Building Pressurization Control and Outdoor Air

by Leonard A. Damiano, *EBTRON, Inc.* March 2016

Overview

Building pressure and outdoor airflow control must be integrated for proper system performance. Pressure results from the development of a pressurization flow between adjacent pressure zones. A zone will be positive to an adjacent zone if the pressurization flow across the zone barrier is positive. Generally, outdoor air is required to pressurize a zone.

Designers should exercise caution when implementing demand based ventilation schemes that reduce the outdoor air without provisions for assuring that the pressurization flow is maintained (i.e. the relationship between the outdoor air and the exhaust air is maintained). When the outdoor air dew point approaches or exceeds 60 F, it is essential to create a net positive pressurization flow to prevent the transport of water and outdoor air contaminants into the building or its envelope. Excessive moisture can result in mold growth, structure damage and poor indoor air quality. Net positive pressure can dry the building envelope and help assure proper temperature and humidity control within the building.

The concept of “net” pressure must be understood for building systems. Wind pressure acting on the exposed building surfaces cannot be overcome with the mechanical system alone without potential damage to the envelope integrity. Therefore, a net positive pressure (average differential pressure across all exposed surfaces) is the best scenario that can be achieved. This is difficult to do without very precise volumetric controls and nearly impossible with dP inputs alone. If we assume this objective is attainable, even a properly pressurized building can have exterior walls pressurized or depressurized for short periods of time, at presumably very low flow rates. When the outdoor air temperature is less than the indoor air dew point (i.e. winter heating season), as close to net neutral pressurization flow as the control system and instrumentation allow, should be maintained.

To help counteract stack pressures, multi-story structures can be designed with each floor as a separate space to allow airflow and pressure control, continuously. If we don’t, weather (wind and stack effects), poorly designed or implemented controls or poor operational methods can easily lead to excessive moisture infiltration. Stack and wind effects on pressure relationships and the direction of mechanically produced airflows has been recognized. Now, our standards require that systems attempt to balance these dynamic pressures to better control the direction of flow.

ANSI/ASHRAE Standard 62.1-2016

The current Exfiltration section is approved and reads as follows:

> **5. Systems and Equipment**
> **5.9.2 Exfiltration.**
> Ventilation system(s) for a building shall be **designed to ensure that the total building outdoor air intake equals or exceeds the total building exhaust <u>under all load and dynamic reset conditions</u>.**
> **Exceptions:**
> **1.** Where excess exhaust is required by process considerations and approved by the authority having jurisdiction, such as in certain industrial facilities.
> **2.** When outdoor air dry-bulb temperature is below the indoor space dew-point design temperature.
>
> ***Note:*** Although individual zones within a building may be neutral or negative with respect to outdoors or to other zones, net positive mechanical intake airflow for the building as a whole reduces infiltration of untreated outdoor air.
>
> DEFINITIONS
> - ***exfiltration:*** uncontrolled outward air leakage from conditioned spaces through unintentional openings in ceilings, floors, and walls to unconditioned spaces or the outdoors caused by pressure differences across these openings due to wind, inside-outside temperature differences (stack effect), and imbalances between outdoor and exhaust airflow rates.

Mold - The Bogey Man of IAQ

Mold Growth Only Needs:

- Moisture/Humidity

- Temps above 58°F
- Food source
- and a min. 3 - 6 hours

Example: At 65.3°F (with adequate RH and inadequate substrate) mold grows on building materials after 6 hours

There are many forces behind uncontrolled moisture migration, an essential element for mold. Most are likely to create moisture and mold problems ... and ALL can be prevented with reliable control of "pressurization flow".

Vapor diffusion
Solar radiation
Capillary action
Return air plenum located near exterior wall
Gravity
Surface tension
Wind pressure
Differential pressure
Stack pressure (temperature differential)
Improper design,
Improper construction or
Improper operation of mechanical systems

One of the industry's most celebrated experts and prolific writer on moisture in buildings, listed a number of recommendations for avoiding mold. This paper is now almost 10 years old. In it, he recommended the following anti-mold strategies for Hot/Humid climates. All are important, but the first one is begging for recognition.

