# Increasing Efficiency With VAV System Static Pressure Setpoint Reset

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Supply air fans on variable air volume (VAV) systems are typically controlled to maintain static pressure in the duct system at a given setpoint. Since 1999, ASHRAE Standard 90.1[1] has required that this setpoint be reset for systems with direct digital controls (DDC) at the zone level, specifically:

> ***Setpoint Reset.*** *For systems with direct digital control of individual zone boxes reporting to the central control panel, static pressure setpoint shall be reset based on the zone requiring the most pressure; i.e., the setpoint is reset lower until one zone damper is nearly wide open.*

California's Title 24 Energy Standards[2] include a similar requirement. This article discusses the energy benefits of static pressure setpoint reset and describes successful setpoint reset control sequences.

## Energy Savings

*Figure 1* depicts the part load energy performance of a typical centrifugal fan with a variable speed drive at various static pressure setpoints. These curves include the impact of variable speed drive and motor efficiency as a function of load and fan efficiency as a function of operating point, but for simplicity they assume pressure drop varies as the square of airflow.[3] The figure shows that the lower the setpoint, the lower the fan energy and the lower the minimum airflow rate before the fan operates in the surge region. Fans operating in surge can experience substantial vibrations, noise and a drop in fan efficiency.

For systems with DDC at the zone level, Standard 90.1 and Title 24 require that static pressure setpoint be dynamically reset so that one damper is nearly wide open, depicted schematically in *Figure 2*. This is clearly the most efficient operating condition since the fan need not generate any more pressure than required to satisfy the "critical" zone (the zone that

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requires the most pressure). It also improves fan efficiency, which drops off as the fan operates at low load and high static pressure, in particular if the fan operates in surge. If the static pressure is perfectly reset, at zero airflow, zero static pressure would be required and the system would operate on the "Ideal" line (*Figure 1*). Because of their complex physical layouts, varying system geometry as VAV dampers open and close, non-simultaneous variations in zone loads, and other factors, real fan systems will not perform quite this well. Nevertheless, reset can generate fan energy savings on the order of 30% to 50% compared to fixed setpoints.[4,5]

## Zone Static Pressure Demand

Static pressure setpoint reset logic requires that the demand for static pressure be known for each zone since the critical zone varies depending on zone loads and their location in the distribution system. Options include:

1. **Damper signal (analog actuators).** Some DDC VAV controllers use analog (also called "proportional") actuators on the VAV box damper. The signal to the actuator can be used as an indicator of damper position.
2. **Calculated damper position (floating actuators).** Probably the most common damper actuator type used on DDC VAV box controls is a floating point actuator. While an analog actuator is controlled by an analog signal (e.g., 2 – 10 vdc), a floating actuator is controller by two binary output contacts, one to drive the damper open and one to drive it closed. With this type of actuator, actual damper position is not directly known. But position can be calculated by timing the pulse-open and pulse-closed commands scaled by the drive time of the actuator. The resulting estimated position is not very accurate even with frequent re-zeroing, but it is generally sufficient for static reset purposes in comfort air-conditioning applications.
3. **Damper position feedback (floating actuators).** Many DDC VAV controllers include damper position feedback option for an accurate indication of damper position. This is a position indicator within the actuator tied to a DDC analog input.
4. **Damper full-open end-switch (floating actuators).** A slightly less expensive option to damper position feedback is a switch on the actuator that closes when the damper is full open, tied to a DDC binary input. This option only indicates that the damper is full open so it cannot be used with the PID reset logic discussed below that requires knowledge of damper position.
5. **Low airflow (floating actuators).** Another option similar to the previous is to deduce that the damper is full open if the zone is unable to maintain airflow at setpoint by a certain threshold for a period of time (e.g., airflow is less than 90% of setpoint for more than two minutes). Again, actual damper position is not known so this approach cannot be used with the PID reset logic discussed below that requires knowledge of damper position.

