Smart Dedicated Outdoor Air Systems

By John Murphy, Member ASHRAE

While not a new concept,[1] dedicated outdoor air systems are increasingly popular. However, many of the systems designed and installed today are suboptimal. This article discusses ways to optimize the design and control of dedicated outdoor air systems to lower both installed cost and energy use.

Basic, constant-volume HVAC equipment is traditionally *selected* with sufficient cooling capacity to handle the peak cooling load and *controlled* by a thermostat that matches the sensible cooling performed by the equipment to the sensible cooling load. Therefore, as the sensible cooling load in the space decreases, the total cooling (both sensible and latent) provided by the HVAC equipment also decreases. In many applications, this results in elevated space relative humidity levels at part-load conditions.[2]

A dedicated outdoor air system uses a separate unit to condition all of the outdoor air brought into the building for ventilation, and then delivers it either directly to each occupied space or to the individual local units or air handlers

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serving those spaces (*Figure 1*). Meanwhile, local HVAC units in or near each space maintain space temperature by treating just recirculated indoor air. Treating the outdoor air *separately* from recirculated return air makes it easy to verify sufficient ventilation airflow and enables enforcement of a maximum humidity limit in the occupied spaces.

To optimize both installed cost and energy use of dedicated outdoor air systems, consider the following.

1. Deliver Conditioned OA Drier Than the Space

Regardless of where the conditioned outdoor air is delivered, the dedicated outdoor air unit should dehumidify the outdoor air so that it is drier than the space. Delivering the air drier than the space offsets the latent cooling loads associated with ventilation. If the dew-point temperature of the conditioned outdoor air (CA) is lower than the dew point in the space (*Figure 2*), it also can offset some, or all, of the space latent loads.

This adequately limits indoor humidity at both full load and part load without needing additional dehumidification enhancements in the local HVAC units. The local units only need to offset the space sensible cooling loads. Some refer to this as "decoupling" the dehumidification load from the space sensible load.

A side benefit of this approach is that the local units operate with dry coils under most conditions. With the dedicated outdoor air unit offsetting the space latent loads, the space dew point often will be below the dry-bulb temperature of the air supplied by the local units. Under such conditions, little or no moisture condenses on local cooling coils, reducing the potential to clog and overflow drain pans. (In draw-through applications, special condensate traps may be necessary to maintain an air seal.)

To provide the desired dehumidification, the dedicated outdoor air unit commonly is sized to offset the sensible and latent loads of the outdoor air brought into the building for ventilation, and to deliver the air dry enough to also offset the space latent loads. Previous *ASHRAE Journal* articles[3,4] included a step-by-step method for sizing the dedicated outdoor air unit using this approach.

For most comfort-cooling applications, sizing the dedicated outdoor air unit to limit space relative humidity to 60% or 65%, at worst-case conditions, is generally considered acceptable and complies with requirements recently added to ANSI/ASHRAE Standard 62.1-2004, *Ventilation for Acceptable Indoor Air Quality* (Section 5.10).[6] Designing for lower indoor humidity levels is certainly possible, but requires larger equipment, increasing installed cost and energy consumption.

2. Deliver Conditioned OA Cold Rather Than Neutral

Many dedicated outdoor air systems are designed to dehumidify the outdoor air so it is drier than the space, and then reheat it to approximately space temperature (neutral). If the conditioned outdoor air is delivered directly to the space, delivering it at a neutral dry-bulb temperature can simplify local comfort control because it has no impact on space sensible loads.

However, when a chilled-water or DX coil is used to dehumidify the outdoor air, a byproduct of that process is that the dry-bulb temperature of the air leaving the coil is colder than the space (*Figure 2*). If the dehumidified outdoor air (DH) is reheated to neutral (CA), the sensible cooling performed by the dedicated outdoor air unit is wasted.

In contrast, if the dedicated outdoor air unit dehumidifies the outdoor air, but then delivers the conditioned air "cold" (not reheated to neutral), the low dry-bulb temperature offsets part of the sensible cooling load in the space. At design load, this means less cooling capacity is required from the local HVAC equipment than in a neutral air system.

