



# **VERY HIGH EFFICIENCY DEDICATED OUTSIDE AIR SYSTEM COMPREHENSIVE DESIGN GUIDE**

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SEPTEMBER 2020



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## INTRODUCTION AND DEFINITIONS

This design guide for very high efficiency dedicated outside air systems (very high efficiency DOAS) is an educational and reference tool for industry stakeholders, building owners and designers in the Northwest. It is intended to expand application of the very high efficiency DOAS approach—developed at the Northwest Energy Efficiency Alliance (NEEA)—by building interest and capabilities throughout the industry. This guide is the result of pilot installations, research, cost-effectiveness analysis, and market knowledge of the very high efficiency DOAS approach. The guide was developed for BetterBricks, a commercial resource administered by NEEA on behalf of Northwest utilities.

*Disclaimer: This design guide, and any guidance and recommendations included herein, are only intended to assist the recipient in understanding design options and approaches for achieving the energy performance levels of a very high efficiency DOAS; it should not be used in lieu of professional design or engineering services. Moreover, the design guide 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.*

*All enclosed diagrams and figures are for illustration purposes only and do not reflect the exact configuration or options of all manufacturers' products.*

### WHAT IS VERY HIGH EFFICIENCY DOAS?

ASHRAE defines DOAS 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."

Very high efficiency DOAS improves the efficiency of the DOAS approach by 1) fully decoupling heating and cooling from a building's ventilation system to provide optimal control of each critical function, 2) pairing a high-performance heating/cooling system with a very high efficiency heat recovery ventilator (HRV) or energy recovery ventilator (ERV) with  $\geq 82\%$  sensible effectiveness, and 3) optimizing the system design by optimally sizing equipment and minimizing fan power by using design principles to minimize pressure drop and operate ventilation fans at ideal conditions.

[Figure 1: Very High Efficiency DOAS installed on rooftop in Portland, Oregon]

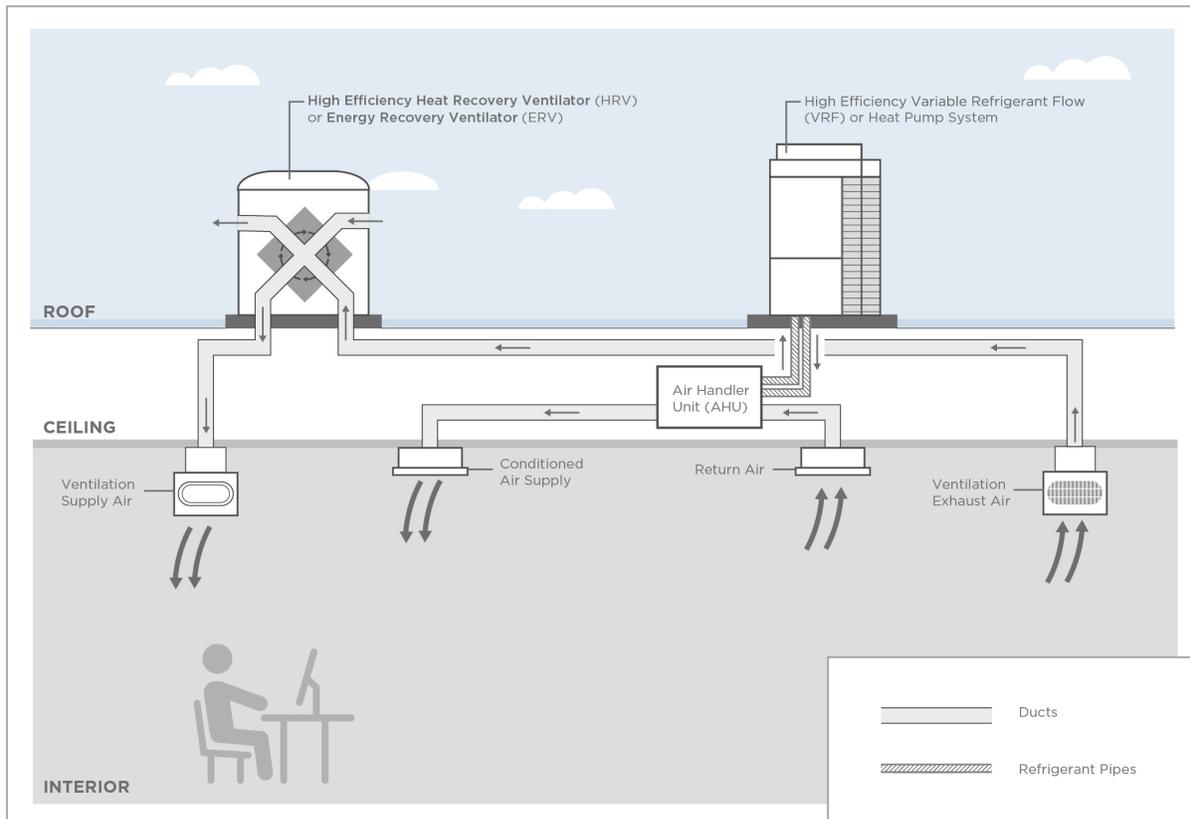


In the very high efficiency DOAS approach, the HRV/ERV provides ventilation to occupied spaces independently from heating/cooling in a fully decoupled system, and pre-conditions incoming outside air by recapturing heat (or rejecting it when in cooling mode) from the outgoing airstream without supplemental heating or cooling of the ventilation air (in most cases). In these systems, it is critical to select high efficiency HRV/ERV technology and to right-size the high-efficiency heating/cooling equipment for the best energy performance.

There are several types of high-performance heating/cooling systems particularly suited to the very high efficiency DOAS 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.

In Figure 2 below, the ventilation and heating/cooling systems depicted represent examples of specific technology types (counter-flow HRV and VRF), but other equipment types and systems are eligible. For further details, please see the Minimum Equipment Performance and Required Capabilities section of this guide located on [page 14](#).

[Figure 2: Very High Efficiency DOAS Schematic]



For an HVAC system to be considered very high efficiency DOAS, it must meet or exceed the following criteria:

- **Include an HRV that meets the following requirements:** (Note: this guide uses the term “HRV” to refer to and HRV or ERV interchangeably, unless otherwise noted).
  - Passive House Institute (PHI) certified, or minimum 82% sensible heat exchange effectiveness at standard testing conditions.
  - PHI certified, or minimum 1.4 cfm/watt total HRV fan efficacy at 50% airflow and 0.5” external static pressure.
  - Control capabilities that include time-of-day scheduling and variation in fan airflow as a function of an external input such as CO<sub>2</sub> or duct-static pressure.
  - Economizer function capable of proportional economizer control up to 100% outside air when OSA temperature is suitable to provide free cooling.
  - Crossflow leakage (or exhaust air transfer ratio) of less than 3%.
- **Include a high efficiency heating/cooling system:**
  - Air-source heat pump, including VRF systems.
  - Ground-source or ground-water heat pump.
  - Hydronic systems utilizing air-water heat pump as central plant.

- Comply with the following critical system design requirements:
  - Decoupled system design where ventilation and heating/cooling system are controlled separately with independent ducting and zoning.
  - Design operating conditions with minimum HRV heat exchange of 75% and fan efficacy of 1.3 cfm/watt.
  - Right-sized heating/cooling systems supported by load calculations and not buffered with safety factors greater than 10%.

More detail on these criteria can be found in the Detailed Design Guidelines for Very High Efficiency DOAS, on [page 13](#). For more information on achieving optimum performance and energy efficiency, refer to [page 32](#).

## WHAT VERY HIGH EFFICIENCY DOAS IS NOT

The following characteristics would disqualify an HVAC system from being a very high efficiency DOAS:

- DOAS that primarily uses supplemental heating/cooling energy to condition ventilation air.
- Systems that use the same ducts to deliver heating, cooling and ventilation.
- HRVs that have lower sensible heat recovery than 82% at 75% of their rated airflow.
- Variable air volume (VAV) systems with heat recovery, or any system in which heating/cooling air and ventilation air are combined.
- Systems using terminal conditioning for supplemental heating/cooling of ventilation air, such as terminal reheat systems.
- VRF systems with simultaneous heating and cooling (often designated as “heat recovery”) are discouraged. In this instance, zoning plans and energy savings analysis would be required.

## VERY HIGH EFFICIENCY DOAS COMPARED TO WASHINGTON STATE ENERGY CODE (WSEC 2018) DOAS

DOAS with heat recovery ventilation are now required in some jurisdictions, including Washington State. The table below details the key elements that differentiate very high efficiency DOAS from more the typical DOAS with heat recovery required by Washington State Energy Code (WSEC 2018).

SIMILARITIES	DIFFERENCES
<ul style="list-style-type: none"> <li>• Similar target occupancies</li> <li>• Both require complete separation of ventilation air from heating/cooling system</li> <li>• Both require high-performance HRVs on the DOAS</li> <li>• Both include high-efficiency fan-performance requirements</li> </ul>	<p><i>In contrast to WSEC 2018, very high efficiency DOAS:</i></p> <ul style="list-style-type: none"> <li>• Requires higher sensible-heat-recovery effectiveness</li> <li>• Requires variable fan control to enable demand control ventilation</li> <li>• Encourages use of economizer</li> <li>• Limits the amount of crossflow leakage of the HRV</li> </ul> <p><i>In contrast to very high efficiency DOAS, WSEC 2018:</i></p> <ul style="list-style-type: none"> <li>• Requires lower fan efficacy in base code and higher fan efficacy in the WSEC High Performance DOAS Option</li> </ul>

The table in Appendix 1 on [page 36](#) provides a more comprehensive comparison of very high efficiency DOAS as described in this guide with comparisons between the WSEC 2015 requirements and the WSEC 2018 requirements for DOAS (effective in February 2021).

# BENEFITS OF VERY HIGH EFFICIENCY DOAS

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## ENERGY, ENERGY-COST, AND FIRST-COST SAVINGS

Very high efficiency 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 very high efficiency DOAS, as benchmarked and monitored for energy performance before and after installation, demonstrates an average of 42% whole-building energy savings and a 70% reduction of HVAC energy use compared to a code-minimum replacement of existing equipment. More information on these eight pilot studies can be found at: [betterbricks.com/resources/vhe-doas-pilot-project-summary-report](https://betterbricks.com/resources/vhe-doas-pilot-project-summary-report).

## ENERGY-SAVINGS POTENTIAL

Very high efficiency DOAS results in substantial energy savings due to:

- **High efficiency heating/cooling equipment**
- **Heat recovery from 82% sensible heat exchange effectiveness:** The HRV efficiency can eliminate the need for supplemental heating/cooling of the ventilation air because the incoming air is pre-heated or pre-cooled to within 3–5 degrees F of the conditioned space temperature. This ultimately decreases the run time and energy consumption of the heating/cooling system.
- **Fan energy reduction** by using smaller, more efficient fans in heating/cooling equipment and more efficient HRV fans.
- **Right-sized heating/cooling equipment** to reduce 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. Additionally, equipment is traditionally oversized in current buildings. Improvements in lighting power density, plug loads, envelope, and over-cautious safety factors represent overall reductions in loads and, therefore, the systems that accommodate those loads.
- **Decoupled systems:** Separating the ventilation air from the heating/cooling system also leads to energy savings. 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.
- **Enabled demand control ventilation (DCV):** Ventilation rates in very high efficiency DOAS 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.
- **Integrated design:** Very high efficiency 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. Note that this type of conversion, using brand new HRV technology (in the U.S.), is unfamiliar to most project teams. Given these interactions between technical components and professional expertise, cross-team communication is critical for successful realization of very high efficiency 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.

