Pacific Northwest
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PNNL-34452

MODELING APPROACH FOR VERY HIGH EFFICIENCY DEDICATED OUTDOOR AIR SYSTEMS IN NEW CONSTRUCTION AND MAJOR RENOVATION

Update to the January 2020 Report

July 2023

Jeremy Lerond
Reid Hart
Supriya Goel
Michael Rosenberg

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

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Pacific Northwest National Laboratory
Richland, Washington 99354

1.0 Introduction

Based on a draft program requirement for very high efficiency dedicated outdoor air systems (VHE DOAS) provided by NEEA, a more detailed report (Hart, Lerond, Goel, & Rosenberg, 2020) proposed sequences of operation and modeling strategies for such equipment. Simulations were carried out to estimate savings potential of these sequences of operation.

Since then, NEEA has updated their requirements from a strict set of requirements for what constitutes a VHE DOAS to having different levels of performance: minimum requirements, best practices, and design recommendations.

This short report builds on the previous one by providing updated saving estimates for the different level of performance of NEEA's new VHE DOAS program. The following section provides a description of the modeling approach and goes over the general modeling assumptions. The third and final section provides the updated saving estimates and a discussion of the results. This brief report should be reviewed in context of the original more detailed report (Hart, Lerond, Goel, & Rosenberg, 2020).

2.0 Modeling VHE DOAS

To provide a consistent analysis with the earlier report (Hart, Lerond, Goel, & Rosenberg, 2020), different VHE DOAS packages were compared to the Washington State TSPR baseline case for a small to medium office building model. As mentioned in the introduction, the new program includes three different levels of performance for VHE DOAS. As such, two different sets of assumptions were created and are detailed in Table 1. One of the packages aims to capture only the minimum requirements of the program. The other package aims to capture both the best practices and design recommendations of the program in addition to the minimum requirements.

Table 1 – DOAS Configuration and Modeling Assumptions

System/Component	Baseline (TSPR Baseline)	VHE DOAS - Minimum Requirements (package 1)	VHE DOAS – Best practices and design recommendations (package 2)	Notes
Primary heating and cooling (PHC) system	Variable Refrigerant Flow	Variable Refrigerant Flow	Variable Refrigerant Flow	
PHC fan power (W/cfm)	0.53	0.35	0.35	Value for (package 1) and (package 2) was provided by NEEA based on field observations
PHC heating efficiency (COP)	3.3	3.4	3.4	Assuming units of 65 kBtu/h to 135 kBtu/h
PHC cooling efficiency (COP)	11.0	14.2	14.2	Assuming units of 65 kBtu/h to 135 kBtu/h
PHC economizer	No	No	No	
PHC system sizing factors	1.25 for heating 1.15 for cooling	1.20 for heating 1.15 for cooling	1.10 for both heating and cooling or 750 ft2/ton, whichever is greater	
DOAS ERV sensible effectiveness	70%	82%	82%	
DOAS ERV fan power (W/cfm)	0.82	0.77	0.50	Value for (package 2) was provided by NEEA based on field observations
DOAS economizer	No	No	Yes	See Section 2.1
DOAS demand controlled ventilation (DCV)	No	No	Yes	See Section 2.1
DOAS ERV bypass control	No	No	Yes	See Section 2.2
DOAS MERV13 Filter	Yes	Yes	Yes	

2.1 Economizer and DCV

Economizer operation was modeled identically to what is included in (Hart, Lerond, Goel, & Rosenberg, 2020). Two economizer modes are modeled: “partial” and “pre-economizer”. The former manages economizer operations below 70°F while the latter manages economizer operations between 70°F and below 75°F. For more details refer to Section 3.1 of the report. Demand controlled ventilation (DCV) was also modeled as in the earlier study (Hart, Lerond, Goel, & Rosenberg, 2020), which is based on the approach used in the TSPR tool: outdoor air requirements are adjusted down by a certain percentage following a set of regression equations that have been developed to account for outdoor air reduction based on percentage of high-density zones that require DCV.

2.2 Energy Recovery Ventilator Bypass Control

(Hart, Lerond, Goel, & Rosenberg, 2020) provides results for a few different types of energy recovery (ERV) bypass control, the one showing the lowest energy use was a simple strategy where the ERV attempts to control the supply air temperature to a fixed temperature of 60°F. This ERV bypass control works in conjunction with the economizer operation: bypass dampers are fully open when the outdoor air is greater 60°F and they modulate to maintain 60°F when the outdoor air is less than 60°F, this results in a full bypass between 60°F and 75°F. While 60°F may seem like a low delivery temperature for ventilation air, several things should be considered about this choice:

- Compared to an outside air reset of the bypass supply air control this strategy performed better. It performed about the same as a return air reset strategy that captured the overall space heating and cooling loads but would be more complex to implement.

- Climate Zone 4C is relatively mild and does not benefit much from a shutoff of bypass at lower temperatures.

- The air volume delivered by the DOAS is substantially less than full supply air for the space, and consequently does not overcool at a lower temperature.

- Office and other commercial buildings have a relatively high internal load profile and are often in cooling mode.

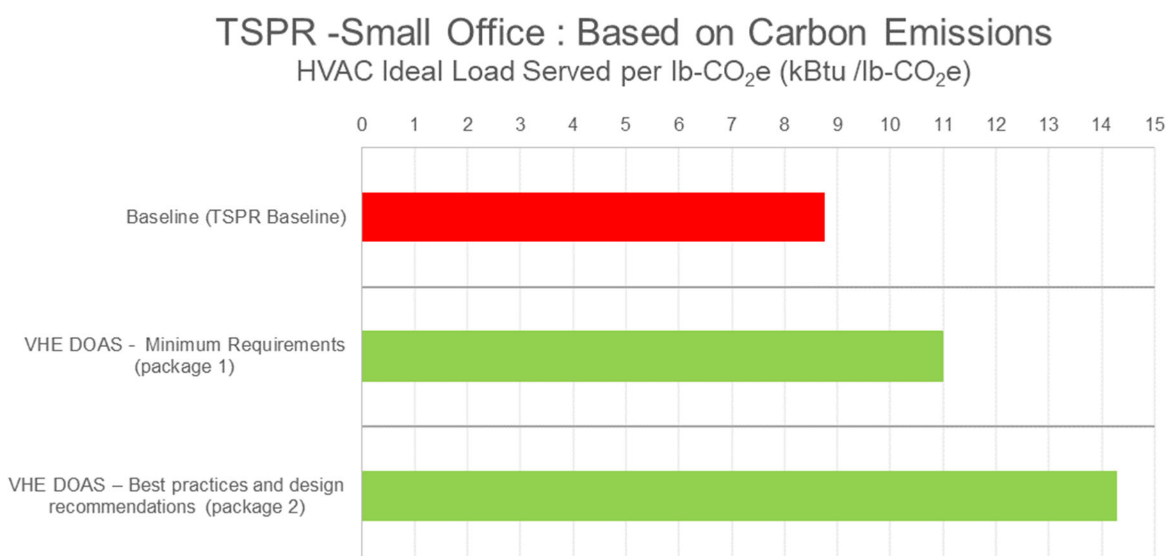
- The desired setpoint for buildings would vary depending on the proportion of core and perimeter zones. In fact, a design recommendation to separate such zone types in larger buildings should be considered for the next release of program recommendations.

