

LOW-RISE-BUILDING PRESSURE:

Basics and Case Studies

Understanding how buildings get to be pressurized so HVAC operating problems can be identified, diagnosed, and corrected

The first-cost focus of new construction often results in buildings—HVAC systems in particular—that don't work. Seeming to catch consultants and contractors by surprise are problems associated with building pressurization. These can take the form of automatic doors in violation of codes protecting people with disabilities, as well as mold and mildew, carpet staining, insufficient HVAC capacity, and poor indoor-air quality.

This article will discuss how buildings become pressurized and examine two real-life buildings that

had serious problems with building pressurization.

THE BASICS

Building pressurization—both positive and negative—comes about by two means. The first is natural—the effects of ambient air and wind. The second—and usually predominant—is the HVAC system. Particularly with respect to the latter, building pressurization is determined by a variety of factors, including the airtightness of the building, the airtightness of the ductwork, the configuration of the HVAC system, and how the HVAC system is adjusted.

Looking at Figure 1, we can see that if the return-air ductwork is excessively restrictive, the outside-air damper is not completely airtight, and the construction of the building is relatively loose, the building will be positively pressurized because it is easier for the HVAC system to draw in air through the outside-air damper and push it out through the envelope of the building than push it back through the restrictive return-air ductwork. Conversely, if the supply-air ductwork is leaky, and the return-air

By **JAMES P. WALTZ, PE, CEM, ACFE**
Energy Resource Associates Inc.
Livermore, Calif.

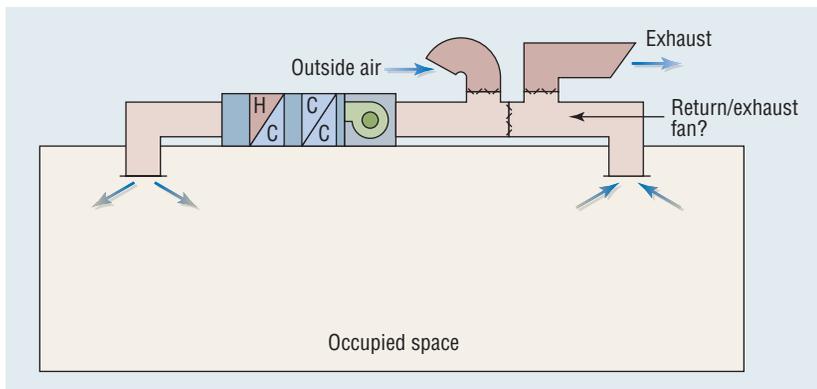


FIGURE 1. A simplified HVAC schematic.

Acknowledged as a pioneer in the field of energy management, James P. Waltz, PE, CEM, ACFE, is president of Energy Resource Associates Inc., a firm specializing in the renewal of mechanical, electrical, and control infrastructure systems of existing buildings. He is a founding member of the Association of Energy Engineers, through which he has taught nationwide seminars and authored books on building simulation and performance contracting, and a member of the American Society of Heating, Refrigerating and Air-Conditioning Engineers; the American College of Forensic Examiners; the Association of Energy Services Professionals; and the Demand Side Management Society. Since 2000, he has served on HPAC Engineering's Editorial Advisory Board.

ductwork is oversized, it will be easier to push out air through the leaks in the supply ductwork and draw in air through the openings in the building, causing the building to be negatively pressurized.

In other words, the pressure condition of an occupied space may be impossible to predict based on the building and HVAC design because it may depend largely on qualitative construction issues, such as the airtightness of the building and/or HVAC ducts, which often are not predictable.

To understand why building pressurization is so important, consider codes

Even simple low-rise buildings need real engineering.

regarding automatically closing doors. These codes are very specific about the maximum amount of force a person with a disability should have to exert to overcome the force exerted by an automatic door closer. If a building has an outside-air economizer and is pressurized, the air pressure will overcome most of the force of an automatic door closer so that one only has to touch the door to cause it to open. If an outside-air economizer is not in operation, one must overcome the entire force exerted by the door closer. The maximum force allowed is 8.5 lb. It is assumed that this force is applied in the middle of the door. We can sum the moments around the hinge point of the door and calculate the balanced forces. Eight pounds times half the width of the door is 1.5 ft, or 12 ft-lb of torque. Because the center of force of pressure on the door is the center of the door as well, and we assume the door to be approximately 3 ft by 6 ft 8 in., or 20 sq ft, then 8.5 lb divided by 20 sq ft (2,880 sq in.) is approximately 0.003 psi. Because 1 psi is equal to approximately 2.3 ft, or 28 in. of water, then 0.003 psi times 28 in. is approximately 0.1 in. of water static pressure. To account for the fact that all

doors cannot be adjusted perfectly and that a bit of extra door-closure pressure is needed for a door to close reasonably quickly and securely and latch upon closing, 0.05 in. of water gauge should be used as the practical limit for building pressurization to meet the codes.

