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Minimizing Reheat in Multiple-Zone VAV Systems

Multiple-zone variable air volume (VAV) systems often use zone-level reheat to ensure individual comfort in different zones. However, the common practice of setting VAV minimum airflow setpoints at a fixed 30 percent can lead to excessive reheat energy consumption. This document examines various design and control strategies that can help minimize reheat in this type of system, with the goal of reducing energy costs and environmental impact while still maintaining occupant comfort and high indoor air quality.

Multiple-zone VAV systems serve several zones from a single central air-handling unit (AHU), rooftop unit (RTU) or self-contained unit. Each zone is served by a VAV terminal unit that varies the flow of primary air to the zone and if needed reheats this air to maintain the desired zone temperature and provide sufficient ventilation. The central unit modulates the airflow rate delivered to the VAV terminals, and conditions this supply air to the desired temperature setpoint (such as 55°F during cooling operation).

VAV terminal units commonly have a zone temperature sensor installed in each independently-controlled zone, allowing individual zone temperature control. Typically, the VAV terminal contains a damper used to modulate the flow of air, a reheat coil (hot water coil or electric heater), and a controller to communicate with the zone temperature sensor. When the cooling demand of the zone has decreased to the point that the VAV damper has closed to its minimum airflow setpoint, and this cooling demand continues to drop, the reheat coil tempers (reheats) the supply air just enough to prevent overcooling the zone.

The minimum airflow setpoint of the VAV terminal (for both cooling and heating modes) is typically determined by the system designer and then implemented during startup. It must consider comfort (air circulation), building pressurization, equipment turndown limitations, and minimum ventilation requirements.

A commonly used rule-of-thumb in the industry has been 30 percent of the peak zone cooling airflow for the cooling and heating minimum airflow setpoints. This value was likely due to limitations of equipment controllers in the 1970s and 1980s, when a pneumatic differential pressure sensor would lose control precision at low airflows.[1] With DDC controls, the minimum airflow setpoints can often be much lower, if ventilation requirements are still met. Manufacturer limitations must still be followed to ensure control precision.

Minimizing reheat in multiple-zone VAV systems is important for both economic and environmental reasons. The most immediate benefit is energy cost savings. Using a rule-of-thumb for the minimum airflow setpoints in VAV terminals often results in large amounts of overcooling and reheating. Reducing unnecessary reheat lowers total HVAC energy consumption and can significantly reduce operating costs. But it is important to remember that the energy meter is on the building, not on a single VAV terminal unit. Fan energy consumption must be considered since temperature and airflow are dependent on one another.

Another important reason to reduce reheat is to support decarbonization efforts in building design and operation. Sustainability goals are driving efforts to lower the carbon footprint of buildings by reducing emissions from fuel combustion. In HVAC systems, decarbonization often includes electrification of heat. Reducing reheat supports electrification efforts as it reduces the heating load, lowering emissions from electricity production.

Finally, reheat is not allowed by ASHRAE® Standard 90.1[2] in many circumstances, unless recovered energy is used (like heat recovered from the condenser of a water chiller or heat recovered from hot gas in a DX refrigeration system).

The following are a few design and control strategies that can help minimize reheat in a multiple-zone VAV system:

- Proper sizing of VAV terminal units
- Proper zoning
- Reduce minimum VAV airflow setpoints
- Reset supply-air temperature setpoint during mild and cold weather
- Consider fan-powered VAV terminal units

Proper Sizing of VAV Terminal Units

When terminal units are oversized, even a very low primary airflow setpoint can overcool the space, requiring a large amount of reheat. For a new building, it is recommended to run a load calculation simulation to determine the right size for each VAV terminal unit. For an existing building, consider trending each zone's airflow to better understand the actual demand and avoid installing oversized VAV terminals. If most VAV terminal units remain at their minimum airflow setpoint most of the time, this could be a sign that they are oversized.

Proper Zoning

Satisfying both perimeter and interior zones with a single, central air-handling unit could be challenging since the load in perimeter zones may fluctuate more due to changing outdoor temperatures and sun exposure. A single central unit will need to supply air at a temperature that is low enough for the most critical zones. This could lead to overcooling the other zones, forcing them to use reheat. Separating large perimeter and interior zones to be served by different AHUs can satisfy their specific needs while reducing reheat.

