likely that both the VRF manufacturer's and engineer's energy modeling software did not adequately account for the reduction in heating/cooling loads and was not able to accommodate common recalibrations to improve accuracy. Nearly all of the modelers in this example pilot agreed that the version of eQuest in use at the time was not capable of accurately modeling VHE DOAS. The energy modeling software, eQuest, has since been updated to DOAS systems with energy recovery. The remaining pilot projects were modeled using EnergyPlus, which resulted in recommendations for downsizing certain system capacities, but the results still failed to adequately simulate a fully optimized system. As it becomes more common, it is likely that modeling in the future will more accurately accommodate VHE DOAS.

APPLICATIONS: RETROFITS AND NEW CONSTRUCTION

VHE DOAS is applicable for most small-to-medium commercial new construction buildings, major renovations, and existing building retrofits. Existing building retrofits require a system conversion to replace conventional HVAC equipment, such as a packaged RTU. In these retrofit applications, a high efficiency HRV/ERV replaces the existing RTU to serve the ventilation load, with a high efficiency heating/cooling system (such as VRF) concurrently installed to provide heating and cooling. In new construction, VHE DOAS is included in the planning and design process.

SPECIFIC CONSIDERATIONS FOR RETROFIT APPLICATIONS

Figure 10 shows a retrofit application to compare a typical HVAC retrofit to a VHE DOAS retrofit.

[FIGURE 10: PROPOSED RETROFIT BUILDING]

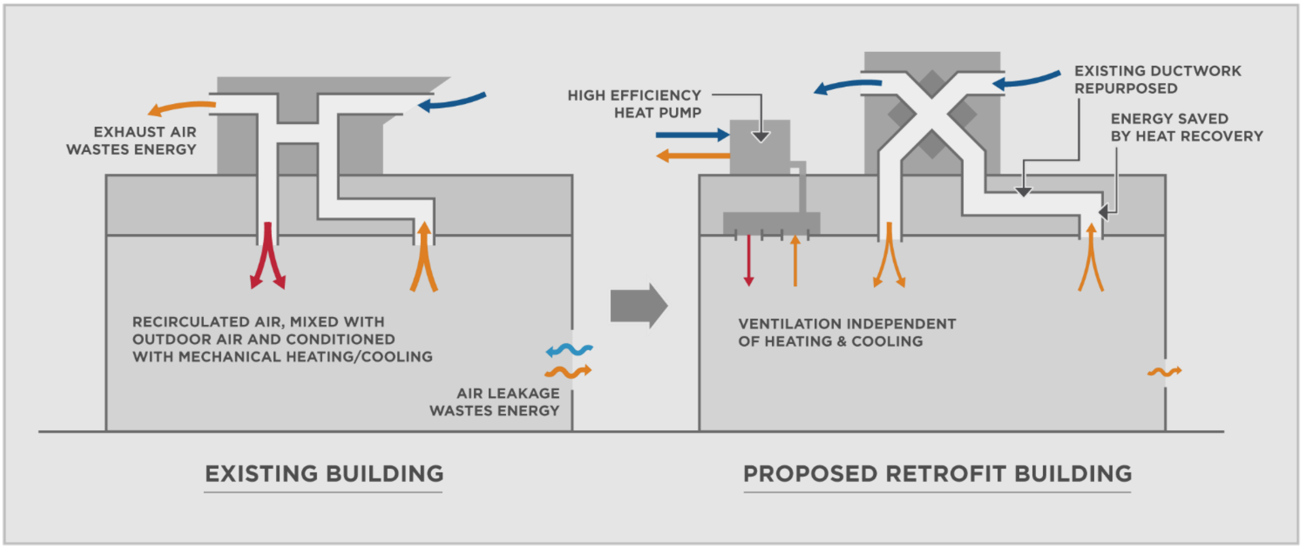

Figure 11 shows a comparison of each system’s footprint. As demonstrated, the VHE DOAS system uses less rooftop space than the traditional air-handling unit. The cross-section of an example rooftop very high efficiency HRV/ERV is shown in Figure 11 to highlight the benefits of a very high efficiency HRV/ERV, including:

- Very high heat recovery efficiency
- Very high efficiency motor and fan
- High-flow economizing
- Energy-saving controls
- Ability to adapt to existing RTU curbs for retrofit installations (applicable for some manufacturer brands)

[FIGURE 11: RTU EXAMPLES]

(The example above is based on Ventacity Systems' product configuration. Other manufacturer product configurations may vary.)

FURTHER CONSIDERATIONS:

Existing Building Applications

Existing buildings can be unique. Many buildings have unique physical or code obstacles that make conventional guidelines inapplicable.

For example, restaurants are particularly difficult due to increased airflow with vent hood operation, and energy use dominated by cooking, hot water, and refrigeration loads. These unique situations can affect the percentage of energy saved and increase installation difficulty and complexity.

This system requires more than simply removing and replacing the existing RTUs—the design of this integrated system can benefit from energy modeling or specially designed calculation tools.