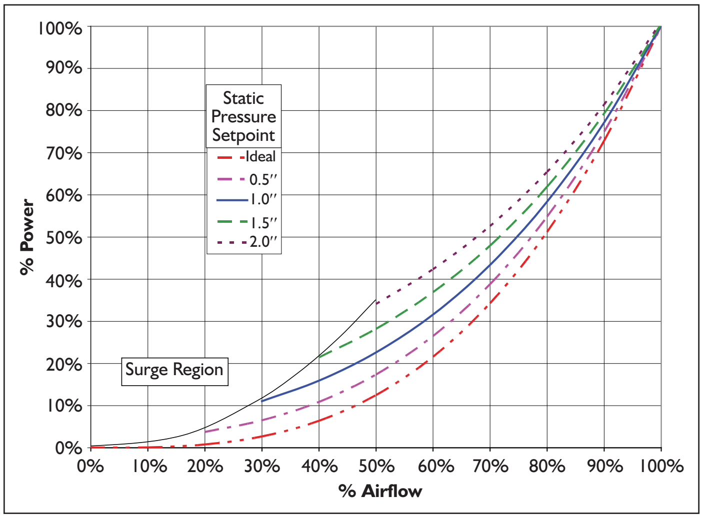

*Figure 1: VAV fan performance as a function of static pressure setpoint.*

Options 1 and 3 are generally preferred since they accurately indicate damper position, but they also can cost more depending on the DDC manufacturer.

## Setpoint Reset Logic

The basic logic behind static pressure setpoint reset is straightforward: simply adjust the setpoint until one VAV damper is wide open. But, achieving this in a stable manner is difficult because damper position and static pressure are highly interactive in systems using pressure-independent logic, which is the case for almost all DDC VAV box controllers. As duct pressure rises, airflow increases, which causes the VAV box controller to immediately start to close the damper to maintain airflow setpoint. The reset logic controller senses the damper closing, dropping the static pressure setpoint. This, in turn, will cause static pressure to fall and the damper to open. The cycle will repeat and be very unstable unless the reset logic can be properly tuned.

Approaches for implementing the reset logic include:

- **PID loop on VAV damper position.** This approach uses a standard proportional-integral-derivative (PID) control loop to adjust static pressure setpoint to maintain the most-open VAV damper position at 90% open. (90% is used rather than 100% since a PID loop requires that there be error from

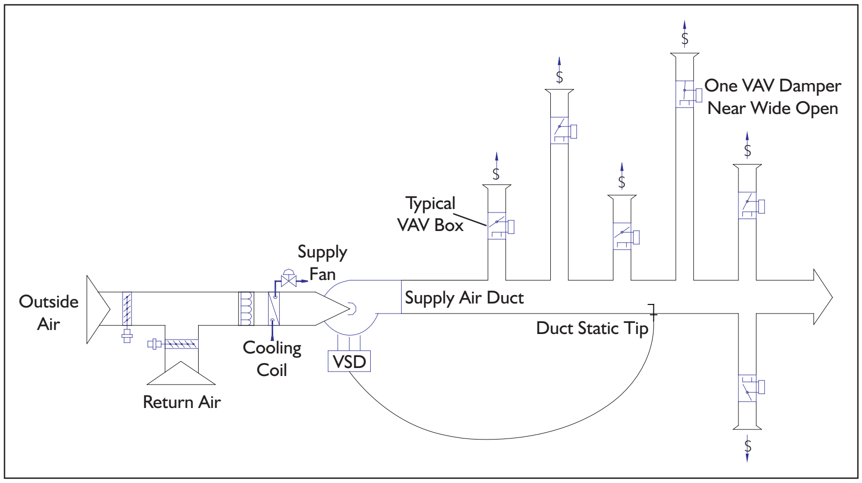

*Figure 2: VAV system schematic.*

setpoint on both sides of the setpoint.) To use this logic, knowledge of damper position is required, so Options 4 and 5 discussed previously cannot be used.

- **"Trim and Respond" logic based on zone static pressure requests.** With this approach, static pressure setpoint is trimmed slowly and regularly until a zone indicates through a pressure request that more static pressure is required; in which case, the controller responds by bumping the setpoint up a small amount.

The first approach (PID logic) has been used with reasonable success on several of the author's early DDC projects, but we now exclusively use Trim & Respond logic for the following reasons:

- **It is easier to tune.** The Trim & Respond logic includes several fairly intuitive tuning parameters (see detailed sequences below), while the PID logic includes only proportional and integral gains (the derivative gain is not used).
- **It can "respond" more quickly than "trim," i.e., the setpoint trim rate can be adjusted to be much slower than the respond rate.** A very slow trim rate improves stability, but a comparatively fast respond rate ensures that zone demands for increased airflow can be quickly addressed. PID loops typically have only one speed: if the loop is slow when decreasing the setpoint, it is slow when increasing it. Hence, if the loop is made slow enough to avoid instability, it may be so slow that zones are starved of airflow when zone demand rises.
- **It does not require knowledge of damper position.** Any of the five options for determining zone demand can be used

