DEDICATED OUTDOOR AIR SYSTEMS

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DEDICATED outdoor air systems (DOASs) use separate equipment to condition all of the outdoor air brought into a building for ventilation, and deliver 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. Figure 1 shows a typical DOAS configuration for a large retail store. A DOAS unit can be simple, with just a few components (e.g., a fan and a cooling coil), or more complex, with several energy recovery devices, cooling coils, heating coils, and one or more fans. Generally, the objective of a DOAS is to condition incoming outdoor air before it mixes (and is diluted) with the remainder of the building air so it is easier to dehumidify and clean, and so energy in outgoing air can be recovered to precondition incoming outdoor air.

1. APPLICATIONS

A DOAS can be effectively incorporated into nearly any commercial, institutional, industrial, or multifamily building. Although all building types can benefit from DOAS, those with strict requirements for indoor air quality, ventilation, humidity, or energy efficiency make particularly good candidates. As the amount of outdoor air rises in proportion to recirculated return air, DOAS benefits rise accordingly (Kosar

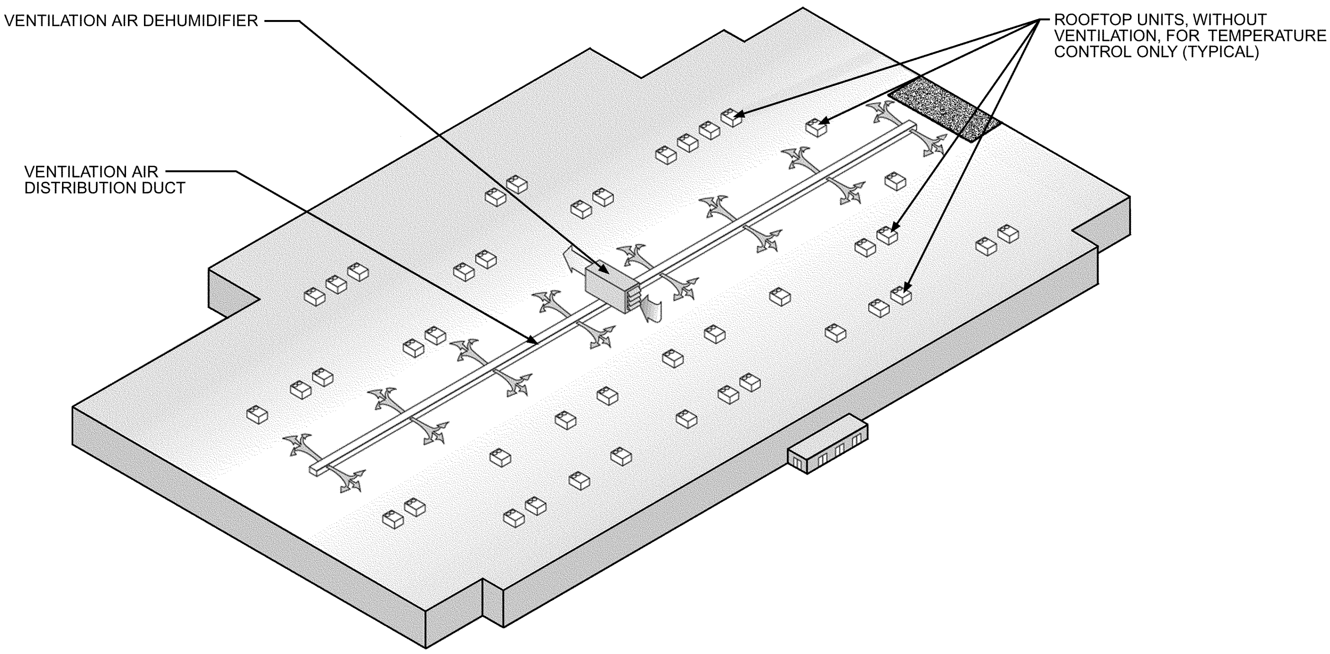

Fig. 1 Typical DOAS Configuration for Large Retail Store
(Harriman et al. 2001)