New Construction Applications

VHE *DOAS is a beneficial option for new construction projects, and, as the design will accommodate the needs for the distributed heating/cooling systems, the design implementation will likely be more straightforward than in retrofit projects.*

To determine energy-savings potential for a new construction project, the savings will be compared to a code-minimum HVAC installation, rather than an existing configuration. This may impact the total savings, as existing installations are often much less efficient than new equipment that meet current, more aggressive code minimums. Modeled whole-building energy use based on three building prototypes (office, retail and schools in the three Northwest climate zones) found a range of savings of 27%, 23%, and 15%, respectively, with an overall average savings of 22%.

VALUE PROPOSITION: COST-EFFECTIVENESS AND NON-ENERGY BENEFIT CONSIDERATIONS

COST EFFECTIVENESS

VHE DOAS can reduce a building's total energy costs by using significantly less energy than most other HVAC systems. Analysis of several Northwest pilot installations of VHE DOAS, as benchmarked and monitored for energy performance before and after installation, demonstrates an average of 48% whole-building energy savings and a 69% reduction of HVAC energy use compared to a code-minimum replacement of existing equipment. These Northwest demonstration projects were retrofits for existing buildings in which a large central RTU was replaced with a high efficiency HRV/ERV and a VRF system, resulting in a VHE DOAS configuration. Pilot projects were carried out in collaboration with building owners, alliance partners and BetterBricks from 2015–2021.

Detailed project information and analysis on the initial eight projects can be found at betterbricks.com/resources/vhe-doas-pilot-project-summary-report, and case studies on all projects to-date can be viewed at betterbricks.com/solutions/very-high-efficiency-doas.

In addition to the pilot projects, Red Car Analytics recently completed a report[14] summarizing energy modeling and analysis of VHE DOAS related efficiency parameter. The analysis compared various levels of DOAS based HVAC systems to standard rooftop heat pump units (RTU HPs). Red Car Analytics considered six parameters in the energy modeling including:

1. HRV/ERV efficiency
2. Coupled or decoupled ventilation
3. Ventilation system fan power
4. Heating and cooling system sizing (right sized)
5. Ventilation post heat efficiency
6. Supply air temperature control

Red Car Analytics modeled three building types including retail, small office, and small school and two building vintages including a new building prototype (new construction built to T24 2022) and an existing building prototype (pre-1980's construction ASHRAE CZ3C). They also modeled the system in three climate zones including Portland, OR, Boise, ID, and Helena, MT.

FINDINGS

Red Car Analytics evaluated 5,000 simulations comparing VHE DOAS efficiency parameters to RTU HPs and found that more than 50% of iterations resulted in HVAC energy savings ranging from 43% to 60%; however, some iterations showed savings as high as 80%. Only 39 iterations had zero or negative savings. Negative energy savings was typically due to either high fan energy (due to increased external static pressure assumptions) or inefficient temperature control of the ventilation supply air.

In addition to a baseline RTU heat pump system, Red Car Analytics evaluated the following levels or "efficiency packages" for HVAC systems comprised of a VRF system for space heating and cooling paired with a standalone HRV for dedicated ventilation. The HVAC Efficiency Package varied efficiency parameters as follows:

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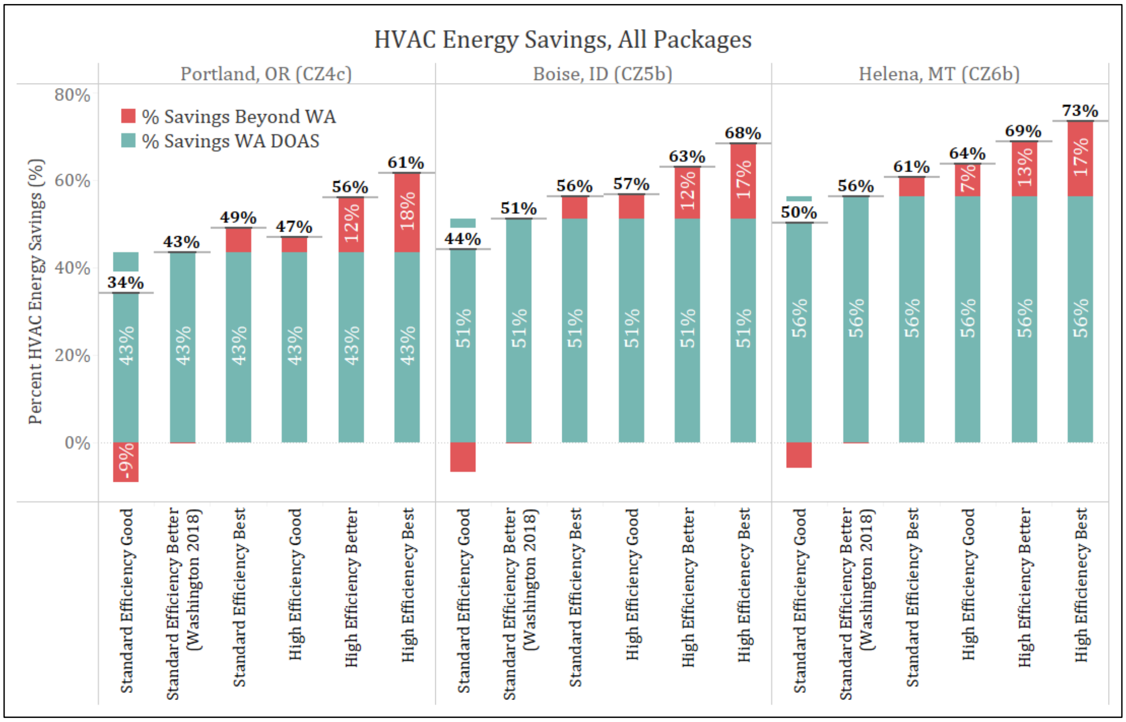
[14] Analysis of Expanded Efficiency Parameters for Very High Efficiency DOAS. Red Car Analytics. May 4, 2022.

