

Ventilation Control In Terminal Units With Variable Speed Fan Control

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Today, many terminal-style HVAC products are equipped with variable speed fan control. Ensuring that code-required outdoor airflow is delivered to the zone as the fan speed changes can be a challenge. This article explains how changing the terminal fan speed impacts ventilation, and describes various solutions to address this challenge.

For the purpose of this article, a “terminal unit” is a piece of HVAC equipment located in or near each thermal zone, which provides cooling and/or heating for the zone. Common examples of terminal units that can be equipped with variable speed fan control include water-source heat pumps (WSHP), fan coils, blower coils, classroom unit ventilators, and variable refrigerant flow (VRF) terminals.

In some applications, outdoor air for ventilation enters the building through each terminal unit directly; while in others, it enters through a separate, dedicated outdoor air system (DOAS).

When OA is Brought in Through Each Terminal Unit Directly

Introducing outdoor air directly through each terminal unit is a common approach used with classroom unit ventilators, blower coils, and rooftop-style WSHPs. In this case, the terminal unit is typically equipped with an outdoor air (OA) damper.

If the terminal unit is equipped with constant speed fan control, proper ventilation can be achieved by setting the

position of the OA damper during startup and balancing so that the code-required outdoor airflow enters the zone. Whenever the zone is in the occupied mode, the controller opens the OA damper to this predetermined position.

However, if the terminal unit is equipped with variable speed fan control, ensuring proper ventilation is not as simple. To demonstrate, *Figure 1* depicts the static pressure as air moves through the various components of an example terminal unit.

The fan inside the terminal unit must create a high enough pressure at the fan discharge (A) to overcome the pressure losses associated with pushing the air through the supply ductwork and diffusers, and into the zone. In addition, the fan must create a low enough pressure at its inlet (B) to overcome pressure losses associated with drawing the return air out of the zone and through the return air path (which might include a return grille, ceiling plenum, and some ductwork), and then to draw the air through the return air damper, filter, and coils inside the terminal unit.

For this example, the mixing box is where outdoor air mixes with the recirculated air. Due to the pressure loss through the return air path and damper, the static pressure inside this mixing box (C) is negative (lower than the pressure outside the building). This causes outdoor air to be drawn into this mixing box. During startup and balancing, the return-air damper is adjusted so that the pressure inside the mixing box is low enough to ensure that the code-required outdoor airflow enters through the OA damper.

In a terminal unit with variable speed fan control, the fan slows to reduce supply airflow during part-load operation. Pushing less air through the supply ductwork and diffusers results in less pressure loss, so less pressure is needed at the fan discharge (D). In the same manner, moving less air through the return air path also results in less pressure loss. This causes the static pressure inside the mixing box (E) to increase (that is, it is not as negative as at design airflow).

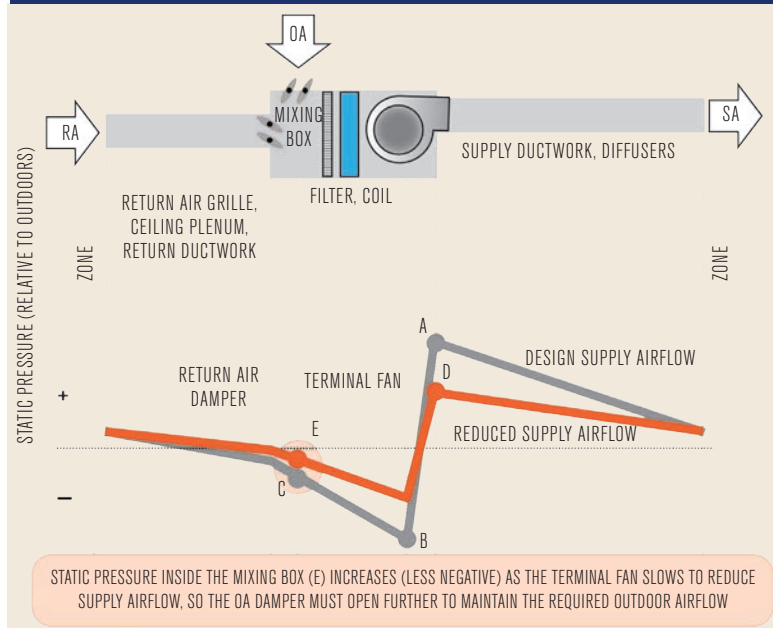
The static pressure inside the mixing box (E) has a direct effect on how much outdoor air enters the terminal unit. If the OA damper remains set at a fixed position, the quantity of outdoor air entering through this damper decreases when the pressure inside the mixing box is not as negative. The result is that outdoor airflow decreases as fan speed and supply airflow are reduced.