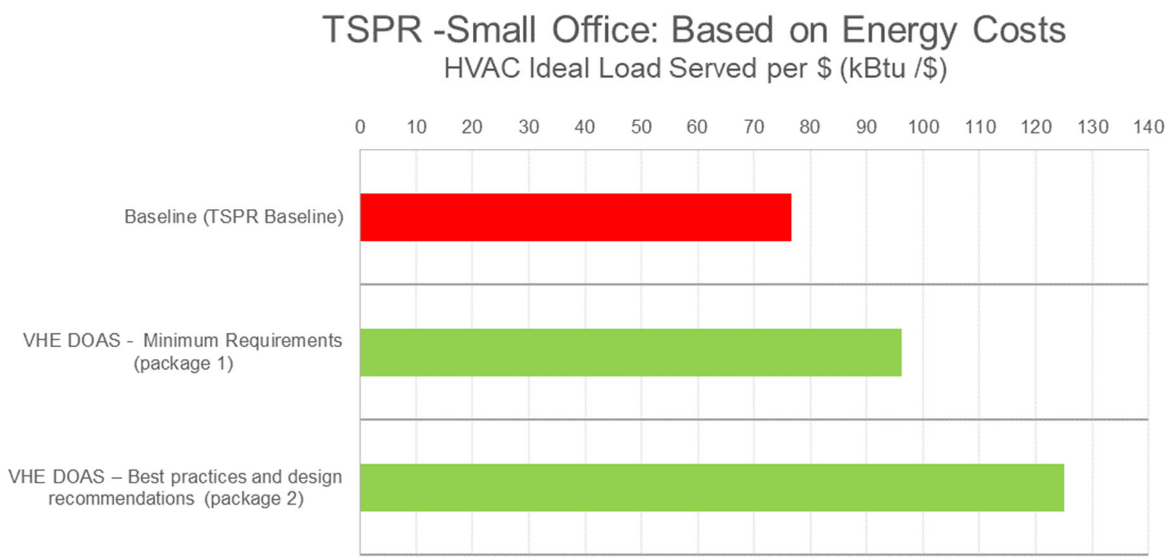
3.0 Energy Savings Estimates

	Baseline (TSPR Baseline)	VHE DOAS - Minimum Requirements (package 1)	VHE DOAS – Best practices and design recommendations (package 2)
TSPR* (Energy Cost 0.08 $/kWh, 0.76 $/therm)	76.69	96.14	125.01
TSPR* (CO2e- Electric 0.7 lb/kWh, Gas 11.7 lb/therm)	8.76	10.99	14.29
Site Energy Use (kBtu/ft2)			
Heating	1.0	0.8	1.3
Cooling	2.1	1.7	1.1
Fan	2.8	2.2	1.2
Total HVAC Site Energy Use	5.9	4.7	3.6
Whole Building Site Energy Use (kBtu/ft2)	24.0	22.9	21.8
Site Energy Cost ($/ft2)			
Total HVAC Site Energy Cost ($/ft2)	0.14	0.11	0.08
Whole Building Site Energy Cost ($/ft2)	0.56	0.54	0.51

*TSPR or Total System Performance Ratio is a metric that indicates how much HVAC service in terms of heating, cooling, and humidity control is delivered to the building per input energy cost or emissions. Consequently, a higher TSPR indicates a more efficient overall HVAC system.

The following bar graphs illustrate the difference in TSPR between the baseline with standard ERV, a VHE DOAS with the minimum requirements, and a VHE DOAS with best practices and design recommendations.




TSPR -Small Office: Based on Energy Costs
HVAC Ideal Load Served per $ (kBtu /$)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Baseline (TSPR Baseline)
VHE DOAS - Minimum Requirements (package 1)
VHE DOAS – Best practices and design recommendations (package 2)

4.0 References

Hart, R., Lerond, J., Goel, S., & Rosenberg, M. (2020). *Modeling Approach For Very High Efficiency Dedicated Outdoor Air Systems in New Constriction and Major Renovation.* Richland: PNNL-29561.

Appendix A - Original Report

Pacific Northwest
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PNNL-29561

MODELING APPROACH FOR VERY HIGH EFFICIENCY DEDICATED OUTDOOR AIR SYSTEMS IN NEW CONSTRUCTION AND MAJOR RENOVATION

January 2020

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Modeling Approach for Very High Efficiency Dedicated Outdoor Air Systems

Dedicated outside air systems (DOAS) separate heating and cooling from the outside air (OSA) ventilation system, which allows for optimal control of each of these critical building functions. A very high efficiency DOAS (also referred to as VHE DOAS) improves the efficiency of a DOAS system by pairing a high-performance heating and cooling system, such as a heat pump or VRF, with a very high efficiency heat recovery ventilator (HRV) or energy recovery ventilator (ERV).

Pacific Northwest National Laboratory (PNNL) developed a sequence of operations for VHE DOAS systems based on the information received from the Northwest Energy Efficiency Alliance (NEEA) and has developed the modeling approach for the same to identify the possible energy savings of these systems over the Washington State Energy Code baseline systems developed for the Total System Performance Ratio (TSPR) approach.

This memo summarizes our understanding of program approach (Section 1), the sequence of operations defined by PNNL for VHE DOAS systems (Section 2 and Section 3), the modeling approach developed for implementing the same using EnergyPlus (Section 4), the savings achieved by these systems (Section 5) as well as the additional capabilities (Section 6) that will need to be added for TSPR tool to implement the same.

1 General VHE DOAS Program Requirements

Based on a review of the draft program requirements provided by NEEA, the sequences of operation and modeling strategy for multiple zone systems are based on the following:

- Outside air ventilation delivery is separate from local zone heating and cooling.
- A VHE exhaust air energy recovery device with very high sensible effectiveness is used to pre-heat or pre-cool outside air when appropriate.
- Demand controlled ventilation (DCV) is used to reduce the amount of outside air required:
    - All zones are equipped (where allowed by ASHRAE Standard 62.1) with occupancy sensor shutoff
    - High density zones have CO_2 DCV to modulate outside air between space and people requirements
- The DOAS is equipped with a very high efficiency fan.
- Space conditioning fans are cycled off when there is no need for zone heating or cooling.
- For systems that do not have outside air economizers on the space conditioning system, the DOAS is sized for double the minimum required outdoor airflow with a reasonable fan power, and the HRV/ERV system is selected for VHE at the design outside airflow rate.
- The DOAS is equipped with bypass dampers to allow adjustment of the DOAS leaving air temperature (LAT) in response to either zone demand or outside air conditions.