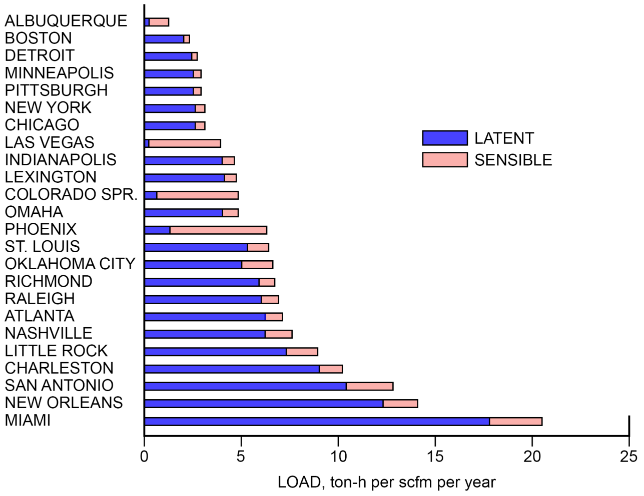

Fig. 2 Annual Cumulative Latent (Dehumidification) and Sensible Cooling Loads from Outdoor Air
(Harriman et al. 2007)

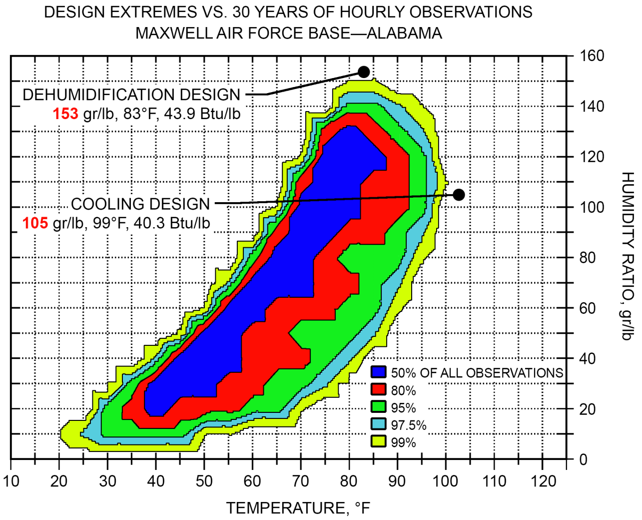

Fig. 3 Design Extremes
(Harriman et al. 2000)

1989). For example, buildings in very humid climates provide a good application for DOAS. Other particularly good candidates include facilities that require ventilation rates above the minimum required by code, such as those that handle pollutants that should not be recirculated to other spaces (e.g., hospitals, laboratories). Facilities using DOAS also typically benefit from the use of energy recovery.

There are many reasons to use DOAS. Some of the most common include (1) improving indoor humidity control, (2) reducing energy use, (3) simplifying ventilation system design and control, (4) the desire to use heating and cooling equipment that does not provide ventilation and/or dehumidification (e.g., radiant panels, passive chilled beams), and (5) reducing installation cost.

1.1 HUMIDITY CONTROL

In many locations worldwide, for both residential and commercial buildings, mechanical ventilation is either a code requirement or an industry standard practice. Introducing outdoor air often increases dehumidification loads: incoming outdoor or makeup air typically carries more than 80% of a building's annual dehumidification load (see Chapter 62 of the 2015 *ASHRAE Handbook—HVAC Applications*).

Annual cumulative latent outdoor air loads typically exceed sensible outdoor air cooling loads by 3:1 to 5:1 in all but high-altitude and desert climates [see, e.g., Harriman et al. (1997)]. Figure 2 shows the annual cumulative latent (dehumidification) and sensible cooling loads from outdoor air for several climates. In addition, the outdoor air humidity ratio at cooling design conditions is typically much lower than at the dehumidification design conditions, as is shown for a sample climate in Figure 3. Traditional cooling system designs may be ill equipped to handle such high latent loads (Kosar et al. 1998) over the wide range of ambient conditions. A dedicated dehumidification component in a DOAS can remove the latent outdoor air load, along with the latent indoor load when outdoor air is dried deeply, often avoiding the need for reheat because the local cooling equipment cooled the air too much for the sensible cooling load (Figure 4).