To ensure that the same quantity of outdoor air enters the zone, the OA damper needs to be opened further as the fan speed is reduced. This requires a control strategy beyond the “set it and forget it” fixed-position OA damper that is used with a constant speed fan.

While there are certainly other approaches, a few ways to ensure proper outdoor airflow in a terminal unit equipped with an OA damper and variable speed fan control are discussed next.

Two-position OA damper control. For a terminal unit equipped with automatic, two-speed fan control, two position setpoints can be used to control the OA damper. When the fan operates at high speed, the OA damper position is set to bring in the code-required quantity of outdoor air. Whenever the controller switches the fan to operate at low speed, the OA damper is adjusted to a further-open position to bring in the same quantity of outdoor air.

FIGURE 1 Need for outdoor airflow control when variable speed fan control is used.



Also, note that these are minimum position setpoints. If the terminal unit includes an airside economizer, the OA damper may be opened further when conditions are suitable for economizer cooling.

Proportional control of OA damper. For a terminal unit equipped with variable speed fan control, one solution could be to modulate the position of the OA damper in proportion to the changing supply fan speed (Figure 2).

With the terminal unit operating at design supply airflow (maximum fan speed), the OA damper position is set to bring in the quantity of outdoor air required by code (OA damper position at maximum fan speed). Then with the terminal unit operating at minimum airflow (minimum fan speed), the OA damper is opened further to bring in the same quantity of outdoor air (OA damper position at minimum fan speed).

During operation, the controller modulates the position of the OA damper in proportion to the change in fan speed. Again, this is the minimum damper setpoint, so the OA damper may be opened further when conditions are suitable for airside economizing.

This method is not perfectly accurate over the entire range of airflows, since damper performance is nonlinear. Therefore, this approach results in some over-ventilation in the middle of the fan speed range, but much less over-ventilation than if a fixed-position OA damper is used (see sidebar, “Fixed-Position OA Damper With Variable Speed Terminal Fan Control”). However, since

this is a relatively inexpensive solution, it is likely to be used in most applications that use smaller terminal units.

Direct OA flow measurement and control. Another method for controlling ventilation could be to measure the outdoor airflow and control it directly. This might be accomplished using a flow-measuring device in the outdoor airstream.

This method is more accurate over the full range of airflows than proportional control, and responds to pressure fluctuations caused by wind or stack effect. However, outdoor airflow measurement requires space, so it is not always feasible in smaller terminal units; and it increases terminal unit cost and maintenance. For these reasons, this approach is more likely to be used in larger equipment and less likely in smaller terminal units.

Deliver OA directly to each zone with a DOAS. Alternatively, a dedicated outdoor air system could be used to deliver outdoor air directly to each zone. This approach is discussed next.

When OA is Delivered by a Separate DOAS

Using a separate system to condition and deliver outdoor air for ventilation is a common approach with water-source heat pumps, fan-coils, or VRF terminals.

In some applications, the DOAS delivers the conditioned outdoor air (CA) directly to the inlet side of each terminal unit (Figure 3). For equipment installed in the ceiling plenum, the outdoor air might be ducted to a mixing box on the terminal unit. For equipment installed in a mechanical “closet” adjacent to the zone, the outdoor air might be ducted to the closet, which is used as a mixing chamber

FIGURE 2 Proportional control of OA damper.

