

Dedicated Outdoor Air Systems Revisited

By **John Dieckmann**, Member ASHRAE; **Kurt Roth, Ph.D.**, Associate Member ASHRAE; and **James Brodrick, Ph.D.**, Member ASHRAE

Most commercial building air-conditioning systems combine ventilation makeup air with return air from the building, condition (cool or heat) this air as needed, and distribute the conditioned air to the interior space, with or without zoned temperature control. Dedicated outdoor air systems (DOAS) condition the outdoor ventilation makeup air (OA) separately from the return air from the conditioned space.

Unfortunately, VAV systems do not always achieve good ventilation performance because thermal loads of individual zones do not necessarily vary with the ventilation requirements. As a result, VAV systems often require higher total ventilation airflows to ensure acceptable zone ventilation at all operating conditions, e.g., 20% to 70% more.¹⁻⁵

In addition, many unitary systems use constant air volume (CAV), which can encounter difficulties maintaining acceptable indoor humidity levels, particularly when sensible loads decrease but latent loads remain relatively high. Under those conditions, the supply airflow remains constant and the system delivers supply air at higher temperatures than at full load. However, this decreases the dehumidification capacity and, in some instances, can preclude the unit from providing adequate dehumidification. Thus, indoor humidity levels rise.⁶

A DOAS overcomes these issues by directly delivering separately conditioned OA to the conditioned space, allowing the ventilation makeup air system to be sized and operated to provide the OA rate required by ANSI/ASHRAE Standard 62, *Ventilation for Acceptable Indoor Air Quality*. The ventilation rate can be constant, or it can be varied based on the building operating/occupancy schedule or in response to the actual occupancy (i.e., with demand-controlled ventilation).

A DOAS also improves humidity management. In most climate areas, the moisture in the OA accounts for the largest portion of humidity loads in most commercial buildings (in hot weather). Consequently, separately conditioning the OA from the internal cooling loads enables efficient removal of most of the OA moisture load (along with additional humidity removal to cover internal moisture sources). This enables deployment of sensible-only cooling approaches, such as radiant ceiling cooling, even in humid climates if the building has a tight envelope and minimal indoor moisture sources.

These advantages can be realized in either a single-zone or a multi-zone HVAC system layout.

Typically, a DOAS also includes an energy wheel (EW) to enable enthalpy exchange between the DOAS OA intake and the exhaust air. This decreases OA conditioning loads as well as the size of the OA cooling coil. In addition, a DOAS may or may not include a heat wheel (HW) located after the cooling coil to (in effect) reheat the conditioned OA using heat transferred from the warmer exhaust airflow. An HW has appreciably greater value for a DOAS serving spaces with high design occupancy levels than for spaces with lower design occupancy levels because the higher OA volumes required for the high design occupancy spaces have a greater potential to over-cool spaces at off-peak conditions.⁷

Energy Savings Potential

A DOAS with a sensible-cooling-only VAV system saves energy in at least five ways.

First, it reduces ventilation energy consumption by reducing the total OA needed to meet Standard 62 due to the inherent precision of the DOAS in delivering required OA in the aggregate and to the individual zones in the building. As noted earlier, VAV systems appear to overventilate zones by 20% to 70%.

Second, reductions in the total OA also decrease the energy expended to condition the OA during cooling and heating seasons.

Third, because the OA is separately conditioned from the internal loads, with the entire building humidity load handled in the process, the recirculated indoor AC system can be operated to maintain temperature control. This enables higher chilled water temperatures for internal (sensible) loads (approximately 55°F [13°C] evaporating temperature vs. 40°F to 45°F [4°C to 7°C]), increasing the COP of the compressor.

Fourth, by decoupling temperature and humidity control, it creates an ideal situation for VAV, where the volume of conditioned airflow rate varies in proportion to the net cooling or heating load. This significantly reduces blower power during the large portion of the year when full heating or cooling capacity is not required. Note that this applies to both chilled water based systems and to DX systems.

Fifth, a DOAS with an EW and an HW can greatly reduce or

eliminate the use of reheat to avoid providing over-cooled air under conditions when dehumidification drives AC operation.^{6,8}

By effectively managing indoor humidity levels, a DOAS also enables the application of energy-efficient radiant ceiling systems for sensible cooling, where water is used to transport cooling instead of air. Similarly, the DOAS architecture readily incorporates energy recovery heat exchange (i.e., the EW) between the OA and exhaust, reducing peak and seasonal cooling and heating loads needed to condition the OA.