Reduce Minimum VAV Airflow Setpoints

Use ASHRAE Standard 62.1 for minimum primary airflow setpoint

One of the best ways to reduce reheat energy use is to lower the minimum airflow setpoints in VAV terminals. As noted previously, the minimum airflow setpoint in a VAV terminal must consider comfort (air circulation), building pressurization, equipment turndown limitations, and minimum ventilation requirements. When ventilation is the primary consideration (see sidebar for space types where this is not the case), match the minimum primary airflow setpoint with the requirements of the Simplified Procedure of the Ventilation Rate Procedure in ASHRAE Standard 62.1[3].

ASHRAE Standard 90.1 (§6.5.2.1) generally restricts use of energy to reheat previously cooled air (or mixing heated and cooled air), although certain exceptions apply.

Exception 1 allows the use of reheat in DDC systems when the minimum primary airflow rate ($V_{pz\text{-}min}$) meets the requirements of the Simplified Procedure in ASHRAE Standard 62.1 (§6.2.4.3.2). This "Zone Minimum Primary Airflow" for each zone is calculated as:

$V_{pz\text{-}min} = V_{oz} \times 1.5$, where V_{oz} is the required zone outdoor airflow.

Exception 2 allows the use of reheat in DDC systems when all the following conditions are met:

- The airflow rate in the deadband is equal to $V_{pz\text{-}min}$ required by the Simplified Procedure in ASHRAE Standard 62.1 (see Exception 1).
- The airflow rate that is reheated must be less than 50 percent of the zone's design (peak) supply airflow rate.
- The "Dual Maximums" VAV control sequence is used.

In **healthcare** and **laboratory** spaces, there may be less opportunity to lower the minimum airflow setpoints in VAV terminal units.

For a healthcare space, the minimum supply airflow is regulated by ASHRAE Standard 170[4], which prescribes a minimum number of air changes per hour (ACH) for odor control and asepsis (free from pathogenic microorganisms). Tables in the standard establish a *Minimum Outdoor ACH* and a *Minimum Total ACH* for these space types, so the VAV minimum airflow setpoints cannot be reduced below these thresholds.

For a laboratory, the minimum supply airflow might be dictated by space-to-space pressurization requirements, rather than ventilation. For this reason, the VAV minimum airflow setpoints may not be able to be reduced as far.

Use the "Dual Maximums"[5] control sequence for VAV terminal units

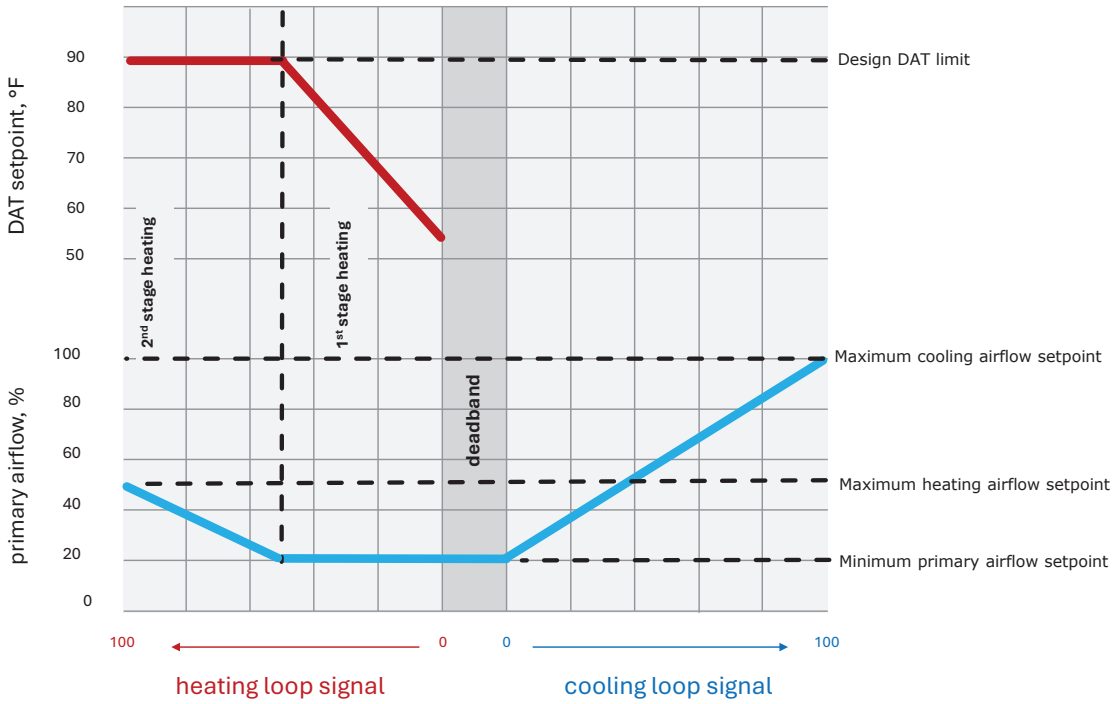
The "Dual Maximums" control sequence allows separate maximum airflow settings for cooling and heating. By permitting a higher primary airflow rate for peak heating, it uses a lower minimum airflow setpoint in the deadband, which can help reduce reheat. Figure 1 demonstrates how this control sequence operates.