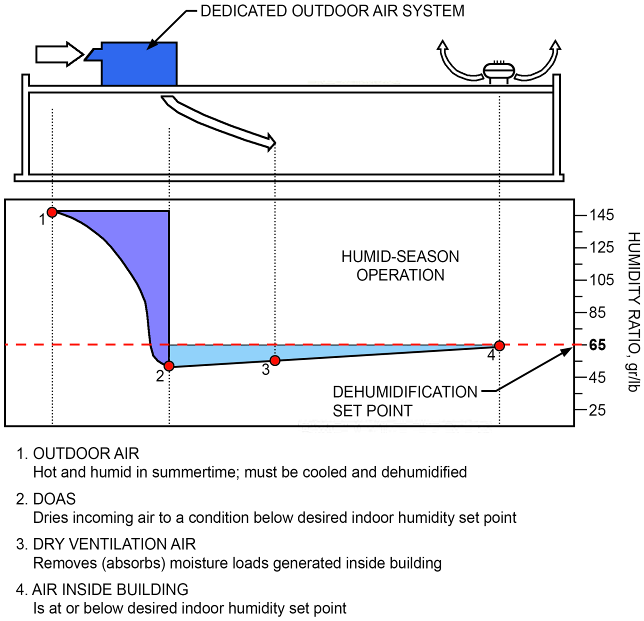

Fig. 4 Typical DOAS Configuration Diagram during Humid-Season Operation
(Harriman et al. 2001)

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 outdoor air load has remained high. Consequently, in many cases, using a DOAS to separate the dehumidification work from the space sensible cooling work may reduce the overall cost of the mechanical system (particularly if energy recovery is included in the DOAS), because the sensible cooling equipment often can be downsized to help offset the cost of the DOAS.

1.2 ENERGY USE

The goal of reducing energy consumption in buildings has had a much greater influence on design decisions over recent years. Due in part to this increased awareness of efficiency, DOAS has gained in popularity and emerged 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 solely for sensible cooling. Dehumidified outdoor air may eliminate (or limit) the use of reheat energy, as required by ASHRAE *Standard* 90.1 (Murphy 2006).

Another energy benefit is that less outdoor air may need to be introduced to the building, compared to a typical mixed-air system that must meet the multiple-zone recirculating system requirements of ASHRAE *Standard* 62.1. Reducing outdoor air intake saves energy by reducing the outdoor air heating, cooling, and dehumidification loads.

In addition, DOAS can make it easier to implement demand-controlled ventilation (DCV) strategies. Traditional designs often ignore the issue of reducing outdoor air when spaces are partially occupied or unoccupied, which affects energy consumption (Crowther and Ma 2016; Persily et al. 2005). With the right components installed, a DOAS can allow outdoor air to be reduced in response to changes in space occupancy. Figure 5 shows an example of the potential DOAS energy savings available from implementing DCV. This figure depicts the annual costs for an example building in Chicago using either (1) a constant-volume (CV) DOAS unit with no energy recovery providing outdoor air directly to the spaces, (2) a CV DOAS unit with energy recovery, or (3) a variable-volume DOAS unit with energy recovery and DCV. This analysis assumes 50% average occupancy during operating hours and 55°F summer supply air temperature from the DOAS, which is then reset to 65°F in winter. DCV with energy recovery results in 72% DOAS energy savings and a 59% energy cost savings compared to the CV DOAS unit with no energy recovery (Crowther and Ma 2016).

Finally, the centralization of outdoor 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 air-to-air energy recovery, which may be required by ASHRAE *Standard* 90.1. The DOAS may also include energy recovery to precool incoming outdoor air, and transfer this energy to reheat the dehumidified air before it discharges from the unit, thus improving overall operating efficiency.

Increasing awareness of the energy associated with dehumidification is reflected in new equipment rating metrics. The moisture removal efficiency (MRE) assesses the dehumidification energy efficiency of a direct-expansion (DX) DOAS unit in terms of moisture removed per kilowatt-hour. The integrated seasonal moisture removal efficiency (ISMRE) is a weighted calculation of MRE at four different conditions that provides a dehumidification efficiency metric on an annual basis. The first implementation of this metric was in the 2016 version of ASHRAE *Standard* 90.1, which requires the DX-DOAS unit to remove at least 4 lb of water vapor per kilowatt-hour on an annual basis. See ANSI/AHRI *Standard* 920-2015 and ASHRAE *Standard* 90.1-2016.

