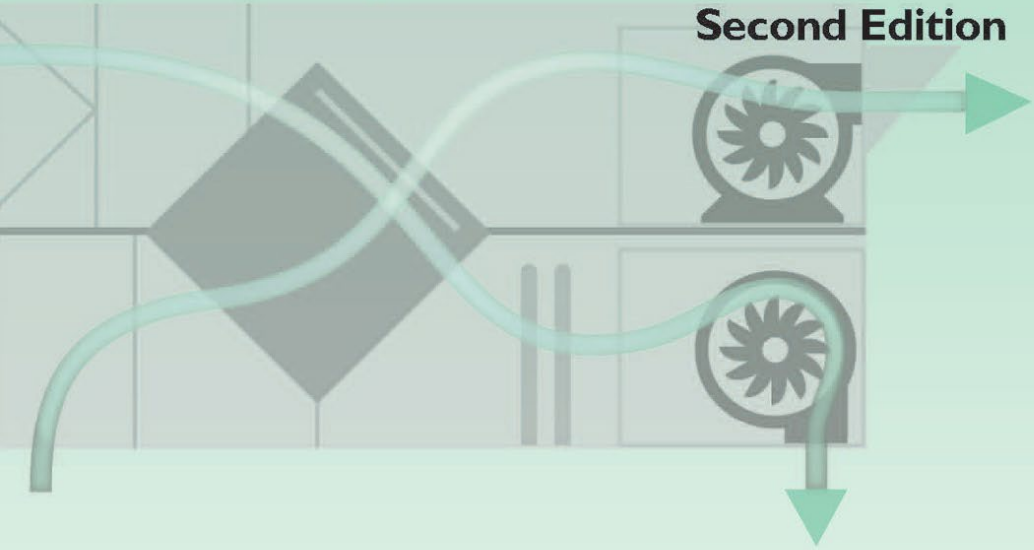
ASHRAE DESIGN GUIDE for Dedicated Outdoor Air Systems

Second Edition



design

installation

operation and maintenance

ASHRAE Design Guide for

Dedicated
Outdoor
Air
Systems

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RP-1712

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Peachtree Corners

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PREFACE

PURPOSE

The purpose of this book is to help technical professionals design dedicated outdoor air systems (DOAS) for commercial and institutional buildings. If you are interested mostly in residential or industrial buildings, this book may not meet all of your needs.

Additionally, this book is focused on design considerations that are specifically relevant to DOAS. It is not intended to be a general guide for designing any HVAC system. Rather, its intent is to highlight issues that should be considered when incorporating DOAS into your overall HVAC design.

ASSUMPTIONS

We assume the reader is an HVAC designer, although not necessarily one with an engineering degree, and has a basic understanding of HVAC systems, terminology, psychrometry, and the common variables of equations used in designing HVAC systems.

As an overall focus, we write for the system designer who "has to get it done by Friday." We expect that the guide may also be useful to others, such as architectural designers, building developers and owners, maintenance professionals, regulators, utility policy makers, students, teachers, and researchers. However, where decisions have been made about technical depth and detail, we have tried to meet the needs of the HVAC designer first.

ORGANIZATION OF THE GUIDE

This book has been organized into seven main chapters. Chapter 1 is designed to give the reader some background on DOAS as well as describe the primary motivations behind developing this Guide. Chapters 2 through 5 contain the core guidance for designing a successful DOAS. These chapters cover outdoor air and load requirements, system selection, detailed design considerations, and controls, respectively. Chapter 6 familiarizes the reader with items to consider during the construction process, and Chapter 7 focuses on DOAS operation and maintenance.

Some of the topics covered in this book are relevant to more than one piece of the design process. Rather than reiterate the same information in multiple chapters, choices have been made regarding where to place these subjects. We have tried to organize the content in this book such that subjects are placed in the chapter most relevant to them, and the reader is referred to that section when that subject comes up again in other places.

