



## Very High Efficiency Dedicated Outside Air System for Commercial Buildings

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# System Requirements, Recommendations, and Compliant Systems

### INTRODUCTION

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.

To qualify as a very high efficiency DOAS, systems must meet the Minimum Equipment Performance and Critical System Design Requirements as documented in Tables 1 and 2 below, respectively. The Recommended Guidelines to Achieve Optimum Performance listed in Table 3 are encouraged as best practices, but are not required. Heat / energy recovery equipment currently compliant with these requirements are listed on [Page 19](#).

For more detailed information, view the Very High Efficiency DOAS Comprehensive Design Guide at: [betterbricks.com/resources/vheodascomprehensive-design-guide](https://betterbricks.com/resources/vheodascomprehensive-design-guide).

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Table 1: Minimum Equipment Performance [ <a href="#">learn more</a> ]	
Heat Recovery Ventilation [ <a href="#">learn more</a> ]	
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.
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.

<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.

<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).

Table 1: Minimum Equipment Performance [ <a href="#">learn more</a> ]	
Heating and Cooling System [ <a href="#">learn more</a> ]	
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>
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>

<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 2: Critical System Design Requirements [\[learn more\]](#)**

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>2.1 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>
3.	<p><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.</p>
4.	<p><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).</p>

<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 <a href="#">[learn more]</a>	
5.	<p><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).</p>
6.	<p><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.</p> <p>TAB report shall include the following documentation, at a minimum:</p> <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.	<p><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.</p>

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

Table 3: Recommended Guidelines to Achieve Optimum Performance <a href="#">[learn more]</a>	
1.	<p><u>HRV 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.</p>
2.	<p><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.</p>
3.	<p><u>Energy modeling:</u> Use non-standard work-arounds as needed.</p>

<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.

# System Requirements and Recommendations

## Supplemental Information

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The following information expands on the performance requirements and recommendations listed in the preceding summary tables. Background information includes a problem statement as derived from Northwest Energy Efficiency Alliance (NEEA) research and demonstration project experience. These requirements and recommendations are designed for the Pacific Northwest's climate zones. Design guidelines provide added insight into the performance specification parameters and methods, and approaches for meeting corresponding requirements.

For more detailed information, view the Very High Efficiency DOAS Comprehensive Design Guide at: [betterbricks.com/resources/vheodascomprehensive-design-guide](https://betterbricks.com/resources/vheodascomprehensive-design-guide).

### MINIMUM EQUIPMENT PERFORMANCE [FROM TABLE 1]

#### Heat Recovery Ventilation

##### 1. Minimum Efficiency.

Background. Currently, the majority of HRV and 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 and 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 for 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 Pacific 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 version 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, tested according to AHRI 1060.4. The key reason for the recovery efficiency specification set at the level specified in Table 1 is to require that systems will 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 targeted requires the use of either a counter-flow, 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.

Additional Note: Designers should note that 82% sensible effectiveness is intended to provide airflow temperatures that do not cause occupant discomfort in Climate Zone 4. Additional tempering may be necessary at design temperatures in climate zones 5 and 6, with the goal of minimizing use of this supplemental heat.

## 2. **Minimum Fan Efficacy.**

Background. As in the case of recovery efficiency, the majority of HRV and 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 and cooling system is very efficient (e.g., a VRF- or 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 or 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 and 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 variable speed fans, likely achieved with electronically commutated (EC) motors. 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.)

## 3. **Capacity Control Capabilities.**

Background. When ventilation air is completely separated from heating and cooling air (a critical system requirement for this DOAS concept), the ventilation air volume should then be managed for occupancy and level of occupancy. Demand controlled ventilation, for example, is an energy code requirement for many commercial building occupancy categories that experience high occupant densities, such as conference rooms.

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. Variable fan speed capability is also required either through EC motors or variable frequency drives (VFDs.) By locating modulating dampers controlled to CO2 level (or two-position dampers controlled to occupancy sensor signals) in high occupancy zones, this feature allows for DCV to be implemented in the critical zones.

This section of the Critical System 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.

#### 4. Economizer Control Capabilities.

Background. In current non-DOAS systems 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 and cooling system, so any economizer functionality must be provided through the HRV or ERV.

Depending on technology type, there are multiple strategies to provide economizing when conditions allow, with little or no heat exchange occurring. For counter-flow 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.

#### 5. Defrost Control Capabilities.

Background. In many climates, heat recovery systems will have a need to defrost 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, and 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 or ERVs because these units recover so little energy that the exhaust airstream rarely reaches freezing temperatures.

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 resulting in an unbalanced system and potentially compromising indoor-air quality.

Requirement. This section of the Critical System 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, while providing 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 rpms) 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.

## 6. Crossflow Leakage.

Background. Many occupancies, 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 or ERV unit's operating range. (AHRI refers to this as Exhaust Air Transfer Ratio (EATR)). To meet this designated performance specification, crossflow air leakage must be tested according to the equivalent of PHI protocols.

