# Energy Efficient Pressure Control for Recirculating Systems

by Leonard A. Damiano, *EBTRON, Inc.* & Jerry Tey*, FESV Technologies Pte. Ltd.* May 2016

## INTRODUCTION

Building pressurization can only be created and maintained by a building's own mechanical system. Period! The mechanical system is therefore central to controlling pressurization to a predetermined, effective and energy efficient level. The mystery to most people is how to accomplish these objectives, simultaneously.

For our purpose here, we need to illustrate the concepts being discussed with simple and direct examples, using simple computer modeling. The building pressure model creates a directional airflow through the exterior walls of the structure using the airflow generated by our mechanical system. This pressure flow can also be called exfiltration ($Q_P$) or infiltration, depending on the direction of the airflow.

$$Q_P = Q_{OA} - (Q_{REL} + Q_{EX})$$

This model shows us that the mechanically generated pressure flow rate ($Q_P$) is the difference between the outdoor air intake rate minus all of the exhaust/relief airflows. Because of the many difficulties involving the indirect control of space pressurization flow ($Q_{OA} - Q_{EX}$) when using static pressure sensing, HVAC designers are encouraged to consider the use of differential flow control or volumetric (fan) tracking to provide greater control stability, precision, power efficiency and potentially less maintenance. This concept has been used in hospitals and labs for many years, very successfully, but mostly with health and safety driving more than energy efficiency. Without affordable, reliable differential measurements, safety requires that more volumetric flow than necessary is used.

It is important to recognize that since the airflow differential between the supply and return air paths of each air handling system is essentially the pressurization airflow for the building, the control of supply and return (or relief) fans are crucial to proper building pressurization. Systems that trivialize the importance of this differential and use either variable speed fan drive-slaving or low accuracy airflow measurement devices for fan tracking will have serious pressure control problems when air is being relieved at the air handler.

## UNDERSTANDING BUILDING PRESSURE

The term "pressure" is somewhat of a misnomer. Building pressure is observed as the result of a differential airflow created by the mechanical system across a pressure barrier. It is often referred to as the "pressurization airflow" or pressure flow. Although the pressurization airflow will result in a measurable pressure drop across interior and exterior walls, direct static pressure control of building pressure flow will not ensure proper space pressurization.

## PROBLEMS WITH PRESSURE CONTROL

Static (or differential) pressure control is widely implemented as a technique to control pressure flow. In most applications, a low cost differential pressure sensor is connected between the exterior of a building or room and an internal reference position within the pressure zone. These sensors are subject to both short and long-term drift, are affected by ambient temperature changes and have questionable accuracy at the low pressures required for proper net pressurization control. Depending on the strategy used, either a return or relief/exhaust fan or damper is modulated to maintain the differential between the reference position and building exterior. Unfortunately, the differential pressure measured will typically NOT represent the actual net building pressure because of:

- wind pressure effect on the reference tap outside of the building
- internal pressure variations that result from air flow through open doors or under closed doors
- sampling error due to the single location of the interior tap, and no valid means to average multiple sensors
- Pressure sensors drift over time, with ambient temperature change, and require periodic zeroing or recalibration

In addition, pressure control is extremely problematic in systems with multiple pressure zones or multiple air handling units serving connected zones, because of pressure interactions. One fan system will respond to changes on its zone sensor and as a result influence the operation of another fan system.

These types of situations are unable to overcome stack effect because multiple air handlers cannot act independently when using a static pressure control strategy. What is the solution?

Airflow control will result in independent pressure zone control without interaction. How?

- Control airflow rates onto and off of each floor, or in/out of each pressure zone.
- Building construction design and quality are critical.
- Pay close attention to potential airflow paths between floors and take action to minimize such paths (leaks, elevator shafts, etc.)
- Do not sum traditional VAV box flow sensors to determine the supply airflow rate. They are not designed to measure absolute values and are very inaccurate.

Stability is also affected by transient wind gusts, door open/close events (interior and exterior) and pressure sensor stability. Very small changes in pressure equal large changes in the airflow needed to create those pressures. The effect of this square root relationship can be easily seen on any typical air pressure to velocity graph.