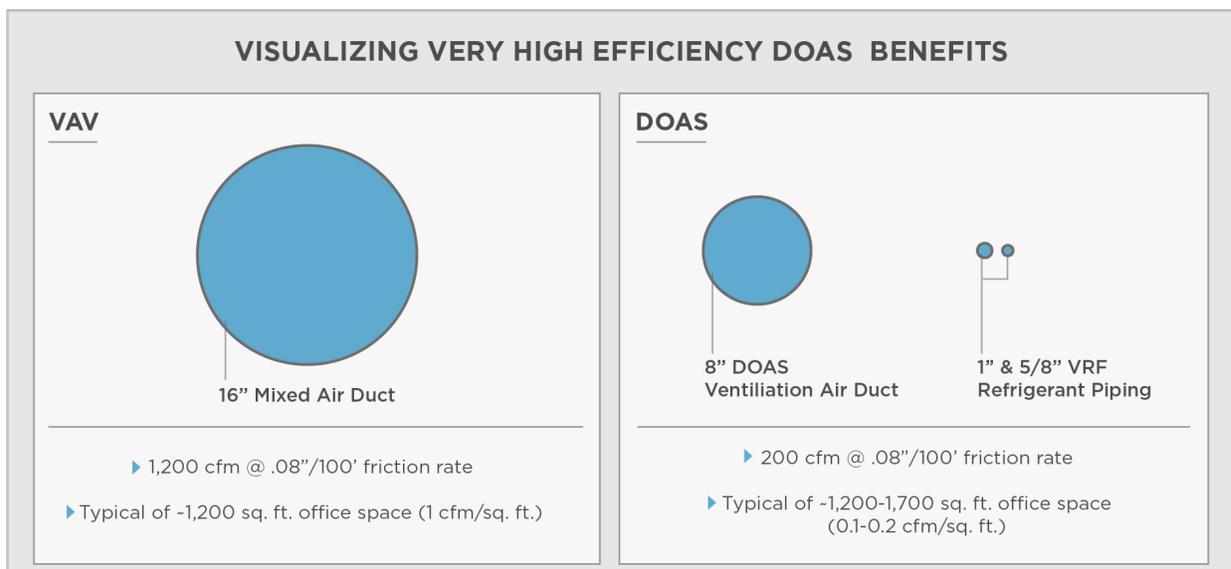
The Northwest pilot projects utilized these strategies to realize significant energy savings. Some pilot project sites were able to downsize the heating/cooling system by up to 50%. These savings are based on a one-to-one replacement where building occupancy, schedule, and use did not change in the renovation. Equipment efficiency and size accounted for roughly 15–20% of the savings, with 30% of the savings realized by eliminating the simultaneous heating/cooling on the existing dual-duct HVAC systems. In renovations where downsizing the heating/cooling system is not feasible, subsequent energy savings will likely be less significant.

## BENEFITS BEYOND ENERGY EFFICIENCY

- **Improves indoor air quality:** The HRV 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.
- **Improves 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.
- **Simplifies or reduces 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, very high efficiency DOAS can improve building management through simplified zone controls, self-commissioning and performance monitoring.
- **Saves space with smaller equipment:** The smaller footprint of the very high efficiency 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, very high efficiency DOAS can reduce duct sizes by as much as 50% due to the ventilation air being decoupled from the heating/cooling system. Figure 3 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 3: Saving Space Through Duct Size Reduction]



## ECONOMIC ANALYSIS

Cost is often a barrier to the adoption of new technological approaches. While very high efficiency DOAS has been adopted widely in Europe, cost barriers have slowed adoption in the U.S. For example, the payback period of very high efficiency DOAS is currently higher in the U.S. than in Europe, even though the latter has higher energy costs. However, our analysis shows that very high efficiency DOAS is 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.

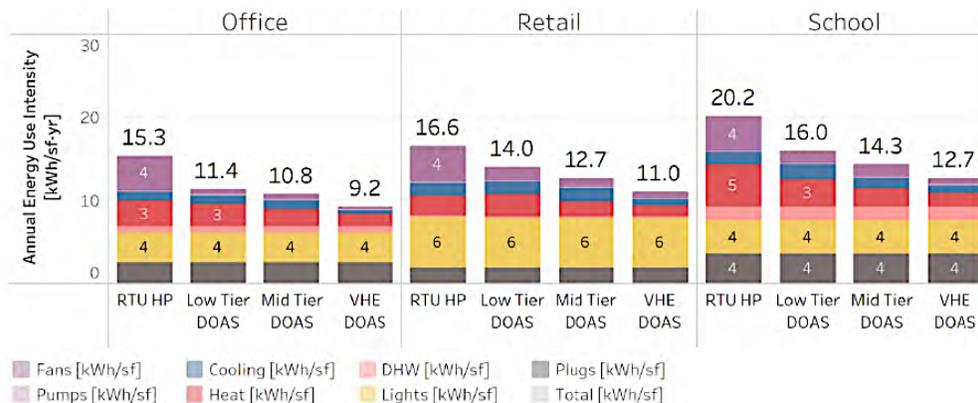
Economic analysis shows very high efficiency DOAS to have the highest net-present value across Northwest climate zones compared to two other HVAC strategies that were studied. In this study, a cost and energy analysis provides a broader understanding of the economic benefits of converting an existing commercial building's HVAC system. It examines three different HVAC configurations with varying levels of energy efficiency (very high efficiency DOAS, mid-tier DOAS, and low-tier DOAS (WSEC equivalent)) in three building types (office, retail and schools) and three climate zones (4C, 5A, 5B). Working with contractors, designers, and equipment vendors, costs were compared to relevant case studies to substantiate estimates and ensure they reflected construction best practices.

The analysis found the very high efficiency DOAS approach to have the highest net-present value over the 20-year estimated life of the equipment in all climate zones and building types analyzed. The mid-tier DOAS package, which was developed as part of this study, was found to be a positive net-present value in all climates and buildings, with one exception (retail in Climate Zone 4), and had a lower net-present value than the very high efficiency DOAS package. The low-tier DOAS was found to be positive in Climate Zone 6 for the office and school building only, with the retail building not paying back in 20 years. In the retail buildings, all the baseline RTU electric heat pump (RTU HP) systems include airside economizers and variable speed fans (VSFs). Baseline RTU HP systems for other building types included a mix of economizer and non-economizer systems with higher energy use.

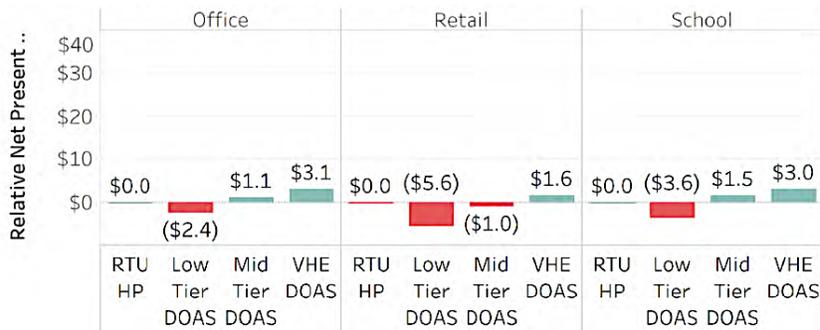
In real-world applications, higher initial cost of equipment was a key barrier encountered in the Northwest pilot projects. Most pilots, which were completed between 2016 and 2018, cost less than \$25/sq. ft. to implement. However, in many cases, the initial bid submitted was significantly higher than the actual cost. The heightened bid pricing was most likely due to 1) new technology pricing, 2) lack of experience in designing and installing this system, and 3) the tendency to not downsize the heating/cooling equipment in initial bids.

Figure 4 and 5 show the energy use and net-present value of a select set of the analysis. The charts show results for a small commercial office, retail, and school building, operating west of the Cascade Mountains in ASHRAE Climate Zone 4c. The energy use is shown annually in kBtu/sq. ft. of floor, and the relative net-present value compared to the RTU HP system is shown in \$USD/sq. ft. from the energy-cost savings over 20 years.

[Figure 4: Energy Use Intensity (kWh/sq. ft. per year) – (CZ4c) Mixed Marine]



[Figure 5: Relative Net Present Value (\$/sq. ft.), 20-year (CZ4c) Mixed Marine]



More information related to this study can be found in the economic analysis completed by Red Car Analytics at: [betterbricks.com/uploads/resources/NEEA-DOAS-Analysis-Report\\_Red-Car\\_Final.pdf](https://betterbricks.com/uploads/resources/NEEA-DOAS-Analysis-Report_Red-Car_Final.pdf).

## APPLYING VERY HIGH EFFICIENCY DOAS IN PROJECTS

Very high efficiency 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 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, very high efficiency DOAS is included in the planning and design process.

Very high efficiency DOAS is still new to the U.S., with the advanced HRV/ERV technology required in the design of this system only becoming available in 2016. For this reason, it is recommended that those in the industry first familiarize themselves with straightforward applications (e.g., office, retail, schools, etc.) to learn how to design, install, and manage very high efficiency DOAS before undertaking more difficult projects. Certain building types, such as restaurants, hospitals, and warehouses, are either more complex or not a good fit for very high efficiency DOAS, and therefore require careful analysis and design to be effective.

## SPECIFIC CONSIDERATIONS FOR RETROFIT APPLICATIONS

Figure 6 shows a retrofit application to compare a typical HVAC retrofit to a very high efficiency DOAS retrofit.

[Figure 6: Proposed Retrofit Building]

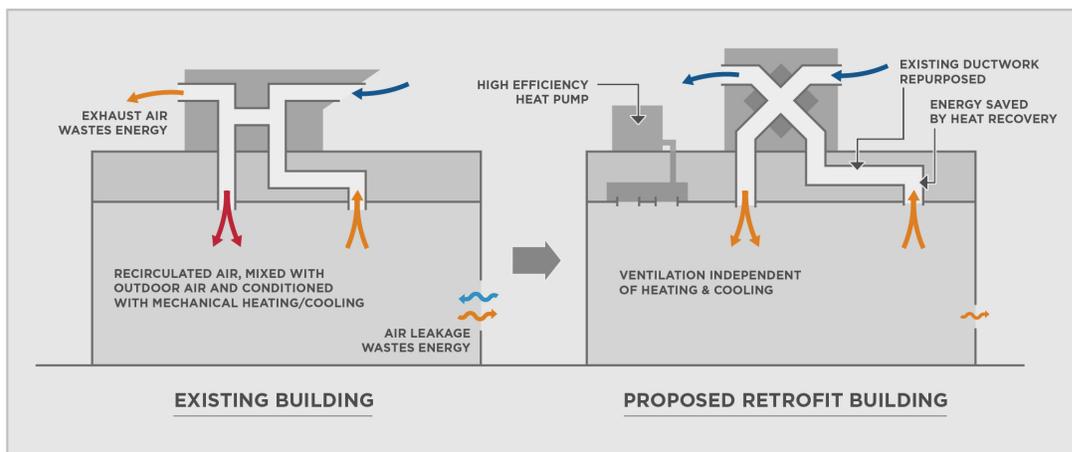


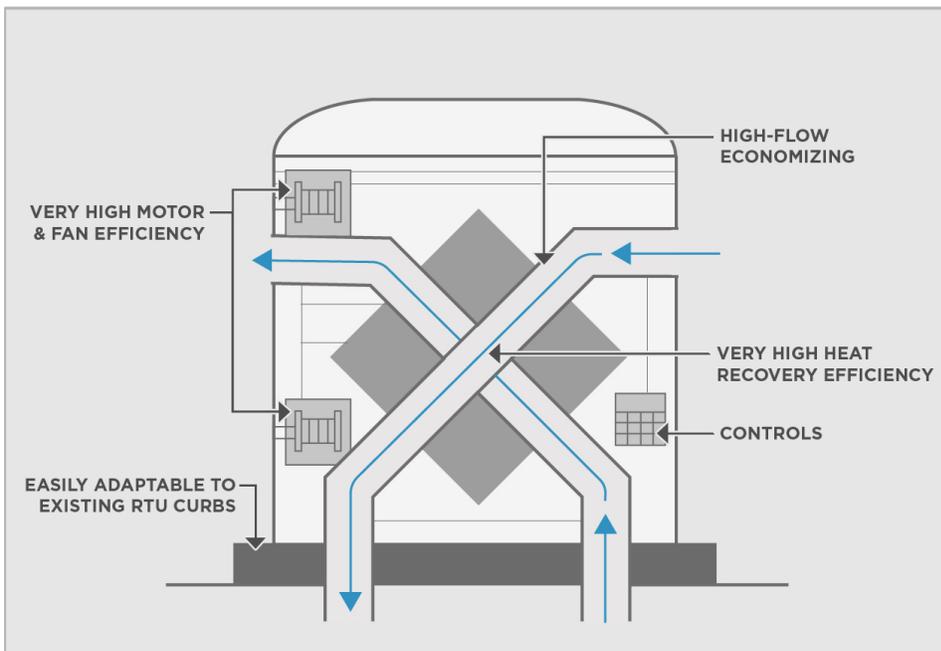
Figure 7 shows a comparison of each system's footprint. As demonstrated, the very high efficiency DOAS system uses less rooftop space than the traditional air-handling unit. The cross-section of an example rooftop very high efficiency HRV is shown in Figure 8 to highlight the benefits of a very high efficiency HRV, including:

- Very high energy 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 7: RTU Examples]



[Figure 8: Very High Efficiency HRV]



(The illustration 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

*Very high efficiency 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%.*

## NORTHWEST PILOT EXAMPLE INSTALLATIONS

The Northwest pilot projects were carried out in collaboration with building owners, alliance partners and BetterBricks from 2015–2018. The pilots were conducted to better understand the design, modeling, and installation process of very high efficiency DOAS in small-to-medium commercial buildings, as well as validate energy savings.

These projects achieved their overall goal of demonstrating the potential for cost-effective and substantial energy savings in existing commercial buildings, while maintaining or improving indoor air quality and occupant comfort. The overall goals of the project were most successfully achieved in the pilots when the project specifications and guidelines were followed. On average, participants saw a 70% reduction of their actual HVAC energy use and a 42% reduction in actual whole-building energy use. Even if these pilot buildings had started with standard code-minimum equipment prior to the conversion, modeling still shows significant average energy savings of 65% for HVAC energy use and 36% for whole-building energy use.