If a building were operated on 100-

percent return air, with its supply-air and return-air ductwork leaktight and all of its dampers leaktight when closed, the building pressurization would be neutral (i.e., equal to the atmosphere). The only way to pressurize a building positively or negatively is to deliver more air to an occupied space than is removed

or vice versa. In this case, because the supply-air and return-air ductwork is leak-tight, and the outside- and exhaust-air dampers are closed and also leaktight, the amount of air supplied to the occupied space and the amount returned are the same, meaning the space could be neither positively nor negatively pressurized. In

examining the pressures in the ductwork, we would realize that the pressure in the supply duct was positive, allowing air to move from the duct into the neutral space, while the pressure in the return duct was negative, allowing air to move there from the space. If the return-air ductwork were grossly oversized, and

there were no static-pressure losses in it, we could assume that the pressure on the suction side of the fan was the same as the atmospheric pressure and that there was only positive pressure in the supply ducts. And if we were to open the outside-air damper to introduce ventilation into the building, no air would flow into the outside-air damper because the pressure would be the same on both sides of the damper. To introduce ventilation into the building, we would need to close the return-air damper slightly, which would

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cause restriction and a negative pressure between the return-air damper and the supply fan, which, in turn, would cause ventilation air to enter the outside-air damper and the building to be slightly positively pressurized, with the same amount of air leaking out of the building as coming in through the outside-air damper. If the ventilation air were to cause the building to be pressurized more than we desired, we could relieve the excess pressure by opening the exhaust-air damper.

Of course, we do not have such perfect buildings, nor do we have perfect HVAC systems. For example, it is rather common for return-air duct systems in multi-story buildings to have a static-friction loss in the neighborhood of $\frac{1}{4}$ to $\frac{1}{2}$ in. of water. What this means is that a building with an outside-air economizer would have to be pressurized to $\frac{1}{4}$ to $\frac{1}{2}$ in. of static (at $\frac{1}{2}$ in., the force required to move the door would be close to 50 lb!). Experience has shown this will not work, which means building pressurization

needs to be actively controlled. There are two ways to do this:

1) Design a building that has virtually no static-friction losses in the return-air ductwork and/or is extremely leaky. What comes to mind are single-story retail spaces such as lumber stores or home-supply stores, where there is no suspended ceiling, the rooftop unit sucks air directly out of the space, and there usually is a wide-open warehouse loading-dock door. What also comes to mind are portable buildings with sidewall-mounted packaged air-conditioning units that essentially suck return air directly out of the space. These sorts of buildings generally do not have problems with excessive building pressurization.

2) Use a return/exhaust fan as part of the HVAC system. Such a fan will overcome the static-friction losses in the return-air ductwork. By adjusting its speed and properly setting the dampers, we can achieve a neutral space, a negatively pressurized space, or a positively pressurized space.

Any building more than one story tall probably is going to require a return/exhaust or economizer relief fan to work properly and not be excessively pressurized during economizer operation. Because outside-air economizers are required by Title 24 of the California Codes and ANSI/ASHRAE/IESNA Standard 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings*, for systems of all sizes, any building above a single story should have a return/exhaust fan as part of its HVAC system. Note that, unless you have designed a “perfect” building and a return-air system with virtually no return-duct losses, even a relief fan will not do the job because the building almost certainly will be excessively positively pressurized under return-air operation. Of course, once you have the system installed, you still will have to balance the dampers and return/exhaust-fan speed, which is not a trivial matter.

To give an idea of the sorts of problems that can be encountered, the following case studies are provided.

**CASE STUDY:
MEDICAL ADMINISTRATION BUILDING**

When a large regional acute-care medical center in Northern California merged with another medical center, the new health-services association elected to co-locate all management and financial functions in a shared office facility. A building—a former data center—was purchased, and an architect was hired. Unfortunately, some pre-existing deficiencies in the building’s HVAC systems were not addressed, as the architectural firm had its engineering consultants address their work as a tenant improvement project, rather than a base-build rehabilitation (even though a new exterior skin was being put on the building, and other basic building elements were being addressed). This resulted in some very untoward HVAC-system problems once the building was occupied. Our firm was engaged to determine the physical conformation of the HVAC

systems and observe and in-situ test them under different modes of operation. In addition, remediation schemes were developed and expert testimony provided during settlement meetings with the architect. The building as it existed at the time of our investigation is shown in Figure 2.