HOW TO USE THIS GUIDE

Readers will get the most use out of this guide if they come to it with a clear understanding of the goals and requirements of the specific project they are working on. With these in mind, it will be easier to narrow down the types of systems and equipment configurations that would be most appropriate for their particular application. It is also important to remain aware of any specific climate considerations for the project in question.

This book has been organized such that someone designing their first DOAS could read the book from start to finish and receive DOAS-specific guidance for each step in the design. Readers who have already started their design or have previous experience with DOAS should skip to the areas of the book that are relevant to their project or that present DOAS variations they might be less familiar with. We recommend that all readers pay some attention to controls, construction, and operation, as these are the elements that can make the difference between a marginally functional DOAS and a fully optimized DOAS.

ACKNOWLEDGMENTS

This work was made possible by the contributions and assistance of many individuals and organizations. We are particularly grateful to John Murphy and Lew Harriman for their encouragement and support throughout this enormous task. The entire project monitoring subcommittee (John Dieckmann, Chris Gray, Lew Harriman, Scott McGinnis, John Murphy, and Paul Pieper) was instrumental in providing insightful guidance and feedback. Many of our best graphics were either borrowed from or inspired by existing ASHRAE publications, and we thank those authors for helping to pave the way. We are also deeply appreciative of all of the engineers, building owners, building managers, and market stakeholders who took part in interviews and/or showed us around their buildings as we prepared to write this guide.

The revision committee for this second edition included Peter Luttik, Svein Morner, Kevin Muldoon, and John Murphy.

READER INPUT

As the use of DOAS becomes more common, the applied experience of our readers will also grow. This book should be thought of as a starting point for the discussion on DOAS. We encourage any feedback or suggestions from our readers that

could be used to improve this guide. Please send your recommendations to one of our authors at TC0810@ashrae.net:



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CHAPTER 1

INTRODUCTION



Figure 1.1 Changing seasons.
George Hodan, The Four Seasons, www.publicdomainpictures.net

DEFINITION

For the purposes of this book, all material is based on the following definition of a *dedicated outdoor air system* (DOAS):

A dedicated outdoor air system (DOAS) uses separate equipment to condition all of the outdoor air brought into a building for ventilation and delivers it to each occupied space, either directly or in conjunction with local or

central HVAC units serving those same spaces. The local or central HVAC units are used to maintain space temperature.

As shown in Figure 1.1, outdoor air conditions can vary drastically from season to season, and even throughout the day. What doesn't change is that buildings need to be ventilated with fresh outdoor air. DOAS are designed to ensure that a building receives the required amount of outdoor air, delivered at conditions that ensure occupant comfort—regardless of what the weather is doing outdoors.

Why This Book Was Written

The use of DOAS has become increasingly popular throughout the world. However, the early adoption of all new technologies and approaches is often fraught with challenges. Because of the current lack of DOAS exposure and experience, many DOAS designed and installed today do not always take full advantage of all the benefits DOAS can offer. Often, they are designed to achieve only one or two of their many available functions. They may cool the air efficiently, but not dry it; they may dry the air, but not recover heat; or they may not vary outdoor airflow in response to building occupancy, forgoing substantial energy savings. Some use overly simplified control strategies, improperly apply exhaust air energy recovery, and/or deliver conditioned outdoor air to the building in a manner that reduces or limits the benefits of decoupling ventilation from space conditioning.

This guide was developed to assist engineers in designing optimal DOAS. Although, over time, a sizable body of literature has accumulated pertaining to the design, installation, and operation of DOAS, it is widely scattered and time-consuming to search out. Such searches are particularly impractical for design engineers with pressing deadlines. In this book, we aim to consolidate much of the existing material into one volume, focusing on the overview and major issues while referring the reader to supplemental sources for more specialized or in-depth information.

REASONS FOR USING DOAS

There are many reasons to use DOAS. Some of the most common drivers are (1) improving humidity control, (2) reducing energy use, (3) the desire to simplify ventilation design and control, (4) the desire to use heating and cooling equipment that does not provide ventilation and/or dehumidification (e.g., radiant panels or passive chilled beams), and (5) reducing installation cost. Here is how these driving factors have encouraged a rise in DOAS installations over the last few decades.