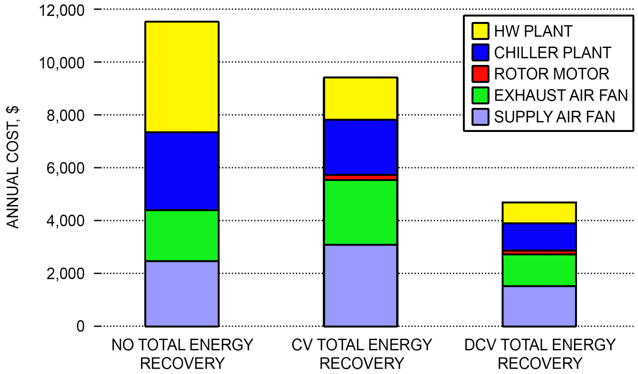

Fig. 5 Demand-Controlled Ventilation Benefits in DOAS
(Crowther and Ma 2016)

1.3 SYSTEMS WITHOUT VENTILATION CAPABILITIES

Over the last few decades, improvements in envelope technology, lighting, and other interior equipment have generally lowered sensible cooling demands per unit area. This has resulted in the development and increased use of less traditional cooling and heating equipment, which may be able to meet these comparatively lower cooling loads more efficiently than all-air systems. Examples include radiant heating and cooling, chilled beams, water- or ground-source heat pumps, sensible-cooling fan-powered units, and variable-refrigerant-flow (VRF) systems, among others. However, because this equipment typically has very limited dehumidification capacity, they rely on a separate DOAS to dehumidify outdoor air being brought into the building for ventilation. In some cases, this equipment cannot provide any dehumidification (i.e., sensible cooling only), so the DOAS must remove the entire latent load of the building (e.g., outdoor air plus internal latent loads from people and infiltration).

1.4 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 separately, however, a DOAS may be able to reduce the heating and cooling loads that must be met by other components of the HVAC system. This can allow downsizing of these other components (e.g., terminal units, chillers, boilers, air-handling units, ductwork, piping). For example, using a DOAS that handles the entire (outdoor air and internal) latent load with an energy recovery device and a cooling coil at a school might allow downsizing the classroom units' capacity; reducing the central heating and cooling equipment capacities; and reducing the size of piping, ductwork, and electrical distribution.

2. AIR DISTRIBUTION

DOAS units can be described as independent air handlers that condition outdoor air entering a building. They can be integrated with almost any type of heating and cooling system, and typically duct conditioned outdoor air to each zone throughout a building, but there are several options for how the outdoor air is delivered at the zone level (directly to the zone, to local equipment, etc.) The following is an overview of four common DOAS air distribution configurations.

2.1 DIRECT SUPPLY TO EACH ZONE

In this configuration, the DOAS unit supplies conditioned outdoor air directly to each zone through a dedicated duct system and independent space diffusers, as shown in Figure 6. The DOAS unit may be sized to meet both the outdoor air and internal latent loads for the building, allowing the other equipment (either local or central) to address space sensible loads only. This approach is often used when local units are installed in the occupied space, such as packaged terminal air conditioners (PTACs), fan-coils, water-source heat pumps, VRF terminals, passive chilled beams, or radiant panels. This strategy can also be used if the local units are installed in the ceiling plenum, on the roof, or in a closet near the space.

One major advantage of this approach is that it is easy to ensure that the required outdoor airflow reaches each zone, because it can be measured through dedicated diffusers during start-up and balancing. In addition, if outdoor air is delivered at a cold temperature, rather than reheated to close to space set-point temperatures, this configuration offers the opportunity to downsize the local sensible cooling equipment.

The main drawback of this configuration is that it requires installation of additional ductwork and separate diffusers, resulting in added first costs. These costs can be largely offset, however, by downsizing sensible cooling equipment and saving energy by cycling local sensible-cooling equipment fans off when space temperature is satisfied.

2.2 SUPPLY TO INTAKE OF LOCAL UNITS

This configuration delivers conditioned outdoor air directly to the intake of each local unit, where it mixes with recirculated air from the zone. The local unit then conditions the mixture and delivers it to the space, thereby ensuring that required outdoor airflows are met. This approach is often used when local units are installed in the ceiling plenum, on the roof, or in a closet. Examples include water-source heat pumps, fan-coils, small rooftop units, or variable-refrigerant-flow (VRF) terminals.