2 Sequence of Operations for VHE-DOAS associated with VRF, WSHP, FCU or Split Dx systems

This section summarizes the sequence of operation defined for VHE DOAS systems when coupled with variable refrigerant flow (VRF) systems, water source heat pumps (WSHP), fan coil units (FCU) or split DX systems.

2.1 Modes of Operation

2.1.1 Normal Occupied Mode

Normal Occupied Mode occurs during all occupied times when the unit is not in economizer mode.

2.1.2 Partial[1] Economizer Mode

Partial Economizer Mode occurs during occupied times when at least one zone has a call for PRECOOL and the outside air is below 70°F.

2.1.3 Pre-Economizer Mode

Pre Economizer Mode occurs during occupied times when at least one zone has a call for PRECOOL and the outside air is greater than or equal to 70°F and below 75°F.[2] Fan speed is limited to 50% of full speed.

2.1.4 Unoccupied Mode

Unoccupied Mode occurs during all unoccupied times, including building warmup.

2.2 Central HRV Unit Controls (serving more than one zone)

There are two general approaches to design and control of the zone air delivery:

- Zone dampers that are pressure dependent set to operate based on two different central DOAS fan conditions: LOW SP and HIGH SP; set depending on the availability of OSA economizer conditions and the need for building cooling. The main sequence is written for this approach.
- Zone dampers that are pressure independent set to operate based on zone demand with a fixed central fan static pressure, including an upper limit on fan speed at 50% unless there are very favorable OSA economizer conditions and a need for building cooling. The alternative sequence follows this approach.

2.2.1 DOAS Fan control

Fan speed shall be variable and controlled to maintain appropriate static pressure (SP) setpoint.

- Normal Occupied Mode: maintain LOW SP setpoint.
- Partial Economizer Mode: maintain HIGH SP setpoint.
- Pre-Economizer Mode: maintain LOW SP setpoint.

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[1] This is “partial” because the DOAS does not typically provide the full supply air volume—even in the double ventilation design, as is required with a full economizer.

[2] Based on a cooling setpoint of 75°F, increasing the fan speed as called for in partial economizer mode will increase energy use unless there is at least about a 5°F temperature difference between outside and zone air.

- Unoccupied Mode: Fan is off

LOW SP setpoint provides area outside air ventilation rate when all zone dampers are set at LOW AREA VENT
HIGH SP setpoint provides area outside air ventilation rate when all zone dampers are set at HIGH AREA VENT
Note: Determine HIGH SP with all zones in HIGH ECONO position and at least one zone damper full open. Then set HIGH AREA VENT zone positions with all zone dampers are set at HIGH AREA VENT.

2.2.2 HRV bypass control

- **Normal Occupied Mode**: Bypass dampers closed unless needed for defrost.
- **Partial Economizer Mode and Pre-Economizer Mode**: Bypass dampers full open when OA is greater than 53°F; modulate to maintain 53°F supply air when OA is less than 53°F. Note: Results in full bypass between OA of 53°F & 75°F. When all zones served by the DOAS are perimeter zones, lockout bypass control below a temperature between 40°F and 45°F.
    - **Optional enhanced control**: Reset DOAS supply air temperature between 60°F and 53°F based on number of zone calls for precooling.[3]
- Unoccupied Mode: Bypass and core dampers closed

2.2.3 HRV defrost control

During cold outside conditions, entering outside air shall be electrically preheated when leaving exhaust air falls below 35°F. At maximum heater capacity, outside air is bypassed around heat exchanger to maintain leaving exhaust air above freezing.

2.3 Zone Control

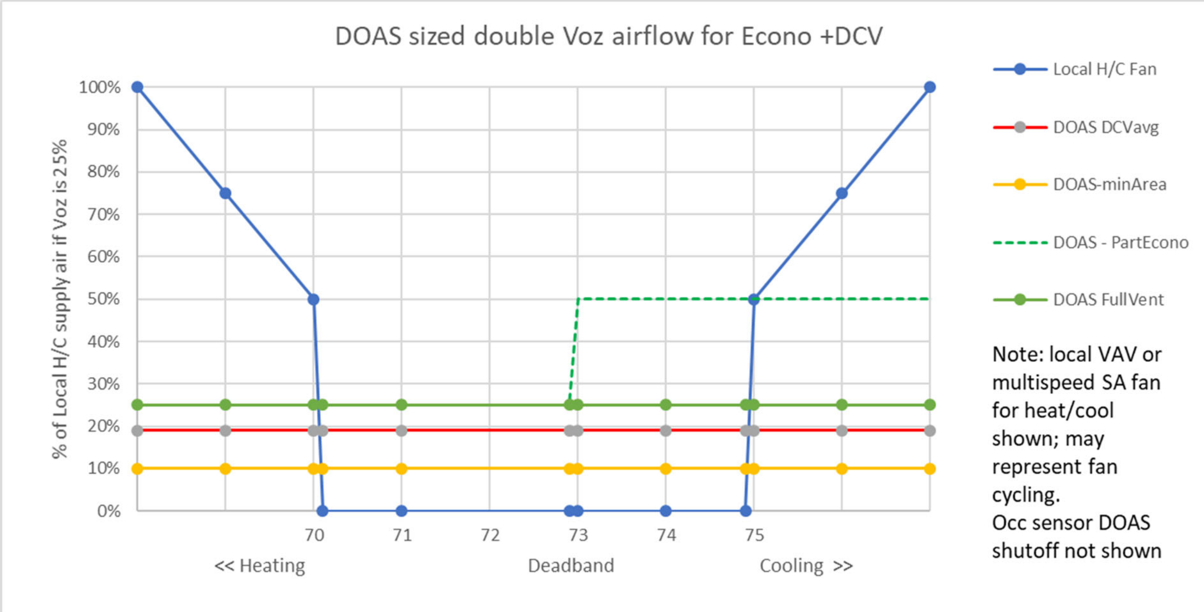
Proper zone control for this system requires integration of the zone outside air ventilation control, zone heating and cooling control, and the central DOAS economizer condition and DOAS LAT reset.