The pilot projects involved a wide array of building types and installation scenarios, including a dormitory in Darby, Mont., office buildings in several Northwest locations, and two small, limited-seating restaurants. Each project had unique challenges requiring careful design considerations. For example, the restaurants have less energy savings because of larger ventilation loads from exhaust hoods and added complexity with pressure management between the kitchen and dining areas.

The following table shows other pilot examples including overall characteristics and cost/energy savings. For additional examples and more information about the pilot projects refer to the [Very High Efficiency DOAS Pilot Summary Report](https://betterbricks.com/solutions/hvac) (betterbricks.com/solutions/hvac).

				
<b>Location</b>	Portland, OR	Corvallis, OR	Seattle, WA	Corvallis, OR
<b>Building type</b>	Second-story law office space	Single-story government office building	Third-floor office space	Restaurant
<b>Conditioned area (sq. ft.)</b>	11,615	3,770 of 13,200	5,911	1,360
<b>Total project cost (per sq. ft.)</b>	\$15.61	\$11.47	\$16.83	\$27.50
<b>Reduction in building energy use</b>	63%	39%*	42%	8%**
<b>Reduction in HVAC energy use</b>	72%	70%*	69%	43%**
<b>Existing HVAC system</b>	9 RTUs (35 tons in total)	2 4-ton RTUs (in the 3,770 sq. ft. retrofitted zones)	14-ton electric resistance RTU	7.5-ton RTU
<b>New HVAC system</b>	16-ton Mitsubishi VRF 4 Ventacity VS100ORT HRVs	4-ton Mitsubishi multi-zone mini-split heat pump 1 Ventacity VS100ORT HRV	14-ton Mitsubishi VRF 1 Ventacity VS100ORT HRV	2-ton Fujitsu single-zone ductless heat pump 3 3-ton Daikin single-zone ductless heat pumps 1 Ventacity VS100ORT HRV

\*The HVAC upgrade was limited to two (28% of floor area) of the five zones, and saved 11% of whole-building energy use and 19% in HVAC energy use. For a more accurate illustration of total HVAC and whole-building energy use, the results in the table above are extrapolated and represent whole-building impacts if all systems and zones were converted in the same manner.

\*\*This was atypical for restaurants due to low occupancy and high take out in a small floor area arrangement; some building uses such as restaurants, hospitals and warehouses are less ideal for this HVAC system and require careful analysis and design to be effective.

				
<b>Location</b>	Seattle, WA	Darby, MT	Libby, MT	Portland, OR
<b>Building type</b>	Airport terminal building	Dormitory	Office building	Restaurant
<b>Conditioned area (sq. ft.)</b>	25,200	11,000 (per dorm)	5,735	1,147
<b>Total project cost (per sq. ft.)</b>	\$36.85	\$9.64	\$21.90	\$30.99
<b>Reduction in building energy use</b>	61%	24%	29%	20%
<b>Reduction in HVAC energy use</b>	85%	52%	45%	73%
<b>Existing HVAC system</b>	3 RTUs (95 tons in total)	5 electric forced-air furnaces 1 exhaust fan	1 electric boiler 2 swamp coolers 1 6-ton heat pump RTU 1 server room heat pump	1 3-ton RTU
<b>New HVAC system</b>	4 Mitsubishi VRF systems (32 tons in total) 3 Ventacity VS1000RT HRVs	4 3-ton York split system heat pumps 1 4-ton York split system heat pump 1 Ventacity VS1000RT HRV	2 4.5-ton Mitsubishi heat pump units 1 Ventacity VS1000RT HRV	1 3-ton Daikin multi-zone ductless heat pump 1 Ventacity VS1000RT HRV

## APPLICABILITY OF VERY HIGH EFFICIENCY DOAS ACROSS CLIMATES

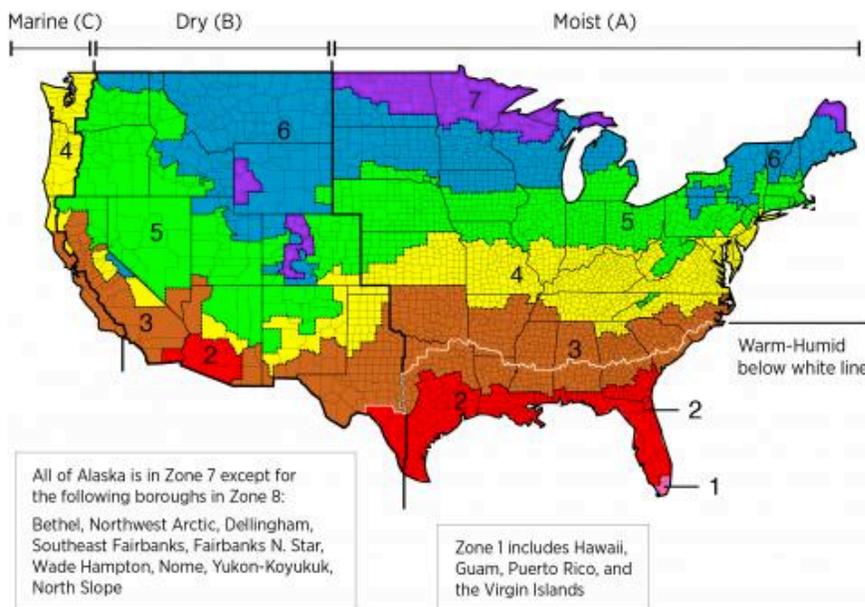
The Northwest climate is not uniform, but it is mostly limited to the three primary zones of 4C, 5B, and 6B, as shown in Figure 9. The coastal areas west of the Cascade Mountains, with generally milder temperatures and relatively low humidity, have little need for frost protection or dehumidification. These areas often don't require supplemental heating and cooling of the ventilation air. According to analysis from BetterBricks, an HRV with 82% sensible effectiveness can provide room-neutral air at all anticipated design conditions. 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.

In colder climates, heat recovery systems will also need to protect against frost on the heat exchanger medium when outside ambient temperatures approach and go below freezing. In the most efficient systems, frost occurs

on the exhaust side of the heat exchanger when warm, moist indoor air cools to near freezing temperatures as heat transfers to the incoming outside airstream. This freezing condition rarely occurs in less efficient HRVs/ERVs because these units recover less energy and the exhaust airstream rarely reaches freezing temperatures. High efficiency HRVs/ERVs, such as those in the very high efficiency DOAS design, require defrost control to ensure high efficiency operation in cold conditions. Note that 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 very high efficiency DOAS systems. More detail on these requirements can be referenced in the Minimum Equipment Performance & Required Capabilities section on [page 14](#). Frost prevention systems typically either 1) pre-heat outside air with an 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 very high efficiency DOAS requirements prohibit the use of recirculation as a means for frost protection. Additionally, if electric resistance is used as a frost protection strategy, it must be variable or modulating and provide the minimum amount of energy required to prevent frost. Variable defrost control for plate-style heat exchangers is often accomplished using a silicon-controlled rectifier (SCR control).

[Figure 9: IECC Climate Zones Map]



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

## DETAILED DESIGN GUIDELINES FOR VERY HIGH EFFICIENCY DOAS

The following system requirements and recommendations are intended to provide guidance to manufacturers of components of these systems, as well as the designers and specifiers of these systems. They were developed over the course of several years of research, market analysis, and pilot project installations, and have evolved in an effort to decrease energy consumption, improve indoor air quality and improve occupant comfort over conventional systems. The very high efficiency DOAS systems addressed in this guideline include high-efficiency HRV systems to serve the ventilation load installed in combination with a high-efficiency heating/cooling system.

Often, the heating and cooling is provided by multi-zone air-source heat pump systems, commonly referred to as variable refrigerant flow/variable refrigerant volume (VRF/VRV) systems; however, other high-efficiency technologies such as ground-source heat pumps, groundwater-source heat pumps, and air-to-water heat pump central plant systems can also meet the requirements.

In order to be considered very high efficiency DOAS, systems should meet the Minimum Equipment Performance and Critical System Design Requirements as outlined in Sections 1 & 2 below. The best practices listed in Recommended Guidelines to Achieve Optimum Performance in Section 3 on [page 32](#) are highly encouraged. Please note that these guidelines were developed for the Northwest climate zones.

Each section includes a summary of the requirement, background information about how or why that requirement was established, detail on the requirement, and design considerations. A summary of these requirements can be found in Appendix 2: System Requirements and Recommendations tables on [page 39](#).

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## 1. MINIMUM EQUIPMENT PERFORMANCE & REQUIRED CAPABILITIES

### HEAT RECOVERY VENTILATION REQUIREMENTS

Very high efficiency DOAS performance relies on HRVs employed with several key minimum performance specifications and capabilities. The following is a summary of the requirements that result in optimal system performance.

#### 1. Minimum HRV/ERV Efficiency.

- PHI certified, OR
- Minimum 82% Sensible Effectiveness of heat exchanger (HX) at Air-Conditioning, Heating & Refrigeration Institute (AHRI) Standard 1060 winter conditions at 75% of rated flow verified by independent third-party testing.

*Notes: While AHRI 1060 and PHI requirements are not exactly equivalent due to differences in test procedures and rating conditions, the intent is to require very high efficiency heat recovery based on the testing and certification path chosen by the manufacturer. ERVs meeting the 82% Sensible Effectiveness threshold are also allowed. Rated flow, often synonymous with nominal flow, refers to the flow measured during testing AHRI 1060 winter conditions: 35F DBT, 33F WBT (OA); 70F DBT, 58F WBT (RA) at 75% and 100% of rated airflow. Supply and exhaust airflows must be balanced to within 1.5%, in accordance with AHRI 1060 requirements. For the purposes of these requirements, third-party verification testing may be conducted at an independent laboratory (with or without manufacturer personnel present, provided they do not interfere with conduct of the test), or at a manufacturer's laboratory (if testing is conducted and overseen by personnel from an independent lab not affiliated with the manufacturer and with no conflicts of interest regarding the test results).*

**Background.** Currently, the majority of HRV/ERV products used for recovering ventilation airflow energy losses feature sensible recovery efficiency ratings between 50 and 70%. Most of these products are either wheel-type ERVs or ERVs/HRVs that have crossflow plate-core HX—both of which typically limit sensible heat exchange efficiency to about 80% or less.

In addition, these recovery efficiency ratings derive from a limited test procedure that measures the temperature difference between the outgoing exhaust and delivered fresh air to compute the fraction of energy in the outgoing air returned to the incoming airstream. This measurement does not account for many associated energy flows and their origins (e.g., case or housing energy losses, fan/motor losses, crossflow air leakage, etc.).

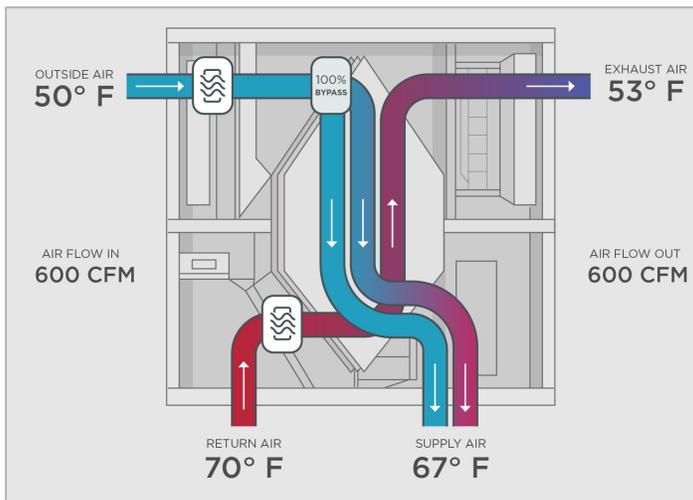
When the building heating/cooling system efficiencies generating the energy being recovered in the ventilation airflows are low (COP 0.6–0.8 for heating, COP 1.5–2.5 in cooling), recovering some of the energy this way is sensible, though cost-effectiveness would vary based on the cost of the energy being

recovered. The minimum HRV efficiency requirement for very high efficiency DOAS in the Northwest is focused on sensible energy recovery, as latent energy recovery or rejection is seldom a priority in this climate. Other parts of the country that have significant latent cooling loads would benefit from using a high-efficiency ERV and might wish to add a minimum latent recovery specification (around 55% at 75% of system nominal full airflow rate).

**Requirement.** Minimum sensible heat recovery efficiency (referred to as “effectiveness” by some manufacturers) must be satisfied in heating mode, and tested according to AHRI 1060.4. The key reason for the recovery efficiency specification set at this level 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 operating hours in Climate Zones 4–6. This not only reduces the heating and cooling load significantly, but allows a significant reduction in the heating and cooling capacity required for the building. 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.