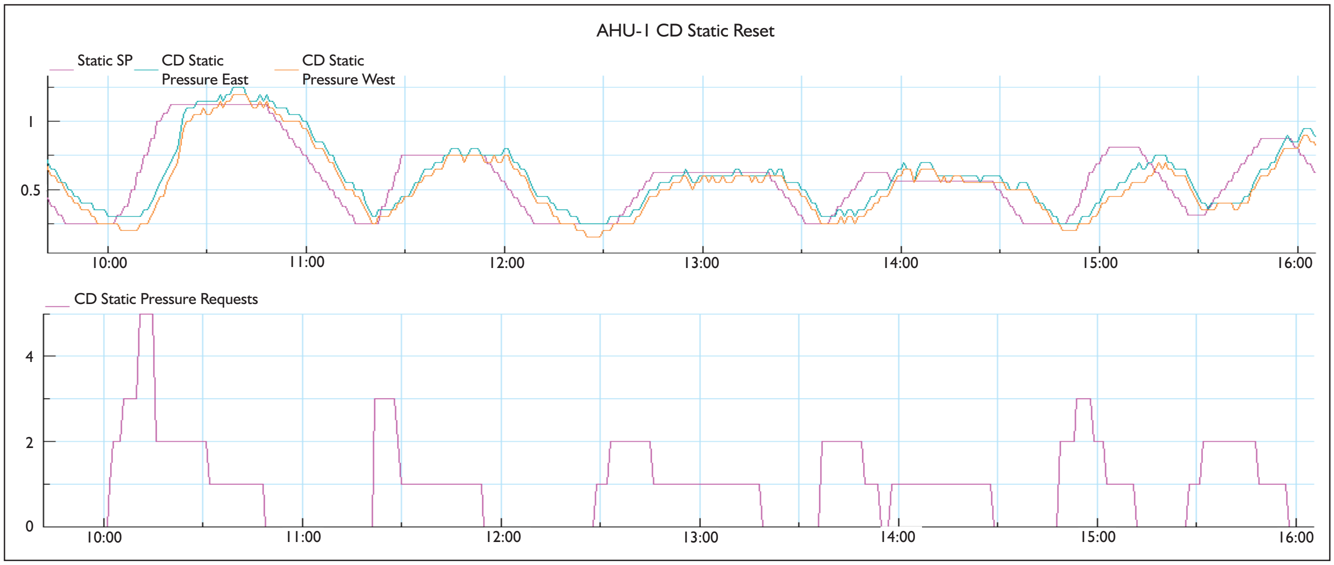

***Figure 3:** **Actual static pressure, static pressure setpoint, and pressure requests.***

to indicate zone pressure requests. PID logic requires that analog damper position be known, so only Options 1 to 3 can be used, potentially increasing first costs.

- It is easier to ignore rogue zones. As discussed later in this article, rogue zones must be addressed if static pressure reset is to be successful. Rogue zones can require high static pressure almost constantly, preventing reduced static pressure setpoint even at low loads. With Trim & Respond logic, it is simple to ignore one or more zones (see detailed sequences below), diminishing the impact of rogue zones. This is more difficult to do with PID logic—generally the rogue zones would need to be identified through trend reviews and removed from the high position selector block that picks the most open damper in the DDC programming.

## Detailed Trim & Respond Logic

There are several variations on Trim & Respond logic. One variation is:

> *Static pressure setpoint shall be reset using Trim & Respond logic within the range 0.15 in. w.g. to 1.3 in. w.g. (35 Pa to 325 Pa). When the fan is off, the setpoint shall be 0.5 in. w.g. (125 Pa). While the fan is proven on, every two minutes, trim the setpoint by 0.04 in. w.g. (10 Pa) if there are two or fewer zone pressure requests. If there are more than two zone pressure requests, respond by increasing the setpoint by 0.06 in. w.g. (15 Pa).*

The 1.3 in. w.g. (325 Pa) high point of the range should be set in the same way as if there were no reset control, i.e., it should be the pressure required at the sensor to satisfy all zones downstream of the pressure sensor at design airflow rates with at least one VAV box damper wide open. If the reset logic works flawlessly, then setting an arbitrarily high setpoint limit does not affect performance since the reset logic itself limits the duct pressure setpoint. But for real systems, limiting the setpoint in the conventional manner is still recommended since it can improve performance if the system has rogue zones, discussed further below. For the same reason, the static pressure sensor should be located as far out into the duct system as is practical so that the high end of the setpoint range (1.3 in. w.g. [325 Pa] in this example) can be as low as possible. This will allow for efficient operation (*Figure 1*) even if the reset logic has failed due to a rogue zone or other problem.