2.3.1 Local Heating/Cooling Fan control

Local heating/cooling fan operates only in heating or cooling mode. **Fan off** in ventilation only mode during deadband, Partial Economizer Mode, or Pre-economizer mode when mechanical cooling is not required.

[3] This can be modeled with a RAT reset control where there is strict zone setpoint management around a deadband. However, in field application success requires that the reset be based on zone cooling and heating requirements. These can be based on weighted zone heating and cooling thermostat calls.

2.3.2 Integration of Local Heat/Cool and DOAS Operation



2.3.3 Zone Outside Air Ventilation Control

Each zone shall have a zone damper to maintain appropriate outdoor airflow. Each zone with people density of 15 people per 1000 square feet or greater shall have a CO_2 sensor.[4] All zones shall have an occupancy sensor[5] and an interface with the local cooling system to signal PRECOOL when room temperature exceeds a setpoint of 1 to 2°F below local first stage cooling setpoint (no local heating call).

2.3.3.1 Normal Occupied Mode (economizer not available): zone damper to sequence as follows

- Closed when occupant sensor indicated space is unoccupied[5]
- LOW AREA VENT position when CO_2 sensor is less than 500 ppm
- Modulate proportionately to LOW FULL VENT position when CO_2 sensor is at FULL VENT CO_2 ppm zone setting

2.3.3.2 Pre-Economizer Mode: zone damper to sequence as follows

- Closed when occupant sensor indicates space is unoccupied[1] unless there is a PRECOOL call
- LOW AREA VENT position when CO_2 sensor is less than 500 ppm
- Modulate proportionately to LOW FULL VENT position when CO_2 sensor is at FULL VENT CO_2 ppm zone setting
- Open the damper full when the there is a zone PRECOOL call

2.3.3.3 Partial Economizer Mode: zone damper to sequence as follows

- Closed when occupant sensor indicates space is unoccupied[1] unless there is a PRECOOL call

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[4] This generally applies to retail sales space, bank lobby, or break room.
[5] All zones shall have occupancy sensor and closed occupied standby position except where occupied standby shutoff is not allowed by ASHRAE standard 62.1 – (some education and other space types)

- HIGH AREA VENT position when CO_2 sensor is less than 500 ppm
- Modulate proportionately to HIGH FULL VENT position when CO_2 sensor is at FULL VENT CO_2 ppm zone setting
- Open the damper to HIGH ECONO position when the there is a zone PRECOOL call

2.3.3.4 Unoccupied Mode: Zone OSA ventilation Damper is closed.

2.3.3.5 **FULL VENT** CO_2 ppm zone settings

As specified in ASHRAE Guideline 36, with the caveat that the maximum setting should be 1650 ppm to avoid sensor saturation. Examples are Office = 894 ppm; Dining = 1418 ppm; Retail sales = 1069 ppm; Conference = 1620 ppm; Classroom (age 9+) = 942 ppm

- LOW AREA VENT position is set at LOW SP to deliver the area component of outside air (Ra*Az)
- HIGH AREA VENT position is set at HIGH SP to deliver the area component of outside air (Ra*Az)
- LOW FULL VENT position is set at LOW SP to deliver the full zone outside air (Voz)
- HIGH FULL VENT position is set at HIGH SP to deliver the full zone outside air (Voz)
- HIGH ECONO position is set at HIGH SP to deliver double the full zone outside air 2*(Voz)

2.3.4 Alternative Zone OSA Ventilation Approach:

Use pressure independent zone boxes for DOAS ventilation air delivery with the following setpoints:

- AREA VENT position is the box minimum to deliver the area component of outside air (Ra*Az)
- FULL VENT position is set to deliver the full zone outside air (Voz), and is maximum delivered at FULL VENT CO_2 sensor setting.
- ECONO position is set to deliver double the FULL VENT outside air 2*(Voz); this operates from a zone sensor, increasing damper position to meet cooling load with the temperature setpoint 1 to 2 degrees F below the mechanical cooling setpoint for the zone cooling equipment.

3 Sequence of Operations for DOAS associated with VAV reheat, packaged RTU, or built-up AHU systems

3.1 Modes of Operation

3.1.1 Normal Occupied Mode
Normal Occupied Mode occurs during all occupied times when the unit is not in economizer mode.

3.1.2 Full Economizer Mode
Economizer Mode occurs during occupied times when at least one zone served by the DOAS has a call for PRECOOL and the outside air is below 75°F or whatever the economizer high limit setpoint for the main air supply unit is. Note: the economizer air is provided by the main unit(s), and the HRV unit bypass is coordinated with it. Hence, it is essential that the economizer high limits for all units served by one DOAS be the same.

3.1.3 Unoccupied Mode
Unoccupied Mode occurs during all unoccupied times, including building warmup.

3.2 Central HRV Unit Controls

3.2.1 Fan control
Fan speed shall be variable and controlled to maintain appropriate static pressure (SP) setpoint.

- Normal Occupied Mode: maintain NORMAL SP setpoint.
- Full Economizer Mode: maintain NORMAL SP setpoint.
- Unoccupied Mode: Fan is off

NORMAL SP setpoint provides area outside air ventilation rate when all zone dampers are set at NORMAL AREA VENT
Note: Determine NORMAL SP setpoint with at least one zone damper is full open and all zone dampers in the NORMAL FULL VENT (or NORMAL ECONO if higher) damper position.

3.2.2 HRV bypass control
- Normal Occupied Mode: Bypass dampers closed unless needed for defrost.
- Full Economizer Mode: Bypass dampers full open when OA is greater than 60°F; modulate to maintain 60°F supply air when OA is less than 60°F. Note: Results in full bypass between OA of 60°F & 75°F
- Unoccupied Mode: Bypass and core dampers closed

3.2.3 HRV defrost control
During cold outside conditions, entering outside air shall be electrically preheated when leaving exhaust air falls below 35°F. At maximum heater capacity, outside air is bypassed around heat exchanger to maintain leaving exhaust air above freezing.

3.2.4 Local Heating/Cooling Fan control
- Non VAV systems: Local heating/cooling fan operates only in heating, economizer or cooling mode. **Fan off** in outside air ventilation only mode during deadband.

- VAV systems: terminal box minimum in deadband set full closed. When all zones are in deadband, central fan is off.

3.2.5 Zone Outside Air Ventilation control

Each zone shall have a zone damper to maintain appropriate airflow. Each zone shall have a CO_2 sensor, an occupancy sensor[6] and an interface with the local cooling system to signal digital PRECOOL when room temperature exceeds a setpoint 2°F below local first stage cooling setpoint.