## 7. Filters.

Background. Without proper filtration of the outside airstream before entering the HX, 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 in order 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 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 to help keep the plates and media clean, especially if no filtration is present on the heating and cooling system.

## 8. Control Communication Protocol Capabilities.

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 or ERV product should have the capability to ensure this kind of connectivity in order 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 building control systems and can also be used to integrate the functions of the ventilation system and the heating and cooling system when desired. This is important in operational modes such as economizing, where the HRV controls should be able to evaluate the heating and cooling system setpoints and temperatures during economizing hours. Often, VRF or VRV heating and 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.

## 9. Installation Location Options.

Background. Many HRV or 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 or ERV will need to be located on a building rooftop, or in an outdoor location. In order to preserve the installation flexibility to be installed in a wide variety of commercial building applications, and to preserve the efficiency of the system in operation, the HRV or 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 shall 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, unit shall be PHI-certified, or the casing insulation shall be R-8 or better.

## Heating and Cooling System

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

### 1. System Type.

Background. In commercial buildings, there are many heating and cooling system types that can provide temperature control. The typical existing system type target for very high efficiency DOAS retrofits is a packaged rooftop unit (RTU), which is also the predominant system type for small commercial buildings

across the Pacific 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.

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 variable refrigerant flow (VRF) or variable refrigerant volume (VRV) 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 and 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 variable speed fan 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 variable speed fan 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.

## 2. Heating Efficiency.

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 or 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. Compliance with the heating and 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.

## 3. Cooling Efficiency.

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 the SEER as determined by AHRI 210/240. For use with these requirements, large system cooling efficiencies shall be based on the 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.

## CRITICAL SYSTEM DESIGN REQUIREMENTS [FROM TABLE 2]

This section focuses on system design requirements, reinforcing the equipment requirements in the previous section. Design guidelines are provided for meeting these requirements.

### 1. Decoupled System Design.

Background. Decoupled system design refers to complete separation of ventilation air from heating and 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 from the indoor fan unit. Decoupled system design is critical to the performance of the overall VHE-DOAS system, as significant benefits and energy savings come from controlling these two air streams independently.

Design Requirement. Such practices violate the intention of the requirements and will compromise the performance of very high efficiency DOAS, compromising the significant benefits and energy savings that come from controlling these two airstreams independently. The ventilation air should never be combined with the heating and cooling air prior to entering the occupied space. In the most extreme climates, where a slight tempering of the ventilation air is advised, this function should be provided separately from the heating and cooling air that provides comfort conditioning directly to the building zones.

#### 1.1 Balancing.

Background. Without available flow balancing devices, the 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 re-balancing and installing such devices after the mechanical system installation is substantially complete.

Design Requirement. This requirement helps ensure a sufficient number of balancing devices exist 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.

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 reduces 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 feet of straight-length duct at the maximum ventilation airflow that the system is expected to operate at (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.**

Background. Many mechanical engineers and contractors establish other priorities beside ventilation effectiveness as the primary basis for air distribution design, (i.e., 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.

### **1.4 Return Air Path.**

Background. The demonstration projects have verified that in smaller spaces with doors that are often closed, a lack of return air inlets for heating and 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.

### **1.5 Duct Sealing and Insulation.**

Background. There is a tendency for designers and contractors to dismiss critical air distribution system performance issues because the air being moved around is at, or close to, room temperature. The demonstration 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 or 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, 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 exterior 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.

## 2. Design Operating Conditions.

Background. To distinguish quality products, it is helpful to set a minimum heat exchange effectiveness and fan power efficacy, but it 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. By requiring a minimum design operating condition, this 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 and Cooling Sizing.

Background. The demonstration projects show that the efficiency of the very high efficiency DOAS conversion makes it possible to significantly downsize the capacity of the heating and cooling system components. This is a significant source of both energy and demand savings for the conversion. Even efficient heating and cooling systems do not always cycle efficiently under low-load conditions. Significant 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 below, 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 Washington State Energy Code, and/or equivalent for other states).

## 4. Integral Refrigerant System Heat Recovery.

Background. For larger VRF or 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 and 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- or 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.

## 5. **Submittals.**

Background. In the world of small commercial building HVAC work, contractors sometimes provide inadequate detail about the systems they propose to building owners. While this may work well enough in the case of a simple RTU replacement, when the complete conversion of the existing system is proposed, detailed plans, specifications, and supplemental submittals are needed to ensure that the system is designed and specified properly, that the ducting is properly sized and configured, that the appropriate control sequences and sensors are being used, and that project costs are reasonable.

Design Requirement. This requirement is designed to allow both the building owner and the program manager some assurance that the project proposed is likely to meet the performance required, at a reasonable cost, and to provide information regarding critical system design and specification areas (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 package includes documentation of the rated performance of the heat pump systems and the HRV systems. Documentation shall confirm compliance with all performance specification requirements. Also included as required submittals are the control specifications including sequence of operations, and an air distribution system and equipment layout plan. The 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. **Start-up and Testing, Adjusting, Balancing (TAB).**

Background. TAB is often included as a completion activity for major HVAC projects. At a minimum, the manufacturer, or representative, should provide start-up 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 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. Start-up and TAB should be executed on both the HRV and the heating and 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 un-ducted), 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 un-ducted 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 the Critical System Design Requirements table.