Through our investigation, we learned that:

- During full-recirculating-air (full return air) mode, air moved through the building along many unusual and unintended pathways (namely, the elevator shafts and the stairwells instead of the return-air shafts) on its way back to the rooftop air-conditioning units. The lower two floors were positively pressurized (air was leaking out), while the third floor was negatively pressurized (air was leaking in).
- During “economizer” (full outside air) mode, the entire building was positively pressurized so extensively that exte-

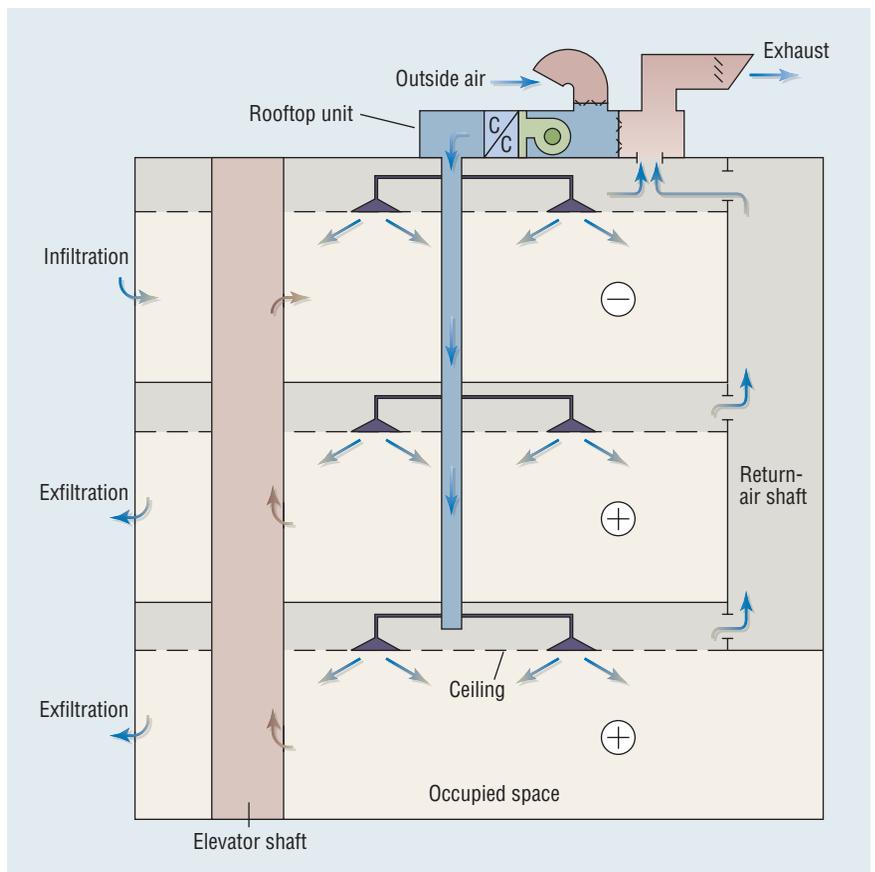


FIGURE 2. The pre-retrofit medical administration building.

rior doors remained open once they were unlatched.

- The building also suffered from a shortage of cooling on hot days.

Insufficient return-air pathway. When the building was constructed originally, a contiguous, uninterrupted return-air pathway from the occupied spaces back to the rooftop units was not provided. A return-air pathway was provided from the ceiling plenum on the first floor all the way to the ceiling plenum on the third floor, but then was interrupted. Apparently, the original designer hoped that the air from the first and second floors would magically combine with the air from the third floor and flow into the return-air inlet below each rooftop unit in the ceiling-plenum space on the third floor. The intended return-air pathway for the first and second floors was insufficient and resulted in the return air seeking its own way through the building by means of the paths of least resistance, which primarily

consisted of three stairwells and the elevator shaft. This literally would cause a “bad-hair day” for those entering the elevators on the third floor. Furthermore, because the intended return-air pathway from the first and second floors was so inadequate, the air-conditioning systems were “starving” for air and caused the third floor to be underpressurized (negative to the outdoors) and draw in air from the outside at the exterior doors (including those on executive office patios—quite a problem in rainy winter weather). Conversely, because the air delivered to the first and second floors could not easily get back to the rooftop units, these two floors were overpressurized (positive to the outdoors) and leaked air out of the building at the exterior doors.