3.2.5.1 Normal Occupied Mode: zone damper to sequence as follows

- Closed when occupant sensor indicated space is unoccupied[1]
- NORMAL AREA VENT position when CO_2 sensor is less than 500 ppm
- Modulate proportionately to NORMAL FULL VENT position when CO_2 sensor is at FULL VENT CO_2 ppm zone setting

3.2.5.2 Full Economizer Mode: zone damper to sequence as follows

- Closed when occupant sensor indicates space is unoccupied[1] unless there is a PRECOOL call
- NORMAL AREA VENT position when CO_2 sensor is less than 500 ppm
- Modulate proportionately to NORMAL FULL VENT position when CO_2 sensor is at FULL VENT CO_2 ppm zone setting
- Open the damper to NORMAL ECONO position when the there is a zone PRECOOL call

3.2.5.3 Unoccupied Mode: Zone Damper is closed.

3.2.6 CO_2 Sensor FULL VENT CO_2 ppm zone settings

As specified in ASHRAE Guideline 36, with the caveat that the maximum setting should be 1650 ppm to avoid sensor saturation. Examples are Office = 894 ppm; Dining = 1418 ppm; Retail sales = 1069 ppm; Conference = 1620 ppm; Classroom (age 9+) = 942 ppm

- NORMAL AREA VENT position is set at NORMAL SP to deliver the area component of outside air (Ra*Az)
- NORMAL FULL VENT position is set at NORMAL SP to deliver the full zone outside air (Voz)
- NORMAL ECONO position is set at NORMAL SP to deliver the full zone outside air (Voz)

Note: NORMAL FULL VENT and ECONO are typically the same, although the ECONO position could be slightly higher if there is excess fan capacity in the DOAS – If that is desired, then the sequence would be similar to the one serving VRF, etc. However, additional savings is not likely to justify the complexity; and may be offset by increased fan power.

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[6] Occupancy sensor and closed occupied standby position not required and where occupied standby shutoff is not allowed by ASHRAE standard 62.1 – (some education and other space types)

4 Modeling Approach and Changes Required for TSPR Tool

The sequence of operations for very high efficiency dedicated outdoor air systems (VHE DOAS) has been described in Section 2 of this document. To allow a user to analyze such systems, four predominant capabilities would need to be added to TSPR tool. The modeling approach for these capabilities that need to be added to the TSPR tool are been described below.

4.1 ERV Defrost Control

4.1.1 Modeling Approach

TSPR tool does not model any kind of defrost control for DOAS systems. During winter weather, humid exhaust air entering the heat exchanger can form frost on the cold heat exchanger surfaces, which can reduce air flow and the amount of energy recovery. Several methods are used to control or eliminate frost formation, including supply air preheat, minimum exhaust air temperature control, exhaust air recirculation etc. For supply air preheat frost control, a separate heating coil object must be placed in the supply inlet air stream to keep the air temperature above the frost threshold temperature, i.e when the leaving exhaust air falls below 35 ℉ (2 ℃). Supply air preheat using an electric resistance pre-heat coil has been proposed for VHE-DOAS systems. TSPR tool would need to add the capability to model this control.

4.1.2 Inputs Required for TSPR Tool

A new input would need to be added to the tool to ask a user if the system includes electric resistance preheat coils for ERV defrost control. An additional input for frost threshold temperature can be added or this value can be fixed to a default of 35 F.

4.2 DOAS SAT Temperature Control/ ERV Bypass Control

4.2.1 Modeling Approach

DOAS SAT control has been analyzed using the following approaches

4.2.1.1 Fixed, 53 F: Fixed SAT for the DOAS system, at 53 F setpoint. ERV is bypassed to meet this setpoint.

4.2.1.2 Fixed 60F- Fixed SAT for the DOAS system, at 60 F setpoint

4.2.1.3 Reset based on Outside Air Temperature

EnergyPlus natively supports HRV/ERV bypass control when using an economizer. The VHE DOAS control strategy calls for a bypass based on outdoor air temperature which cannot be done natively in EnergyPlus. To achieve the proposed sequence of operation, a simple EMS program has been used which uses an outdoor air drybulb sensor to render the ERV unavailable during the partial economizer or pre-economizer mode (between 53 ℉ and 75 ℉). For all other OAT conditions, the program linearly ramps the setpoint of the DOAS system based on the OAT with the minimum and maximum limits set to 53F and 60F respectively. In EnergyPlus, the EMS program sets the value of a 'Schedule:Constant' which is used in conjunction with a 'SetpointManager:Scheduled' to control the temperature setpoint of the DOAS system supply outlet node.

4.2.1.4 Reset based on Return Air Temperature[7]

Similar to the reset based on outdoor air temperature, EMS is used to set the SAT of the DOAS system and render the ERV available or unavailable based on the setpoint. A program similar to the one described in Section 4.2.1.3 is used to set the DOAS system SAT based on the return air temperature (RAT) of the system.

4.2.2 Inputs Required for TSPR Tool

TSPR tool has an input for a user to specify whether the DOAS system includes ‘ERV Supply Temperature Control’. If set to ‘True’ the tool then asks a user to specify the DOAS SAT setpoint.

This capability would need to be modified based on the DOAS SAT control strategy selected for VHE DOAS systems. For example, if reset based on RAT is selected for VHE DOAS systems, a new input for ‘DOAS Supply Air Temperature Control Strategy’ will be added with options for ‘Fixed’ and ‘Reset based on Return Air Temperature’.

When specified as ‘Fixed’ the tool will prompt the user to specify the SAT setpoint and when ‘Reset based on RAT’ the tool will prompt the user to specify the minimum and maximum setpoints (or use defaults of 53F and 60F).

4.3 DOAS Fan and OSA Ventilation Control

4.3.1 Modeling Approach

The sequence of operation includes three fan modes: normal occupied mode, pre-economizer mode, and partial economizer mode.

- In the normal occupied mode, the DCV/OSA ventilation rate is provided by the system,
- the pre-economizer mode allows for economizer operation between 70 °F and 75 °F OAT and limits the fan speed/flow to 50%
- The partial economizer mode is similar but occurs below 70 °F and allows 100% speed/flow.

EMS programs have been used to control the different economizer/OSA ventilation modes.

4.3.1.1 EMS Program 1

This program retrieves the predicated zone total sensible cooling load for each timestep.

4.3.1.2 EMS Program 2

Another program calculates the airflow needed to meet the zone total predicated sensible cooling load based on supply air temperature, the zone mean air temperature and the specific heat of the air at the particular timestep conditions (using the SAT and humidity ratio)[8].

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[7] The modeled reset based on return air temperature will reflect the balance of heating or cooling requirements in the building where the zone setpoints can be consistent. This modeling strategy is intended to match reset from zone heating or cooling mode. RAT reset is likely to fail in the field with inconsistent zone setpoints.