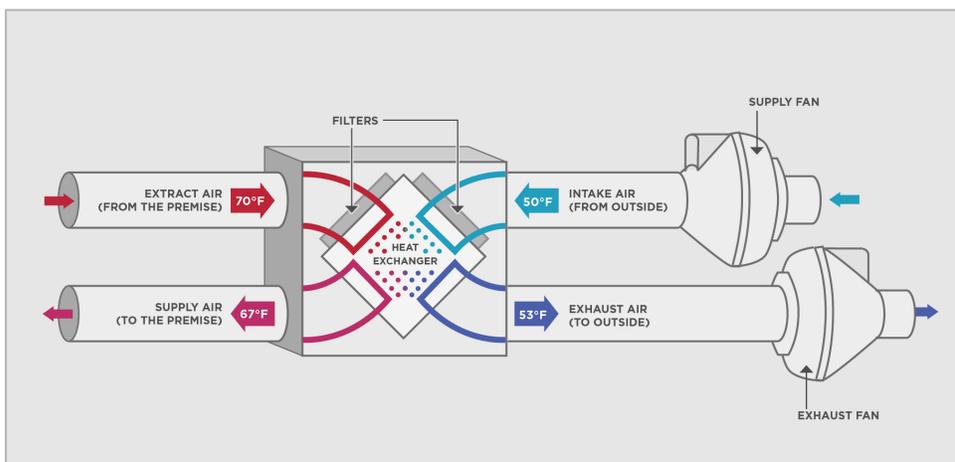
This level of efficiency in the size of HRVs/ERVs targeted requires the use of either a counterflow, wheel-type, or dual-core HX that also meets the conditions defined in criteria 2 through 9 below. **The minimum sensible effectiveness must be met whether an HRV or ERV is selected.**

[Figure 10: Example Heat Recovery Visualization]

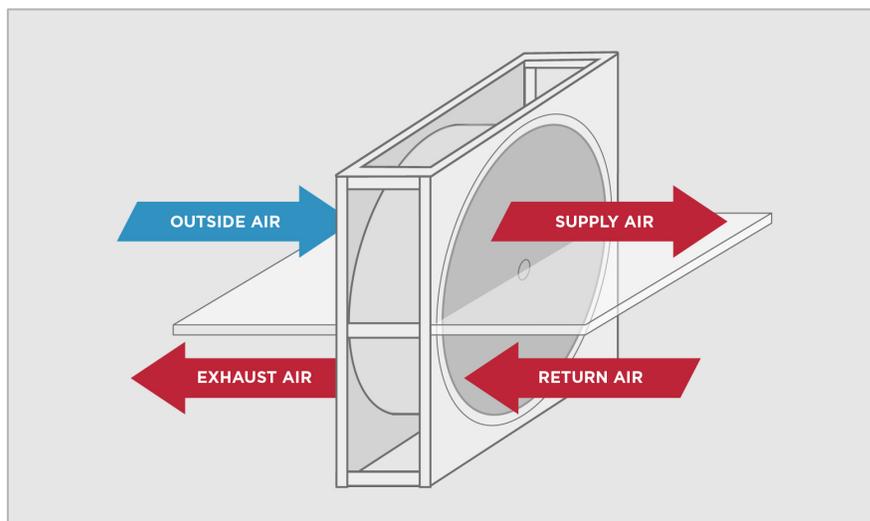


(Note: The illustration above is based on Ventacity Systems’ product configuration. Other manufacturer product configurations may vary.)

[Figure 11: Plate Heat Exchanger]



[Figure 12: Enthalpy Wheel Heat Exchanger]



**Design Consideration.** Designers should specify an HRV that is PHI Certified or with at least an 82% sensible efficiency 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 HRVs 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 above ceilings.

It can be a challenge to find HRVs at higher airflows that meet this requirement. Currently, the largest capacity HRV that meets this requirement delivers a maximum of 5,300 cfm. Projects requiring more than 5,300 cfm of ventilation air will require multiple units.

## 2. Minimum HRV/ERV Fan Efficacy.

- PHI certified, or minimum 1.4 cubic feet per minute per watt (cfm/watt) at 0.5" water gauge (w.g.) external static pressure (ESP) at 75% of rated full airflow.

*Note: Measured during certification or application-rating testing as per Air Movement and Control Association International (AMCA) 210 test standards.*

**Background.** As in the case of recovery efficiency, the majority of HRV/ERV products sold in the North America used for recovering ventilation airflow losses feature poor fan efficiencies. Typical fan efficacies range 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. This would render the expenditure on HRV/ERV systems for ventilation air inadvisable.

**Requirement.** The specification set at this level (1.4 cfm/watt, or 0.714 watts/cfm) 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, 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.

Meeting the overall specifications for HRV units requires efficient VSFs, likely achieved with electronically commutated motors (ECMs). Detailed fan and fan motor data is often shown presented in curve or table form with performance shown at different airflow rates and static pressure conditions. The performance specification requirement is related to a specific point on the fan curve (at 75% of rated unit full flow and 0.5" w.g. external static pressure).

**Design Consideration.** Designers should specify an HRV with efficient fans that at a minimum have a total unit performance of 1.4 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 535 watts when supplying 750 cfm of supply air at 0.5" ESP (750 cfm supply / 535 watts supply and exhaust fan power = 1.4 cfm/watt). The majority of HRVs that meet this requirement utilize direct-drive backward-curved centrifugal fans with variable speed capability, often achieved with ECMs in the smaller sizes.

### 3. HRV/ERV Capacity Control Capabilities.

- Time-of-day scheduling, capability to vary the fan airflow as a function of load, inputs for CO<sub>2</sub>, and duct static pressure at a minimum.

*Note: Input for CO<sub>2</sub> and duct static pressure may be accomplished via integral sensors, auxiliary third-party sensors, or capability to receive 0-10 mV (or similar) signal from Building Management System (BMS) and respond accordingly.*

**Background.** When ventilation air is completely separated from heating/cooling air (a critical system requirement for the very high efficiency DOAS concept), the ventilation air volume should be managed for occupancy and level of occupancy. 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 fan energy and heating/cooling energy required to condition the outside air.

**Requirement.** 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<sub>2</sub> 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 must 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. VSF capability is also required either through EC motors or variable frequency drives (VFDs). By locating modulating dampers controlled to CO<sub>2</sub> 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 requirement is to ensure the HRV has the capability to provide this functionality, not that the designer must use DCV in all applications.

This section of the Design Requirements lists all of the necessary control modes required for appropriately controlling ventilation air in the building and space types that are encountered in commercial building occupancies.

*European HRV/ERV equipment generally uses some of the world's most efficient fans, with whole-system efficacies ranging from 2–6 cfm/watt (0.5 to .15 watts/cfm). At this level of performance, it always makes sense to recover energy from the outgoing ventilation airstream, nearly eliminating the heating/cooling load associated with ventilation air provision.*

**Design Consideration.** Not all applications will require zone-level DCV or varying fan speeds, so this requirement is primarily directed towards HRV manufacturers. 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 CO<sub>2</sub> level in the return airstream, as this is a reasonable proxy for average zone conditions.

#### 4. HRV/ERV Economizer Control Capabilities.

- Capability of proportional economizer control through bypass, damper control, or via wheel-speed control when outside air temperature is suitable to provide free cooling to offset mechanical cooling.

*Note: Proportional control allows for partial economization that avoids heat exchange to meet a minimum supply-air temperature setpoint at low outside-air temperatures.*

**Background.** In current non-DOAS approaches that combine ventilation air with heating and cooling air, provision must be made for utilizing free cooling during hours when outside air dry-bulb temperature is sufficiently low to provide the cooling function for the building without the added energy use for the cooling system compressor. 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.

**Requirement.** When separating the ventilation function from the heating and cooling function, the outside air connection is not associated with 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 HX, the HRV must be equipped with integral and variable bypass dampers that allow the outside air to bypass the HX core and be introduced to the space without supplemental tempering of the air. For wheel-type HX, 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.

In all applications, controls must be able to designate operational conditions when economizer functionality is desirable, and increase fan speed (as applicable) to operate at an optimized economizer flow rate. As an example, during the cooling season, designated economizer operating conditions might be determined by comparing outdoor temperature to indoor temperature.

**Design Consideration.** 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 economization 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.

#### 5. HRV/ERV Defrost Control Capabilities.

- Recirculation is not permitted as a means of defrost protection. If required, variable defrost control must be provided to ensure frost-free operation to 5F. Where electric resistance heating is provided as a means of defrost control, it must include modulating control (most commonly using a silicone-controlled rectifier (SCR)).

*Note: Variable defrost control refers to proportional or continuous control (not stepped control).*

**Background.** In many climates, heat recovery systems will require defrosting of the HX core or wheel when outside ambient temperatures approach freezing. In the most efficient systems, freezing occurs on the exhaust side of the HX when warm, moist indoor-air cools to near freezing temperatures as heat transfers to the incoming outside airstream. This freezing condition rarely occurs in less efficient HRVs/ERVs because these units recover so little energy that the exhaust airstream rarely reaches freezing temperatures.

**Requirement.** This section of the Design Requirements prohibits recirculation and requires 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 at or below freezing. This strategy also provides very high levels of heat or energy recovery. 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. For wheel-type HRVs, 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 Consideration.** 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.

*Frost prevention systems typically either pre-heat outside air with an electric resistance heater or mix incoming air with return air to increase the temperature of the air upstream of the HX core. Some frost prevention strategies close the outside air damper entirely, operating as an exhaust-only system until the temperature increases enough to open the damper. Each strategy has drawbacks. While electric heaters use more electricity and reduce overall HRV efficiency, return-air recirculation (or closing the outside air damper entirely) reduces the heat exchanged and the amount of fresh air that is introduced to the space, which results in an unbalanced system and potentially compromised indoor-air quality.*

## 6. HRV/ERV Crossflow Leakage.

- Crossflow leakage or Exhaust Air Transfer Ratio (EATR): Less than 3%.

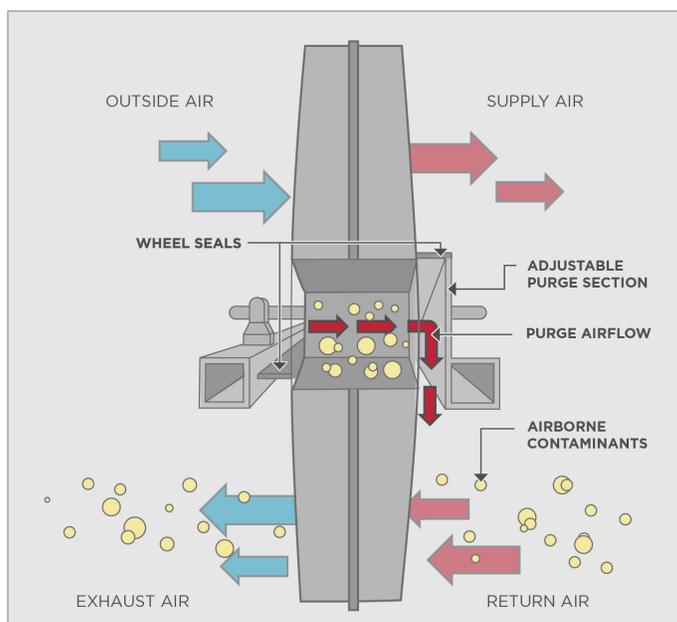
*Notes: Based on independent third-party testing in accordance with PHI or AHRI 1060. For PHI, the internal leakage must meet the specified requirement. For AHRI 1060, the EATR must meet the specified requirement at all required test conditions. (75% and 100% of the rated airflow and all tested pressure differential conditions.)*

**Background.** Many occupancy types, such as healthcare, make it unacceptable to have inadvertent recirculation of contaminated exhaust air across the HX to the fresh supply air. In all cases, recirculation of potentially contaminated exhaust air back into the building is problematic. Crossflow leakage also compromises the efficiency of the heat exchange process, sometimes significantly.

**Requirement.** Limiting crossflow leakage to less than 3% (under specific test conditions) is designed to eliminate the poor performance issues as much as possible. Crossflow leakage, or air tightness, 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.) To meet this designated performance specification, crossflow air leakage must be tested according to the equivalent of PHI protocols.

[Figure 13: Crossflow Wheel System Leakage]



**Design Consideration.** The PHI and AHRI procedures test leakage rates at specific airstream differential pressure conditions. If an HRV/ERV is selected to operate at differential pressure significantly different than those at which the unit was tested, designers should ensure that the leakage rate at design conditions is still acceptable. This is particularly important in applications in which the differential pressure between the outside air entering and the exhaust air leaving the HRV is expected to be significant, such as an indoor installation with long duct runs to the exterior.

## 7. HRV/ERV Filters.

- Minimum Efficiency Reporting Value (MERV) 13 filters or better on outside air intake.

**Background.** Without proper filtration of both the outside and return airstreams before entering the heat exchanger, the 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. Although not required, it can also help to filter the return air as it enters the core.

**Requirement.** This HRV/ERV equipment requirement promotes a high level of HX performance (high MERV) and indoor-air quality is maintained over time. While not required, it is 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 is present on the heating/cooling system.