Humidity Control

In many locations worldwide, for both residential and commercial buildings, mechanical ventilation is either a code requirement or an industry-standard practice. With the introduction of outdoor air often comes an increase in dehumidifica-

tion loads. In fact, incoming ventilation and makeup air typically carries more than 80% of a building's annual dehumidification load (ASHRAE 2019b, Chapter 64).

Annual cumulative latent ventilation loads typically exceed sensible ventilation cooling loads by 3:1 to 5:1 in all but high-altitude and desert climates (Harriman et al. 1997). Figure 1.2 shows the annual cumulative latent and sensible cooling and dehumidification load from ventilation for sample climates. In addition, the peak sensible-cooling conditions are typically not close to the peak latent load conditions, as is shown for a sample climate in Figure 1.3. Ventilation latent loads peak at more moderate temperatures, not necessarily the peak dry bulb condition. Traditional system designs may be unequipped to handle such high latent loads (Kosar et al. 1998) over the wide range of ambient conditions. A dedicated dehumidification component, such as that typically included in a DOAS, can remove the ventilation latent load, often avoiding the need for the cooling equipment to cool the air too low for the sensible load to a temperature lower than required for the sensible load, thereby requiring the need to use extensive reheat. Desert-like climates (such as Albuquerque and Las Vegas) may have no significant latent loads and might be

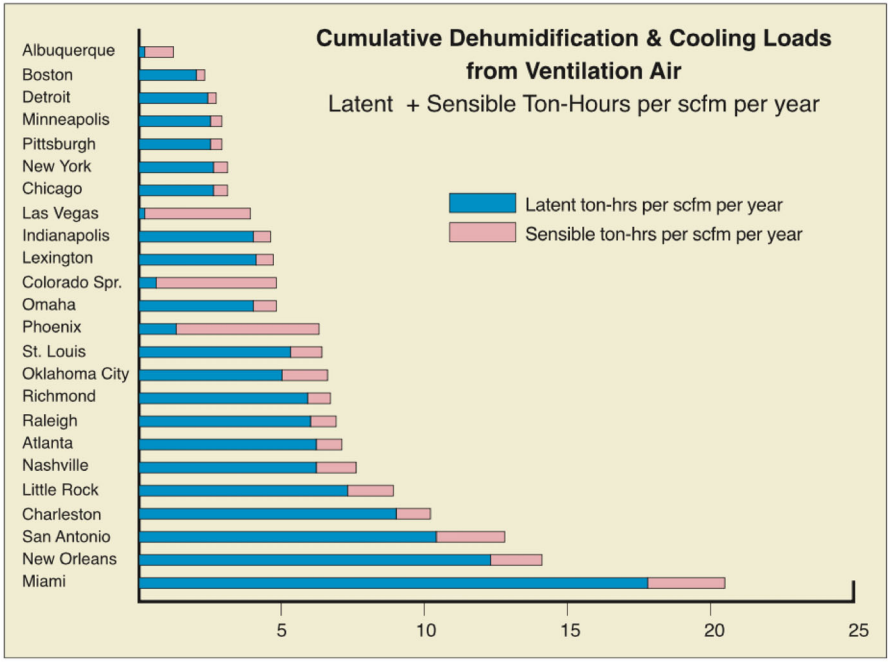


Figure 1.2 Annual cumulative latent (dehumidification) and sensible-cooling load from ventilation air.

Harriman et al. (1997)

served with alternative solutions, including traditional HVAC equipment with makeup air units.

