COLUMN ENGINEER'S NOTEBOOK

Steven T. Taylor

Return Fans in VAV Systems

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Air-handling systems with outdoor air economizers must include a means to relieve excess outdoor air supplied to the building to prevent the building from being over-pressurized. Over-pressurization causes exterior doors to stand open if they open to the outside (a potential security issue) or cause doors to be difficult to open if they open to the inside (a potential safety and ADA issue) and may cause air to whistle through exterior doors and elevator doors.

There are three common types of relief systems:

- Relief dampers (aka barometric relief);
- Relief fans (aka powered exhaust fans); and
- Return fans (aka return/relief fans).

For most applications, this list is also in order of first cost (low to high) and energy efficiency (best to worst) (see References 1 and 2 for detailed comparisons). While typically the most expensive and least efficient option, return fans are the system of choice for applications with high return air pressure drops (greater than about 1 in. w.c. [250 Pa]), such as fully ducted return systems. This month's column focusses on two schemes for controlling return fan speed for building pressure control: Airflow Tracking and Direct Pressure Control. My next column (in November) will outline how to design and control economizer dampers in these systems, including how to maintain minimum ventilation outdoor rates.

Before getting into the details, it is important to note that building pressure control need not be precise. The maximum building pressure to avoid the pressurization problems described above is typically about 0.05 to 0.10 in. w.c. (12 to 25 Pa).[3] But lower pressures down to neutral are generally acceptable (e.g., per Section 5.9.2 of ASHRAE Standard 62.1[4]) and slightly negative pressures may even be preferred in cold climates for buildings with internal moisture sources to minimize condensation in the envelope. So there is a wide range of acceptable building pressure allowing some "slop" in the controls.

Option 1: Airflow Tracking

Figure 1 shows a typical VAV system with a return fan using Airflow Tracking (aka volumetric fan tracking) controls. With Airflow Tracking, the return fan speed is controlled to maintain the return airflow rate at a setpoint equal to the supply airflow rate less a fixed differential airflow rate. This differential indirectly maintains the building at a positive building pressure and is on the order of 0.05 to 0.15 cfm/ft^2 (0.3 to 0.8 $L/s{\cdot}m^2$) for typical buildings, with the range a function of building air tightness and desired level of pressurization. The setpoint is often determined empirically by field tests during the commissioning phase; simply adjust the differential airflow setpoint in the field until the desired building pressure (e.g., 0.05 in. w.c. [12 Pa]) is achieved using a handheld differential pressure (DP) sensor across an entry door.

Return airflow is commonly measured using one of the following:

a) Sum of Zone Airflow. If the return air system has airflow control VAV boxes, as in some hospital applications, the return airflow rate may be determined by simply summing zone airflow rates as measured by VAV box velocity pressure sensors. VAV box airflow measurements are fairly accurate,[5,6] and, as noted above, extreme accuracy is not required for building pressure control, so the accumulated error from summing up measurements from several zones is generally acceptable.

b) Speed Tracking. In a system with a high return air pressure drop with fixed geometry, such as a manually balanced ducted return system (no return air VAV boxes), fan speed will track fan airflow fairly well per the fan laws. The only moving parts in the system are the relief air and return air dampers but if they are properly selected and controlled (to be discussed in my November

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column), and because their pressure drop is small relative to the overall return system pressure drop, they will have only a small impact on the fan speed vs. airflow relationship. Again, this is not precise but precision is not needed.

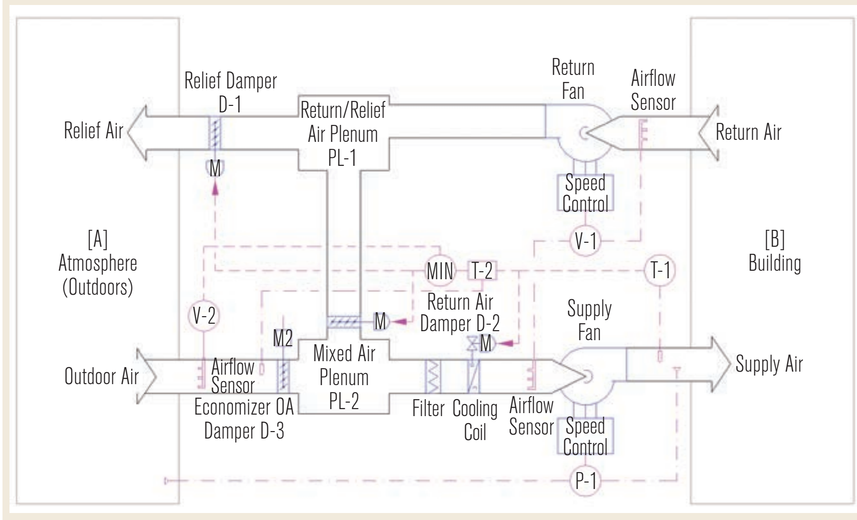
c) Airflow Measuring Station (AFMS). Return airflow can be measured at the air handler by a number of different devices:

- Sensor array, as shown schematically in *Figure 1*. This may be a pitot array or thermal anemometer array. The latter is preferred if low return airflow rates can be expected because they have much lower minimum velocity limits. One major disadvantage of this option is the space required both upstream and downstream of the AFMS for accurate readings.
- Inlet bell sensors. Airflow for centrifugal fans can be measured using pitot or thermal anemometer sensors mounted in the inlet bell. This provides an accurate airflow reading but can generate noise and adds to pressure drop. Several manufacturers offer differential pressure sensors mounted across the inlet bell with differential pressure factory correlated to airflow. This design is the best option for fan airflow sensing, if available, because it has lower costs and zero pressure drop. For multi-fan arrays, airflow sensors may be installed in a subset of fans (typically no fewer than two for redundancy) to reduce costs while still maintaining reasonable accuracy. But control logic needs to be adjusted if the fan(s) with the airflow sensor fail(s).

Supply airflow can be measured using options similar to a) or c) above. Option b) should not be used for supply air fans because it is not sufficiently accurate; VAV box dampers significantly vary system geometry so fan speed and airflow do not closely track. Option a) is generally preferred for supply airflow measurement since it always is available for VAV systems with digital controls at no added cost (other than programming) and thus is the least expensive option and requires no added space in the air handler.

If there are significant variable or intermittent exhaust fans that are monitored by the control system, the return fan airflow setpoint can be adjusted accordingly so that acceptable pressurization is maintained. For example, if the air handler provides makeup air to an intermittently operated kitchen, the return fan setpoint can be adjusted by the design kitchen exhaust fan airflow rate when the fan status (e.g., current switch) indicates the fan is on. Airflow tracking would not work well if intermittent exhaust rates were significant and not known by the control system since the building may be drawn negative.

FIGURE 1 Airflow tracking control (adapted from ASHRAE Guideline 16).



Direct Pressure Control

Figure 2 shows a VAV system with Direct Pressure Control, which is the control logic recommended by ASHRAE Guideline 16[7] and ASHRAE Research Project RP-1455[8] for systems with return fans.

The relief damper is controlled to maintain building pressure directly using a pressure sensor located in a representative space inside the building. The pressure setpoint is typically +0.05 in. w.c. (12 Pa). The range of the sensor may be as low as ±0.1 in. w.c. (±25 Pa) but spikes due to wind and other factors may cause a higher range of pressures to occur so a ±0.25 in. w.c. (±60 Pa) range is recommended.

Locating the DP sensor port pickup inside the building can be a challenge. While one of the main purposes of building pressure control is to prevent high pressures at entry doors, the pickup should never be located in entry lobbies. This is because the reading will fluctuate dramatically as entry and elevators doors open and close, causing control instabilities. A better location is in an interior space physically separated by walls from exterior doors and elevator lobbies. For high rise buildings, multiple sensors can be installed with the highest reading used for control.* The inside port of the DP sensor could simply be an open tube popped through a wall or ceiling, but since its purpose is not obvious, it is not uncommon for these terminations to be shoved back into the wall or ceiling or spackled over by painters. So the port should be connected to a plate pressure pickup mounted in either a "permanent" ceiling or wall. "Permanent" in this case means not likely to be removed when tenant improvement upgrades are made in the future.

FIGURE 2 Direct pressure control (adapted from ASHRAE Guideline 16).

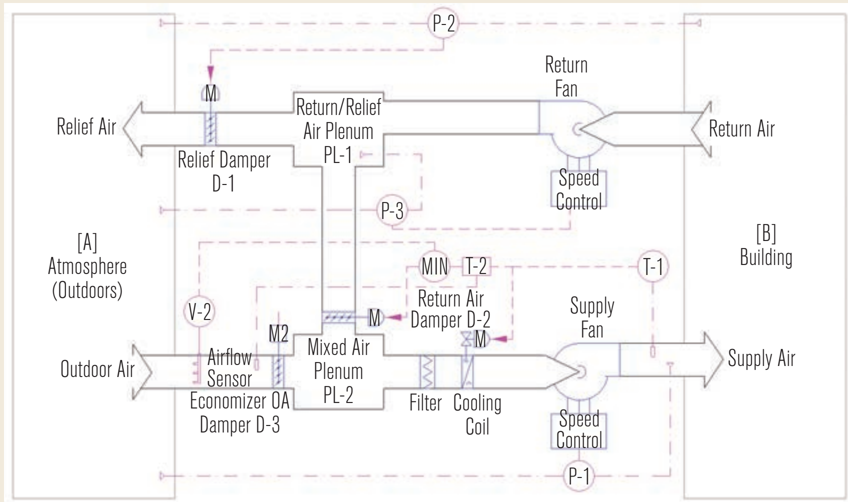
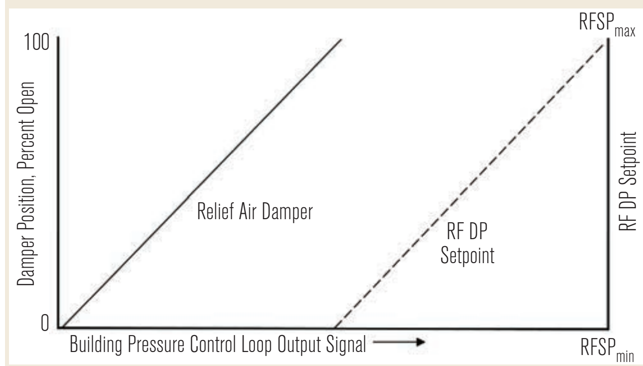


FIGURE 3 Relief damper control and return fan setpoint reset.