In cooling mode, when the zone temperature rises above the active cooling setpoint, the controller modulates primary airflow between its minimum and maximum airflow setpoints, to maintain zone temperature at the active cooling setpoint (e.g., 75°F), while reheat is off.

When the zone temperature is in the deadband between the active heating and cooling setpoints (e.g., between 70°F and 75°F), the controller reduces primary airflow to the minimum primary airflow setpoint, while reheat is off.

In heating mode, when the zone temperature drops below the active heating setpoint (e.g., 70°F), the first stage of heating maintains the primary airflow at the minimum primary airflow setpoint while the controller modulates heating capacity (hot-water valve or SCR electric heater) to maintain zone temperature at the active heating setpoint. If the requested heating capacity has increased to the point where the discharge air temperature (DAT) reaches the design DAT limit (90ºF in this example), the second stage of heating modulates the primary airflow between its minimum and maximum heating airflow setpoints, to maintain zone temperature at the active heating setpoint, while modulating heating capacity to maintain the discharge air temperature at this design DAT limit.

Figure 1. "Dual Maximums" control of a VAV terminal unit with modulating heat (hot-water coil or SCR electric heater)



Notice the minimum primary airflow setpoint is the same for both cooling and heating modes. To meet Standard 90.1, the maximum heating airflow setpoint must be less than 50 percent of the zone's maximum cooling airflow setpoint.

Use Occupied Standby mode

Occupied Standby mode[6] allows ventilation to be reduced to zero, in some space types, when people are not present in the zone during the normal scheduled occupied time. With no ventilation required, the minimum primary airflow setpoint in the VAV terminal can also be reduced (maybe even to zero), which can reduce or eliminate reheat.

Beginning with the 2016 version, Standard 62.1 allows this approach for specific space types listed in Table 6-1 of the standard, including break rooms, conference rooms, lobbies, and office spaces. When an occupancy sensor indicates that no people are currently in the zone, the outdoor airflow can be lowered to zero as long as it returns to the design rate whenever occupancy is detected (§6.2.6.2). To implement this mode, an occupancy sensor is required in combination with a time-of-day schedule to indicate if the zone is truly unoccupied even though the BAS has scheduled it as occupied.

Example: A 1000 ft² conference room with a design zone population of 50 people requires 310 cfm of outdoor airflow during occupied mode (Table 1). However, during Occupied Standby mode, the outdoor airflow can be reduced to zero. With no ventilation required, the minimum primary airflow setpoint could also be reduced, possibly to zero. At the same time, all or some of the lights in that zone could be shut off, and the temperature setpoint could be raised or lowered to save even more energy.

For some types of spaces, including classrooms and offices, ASHRAE Standard 90.1 (§6.5.3.9) requires that within 5 minutes of the space entering Occupied Standby mode, the active heating setpoint be lowered by at least 1°F, the active cooling setpoint be raised by at least 1°F, and all airflow supplied to the zone be shut off when space temperature is in the deadband.