Because of widespread adoption of light-emitting diode (LED) lighting and low solar heat gain coefficient windows, internal sensible-cooling loads have been greatly reduced while the ventilation load has not. The consequence of these technology advancements is that, in many cases, separating the latent cooling from the majority of the sensible cooling with a DOAS may reduce the cost of the mechanical system (in particular, if using an energy recovery device in the DOAS) because of downsized sensible-cooling equipment, which can help pay for the cost of dehumidification, cooling, heating, and filtering the ventilation air in the DOAS. In addition, the efficiency of local HVAC units (used to cool recirculated air only) can be improved significantly if they are not required to dehumidify. However, most sensible-only cooling equipment (such as chilled beams and radiant panels) cannot filter air in the occupied space. In this case, filtration is left to DOAS, especially if the primary need for filtration is due to the outdoor air conditions.

Humidity control also plays a vital role in maintaining healthy buildings and occupant health. Persistent indoor dampness is neither normal nor desirable and can lead to health risks for occupants in the short term and, ultimately, to structural risks (ASHRAE Short Course, 2021). During the COVID-19 pandemic, the ASHRAE Epidemic Task Force shared guidance on how indoor humidity plays a role in reducing the spread of airborne infectious aerosols. Scientific literature generally reflects the most unfavorable survival for micro-organisms when the relative humidity is between 40% and 60% (ASHRAE Research Project CO-RP-03, 2019).

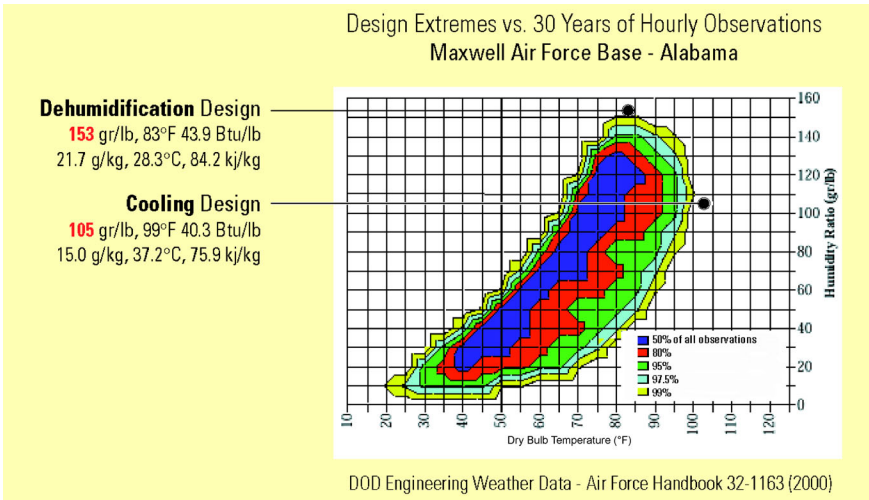


Figure 1.3 Design extremes.

Harriman et al. (2000)

However, raising the indoor humidity level during cold weather can result in condensation forming on inside surfaces of windows or walls, thus requiring an assessment of the building envelope as well.

Energy Impacts

The goal of reducing energy consumption in buildings has had a much greater influence on design decisions in recent years. Due in part to this increased awareness of efficiency, DOAS has gained in popularity and is emerging as an effective, cost-efficient approach to reducing energy use.

For example, one important way that DOAS contributes to energy savings is by removing humidity from the outdoor air, which allows the remaining cooling components to operate based solely on dry-bulb temperature. Removing humidity from outdoor air eliminates the need to overcool and reheat supply air, and allows the local cooling equipment to operate at a warmer temperature, which can reduce compressor lift and improve efficiency.

Another energy benefit of DOAS is that less outdoor air may need to be introduced to the building compared to, for example, a typical mixed-air system that must meet the multiple-zone recirculating system requirements of ANSI/ASHRAE Standard 62.1 (ASHRAE 2019c). Reducing excessive outdoor air intake saves energy by reducing total outdoor air heating and cooling loads.

In addition, DOAS can make it easier to implement demand-controlled ventilation strategies. Traditional designs often ignore the issue of reducing outdoor air when spaces are unoccupied, which impacts energy consumption (Crowther and Ma 2016; Persily et al. 2005). With the right components installed, DOAS can allow outdoor air to be reduced in response to changes in occupancy.