[8] Currently, the EMS program actually uses the outdoor air temperature (OAT) and not the supply air temperature (SAT). This was done as initial simplification to make sure that the program worked but it should probably be the SAT and not the OAT. PNNL will investigate the modeling approach and impact of this change in the next phase of work.

4.3.1.3 EMS Program 3

A final program models the economizer operation based on the rules outlined in the sequence of operation and the output of the EMS Program 2. This program adjusts VAV boxes minimum damper position for each zone served by the DOAS system. Additional OA is provided only to zones that request cooling during pre and partial economizer operation. The OA flow calculated by the EMS Program 2 is compared to the design OA flow to determine the zone minimum damper position. The OA flow is capped to the zone terminal maximum air flow (design OA flow) and to the minimum air flow which is the average building DCV air flow or minimum required air flow. If the air flow needed to meet the load results in a minimum damper position of 1, it is assumed that the remaining of the cooling load will be met by the zone HVAC equipment. These three EMS programs determine the flow required at each zone to meet the zone cooling load and are used to set the DOAS fan air flow rate as well as the minimum damper position for the zone terminal. The 'Economizer Boost' mode has been modeled using this approach.

4.3.2 Inputs Required for TSPR Tool

An additional input would be added to ask if the DOAS system includes an 'Economizer Boost Mode'

This could be a checkbox where selecting it would model a VAV fan controlled as described above.

For systems with DOAS systems with 'Economizer Boost', a user would be required to specify the '% of Outside Air During Economizer Boost Mode' and this value would have an input range of 100%-300%, with 200% being the minimum value for a DOAS system to qualify as a VHE DOAS.

4.4 DCV Control

TSPR tool has the capability to model DCV control based on occupancy. This approach would have to be modified to account for CO2 sensor control. Regression equations have been developed to account for outdoor air reduction based on percentage of high-density zones that are controlled by occupancy sensors or CO2 sensors or both.

4.4.1 Inputs Required for TSPR Tool

TSPR tool already contains an input for a user to specify if a HVAC system includes DCV control. When specified as 'Yes' by the user, the tool asks the user for '% area with DCV control'.

This input would need to be modified and an additional input would be added to ask a user-

- '% Area with DCV control through occupancy sensors'
- '% Area with DCV control through CO2 sensors'

4.5 VHE DOAS for VAV Reheat, Packaged RTU, or Built-up AHU Systems

DOAS systems coupled with VAV reheat systems are not currently supported by TSPR tool. Packaged RTU and built-up AHU systems have DOAS modeled using a workaround in EnergyPlus (Energy Management Systems or EMS) and hence cannot be modified to reflect the VHE-DOAS sequence of operations. PNNL already plans to add the capability to model DOAS systems coupled with VAV reheat, packaged RTU and built-up AHU systems in early 2020, after which VHE-DOAS systems can be added for these systems as well.

5 Energy Savings

The table below summarizes preliminary results for TSPR – carbon emissions, TSPR energy cost and HVAC energy use by end use for the systems analyzed. The System details are summarized in Table 3. These results are based on the initial analysis done by PNNL and might change based on discussions with NEEA or RDH.

Table 1: TSPR and HVAC Energy Use Results for Various HVAC Systems Analyzed

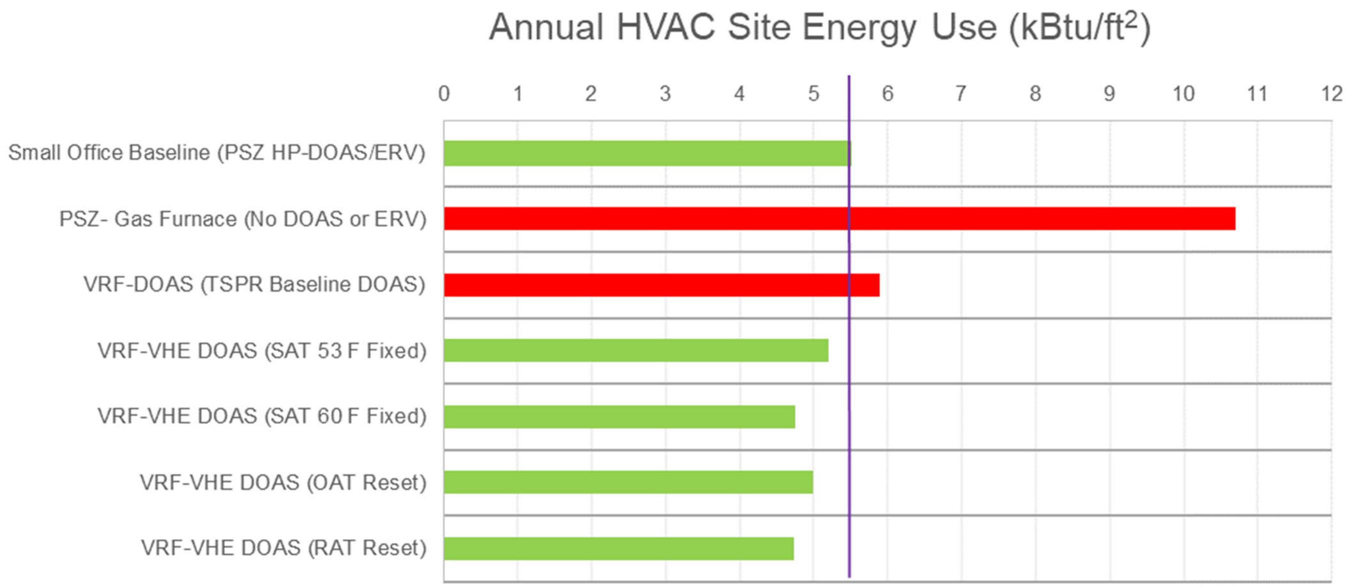
	Small Office Baseline (PSZ HP-DOAS/ERV)	PSZ-Gas Furnace (No DOAS or ERV)	VRF-DOAS (TSPR Baseline DOAS)	VRF-VHE DOAS (SAT 53 F Fixed)	VRF-VHE DOAS (SAT 60 F Fixed)	VRF-VHE DOAS (OAT Reset)	VRF-VHE DOAS (RAT Reset)
TSPR (Energy Cost 0.08 $/kWh0.76 $/Therm	80.96	49.91	76.69	85.45	95.27	90.56	95.65
TSPR (CO2e- Electric 0.7 lb/kWh, Gas 11.7 lb/Therm)	9.25	5.36	8.77	9.77	10.88	10.35	10.93
Site Energy Use (kBtu/ft2)							
Heating	0.3	2.4	1.0	2.0	1.41	1.7	1.47
Cooling	3.0	2.8	2.1	1.3	1.41	1.4	1.37
Fan	2.2	5.5	2.8	1.9	1.93	1.9	1.89
Total HVAC Site Energy Use	5.5	10.7	5.9	5.2	4.75	5.0	4.73
Whole Building Site Energy Use (kBtu/ft2)	23.7	28.8	24	23.4	22.89	23.1	22.87
Site Energy Cost ($/ft2)							
Total HVAC Site Energy Cost ($/ft2)	0.13	0.21	0.14	0.12	0.11	0.12	0.11
Whole Building Site Energy Cost ($/ft2)	0.56	0.64	0.57	0.55	0.54	0.55	0.54