Even if ventilation and primary airflow can be reduced to zero in a zone, the central unit might require some (not zero) primary airflow due to equipment limitations in airflow turndown, pressurization requirements, humidity control, or local code requirements.

Optimize ventilation

ASHRAE Standard 62.1 permits dynamic reset of outdoor airflow as operating conditions change, if the system provides at least the required breathing-zone outdoor airflow whenever a zone is occupied. In a multiple-zone VAV system, "zone-level" ventilation control must be coordinated with control of the outdoor-air damper in the "system-level" (central) unit. The building automation system (BAS) can be used for the following strategies:

a) Ventilation Optimization and Demand Control Ventilation (DCV)

Standard 62.1 (§6.2.6.1) allows dynamically resetting the outdoor airflow delivered to a zone (V_{oz}) in response to variations in population, using a time-of-day schedule, occupancy sensor, or a CO_2 sensor. This reset is referred to as DCV. And §6.2.6.3 allows dynamically resetting the central outdoor-air damper position in response to variations in system ventilation efficiency (E_v), as system airflows change (strategy known as Ventilation Optimization). As the required zone outdoor airflow is reduced via DCV, the VAV terminal can also lower the minimum primary airflow setpoint, which might decrease reheat energy use.

For DCV, during occupied mode, the breathing-zone outdoor airflow shall not be less than the building component for the zone ($R_a \times A_z$). But as mentioned previously, for some zone types, Occupied Standby mode could allow this to be reduced to zero.

b) Dynamically reset minimum primary airflow setpoints using the system's maximum zone outdoor-air fraction (max Z_{pz})

ASHRAE Standard 90.1 (§6.5.3.3) requires multiple-zone VAV systems to include a means to automatically reduce outdoor airflow in response to changes in system ventilation efficiency (Ventilation Optimization), defined in Appendix A of ASHRAE Standard 62.1.

An energy-saving enhancement to the Ventilation Optimization control strategy is for the BAS to enforce a maximum OA fraction (max Z_{pz}), which could force the VAV terminal serving the "critical zone" (the zone with the highest Z_{pz}) to increase its minimum primary airflow setpoint at low-load conditions. While this would activate reheat to avoid overcooling that one zone, if it is hot or cold outside, the energy saved by avoiding the need to increase system-level intake airflow (V_{ot}) will likely outweigh the small amount of reheat needed for this one zone (or few zones).

However, this could reduce overall reheat energy use because it can allow the minimum primary airflow setpoints in all VAV terminals to be set very low (even zero), since each VAV controller will dynamically determine its minimum primary airflow setpoint based on the "max Z_{pz}" communicated by the BAS.

Table 1. Example of Occupied Standby mode

Variable	Occupied mode	Occupied Standby mode
Lights	On	Off
Zone cooling setpoint	75ºF	77ºF
Outdoor airflow required	310 cfm	0 cfm
Minimum primary airflow setpoint	465 cfm	0 cfm

According to Table 6-1 of ASHRAE Standard 62.1, the required outdoor airflow rates for a conference room are: R_p= 5 cfm/p, R_a = 0.06 cfm/ft².

During occupied mode: $V_{bz} = R_p \times P_z + R_a \times A_z$ = 5 cfm/p x 50 people + 0.06 cfm/ft² x 1000 ft² = 310 cfm.

c) Time-Averaged Ventilation (TAV)

One of the challenges of lowering VAV minimum airflow setpoints is the manufacturer's recommended limit for controllability. If a zone needs less primary airflow than the VAV controller can reliably measure, ASHRAE Guideline 36[7] recommends using Time-Averaged Ventilation, based on the "Short-Term Conditions" section of ASHRAE Standard 62.1 (§6.2.5.2). This time-averaging method allows for primary airflow to cycle between the VAV terminal's minimum controllable airflow (Vm) and zero (VAV damper closed) over an averaging time period (T), determined by Equation 6-11 from Standard 62.1:

$T = 3v/V_{bz}$

where

T = averaging time period, minutes

v = volume of the ventilation zone, ft^3

V_{bz} = breathing-zone outdoor airflow using the design zone population P_z, cfm

Guideline 36 (§5.2.2.1) provides a sequence to cycle the VAV damper open and closed so it can achieve an average airflow that is lower than the VAV terminal's minimum controllable airflow (Vm).