[TABLE 3: STANDARD AND HIGH EFFICIENCY DOAS (WITH VRF) PACKAGES]

	Standard Efficiency	High Efficiency
Good	• Standard efficiency core, 60% • Standard heating efficiency post heat = 1.0 COP • Ventilation fan systems operation > than 1.00 cfm/Watt • Coupled ventilation system to zone fan coils	• High efficiency core, 82% • Heating efficiency post heat > than 1.7 COP • Ventilation fan systems operation > than 1.3 cfm/Watt • Coupled ventilation system to zone fan coils
Better	• Standard efficiency core, 60% • Standard heating efficiency post heat = 1.0 COP • Ventilation fan systems operation > than 1.00 cfm/Watt • **Decoupled ventilation system to each space**	• High efficiency core, 82% • Heating efficiency post heat > than 1.7 COP • Ventilation fan systems operation > than 1.3 cfm/Watt • **Decoupled ventilation system to each space**
Best	• Standard efficiency core, 60% • Standard heating efficiency post heat = 1.0 COP • Ventilation fan systems operation > than 1.00 cfm/Watt • **Decoupled ventilation system to each space** • **Rightsized heating/cooling systems**	• High efficiency core, 82% • Heating efficiency post heat > than 1.7 COP • Ventilation fan systems operation > than 1.3 cfm/Watt • **Decoupled ventilation system to each space** • **Rightsized heating/cooling systems**

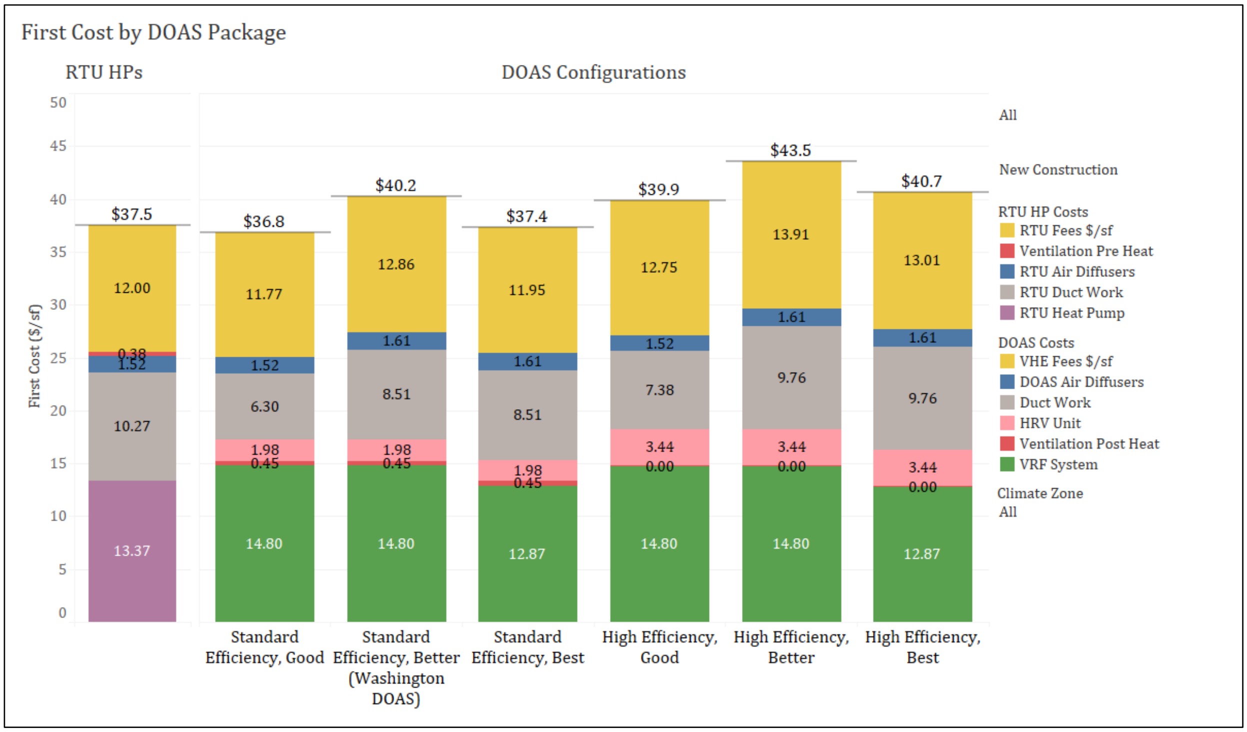
The analysis compares each DOAS Efficiency Package against two baselines, RTU HPs and the Washington code definition of a DOAS system for the average HVAC energy savings from the building prototypes, climates, and vintages evaluated in this report.