For an example elementary school, the dedicated outdoor air unit cools and dehumidifies the outdoor air to 52°F (11°C)

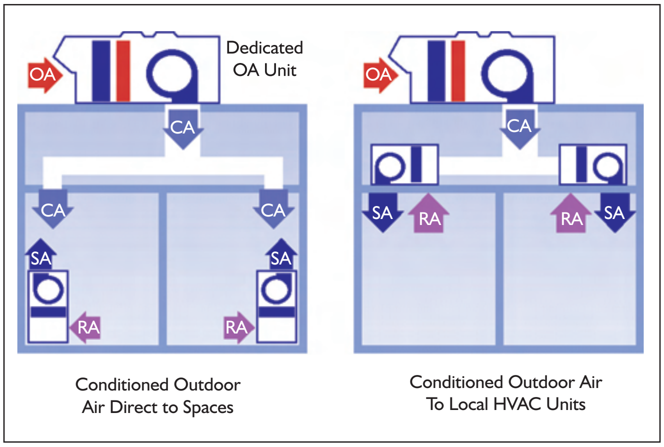

Figure 1: Common dedicated outdoor air system configurations.

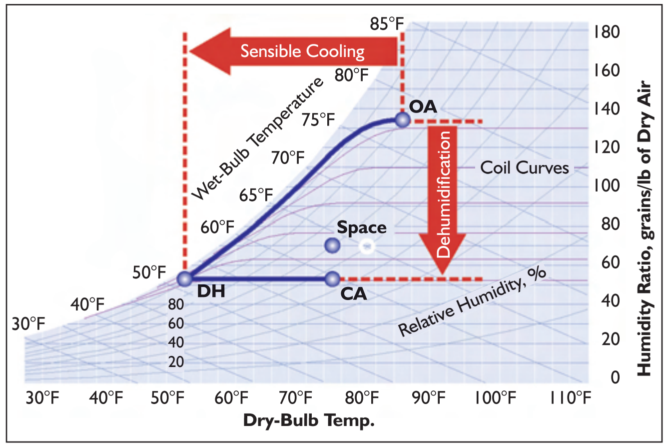

Figure 2: Sensible cooling is a by-product of 'cold-coil' dehumidification.

dew point, then reheats the air to 71°F (22°C) dry bulb before delivering it directly into the classrooms. The dew point of this conditioned outdoor air is low enough to offset the latent load in the classrooms, but because it is delivered at a dry-bulb temperature that is near the space temperature (74°F [23°C]), it offsets only a small portion of the sensible cooling load in the classrooms.

Consider, however, if the dedicated outdoor air unit dehumidifies the outdoor air to the same dew point, but delivers it cold (not reheated). The conditioned outdoor air is still dry enough to offset the latent load in the classrooms, but because it is delivered at a dry-bulb temperature that is much lower than the space temperature (52°F [11°C] vs. 74°F [23°C]), it offsets a significant portion of the sensible cooling load in the classrooms. This reduces the sensible load that must be offset by the local HVAC unit, allowing the local units to be sized for less airflow and less cooling capacity than in a neutral air system (*Table 1*).[7]

Dedicated OA System Configuration	Cooling Capacity Of Local HVAC Unit	Supply Airflow Of Local HVAC Unit
"Neutral" To Space	2.8 tons (9.8 kW)	1,500 cfm (0.7 m³/s)
"Cold" To Space	1.8 tons (6.3 kW)	1,050 cfm (0.5 m³/s)
"Neutral" To Units	2.8 tons (9.8 kW)	1,500 cfm (0.7 m³/s)
"Cold" To Units	1.8 tons (6.3 kW)	1,500 cfm (0.7 m³/s)

Table 1: Delivering conditioned OA "neutral" vs. "cold."

Since both systems dehumidify the same quantity of outdoor air to the same leaving air dew point, the required cooling capacity and airflow of the dedicated outdoor air unit are the same whether the outdoor air is delivered neutral or cold.

Compared with a neutral air system, a dedicated outdoor air system that delivers *cold* air directly to the occupied spaces:

- Requires less overall cooling capacity. The required cooling capacity of each local HVAC unit is less than in a neutral air system, and the required capacity of the dedicated outdoor air unit is the same for both configurations.
- Requires less overall cooling energy for much of the year. By taking advantage of the sensible cooling already done by the dedicated outdoor air unit, the cold air system requires less cooling energy at each local HVAC unit. The neutral air system throws away this sensible cooling benefit by reheating the air to approximately space temperature.
- May require less reheat energy. If "new" (not recovered) energy is used to reheat the dehumidified outdoor air, a cold air system avoids the energy costs of reheating for much of the year.
- Requires less overall fan airflow and, therefore, less overall fan energy. The supply airflow delivered by each local HVAC unit is less than in a neutral air system, and the airflow delivered by the dedicated outdoor air unit is the same for both configurations.

Less supply airflow and less cooling capacity mean smaller local HVAC equipment, which can lower the initial cost and increase usable floor space, *or* provide an acoustical benefit by keeping the same sized cabinet and operating the fan at a lower speed.