**Design Consideration.** Filtration of the outside airstream is required by code and the MERV 13 requirement ensures 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 static 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.

## 8. HRV/ERV Control Communication Protocol Capabilities.

- Option to incorporate BACNet and/or Modbus interface for connecting to direct digital controls (DDCs) or other BMS.

**Background.** Most building automation control systems use the BACNet protocol to ensure that the various components of an HVAC system can communicate to one another. In addition, the Modbus protocols are often used to allow one system to manage another, and to collect data and deliver instructions. A packaged HRV/ERV product should have the capability to ensure this kind of connectivity to be part of an integrated building HVAC system.

**Requirement.** This part of the system requirements ensures that the HRV/ERV can be managed by existing BMS and can also be used to integrate the functions of the ventilation system and the heating/cooling system when desired. This is important in operational modes such as economizing, during which the HRV/ERV controls should be able to evaluate the heating/cooling system setpoints and temperatures. Often, VRF or VRV heating/cooling systems will be installed with vendor-specific DDC systems. Ideally, these systems will eventually be able to interface with the HRV controls. Preferred control interface functionality includes a single user-interface and read/write capability between systems for critical control variables (e.g., space and outside-air temperatures). As many small building applications will not have a BMS or central controls system, this equipment criteria only requires that a qualifying HRV has the option (or capability) to add a BACNet and/or Modbus interface.

**Note:** As controls can be particularly difficult and complex, especially with heating/cooling systems, you can expect system installation mistakes. Most VRF manufacturers offer an abundance of operation and programming options and many building occupants or operations staff might not understand which settings to select for optimal performance.

## 9. HRV/ERV Installation Location Options.

- Products intended to be mounted outside must be rated for outdoor installations. Outdoor mounted units must be PHI certified or include casing insulation  $\geq$  R-8 and gasketed seams and doors.

**Background.** Many HRV/ERV systems or components are not designed to be installed outdoors or on the roof of a building. However, in many commercial retrofit applications, the HRV/ERV will need to be located on a building rooftop, or in an outdoor location. To preserve flexibility for installation in a wide variety of commercial building applications, and to preserve the efficiency of the system in operation, the HRV/ERV must have installation options and operate in indoor or outdoor roof-mounted environments.

**Requirement.** For outdoor-rated applications, a system manufacturer is required to certify that the equipment is rated to be in an outdoor environment, and configured for roof mounting and ducting. Units certified for outdoor installation must be designed to operate well in extreme weather conditions (i.e., temperature, humidity, rain, or snow), and be insulated and air-sealed well enough to prevent significant heat loss or gain to the ventilation airstreams. For outdoor applications, the unit must be PHI certified, or the casing insulation must be R-8 or better.

**Design considerations.** The current list of qualifying HRVs contains units suitable for both outdoor and indoor applications. Low profile units (12–19" height) are available in rate airflows ranging from 250–1,200 cfm. These units can easily be mounted above typical commercial ceilings with as little as 2–3 ft. of vertical space required, and minimal horizontal clearance required for access to the control cabinet. Access from below the unit is typically required for filter maintenance. Indoor installations will require ducting to the outside for exhaust and intake air—these ducts should be insulated with a minimum of R-19 insulations (see Section 2.1.5 Duct Sealing & Insulation in the Critical System Design Requirements section on [page 26](#)).

Most outdoor-rated units come standard with insulated casing and other weatherproofing features, but designers should also consider opting for additional accessories such as weather hoods and air-damper modules on intake and exhaust air inlets/outlets, depending on climate and installation location. Depending on the orientation of the unit, designers should also consider whether exhaust air has the potential to short-cycle into the outdoor-air intake stream. If so, designers should consider adding exhaust-air ductwork to direct the air away from unit.

## **MINIMUM HEATING/COOLING SYSTEM REQUIREMENTS**

Very high efficiency DOAS improves upon typical DOAS approaches by fully decoupling the ventilation and space conditioning systems and then pairing a high efficiency heating/cooling system with a very high efficiency HRV to serve the ventilation load. 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 ventilation system from the heating/cooling system to operate only when necessary.

The heating/cooling system that is installed and operates with the HRV/ERV is critical to achieving overall energy performance associated with very high efficiency DOAS. The following performance requirement descriptions address the heating/cooling system in a manner similar to the descriptions provided for HRVs/ERVs.

### **1. Heating & Cooling System Type.**

- Small (< 65 kBtu/hr.): Multi-zone or single zone air-source split system heat pumps;
- Large ( $\geq$  65 kBtu/hr.): VRF or VRV air-source heat pump, air-to-water heat pump, ground-source or ground-water heat pumps.

Notes:

- *Water-source heat pumps are allowed as an exception if they already exist in the building and are not being replaced.*
- *Air-to-water heat pumps 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.*

**Background.** In commercial buildings, there are many heating/cooling system types that can provide temperature control. Packaged RTUs are the typical existing system-type target for very high efficiency DOAS retrofits. This is also the predominant system type for small commercial buildings across the Northwest. Also frequently installed in both retrofits and new construction are packaged heat pumps (both air-source and groundwater-source), and built-up air-handling systems of various configurations coupled with centralized hydronic systems.

**Requirement.** For smaller systems (defined as having a nominal outdoor unit cooling capacity less than 65,000 Btu/hr.), these system requirements specify that heating/cooling systems be air-source ductless split system heat pumps. 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.

Indoor units can be ductless or ducted, and equipped with VSF motors. For large systems ( $\geq$  65,000 Btu/hr.), system type shall be air-source VRF or VRV, air-to-water, groundwater-source, or ground-source multi-zone heat pump systems. Outdoor units shall be equipped with variable-speed inverter-driven compressors. Indoor units can be ductless or ducted, and equipped with VSF motors and software settings to establish appropriate fan operating range for required external static pressure, along with condensate drain provisions. Efficiencies shall be as specified in the following sections.

**Design Consideration.** 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. 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.

*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.*

## 2. Rated Heating Efficiency.

- Heat Pump/VRF heating (ducted/un-ducted):  
( $< 65$  kBtu/hr.) Heating Seasonal Performance Factor (HSPF) 9.5  
( $\geq 65$  kBtu/hr.) Coefficient of Performance (COP) @ 47F 3.4, COP @ 17F 2.25
- Air-to-water heat pump heating: 1.7 COP@ 5F dry bulb and leaving water temperature (LWT) of 110F
- Ground-source heat pump: 3.6 COP@ 32F entering water temperature (EWT)
- Groundwater-source heat pump: 4.1 COP@ 50F EWT  
Notes: These heat pump ratings are equivalent to ENERGY STAR® required levels. For geothermal heat pumps, COP = (highest rated capacity COP + lowest rated capacity COP) / 2

Note: Geothermal heat pump COP = (highest rated capacity COP + lowest rated capacity COP) / 2

**Background.** The intent of this section is to have high efficiency equipment in each category equivalent to, or better than, ENERGY STAR levels.

**Requirement.** Small system heating efficiencies shall be based on HSPF levels as determined by AHRI 210/240. Large system heating efficiencies shall be based on COP at two outdoor air conditions, as defined in AHRI 1230 for VRF/VRV systems. Air-to-water heat pumps should meet the required COP as defined in AHRI 550, and ground-source/groundwater-source heat pumps should meet the required COP as defined by ISO 13256-1:1998. To comply with the heating/cooling system performance requirements requires that the rated and test COPs exceed the specified requirement for both conditions (where applicable). Manufacturer documentation of rated and tested efficiencies shall be provided with required submittals.

**Design Consideration.** While nearly all VRF and split-system 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 necessary.

### 3. Rated Cooling Efficiency.

- DHP/VRF Cooling (Ducted/Un-ducted):
  - < 65 kBtu/hr.: Seasonal Energy Efficiency Ratio (SEER) 16
  - ≥ 65 kBtu/hr.: Integrated Energy Efficiency Ratio (IEER) 21
- Ground-Source Heat Pump Cooling: 17.1 Energy Efficiency Ratio (EER) @ 77F EWT
- Ground-Water Heat Pump Cooling: 21.1 EER @ 59F EWT

**Background.** The intent of this section is to have high-efficiency equipment in each category equivalent to or better than ENERGY STAR levels.

**Requirement.** For use with these requirements, small system cooling efficiencies shall be based on Seasonal Energy Efficiency Ratio (SEER) as determined by AHRI 210/240. For use with these requirements, large system cooling efficiencies shall be based on Integrated Energy Efficiency Ratio (IEER) as determined by AHRI 1230, AHRI 550 or ISO 13256-1:1998, respectively. Manufacturer documentation of rated and tested efficiencies shall be provided with required submittals.

**Design Consideration.** Similar to the minimum rated heating efficiency, the largest VRF systems will typically not meet the cooling efficiency requirement. All equipment should meet both efficiency requirements.

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## 2. CRITICAL SYSTEM DESIGN REQUIREMENTS

The following section focuses on system design requirements as a reinforcement of the equipment requirements in the previous section. There are two critical system design requirements that must be met for a system to be considered very high efficiency DOAS: 1) decoupled system design (requirements 1.1–1.5 below), and 2) specific design operating conditions (requirements 2.1–2.2 below).

### 1. Decoupled System Design.

- Ventilation and heating/cooling system should be controlled separately with independent ducting and zoning. Ventilation air shall be delivered directly to the occupied space, except in the case of systems using active chilled beams.

**Background.** Decoupled system design refers to complete separation of ventilation air from heating/cooling air. Mechanical engineers and HVAC contractors rarely design and specify systems that provide ventilation and heating/cooling separately, especially for smaller buildings. The common packaged RTU system integrates ventilation and heating/cooling by design intent. With other system configurations, it is standard practice to integrate the ventilation air into a mixed air duct configuration upstream of the indoor fan unit.

**Design Requirement.** Decoupled system design is critical to the performance of the overall very high efficiency DOAS system, as significant benefits and energy savings come from controlling these two air streams independently. At no time, prior to entering the occupied space, should the ventilation air be combined with the heating/cooling air. In the most extreme climates where a slight tempering of the ventilation air is advised, this function should be provided separately from the heating/cooling air that provides comfort conditioning directly to the building zones.

**Design Consideration.** The primary reason for a fully decoupled design is to ensure the heating/cooling system can turn off whenever zone temperatures are satisfied. When ventilation air is required to be delivered via the heating/cooling system indoor units, the system typically remains in operation and unnecessarily wastes fan energy.

Ventilation duct system must include the following at a minimum:

## 1.1 Air Balancing.

- Ability to adjust flow for balancing at each diffuser.

**Background.** Without available flow balancing devices, the testing, adjusting and balancing (TAB) contractor will be unable to correctly balance the system for design flows. In new construction, most mechanical codes require volume dampers installed at each branch duct, or at each individual diffuser, register, or grille. However, when retrofitting existing ductwork and creating new branch takeoffs, this practice isn't always followed or enforced. Neglecting to provide a means to balance a branch can result in wasted time for rebalancing and installing such devices after the mechanical system installation is substantially complete.

**Design Requirement.** This requirement helps ensure a sufficient number of balancing devices exists during the construction phase so that the TAB contractor can correctly balance the system after it is installed. It is also best practice, and a minimal added cost during the design phase, to include balancing devices on takeoffs or at the air outlets.

## 1.2 Duct Sizing and Friction Loss.

- Supply and return/exhaust ductwork sized for maximum flow at a friction loss not to exceed 0.08" w.g. per 100 ft. of straight-length duct.

**Background.** When sizing ductwork for a given ventilation airflow there is a tradeoff between cost and fan power. Mechanical engineers should seek a balance between upsizing ductwork (which saves fan energy and therefore operating costs) and downsizing ductwork (which saves first cost).

**Design Requirement.** 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 boost 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 right ducts. If rectangular ductwork is specified, be sure to use turning vanes in all elbow fittings.

## 1.3 Diffuser Location.

- Except where site conditions limit or restrict this approach, the ventilation supply-air shall be delivered to one side of space, with exhaust air extracted from opposite side. Do not locate exhaust grille where ventilation air will be short-circuited.

**Background.** Many mechanical engineers and contractors establish other priorities over ventilation effectiveness as the primary basis for air distribution design, (e.g., minimizing duct runs). As a result, it is common to see sub-optimal ventilation distribution systems.

**Design Requirement.** This guideline reminds designers of this simple, but often unknown or neglected, ventilation system design principle. For very high efficiency DOAS retrofits, the most straightforward compliant configuration is to introduce supply-air on the opposite side of a room from the exhaust outlet.

**Design Consideration.** With proper diffuser selection, the air is well-mixed. So, in systems with coupled ventilation and primary heating/cooling air, it is not always required for supply and return diffusers to be located on opposite sides of the room. With a fully decoupled DOAS design, the ventilation air enters the room at very low flows and velocities. Therefore, without careful diffuser selection, the ventilation air may be short-circuited without fully benefitting the room 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.