The timing parameter (2 minutes in this example) and Trim & Respond differentials, (0.04 in. w.g. and 0.06 in. w.g. [10 Pa and 15 Pa], respectively), must be adjustable for tuning, discussed under Commissioning.

The zone pressure requests are generated by one of the five options listed above. For instance, if damper position is known, for each zone the logic might be:

> *A zone pressure request is generated when the VAV damper is greater than 95% open until it drops to 80% open.*

A more conservative variation to reduce the chance that a zone will be starved (at the expense of fan energy) is to allow zones to create multiple requests depending demand, such as:

> *One zone pressure request is generated when the VAV damper is greater than 85% open until it drops to 70% open. Two pressure requests are generated when the damper is greater than 99% open until it closes to 85%.*

The logic in the Trim & Respond example above allows for two pressure requests to be ignored before the logic responds by raising the setpoint. This is a means of ignoring rogue zones to improve energy performance. However, it can lead to comfort problems in these zones, as discussed below.

A variation on the Trim & Respond logic is to weight the response by the number of pressure requests. This will increase the rate of response when there are many requests such as when the system is first turned on. The following example is the standard Trim & Respond logic used by a major controls vendor:

> *Static pressure setpoint shall be reset using Trim & Respond logic within the range 0.15 in. w.g. to 1.3 in. w.g. (35 Pa to*

*325 Pa). When the fan is off, the setpoint shall be 0.5 in. w.g. (124 Pa). While the fan is proven on, every 2 minutes, trim the setpoint by 0.04 in. w.g. (10 Pa). Respond by increasing the setpoint by 0.03 in. w.g. (7.5 Pa) times the number of pressure requests but no more than 0.12 in. w.g. (30 Pa).*

### Commissioning

Tuning by trial and error after installation is almost always required. Every system and application is different and few will work well with the parameters listed in the example Trim & Respond logic above. As previously noted, the reset must be relatively slow or a cyclic instability results. This is done by adjusting the tuning parameters in the Trim & Respond logic (trim timing and decrement, response increment).

The primary way to test stability is to plot pressure setpoint and pressure requests over time. *Figure 3* is a trend log from a classroom-office building showing actual static pressure (measured near the end of two duct mains), and static pressure setpoint in the top graph, and zone pressure requests in the bottom graph. The reset is clearly too fast; static pressure setpoint is reset from the minimum of 0.25 in. w.g. (62 Pa) to near the maximum of 1.3 in. w.g. (325 Pa) over about a one-hour period. The stability of this system was improved by reducing the trim decrement.

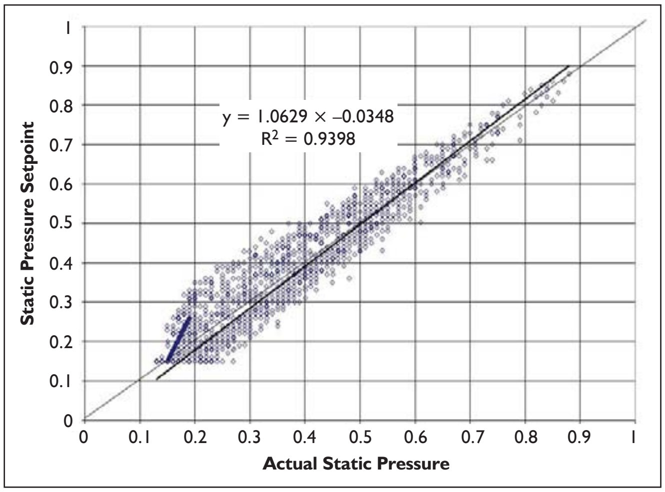

***Figure 4:** Actual static pressure versus setpoint.*

Another way to test if the reset is working is to plot the actual static pressure versus static pressure setpoint, as shown in *Figure 4*. This plot is particularly useful in showing if rogue zones are limiting the range of the reset. The system in *Figure 4* is clearly working quite well in that regard, with most of the hours operating at very low setpoints. This plot also reflects the stability of the fan static pressure control loop. The system in *Figure 4* is reasonably well tuned; the fact that the scatter plot is more spread out at low static pressures is common and is because the loop

was tuned when the static pressure was on the high end of the range.