Figure 1.4 shows an example of the potential energy savings available from implementing demand-controlled ventilation in a DOAS. Annual costs are shown for an example building in Chicago using a constant-volume (CV) DOAS unit providing ventilation directly to the spaces with no energy recovery, a CV DOAS unit with energy recovery, and a demand-controlled ventilation (DCV) variable-volume DOAS unit with energy recovery. It is based on 50% average occupancy during operating hours and 55°F (12.8°C) summer conditioned outdoor air temperature reset to 65°F (18.3°C) in winter. Going from no energy recovery to demand-controlled ventilation with energy recovery results in a 72% energy savings and a 59% cost savings (Crowther and Ma 2016).

Finally, the centralization of ventilation air conditioning provided by DOAS can make it easier to recover both heating and cooling energy from exhaust air. From an installation and operational point of view, DOAS is often the easiest way to provide the air-to-air energy recovery required for large airstreams by ANSI/ASHRAE/IES Standard 90.1 (ASHRAE 2019d). If exhaust air cannot be easily routed to the DOAS equipment, other energy recovery methods should be employed. These methods include a precool/post-heat heat exchanger, liquid desiccant dehumidifica-

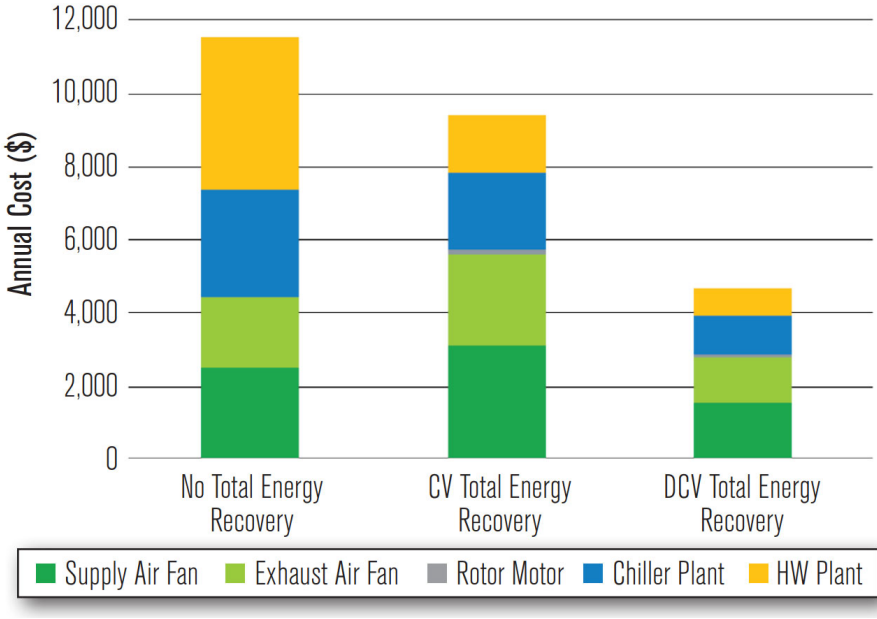


Figure 1.4 Demand-controlled ventilation benefits.
Crowther and Ma (2016)

tion, or hot gas reheat. Considering these various technologies, decisions should concentrate on overall system efficiency rather than specific technology choices.

Advances have recently been made toward increasing awareness of the energy associated with dehumidification. The new metrics of Moisture Removal Capacity (MRC), Moisture Removal Efficiency (MRE), and Integrated Seasonal Moisture Removal Efficiency (ISMRE) provide a means of assessing the dehumidification capacity and energy efficiency of a DOAS unit. The first implementation of these metrics was in the 2016 version of ASHRAE/IES Standard 90.1, which added minimum equipment efficiency requirements for direct expansion (DX) DOAS units based on ISMRE rated in accordance with ANSI/AHRI Standard 920 (AHRI 2015).