## 1.4 Return Air Path.

- Supply and return outlets/inlets are required for ducted heating/cooling systems. For ventilation systems, separate supply outlets are required for all spaces and shall include either a ducted return or a non-ducted return path with free area sized so that velocity does not exceed 300 ft. per minute (fpm).

**Background.** The Northwest pilot projects verified that in smaller spaces with doors that are often closed, a lack of return air inlets for heating/cooling air at flow rates above 25 cfm will pressurize the space by 10 Pa or more. This results in unwanted increases in fan power for heating/cooling and ventilation. Because ventilation flow rates for smaller spaces are almost always under 25 cfm, exhaust inlets 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.

**Design Requirement.** This guideline attempts to 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.

### **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 ducts and HRVs, and, when structurally feasible, bringing fresh supply-air in on one side of an occupied space and out the other to avoid mixing.*

## 1.5 Duct Sealing & Insulation.

- Outside air (entering heat exchanger) and HRV exhaust air (leaving heat exchanger) ducts shall have minimum R-19 insulation in both conditioned and unconditioned spaces. Existing ductwork used as ventilation supply or return/exhaust shall be sealed to SMACNA Seal Class B standards where accessible, or if delivering greater than 500 cfm at design conditions. Aerosol sealants can be used for inaccessible ductwork, with duct mains and risers considered the first priority. Insulate ventilation supply and exhaust as per code requirements for heating and cooling ductwork.

**Background.** Designers and contractors will sometimes dismiss critical air distribution system performance issues because the air being moved around is at, or near, room temperature. 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/or 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 a near certainty unless the ducting is adequately insulated.

**Design Requirement.** This part of the guideline attempts to 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.

[Figure 14: Example Exterior Duct Sealing]



**Design Consideration.** R-19 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.

### **Further Design Considerations:**

Properly sealed ductwork is a critical component to ensure very high efficiency 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 in 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 adjusts the temperature of the delivered fresh-air supply.
- Very high efficiency 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.

## **2. Design Operating Conditions.**

Equipment selection shall indicate the following operating conditions are met at design airflows when calculated based on values provided by the manufacturer (or approved representative):

- 2.1** Minimum HRV heat exchange of 75% sensible effectiveness at heating and cooling design temperatures.

Note: As determined by the following equation at design conditions:

$$\frac{\text{Supply cfm} \times (\text{Supply Air Temperature} - \text{Outside Air Temperature})}{\text{Exhaust cfm} \times (\text{Return Air Temperature} - \text{Outside Air Temperature})}$$

- 2.2** Minimum fan efficacy rating of 1.3 cfm/watt.

Note: As determined by the following equation at design conditions:

$$\frac{\text{Supply cfm}}{\text{Total Fan Power (Supply Fan watts + Exhaust Fan watts)}}$$

**Background.** To distinguish quality products, it is helpful to set a minimum heat exchange effectiveness and fan power efficacy for the equipment. But keep in mind, this is not a fail-safe method to ensuring the HRV is designed and operated properly in the field. The sensible recovery and fan efficacy requirements from Table 1 are at test conditions and do not take into account the actual external static pressure of the distribution

system. Due to this, it is common for high-efficiency HRVs to perform at a lower efficiency than predicted due to inadequate duct design, improper unit selection, or possible miscommunication between the designer and manufacturer's representative on the differences between operating conditions and test conditions.

**Design Requirement.** The minimum design operating condition requirement attempts to mitigate potentially high-efficiency products from performing poorly once installed in the field. Requiring the manufacturer's representative to provide the designer with ratings for sensible recovery and fan efficacy at selected design conditions will guard against inadequate ventilation, poor heat recovery, or increased fan usage once installed. Designers should take care in estimating external static pressure of the distribution system to accurately select the correct HRV and ensure it operates within the design parameters stipulated in this section.

### 3. Heating/Cooling Sizing.

- **Heating/cooling sizing:** Right-size the heating/cooling system using load calculations. Do not include safety factors greater than 10%. Otherwise, for Climate Zones 5/6, use no less than 600 sq. ft./ton of system cooling capacity, and for Climate Zone 4, use no less than 750 sq. ft./ton.

**Background.** The Northwest pilot projects show that the efficiency of the very high efficiency DOAS conversion makes it possible to significantly downsize the capacity of the heating/cooling system components. This is a substantial source of both energy and demand savings for the conversion. 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 Requirement.** Except where modeling or advanced load calculations are used, the system size shall be no greater than what is specified here, depending on Climate Zone. In Climate Zone 4, the total nominal cooling capacity should be sized at no less than 750 sq. ft./ton. In Climate Zone 5 and 6, nominal total cooling capacity should be no less than 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). A 20-ton system would not meet this requirement without load calculations showing the additional capacity as necessary, as it would result in a 500 sq. ft. metric.

This guideline is designed to flag an oversized system. An exception is allowed if actual load calculations have been developed and are submitted as the basis of system sizing. Calculations shall comply with the requirements for commercial buildings as included in applicable energy codes (C403.2.1 and C403.2.2 in the 2015 WSEC, and/or equivalent for other states).

**Design Consideration.** The following are common issues that lead to oversizing heating/cooling systems in very high efficiency DOAS projects:

- 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

#### **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.*

- Failing to account for very high efficiency heat recovery of HRV 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 similar spaces 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.)

#### 4. Integral Refrigerant System Heat Recovery.

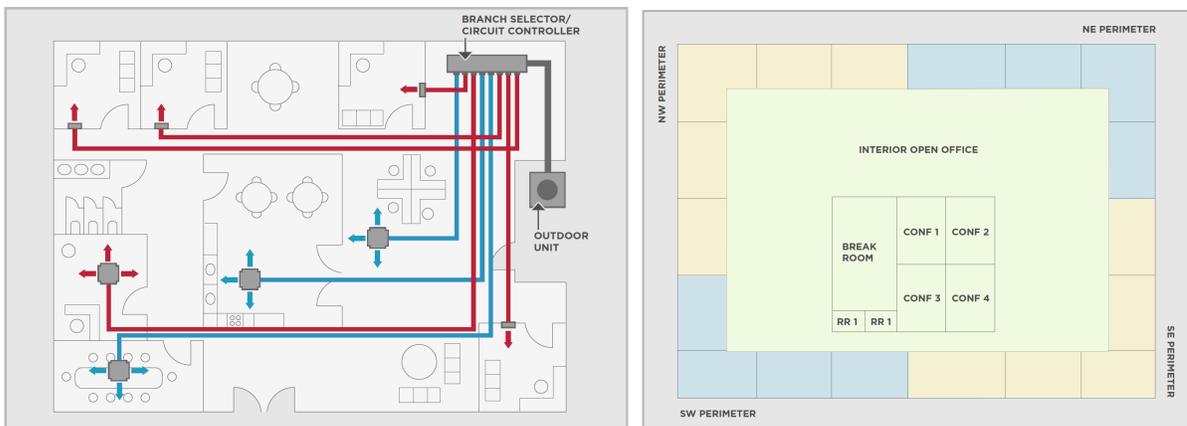
- Integral refrigerant heat recovery is not allowed without a zoning plan and analysis of energy savings that demonstrates effective utilization of this feature (e.g., core/perimeter).

**Background.** For larger VRF/VRV 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 useful feature to move heat where it is needed and save energy. Often, integral heat recovery is specified in a design to allow exemption from the energy code requirements for economizer cooling, but it is rarely a cost-effective choice for very high efficiency DOAS installations.

**Design Requirement.** This specification is in place to eliminate the significant cost of this feature of VRF/VRV-type systems, if such investment will not produce measurable additional energy savings. An exception is allowed if an energy analysis is performed that demonstrates usefulness of this feature along with a zoning plan that documents the analyzed basis for applicable heating and cooling demands. The analysis shall be based on the zones served by a single heat-recovery-capable refrigerant flow controller. Both the analysis report and the zoning plan shall be included in submittals to demonstrate compliance with this exception.

[Figure 15: Example Zoning Plans]



**Design Consideration.** 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-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.

## 5. Submittals.

- Required: Heating/cooling system rated performance, HRV rated performance, control specifications and sequence of operations, all relevant mechanical equipment schedules, duct layout with sizing, reflected ceiling or diffuser placement plan, and system diagrams.
- Optional (depending on exceptions taken): Zoning plan, energy-savings analysis (if including integral refrigerant system heat recovery per Critical System Design Requirement #4 above), and load calculations (if exceeding Critical System Design Requirement #3 above).

**Background.** Small commercial building HVAC contractors sometimes provide inadequate detail about the systems they propose to building owners. However, when the complete conversion of the existing system is proposed, detailed plans, specifications, and supplemental submittals are needed to ensure 1) the system is designed and specified properly, 2) the ducting is properly sized and configured, 3) the appropriate control sequences and sensors are being used, and 4) project costs are reasonable.

**Design Requirement.** This requirement is designed to provide both the building owner and the project manager with assurance that the proposed project is likely to meet the required performance at a reasonable cost, and to provide information regarding critical system design and specification (e.g., system capacity, heat recovery, duct system design, control strategies, etc.). This requires project information to be submitted in the form of a required submittals package and an optional submittals package.

The required submittals include documentation of the rated performance of the heat pump systems and the HRV systems. Documentation shall confirm compliance with all performance specification requirements. Additional required submittals are the control specifications including sequence of operations, and an air distribution system and equipment layout plan. This plan shall provide sufficient information to confirm compliance with system-sizing and ventilation-effectiveness requirements.

The optional submittal package is only required with exceptions that are taken to any specification requirements. The required optional submittal content shall be as specified in the design guidelines above.

## 6. Startup TAB.

- Testing and balancing shall encompass the entire airside system, including duct air-tightness and ventilation system airflow verification. The manufacturer (or manufacturer-approved technician) shall provide start-up of HRV at a minimum. Contractor (or approved agent) shall provide verification testing of control sequences.

TAB report shall include the following documentation at a minimum:

- A. Air at each diffuser tested and balanced to within +/- 10% (or 5 cfm, whichever is greater) at design flow.
- B. If utilizing a DCV control strategy, diffuser airflow testing at minimum design flow.
- C. System airflow tested and balanced to within +/- 5% of design airflow at HRV unit.
- D. Duct leakage testing results of representative sections of all ducted systems (both ventilation and heating/cooling system if ducted) totaling at least 25% of the duct area.

*Notes: For testing and balancing, technician must use a flow hood measuring accurately down to 10 cfm. For system airflow test, this should be accomplished using reliable duct traverse at HRV unit discharge, or manufacturer's on-board control output values. Ducts should be leak-tested in accordance with SMACNA HVAC Air Duct Leakage Test Manual.*

**Background.** 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 to ensure all components are operational and performing as specified. Additionally, it is important to run the HRV through its set of control sequences to ensure it operates as intended.

With very high efficiency DOAS, however, 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 Requirement.** Startup and TAB should be executed on both the HRV and the heating/cooling system as part of the completion of a very high efficiency DOAS project. Comprehensive TAB includes airflow measurement, adjustment, and final verification of adequate airflow on the HRV (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. At a minimum, the TAB report shall include the documentation specified in A–D noted above.

## 7. Heating/Cooling System Fan Operation.

- Heating/Cooling system fans shall turn off when there is no call for heating or cooling.

**Background.** 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 Requirement.** 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 logic on the heating/cooling system, or through a tie-in with a central control system.

**Design Consideration.** This requirement 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.

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## 3. RECOMMENDED GUIDELINES TO ACHIEVE OPTIMAL PERFORMANCE

The following guidelines are not required for a system to be considered very high efficiency DOAS, however, they are suggested as best practices for maximizing performance and energy efficiency.

### 1. HRV/ERV Sizing.

Individual units should be controlled to run between 40–60% of rated full flow when meeting ASHRAE 62.1 ventilation rates (fully occupied, non-boosted). Supply ducting shall be sized for maximum flow at an average friction loss of 0.08" w.g. per 100 ft. of straight-length duct.

**Background.** 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 model that can meet the design condition. This sizing approach can significantly limit the system's performance. HRV system efficiency varies inversely and non-linearly with flow rate, both in recovery efficiency (i.e., lower flow means higher heat exchange rate) and fan efficacy. The optimal target for design efficiency is in the middle of the flow range of the HRV/ERV. In addition to being highly efficient, this design balances the number of individual units needed to meet the full ventilation requirements of the

building. It also provides head room for higher-flow boost when increased airflow may be needed (i.e., for above-normal occupancy, heat load, or economizing).

Ventilation airflows are typically much lower than heating and cooling airflows, with heating and cooling fans typically providing the economizing function. For the HRV/ERV to provide this function effectively, it will need to be able to run at a notably higher flow rate than typically used for the ventilation function.