1. **Pressurize conditioned and interstitial spaces with air dried below a dew point of 55°F (13°C**).
2. Locate vapor barriers toward the exterior of building assemblies. Avoid vapor barriers such as vinyl wall coverings toward the interior of building assemblies.
3. Provide air barrier systems that limit air infiltration and wind washing from the exterior.
4. Provide adequate dehumidification capacity under part load conditions when sizing air-conditioning equipment.
5. Dehumidify makeup air to a dew point of 55°F (13°C) before it is introduced.
6. Keep the indoor dew point below 55°F (13°C).
7. Insulate cold water piping and cold duct distribution systems.
8. Do not overcool interior spaces.
9. Design the exterior wall so that wet or moist materials used in construction can dry towards the interior.

**Moisture Control for Buildings*, ASHRAE Journal, February 2002, By Joseph Lstiburek, Ph.D., P.Eng.

Negatively pressurized buildings use the building envelope as the first stage of filtration!
Mold growth may occur in negatively pressurized buildings when the outdoor air dew point is greater than 65 ºF. It only takes a few hours for it to get established, after which it is very difficult and expensive to eradicate.

Pressurization Flow control works to reduce the potential for mold because Net Positive pressure flow will result in a Net Drying Effect when outdoor dew points are elevated.

How Much Differential Pressure is Sufficient?

Differential pressures **as low as +0.004" WG** [+1 Pa] are sufficient to prevent outdoor air infiltration problems. (Florida Solar Energy Center, 1996)

More *precise* control can offer practical solutions, with potentially huge energy savings.

Ultra-low differential pressure control is realistic, simple and economically attractive **IF** you use:
(1) leakage performance in your construction quality goals and
(2) the correctly apply air barriers, vapor retarders, and
(3) properly selected instrumentation and volumetric air controls.

NOTE: +0.004" WG equates to a *Pressurization Flow* of approximately +253 fpm.

Most designers seem to think 0.05" to 0.10" is an aggressive target for design due to the difficulty in control precision and stability with traditional methods and designs, but is more than 10 times the absolute minimum for effectiveness.

Indoor Climates Change Continuously

Preventative strategies should be addressed at the design stage or many more millions can be spent to "fix" problems later on ….. Pay now or pay later.

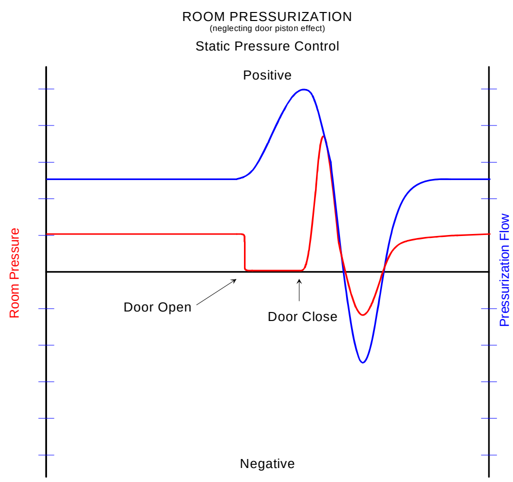
Contemporary studies indicate costs can range from an additional $1.50 - $15 / ft^2 for design improvements (or preventive actions prior to mold) or $30 - $65 / ft^2 for mold remediation and repair. [Ron & Holly Bailey, Bailey Engineering, Jupiter, FL, 2004]

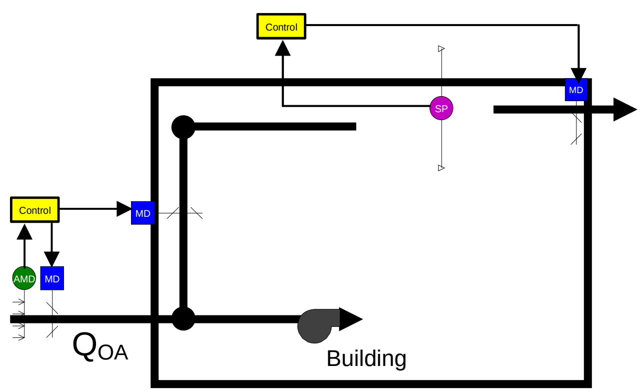
Continuous Pressurization?

