How DOAS will be a Key Contributor to Building Decarbonization

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ABSTRACT

Dedicated Outdoor Air Systems (DOAS) equipped with energy recovery have been a frequent topic at ACEEE and are continuing to make their way into progressive demand side management programs looking to expand a portfolio of HVAC offerings. With reductions in HVAC energy use of 70% in some climates, DOAS with energy recovery is a key strategy to reducing overall building energy use.

While DOAS has been proven as a reliable solution for significantly reducing energy consumption, it also has potential to significantly decarbonize buildings. Annual carbon emissions reductions of 40% or more have been found when comparing DOAS to existing gas technologies. Furthermore, these reductions can be achieved in small-to-medium size buildings which make up both a significant portion of the U.S. commercial building stock and the packaged rooftop unit market, which is dominated by gas-fired equipment. The wide applicability of a DOAS across various building types and configurations positions it well as a potential solution for both the retrofit and new construction sectors.

Despite past DOAS installation success stories, there are gaps in understanding the decarbonization benefits this technology can provide, especially when employed in different areas of the country. How important are regional emissions rates to moving this technology forward? This paper builds upon previous projects completed in the Northwest using DOAS with energy recovery. It focuses on the benefits this system choice can bring to future building decarbonization efforts, highlighting findings from 16 field installations and associated carbon emissions reductions (exceeding 55% in some areas) when installing DOAS with energy recovery.

Introduction

In states across the country, climate policies are evolving with a focus on buildings to play a significant part of carbon emissions reduction goals. Aggressive climate policies in New York, Vermont, Washington, and California (C2ES 2024) are striving to reduce emissions to 80% or more by 2050, with many setting interim goals of 40% or more below 1990 levels beginning as early as 2030 (a mere 6 years away!). While transforming the power generation and transportation sectors will significantly impact emissions, improving building energy performance will undoubtedly play an integral part in achieving these aggressive goals.

Although renewables and electric vehicles dominate the generation and transportation sectors as proven solutions, the buildings sector does not yet have a silver-bullet HVAC technology that can both significantly reduce emissions and is flexible enough for the myriad of building types and climate zones. Commercial buildings commonly rely on gas-fired boilers to produce hot water or steam, or gas-fired rooftop units (RTUs) to provide warm air as a means for comfort heating. Furthermore, while a lot of attention is being paid to heat pumps as direct-replacement solutions for these types of fossil fuel heating sources, there are still barriers to address before they are realized as viable alternatives in most building types. First, most direct-replacement heat pump designs suggest maintaining the status quo of mixing ventilation and comfort conditioning loads together, thereby lessening the net energy reduction potential of such a switch. Second, converting low-cost boilers and RTUs to electrically-driven heat pumps can often be cost-prohibitive, and old equipment is routinely maintained for decades past its expected useful life, bringing along inefficiencies as well as diminishing value propositions (why should a building owner invest in capital equipment upgrades when a boiler maintenance contract can be much cheaper and a less risky option?). For a building owner to consider switching from cheap gas equipment to more expensive electric heat pumps, the savings and benefits of such a transition need to be compelling. If the building sector is expected to play a significant part in state – and perhaps one day federal – carbon reduction goals, solutions that work both technologically as well as economically will be needed to both reduce energy use and emissions. Based on our experience, high efficiency DOAS can be a major player in this respect, both because of its widespread applicability as well as its significant energy savings potential and cost-effectiveness compared to other alternatives.

However, there are gaps in understanding where commercially available HVAC solutions like DOAS make the most sense, especially when linking energy savings initiatives with carbon reduction goals. While the energy savings potential of DOAS is large across a variety of building types (NEEA 2020), the carbon reduction potential is dependent on the emissions rate of the local grid. In this paper we build upon our understanding of the energy saving potential of DOAS while focusing on proven DOAS solutions and their associated emissions reduction potential. We also highlight which system configurations and geographic locations may best reduce HVAC emissions to help utility programs and policymakers reach their decarbonization goals.

What exactly is high efficiency DOAS?

Despite the naming convention, the term "dedicated outdoor air system" often means different things to different entities. In most cases, DOAS refers to a system dedicated to providing ventilation air, often equipped with heating and cooling coils and/or an energy recovery device. Distribution ductwork can either be fully-decoupled as shown on the left in Figure 1 below or connected to the supply or return of an air handler as shown in the other two configurations.

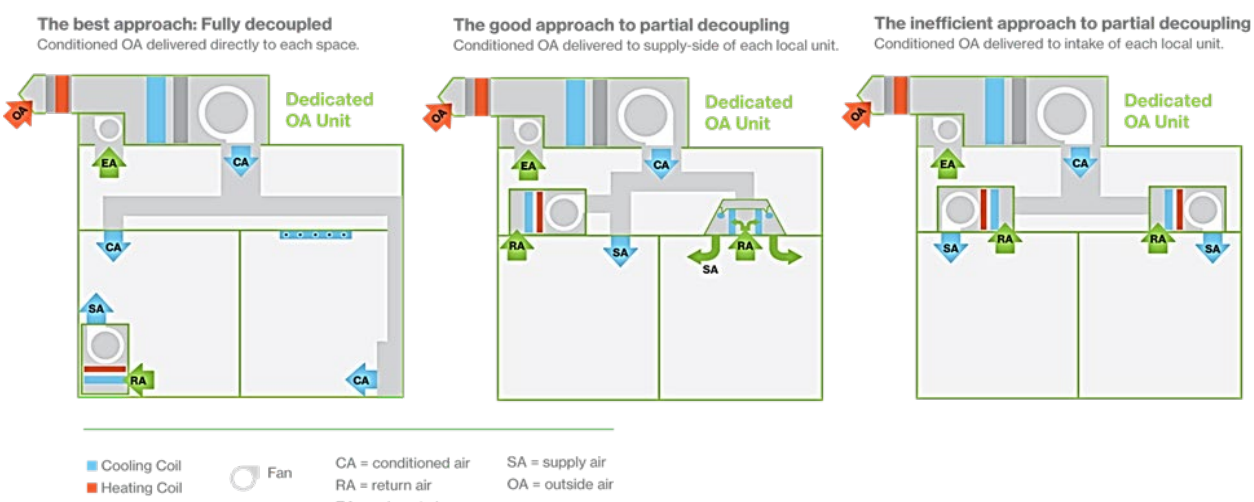

Figure 1. Typical DOAS ventilation configurations. *Source*: NEEA, Keep 'em separated: The many benefits of decoupling, 2024a

For our analysis, we define high efficiency DOAS as one of two system types depending on the purpose and configuration:

1. For Sensible Heat Recovery Only: Uses a heat recovery ventilator (HRV) with a very high Sensible Recovery Effectiveness (SRE) of 82% or greater, and very low fan power of 0.77 W/cfm or less.
2. For Sensible and Latent Heat Recovery: Uses an energy recovery ventilator (ERV) with a Sensible/Latent Recovery of 77%/60% respectively, and very low fan power of 1.0 W/cfm or less.