Ventilation Control

DOAS offers a simple and elegant way to address outdoor air loads. Because DOAS airflow is independent of building heating and cooling loads, it is relatively simple to control and operate. If the DOAS is designed as a constant-volume system, it might simply be activated whenever the building is occupied. Or, as mentioned previously, DOAS can make it easier to implement demand-controlled

ventilation strategies, which requires designing the DOAS for variable airflow, as an effective means of meeting outdoor air requirements under all conditions.

When demand-controlled ventilation is implemented, ensure that building pressure is controlled as intake airflow is reduced. If sensible-only cooling equipment is used, the DOAS is the only source of dehumidification, so DCV must ensure that space humidity control is not lost.

Systems without Ventilation Capabilities

Over the last few decades, improvements in envelope technology, lighting, and other interior equipment have resulted in generally lower sensible-cooling demands per unit area than were previously required. This has resulted in the development and increased use of less traditional cooling and heating equipment that can meet these comparatively lower cooling loads more efficiently than mixed-air systems. This includes radiant cooling, chilled beams, and variable-refrigerant-flow systems, among others. However, because some kinds of equipment typically have very limited dehumidification capacity, they rely on a separate DOAS to provide dry air ventilation for the building. And, in other cases, this equipment is not capable of providing any dehumidification (sensible cooling only), so the DOAS must remove the entire latent load of the building. In addition, most sensible-only cooling equipment cannot filter air in the occupied space. This may require separate filtration equipment or relying on the DOAS to filter the air.

Even if the local HVAC units have some dehumidification capability, designing the DOAS to allow them to operate dry (providing sensible cooling only) can improve their efficiency and affords the opportunity to eliminate the condensate drainage system.

First Cost Reduction

It may sound contradictory that adding a system could reduce the first cost of a project rather than increase it. By addressing outdoor air loads, however, DOAS can reduce the heating and cooling loads that must be met by other components of the HVAC system (Table 1.1). This can result in the downsizing of these other components (e.g., terminal units, chillers, boilers, air-handling units, ductwork, and/or piping). For example, using a DOAS that handles the entire (external and internal) latent load with an enthalpy exchanger and a cooling coil at a school might allow for downsizing the tonnage of classroom units; reduce the central heating and cooling equipment capacities; and reduce the piping, ductwork, and electrical installation.

APPLICATIONS

DOAS can be effectively incorporated into nearly any commercial, institutional, industrial, or multifamily building. While all building types can benefit from DOAS, those with strict indoor air quality, ventilation, humidity, or energy-

Table 1.1 Example Impact of DOAS on Downsizing Local HVAC Units

System Configuration	Local HVAC Unit Capacity	DOAS Capacity	Total Cooling Capacity
Local mixed-air system (no DOAS)	8.3 tons (29.2 kW)		8.3 tons (29.2 kW)
DOAS with local HVAC unit: OA dehumidified to offset ventilation latent load only	7.0 tons (24.6 kW)	1.3 tons (4.6 kW)	8.3 tons (29.2 kW)
DOAS with local HVAC unit: OA dehumidified to offset ventilation plus entire space latent load	6.3 tons (22.2 kW)	2.0 tons (7.0 kW)	8.3 tons (29.2 kW)

ASHRAE Short Course (2021)

efficiency requirements make particularly good candidates, and as the ratio of outdoor air to the recirculated air increases, DOAS benefits rise accordingly (Kosar et al. 1998). For example, buildings located in very humid climates provide a good application for DOAS. Facilities with extended occupancy schedules benefit more from DOAS than buildings with longer unoccupied periods, obtaining higher annual savings through use of the technology. Other particularly good candidates for DOAS are facilities that require more than just standard or code-required minimum ventilation rates, such as those that handle pollutants that should not be recirculated to other spaces (e.g., hospitals and laboratories).