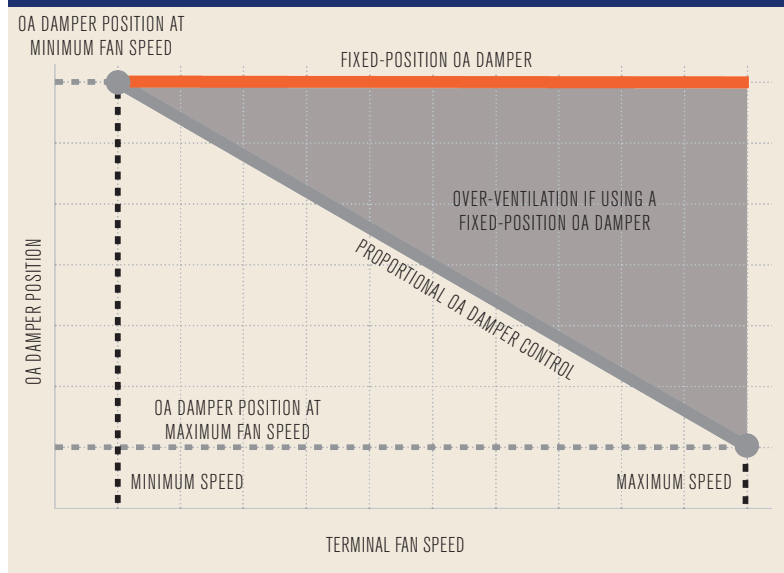
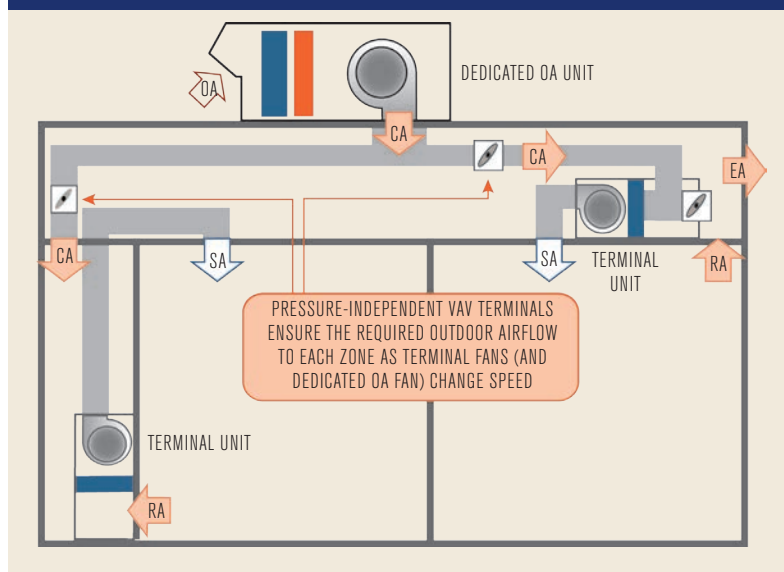


FIGURE 3 Conditioned OA delivered to the inlet of each terminal unit.



(see sidebar, “Conditioned OA Delivered to the Open Ceiling Plenum, Near Each Terminal Unit”).

As described earlier, when a terminal unit is equipped with variable speed fan control, the static pressure

Fixed-Position OA Damper With Variable Speed Terminal Fan Control

Section 5.3 of ASHRAE Standard 62.1-2010 states:

“The system shall be designed to maintain no less than the minimum outdoor airflow as required by Section 6 under any load condition. Note: Variable Air Volume (VAV) systems with fixed outdoor air damper positions must comply with this requirement at minimum system primary airflow.”

This means that the OA damper position must be set to bring in the minimum required outdoor airflow when the fan is operating at minimum speed, which results in more-than-minimum outdoor airflow (over-ventilation) and increased energy use when the fan operates at higher speeds (Figure 2).

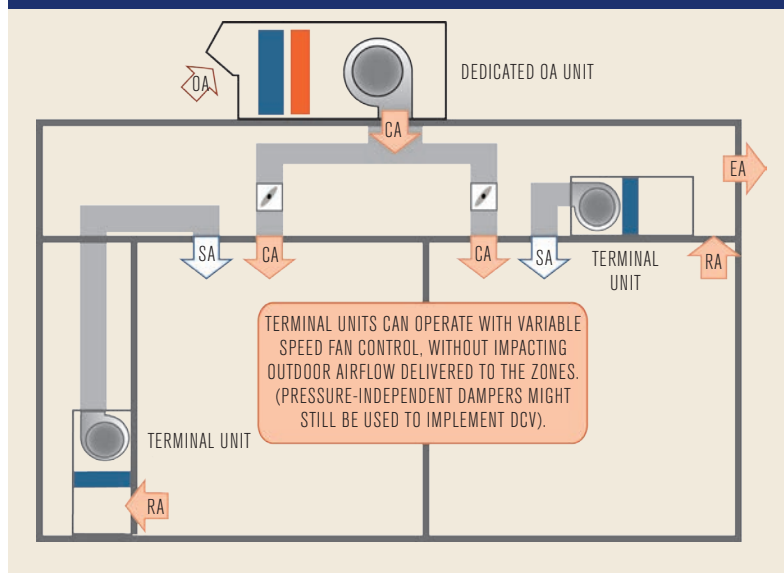
inside the mixing box is not as negative when the terminal fan slows to reduce supply airflow; so outdoor airflow will decrease. An added challenge is that outdoor air is delivered to this mixing box by a separate fan in the dedicated OA unit, and the static pressure inside the ventilation system ductwork is influenced by the changing operation of all the terminal unit fans served by that dedicated OA system.