In both cases the ventilation system is decoupled from a high efficiency heat pump heating and cooling system, commonly a Variable Refrigerant Flow (VRF) system. Key components to both system types are the decoupling of the ventilation air from the space conditioning equipment and the right-sizing of equipment to meet the space demands. An example of this configuration and the key components involved is shown in Figure 2 below.

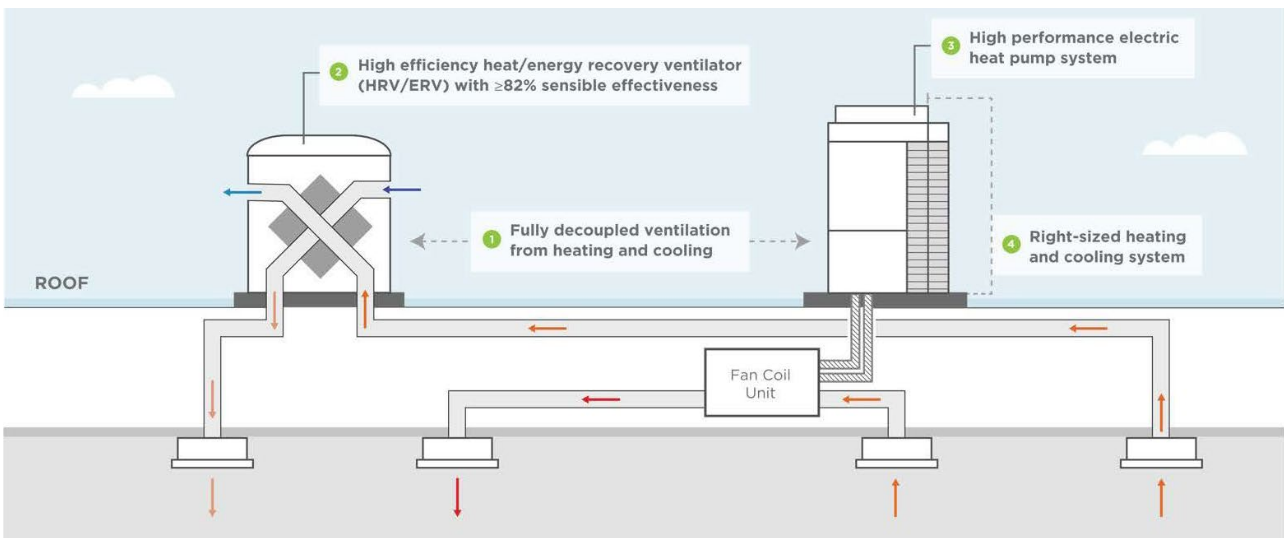

Figure 2. Key Components of High Efficiency DOAS. *Source*: NEEA, Very High Efficiency Dedicated Outdoor Air Systems Design Guide, 2024b

Past success with High Efficiency DOAS

For close to a decade the Northwest Energy Efficiency Alliance (NEEA) has worked to demonstrate the energy savings potential of high efficiency DOAS through a series of demonstration projects. NEEA maintains a regularly updated document outlining minimum system efficiencies, compliant product lists, and construction best practices to ensure projects adhere to optimum design and installation principles (NEEA 2024b) While the individual technologies that make up the system are not necessarily new, constructing a program that requires good design principles paired with highly efficient equipment is a novel approach. Table 1 shows a list of completed and verified demonstration projects in climate zones 4 and 5 and the energy savings realized from them (Pratt, Murphy, and O’Neil 2022).

Table 1. Project pre & post energy use intensity (EUI in kBtu/ft^2) comparison

ID #	Pre-Conversion		Post-Conversion		Reduction			
	Gas Use (kBtu/ft^2-yr)	Elec. Use (kBtu/ft^2-yr)	Gas Use (kBtu/ft^2-yr)	Elec. Use (kBtu/ft^2-yr)	Gas Red. (kBtu/ft^2-yr)	Elec. Red. (kBtu/ft^2-yr)	Building EUI Savings (%)	HVAC EUI Savings (%)
1	32.4	18.9	0	19.1	32.4	-0.1	63%	73%
2	20.0	25.9	2.0	26.1	18.1	-0.2	39%	71%
3	1,202	268.0	1,028	323	174	-55.3	8%	43%
4	0	98.0	0	70.0	0	28.0	29%	45%
5	684.7	189.8	503.7	197.3	181.0	-7.5	20%	73%
6	0	51.3	0	29.7	0	21.6	42%	69%
7	45.3	76.8	0.7	47.4	44.6	29.4	61%	85%
8	0	67.9	0	51.5	0	16.4	24%	52%
9	0	59.3	0	35.7	0	23.6	40%	57%
10	0	52.7	0	34.2	0	18.6	35%	50%
11	0	25.7	0	12.9	0	12.8	50%	58%
12	35.8	31.6	0	24.2	35.8	7.4	63%	79%
13	52.7	9.6	0	13.3	52.7	-3.6	79%	84%
14	54.6	27.7	0	32.9	54.6	-5.1	60%	71%
15	0	62.4	0	28.9	0	33.5	54%	58%
16	76.4	71.6	2.6	47.2	73.8	24.4	66%	70%
Avg*	22.7	48.5	0.4	33.8	22.3	14.8	50%	66%

* Average does not include the two restaurant projects (ID #3 and #5) in the dataset.