- Pressurization flow of approximately 0.05 cfm/ft^2 is required for a NET building pressure of 0.03 to 0.05 in. WG
- This correlates well with extrapolated building envelope leakage requirements and independent research using published envelope leakage data (Mumma).
- In many cases, the pressurization flow is close to the floor component requirement of ASHRAE Standard 62.1-2016
- Offices, theatres, conference rooms - 0.06 cfm/ft^2.
- In other cases, the pressurization flow is higher
- Classrooms, libraries, museums – 0.12 cfm/ft^2
- This implies that a minimum, pressurization flow should be maintained at all times to avoid buildup of moisture during high dew point periods (not just occupied periods).
- This has a profound affect on the design of systems and the use of energy recovery systems.

What's Wrong with Space Static Pressure Control?

The historic and least expensive first-cost method of automated pressure control is the use of static or differential pressure sensors. Generally, they directly control or reset damper position or fan speed. The challenges presented in their application begin with the relationship between very small pressure changes and the large equivalent airflow needed to establish that pressure. The inverse proportions set the stage for control volatility.





Directly controlling space static pressure will usually result in very unstable and unreliable control for several reasons.

- Location of the inside reference not representative of net building pressurization (office partitions, mechanical rooms, elevator lobbies can all cause problems with ΔP)
- Control Stability / Sensitivity transient wind gusts, doors open and close,
- Pressure sensors drift over time, with ambient temperature change, zeroing or recalibration
- Control interaction with multi-sensor systems
    - Multiple air handlers cannot act independently using a static pressure control strategy (this diagram).

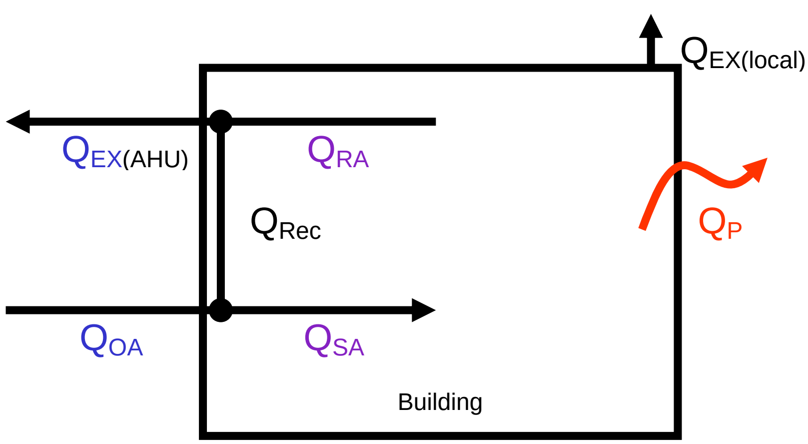
    - Airflow control will result in independent pressure zone control without interaction.
- Inability to overcome stack pressure effects
    - Multiple air handlers cannot act independently using a static pressure control strategy (this diagram above) due to control interactions between AHUs.
    - Airflow control will result in independent pressure zone control without interaction.
    - **Control airflow rates onto and off of each floor or pressure zone**. **Do not** sum traditional VAV box flow sensors to determine the supply airflow rate. 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, stairwells, etc.)

Mechanical components create pressurization flow. Not wind, nor any other source of airflows that influence the differential across the building envelope. To control pressurization flow, the mechanical system controls must be isolated from other pressure sources. This is the reason differential or static pressure control does not work well because it responds not only to changes created by mechanical flows, but also to wind and stack pressure effects.