In addition, if the fan in the local HVAC unit cycles on and off with the compressor or two-position water valve—as may be the case in a water-source heat pump or a fan-coil unit—the runtime of the local fan will be less at part-load conditions than in a neutral air system.

What happens if conditioned outdoor air is delivered to the local HVAC units, rather than directly to the spaces? When the conditioned outdoor air is delivered cold to the local HVAC units, it mixes with recirculated return air from the space (*Figure 1,* right-hand graphic). The resulting mixed air enthalpy is lower, which reduces the cooling capacity required by the coils in the local units. Because the conditioned outdoor air is not delivered directly to the space, the sensible cooling load in the space is unchanged, so supply airflow is unaffected (*Table 1*). Also, since the local fan is tasked with delivering the outdoor air to the space, it cannot cycle off without interrupting ventilation to the space.

When should the conditioned OA be reheated? While the conditioned outdoor air should be delivered cold whenever possible, there are times when the dedicated outdoor air unit should reheat the dehumidified outdoor air.

The first consideration is **occupant comfort**. As explained earlier, delivering the conditioned outdoor air at a dry-bulb temperature colder than the space offsets part of the sensible cooling load in the space.

As the space sensible cooling load decreases—due to changes in outdoor conditions and internal loads—it is possible that the cold, conditioned outdoor air may provide more sensible cooling than the space requires. The result is that the space dry-bulb temperature drops.

To avoid overcooling, the local HVAC unit could add heat to the space if a source of heat is available (i.e., if the boiler is not shut off for the season). If this occurs in only a few spaces, the sensible cooling energy benefit to the remaining spaces may offset the heating energy needed for these few spaces. However, if the source of reheat energy in the dedicated outdoor air unit is recovered from another part of the system (hot gas reheat or an air-to-air heat exchanger, for example), it may be more economical to reheat the conditioned outdoor air to avoid overcooling any of the spaces. This will be discussed further in the next section of this article.

In hotel guestrooms or dormitories, where the sensible cooling loads are often drastically different in various spaces, there may be many hours when overcooling occurs in at least one space. For these applications, it may be simpler to deliver the conditioned outdoor air at a neutral temperature because the benefit of delivering the air cold occurs less frequently. But in classrooms or offices, space sensible cooling loads are relatively high during daytime hours. In fact, for some climates, classrooms may never reach the point when overcooling occurs during occupied hours. These applications are well-suited for delivering the conditioned outdoor air cold.

Finally, for applications that require lower-than-normal space dew points, the outdoor air may be dehumidified to the point where the dry-bulb temperature of the air leaving the cooling coil is colder than the designer is willing to discharge directly into an occupied space—below 45°F (7°C) for example. In this case, the dehumidified outdoor air could be reheated to a more traditional supply air temperature—55°F (13°C) for example.

The second consideration has to do with **proper selection of the local units**. The pre-matched components of packaged DX equipment (rooftop units, packaged terminal air conditioners, water-source heat pumps) typically limit selection to a finite cfm/ton (m^3/s/kW) range of application.

As explained earlier, if cold, conditioned outdoor air is delivered *directly to the local HVAC units*, it reduces the cooling capacity (tons [kW]) required by the local unit. However, supply airflow (cfm [m^3/s]) is unaffected. This lowers the cfm/ton (m^3/s/kW) required of the local unit, possibly below the minimum allowed for the equipment.

In the case where conditioned outdoor air is delivered directly to local HVAC units that have a limited cfm/ton (m^3/s/kW) range for selection, the dehumidified outdoor air should be reheated (but not necessarily all the way to neutral) to allow proper selection of the local units. This is not an issue if the conditioned outdoor air is delivered directly to the space.

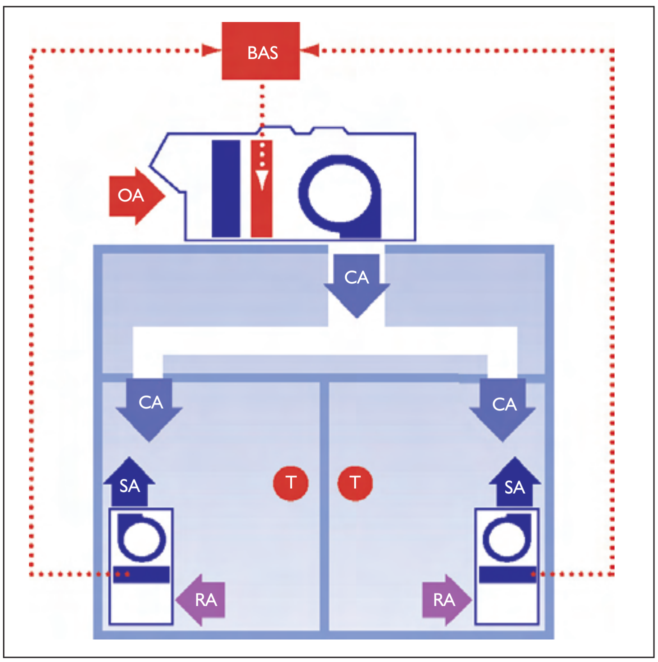

Figure 3: Resetting CA dry bulb based on critical space.