Most of the work done on quantifying the energy saving benefits of high efficiency DOAS has been in the Northwest (NEEA 2020) and California (Bulger and Sawford 2023, and Bulger and Weitz 2024). Pilot demonstration projects equipped with detailed data logging and follow-up measurement and verification have been instrumental to establishing the approach to high efficiency DOAS and ensuring that savings persist over time (Yoder, Piazza, and Pratoomratana 2023). As such, high efficiency DOAS is now becoming more widely-accepted in these regions. Its ability to maintain comfort while significantly reducing energy use with readily available technology (over 40% reduction on average) is helping establish the value proposition of this system approach to both designers and building owners. While these represent only sixteen projects in one part of the country, we see several important reasons for optimism surrounding more wide-spread adoption of a system like this.

First, as explained in our 2022 ACEEE paper (Pratt, Murphy, and O'Neil 2022), the results from these demonstrations are extraordinarily consistent. It bears repeating that despite the wide range of HVAC EUIs *before* conversion (as low as 22 kbtu/sqft for a net-zero school and up to 87 kbtu/sqft for an assembly space), the end-result was an extremely consistent post-conversion HVAC EUI of 14.8 kbtu/sqft on average (Pratt, Murphy, and O'Neil 2022). That's an encouraging value proposition for utility programs and policy makers. Furthermore, with many states beginning to implement building performance standards for both new and existing facilities, having a sense of where HVAC EUI is likely to end up is a valuable piece of information for a building owner, particularly when they may be considering various mitigation measures to demonstrate compliance.

Second, these systems have the flexibility to be adaptable to multiple building types and configurations. While high efficiency DOAS has been featured prominently in offices of varying sizes, they have also been successful in a variety of other building types including schools, daycare centers, assembly spaces, and restaurants. Similar to other efficient HVAC solutions that could potentially assist with decarbonization efforts, such as high efficiency Variable Air-Volume systems (VAV) for multi-tenant office buildings, high efficiency DOAS is extremely scalable and can be employed in a wide variety of use cases. Additionally, many high efficiency DOAS solutions rely on simpler controls, leading to fewer issues for building maintenance staff over time when compared to larger HVAC systems.

Carbon emissions of the built environment

One of our goals for this analysis was to understand whether high efficiency DOAS could be used across the country to assist states with meeting their carbon emission reduction goals. Furthermore, while high efficiency DOAS showed significant energy reduction for several building types in the Northwest, we also wanted to understand the potential for its ability to reduce carbon emissions when applied to the larger building stock. To get a sense of the existing emissions from buildings throughout the U.S. we looked at energy intensity data across a wide range of building types and climates. We first utilized Lawrence Berkely National Labs Building Performance Database (BPD) to understand the makeup of buildings across the US and their energy use characteristics[1] (LBNL 2024). We then sorted the data by commercial building types that commonly have a mix of fuels (i.e., excluding electric-only types such as data centers and parking garages). Although decarbonization efforts may also focus on electric efficiency improvements, particularly for buildings that rely on electric resistance as the heating source, we chose to focus on the benefit from reducing gas-fired equipment used for heating purposes.

The BPD provides data on the split in heating fuels by building type and size, and out of the 307,000 commercial buildings that utilize a mix of HVAC fuels in the database, 65% utilize gas as the main heating fuel. When the building size is narrowed down to 50,000 ft^2 buildings only, (to better represent the potential for retrofitting to high-efficiency DOAS) the gas fuel split of those remaining buildings rises to 69%. These smaller buildings not only utilize gas-fired equipment as the heating source by an even wider margin, but they also comprise over 45% of the existing U.S. building stock floor area. That represents a large portion of the building stock that could be eligible for replacement with a high efficiency DOAS solution.

Modeling Prototypes

For purposes of evaluating carbon reduction benefits of high efficiency DOAS in different areas of the country we focused on several common configurations used in many of the Northwest demonstration projects. These include a high efficiency (HE) case and a standard efficiency (SE) case configuration, (shown in Table 2 below) based on past experiences of what

[1] The BPD combines, cleanses and anonymizes data collected by federal, state and local governments, utilities, energy efficiency programs, building owners and private companies.

is typically installed, as well as what equipment efficiency level is practical for a high efficiency DOAS application. We focused on sensible heat recovery in colder/drier climates and total energy recovery typically utilized in hotter and more humid climates where dehumidification is a concern. As such, the most efficient case in colder climates does not match the equipment selected for more humid climates, however both were chosen to be reflective of geographic market choices and likely equipment selections to maintain occupant comfort. The primary differences between system types and associated climate zones used in the modeling are detailed in Table 2 below.

Table 2. DOAS configuration and setpoints by climates analyzed

Efficiency Criteria	High Efficiency (HE) DOAS with HRV	Standard Efficiency (SE) DOAS with HRV	Standard Efficiency (SE) DX-DOAS with ERV	High Efficiency (HE) DX-DOAS with ERV
Climate Zone	Colder/Drier Climates (CZ 4C, 5B, 6A)		Hotter/More Humid Climates (CZ 2B, 3A, 5A)	
Dehumidification Control	No		Yes	
Variable Refrigerant Flow (VRF) Heat Pump Efficiency	Decoupled fans (0.4 W/cfm) 11 EER (18 IEER), 3.25 COP_{47})			
Sensible Efficiency (%)	82%	77%	60%	77%
Latent Efficiency (%)	N/A	N/A	50%	60%
DOAS Fan System	0.77 W/cfm	1.00 W/cfm	1.10 W/cfm	1.00 W/cfm
DX Cooling SAT (°F)	60°F	51°F	60°F	51°F
DX Heating SAT (°F)	60°F	60°F	60°F	60°F
Defrost Outside Air (°F)	34°F	1°F	-10°F	1°F
HRV/ERV Defrost Control	Electric Coil on O/A	Electric Coil on O/A	Electric Coil on O/A	Electric Coil on O/A
Ventilation Sizing (ASHRAE 62.1)	100%	100%	100%	100%
Supply Air Temp (SAT) Setpoint	60°F	60°F at 51°F / 70°F at 45°F	60°F	60°F at 51°F / 70°F at 45°F
Supply Air Temp (SAT) Control	Fixed	O/A Reset	51°F when cooling to remove moisture	O/A Reset
DOAS Cooling Coil	N/A	8.4 EER (approx. for 5.2 ISMRE)	8.4 EER (approx. for 5.2 ISMRE)	8.4 EER (approx. for 5.2 ISMRE)
DOAS Heating Coil	N/A	3.25 COP47 (approx. for 3.3 ISCOP)	3.25 COP47 (approx. for 3.3 ISCOP)	3.25 COP47 (approx. for 3.3 ISCOP)