The ambient pressure port should be connected to a pickup designed to stabilize readings by dampening pressure fluctuations caused by wind gusts. These pickups, available from several manufacturers, can be fitted with a pneumatic signal dampener to further reduce spikes.

Return fan speed is controlled to maintain a positive pressure in the return/relief plenum to ensure no backflow of outdoor air through the relief damper. To minimize energy use, the plenum pressure setpoint should be reset as shown in *Figure 3*. The x-axis is the output of the building pressure control loop that is maintaining building pressure at setpoint. The loop output is mapped to first open the relief dampers then to raise the return/relief plenum pressure setpoint from $RFSP_{min}$ to $RFSP_{max}$. $RFSP_{min}$ is the pressure required to deliver the design return air volume across the return air damper when the supply air fan is at design airflow and supplying minimum outdoor air, but no less than 0.01 in. w.c. (±2.5 Pa). (It must be positive so outdoor air is not drawn backwards through the relief damper.) $RFSP_{max}$ is the pressure required to relieve enough air to maintain building pressure at setpoint when the supply air fan is at design airflow (or whatever the maximum is when in economizer mode) and supplying 100% outdoor air.

One potential disadvantage of Direct Pressure Control logic is control stability. A footnote in Guideline 16 says:

> *Due to the potential for interaction between the building pressurization and return fan control loops, extra care must be taken in selecting the parameters that determine the dynamic response of the digital filters and feedback controllers. To prevent excessive control loop interaction, the closed loop response time of the building pressurization loop should not exceed one-fifth of the closed loop response time of the return fan control loop. This can be accomplished by decreasing the gain of the building pressurization controller. To prevent fluctuations in outdoor*

*For high rise buildings in very cold or very warm climates, controlling building pressure for many floors with one sensor and airflow control point may not be possible due to stack effect. DP sensing and control on every floor or a range of a few floors, typically using modulating return air smoke dampers, will ensure more uniform building pressure. Relief dampers in this case should be controlled to maintain return air shaft pressure with the setpoint reset based on return air smoke damper position, similar to DP setpoint reset for supply air fans.[9]

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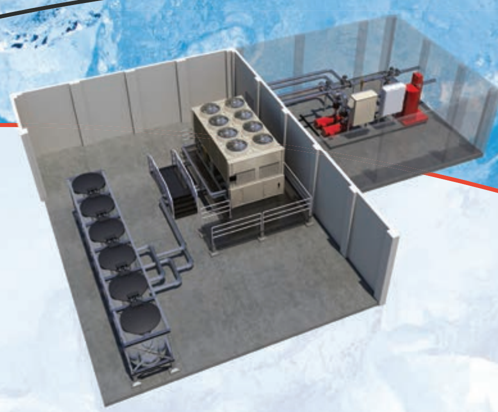

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air pressure attributed to wind gusts from exciting the control systems, digital filters should be configured to reject input spikes and/or provide a moving average of the building's differential pressure signal.

In other words, the building pressure control loop must be very slow relative to the return fan control loop, and the building pressure control point should not be the realtime DP reading but instead a moving average of the DP reading to prevent spikes from causing relief damper control instability.

Discussion and Conclusions

Airflow Tracking and Direct Pressure Control have both advantages and disadvantages:

First costs. Airflow tracking control costs are higher than Direct pressure control if return and/or supply airflow sensors are installed. But if Option a) (sum of zone airflow) or b) (speed tracking) described earlier are used for return airflow measurement and Option a) is used for supply airflow measurement, then Airflow Tracking costs are lower.

Energy costs. Fan energy is similar for the two control schemes unless the building has some other intermittent relief exhaust paths, such as operable windows or doors. If so, then Direct Pressure Control logic will sense the lower building pressure and reduce the amount of relief airflow at the air handler, reducing return fan energy use. Because Airflow Tracking logic only indirectly controls building pressure, it will relieve the same amount of air at the air handler regardless of other relief paths.

Control stability and reliability. Airflow tracking logic relies on airflow measurements that are seldom accurate, but fortunately extreme accuracy is not needed for building pressure control. The control logic is inherently reasonably stable provided dampers are properly selected and controlled (which will be the subject of my next column in November 2014). Direct pressure control relies on a representative and stable building pressure signal, which requires care in sensor port placement and type. And, as noted in Guideline 16, control can be unstable if the building pressure and return fan discharge pressure control loops are not properly tuned.

So both Airflow Tracking and Direct Pressure Control are valid building pressure control schemes for VAV systems with return fans and outdoor air economizers. But Direct Pressure Control is favored by both Guideline 16 and the master control sequences developed by RP-1455, and by the author,** because it is a more direct approach to building pressure control.

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**Full disclosure: The author was involved in the development of both Guideline 16 and RP-1455.