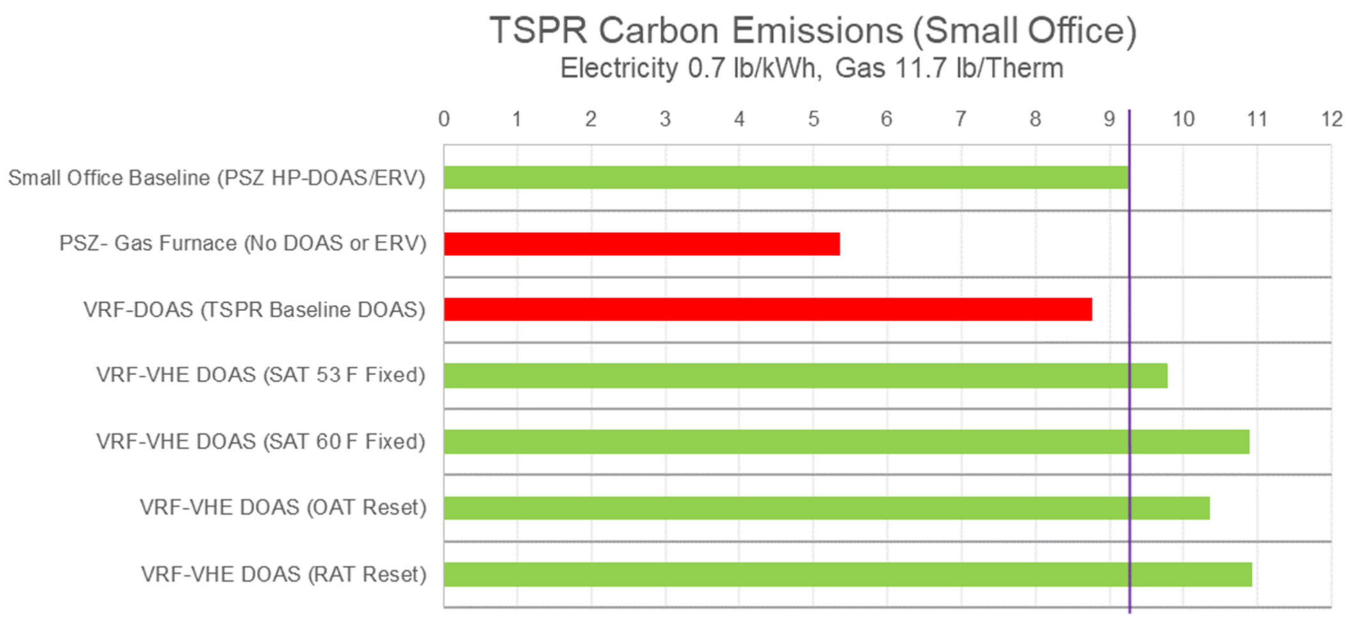
Results for VRF-VHE DOAS with RAT reset compared to PSZ-gas furnace

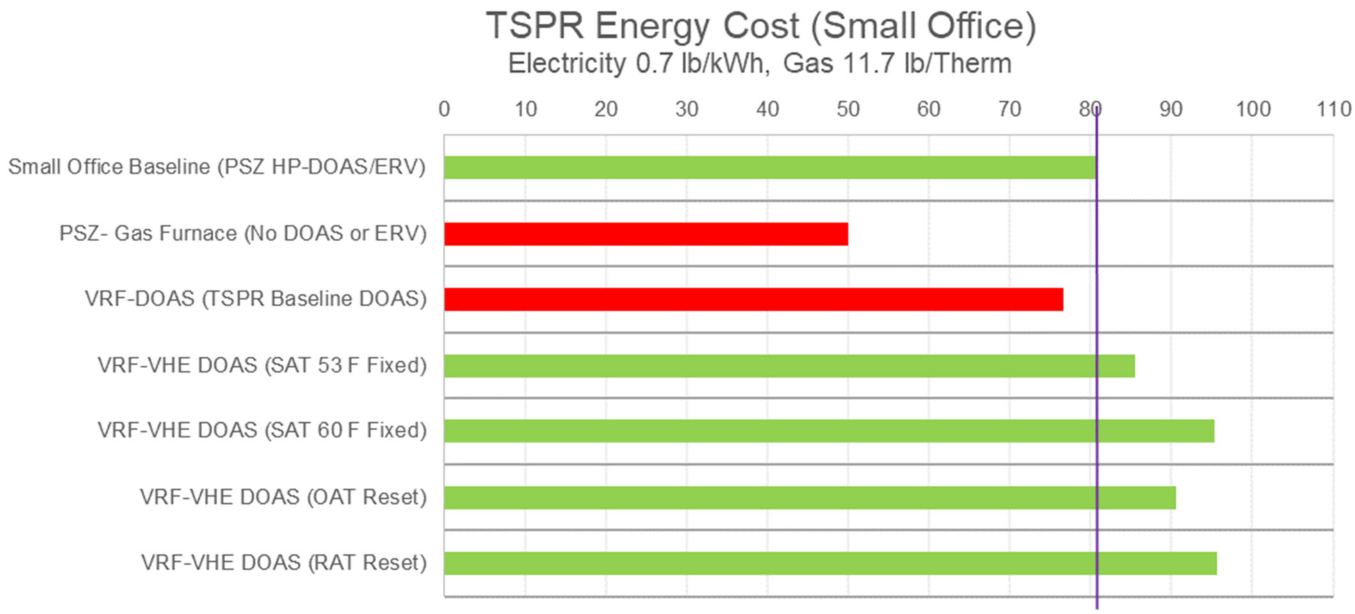
- VRF-VHE DOAS (RAT Reset) compared to a packaged gas furnace results in 56% HVAC only site energy savings and 47% HVAC only energy cost savings.
- VRF-VHE DOAS (RAT Reset) compared to a packaged gas furnace results in 20.6% whole building site energy savings and 15.6% whole building energy cost savings.