To simplify the analysis, all systems were evaluated with a single building prototype, utilizing a small office building, sourced from the Department of Energy building prototypes (DOE 2023). We built an annual energy simulation using EnergyPlus 22.1 and conducted a parametric analysis using a batch processing tool called ModelKit. Past analysis found similar levels of relative energy savings in other building prototypes with different occupancy, hours of use, and ventilation requirements, when comparing energy use savings of DOAS with rooftop units (Bulger, N. 2019). Although some savings fluctuations are expected among the varying building types and uses, for the purposes of establishing a range of percent HVAC EUI reduction for this analysis, using a general 5,500 ft^2 building prototype was acceptable to represent the carbon reduction benefit of high efficiency DOAS.

Modeled results for buildings in climate zones 4C and 5B tracked closely with demonstration project savings estimates, indicating they were well-calibrated to real-world energy use. From there we expanded the building prototypes to other representative climate zones across the country. Figure 2 below shows the results of the parametric analysis, quantifying the HVAC EUI reduction from a 2-speed gas-fired rooftop unit in each case (with a 0.87 W/CFM fan variable down to 75% of peak flow). Bars highlighted in orange indicate the representative system selected for each climate zone based on likeliness of installation. It is important to note that in the humid climate zones (2B & 3A), the use of an HRV often indicates higher savings potential than an ERV. However, because it does not control indoor humidity it is therefore less likely to be used in practice. As such, a DX-DOAS with an ERV and active dehumidification was selected as the likely system type in those more humid climate zones.

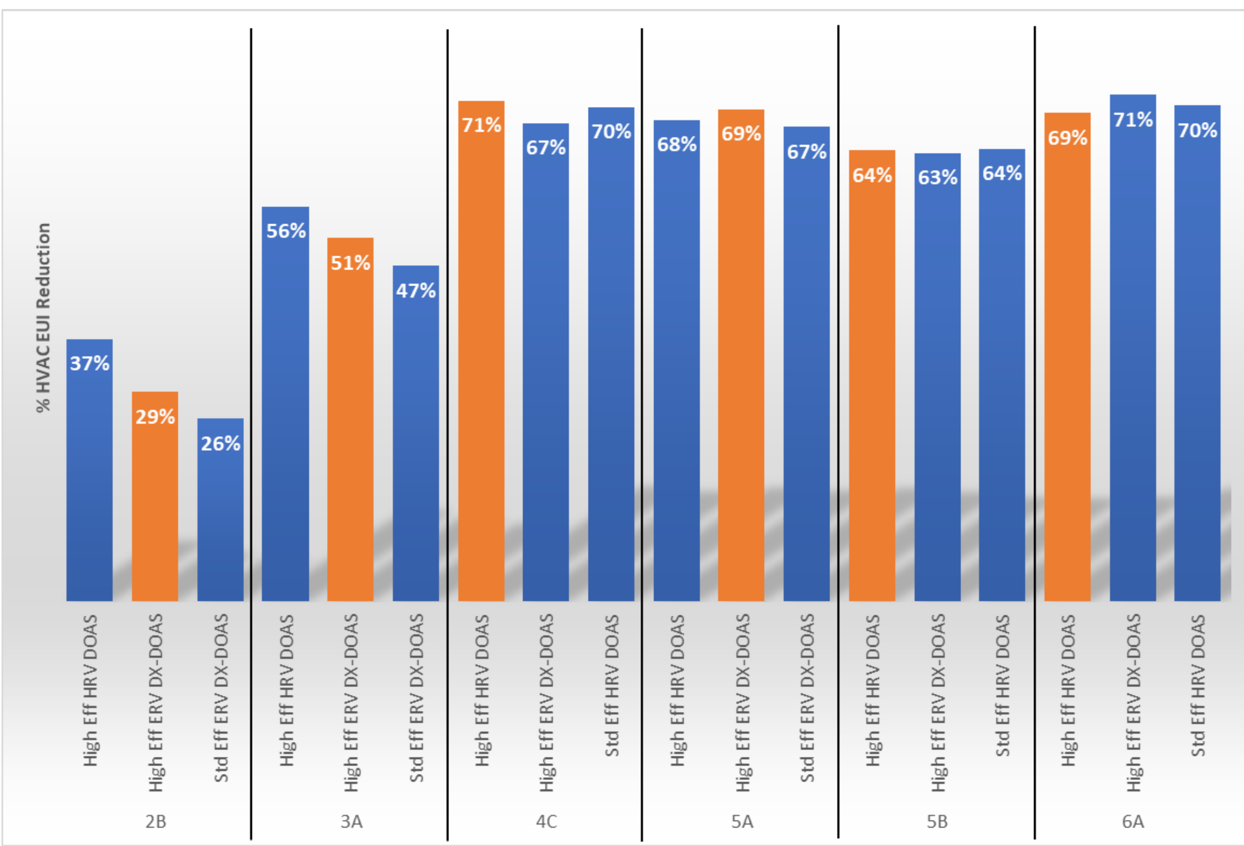

Figure 2. HVAC EUI reduction based on DOAS system architecture and climate zone

Results from this analysis corroborate the findings from demonstration projects in the Northwest. They indicate that a high efficiency DOAS approach (i.e., an efficient heat pump paired with a heat recovery DOAS unit) has the ability to significantly reduce HVAC EUI when converting from a gas-fired system. The results indicate that on average, DOAS equipped with HRVs can reduce HVAC EUI by more than 61%, (ranging from 71% in cooler climates to 37% in warmer ones) and those equipped with ERVs by more than 59% (ranging from 71% in cooler climates to 29% in warmer ones). Though all climate zones show savings, they are greatest in climate zones where heating makes up a significant portion of total load, as the heat recovery benefits during the winter months are key contributors to energy savings.