In reality, the only time that static pressure represents net space or building pressure is when there is no wind and all of the interior doors in a pressure zone are open.

## PRESSURE FLOW CONTROL

Although conceptually simple, implementation gets complicated in the real world when the physical limitations of measuring intake and exhaust air streams are considered.

Without relief at the AHU (Fig. 1), pressurization can be measured and controlled solely by the minimum outdoor airflow rate. When remote exhaust is significant and variable, then continuous monitoring and control would be advisable. If the exhaust is fixed and fan status can be identified, air balance measurements can be used to calculate the needed outdoor air rate without measurement.

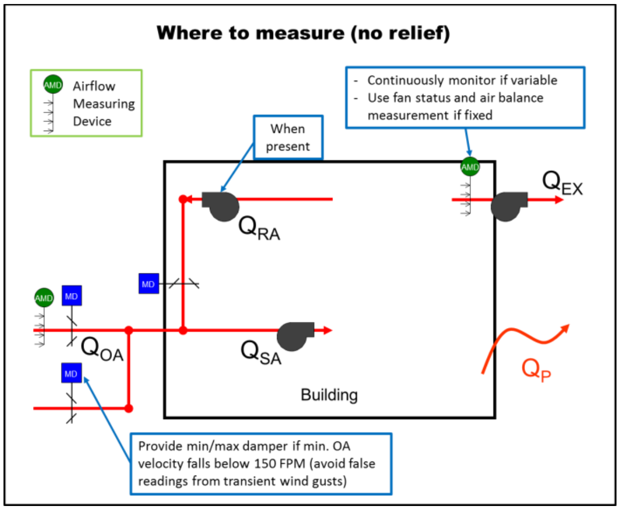


Figure 1

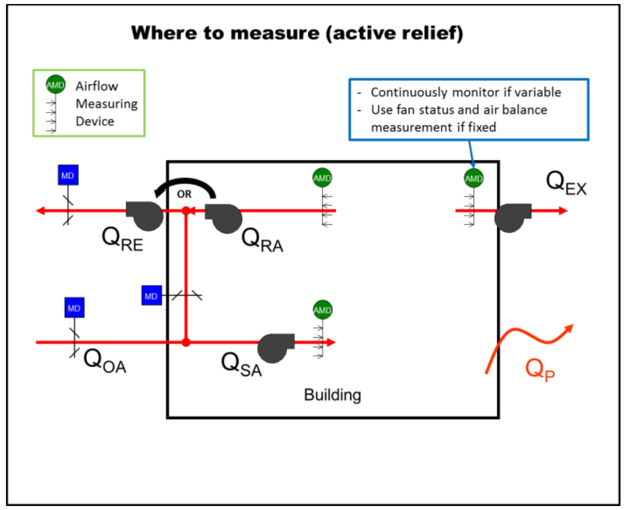


Figure 2

The situation changes when active relief is used (Fig.2), as measurement is generally not accurate enough for tracking the differentials.

Due to the difficulties or impossibility of measuring active relief airstream at the AHU, we need to look for an alternative that provides greater reliability in measurement for volumetric differential tracking. If we look to further simplify the equation for our system model, nodal analysis can provide us with additional variables to use in determining the mathematical equivalence of the differential $Q_{OA}$ - $Q_{EX}$.

$$Q_{Rec} + Q_{OA} = Q_{SA}$$
$$Q_{Rec} + Q_{REL} = Q_{RA}$$
*subtract 2 equations, leaving* $Q_P$ =
$$Q_{OA} - Q_{REL} = Q_{SA} - Q_{RA}$$

With a little algebra, we can readily see that $Q_{OA} - Q_{REL}$ is equivalent to $Q_{SA} - Q_{RA}$., which can provide the means to control pressure flow when $Q_{REL}$ cannot be reliably measured.