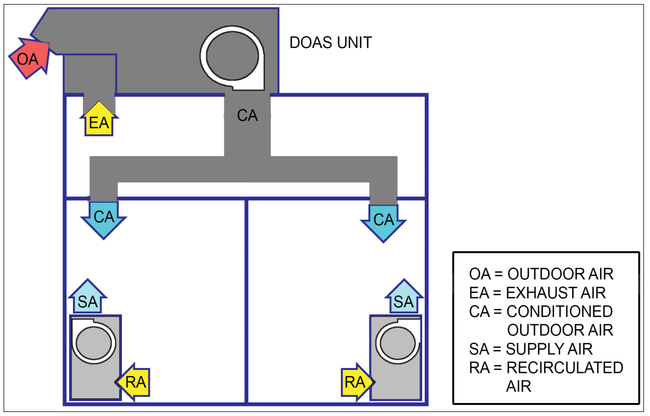

Fig. 6 Schematic of DOAS Supplying Conditioned Outdoor Air Directly to Each Zone
(Mumma et al. 2013)

This approach avoids some of the cost and space required to install additional ductwork and separate diffusers. However, because the local fan is used to deliver outdoor air to the zone, it must operate continuously whenever outdoor air is needed during occupancy. If it cycles on and off, or varies its speed, outdoor air delivery is compromised because of the pressure variations. Also, if the local unit ever delivers air at a temperature warmer than the space, outdoor airflow may need to be increased to account for a zone air distribution effectiveness E_z of <1.0 (see ASHRAE *Standard* 62.1). In addition, when the outdoor air is delivered at a cold temperature, it results in cool air entering the coil in the local unit. This must be considered during equipment selection, because it may affect cooling coil capacity and the need for reheat at the local unit.

Measurement/verification of outdoor airflow and balancing are typically more complicated in this scenario than if the outdoor air were delivered directly to the space.

2.3 DELIVERY TO SUPPLY SIDE OF LOCAL UNITS

In this configuration, conditioned outdoor air is ducted directly to the supply side of each local unit, where it mixes with supply air before being delivered to the zone through a common set of diffusers. This approach also ensures that required outdoor airflows are met, but in this case the local unit conditions only recirculated air.

This strategy is typically used when local units are installed in the ceiling plenum, on the roof, or in a closet. Examples include water-source heat pumps, fan-coils, small rooftop units, active chilled beams, or VRF terminals. If the outdoor air is delivered at a cold temperature, rather than reheated to near space temperature, this configuration offers the opportunity to downsize the local units.

Measurement and balancing, however, are more difficult than for direct delivery of outdoor air to the space. Additionally, the local fans typically need to operate continuously during occupancy to ensure sufficient outdoor air delivery. If the local fan cycles off or varies its speed, pressure in the supply duct decreases; this can interfere with air balancing of the DOAS and may result in backflow through the local units.

One solution is to install a pressure-independent damper or variable-air-volume (VAV) terminal in the DOAS ductwork to each zone to respond to changes in pressure, ensuring that the required outdoor airflow is delivered to the zone regardless of whether the local fan is operating. Including this VAV terminal has the added benefit of providing a means of incorporating demand-controlled ventilation.

If the local unit ever delivers air at a temperature warmer than the space, ventilation may need to be increased to account for $E_z < 1.0$ (ASHRAE *Standard* 62.1).

2.4 SUPPLY TO PLENUM NEAR LOCAL UNITS

In this approach, conditioned outdoor air is delivered to the open ceiling plenum (or closet), near the intake of each local unit. The outdoor air mixes with recirculated air in the plenum or closet before being drawn in through the intake of the local unit.

This strategy is sometimes used when local units are installed in the ceiling plenum or closet, such as water-source heat pumps, fan-coils, or VRF terminals. The primary advantage of this configuration is that it avoids much of the cost and space needed to install additional ductwork, separate diffusers, or mixing plenums on the local units.

However, it is difficult to ensure that the required amount of outdoor air reaches each zone, because it is not ducted directly. For this reason, ASHRAE *Standard* 62.1 contains words of caution about this approach. ASHRAE (2016) provides guidance on how (and how not) to design this type of system to minimize this drawback. For example, the DOAS ductwork should deliver conditioned outdoor air close to the intake of each local unit, and include some means of balancing to ensure that the correct amount of air is supplied to each unit. Additionally, the conditioned outdoor air typically cannot be delivered at a cold temperature in this configuration; in most cases, it must be reheated to avoid condensation on surfaces within the plenum or closet.

Because of these drawbacks, it is wise to consult both local codes and ASHRAE standards before designing a system that uses this configuration.