[FIGURE 12: AVERAGE HVAC ENERGY SAVINGS BY EFFICIENCY PACKAGE COMPARED TO RTU HP REPLACEMENT (GREEN) AND 2018 WSEC DOAS PROVISIONS (RED)]

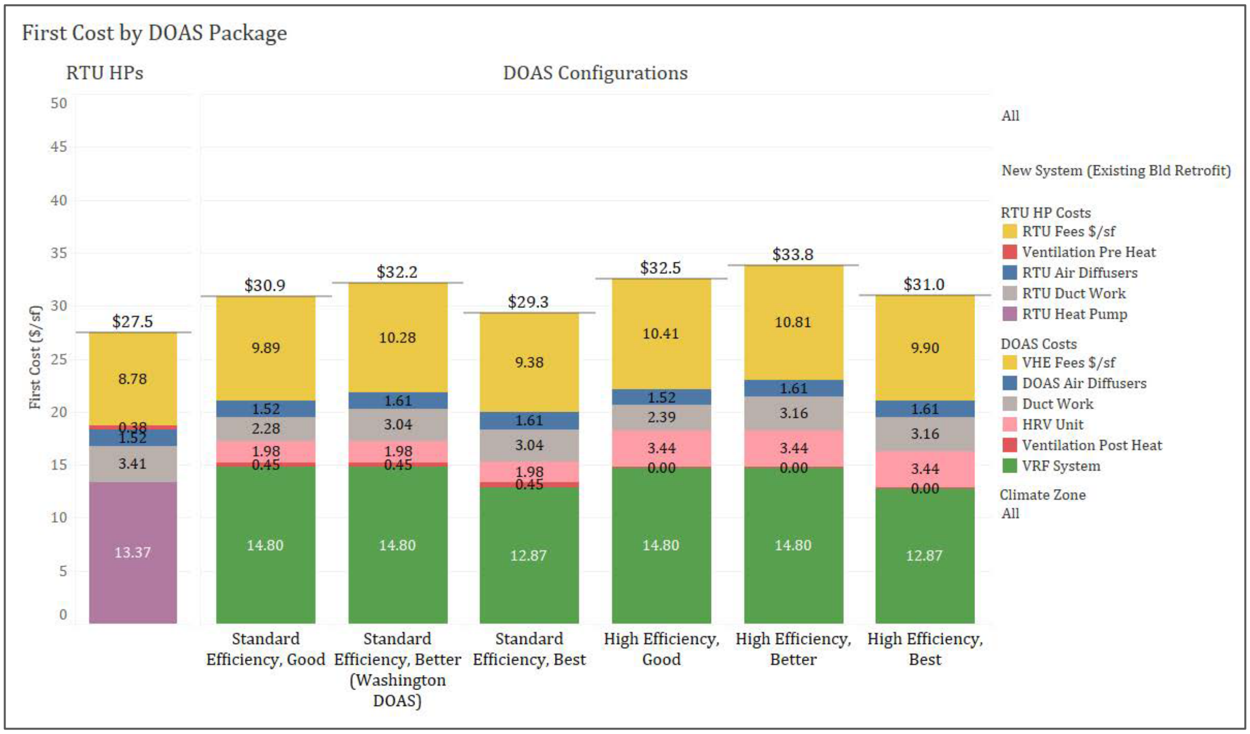


In addition, Red Car estimated first cost comparisons for each DOAS efficiency package and the baseline RTU HP system to evaluate payback timeframes for each scenario. First costs for both new construction and existing building retrofits are shown in figures 13 and 14 below, respectively.

[FIGURE 13: FIRST COST OF HVAC SYSTEM, BASED ON DOAS EFFICIENCY PACKAGE (NEW CONSTRUCTION BUILDING)]



[FIGURE 14: FIRST COST OF HVAC SYSTEM, BASED ON DOAS EFFICIENCY PACKAGE (EXISTING BUILDINGS WITH NEW HVAC INSTALLED)]



Pulling the three prior figures together, NEEA has found that the incremental cost of a best-in-class VHE DOAS system results in a simple payback averaging 8 years, with an overall HVAC savings that exceeds the 2018 WSEC (which is the most stringent in the US) by more than 15%.

One interesting finding is that the "Best" systems that prioritize right-sizing of the heating/cooling system have a lower first cost than the "Better" systems despite being higher efficiency. This is due to first cost savings associated with downsizing the heating/cooling system to accurately account for the load reduction from the HRV/ERV. NEEA found during pilot studies that many designs were not accounting for this load reduction, and it has a significant impact on system first cost and cost effectiveness.

Red Car Analytics also developed cost estimates using a variety of sources and considered both first costs and maintenance and operational costs. The analysis compared RTU HPs to various configurations of VHE DOAS systems using right sized heating and cooling equipment. The analysis found that incremental costs ranged from negative $4.50/sq. ft. up to $6.50/sq. ft. with most falling at or below $2.50/sq. ft.[15] The median energy savings for right sized systems was 3.3 kWh/sq. ft. resulting in a 5.3-year payback.[16]

For more information, the full report on Better Bricks at: betterbricks.com/resources/analysis-of-expanded-efficiency-parameters-for-very-high-efficiency-doas.