Inadequate building-pressure relief for economizer operation. During economizer operation, when it was cool outside and cooling was needed, the building would be flooded with 100-percent out-

side air. A “natural” or “barometric” means of building relief was provided in the form of “flapper” relief dampers at the rooftop units. Unfortunately, this natural means of building relief relied on pressurizing the building and using that pressure to force air up the return-air pathway and out through the relief dampers. Again, the amount of pressure required to cause the air to take this pathway resulted in excessive pressurization, which caused doors to stand open when the building was in the economizer mode of operation. This was particularly troublesome during late-evening hours, when the building was lightly occupied and the security system went into alarm anytime someone left or entered the building. As a stopgap measure, the economizers were disabled and the building placed on 24-hr operation, with the refrigeration compressors providing continuous cooling.

Insufficient cooling capacity. The building “occupancy”—including human-occupant density, the intensive use of computer peripherals, and open office landscape furniture (with built-in lighting)—resulted in the building requiring more cooling than the rooftop units could provide.

This was evidenced by numerous “hot” complaints from occupants and confirmed by the operating engineers, who observed the rooftop units being unable to maintain an acceptable cool-air-supply temperature (only 65-F air could be produced on a hot day with all of the cooling equipment operating properly). This was further confirmed by the air-balance testing done at the completion of the remodeling work, which indicated that the intended or “design” airflow into the various spaces exceeded the airflow available from the rooftop units (both as tested and as indicated by the manufacturer’s cataloged performance data).

The solution. All of these problems could be solved by opening the roof at the top of the existing shafts, ducting from there to the rooftop units, adding return/exhaust fans to each of the rooftop units, adding supplemental cooling by

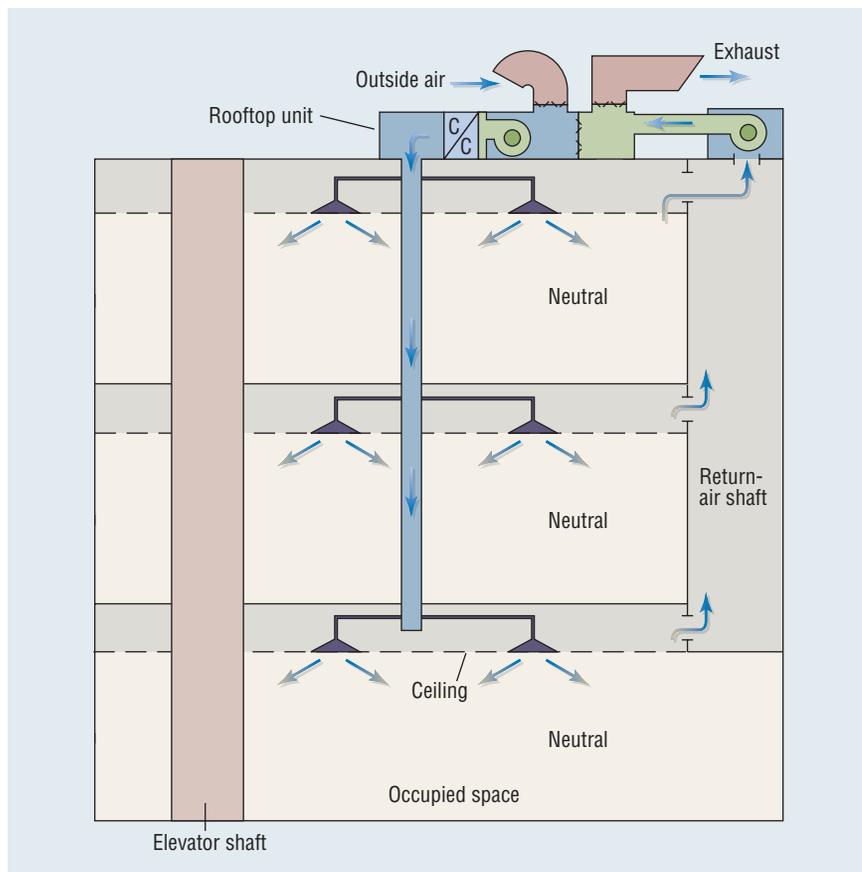


FIGURE 3. The post-retrofit medical administration building.