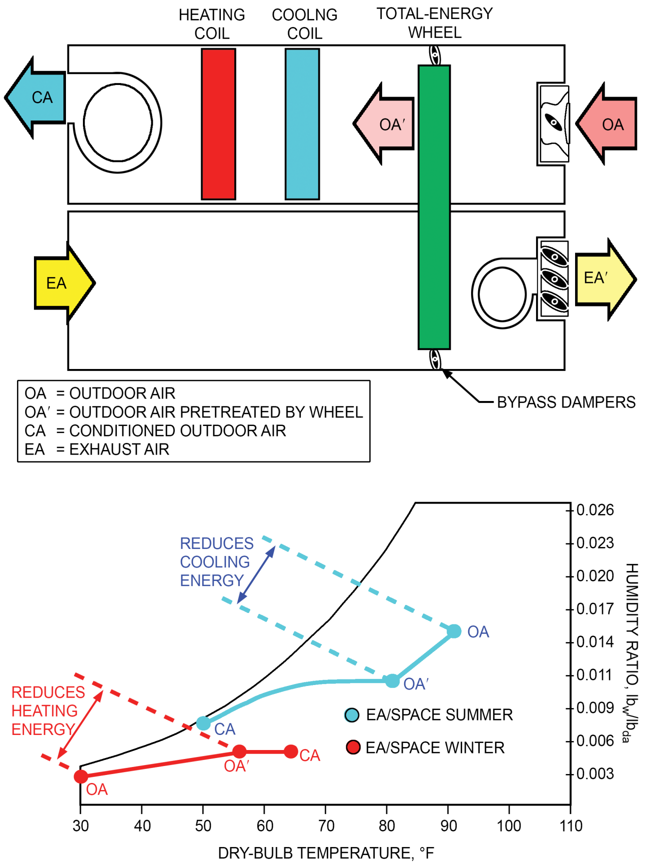

Fig. 7 Common DOAS Equipment Configuration with Total-Energy Wheel
(Mumma et al. 2013)

3. EQUIPMENT CONFIGURATIONS

DOAS units can incorporate a wide range of components, depending on the specific needs of the project. Common equipment components include

- Supply and/or exhaust fans
- Variable-speed drives
- Air-to-air energy recovery devices (coil loops, heat pipes, plate or membrane heat exchangers, wheels)
- Cooling coils (DX, chilled water)
- Desiccant dehumidification wheels
- Heating coils (hot water, indirect gas fired, or electric)
- Humidifiers
- Condenser heat recovery coils (hot-gas reheat)
- Motorized dampers
- Filters and other air cleaning devices
- Ultraviolet lights

The chosen combination of these components varies, depending on the application and climate. The following are common combinations (all units are assumed to include, at a minimum, a supply fan, a filter, and a cooling or heating coil):

- Cooling coil and reheat
- Exhaust air energy recovery
- Energy recovery and sensible reheat recovery
- Energy recovery and desiccant wheel

One typical configuration, shown in Figure 7, includes a total energy recovery wheel, a cooling coil, and a heating coil. The process is shown in the psychrometric chart for a winter and a summer condition. The outdoor air is preconditioned by the total energy wheel, reducing the amount of cooling and dehumidification required in the summer and reducing the amount of heating required in the winter. The heating coil preheats the outdoor air before the air leaves the DOAS when it is cold outdoors, and the cooling coil dehumidifies and cools the outdoor air when it is hot and/or humid.