Increased Efficiency Through Integrated Design

VHE DOAS can gain the most efficiency through an integrated approach in conjunction with other needs and services of the building (e.g., envelope, loads, and operations). This will maximize the energy performance and enhance comfort and system usability. Given the interactions between technical components and professional expertise, cross-team communication is critical for successful realization of VHE DOAS. In some Northwest pilot projects where team members were not well aligned in regard to design and installation, the teams encountered numerous problems, increased cost, and installation mistakes or failures.

NON-ENERGY BENEFITS

VHE DOAS has clear energy efficiency benefits, and also offers benefits beyond energy efficiency including improved indoor air quality, improved occupant comfort, simplification and/or reduction of system maintenance, and saving space due to smaller equipment.

- **Improved indoor air quality:** The HRV/ERV delivers 100% fresh and filtered outside air when the system is running with no air recirculation. This results in improved indoor-air quality, and better occupant perceptions of comfort.
- **Improved occupant comfort**: Building occupant comfort can be improved through a combination of 1) improved air quality, 2) fresh air delivered close to room temperature, 3) heating/cooling controls by zone and occupancy rates using DCV strategies, and 4) occupant acoustic comfort. Improved health and comfort can result in lower tenant turnover.

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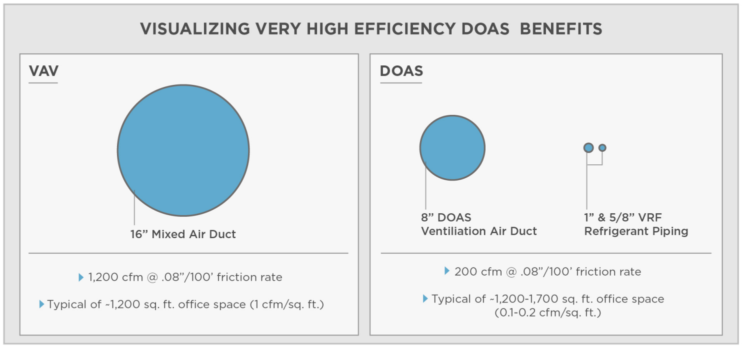
[15] Results differ when analysis assumes a WSEC baseline. Please reference original report for additional details on WSEC baseline analysis.

[16] Analysis assumed electric rate was $0.08/kWh.

- **Resilience to extreme temperatures**: VHE DOAS installations have demonstrated the ability to maintain comfortable indoor air conditions during recent record-breaking summer temperatures. In a Portland case study, the system maintained 77°F indoors at outside temperatures of 112°F.[17]
- **Simplified or reduced system maintenance**: Depending on the system being replaced, fewer components and advanced controls can help to simplify or reduce system management, maintenance, and unnecessary operation. Additionally, VHE DOAS can improve building management through simplified zone controls, self-commissioning and performance monitoring.
- **Saved space with smaller equipment**: The smaller footprint of the VHE DOAS system compared to typical packaged rooftop units (RTUs) sometimes means more available roof space for other amenities (e.g., PV arrays, green roofs, skylights, etc.).

  In some cases, VHE DOAS can reduce duct sizes by as much as 50% due to the ventilation air being decoupled from the heating/cooling system. Figure 15 compares the relative sizing difference of a 16-inch round duct for a 1,200 cfm VAV space to an 8-inch DOAS duct delivering 200 cfm of ventilation air only.

[FIGURE 15: SAVING SPACE THROUGH DUCT SIZE REDUCTION]



More information on the non-energy benefits of DOAS, visit betterbricks.com/resources/literature-review-of-non-energy-benefits-associated-with-dedicated-outside-air-systems-doas.

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[17] https://betterbricks.com/uploads/resources/VHEDOAS_Energy-350_Case-Study.pdf

APPENDIX A: HRV/ERV MINIMUM REQUIREMENTS

The following table describes the detailed requirements to meet the first key component of the VHE DOAS requirements—a high efficiency HRV/ERV—outlined in Table 1.

HRV/ERV equipment can meet core VHE DOAS System Requirements in one of two ways:

1) Equipment can satisfy the Prescriptive Requirements listed in the **left column below**, in which case they will be **listed on the Compliant Products List (CPL)** updated quarterly at: betterbricks.com/resources/very-high-efficiency-doas-system-requirements.
2) Designers have the option of selecting HRV/ERV equipment not on the CPL by proving the equipment will be selected to meet all Design Requirements listed in the **right column below** when at **design conditions**.