Additional Notes: For testing and balancing, technician must use a flow hood measuring accurately down to 10 cfm, for both supply and exhaust air flows, in a typical ventilation system. 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.

## 7. Heating and Cooling System Fan Operation.

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 and cooling system have the capability to turn fans off when the space is either unoccupied or has no call for heating or cooling.

Design Requirement. Heating and 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 and cooling system, or through a tie-in with a central control system.

## RECOMMENDED GUIDELINES TO ACHIEVE OPTIMAL PERFORMANCE [FROM TABLE 3]

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

### 1. HRV Sizing.

Background. Most 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. Sometimes this is driven by first cost, while other times it is driven by the available space for equipment installation. Whatever the reason, this is a sizing approach that 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 or ERV. This results in very good efficiency while balancing 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).<sup>18</sup>

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<sup>18</sup> Ventilation airflows are typically much lower than heating and cooling airflows. The heating and cooling fans typically provide the economizing function. If the HRV or ERV is 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 or 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)

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 or ERV technology specified here. But, as for any HVAC system, adequate Cx is required to ensure that the system is performing in accordance with design intent and specification. The 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.

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 demonstration projects, and by expert modelers providing post-project analyses.

Design Guideline. Special modeling considerations and non-standard work-arounds include:

- 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 Watts/cfm.
- HRV control sophistication can enable economizer function, respond to CO<sub>2</sub> sensors (demand control), and optimize frost-control cycle. Ensure the inputs/approaches related to controls are aligned with the proposed equipment and scope. Consider use of post-process calculations within a spreadsheet using hourly output results.
- In-service performance (baseline model) has been found to be considerably worse than the rated efficiency, with efficiency most significantly compromised at part load. Include baseline RTU cooling part load performance degradation.
- Approximate the variable air volume 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 (i.e., operating hours, night cycling, temperature setpoints and setbacks) and miscellaneous electrical loads (e.g., plug loads, lighting, server room, etc.), as these have a large impact.

# Compliant and Pending Heat and Energy Recovery Equipment

## COMPLIANT

The following heat and energy recovery equipment is compliant with the minimum equipment performance requirements listed in [Table 1 above](#):

Manufacturer	Model #	HRV/ERV
Swegon	Gold RX 05	HRV
Swegon	Gold RX 07	HRV
Swegon	Gold RX 08	HRV
Swegon	Gold RX 11	HRV
Swegon	Gold RX 12	HRV
Swegon	Gold RX 14	HRV
Swegon	Gold RX 20	HRV
Swegon	Gold RX 25	HRV
Swegon	Gold RX 30	HRV
Swegon	Gold RX 35	HRV
Swegon	Gold RX 50	HRV
Ventacity	VS1000 RTh	HRV
Ventacity	VS1000 RTe	ERV
Ventacity	VS3000 RTh	HRV
Ventacity	VS3000 RTe	ERV

## PENDING COMPLIANCE

The following equipment is compliant with the minimum equipment performance requirements listed in [Table 1 above](#) based on information provided by the manufacturer, but is pending third-party test results\*:

Manufacturer	Model #	HRV/ERV
Swegon	Gold RX 05	ERV
Swegon	Gold RX 07	ERV
Swegon	Gold RX 08	ERV
Swegon	Gold RX 11	ERV
Swegon	Gold RX 12	ERV
Swegon	Gold RX 14	ERV
Swegon	Gold RX 20	ERV
Swegon	Gold RX 25	ERV
Swegon	Gold RX 30	ERV
Swegon	Gold RX 35	ERV
Swegon	Gold RX 50	ERV

Manufacturer	Model #	HRV/ERV
Tempeff	RG 1000	HRV & ERV
Tempeff	RG 1500	HRV & ERV
Tempeff	RG 2000	HRV & ERV
Tempeff	RG 3000	HRV & ERV
Tempeff	RG 4000	HRV & ERV
Tempeff	RG 5500	HRV & ERV
Tempeff	RG 6500	HRV & ERV
Tempeff	RGL 1000	HRV & ERV
Tempeff	RGL 1500	HRV & ERV
Tempeff	RGL 2000	HRV & ERV
Tempeff	RGL 3000	HRV & ERV
Tempeff	RGL 4000	HRV & ERV
Tempeff	RGL 5500	HRV & ERV
Tempeff	RGL 6500	HRV & ERV

*\*Manufacturers who are pursuing AHRI 1060 testing or Passive House certification may meet NEEA's Table 1 HRV requirements based on internal testing but have not yet undergone/completed third-party testing. Test results must be submitted to NEEA within nine months to remain on the compliant list.*