On the other hand, a DOAS may have an appreciably smaller airside economizer capacity relative to conventional systems. The magnitude of this deficit depends on ventilation OA requirements for each space relative to supply air required to deliver cooling loads.

Some studies have evaluated the energy savings potential of DOAS. Jeong, et al.,⁹ simulated the energy performance of a DOAS with an EW and radiant ceiling panels to that of a VAV system without an EW for a space in an educational building. They found that the DOAS reduced cooling and ventilation energy consumption by 41%, with the greatest savings in ventilation energy (71%). In addition, it decreased chiller capacity by 29%. To some extent, this overstates the saving potential of solely using a DOAS because the base case did not—but could—use an EW. Simulations of a large retail store found that a DOAS saved between 14% and 27% of annual (presumably) HVAC energy consumption in four different climates, while also reducing cooling capacity by 15% to 23%.¹⁰ In addition, simulations of a two-story office building in five distinct climates compared the performance of a DOAS to a VAV system with an economizer.¹¹ The study found primary energy reductions of between 20% and 37%, with the largest savings accrued in colder climates. As with the Jeong, et al., study, this somewhat overstates DOAS energy savings potential because the base case does not—but could—include an EW.

Overall, the data suggest that a DOAS can achieve annual HVAC primary energy savings of approximately 15% to 30%, with greater savings possible in systems that also use radiant ceiling panels. On a national basis, this translates into primary energy savings of between 0.7 and 1.4 quad in commercial buildings.

Market Factors

In addition to energy savings, improved IAQ ranks as a main benefit of DOAS. Limited field data support the assertion that a DOAS provides superior humidity control relative to conventional HVAC systems. Fischer and Bayer¹² found that, of 10 schools studied in Georgia, the three that used DOAS had the lowest humidity levels and the best indoor air quality. Similarly, a comparison of schools in Florida using DOAS with those using conventional systems found that the schools with DOAS had about 10% lower relative humidity levels.¹⁰ In addition, another evaluation of two otherwise identical test sites found that the DOAS provided superior comfort and humidity control.¹³ Finally, a DOAS readily allows verification that adequate OA is delivered to spaces.^{6,8}

A general perception exists that replacing one single purpose system with two parallel systems will result in increased installed equipment costs due to installation of additional equipment. In

new construction or major renovations this is not necessarily accurate. Mumma¹⁴ lists nine categories of building mechanical system and overall building costs reduced by separate DOAS:

1. Reduced chiller (or DX system) tonnage;
2. Reduced chilled capacity;
3. Reduced condenser water pump capacity;
4. Reduced ductwork size and cross-section;
5. Smaller air-distribution plenums and terminal boxes;
6. Air handler size reduction;
7. Reduced electrical service in line with reduced peak chiller, blower and pump power draw;
8. Less “rentable” space consumed by mechanical equipment; and
9. Reduced total floor height.

Thus, the potential exists for DOAS implementation with little or no first cost penalty, with energy cost savings and the benefits of drastically improved humidity control and improved occupant productivity providing an instant payback and continuing savings.

DOAS can be implemented in engineered cooling systems with commercially available components and systems. For applications using unitary AC equipment, i.e., single package rooftop units (RTUs), DOAS can be realized using a combination of 100% OA makeup air units and RTUs conditioning indoor air. This can be readily done in “big box” retail spaces, which commonly use many RTUs distributed over the roof area. Unitary AC equipment incorporating DOAS and return AC in a single package is not, however, commercially available.