You can't control what you don't measure.

What is Pressurization Flow?

This is the mechanically induces flow through a buildings envelope, which cannot be measured directly. It can flow in either direction (as infiltration or exfiltration). Ref. 2015 ASHRAE Applications Handbook §47.10, Fig. 18 – $\mathbf{Q_p = Q_{oa} - Q_{ex} = Q_{sa} - Q_{ra}}$ It shows the equivalent mechanical flows that should be controlled to optimize pressurization control performance. The nodal analysis is the basis of the Applications Handbook section §47.10, and Fig. 18 containing a generic building pressurization model. It concludes that volumetric differentials between exhaust and intake, OR return and supply airflows can be used to determine and more reliably control pressurization flow.



Building Pressure Model: $Q_P = Q_{OA} - Q_{EX}$

Mathematical Equivalent:

$Q_{Rec} + Q_{OA} = Q_{SA}$

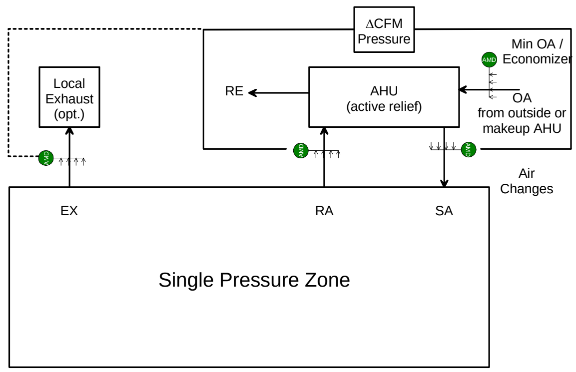
$Q_{Rec} + Q_{EX} = Q_{RA}$

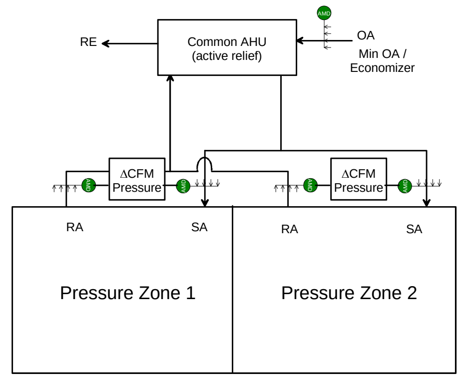
$Q_{OA} - Q_{EX} = Q_{SA} - Q_{RA}$ (a.k.a. ΔCFM)

Pressurization Flow Control Design Process

The design process for pressurization control is very straightforward.

1. **Define** the <u>pressurization compartments</u> in your building.
2. **Determine** (estimate) the total <u>envelope leakage flow</u> and compare it to the airflow rate required for dilution (ventilation for IAQ). *The larger value determines the minimum outdoor air required.*
3. **Maintain** the <u>pressurization flow</u>.