While these results shed more light on the net energy savings potential by converting from gas to electric in diverse geographic areas of the country, they do not yet answer whether this switch is beneficial from a decarbonization perspective.

When can DOAS be used to curb carbon emissions

To better understand the potential for high efficiency DOAS to contribute to carbon emissions reductions throughout the U.S., we overlaid results from the energy savings analysis with climate zone regions according to the Emissions & Generation Resource Integrated Database (eGRID) subregions, shown in Figure 3 below (EPA 2022). Doing so provided a mapping of the HVAC EUI reduction potential of each climate zone to the associated carbon emissions rates based on the unique generation mix of each subregion.

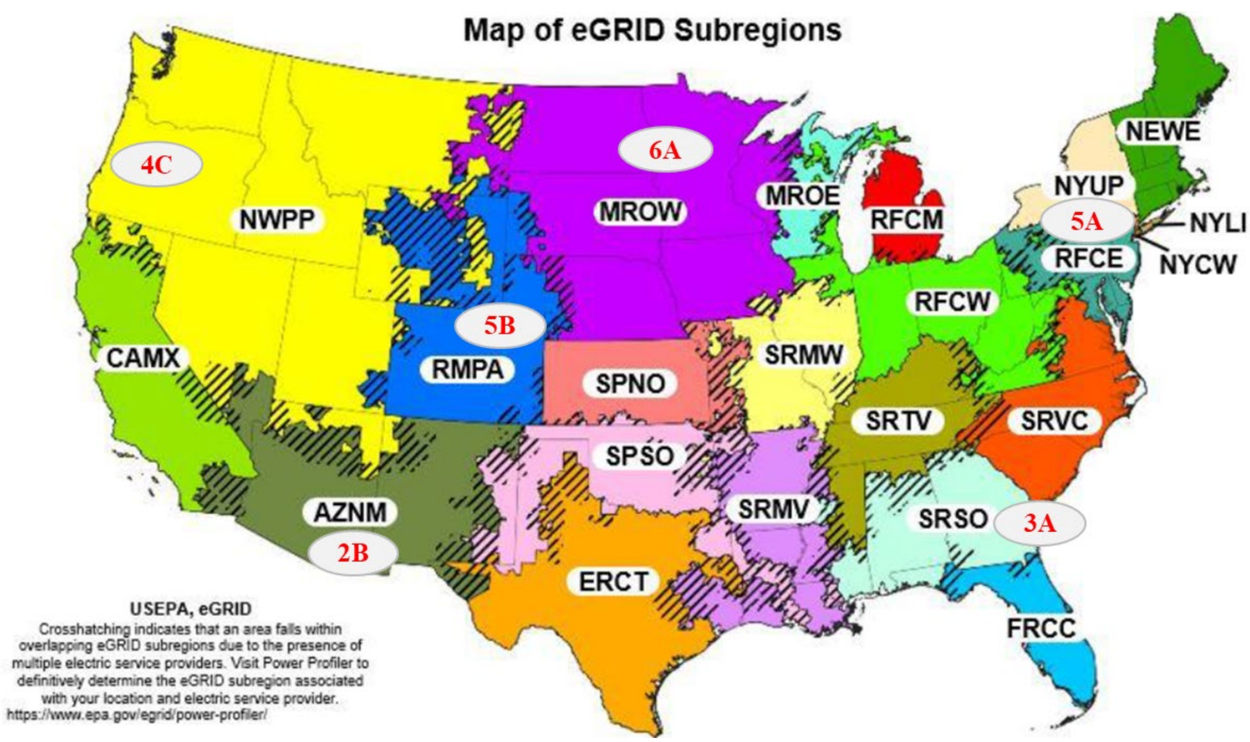

Figure 3. Overlay of climate zones modeled with eGRID subregions. *Source*: EPA 2022.

Since our analyzed opportunity was an all-electric high efficiency DOAS replacing an existing gas fuel source, we relied on the Carbon Dioxide Equivalent (CO_2e) or the marginal electric emission rate instead of the total output emission rate. This is due to efficiency upgrades being more likely to displace marginal emissions rather than baseload emissions. In Table 3 below we list the modeled climate zones along with their associated HVAC EUI reduction based on the system type selected in Figure 2 and eGRID's corresponding subregion marginal CO_2e rate given in pounds per Megawatt-hour (lbs/MWh).

Table 3. Modeled climate zones and representative marginal CO_2e generation emissions

Climate Zones Modeled	Modeled HVAC EUI Reduction	eGRID Subregion Represented	Marginal CO_2e lbs/MWh	% Cleaner than US Average*
2B	29%	AZNM	1209.5	14%
3A	51%	SRSO	1361.1	4%
4C	71%	NWPP	1524.7	-8%
5A	69%	NYCW	973.0	31%
5B	64%	RMPP	1685.1	-19%
6A	69%	MROW	1807.0	-28%

* The eGRID average marginal emissions rate is calculated as 1,412.5 lbs/MWh

The results shown in Table 3 indicate that although high efficiency DOAS has the potential to significantly save energy across all climate zones, the vastly different emissions rates of eGRID subregions will result in distinctive carbon reduction benefits. Therefore, to get a better idea of whether the EUI reduction associated with high efficiency DOAS will be beneficial when switching from gas to electric we need to compare the net benefit of the increased electric load to the gas load reduction. Using a range of marginal electric emission rates and a natural gas emission rate of 116.65 lbs/CO_2e per million BTU (MMBtu) we can then determine the benefit breakeven point of each eGRID subregion.

As demonstrated in Figure 4 below, a gas conversion project can result in a wide range of carbon reduction percentages[2] given the percent HVAC EUI reduction and marginal emissions factor for the local eGRID subregion. For the high-efficiency DOAS projects in climate zone 4C for example, this corresponds to an average HVAC EUI reduction of 71% and the Northwest Power Pool (NWPP) marginal grid emissions rate of 1,524.7 lbs/MWh. The intersection of these values indicates that there is approximately an 47% net carbon reduction benefit when switching the HVAC system from gas to electric. As expected, while a similar HVAC EUI reduction was found in climate zone 6A (69%), based on the associated Eastern Power Grid – West eGRID subregion (MROW) and a higher marginal emissions rate of 1,807 lbs/MWh, switching from gas to electric is expected to yield a slightly less significant 44% benefit.