## DETERMINING THE PRESSURIZATION AIRFLOW REQUIRED

Typically for most climates, the objective of building pressurization is to maintain slight positive pressurization airflow. A rule of thumb is to provide between 0.03 and 0.05 CFM/ft$^2$ (0.153 – 0.254 L/s/m$^2$) of pressurization airflow per floor area. In reality, the pressurization air is more a function of the building envelope construction, door/window seals and ceiling height. However, this rule of thumb is applicable to many buildings.

The pressurization airflow can also be estimated using computer models of the building envelope and openings.

Perhaps the best way to determine the pressurization airflow is in the field. Note that on multi-story buildings these techniques should be done on each floor to compensate vertically for stack pressure effects. Two methods are possible, but are not the focus of this paper.

## ACCURACY MATTERS

Measurement reliability (or continuous accuracy) makes a significant difference in pressure flow control through volumetric tracking.  To convey the significance of airflow accuracy in pressure control, we developed a mathematical model that:

1. calculates the statistical uncertainties of airflow measurement,
2. calculates the range of differentials it could provide and finally,
3. converts differential flows to pressure in comparison to a realistic but arbitrary set point.

The results from a variety of input scenarios are indicated on subsequent graphs.

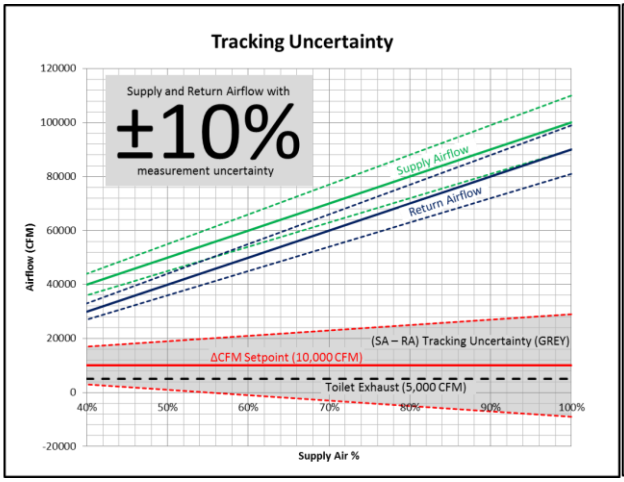


Figure 3

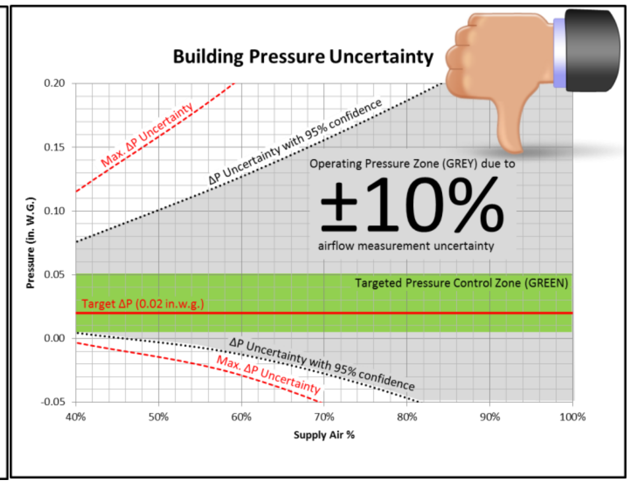


Figure 4

As you can see, the effect on the controllability of space pressurization is unacceptable when using measurement methods and instrument combinations that provide ±10% uncertainty (GREY area outside the GREEN targeted control zone).

However, airflow measurement accuracy in the range of ±3% of reading does show that reliable pressure control is possible throughout the full operating range of the model – 40% to 100% of flow (Fig. 5 & 6).  Pressure control performance does improve accuracy at the lower end of the scale, but that is the area where pressure-based velocity measurement devices are the least accurate.