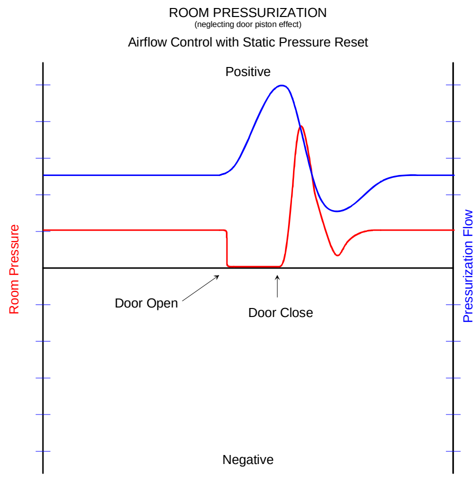


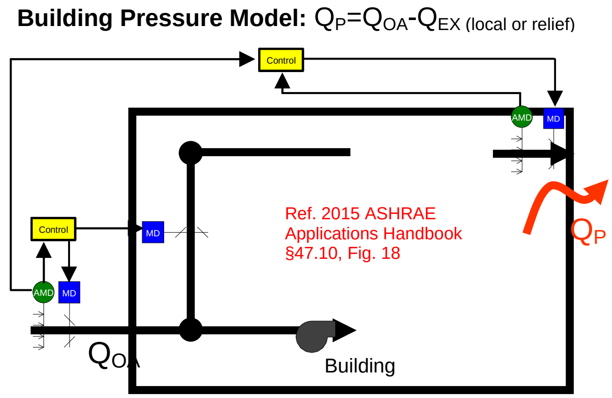
The air into and out of a space (the pressure zone) are maintained at a constant rate to provide a stable differential pressure between it and adjacent spaces. Control is independent from external or internal sources of non-mechanically generated airflows. Pressurization is stable, even with occupant traffic into and out of the space. Door opening and closing has no affect on pressure control. This is how labs and hospitals have been designed for many years. This principle can readily be applied to any occupied or unoccupied space with the decreasing costs of DDC controls and reliable velocity sensors.

Volumetric Pressure Flow Control

Differential airflow for pressure control has been used for decades within hospitals, laboratories, clean rooms, and other facilities Its use is growing due to the increased reliability of airflow measurement instruments, recognition of the inherent stability of control and the growing need to minimize energy usage in buildings. Maintaining the pressurization flow (created by a mechanical differential) is a much more forgiving variable to measure for control. It will result in very <u>stable control</u> and provides a number of <u>advantages</u>.

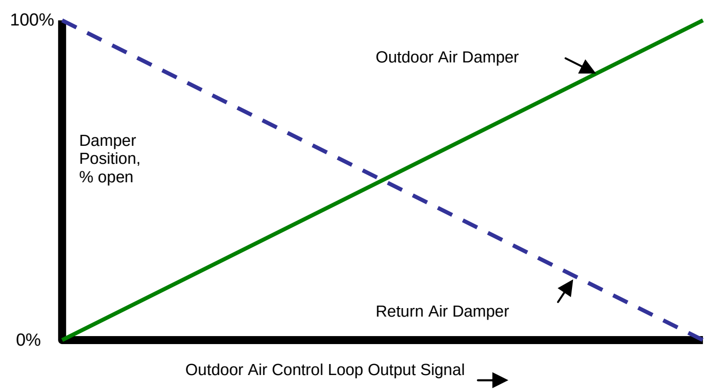
1. Multiple air-handling systems will operate independently when volumetric airflow is controlled.
2. Pressurization control ensures that intake air is treated and filtered before introduction to the occupied environment
3. Helps sustain greater temperature, humidity and contaminant control
4. Preserves interior environmental conditions by preventing the entrance of unfiltered and untreated outdoor air, by providing a counter-flow
5. More stable (more tolerant of variable measurement error) and a precisely controllable variable
6. Codes and standards require and support pressurization control
7. Linkage exists between comfort, energy usage and ineffective pressure control
8. Allows more efficient and effective control of air exchange rates and pressure relationships, while maintaining stable temperature and humidity control
9. Essential for avoidance of distribution problems due to improper pressurization
10. Minimizes energy inputs to compensate for variations
11. Control airflow for specific process requirements
12. Reliable volumetric control for Δp can be used as a security tool for elevator lobbies, public areas and designated refuge areas
13. ADA-compliance (exterior door opening force limit) < 0.36”WC
14. Helps insure efficient compliance with any ventilation design standards and any rate-based codes or regulations, regardless of system operating point (assumes available capacity)
15. Can significantly improve the building’s energy and comfort performance
16. Can be a low-cost method of increasing energy efficiency in existing buildings
17. Provides for a more sustainable design by
    a. Helping to assure indoor environmental quality (comfort and health) and
    b. <u>Long term</u> air system performance at the lowest possible LCC and lowest energy usage