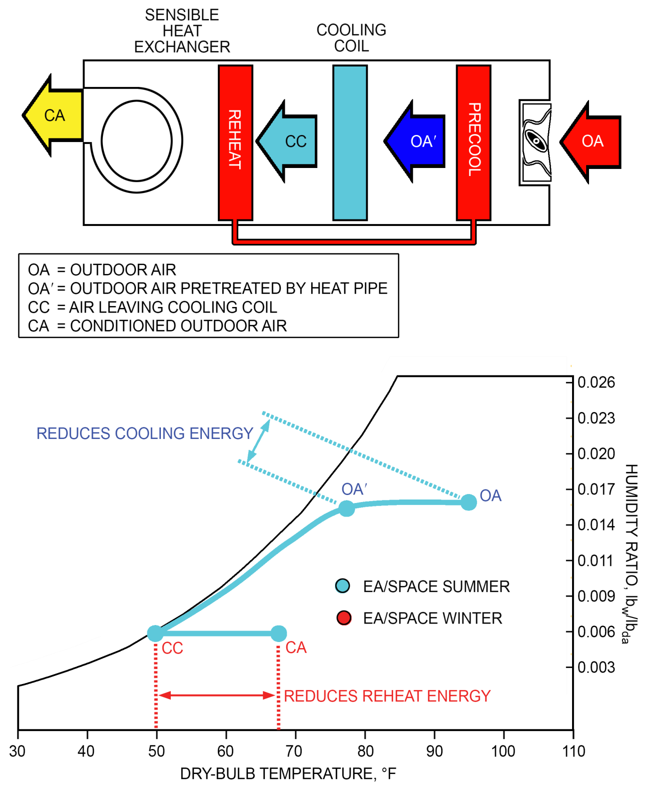

Fig. 8 Common DOAS Equipment Configuration with Heat Pipe

Another configuration, shown in Figure 8, includes a sensible energy recovery device [e.g., heat pipe (shown in Figure 8), coil loop, plate heat exchanger, wheel] in series with a cooling coil. The process is shown in the psychrometric chart for a summer condition. Outdoor air is precooled by the heat pipe, reducing the amount of cooling (and sometimes dehumidification) required. This heat is then transferred to reheat the dehumidified air leaving the cooling coil.

When selecting DOAS system configuration, the designer should be aware that

- Energy consumption of the DOAS fan(s) should be designed to be as small as possible.
- The typical function of DOAS units is to dry incoming outdoor air to a low dew point. If using DX cooling coils, determine what the lowest temperature leaving the DOAS will be, in light of the deepest cooling required of the compressors, and make sure this will not overcool occupied spaces or increase condensation in ducts. Be aware that ASHRAE *Standard* 90.1 cautions that, when reheat is needed to avoid overcooling, it is best to use recovered heat (e.g., condenser or compressor heat, waste heat) rather than new energy.
- Demand-controlled ventilation (DCV) with variable-speed fan drives or multispeed fans should be an option if the required rate of outdoor airflow will vary, as with minimum nighttime or weekend ventilation versus maximum ventilation during fully occupied hours.
- Incoming outdoor air must be filtered to protect the DOAS components. Beyond the minimum needed for equipment protection, be aware that removing particulate matter is a concern, and that filtration of the relatively small outdoor airstream is typically less costly than filtration after the outdoor air is mixed with recirculated return air to form a much larger air volume (Stephens et al. 2016; WHO 2005).
- Avoid overheating incoming outdoor air during swing seasons. The DOAS unit should preferably not use heat or heat recovery to warm the supply air when the building is predominantly in cooling mode; if heating is necessary, it should not be to above 60°F. This may require a controllable heat/energy recovery device. When it is cold outdoors, however, the DOAS unit may be used to heat the incoming air. How much heating capacity is required depends on whether exhaust air energy recovery is used, if the unit will be used for heating during unoccupied periods or morning warmup, and whether the terminal equipment is capable of heating.

3.1 CLIMATE IMPLICATIONS

When choosing a DOAS equipment configuration, the climate is one of the primary drivers.

In hot, humid climates, such as Miami or Singapore, active humidity control is a primary focus, and energy recovery devices combined with deep cooling coils and/or desiccant dehumidification devices are typically used to remove the constantly high latent loads.

For exceptionally hot and dry climates, such as Las Vegas, or dry, high-altitude climates, such as Bogotá or Mexico City, dehumidification may be less of a concern, and sensible heat recovery and cooling are a more constant need.

In cold climates, such as in Minneapolis and Moscow, recovering exhaust heat and/or providing heating in the DOAS is the primary consideration.

In mild climates, such as Seattle and Copenhagen, except for the matter of filtration, outdoor air is within an acceptable range of conditions for a considerable amount of time, so a DOAS might have less energy saving benefit, and a controllable energy recovery device is warranted.

4. CONTROL

Basic DOAS modes of operation for various outdoor conditions are shown in Figure 9 and Table 1. When it is hot and humid outdoors, the DOAS should dehumidify and cool the incoming outdoor air (dehumidification and cooling mode), but if it is hot and dry outdoors, the DOAS may only need to provide sensible cooling without dehumidification (sensible cooling mode). When it is cold outdoors, the DOAS may need to heat the incoming outdoor air (heating mode). For temperate climate conditions, it is beneficial to supply the outdoor air with no or minimal conditioning by the DOAS (ventilation only).