[2] The carbon reduction percentages in Figure 4 are calculated assuming the average gas/electric ratio of the gas-heated pre-conversion demonstration projects and full electrification post conversion (i.e. no gas). The different EUI reduction percentages represent different levels of energy reduction and characterize a reasonable range of expected results based on the findings from both demonstration projects and calibrated modeling.

Electric Emissions Factor (lbs/MWh)	HVAC EUI Reduction (kBtu/ft^2/year)										
	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%
2,000	62%	52%	43%	33%	23%	14%	4%	-5%	-15%	-24%	-34%
1,900	62%	53%	43%	34%	24%	15%	6%	-4%	-13%	-23%	-32%
1,800	63%	53%	(6A) 44%	35%	25%	16%	7%	-3%	-12%	-21%	-30%
1,700	63%	54%	45%	(5B) 36%	27%	17%	8%	-1%	-10%	-19%	-29%
1,600	64%	55%	46%	37%	28%	19%	10%	1%	-8%	-17%	-26%
1,500	65%	56%	(4C) 47%	38%	29%	20%	11%	2%	-6%	-15%	-24%
1,400	65%	57%	48%	39%	30%	22%	(3A) 13%	4%	-4%	-13%	-22%
1,300	66%	58%	49%	41%	32%	24%	15%	7%	-2%	-10%	-19%
1,200	67%	59%	50%	42%	34%	26%	17%	9%	1%	-8%	(2B) -16%
1,100	68%	60%	52%	44%	36%	28%	20%	12%	4%	-4%	-12%
1,000	69%	61%	53% (5A)	46%	38%	30%	22%	15%	7%	-1%	-9%
900	70%	63%	(4C') 55%	48%	40%	33%	26%	18%	11%	3%	-4%
800	72%	65%	58%	50%	43%	36%	29%	22%	15%	8%	1%
700	73%	67%	60%	53%	47%	40%	33%	27%	20%	13%	7%
600	75%	69%	63%	57%	50%	44%	38%	32%	26%	20%	13%
500	78%	72%	66%	61%	55%	49%	44%	38%	33%	27%	21%

Figure 4. CO_2e emissions reduction as a function of marginal emissions rate and HVAC EUI reductions

This matrix of EUI reduction and carbon emissions factors shown in Figure 4 provides utilities and policymakers with a point of reference for when using high efficiency DOAS to transition from gas to electric heating makes the most sense. Regardless of the HVAC EUI reduction however, it is expected that high efficiency DOAS fares worse in subregions with higher carbon producing electric grids than those with cleaner grids. Understandably, subregions that have cleaner electric grids, or expect to increase their mix of renewable resources (or have purchase agreements from cleaner sources) will show more benefit when switching from gas to electric as the generation mix becomes cleaner and emissions in the electric sector begin to drop.

Drilling down into marginal carbon emissions

The emissions rates shown in Table 3 above are current (2022) marginal rates and follow the logic that converting from gas to electric in a region where electric emissions are high may not be beneficial on a carbon basis. Even with technologies like high efficiency DOAS which can save a substantial amount of energy across a wide variety of climate zones, the universal net benefit is less clear from a carbon perspective. Even so, for states looking to advance energy policies in the future, transitioning from gas to electric over the long term can still be beneficial.

If we look at areas of New England that have marginal emissions rates closer to 900 lbs/MWh, we see that it becomes beneficial to transition from gas to electric heating even when the HVAC EUI reduction is as low as 35% (easily achievable by all high efficiency DOAS demonstration projects in that climate zone currently). As another example, we can see what the benefit would be assuming the same high efficiency DOAS were installed in climate zone 4C but on a cleaner electric grid (more aligned with state carbon reduction policies). In this example of an electric grid becoming cleaner, the 47% benefit in climate zone 4C realized by switching from gas to electric would increase to 55% as shown by the 4C' bubble in Figure 3 above.

Though grid emission rate reductions may be farther off for some states, others have already enacted policies aimed at curbing emissions in the near term. In Washington state for example, the 2021 Washington State Clean Energy Transformation Act (CETA) assigned a long run electric marginal emissions rate of 437 lbs/MWh (CETA 2019) as a target for future nonspecified electric generation emissions. The 2021 Washington State Energy code also aligned with this rate for new building design when using the performance path and demonstrates the benefits in a future when the electric grid is cleaner. Using an equivalent emissions rate reduction, all high efficiency DOAS installations across the country would benefit on both an energy and carbon reduction perspective when transitioning from gas to electric.

Sensitivity analysis in the southeast region

While we previously relied on a single eGRID subregion to represent a unique climate zone, it's important to recognize that most climate zones include several electric grids, often with wide ranging marginal emissions rates. Additionally, state policies within a subregion are continuing to drive down emissions rates and that has an impact on the grids in the surrounding areas. While our analysis may indicate that converting from a gas RTU based system to high efficiency DOAS would result in an increase in carbon emissions in some regions, they likely provide a net carbon reduction over the life of the system (which is often 20 years or longer).

Climate zone 3A for example includes six different electric grids with current marginal emissions factors ranging from 1,199 to 1,681 lbs/MWh (eGRID 2022). In the SEC South (SRSO) subregion, currently at 1,361 lbs/MWh, gas to electric conversion is well above the net benefit break-even point with a modeled 51% EUI reduction and 13% net carbon reduction in year 1 using high efficiency DX-DOAS as shown in Figure 5. A slightly less efficient system conversion (i.e., standard efficiency DX-DOAS shown to save 47% HVAC EUI) could result in very little carbon emissions reduction if a building switched from gas to electric in a subregion with greater than 1,700 lbs/MWh. For example, in eGRID's SERC Tennessee Valley (SRTV) subregion (also in climate zone 3A) the marginal emissions rate is currently at 1,681 lbs/MWh, and a 47% EUI reduction is right on the break-even line for a reduction in net carbon emissions. For both grids, converting from a gas to electric HVAC system would result in emissions reduction if HVAC energy savings are at least 45%. This makes it vital for HVAC gas conversion projects in areas with high electric emissions factors to achieve high energy savings.