**Design Guideline.** This guideline attempts to ensure that the HRVs/ERVs are properly sized for ventilation efficiency to maximize savings, and to minimize noise and drafts. 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, shall be used to determine the maximum required ventilation airflow rate for a system (or group of zones). Once determined, an optimally sized HRV will typically be selected at about twice the required maximum flow rate. To allow flexibility, depending on circumstances, the system should be controlled to run somewhere between 40% and 60% of nominal flow. This conservative sizing approach allows for very efficient fan and HX performance, and allows the system to operate at a higher airflow at moderate outside-air temperatures. This provides increased economizer benefit for night-time purge or to provide additional ventilation during increased occupancy conditions.

## 2. Commissioning (Cx).

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

**Background.** 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 HRV/ERV technology specified here. 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 Guideline.** System Cx should include functional performance testing of all control components and sequences of operation in the very high efficiency 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. The logging period should be a minimum of seven consecutive days with sample intervals no greater than five minutes.

## 3. Energy Modeling.

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 very high efficiency DOAS systems. This design guideline recommends using non-standard energy modeling work-arounds as needed. Here, descriptions of non-standard work-arounds can be used by modelers to better calculate energy-savings potential.

**Background.** Conventional modeling practices may misrepresent very high efficiency 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 very high efficiency DOAS, many of the tools do not support explicit modeling of the system's components. As a result, modeling work-arounds 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 Guideline.** Special considerations and some non-standard work-arounds are needed, including:

- Fan-power savings should be significant between an electric RTU system and an HRV DOAS system. Reduce HRV fan power in model to 0.1 to 0.2 watt/cfm.
- HRV control sophistication can enable economizer function, respond to CO<sub>2</sub> sensors (demand control), and optimize frost control cycle. Ensure inputs/approaches related to controls are aligned with proposed equipment and scope. Consider use of post-process calculations within a spreadsheet using hourly output results.
- In-service performance of packaged rooftop HVAC equipment (baseline model) has been found to be considerably worse than the rated efficiency, with the efficiency most significantly compromised at part load. Include baseline RTU cooling part load performance degradation.
- Approximate the VAV capability (for applicable projects) of the installed HRVs by modeling a constant volume approach at the average flow rate.
- Calculate cooling savings from economizer mode (where applicable) with a post-process calculation.
- Adjust heat pump defrost settings in the model to match total heat pump energy from monitoring data at low outdoor temperatures.
- Make adjustments to match operating schedule (operating hours, night cycling, temperature setpoints and setbacks) and miscellaneous electrical loads (plug loads, lighting, server room, etc.). These have a large impact.

**Energy Modeling Review.** Using the special considerations above, energy modeling programs can provide a reasonable means of approximating very high efficiency 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, Ventacity VS1000 HRV has controls to enable economizer function, respond to CO<sub>2</sub> 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 very high efficiency 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 very high efficiency DOAS.*

# APPENDIX

# APPENDIX 1: COMPARISON OF VERY HIGH EFFICIENCY DOAS WITH WASHINGTON STATE ENERGY CODE DOAS REQUIREMENTS

	Very high efficiency DOAS	Washington State Energy Code (2018) for DOAS	Key Takeaway
<b>Definition</b>	An alternative HVAC system for commercial buildings that use a very high efficiency heating/cooling system and a very high efficiency HRV to deliver heating and cooling 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. Includes an integral economizer in the HRV.	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 efficiency and bypass (economizer) requirements. The ERV must provide a change in the enthalpy of the outdoor air of not less than 50 percent of the difference between the outdoor and return air.	Very high efficiency DOAS has more stringent requirements that lead to deepened energy efficiency as compared to WSEC-minimum installations.
<b>Applications</b>	Existing RTU replacement and new construction.	New construction and major renovations.	Similar applications.
<b>Applicable Building Types</b>	Generally for buildings 50,000 sq. ft. or less.	Limited to office, retail, education, libraries, and fire stations.	Very high efficiency DOAS is somewhat more flexible in its targeted applications.
<b>Heat Recovery at Rated Conditions</b>	Minimum Sensible Recovery Efficiency (SRE) of HRV/ERV: 82% sensible effectiveness at 75% of nominal full airflow.	C403.5 (Heat Recovery) requires minimum energy (enthalpy) recovery effectiveness of 50% or sensible recovery of 60%. C406.7 (High Performance DOAS Option) requires minimum sensible heat recovery effectiveness of 80%.	Very high efficiency DOAS requires higher sensible recovery effectiveness, depending on operation point of HRV/ERV.
<b>Fan Efficacy at Rated Conditions</b>	Minimum fan efficacy: PHI certified, or 1.4 cfm/watt at 0.5" w.g. at 75% of nominal full airflow.	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. C403.3.5.1 Energy recovery ventilation with DOAS requires systems less than 5hp use no more than 1 watt/cfm. Fan power for systems greater than 5hp are covered by section C403.8.1.	Very high efficiency DOAS fan efficacy requirement is more clearly defined and slightly less stringent than the WSEC High Performance DOAS Option.

<b>HRV Control Capabilities</b>	<p>HRV/ERV Control capabilities: DCV, by zone; control based on time, occupancy, CO<sub>2</sub>, duct static pressure.</p>	<p>C403.3.5.2 (DOAS) has control requirements requiring cycling off heating and cooling supply air during non-heating hours. There is no requirement for DOAS fan scheduling.  C403.7.1 requires DCV in DOAS if occupancy is ≥25 people per 1,000 sq. ft. and system OA is &gt; 3,000 cfm. Systems with energy recovery are exempt.  C403.7.2 requires OS control of outside air/primary air damper or fan in classrooms, conference rooms (over 500 sq. ft.), auditoriums and gyms unless they have DCV—no exceptions.</p>	<p>Very high efficiency DOAS requires variable fan control for DCV. The WSEC High Performance DOAS Option does not address this beyond standard code requirements.</p>
<b>Economizing</b>	<p>Must be capable of proportional economizer control through bypass, damper control, or via wheel-speed control when outside-air temperature is suitable to provide free cooling to offset or replace mechanical cooling.</p>	<p>C403.5 requires bypass where economizer is required but exempts DOAS systems from needing to provide economizing.  C403.2.2.1 Allows an exception to the 150% outdoor-air rule for economizer or night-flush operation.</p>	<p>Very high efficiency DOAS encourages the use of economizer, as appropriate, whereas WSEC allows complete economizer exception.</p>
<b>Defrost</b>	<p>Variable defrost if required, with no recirculation allowed.</p>	<p>No requirements around defrost or recirculation.</p>	<p>To reduce unnecessary use of defrost and maintain indoor air quality, very high efficiency DOAS is more stringent than WSEC.</p>
<b>Crossflow Leakage</b>	<p>Crossflow leakage: less than 3%.</p>	<p>No requirements for crossflow leakage.</p>	<p>Crossflow leakage limitation is a key difference in very high efficiency DOAS, especially for enthalpy wheels.</p>
<b>Filtration</b>	<p>Minimum MERV 13 filters on outside-air intake and recommended MERV 8 filters on exhaust/return airstreams prior to the heat exchange medium.</p>	<p>No filtration requirement specified.</p>	<p>Very high efficiency DOAS is more stringent than WSEC to ensure premium indoor air quality.</p>
<b>Control Protocols</b>	<p>Option to incorporate BACNet and/or Modbus interface for connecting to DDC or other BMS.</p>	<p>No requirements for interface capability except in larger buildings (&gt; 65 tons cooling). DDC and interface capability required.</p>	<p>To provide a greater level of visibility and control on DOAS performance, very high efficiency DOAS is more stringent than WSEC.</p>

<b>Installation Location</b>	Products intended to be mounted outside must be rated for outdoor installations. Outdoor-mounted units must be PHI-certified or include casing insulation $\geq$ R-8 and gasketed seams and doors.	No requirements around outdoor rating.	Very high efficiency DOAS focuses on outdoor insulation requirements to limit heat loss of units installed on rooftops.
<b>Critical System Design Guidelines</b>			
<b>Decoupled System Design</b>	Ventilation and heating/cooling system must be controlled separately with independent ducting and zoning. Ventilation air must be delivered directly to the occupied space.	C403.3.5 requires complete separation of ventilation air controls from heating/cooling air controls. No requirements around zoning.	Both require decoupled systems.
<b>Design Operating Conditions</b>	<p>Equipment selection must indicate the following operating conditions are met at design airflows when calculated based on values provided by the manufacturer (or manufacturer-approved representative):</p> <ul style="list-style-type: none"> <li>2.1 Minimum HRV heat exchange of 75% sensible effectiveness at heating and cooling design temperatures.</li> <li>2.2 Minimum fan efficacy rating of 1.3 cfm/watt</li> </ul>	The WSEC High Performance DOAS Option does not specify differences between operating condition and rated performance.	Very high efficiency DOAS clearly identifies both rated performance and operational performance requirements, while the WSEC High Performance DOAS Option allows room for interpretation as to how performance is rated.

## APPENDIX 2: SYSTEM REQUIREMENTS & RECOMMENDATIONS SUMMARY

To view a complete list of system requirements and recommendations, visit:

[https://betterbricks.com/uploads/resources/VHE-DOAS\\_Requirements-Summary.pdf](https://betterbricks.com/uploads/resources/VHE-DOAS_Requirements-Summary.pdf)

The following system requirements and recommendations are intended to provide guidance to manufacturers, designers and specifiers regarding the components of very high efficiency dedicated outside air systems (or very high efficiency DOAS). Developed over several years of research, market analysis, and demonstration project installations, these system requirements have been refined to decrease energy consumption, improve indoor-air quality, and improve occupant comfort over conventional systems. The very high efficiency DOAS addressed in this guideline includes high-efficiency energy/heat recovery ventilation (ERV/HRV) systems to serve the ventilation load installed in combination with a high-efficiency heating and cooling system. Often, the heating and cooling is provided by multi-zone air source heat pump systems, commonly referred to as variable refrigerant flow (VRF) or variable refrigerant volume (VRV) systems, however, other high-efficiency technologies, such as ground-source heat pumps, groundwater-source heat pumps, and air-to-water heat pump central plant systems, can also meet the requirements.

Table 1: Minimum Equipment Performance	
Heat/Energy Recovery Ventilation	
1.	<u>Minimum efficiency:</u> Passive House Institute <sup>1</sup> (PHI) certified, or minimum 82% Sensible Effectiveness <sup>2</sup> of heat exchanger (HX) at Air-Conditioning, Heating & Refrigeration Institute (AHRI) Standard 1060 winter conditions at 75% of rated flow <sup>3</sup> verified by independent third-party testing <sup>4</sup> .
2.	<u>Minimum fan efficacy:</u> PHI-certified, or minimum 1.4 cubic feet per minute per Watt (cfm/Watt) at 0.5" water gauge (w.g.) external static pressure (ESP) at 75% of rated full airflow <sup>5</sup> .
3.	<u>Capacity control capabilities:</u> Time-of-day scheduling, capability to vary the fan airflow as a function of load, inputs <sup>6</sup> for CO <sub>2</sub> , and duct static pressure at a minimum.

<sup>1</sup> AHRI 1060 and PHI requirements are not exactly equivalent due to differences in test procedures and rating conditions. The intent is to require very high efficiency heat recovery based on the testing and certification path chosen by the manufacturer.

<sup>2</sup> Energy Recovery Ventilators (ERVs) meeting this Sensible Effectiveness threshold are also allowed.

<sup>3</sup> Rated flow, often synonymous with nominal flow, refers to the flow measured during testing. AHRI 1060 winter conditions: 35°F DBT, 33°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 requirements.

<sup>4</sup> For the purposes of these requirements, third-party verification testing may be conducted at an independent laboratory (with or without manufacturer personnel present, provided they do not interfere with conduct of the test), or at a manufacturer's laboratory (if testing is conducted and overseen by personnel from an independent lab not affiliated with the manufacturer and with no conflicts of interest regarding the test results).

<sup>5</sup> Measured during certification or application-rating testing as per Air Movement and Control Association International (AMCA) 210 test standards.

<sup>6</sup> Input for CO<sub>2</sub> and duct static pressure may be accomplished via integral sensors, auxiliary third-party sensors, or capability to receive 0-10 mV (or similar) signal from Building Management System (BMS), and respond accordingly.

**Table 1: Minimum Equipment Performance**

4.	<u>Economizer control capabilities:</u> Capability of proportional <sup>7</sup> economizer control through bypass, damper control, or via wheel-speed control when outside air temperature is suitable to provide free cooling to offset mechanical cooling.
5.	<u>Defrost control capabilities:</u> Recirculation is not permitted as a means of defrost protection. If required, variable defrost control <sup>8</sup> shall be provided to ensure frost-free operation to 5°F. Where electric resistance heating is provided as a means of defrost control, it must include modulating control; most commonly using a silicon controlled rectifier (SCR).
6.	<u>Crossflow leakage/Exhaust Air Transfer Ratio (EATR):</u> Less than 3%. <sup>9</sup>
7.	<u>Filters:</u> Minimum Efficiency Reporting Value (MERV) 13 filters or better on outside air intake.
8.	<u>Control communication protocol capabilities:</u> Option to incorporate BACNet and/or Modbus interface for connecting to direct digital controls (DDCs) or other building management systems.
9.	<u>Installation location options:</u> Products intended to be mounted outside shall be rated for outdoor installations. Outdoor-mounted units shall be PHI-certified or include casing insulation ≥ R-8 and gasketed seams and doors.