[TABLE 4: HRV/ERV MINIMUM REQUIREMENTS]

<table>
<tr><th colspan="3">Compliant Heat/Energy Recovery Ventilator (HRV/ERV)</th></tr>
<tr><th>Prescriptive Requirements (i.e., CPL)</th><th>- OR -</th><th>Design Requirements</th></tr>
<tr><td colspan="3">HRV/ERV thermal efficiency</td></tr>
<tr><td colspan="2">• Passive House Institute (PHI) certified, OR
• Minimum 82% Sensible Effectiveness of heat exchanger (HX) according to AHRI 1060-2018 certified software when selected at AHRI 1060-2014 winter conditions[18] at 75% of <i>nominal airflow</i>.[19] [20]</td><td>• Minimum HRV heat exchange of 82% sensible effectiveness as selected using AHRI 1060-2018 certified software at winter and summer design temperatures and airflows.</td></tr>
<tr><td colspan="3">ERVs meeting the above minimum sensible effectiveness are allowed and may be preferable in some designs to offset indoor humidity loads and decrease defrost energy requirements.</td></tr>
<tr><td colspan="3">HRV/ERV fan efficacy</td></tr>
<tr><td colspan="2">• PHI certified, OR
• Minimum 1.3 cfm/watt at 0.5” w.g. external static pressure at 75% of rated air flow[21]. Variable speed supply and exhaust fans are required.</td><td>• Minimum 1.3 cfm/watt at design operating conditions[22]. Variable speed supply and exhaust fans are required.</td></tr>
<tr><td colspan="3">Cross-flow leakage/Exhaust Air Transfer Ratio (EATR): Less than 3%.</td></tr>
<tr><td colspan="2">• PHI certified; internal leakage must be <3%, OR
• AHRI 1060-2018, the EATR must be less than 3% when selected at 100% of nominal airflow, at both 0 in w.g. and 0.5 in w.g. differential pressure using AHRI 1060 certified software (or as verified by third party testing).</td><td>• AHRI 1060-2018 certified products, EATR must meet the specified requirement based on AHRI Certified Selection Software when selected at design airflows and external static pressures.</td></tr>
<tr><td colspan="3">Minimum HRV/ERV Capabilities:</td></tr>
<tr><td colspan="3">Ventilation unit shall provide a means for heat recovery defrost control if climate conditions warrant (recirculation of return air for defrost control is prohibited). Where electric resistance heating is provided as a means of defrost control or supplemental tempering, it must include modulating (SCR) control.</td></tr>
</table>

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[18] *AHRI 1060-2014 winter conditions: 35°F DBT, 35°F WBT (OA); 70°F DBT, 58°F WBT (RA) at 75% and 100% of rated airflow. Supply and exhaust airflows shall be balanced to within 1.5%, in accordance with AHRI 1060-2014 requirements.*

[19] *Independent third-party test results demonstrating sensible effectiveness when tested in accordance with the specified conditions (per ASHRAE Standard 84) is acceptable in lieu of AHRI 1060-2018 certified software results.*

[20] ***Nominal airflow** is defined by manufacturer for determination of product compliance with Prescriptive HRV/ERV Requirements (CPL Review) and should represent typical peak application airflow. Defined **nominal airflow** will be used to determine any applicable HRV/ERV program incentive.*

[21] *Fan energy as measured during certification or application rating testing as per AMCA 210 test standards.*

[22] *Fan efficacy shall be determined by the following equation at design operating conditions:* $\frac{Supply\ Fan\ CFM}{Total\ Fan\ Power\ (Supply\ Fan\ Watts + Exhaust\ Fan\ Watts)}$, *with total fan power rated per AMCA 210/211 test standards.*

APPENDIX B: HEATING/COOLING MINIMUM EFFICIENCY REQUIREMENTS

Where applicable, allowable space heating/cooling equipment shall meet ENERGY STAR minimum efficiency requirements. Where ENERGY STAR does not apply, the minimum efficiency requirements in Table 5, below, apply.

[TABLE 5: HEATING/COOLING MINIMUM EFFICIENCY REQUIREMENTS]

Table B1: Allowable Heating/Cooling Equipment and minimum efficiency requirements