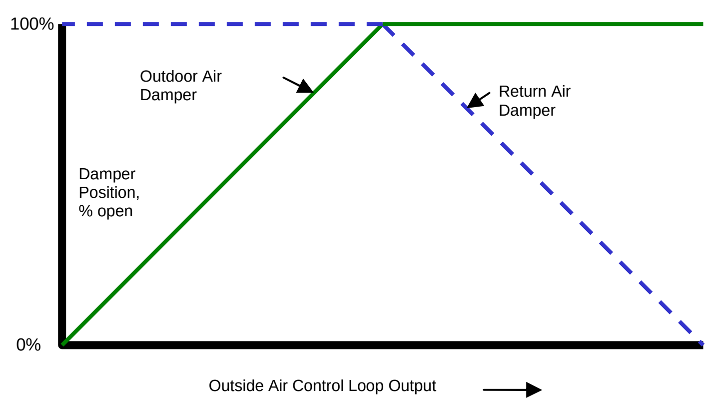
Traditional Outdoor Air Intake Control (without pressure flow control)

This was the historic "go to" damper control method used by most AHU manufacturers. Overlapping (Inverse) Damper Control is typically the least cost method of choice by AHU manufacturers, allowing the use of a single actuator to control both dampers in opposition. Unfortunately, the owner pays for this first-cost saving through the added energy costs that result from the inefficiency of the arrangement and the additional fan horsepower needed to overcome the pressure drop created around mid-stroke with both dampers being held partially open.



Energy Efficient Outdoor Air Intake Control

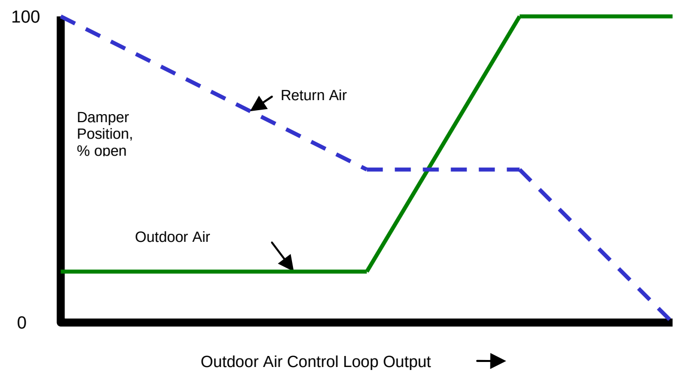
Sequenced (and uncoupled) Damper Control on Supply/Relief Systems can be used to avoid the added pressure losses from partially closed dampers by requiring sequential control, leaving one damper to remain open until the other is unable to reach the outdoor air setpoint.



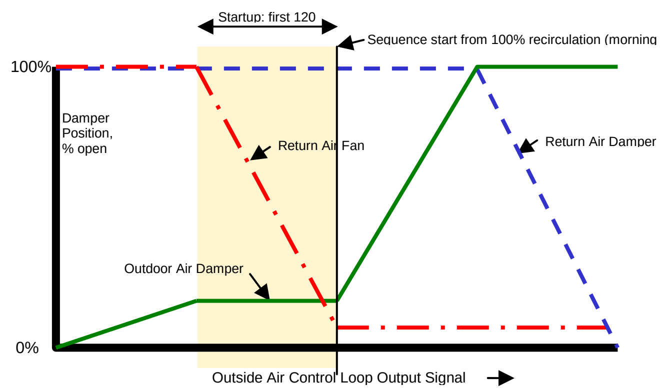
The return/recirculation damper does not begin to close until the intake damper has reached its full-open position having been unable to satisfy the set point for more outdoor air. This minimizes the pressure losses sustained and reduces the energy required to overcome the airflow impediment.

Energy Efficient Sequenced Control

Supply/Return Systems (below - no active relief at AHU) with independently controlled dampers can also avoid unnecessary power costs and inefficiencies.



Supply/Return Systems (below - with active relief at AHU) require a startup routine on some systems to insure that outdoor air louvers actually intake air and not exhaust it. This is a control problem identified on many buildings.