When the active airflow setpoint (Vspt) is less than the lowest possible airflow allowed by the VAV controller (Vm), the VAV damper shall cycle open and closed as follows:

a. The Time-Averaged Ventilation ratio is calculated as TAVratio = Vspt/Vm.
b. The total cycle time (TCT) shall be 15 minutes (adjustable).
c. During the open period (OP), the TAV airflow setpoint (Vspt*) shall be equal to Vm for 1.5 minutes or TCT × TAVratio, whichever is larger.
d. During the closed period (CP), the TAV airflow setpoint (Vspt*) shall be zero (closed) for TCT-OP minutes.
e. The VAV controller continues alternating between open and closed periods until Vspt is greater than Vm.

Example: An office space has a volume of 10,000 ft^3, based on a floor area of 1,000 ft^2 and a ceiling height of 10 feet. The zone has a design supply airflow of 1,000 cfm and a design occupancy of 8 people.

- Zone volume, v = 10,000 ft^3
- Breathing-zone outdoor airflow, V_{bz} = 100 cfm
- Minimum controllable airflow of the VAV controller, Vm = 250 cfm
- Active airflow setpoint, Vspt = 150 cfm
- Total cycle time, TCT = 15 minutes

The minimum controllable airflow of the VAV terminal (Vm = 250 cfm) is higher than the active airflow setpoint of 150 cfm. So the VAV damper alternates between its minimum controllable airflow (250 cfm) during the open period, and 0 cfm during the closed period, such that the time-averaged airflow delivered to this zone equals the desired airflow of 150 cfm.

Step 1: Calculate the allowable averaging time period (T)

Calculate T to ensure that the Total Cycle Time (TCT) is less than or equal to the averaging time period (T), which is required to comply with Standard 62.1 (§6.2.5.2).

$T = 3v / V_{bz} = 3 \times 10{,}000\ ft^3 / 100\ cfm = 300$ minutes

TCT = 15 minutes, which is ≤ T

Step 2: Determine the Time-Averaged Ventilation ratio

TAVratio = Vspt / Vm = 150 cfm / 250 cfm = 0.60

Step 3: Calculate open and closed periods

The open period (OP) is the portion of the cycle during which the VAV terminal delivers the minimum controllable airflow (Vm = 250 cfm) (Figure 2).

OP = TCT × TAVratio = 15 minutes × 0.60 = 9 minutes

- During OP, Vspt* = Vm = 250 cfm

The closed period (CP) is the portion of the cycle during which the VAV damper is closed (0 cfm):

CP = TCT – OP = 15 minutes - 9 minutes = 6 minutes

- During CP, Vspt* = 0 cfm

The VAV terminal alternates between open and closed periods as shown in Table 2. For the first 15-minute cycle from 1:00 to 1:15, the average airflow delivered to the zone is: Vspt = (9 minutes × 250 cfm + 6 minutes × 0 cfm) / 15 minutes = 150 cfm. This average matches the desired active airflow setpoint.