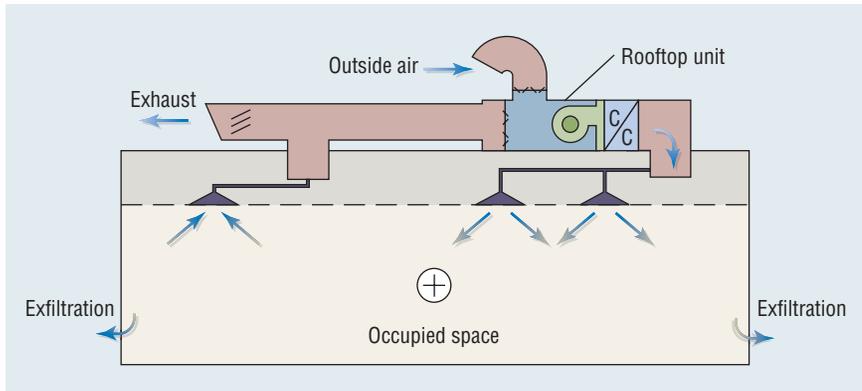


FIGURE 4. The pre-retrofit cineplex.

means of new two-row cooling coils in the return-air chamber of each rooftop unit, and supplying those coils with excess capacity from the existing computer-room chillers (Figure 3). Most importantly, the project could be implemented without serious disruption to the building because the bulk of the work essentially would involve the reuse of existing systems and equipment and be conducted on the roof. As a bonus, the project would pay for itself in less than four years.

CASE STUDY: CINEPLEX

An eight-screen cineplex in Northern California (Figure 4) featured HVAC systems constructed in a design-build fashion. The result was a building that frequently experienced pressurization so severe that extra employees had to be hired to close exit doors following each show—otherwise, the doors would stand open, allowing unpaid entrance. In addition, employees in the ticket office had to be extremely careful in handling paper money; if they were not, the money literally would fly out of their hands through the opening in the ticket-booth glass! Another problem was that the HVAC systems were noisy, both in the lobby (quite severe) and in the theaters (not as severe, but a threat to the cineplex’s Lucasfilms THX certification).

Our firm’s first task was to perform a thorough survey of the building’s HVAC systems. This included contacting the building-automation/direct-digital-control-system vendor (and HVAC service company) to learn how the building’s

HVAC systems were controlled and how to override the controls. The next step was to conduct a whole-building test, placing all 10 HVAC systems in full return-air mode and then full outside-air mode. Simultaneously, building air-pressure measurements were taken and automatic door closers tested to determine their status in each mode. Full-spectrum sound-power tests also were conducted to determine whether the theaters met the THX sound-power criteria (NC-30) in each mode of operation.

What was learned from the testing was that the HVAC system did not utilize return/exhaust fans and required return/exhaust air to pass from each theater through a restrictive return-air duct system and (in full outside-air mode) a metal barometric damper that was part of the rooftop ductwork back to the packaged rooftop HVAC units. Analysis of the return-air/exhaust system revealed that it could not be easily modified to achieve a 0.05-in. static-pressure drop (the maximum allowed if code-compli-

ant automatic door closers are to work effectively). As a result, a remediation scheme that included the enlargement of the return-air pathways (a noise source in full return-air mode, but not under full economizer mode because only a portion of the air went through the return/exhaust duct) was developed. The pathways were enlarged by essentially duplicating the existing return-air ductwork, adding powered (belt-driven) exhaust fans for full outside-air operation, and carefully balancing the supply- and exhaust-air fans under full outside-air operation.

Once the scheme was implemented, the modified theaters were brought into neutral air-pressure balance (Figure 5). Interestingly enough, the severe noise problem in the lobby was the result of an attempt to solve the building-pressurization problem—which was most observable at the lobby doors, but the same throughout the building—by dampering down the supply airflow at the lobby diffusers. Needless to say, this only created another problem: noise.

CONCLUSION

The bottom line to this whole discussion is that HVAC engineers need to be masters of their own destinies with regard to building pressurization. In other words, they will control or be controlled. Even simple low-rise buildings need real engineering.

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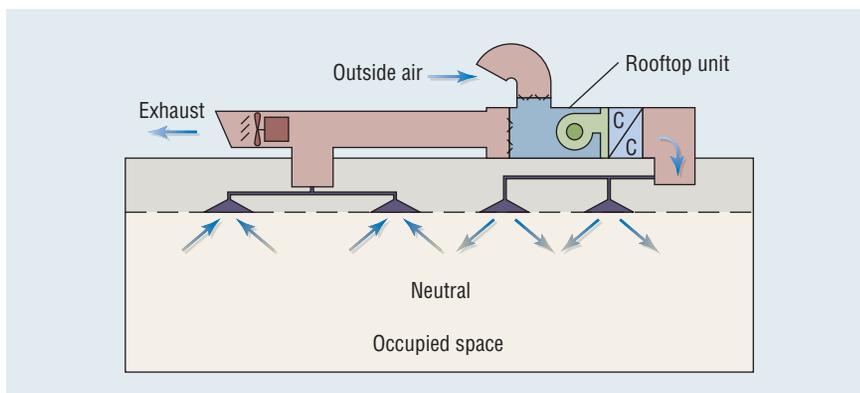


FIGURE 5. The post-retrofit cineplex.