**Heating and Cooling System**

1.	<p><u>System Type:</u>  Small (&lt; 65 kBtu/hr.): Multi-zone or single-zone air-source split-system heat pumps  Large (≥ 65 kBtu/hr.): VRF or VRV air-source heat pump, air-to-water heat pump<sup>10</sup>, ground-source or groundwater-source heat pumps</p> <p>Exception: Water-source heat pumps allowed only if existing in the building and not being replaced.</p>
2.	<p><u>Rated heating efficiency:</u></p> <ul style="list-style-type: none"> <li>Heat Pump/VRF heating (ducted/un-ducted):  (&lt; 65 kBtu/hr.) Heating Seasonal Performance Factor (HSPF) 9.5  (≥ 65 kBtu/hr.) Coefficient of Performance (COP) @ 47°F 3.4, COP @ 17°F 2.25</li> <li>Air-to-water heat pump heating: 1.7 COP<sub>H</sub> @ 5°F dry bulb and leaving water temperature (LWT) of 110°F</li> <li>Ground-source heat pump: 3.6 COP<sup>11</sup> @ 32°F entering water temperature (EWT)</li> <li>Groundwater-source heat pump: 4.1 COP<sup>12</sup> @ 50°F EWT</li> </ul>

<sup>7</sup> Proportional control allows for partial economization that avoids heat exchange to meet a minimum supply-air temperature setpoint at low outside air temperatures.

<sup>8</sup> Variable defrost control refers to proportional or continuous control (not stepped control).

<sup>9</sup> Based on independent third-party testing in accordance with PHI or AHRI 1060. For PHI, the internal leakage must meet the specified requirement. For AHRI 1060, the EATR must meet the specified requirement at all required test conditions. (75% and 100% of the rated airflow and all tested pressure differential conditions).

<sup>10</sup> 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 and cooling systems.

<sup>11</sup> Geothermal heat pump COP = (highest rated capacity COP + lowest rated capacity COP) / 2

<sup>12</sup> Ibid

**Table 1: Minimum Equipment Performance**

3.	<p><u>Rated cooling efficiency:</u></p> <ul style="list-style-type: none"> <li>• DHP/VRF cooling (ducted/un-ducted): ( &lt; 65 kBtu/hr.) Seasonal Energy Efficiency Ratio (SEER) 16 ( ≥ 65 kBtu/hr.) Integrated Energy Efficiency Ratio (IEER) 21</li> <li>• Ground-source heat pump cooling: 17.1 Energy Efficiency Ratio (EER) @ 77°F EWT</li> <li>• Groundwater-source heat pump cooling: 21.1 EER @ 59°F EWT</li> </ul>
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**Table 2: Critical System Design Requirements**

1.	<p><u>Decoupled system design:</u> Ventilation and heating/cooling system controlled separately with independent ducting and zoning. Ventilation air shall be delivered directly to the occupied space.<sup>13</sup> Ventilation duct system must include the following, at a minimum:</p> <ul style="list-style-type: none"> <li>1.1 Ability to adjust flow for balancing at each diffuser.</li> <li>1.2 Supply and return/exhaust ductwork sized for maximum flow at a friction loss not to exceed 0.08" w.g. per 100 feet of straight-length duct.</li> <li>1.3 Except where site conditions limit or restrict this approach, the ventilation supply-air shall be delivered to one side of space, with exhaust air extracted from opposite side. Do not locate exhaust grille where ventilation air will be short-circuited.</li> <li>1.4 Supply and return outlets/inlets are required for ducted heating/cooling systems. For ventilation systems, separate supply outlets are required for all spaces and shall include either a ducted return or a non-ducted return path with free area sized so that velocity does not exceed 300 feet per minute (FPM).</li> <li>1.5 Outside air (entering HX) and HRV exhaust air (leaving HX) ducts shall have minimum R-19 insulation in both conditioned and unconditioned spaces. Existing ductwork used as ventilation supply or return/exhaust shall be sealed to Sheet Metal &amp; Air Conditioning Contractors' National Association (SMACNA) Seal Class B standards where accessible, or if delivering greater than 500 cfm at design conditions. Insulate ventilation supply and exhaust as per code requirements for heating and cooling ductwork.</li> </ul>
2.	<p><u>Design operating conditions:</u> Equipment selection shall indicate the following operating conditions are met at design airflows when calculated based on values provided by the manufacturer (or approved representative):</p> <ul style="list-style-type: none"> <li>2.3 Minimum HRV heat exchange of 75% sensible effectiveness<sup>14</sup> at heating and cooling design temperatures.</li> <li>2.2 Minimum fan efficacy rating of 1.3 cfm/Watt.<sup>15</sup></li> </ul>

<sup>13</sup> Exception: Systems using active chilled beams.

<sup>14</sup> As determined by the following equation at design conditions: 
$$\frac{\text{Supply CFM} \times (\text{Supply Air Temperature} - \text{Outside Air Temperature})}{\text{Exhaust CFM} \times (\text{Return Air Temperature} - \text{Outside Air Temperature})}$$

<sup>15</sup> As determined by the following equation at design conditions: 
$$\frac{\text{Supply CFM}}{\text{Total Fan Power (Supply Fan Watts} + \text{Exhaust Fan Watts)}}$$

**Table 2: Critical System Design Requirements**

3.	<u>Heating and cooling sizing:</u> Right-size the heating and cooling system using load calculations. Do not include safety factors greater than 10%. Otherwise, for Climate Zones 5/6, use no less than 600 sq. ft./ton of system cooling capacity, and for Climate Zone 4, use no less than 750 sq. ft./ton.
4.	<u>Integral refrigerant system heat recovery:</u> Integral refrigerant heat recovery is not allowed without a zoning plan and analysis of energy savings that demonstrates effective utilization of this feature (e.g., core/perimeter).
5.	<u>Submittals:</u> Required: Heating and cooling system rated performance, HRV rated performance, control specifications and sequence of operations, all relevant mechanical equipment schedules, duct layout with sizing, reflected ceiling or diffuser placement plan, and system diagrams. Optional (depending on exceptions taken): Zoning plan, energy savings analysis (if including integral refrigerant system heat recovery per Critical System Design Requirement #4 above), and load calculations (if exceeding Critical System Design Requirement #3 above).
6.	<u>Start-up and testing, adjusting, balancing (TAB):</u> TAB shall encompass entire airside system, including duct air-tightness and ventilation system airflow verification. Manufacturer (or manufacturer-approved technician) shall provide start-up of HRV at a minimum. Contractor (or approved agent) shall provide verification testing of control sequences.  TAB report shall include the following documentation, at a minimum: <ol style="list-style-type: none"> <li>1. Air at each diffuser tested and balanced<sup>16</sup> to within +/- 10% (or 5 cfm, whichever is greater) at design flow.</li> <li>2. If utilizing demand-control ventilation (DCV) control strategy, diffuser airflow testing at minimum design flow.</li> <li>3. System airflow tested<sup>17</sup> and balanced to within +/- 5% of design airflow at HRV unit.</li> <li>4. Duct leakage testing results of representative sections of all ducted systems (both ventilation and heating/cooling system if ducted) totaling at least 25% of the duct area.</li> </ol>
7.	<u>Heating and cooling system fan operation:</u> Heating and cooling system fans shall turn off when there is no call for heating or cooling.

The following are suggested as best practices for optimum performance, but not required.

**Table 3: Recommended Guidelines to Achieve Optimum Performance**

1.	<u>HRV/ERV sizing:</u> Individual units shall be controlled to run between 40-60% of rated full flow when meeting ASHRAE 62.1 ventilation rates (fully occupied, non-boosted). Supply ducting shall be sized for maximum flow at an average friction loss of 0.08" w.g. per 100 feet of straight-length duct.
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<sup>16</sup> TAB technician must use a flow hood measuring accurately down to 10 cfm, for both supply and exhaust airflows, in a typical ventilation system.

<sup>17</sup> Accomplished using reliable duct traverse at HRV unit discharge, or manufacturer's on-board control output values.

**Table 3: Recommended Guidelines to Achieve Optimum Performance**

2.	<u>Commissioning (Cx)</u> : Cx agent shall functionally test equipment installation and all dynamic control components and associated sequences of operation. Cx agent to observe and verify ventilation system air balancing and duct-leak testing. Cx report shall be made available to system operator and building owner.
3.	<u>Energy modeling</u> : Use non-standard work-arounds as needed.

## APPENDIX 3: DEFINITIONS

### Air-to-air heat exchanger

An exchanger that transfers heat from an exhaust airstream to a separated 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.

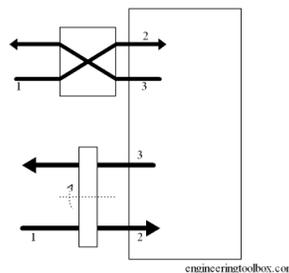
### Counterflow heat exchanger

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.

Cross flow and rotating heat exchangers are illustrated below:



### Crossflow leakage

Crossflow leakage occurs when air leaks from the exhaust side to the supply side through the seals or gaps in the construction

### Decoupled system design

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 return or plenum of the heating and cooling ductwork.

### 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-air intake below design rates when the actual occupancy of spaces served by the system is less than design occupancy.

### Duct static pressure

The actual pressure of the fluid regarding its state, but not its motion. The pressure is exerted uniformly throughout the entire fluid. The portion of the fluid pressure which exists by virtue of the degree of compression only. 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<sub>2</sub>O (kPa).

### Economizer function

(1) A process employing heat recovery equipment or heat exchangers. (2) A device that, on proper variable sensing, initiates control signals or actions to conserve energy. A control system that reduces the mechanical heating and cooling requirement.

### Energy recovery ventilator (ERV)

While both ERVs and HRVs function with one air duct pushing stale air out of a building while the other draws fresh air in, ERVs additionally manage humidity.

### Fan performance curve

Graphical 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 lowering the air temperature in a building by using naturally cool air or water instead of mechanical refrigeration.

**Heat pump**

Thermodynamic heating/refrigerating system to transfer heat. The condenser and evaporator may change roles to transfer heat in either direction. By receiving the flow of air or other fluid, a heat pump is used to cool or heat. Heat pumps may be air source with heat transfer between the indoor airstream to outdoor air, or water source with heat transfer between the indoor airstream and a hydronic source (ground loop, evaporative cooler, cooling tower or domestic water).

**Heat recovery ventilator (HRV)**

An HRV system consists of two air ducts: one that carries fresh air in and one that carries stale air out. 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.

**Heating Seasonal Performance Factor (HSPF)**

For the space-heating season, HSPF is the ratio of the total space heating delivered to the total electrical energy input if the combined appliance is operated exclusively in a space-heating-only mode. The quantity is expressed in units of Btu/Wh. For SI use, compare coefficient of performance.

**Hydronic systems**

A thermal distribution system that uses water or a mixture of water and additives as the 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 heat pumps can be either single zone or multi-zone. Both single zone and multi-zone heat pumps can be ducted or ductless.

**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 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](http://passivehouse.com).

**Plate heat exchanger**

Fixed plates that separate hot and cold fluids and maintain their separation. See also [plate liquid cooler](http://xp20.ashrae.org/terminology) (xp20.ashrae.org/terminology).

**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.

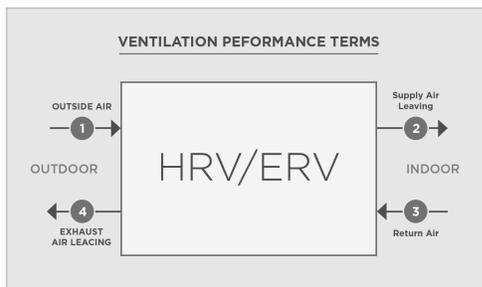
**Rated Flow or Rated Unit Full Flow**

The manufacturer's rating for the unit's full flow capacity.

### Sensible Recovery Efficiency (SRE)

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. The equation below is a simplification that can be used for reference. The actual equation adjusts for other factors such as fan and defrost energy, uses airstream mass flow instead of airflow, and uses the minimum of the two air/mass flows in the denominator.

$$\frac{\text{Supply CFM} \times (\text{Supply Air Temperature} - \text{Outside Air Temperature})}{\text{Exhaust CFM} \times (\text{Return Air Temperature} - \text{Outside Air Temperature})}$$



### 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 at a constant 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.

### 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. VRF utilizes three or more steps of control on common, interconnecting piping.

### Wheel-type 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. To recover the heat energy, it is positioned within the supply and exhaust airstreams of an air-handling system or in the exhaust gases of an industrial process. Other variants include enthalpy wheels and desiccant wheels.

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## ABOUT BETTERBRICKS

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