To address that market gap, a project was recently completed to develop a unitary product that incorporates the DOAS and the supplemental system using separate, parallel airflow paths in the same unit. Ideally, this would decrease the cost of implementing DOAS by consolidating the two systems into a single package, sharing compressors and packaging, and also simplifying installation. Integration of the two systems into a single package turned out to be challenging, due to the space constraints that increased blower energy consumption for the two parallel airflow paths. Nonetheless, at sizeable annual manufacturing volumes, the unit developed had estimated simple payback periods of one to four years relative to a baseline unit using hot gas reheat.¹⁵

Designers’ and contractors’ unfamiliarity with this technology remains a significant barrier to greater use of DOAS. This leads to conservatism in unit specification and operation strategy that do not take advantage of the strengths of DOAS and tend to increase system size and cost and can compromise energy savings.^{7,8,16}

Another challenge for DOAS is selecting the most effective control algorithms for the combination of the DOAS and supplemental indoor cooling systems to minimize energy consumption. For example, to realize their full energy savings potential, DOAS controls need to decide how to vary dehumidification capacity, whether or not to use reheat, and how to operate the EW in response to indoor and outdoor conditions.^{7,8,15}

Finally, a DOAS provides the largest performance advantage when OA accounts for most of the latent loads. Buildings with large internal latent loads, such as health clubs, are not good

candidates for DOAS. More generally, high infiltration levels are an issue in an appreciable portion of buildings and can result in practical challenges to effective use of DOAS in buildings.¹¹

References

1. Stanke, D.A. 1998. "Ventilation where it's needed." *ASHRAE Journal* 40(10):39–47.
2. Kettler, J.P. 1998. "Controlling minimum ventilation volume in VAV systems." *ASHRAE Journal* 40(5):45–50.
3. Shelquist, P. and R. Amborn. 2001. "Ventilation control strategies." *ASHRAE Journal* 43(9):30–35.
4. Chamberlin, G.A., et al. 1999. "VAV systems and outdoor air." *ASHRAE Journal* 41(10):39–47.
5. Mumma, S.A. 2001. "Fresh thinking: dedicated outdoor air systems." *Engineered Systems* 18(5):54–60.
6. Morris, W. 2003. "The ABCs of DOAS: dedicated outdoor air systems." *ASHRAE Journal* 45(5):24–29.
7. Mumma, S.A. and J.W. Jeong. 2005. "Direct digital temperature, humidity, and condensate control for a dedicated outdoor air-ceiling radiant cooling panel system." *ASHRAE Transactions* 111(1):547–558. <http://doas.psu.edu/OR-05-3-3.pdf>.
8. Murphy, J. 2006. "Smart dedicated outdoor air systems." *ASHRAE Journal* 48(7):30–37.
9. Jeong, J.W., S.A. Mumma and W.P. Bahnfleth. 2003. "Energy conservation benefits of a dedicated outdoor air system with parallel sensible cooling by ceiling radiant panels." *ASHRAE Transactions* 109(2):627–636. http://doas-radiant.psu.edu/KC_03_7_1.pdf.
10. Khattar, M.K. and M.J. Brandemuehl. "Separating the V in HVAC: a dual-path approach." *ASHRAE Journal* 44(5):37–42.
11. Emmerich, S.J. and T. McDowell. 2005. "Initial evaluation of displacement ventilation and dedicated outdoor air systems for U.S. commercial buildings." Final Report by the National Institute of Standards and Technology (NIST) prepared for the U.S. Environmental Protection Agency (EPA). <http://tinyurl.com/22h8tv> (or <http://www.fire.nist.gov/bfrlpubs/build05/PDF/b05011.pdf>).
12. Fisher, J.C. and C.W. Bayer. 2003. "Report card on humidity control: failing grade for many schools." *ASHRAE Journal* 45(5):30–37.
13. Brown, S.L. 2007. "Dedicated outdoor air system for commercial kitchen ventilation." *ASHRAE Journal* 49(7):24–35.
14. Mumma, S.A. 2001. "Ceiling panel cooling systems." *ASHRAE Journal* 43(11):28–32.
15. TIAX. 2006. "Roof-top Unitary Air Conditioner with Integral Dedicated Outdoor Air System." Final Report by TIAX LLC to the National Energy Technology Laboratory, U.S. Department of Energy.
16. Jeong, J.W. and S. Mumma. 2006. "Designing a dedicated outdoor air system with ceiling radiant cooling panels." *ASHRAE Journal* 48(10):56–62.

John Dieckmann is a principal and Kurt Roth, Ph.D., is an associate principal with TIAX LLC, Cambridge, Mass. James Brodrick, Ph.D., is a project manager with the Building Technologies Program, U.S. Department of Energy, Washington, D.C. ●

Advertisement formerly in this space.