Direct OA flow measurement and control. One approach to address this challenge could be to install pressure-independent dampers (such as VAV terminals) in the OA ductwork to ensure that the required outdoor airflow is delivered to each zone (Figure 3). As the various terminal fans (or the fan inside the dedicated OA unit) change speed, this damper modulates to maintain the same quantity of outdoor air delivered.

Deliver OA directly to each zone. The approach preferred by this author would be to deliver the conditioned outdoor air (CA) directly to each zone (Figure 4).^{1,2} In this case, the terminal unit conditions only recirculated air (RA). Since the outdoor air is not distributed through the terminal unit fan, it can operate with variable speed fan control (or even cycle off when the zone requires no cooling or heating), without impacting how much outdoor air is delivered to the zone; and pressure-independent dampers may not be necessary.

While maybe not necessary in all cases, HVAC design engineers may still choose to include pressure-independent dampers in the dedicated OA system to allow outdoor airflow to be shut off to zones that are unoccupied while other zones are still occupied. In addition, these

FIGURE 4 Conditioned OA delivered directly to each zone.



dampers could be used to implement demand-controlled ventilation and reduce outdoor airflow delivered to a zone during periods of reduced population.

This “direct-to-the-zone” approach also affords the opportunity to deliver dehumidified outdoor air at a cold temperature, rather than reheated to neutral. This has several installed cost and energy-saving benefits (see sidebar, “Cold Versus Neutral Air Delivery”).

Demand-Controlled Ventilation

The control strategies discussed thus far attempt to ensure that code-required outdoor airflow (design outdoor airflow) is delivered to the zone as the terminal fan speed changes. In some zones, demand-controlled ventilation (DCV) might be used to reduce outdoor airflow during periods of reduced population, in an effort to reduce energy use associated with cooling

Conditioned OA Delivered to the Open Ceiling Plenum, Near Each Terminal Unit

In some DOAS projects, the conditioned outdoor air is ducted to discharge into the ceiling plenum, near the intake of the terminal unit, where it mixes with recirculated air before being drawn in through the intake.

This approach avoids the cost and space needed to install additional ductwork, separate diffusers, or mixing boxes, but it makes it more difficult to ensure that the required outdoor airflow reaches each terminal unit. In addition, the conditioned outdoor air may not be able to be delivered at a cold temperature, due to concerns

over condensation within the ceiling plenum.

While changing the terminal fan speed may not have much effect on the static pressure in a large, open ceiling plenum, balancing the system to ensure that the required outdoor airflow reaches each terminal unit gets complicated when lots of terminal units, each equipped with variable speed fan control, are drawing air out of the same ceiling plenum. Pressure-independent dampers in the OA ductwork are likely needed to ensure that the required outdoor airflow reaches each terminal unit.

or heating the outdoor air.³ In fact, Section 6.4.3.9 of ASHRAE Standard 90.1-2010 requires DCV in any zone with a design occupancy greater than 40 people per 1,000 ft² (100 m²); and the 2013 edition lowers this threshold to any zone with 25 or more people per 1,000 ft² (100 m²).

Section 6.2.7 of ASHRAE Standard 62.1-2010 explicitly permits the use of DCV, and lists some common DCV technologies (such as CO₂ sensors and occupancy sensors). This section also includes requirements for how DCV is to be implemented. For example, while the controls can reduce the people component of the ventilation rate ($R_p \times P_z$) during periods of reduced population, the outdoor airflow delivered to a zone cannot be any lower than the building component of the ventilation rate ($R_a \times A_z$).

“6.2.7.1.2. The breathing zone outdoor airflow (V_{bz}) shall be reset in response to current occupancy and shall be no less than the building component ($R_a \times A_z$) of the DCV zone. *Note:* Examples of reset methods or devices include population counters, carbon dioxide (CO₂) sensors, timers, occupancy schedules or occupancy sensors.”