ROLE OF THE DESIGNER

It is the design engineer's job to work closely with other members of the project team to design and deliver a building that complies with the applicable codes and satisfies the owner's objectives and vision. The specific duties of this role include creating a system that meets owner requirements within the constraints of the project and delivering documentation of that system to help facilitate its successful installation, operation, and maintenance. These duties are present in any HVAC design process and will shape the final result of the system whether DOAS is included or not.

Government policy objectives and utility rate structures can change quickly, as demonstrated during the COVID pandemic and recent shifts in Europe from natural gas heating to heat pumps. Also, technology advances often outpace current building codes. By understanding these trends and working with regulators, the design engineer can propose additional options that may help the building owner manage

future changing requirements. As an example, using heat pump technology for heating, with a gas-fired burner or electric heater as backup, can provide the owner with future options for switching heating fuels when desired.

When choosing to incorporate DOAS, the designer must first identify the loads that the system will be required to meet and note that, in contrast to other loads, outdoor air loads are highly variable. Consequently, it is important to determine how the DOAS will interact with other systems, which components the DOAS unit should include, and how to control those components. DOAS creates new opportunities and present different challenges than more traditional systems.

This guide presents the pros and cons of various options, while remaining focused on DOAS-specific topics. The designer must decide how best to apply DOAS within the constraints and opportunities of a specific project.

ROLE OF UTILITIES AND REGULATORS

Selection of DOAS equipment is likely to be increasingly influenced by regulators and utilities incentivized to reduce energy consumption in buildings. This may result in rebates to reduce the installed cost of high-performing systems or special rates for reducing electrical demand, which could influence control sequences.

Lab testing data, in accordance with AHRI Standard 920, is an indication of the potential savings that can be achieved compared to the minimum efficiency requirements in ANSI/ASHRAE/IES Standard 90.1. However, the benefits of various technologies differ significantly by outdoor conditions; thus, actual energy savings will differ based on climate, operating hours, and building characteristics. The most direct comparison between annual moisture removal requirements for the specific location and the actual energy used for moisture removal is to monitor operation of installed equipment. Alternatively, the AHRI Standard 920 test condition that most closely resembles the actual project location can be used to estimate savings.

A similar issue occurs with demand-controlled ventilation, where the ventilation load (and energy use) during hot/humid and cold weather tends to be higher than during more mild weather, so estimated energy savings needs to be based actual occupied hours.

Peak demand management. Many utilities operate large energy-efficiency discount or rebate programs. To date, few of these programs have focused on DOAS equipment, even though peak electrical demand during summer months can be heavily influenced by the need to condition outdoor air for ventilation. Strategies like energy recovery, demand-controlled ventilation, and time-averaged ventilation (overventilating during portions of the day and underventilating during peak periods) can be used to reduce peak electrical demand. Project teams should work with utility program managers to determine if rebates or discounts can be earned for DOAS strategies that can reduce electrical demand.

Electrification. Because sustainability is a key focus of policy makers, businesses, and consumers, there has been increased interest in reducing buildings' carbon dioxide equivalent footprint (often referred to as "decarbonization"). In the

context of the HVAC system, this involves improving the system's energy efficiency, using low-GWP refrigerants and minimizing leakage of those refrigerants, and reducing the use of fossil fuels by installing electrified HVAC equipment that is served by electrical grids that rely more heavily on carbon-free energy sources such as solar, wind, and other renewables.

With respect to DOAS, electrification typically focuses on the technology used to heat the incoming outdoor air. Following are some strategies that can aide in electrification:

- Incorporating exhaust-air energy recovery and/or demand-controlled ventilation to reduce the wintertime heating loads due to the introduction of outdoor air.
- Using heat pump technology for heating, rather than burners or boilers that use fossil fuels. For projects with sufficient land available, geothermal can be an option. Otherwise, air-source heat pump technology is available in many product platforms.
- If using an air-source heat pump, include a backup heat source in colder climates to avoid delivery of sub-freezing air in the event that the heat pump has insufficient capacity or has to switch temporarily to operate in defrost mode.