While the average electric grid across the U.S. remains above 1,400 lbs/MWh, (the median is closer to 1,500lbs/MWh) policies impacting these subregions do show electric grid emission rates falling lower than 700 lbs/MWh (NREL 2023) within the next decade. At that point, a high efficiency DOAS system conversion would likely realize a beneficial carbon emissions reduction in all cases, regardless of the climate zone. The Virginia/Carolina (SRVC) subregion 2034 emissions rate target is around 200 lbs/MWh, and the SEC South (SRSO) subregion target is around 269 lbs/MWh. By that time, replacing gas with even a standard efficiency DOAS would result in a significant net carbon emission reduction. To illustrate this shift in this climate zone, Figure 5 shows the bounds of a 45% to 55% HVAC EUI reduction (ranges close to Standard Efficiency and High-efficiency DX-DOAS with an ERV in climate zone 3A) between 500 to 1,681 lbs/MWh emissions rates, demonstrating how cleaner grid policies will benefit a range of HVAC system conversions over time even if they are near the carbon break-even point today.

Electric Emissions Factor (lbs/MWh)	HVAC EUI Reduction (kBtu/ft²/year)										
	80%	75%	70%	65%	60%	55%	50%	45%	40%	35%	30%
2,000	62%	52%	43%	33%	23%	[illegible]	4%	[illegible]	-15%	-24%	-34%
1,900	62%	53%	43%	34%	24%	15%	6%	-4%	-13%	-23%	-32%
1,800	63%	53%	44%	35%	[illegible]	16%	7%	-3%	-12%	-21%	-30%
1,700	63%	54%	45%	36%	27%	17%	8%	-1%	-10%	-19%	-29%
1,600	64%	55%	46%	37%	28%	19%	10%	1%	-8%	-17%	-26%
1,500	65%	56%	47%	38%	29%	20%	11%	2%	-6%	-15%	-24%
1,400	65%	57%	48%	39%	30%	22%	13%	4%	-4%	-13%	-22%
1,300	66%	58%	49%	41%	32%	24%	15%	7%	-2%	-10%	-19%
1,200	67%	59%	50%	42%	34%	26%	17%	9%	1%	-8%	-16%
1,100	68%	60%	52%	44%	36%	28%	20%	12%	4%	-4%	-12%
1,000	69%	61%	53%	46%	38%	30%	22%	15%	7%	-1%	-9%
900	70%	63%	55%	48%	40%	33%	26%	18%	11%	3%	-4%
800	72%	65%	58%	50%	43%	36%	29%	22%	15%	8%	1%
700	73%	67%	60%	53%	47%	40%	33%	27%	20%	13%	7%
600	75%	69%	63%	57%	50%	44%	38%	32%	26%	20%	13%
500	78%	72%	66%	61%	[illegible]	49%	44%	38%	33%	27%	21%

HE DOAS; SE DOAS; SRTV 2024; SRVC 2034; 3A

Figure 5. Climate zone 3A regional emissions rate sensitivity

Energy codes and state policy impacts

New Construction codes in many states are becoming more stringent with several jurisdictions pushing decarbonization efforts by restricting new natural gas installs to only certain situations with limited exception criteria. These efforts will continue to push designers to look for less conventional HVAC solutions in building types that historically use simple (and often cheaper) gas heating solutions to comply with energy codes.

Efforts to incorporate DOAS as a compliance pathway for building energy codes is also gaining traction. In Washington state for example, the newly released 2021 Energy Code requires designers to pick from a list of design options to meet a minimum number of credits that are directly tied to carbon emissions. A designer that chooses high efficiency DOAS in compliance with the code provisions can receive over half of the required energy credits for a new construction building, and all required credits for a building addition. This is due to the carbon reduction benefit from this system type and its wide applicability to multiple building types. Similar energy credits for high efficiency DOAS have now appeared in both the 2021 International Energy Conservation Code (IECC) the 2022 version of ASHRAE-90.1, further strengthening the argument that these systems have the capability to save substantial amounts of energy and associated carbon.

Policies such as building performance standards that reward owners with early compliance and penalize those that do not comply by the deadline, are becoming more prevalent in states with aggressive climate policies. These will be a driver of both efficiency and decarbonization efforts, especially where viable technology such as high efficiency DOAS conversions exist to fill the compliance needs.

Energy cost comparison

As demonstrated through numerous demonstration projects and model analyses, high efficiency DOAS has significant potential to save energy. In many areas of the country there is also a net carbon benefit to switch, if not today than in the near future as electric grids continue their push towards becoming cleaner. While those two benefits could justify switching to a high efficiency DOAS, there is a third benefit that is often important to decision makers. As shown below in Table 4, the cost savings realized from the substantial energy savings associated with high efficiency DOAS can also be significant. The subset of projects shown below are for sites where a gas HVAC system was converted to electric through the use of high efficiency DOAS. Even when electricity consumption increased due to switching from gas, the net cost reduction can be close to $0.75/ft^2. In large part this is due to the efficient heat pump heating systems replacing older gas rooftop units and highly efficient heat recovery that eliminates most (if not all) of the pre-heating energy required during the colder months of the year. Even for buildings that use high efficiency DOAS to improve their efficiency from an electric heating source, the net savings is close to $0.62/ft^2 making high efficiency DOAS a significant cost saving option for different building types and heating fuels.

Table 4. Normalized energy cost savings from conversion to high efficiency DOAS ($/ft^2)

ID #	Pre-Conversion		Post-Conversion		Reduction		
	Gas, $/ft^2	Electric, $/ft^2	Gas, $/ft^2	Electric, $/ft^2	Gas Red, $/ft^2	Electric Red, $/ft^2	Net Red, $/ft^2
1	$0.33	$0.53	$0.00	$0.53	$0.33	$0.00	$0.32
2	$0.20	$0.73	$0.02	$0.73	$0.18	$0.00	$0.18
7	$0.46	$2.15	$0.01	$1.33	$0.45	$0.82	$1.27
12	$0.36	$0.89	$0.00	$0.68	$0.36	$0.21	$0.57
13	$0.53	$0.27	$0.00	$0.37	$0.53	-$0.10	$0.43
14	$0.55	$0.78	$0.00	$0.92	$0.55	-$0.14	$0.41
15	$0.00	$1.75	$0.00	$0.81	$0.00	$0.94	$0.94
16	$0.82	$3.82	$0.03	$2.52	$0.80	$1.30	$2.10
Avg* Gas	$0.47	$1.31	$0.01	$1.01	$0.46	$0.30	$0.75
Avg** Elec.	$0.00	$1.67	$0.00	$1.05	$0.00	$0.62	$0.62

* Average does not include the two restaurant projects (ID #3 and #5) in the dataset.