Section 8.3 clarifies that this applies whenever a zone is “expected” to be occupied. That is, the standard does not require this building component of the ventilation rate to be delivered to every zone 24

Cold Vs. Neutral Air Delivery

Many dedicated OA systems are designed to dehumidify the outdoor air—dry enough to offset all or most of the indoor latent loads—and then reheat it to approximately zone temperature (neutral). Delivering the dehumidified outdoor air at a neutral dry-bulb temperature can simplify control because it has no impact on the zone sensible cooling or heating loads.

However, when a chilled-water or direct-expansion (DX) cooling coil is used for dehumidification, a by-product of that process is that the dry-bulb temperature of the air leaving the coil is colder than the zone. If the dehumidified outdoor air is reheated to neutral, most of the sensible cooling performed by the dedicated OA unit is wasted.

If the dedicated OA system delivers air directly to each zone (Figure 4), the dehumidified outdoor air can be delivered cold, rather than reheated to neutral for much of the year. The cold dry-bulb temperature of the conditioned outdoor air (CA) offsets part of the sensible cooling load in the zone, reducing the energy used by the local terminal units. In addition, at design conditions, this may allow the terminal units to be smaller—sized for less airflow and less cooling capacity—than in a neutral-air system.^{1,2}

TABLE 1 Comparison of ventilation control methods used with variable speed terminal fan control.

VENTILATION CONTROL METHOD	ADVANTAGES	DRAWBACKS
Two-Position OA Damper Control	▪ Less expensive and less maintenance than direct flow measurement ▪ Well-suited for use with automatic, two-speed fan control.	▪ Less accurate (more over-ventilation) than proportional control when variable speed fan control is used. ▪ Requires two OA damper position settings by installer.
Proportional Control of OA Damper	▪ Less expensive and less maintenance than direct flow measurement. ▪ More accurate (less over-ventilation) than two-position damper control when variable speed fan control is used.	▪ Less accurate (more over-ventilation) than direct flow measurement. ▪ Requires two OA damper position settings by installer.
Direct OA Flow Measurement And Control	▪ More accurate (less over-ventilation) than two-position or proportional control. ▪ Affords the opportunity to document outdoor airflow delivered.	▪ More expensive, and may require more space, than two-position or proportional control. ▪ Added maintenance of airflow-measurement device.
Deliver OA Directly To Each Zone With a DOAS	▪ Outdoor airflow not impacted by variable speed terminal fan control. ▪ Affords opportunity to dehumidify OA centrally and deliver it cold (rather than reheated to neutral).	▪ May require installation of pressure-independent dampers to enable shutting off airflow to a zone or DCV.

hours/day, seven days/week. Rather, it only requires it to be delivered during the normally scheduled occupied period.

“8.3 Ventilation System Operation. *Systems shall be operated such that spaces are ventilated in accordance with Section 6 when they are expected to be occupied.”*

Since the static pressure in the mixing box of the terminal unit varies as fan speed changes (*Figure 1*), the DCV controls need to prevent outdoor airflow from dropping below this minimum threshold ($R_a \times A_z$).

Likewise, if a zone has some type of minimum exhaust requirement—such as a restroom, kitchen, or locker room—DCV should not be allowed to reduce outdoor airflow any lower than the required exhaust, unless the zone receives makeup air from some other source.

Summary

Variable speed fan control in terminal-style HVAC equipment can significantly reduce fan energy use. But ensuring proper ventilation as the fan speed changes presents challenges not found in terminal units with constant speed fan control.

When designing systems with variable-airflow terminal units, be sure to consider outdoor airflow control during system design (*Table 1*). For smaller terminal units, two-position or proportional OA damper control is probably more likely to be used, while in larger equipment the added cost and maintenance of an airflow-measurement device may be justified.

When a dedicated OA system is used, consider delivering the conditioned outdoor air directly to each zone, rather than to the inlet of the terminal units. And, consider including zone dampers to allow

the dedicated OA system to vary outdoor airflow during periods of reduced population.

References

1. Mumma, S. 2008. “Terminal equipment with DOAS: series vs. parallel.” *Engineered Systems* 25(5):86–89.
2. Murphy, J. 2006. “Smart Dedicated Outdoor Air Systems.” *ASHRAE Journal* 48(7):30–37.
3. ASHRAE. 2011. *62.1-2010 User's Manual: ANSI/ASHRAE Standard 62.1-2010*. ■

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