The third consideration is to **avoid condensation**. Since water-source heat pumps installed in the ceiling plenum traditionally do not have mixing boxes, dedicated outdoor air systems used with that type of equipment sometimes deliver the conditioned outdoor air in *close proximity* to the return air inlet of each heat pump. The outdoor air mixes with the recirculated return air in the ceiling plenum prior to entering each local unit.

In this configuration, the dry-bulb temperature of the conditioned outdoor air delivered to the ceiling plenum should be well above the expected dew-point temperature of the air within the plenum. If cold air is dumped into the ceiling plenum, it could cool surfaces (beams, electrical conduit, ceiling framework). At night, when the dedicated outdoor air unit is off, wind or operating exhaust fans may cause humid outdoor air to leak into the plenum, which might lead to condensation on these cold surfaces.

3. Use System-Level Controls

Many dedicated outdoor air systems are designed to deliver conditioned outdoor air at a constant dry-bulb temperature and dew point that does not exceed a setpoint. This control approach is simple because it allows the dedicated outdoor air unit to operate independently of the local HVAC units. However, implementing a few system-level control strategies can help minimize the additional energy cost of separately treating outdoor air.

Resetting Reheat Capacity

First, in a system delivering the conditioned outdoor air cold, reset the dry-bulb temperature delivered by the dedicated outdoor air unit, so it uses reheat only when needed to avoid overcooling any of the spaces. Why reheat the dehumidified air to neutral on the hottest day of the summer when all spaces need cooling? Instead, deliver the air cold to offset some of the space sensible cooling loads. As mentioned earlier, this can also allow the local HVAC units to be downsized, which helps offset some of the added cost of the dedicated outdoor air system.

How do you control the reheat coil to avoid overcooling any spaces? A simple approach would be to activate the reheat coil—reheating the dehumidified outdoor air to neutral—whenever the ambient temperature drops to the point where the sensible load in some spaces is expected to be low enough to result in overcooling (say 80°F [27°C], but this limit could be changed after a few months of experience in operating the system).

An even more effective way to implement this strategy is to use a building automation system (BAS) to monitor all of the local HVAC units and to identify the critical space—that is, the space with the lowest sensible cooling load, which is most at risk of overcooling (*Figure 3*). If the local units use modulating chilled-water coils, the BAS could monitor the position of each chilled-water control valve. The space with the lowest cooling load is served by the unit whose control valve is the most nearly closed. Alternatively, the BAS could monitor the space temperatures; the critical space is the one with a temperature closest to its heating setpoint.

Based on a signal from the BAS, the dedicated outdoor air unit then increases its *reheat* capacity, resetting the leaving air dry-bulb temperature upward just enough to prevent the critical space from overcooling. (The dew point of the conditioned air is controlled independently to meet the humidity control requirements of the spaces.)

This optimization strategy provides conditioned outdoor air that offsets as much of the sensible cooling loads in the spaces as possible *without* overcooling any space, avoiding the need for any local units to activate their heating coils. This provides the greatest benefit when the dedicated outdoor air unit uses recovered energy for reheat, thereby avoiding the use of "new" energy for reheat, both at the dedicated outdoor air unit and at the local units.

Dynamically resetting the dry-bulb temperature of the conditioned outdoor air provides a unique benefit in a two-pipe system, especially if the dedicated outdoor air unit is a packaged piece of equipment that is not connected to the chiller or boiler plant. When the two-pipe system is in cooling mode (boiler off), the dry-bulb temperature supplied by the dedicated outdoor air unit is reset upward (by modulating the reheat) just enough to prevent overcooling the critical space. When the system is in heating mode (chiller off), the temperature is reset downward just enough to prevent overheating the critical space. This improves occupant comfort during changeover periods, and can save energy by minimizing the number of times the system changes over between cooling and heating modes.