Control Basics

General Sequence for Minimum Outdoor Air Mode (No relief at the Air Handler)

Regardless of the type of system, the pressurization flow rate and outdoor air flow rate are controlled similarly. There is generally no relief at the air handling unit during minimum outdoor air mode.

The outdoor air flow setpoint for dilution ventilation should be established using the guidelines of the section 6 tables and procedures in ASHRAE Standard 62.1-2016. In addition, the outdoor air setpoint for pressurization should be established by adding the pressurization flow requirement to the sum of the local exhausts in the zone served by the air handling system. The greater of the two dictates the outdoor air setpoint. If the outdoor air flow rate for minimum ventilation significantly exceeds that required for pressurization, the free cooling strategy (next section) should be followed.

The outdoor air flow should be actively controlled on all systems, regardless of type (VAV, constant volume, etc.), since wind and stack pressure variations can have a significant effect on the intake flow rates of all systems – some more than others. The most practical way to maintain the outdoor air intake flow rate is to install a permanently mounted airflow measurement device, appropriately selected for use in outdoor air intakes. A number of commercially available airflow measurement devices are available for this task.

Traditionally, the outdoor air damper is modulated or the outdoor air and recirculation dampers are modulated inversely to maintain setpoint. Unfortunately, most dampers are oversized and are ineffective as control valves and stable control is often not achieved. Blade/linkage hysteresis alone can be more than the control tolerance, inducing a constant hunt.

A more reliable approach is to decouple the outdoor air and recirculation dampers by individually actuating each. Depending on the system, the outdoor air flow rate is then controlled by sequencing the dampers. An effective sequence sets the outdoor air damper to a fixed minimum position. The damper is opened if the setpoint is above the measured airflow rate. Once the outdoor air damper is fully opened, the recirculation damper begins to close. On systems with a return fan, the return fan is also used to maintain the outdoor air set point. Fan speed responds more quickly and more precisely than damper blade position.

The sequential control strategy improves performance of oversized dampers and allows the option to use opposed blade dampers for better control. If airflow measuring devices are selected that can measure low airflows (down to 150 fpm) a single outdoor air damper can be used on systems with free cooling, thus simplifying control. Otherwise, a separate minimum outdoor air damper must be installed.

General Sequence for Free Cooling Mode (Airside Economizers)

During free cooling (or any time there is relief at the air handler), the differential between the supply and return airflow rates should be maintained. The difference should equal the sum of the pressurization flow and the local exhausts. Most free cooling systems have either a return or relief fan which should be modulated to maintain the preset supply/return airflow differential.

Modulating free cooling systems achieve mixed air temperature setpoint by modulating the outdoor air and recirculation dampers in sequence as described during the minimum outdoor air control section. When a single intake damper is used, the mixed air temperature setpoint is maintained by resetting the outdoor air flow setpoint. When a min/max damper arrangement is used, the mixed air temperature is achieved by directly controlling the dampers. Resetting the outdoor air flow setpoint will result in more stable temperature control.

The relief air damper should be opened during free cooling. As an added level of security against negative airflow into the relief damper, a differential pressure sensor or bleed airflow sensor should be placed across the relief damper to ensure flow in the proper direction and used as a data point to calculate reset set points.

CONCLUSIONS

Volumetric airflow control for pressurization is a growing method of space pressure control for many projects. It may not be appropriate for all projects, if only due to specific circumstances, size, system application or occupancy types. However, with its demonstrated advantages, together with the availability of significantly lower cost airflow sensors with integrated controls, makes their application very affordable. The nature of the sensors avoids creating a maintenance headache for the user. These are stand-alone, application-specific controllers that usually provide a single control function, and allowing the room thermostat to continue independently as the primary thermal control input.

No longer is differential air volume control the description of a method used only by larger, built-up systems. No longer is the direct control of outdoor air intake diminished to use in those same larger systems. Now, low-rise building occupants served by packaged AHUs as small as 5 tons can receive the benefits of an improved indoor environment, similar to those remaining 20-30% living or working in large high rise buildings.