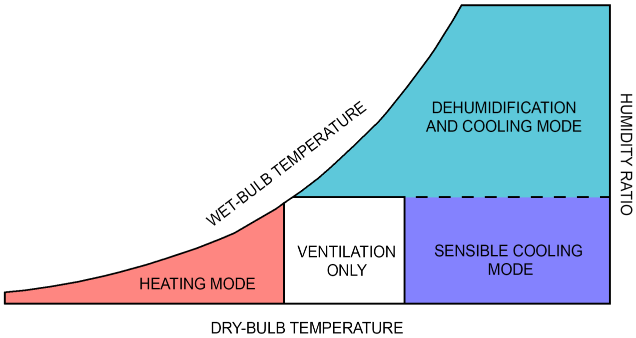

Fig. 9 Example of Dedicated Outdoor Air Unit Control Modes
(Murphy 2012)

Table 1 Example of Dedicated Outdoor Air Unit Control Modes

Control Mode	Outdoor Air Conditions
Dehumidification and cooling	Outdoor air dew point > Dehumidification enable set point
Sensible cooling	Outdoor air dew point ≤ Dehumidification enable set point Outdoor air dry bulb > Cooling enable set point
Ventilation only	Outdoor air dew point ≤ Dehumidification enable set point Heating enable set point ≤ Outdoor air dry-bulb temperature ≤ Cooling enable set point
Heating	Outdoor air dew point ≤ Dehumidification enable set point Outdoor air dry bulb < Heating enable set point

In addition to humidity control during occupied periods when ventilation is required, the DOAS can be used to control humidity during the unoccupied period (especially if equipped with a recirculating air damper). In this mode, the DOAS closes the outdoor air damper and opens the recirculating air damper, allowing recirculated return air to pass through the DOAS and be dehumidified. This ensures that the building stays dry when unoccupied. This can be particularly useful in climates where the outdoor dew point is higher than the occupied indoor temperature, because walls and other indoor surfaces stay cold for a while after a setback is enabled, and infiltration of humid outdoor air may cause the indoor dew point to rise above indoor surface temperatures, causing condensation.

4.1 METHODS TO AVOID OVERCOOLING CONDITIONED SPACES

The dry-bulb temperature at which air leaves the DOAS unit is typically a result of the dehumidification process. Generally, it is most energy efficient and cost effective to deliver the conditioned outdoor air as close as possible to the temperature that results from conditioning (dehumidifying in most cases), as long as it is acceptable for comfort in the space and consistent with the capabilities of the local equipment.

Although controlling the leaving-air temperature of a DOAS is not significantly different from a traditional system, determining whether to reheat may be somewhat different for a DOAS. Although the primary functions of a DOAS unit are outdoor air delivery and dehumidification, it should also assist in addressing space cooling loads if possible.

The amount of air delivered to the spaces from the DOAS is typically less than the minimum setting of a VAV terminal in a mixed-air system, because the DOAS provides only outdoor air. In a few cases, even this relatively small amount of cool air can be too much for the zone. If this happens, there are a few options to avoid overcooling:

- **Implement demand-controlled ventilation:** DCV reduces the flow rate of cool, dehumidified outdoor air delivered to the space during periods of reduced occupancy, reducing the chance that the space temperature will get too low. This is the most energy-efficient method (because it also reduces DOAS fan, cooling, and heating energy use), but has higher first cost.
- **Activate heat in local HVAC unit:** If the space temperature drops too low, local space heating devices (e.g., fan-coils, radiators, heat pumps, VRF terminals) can be activated. When only a few zones require heat, this is more energy efficient than reheating in the DOAS, because the other spaces still benefit from the cooling provided by the DOAS and do not need as much additional local cooling.
- **Reheat dehumidified air at the DOAS unit:** When several zones require heating, it might be more efficient to reheat the dehumidified outdoor air centrally in the DOAS unit, especially if recovered heat is available (e.g., waste heat, heat from DX condensers inside the unit itself).

To minimize the amount of reheat required, the DOAS supply-air temperature might be reset up from the required leaving-air dew-point temperature whenever the outdoor dew-point temperature is lower than the required leaving-air dew-point temperature.

Similar strategies can also be used during cold weather to determine how much to heat the incoming outdoor air.

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