Figure 2. Time-Averaged Ventilation (TAV) example

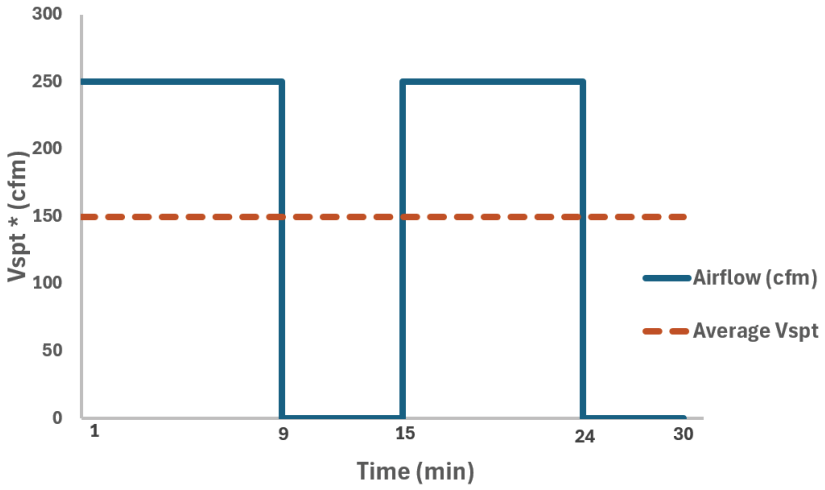


Table 2. Resulting Time-Averaged Ventilation (TAV) periods and airflows

Time	Vspt	Vspt*	Control Action
1:00-1:09	150 cfm	250 cfm	Open period: VAV damper opened to Vm for 9 minutes
1:09-1:15	150 cfm	0 cfm	Closed period: VAV damper closed for 6 minutes
1:15-1:24	150 cfm	250 cfm	Open period: VAV damper opened to Vm for 9 minutes
1:24-1:30	150 cfm	0 cfm	Closed period: VAV damper closed for 6 minutes

Reset Supply-Air Temperature Setpoint During Mild and Cold Weather

Another approach to reducing reheat in a multiple-zone VAV system is to raise the AHU supply-air temperature (SAT) setpoint during mild or cold weather. For those zones in which the cooling demand is low enough that the VAV damper has closed to its minimum primary airflow setpoint, reheat has likely been activated to prevent the zone from overcooling. If the SAT is warmer, this allows those VAV terminals to reheat less, while zones with higher cooling demand can continue to receive the cooling they need by increasing their primary airflow. This strategy should strive to balance cooling, reheating, and fan energy use.

The approach recommended by ASHRAE Guideline 36 (§5.16.2.2) is to reset based on the current outdoor temperature and use trim-and-respond to ensure all zones are satisfied.

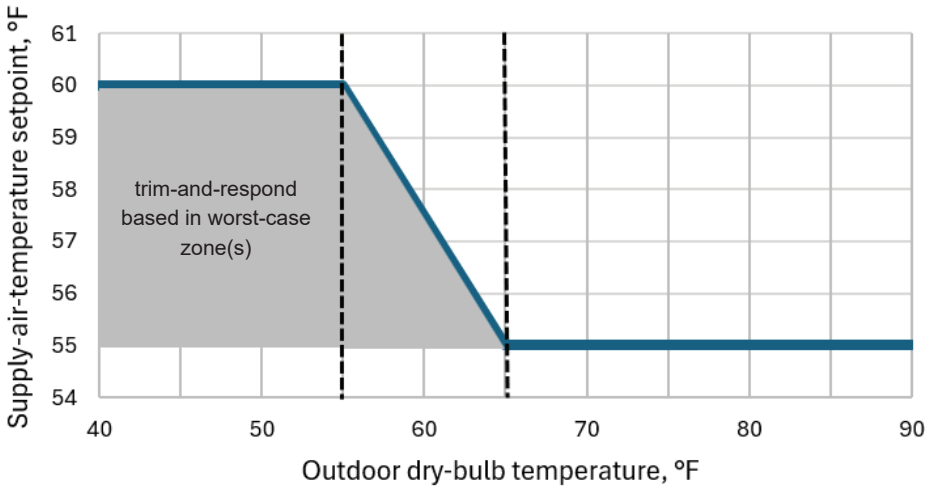
The operation of this reset strategy is depicted in Figure 3.

- When the outdoor temperature is warmer than 65°F, no reset takes place and the SAT setpoint remains at the design value of 55°F.
- When the outdoor temperature is cooler (below 65°F in this example), the controls begin to reset the SAT setpoint upward. At these mild temperatures, raising the SAT setpoint enhances the benefit of the airside economizer, and if there is any zone-level reheat, it is reduced or even avoided. But with this higher SAT, those zones that require cooling will need more airflow, so fan energy might increase.
- Finally, the amount of reset for the SAT is limited—to 60°F in this example—which allows the system to satisfy cooling loads in interior zones without needing to substantially oversize VAV terminals and ductwork.

One possible drawback of this approach is that if a zone has a high cooling load, even when it is cool outside, it is possible that the warmer SAT may not provide enough cooling, causing the zone to overheat. To prevent this from occurring, trim-and-respond should be used to ensure that the SAT remains cold enough to satisfy the cooling demand of the worst-case zone. If dehumidification is a concern, avoid using SAT reset when it is humid outside.