## Rogue Zones

Rogue zones are zones that cause the reset scheme to underperform because they frequently or constantly generate zone pressure requests. Common causes are:

- Undersized VAV box, due to improper selection or unexpectedly high zone loads;
- Cooling thermostat setpoint below design condition; and
- Duct design problem—high-pressure drop fitting or duct section.

The first two items cause the zone to frequently demand maximum or near-maximum zone airflow rates. Depending upon zone location relative to the fan, a constant demand for high airflow rates indirectly causes the zone to generate frequent or constant pressure requests. The third problem directly results in pressure requests; *Figure 5* is an example. This zone had a fire/smoke damper installed in the 6 in. (150 mm) high-pressure duct at the box inlet. Small smoke dampers have little free area so pressure drop was very high, causing pressure requests to be nearly constant even at low loads.

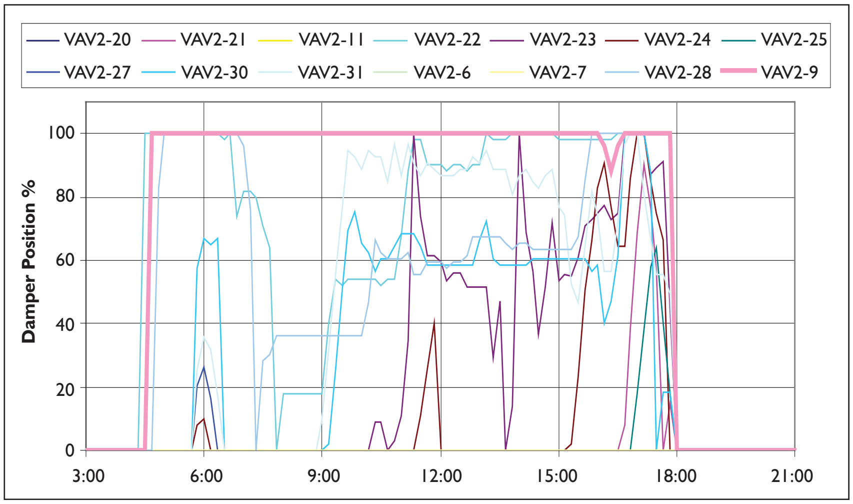

***Figure 5: Rogue zone VAV2-9.***

Ways to mitigate the impact of rogue zones on setpoint reset include:

- **Exclude them from reset sequence.** This can be done by literally ignoring the rogue zone's pressure requests or including logic as in the Trim & Respond sequence above that ignores the first few pressure requests. Of course, ignoring the zone results in failure to meet zone airflow and temperature setpoints. This may not be a problem if the reason the zone is a rogue zone is because the temperature setpoint is too low, but it clearly can be an issue if the zone is more critical (like the boss's office).

- **Limit thermostat setpoint adjustments to a range that is close to space design temperatures.** Virtually all DDC systems include the ability to limit the range occupants can adjust setpoints from the thermostat. This can prevent, for instance, cooling setpoints that are well below design conditions.
- **Fix duct restrictions/sizing issues.** This is clearly a better choice than ignoring the zone and letting it overheat, but the cost to make revisions may be higher that the owner is willing to invest. It is best, of course, to avoid these restrictions in the first place. For instance, we avoid using flexible duct at VAV box inlets, oversize inlet ducts one or two sizes when they extend a long way from the duct main, and avoid small fire/smoke dampers in VAV box inlet ducts.
- **Add auxiliary cooling to augment the VAV zone.** If the problem results from an undersized zone or unexpectedly high loads, a second cooling system, such as a split AC system, can be added to supplement the VAV zone capacity. However, this is also an expensive solution.

## Conclusions

Static pressure setpoint reset based on zone demand is required by Standard 90.1 and Title 24 for systems with DDC at the zone level and has been shown to be extremely effective at reducing fan energy in VAV systems. But implementing the control logic can be difficult because of the highly interactive relationship between duct static pressure and damper position. The author has found that Trim & Respond logic is the more effective approach compared to PID logic. Still, the controls must be tuned in the field, and trend logs of system operation should be used to verify that the logic is stable and that rogue zones are not limiting the reset range.

## References

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