Results for VRF-VHE DOAS with RAT reset compared to standard VRF DOAS-ERV

- VRF-VHE DOAS (RAT Reset) compared to a standard VRF DOAS-ERV results in 20% HVAC only site energy savings and 21% HVAC only energy cost savings.
- VRF-VHE DOAS (RAT Reset) compared to a standard VRF DOAS-ERV results in 4.7% whole building site energy savings and 5.3% whole building energy cost savings.


Annual HVAC Site Energy Use (kBtu/ft2)
0
1
2
3
4
5
6
7
8
9
10
11
12
Small Office Baseline (PSZ HP-DOAS/ERV)
PSZ- Gas Furnace (No DOAS or ERV)
VRF-DOAS (TSPR Baseline DOAS)
VRF-VHE DOAS (SAT 53 F Fixed)
VRF-VHE DOAS (SAT 60 F Fixed)
VRF-VHE DOAS (OAT Reset)
VRF-VHE DOAS (RAT Reset)


TSPR Carbon Emissions (Small Office)
Electricity 0.7 lb/kWh, Gas 11.7 lb/Therm
0
1
2
3
4
5
6
7
8
9
10
11
12
Small Office Baseline (PSZ HP-DOAS/ERV)
PSZ- Gas Furnace (No DOAS or ERV)
VRF-DOAS (TSPR Baseline DOAS)
VRF-VHE DOAS (SAT 53 F Fixed)
VRF-VHE DOAS (SAT 60 F Fixed)
VRF-VHE DOAS (OAT Reset)
VRF-VHE DOAS (RAT Reset)



6 Characteristics of Prototype Building

Table 2 summarizes the characteristics of the small office prototype modeled through TSPR tool and used for analysis of the VHE-DOAS system. Table 3 summarizes the characteristics of the different HVAC systems analyzed.

Table 2: Small Office Geometry and Envelope Inputs for TSPR Prototype

Building Details			
Location		**Seattle, 98109**	
TMY3 Weather file		**Seattle-BFI**	
Geometry			
	Total floor area	5500 (90.8 ft x 60.5 ft)	
	Number of Floors	1	
	Floor to Floor Height	10	ft
	Floor to Ceiling Height	10	ft
	Window-Wall-Ratio	20% N, E, W. 25% S.	
	Thermal Zoning	Perimeter zone depth: 15 ft. Four perimeter zones, one core zone.	
Roofs	Insulation above Deck	U-0.027	Btu/hr-ft2-F
Walls	Steel Framed	U-0.055	Btu/hr-ft2-F
Floor	slab-on-grade (unheated)	F-0.54	Btu/F-ft-h
Window	Non-Metal Framing	U-0.30	Btu/hr-ft2-F
	SHGC (PF<0.2)- S, E, W	SHGC- 0.38	
	SHGC- N	SHGC- 0.51	
Lighting	Office	0.66	W/sq.ft

Table 3: HVAC System Characteristics of Configurations Analyzed

System Type	Baseline: PSZ Heat Pump + DOAS	PSZ- AC and Gas Furnace	VRF-DOAS-ERV Run 1	VRF-DOAS-ERV Run 2	VRF-DOAS-ERV Run 3	VRF-DOAS-ERV Run 4	VRF-DOAS-ERV Run 5
TSPR			TSPR Baseline DOAS Configuration	VHE DOAS - Fixed SAT (53 F)	VHE DOAS - Fixed SAT (60 F)	VHE DOAS - OAT Reset	VHE DOAS - RAT Reset
Primary Heating and Cooling System							
Heating Source, Efficiency	Heat Pump, 3.81 COP (no fan)	Gas Furnace, 80% Et	VRF Heat Pump, 3.484 COP (no fan)	VRF Heat Pump, 3.484 COP (no fan)	VRF Heat Pump, 3.484 COP (no fan)	VRF Heat Pump, 3.484 COP (no fan)	VRF Heat Pump, 3.484 COP (no fan)
Cooling Source, Efficiency	DX, 3.83 COP (no fan)	DX, 3.83 COP (no fan)	VRF Heat Pump, 3.398 COP (no fan)	VRF Heat Pump, 3.398 COP (no fan)	VRF Heat Pump, 3.398 COP (no fan)	VRF Heat Pump, 3.398 COP (no fan)	VRF Heat Pump, 3.398 COP (no fan)
Fan Control, Fan Power (W/CFM)	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM	On-Off, 0.528 W/CFM
Reheat Source	NA	NA	NA	NA	NA	NA	NA
Minimum Airflow Fraction	NA	NA	NA	NA	NA	NA	NA
Economizer Control	No	No	No	No	No	No	No
ERV (Y/N)	NA	No	No	No	No	No	No
ERV Sensible, Latent Effectiveness	NA	NA	NA	NA	NA	NA	NA
DCV Control	No	No	No	Yes	Yes	Yes	Yes
DCV Control Strategy	NA	NA	NA	CO_2 Sensor, Occupancy	CO_2 Sensor, Occupancy	CO_2 Sensor, Occupancy	CO_2 Sensor, Occupancy
DOAS Details							
Coupled with DOAS System?	Yes	No	Yes	Yes	Yes	Yes	Yes
DOAS Cooling Source, Efficiency	No Cooling	NA	No Cooling	No Cooling	No Cooling	No Cooling	No Cooling
DOAS Heating Source, Efficiency	No Heating	NA	No Heating	No Heating	No Heating	No Heating	No Heating
DOAS Fan Control	VAV	VAV	VAV	VAV	VAV	VAV	VAV

DOAS Ventilation Control	Minimum OA	Minimum OA	Minimum OA	Economizer Boost Mode	Economizer Boost Mode	Economizer Boost Mode	Economizer Boost Mode
% of Outside Air During Economizer Boost Mode	NA	NA	NA	200%	200%	200%	200%
DOAS Fan Power	0.819 W/CFM	NA	0.819 W/CFM	0.819 W/CFM	0.819 W/CFM	0.819 W/CFM	0.819 W/CFM
ERV (Y/N)	Yes	NA	Yes	Yes	Yes	Yes	Yes
ERV Sensible, Latent Effectiveness	0.7, 0.0	NA	0.7, 0.0	0.87, 0	0.7, 0.0	0.7, 0.0	0.7, 0.0
ERV Defrost Control	No	No	No	Preheat Coil	Preheat Coil	Preheat Coil	Preheat Coil
ERV Supply Air Temperature Control	Wild	NA	Wild	Bypass	Bypass	Bypass	Bypass
ERV Economizer Bypass	NA	NA	NA	NA	NA	NA	NA
DOAS SAT Control Strategy	NA	NA	NA	Fixed	Fixed	Outdoor Air Temperature Reset	Return Air Temperature Reset
DOAS SAT Setpoint	NA	NA	NA	53 F	60 F	Refer to Section 4.2.1.3	Refer to Section 4.2.1.4