Heating/Cooling Equipment	Minimum Heating Efficiency	Minimum Cooling Efficiency	Efficiency Reference	Notes
Mini-split or ductless multi-zone heat pump (<65 kBtu/hr.)	9.5 HSPF, or 8.1 HSPF2	16 SEER, or 15.2 SEER2	ENERGY STAR Light Commercial HVAC V4.0	HSFP2 and SEER2 are mandatory for equipment purchased after January 1, 2023[23].
Air-source VRF (≥65 kBtu/hr. and <135 kBtu/hr.)	3.4 COP (47°F) 2.25 COP (17°F)	18.9 IEER	ENERGY STAR Light Commercial HVAC V4.0	Applies to both ducted and non-ducted systems and to systems with and without integral refrigerant heat recovery.
Air-source VRF (≥135 kBtu/hr. and <240 kBtu/hr.)	3.25 COP (47°F) 2.07 COP (17°F)	18.0 IEER	ENERGY STAR Light Commercial HVAC V4.0	Applies to both ducted and non-ducted systems, and to systems with and without integral refrigerant heat recovery.
Air-source VRF (≥240 kBtu/hr.)	3.2 COP (47°F) 2.05 COP (17°F)	17.0 IEER	NEEP ccASHP Specification	Applies to both ducted and non-ducted systems, and to systems with and without integral refrigerant heat recovery.
Ground-source heat pump	3.6 COP[16] at 32°F EWT	17.1 EER[17] at 77°F EWT	ENERGY STAR Geothermal Heat Pumps V3.2	Closed loop water-to-air, tested in accordance with ISO 13256-1-1998.
Groundwater-source heat pump	4.1 COP[16] at 50°F EWT	21.1 EER[17] at 59°F EWT	ENERGY STAR Geothermal Heat Pumps V3.2	Open loop water-to-air, tested in accordance with ISO 13256-1-1998.
Air-source Heat recovery or heat pump chiller (Air-Water Heat Pump)	3.29 COP	9.2 EER 15.3 IPLV	ASHRAE 90.1	COP @ 47°F dry bulb and LWT of 105°F EER and IPLV rated per AHRI 550/590
Packaged Terminal Heat Pump (<9100 Btu/hr.)[18]	3.6 COP	13 EER	DOE ZEH Program	COP and EER rated per AHRI 310/380. Allowed in multi-family and lodging occupancies only.
Packaged Terminal Heat Pump (9100 Btu/hr. to 10800 Btu/hr.)[18]	3.5 COP	12 EER	DOE ZEH Program	COP and EER rated per AHRI 310/380. Allowed in multi-family and lodging occupancies only.
Packaged Terminal Heat Pump (10801 Btu/hr. to 12600 Btu/hr.)[18]	3.4 COP	11.6 EER	DOE ZEH Program	COP and EER rated per AHRI 310/380. Allowed in multi-family and lodging occupancies only.

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[23] *HSPF2 and SEER2 are determined in accordance with 10 CFR 430 Appendix M1. Appendix M1 of 10 CFR 430 test procedure and ratings, as issued by the U.S. Department of Energy (82 FR 1426, January 2017) are mandatory for equipment purchased after January 1, 2023.*

[16] *Multi-stage models qualify using the following calculation: EER = (highest rated capacity EER + lowest rated capacity EER) / 2*

[17] *Multi-stage models qualify using the following calculation: COP = (highest rated capacity COP + lowest rated capacity COP) / 2*

[18] *Packaged Terminal Heat Pump performance shall be tested and certified to AHRI Standard 310/380 or AHRI 390. Minimum efficiency levels established using DOE Zero Energy Home Guideline as reference.*

Table B1: Allowable Heating/Cooling Equipment and minimum efficiency requirements				
Heating/Cooling Equipment	**Minimum Heating Efficiency**	**Minimum Cooling Efficiency**	**Efficiency Reference**	**Notes**
Packaged Terminal Heat Pump (>12600 Btu/hr.)[18]	3.3 COP	10.4 EER	DOE ZEH Program	COP and EER rated per AHRI 310/380. Allowed in multi-family and lodging occupancies only.
Electric resistance heat	1.0 COP	Not allowed	N/A	Allowed only in PHIUS certified buildings in spaces with no cooling, or in designated semi-heated spaces (per Table 1)

APPENDIX C: COMPARISON OF VHE DOAS TO WASHINGTON STATE ENERGY CODE

DOAS with heat recovery ventilation are now required in some jurisdictions, including Washington State. The following details the key elements that differentiate VHE DOAS from more the typical DOAS with heat recovery required by Washington State Energy Code (WSEC).

[TABLE 6: COMPARISON OF VHE DOAS TO WSEC]

	VHE DOAS	WASHINGTON STATE ENERGY CODE—2018 (WSEC) FOR DOAS	KEY TAKEAWAY
Definition	An alternative HVAC system for commercial buildings that use a very high efficiency heating/cooling system and a very high efficiency HRV/ERV to deliver heating and cooling air separately from ventilation air so that the control and energy impacts of each can be managed optimally, resulting in significantly reduced whole-building energy consumption.	An HVAC system that delivers 100% outside air without requiring operation of the heating/cooling system fans for ventilation air delivery. Heating/cooling systems and fans must cycle off when there is no call for heating or cooling in zone. Systems must include ERV complying with minimum energy recovery and fan power limitation. The ERV must have a 60 percent minimum sensible recovery or 50 percent enthalpy recovery effectiveness.	VHE DOAS has more stringent requirements that lead to deepened energy efficiency as compared to WSEC-minimum installations.
Applications	New construction and HVAC system replacement (especially ideal in replacing existing RTUs in spaces with open layouts and exposed interior ductwork).	New construction and major renovations where the HVAC system is replaced.	Similar applications.
Applicable Building Types	Generally, for commercial buildings 50,000 sq. ft. or less.	WSEC requires DOAS in a wide range of commercial building types including but not limited to offices, schools (through 12th grade), retail & department stores, theaters and general assembly, banks, casinos, libraries, places of religious worship, and many more	WSEC requires DOAS in many commercial buildings, and VHE DOAS is an excellent solution in many small-to-medium commercial building applications.
Heat Recovery at Rated Conditions	Minimum Sensible Recovery Efficiency (SRE) of HRV/ERV: 82% sensible effectiveness at 75% of nominal full airflow (HRV/ERV can either be selected from a compliant product list or meet the 82% SRE using AHRI 1060-2018 certified software at design conditions).	C403.3.5.1 requires minimum energy (enthalpy) recovery effectiveness of 50% or sensible recovery effectiveness of 60%. C406.7 (High Performance DOAS Option) requires minimum sensible heat recovery effectiveness of 80%.	VHE DOAS requires higher sensible recovery effectiveness and provides a prescriptive or design condition path while WSEC is vaguer in its requirement.
Fan Efficacy at Rated Conditions	Minimum fan efficacy: PHI certified, or 1.3 cfm/watt at 0.5" w.g. at 75% of nominal full airflow.	C403.3.5.1 Energy recovery ventilation with DOAS requires systems less than 5hp use no more than 1 watt/cfm (minimum 1.0 cfm/watt). Fan power for systems greater than 5hp are covered by section C403.8.1. C406.7 (High Performance DOAS Option) requires combined fan power less than 0.5 watt/cfm of outdoor air (2 cfm/watt), with no static pressure requirement.	VHE DOAS fan efficacy requirement is more clearly defined and slightly more stringent than the requirements of WSEC Section C403.3.5.1. The WSEC High Performance DOAS option for additional energy efficiency credit includes required fan efficacy higher than VHE DOAS.