During cold weather, the effect of resetting the SAT setpoint upward is that heating shifts from the VAV terminal units (reheat) to the central AHU.

Figure 3. Supply-air temperature reset based on current outdoor temperature



Consider Fan-Powered VAV Terminal Units

Using fan-powered VAV terminal units in some zones might help reduce reheat energy use.

Fan-powered VAV terminals mix warm air from the ceiling plenum with cool primary air from the central air-handling unit as the first stage of heating/reheating the zone. This type of terminal equipment can help reduce reheat if the plenum temperature is sufficiently warm, combined with the heat generated by the terminal fan itself. There are two types of fan-powered VAV terminals: series and parallel.

A **series fan-powered VAV terminal** has the fan in the same path as the primary air supply (Figure 4). During occupied mode, the fan is always energized and can be controlled for constant-speed or variable-speed operation. By operating continuously, it provides consistent air circulation which can improve comfort and air distribution. While reheat might be reduced by mixing in warm plenum air, continuous fan operation can lead to higher energy consumption, possibly higher noise levels in the space, and increased maintenance.

Parallel fan-powered VAV terminals have the fan in parallel to the primary air supply (Figure 4). This fan only operates when the zone requires heating, so the motor heat is never wasted. When energized, the fan can be controlled for constant-speed or variable-speed operation. They are an excellent choice when minimizing zone heating (reheat) is desired.

Summary

Arbitrarily setting the minimum airflow setpoints in VAV terminals can lead to excessive reheat energy use. Reducing reheat in multiple-zone VAV systems can lower operating costs, improve overall system efficiency, cut emissions from heating energy use, and better position buildings for an electrified and decarbonized future.

While the design and control strategies discussed in this EN can help minimize reheat in multiple-zone VAV systems, some may not be as practical for a retrofit project. Some solutions may require added sensors, airflow measurement devices, BAS upgrades, or even replacement of VAV terminals or ductwork. It is important to balance effectiveness and cost when selecting the strategies to implement for each project.

By Mayra Reyes, applications engineer, Trane.
You can find this and previous issues of the *Engineers Newsletter* at www.trane.com/EN. To comment, send e-mail to ENL@trane.com.

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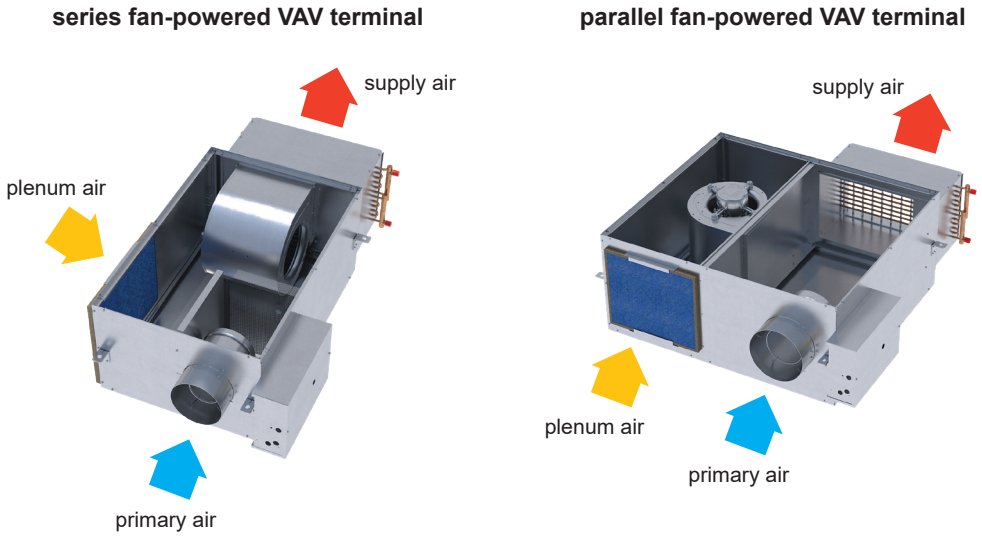
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Figure 4. Series and parallel fan-powered VAV terminals





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