** Electric projects not shown in Table 4.

Conclusions

High Efficiency DOAS has already come a long way towards being accepted as a viable solution to curbing energy waste in commercial buildings. Given the significant savings potential found over the past decade of demonstration projects, high efficiency DOAS has the ability to significantly reduce HVAC energy consumption. Furthermore, in many current state emission rate scenarios, the carbon reduction benefits from this system can also meaningfully assist states with meeting their carbon reduction goals. In most areas of the country, the energy savings and associated carbon emissions make sense to consider switching HVAC systems from gas to electric for a large portion of the commercial building stock. Additionally, since a high efficiency DOAS approach incorporates heat pumps as part of the system, it can benefit from federal and state heat pump legislation aimed at increasing the share of that technology in the market to curb further carbon emissions.

While these benefits are far reaching, it is important to balance the needs of state policies urging decarbonization with promoting technologies that really do result in net carbon reduction. Given that high efficiency DOAS with sensible heat recovery results in over 60% HVAC EUI reduction or more in colder climates, installing this type of system results in a net carbon reduction regardless of the marginal electric emission rates of those service territories. For climates that require the use a DX-DOAS solution with energy recovery for humidity control and realize energy savings around 30%, marginal electric emissions rates need to be closer to 900 lbs/MWh to realize a net benefit when switching from gas to electric. As such, depending on the current generation mix and emissions, especially in more humid climates, implementing a system like high efficiency DOAS might not yield a net carbon benefit in every condition. Ensuring the highest efficiency solutions are implemented is imperative to realizing both energy and carbon savings benefits.

This finding holds true in areas of the country with both high electric marginal emissions rates and where high efficiency DOAS does not contribute to as large of a reduction in HVAC EUI. In those areas, either a much larger HVAC EUI reduction or a lower electric marginal emission rate is needed to justify the benefit of switching from gas to electric heating. For high efficiency DOAS to make sense for decarbonization reasons, policies that drive cleaner grids are likely to be a significant contributor to realizing a net benefit. That is already happening, in places like Washington state, where policies in place now are ensuring that buildings which will be in place for decades should consider technology and fuel choices that are judged on the basis of a cleaner grid. Such policies are helping make the case for switching to electric in the near term to avoid a lost opportunity or a more costly retrofit situation in the future. From an end-user perspective, the energy and cost savings are a strong value proposition to consider installing this type of system. As such, we see value in continuing to promote adoption of a highly efficient DOAS in many building types for most areas of the country to result in energy and cost savings, as well as emissions benefits.

References

C2ES (Center for Climate and Energy Solutions). 2024. *State Climate Policy Maps*. Arlington, VA: Center for Climate and Energy Solutions. www.c2es.org/content/state-climate-policy/.

Bulger, N. 2019. *Economic Analysis of Heat Recovery Equipment in Commercial Dedicated Outside Air Systems*. Portland, OR: RedCar Analytics. betterbricks.com/uploads/resources/NEEA-DOAS-Analysis-Report_Red-Car_Final.pdf

Bulger, N and H. Weitze. 2024. *Energy Efficiency Potential of Dedicated Outdoor Air Systems in Commercial Buildings*. San Francisco, CA: A2 Efficiency. etcc-ca.com/reports/energy-efficiency-potential-dedicated-outdoor-air-systems-commercial-buildings?check_logged_in=1.

Bulger, N and M. Sawford. 2023. *Energy Savings Analysis of Dedicated Outdoor Air HVAC in California Commercial Buildings.* San Francisco, CA: A2 Efficiency. etcc-ca.com/reports/code-readiness-report-energy-savings-analysis-dedicated-outdoor-air-hvac-california

CETA (Clean Energy Transformation Act). 2019. Revised Code of Washington §19.405. Washington State Legislature. https://app.leg.wa.gov/RCW/default.aspx?cite=19.405

DOE (Department of Energy). "Prototype Building Models." EnergyCodes.Gov. Accessed August 4, 2023. www.energycodes.gov/prototype-building-models.

EPA (Environmental Protection Agency). "eGRID Summary Data 2022." EPA.Gov. Accessed May 7, 2024. www.epa.gov/egrid/summary-data.

Lawrence Berkely National Lab (LBNL). “Building Performance Database.” Accessed March 1, 2024. bpd.lbl.gov/explore.

NREL (National Renewable Energy Labs). “Standard Scenario 2023.” Accessed March 1, 2024. scenarioviewer.nrel.gov.

NEEA (Northwest Energy Efficiency Alliance) 2020. *Very High Efficiency Dedicated Outside Air System Pilot Project Report Summary*. betterbricks.com/resources/vhe-doas-pilot-project-summary-report

NEEA (Northwest Energy Efficiency Alliance). 2024a. *Keep ’em separated: The many benefits of decoupling.* betterbricks.com/resources/keep-em-separated-the-many-benefits-of-decoupling

NEEA (Northwest Energy Efficiency Alliance) 2024b. *Very High Efficiency Dedicated Outdoor Air Systems Design Guide.* betterbricks.com/uploads/resources/VHEDOAS_Comprehensive-Design-Guide.pdf

Pratt, J, M. Murphy, and N. O’Neil. 2022. *DO AS We Say (and As We Do): Maximizing HVAC Efficiency, Flexibility, and Resiliency with High Efficiency Dedicated Outdoor Air Systems*. Portland, OR: Energy 350. betterbricks.com/resources/maximizing-hvac-efficiency-flexibility-and-resiliency-with-high-efficiency-dedicated-outdoor-air-systems.

Yoder, T., A. Piazza. S. Pratoomratana. Linda Sandahl. 2023. *Very High Efficiency Dedicated Outdoor Air System Field Site Re-Evaluation*. Richland, WA: Pacific Northwest National Lab on behalf of US Department of Energy. www.pnnl.gov/main/publications/external/technical_reports/PNNL-34419.pdf.