	VHE DOAS	WASHINGTON STATE ENERGY CODE—2018 (WSEC) FOR DOAS	KEY TAKEAWAY
Heating/ Cooling System Efficiency	Heating and cooling equipment must use electric heat pump technology and meet the current ENERGY STAR® minimum efficiency requirements, or meet requirements in Appendix B. As an example, VRF and air-source heat pumps must meet the following minimum Energy-Star efficiencies[25]: ➢ <65 kBtu/h: 16.0 SEER / 9.5 HSPF ➢ >=65 & <135 kBtu/h: 17.4 IEER / 3.4 COP ➢ >=135 & < 240 kBtu/h: 16.4 IEER / 3.3 COP ➢ >= 240 kBtu/h: 16.2 IEER / 3.2 COP	Many different types of gas and electric space heating and cooling system equipment are allowed and must meet the minimum efficiency requirements in Section C403.3.2 VRF and air-source heat pumps must comply with the minimum efficiency requirements of Table C403.3.2(1)C[26]: ➢ <65 kBtu/h: 13.0 SEER / 7.7 HSPF ➢ >=65 & <135 kBtu/h: 14.6 IEER/ 3.3 COP @ 47°F / 2.25 COP @ 17°F ➢ >=135 & <240 kBtu/h: 13.9 IEER / 3.2 COP @47°F / 2.05 COP @ 17°F ➢ >=240 kBtu/h: 12.7 IEER / 3.2 COP @ 47°F / 2.05 COP @ 17°F	VHE DOAS requires electric heat pump systems while WSEC allows a wider range of technologies. Additionally, the minimum efficiency requirements for VHE DOAS are in general higher than what WSEC requires. WSEC includes low-temperature heating efficiency requirements for VRF systems, which VHE DOAS will adopt with the Energy Star Version 4 update January 1, 2023.
Decoupled System Design	Ventilation and heating/cooling system must be controlled separately with independent ducting and zoning. Ventilation air must be delivered directly to the occupied space or downstream of the terminal heating/cooling coils.	C403.3.5 requires ventilation air to be "delivered directly to the occupied space or downstream of the terminal heating and/or cooling coil." Additionally, it requires the heating and cooling fans to "shut off when there is no call for heating or cooling in the zone."	Both have similar requirements around decoupled systems. WSEC is more specific with the operation of heating/cooling system fan cycling.
Peak Heating and Cooling Loads and Equipment Sizing	VHE DOAS requires that the capacity of the heating/cooling system is supported by load calculations with no more than a 20% safety factor. Suggests best practice is to use no more than a 10% safety factor.	C403.1.2 requires that design loads for HVAC systems must be calculated in accordance with ANSI/ASHRAE/ACCA Standard 183 or with an approved "computational procedure". C403.3 requires that the smallest available equipment size that exceeds the peak loads calculated must be selected.	Both VHE DOAS and WSEC require systems are sized based on peak heating and cooling load calculations. VHE DOAS explicitly limits the amount of oversizing used. Over-sizing is common in DOAS systems as the impact of heat recovery is often overlooked in sizing heating/cooling systems. Over-sizing leads to higher overall HVAC energy usage and higher first cost.
HRV/ERV Defrost Control	Where climate conditions warrant, HRV/ERV heat recovery defrost is required. Recirculating return air is prohibited, and if electric resistance is used, it must be modulating.	No requirements around HRV/ERV defrost or recirculation.	To reduce unnecessary use of defrost and maintain indoor air quality, VHE DOAS is more stringent than WSEC.
Crossflow Leakage	Crossflow leakage: less than 3%.	No requirements for crossflow leakage.	Crossflow leakage limitation is a key difference in VHE DOAS, which can be particularly impactful for enthalpy wheels.

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[25] *VRF and heat pump efficiencies will be updated to ENERGY STAR V4 cold climate heat pump requirements as of 1/1/2023.*

[26] *Required cooling efficiency is 0.2 IEER lower for VRF equipment with refrigerant heat recovery capability.*

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