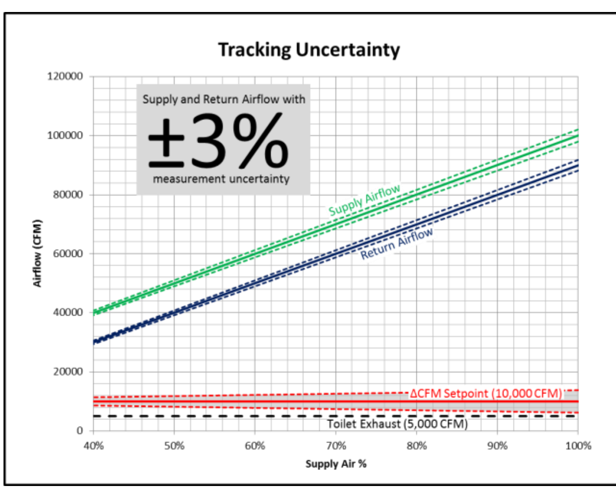


Figure 5

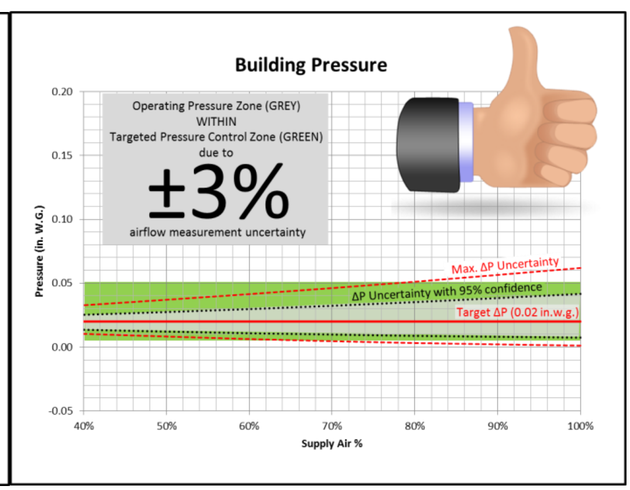


Figure 6

## AHU CONTROL OF SINGLE ZONE PRESSURE AND DILUTION VENTILATION

Generally, most air systems require measurement of total supply, total return and (min) outdoor air to ensure control of pressure flow and intake rates, as operating and environmental conditions change. Relief at the AHU is typically not measureable and as mentioned earlier, exhaust does not need measurement if it is fixed and fan status is identifiable. When exhaust is significant and variable, measurement should be seriously considered.

Independent control loops should be maintained for both Outdoor Air and Volumetric Differential Tracking. Although a mathematical relationship exists between them, the relative difference in their size makes any errors in measuring the larger variable becomes a significant portion of the lesser one (normally outdoor air). OA is measured directly and may be estimated indirectly using volumetric differential, when there is no relief at the AHU. Both are attempting to determine the same value (OA), simultaneously from two different directions. The differential SA-RA will rarely equal and track the typically much smaller OA volume. Set point control errors are almost guaranteed with two conflicting control loops.

Some systems may benefit by ensuring the proper direction of flow by adding a ΔP sensor (or bleed airflow sensor) across the relief damper for positive control of relief flow at all points of operation.

## SUMMARY AND CONCLUSIONS

- Airflow measurement locations are dependent on HVAC system design.
- Static pressure control techniques may appear to function correctly but can easily result in false readings because of wind pressure, internal pressure variations and sensor drift;
- To maximize pressure control performance, buildings should be compartmentalized into unique pressurization zones based on space use and external pressure variations, such as stack effect.
- Pressure control performance and alternatives may be limited by equipment capacity, project design and layout, envelope leakage.
- Volumetric (or fan) Tracking is more precise, more efficient and more stable than indirect static pressure control.
- Supply – Return airflow is the same differential control as Intake – Exhaust, but uses larger volumetric components.
- Systems with active relief at the AHU require airflow measurement devices in the supply, return and outdoor air (at least minimum OA) flow paths.
- Systems <u>without</u> active relief at the AHU only require an airflow measurement device in the outdoor air intake.
    - If exhaust airflow rates are variable, an airflow measurement device should be located in the exhaust airflow path.
- Velocity-pressure devices may be incapable of providing sufficient accuracy to be useful in volumetric differential control, particularly at the lower end of the range (turndown minimums < 50% capacity or 2:1) and as environmental conditions vary in the field.
- Airflow measurement accuracy has a huge impact on pressurization control performance and reliability.