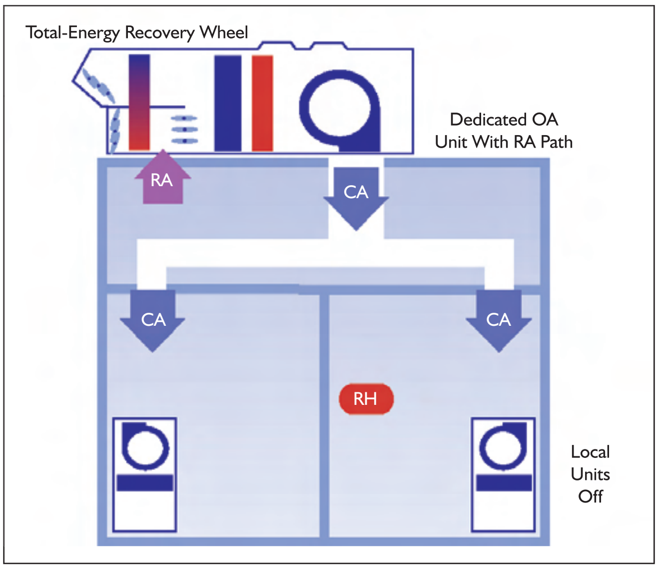

Figure 4: After-hours humidity control.

Resetting Dehumidification Capacity

When the sensible cooling load in the space is high, the local HVAC unit may offset part of the latent load. When the latent load in the space is low, the need for dehumidification is also lessened. In either situation, the dew point for the conditioned outdoor air could be reset upward to reduce dehumidification energy.

A humidity sensor could be installed in each space (or in several representative spaces) with a BAS polling these sensors to determine the critical space—that is, the space with the highest humidity. Based on a signal from the BAS, the dedicated outdoor air unit then reduces its *dehumidification* capacity, raising the leaving air dew point just enough to still maintain the humidity level in the critical space at the desired upper limit. By responding to actual humidity conditions, the system maintains the humidity at or below the desired upper limit in *all* spaces while minimizing dehumidification energy.

4. Consider After-Hours Humidity Control

When the dedicated outdoor air unit delivers conditioned outdoor air directly to the spaces, adding a return air path permits after-hours humidity control *without operating the local HVAC terminals* (*Figure 4*). And, if the dedicated outdoor air unit is a packaged piece of equipment, it eliminates after-hours operation of a central chilled-water plant.

When after-hours dehumidification is required, the dedicated outdoor air unit closes the outdoor air damper and opens the return air damper to avoid conditioning unneeded outdoor air. Due to the low sensible cooling loads during this time, a source of reheat in the dedicated outdoor air unit typically is necessary to avoid overcooling the building.

5. Use Exhaust Air Energy Recovery

Finally, because all the outdoor air is brought in at a central location, consider including an air-to-air energy recovery device to precondition the outdoor air (*Figure 4*). This reduces operating costs and may allow downsizing of the mechanical cooling, dehumidification, heating, and humidification equipment. Also, it can help justify the added cost of routing the building exhaust back to the dedicated outdoor air handler when a return air path is desired for after-hours humidity control. In non-arid climates, total-energy (or enthalpy) recovery devices typically result in a greater potential for equipment downsizing, and more energy savings, than sensible-energy recovery devices.[6]

Summary

Many of the dedicated outdoor air systems being designed and installed today are suboptimal, but there are ways to design and control these systems to lower both installed cost and energy use.

Consider delivering the conditioned outdoor air "cold" whenever possible, and use recovered energy to reheat only when needed. Providing cold (rather than neutral) air from the dedicated outdoor air unit offsets a portion of the space cooling loads, allowing the local HVAC units to be downsized and use less energy. In addition, implementing system-level control strategies and exhaust air energy recovery can help minimize the additional energy cost of separately treating outdoor air.

References

1. Trane. 1965. *Air Conditioning Manual*.
2. Murphy, J. and B. Bradley. 2004. "Better part-load dehumidification." *Trane Engineers Newsletter* 33(2).
3. Morris, W. 2003. "The ABCs of DOAS: dedicated outdoor air systems." *ASHRAE Journal* 45(5).
4. Trane. 2003. *Designing Dedicated Outdoor-Air Systems*. (Trane Applications Engineering Guide SYS-APG001-EN).
5. U.S. Environmental Protection Agency. 2001. *Mold Remediation in Schools and Commercial Buildings*, EPA 402-K-01-001 (March). www.epa.gov/iaq/molds.
6. Murphy, J. 2002. *Air-to-Air Energy Recovery in HVAC Systems.* (Trane Applications Engineering Manual SYS-APM003-EN).
7. Murphy, J. 2002. *Dehumidification in HVAC Systems.* (Trane Applications Engineering Manual SYS-APM004-EN).