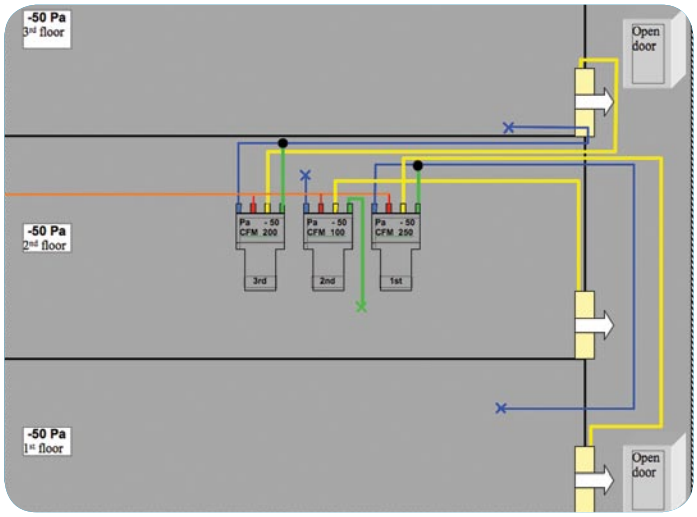
MEASURING LEAKAGE IN HIGH-RISE BUILDINGS

BY COLIN GENGE

The process of measuring air leakage to the outside in single-family homes is fairly well known among home performance professionals and anyone familiar with green building. Door fans are regularly used to measure house leakage and to locate leaks with smoke. ("Blower door " is the colloquial term for this device, but it is actually an axial fan, not a blower, that is fitted into a doorway. "Door fan" most accurately describes the test equipment that I use.) With multifamily buildings, measuring air leakage is a little more complicated. I've been presented with that challenge by building owners and developers who want to qualify their multifamily buildings for certification through the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) program.

LEED requirements are in their infancy for multifamily buildings, but there appears to be a lot of interest in achieving LEED certification among multifamily building owners. Currently, the maximum exterior envelope leakage must be 5 ACH, or less at 50 Pa of pressure. You calculate this value by taking the CFM at 50 Pa, multiplying it by 60, and dividing that by the volume of the building in cubic feet. A 20-unit apartment building will have a volume of about 200,000 cubic feet. If the CFM at 50 Pa is 20,000, the ACH will be 6. An ACH of 3.5 yields two points in the LEED system, and 2 ACH gets three points.

Controlling the flow of air through the exterior building enclosure is critical to reduce heat loss and heat gain and to minimize moisture-related problems. But controlling the flow of air between suites and common spaces within the building is also important. Anyone who has ever lived in an apartment building knows the unpleasantness of involuntarily smelling what the neighbor two floors below is cooking for dinner or smoking after dinner, and of hearing all about the neighbors' marriage



problems. And controlling the air flow within a building doesn't just control sounds and odors; it also reduces the spread of fire, smoke, and contaminants.

A Multifan Solution

LEED standards and increasing indoor air quality (IAQ) problems in high-rise buildings have encouraged my company, Retrotec, to develop equipment and procedures for testing high-rise buildings for air leakage. However, testing a whole building at once would require blowing massive quantities of air from one or two ground level doorways to pressurize all the upper floors. By the time the air flow reached the upper floors through the stairwells, some of the pressure would be lost, causing inaccurate readings. Large buildings would require massive truck-mounted fans, which are time consuming to set up. The solution we came up with is to test each floor individually (see Figure 1). This is the only arrangement that will work for high rises.

A 25-unit apartment building will have a volume of about 250,000 cubic feet. If the CFM at 50 Pa is 20,000, you multiply this by 60 to get 1,200,000 ft^3 /h / 250,000 ft^3 = 4.8 ACH. Therefore at least 20,000 CFM of air flow is required from a fan or fans to test for this level of leakage—well above the ability of a standard residential fan. Typical residential door fans won't do. Retrotec's new 2 hp commercial fans are powerful enough to test an entire floor, yet weigh little more than residential door fans. They are normally powered by a 120 volt 20 amp circuit but can take 240 volts from a dryer or stove outlet as well. Fans will auto switch between voltages. In some commercial applications or in foreign countries, it is useful to be able to use either voltage. Using 120 volts is less secure, because someone could plug another appliance into the same circuit and throw the breaker. Unlike residential fans, these fans can use 50 or 60 Hz without slowing down.

Which Direction to Measure?

At Retrotec, we strongly recommend that multifamily, high-rise buildings be tested in both the positive (pressurized) and the negative (depressurized) directions. Large static pressures caused by wind, stack effect, and HVAC systems can produce offsets that cannot be properly accounted for otherwise. Simply subtracting static pressures, as is common practice in house testing, can throw off high-rise readings by 25%. Static pressures can result from pressure shifts or air flow. Static pressure shifts can be subtracted linearly, but static pressures caused by HVAC flows cannot. For example, the air flow required to raise the test pressure from 0 Pa to 1 Pa is 100 CFM. The flow required to go from 49 Pa to 50 Pa is only 7 CFM. Clearly, just adding 1 Pa to the test pressure does not compensate for a 1 Pa static pressure if it is induced by air flow and not by a static shift.

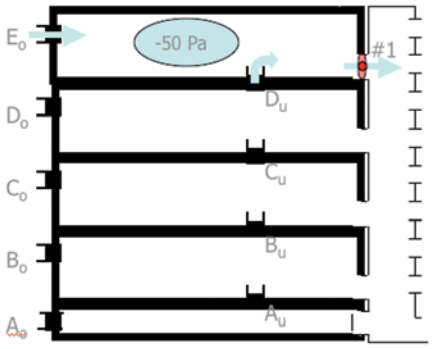
Testing in both directions negates static shifts no matter how they are produced, ensuring repeatable results in all weather conditions. If fresh-air supply fans or exhaust fans are running, testing only one way can skew results. For example, if 20,000 CFM is required to test a building with exhaust fans off, and if 4,000 CFM of exhaust is then turned on, the depressurization flow required to achieve 50 Pa of pressure will be only 16,000 CFM, whereas pressurization flow will be 24,000 CFM. Testing only in the depressurization direction will yield a result of 16,000 CFM at 50 Pa, versus 24,000 CFM at 50 Pa in pressurization—an increase of 50%! Testing both ways and averaging the result will eliminate most of this, but it will still result in an excess measurement of 5%–10% envelope leakage. (To get the most accurate measurement of envelope leakage, it is best is to shut off and seal ventilation fans.)

To measure leakage on multiple floors, each floor must be held at exactly the same pressure; but adjusting a fan on one floor affects the pressure on another. Retrotec's new digital gauge solves that problem with a built-in PID controller that automatically adjusts each fan separately so that it stays at the ideal test pressure of 50 Pa. In our test setup, all the controls and gauges are moved to one central location. Fans are controlled via Ethernet cables that can be more than 100 feet long. This allows the operator to be positioned as advantageously as possible. Readings can be monitored to ensure that the required test pressure is reached on each floor. Since each fan is separately measuring each floor, construction and/or setup problems exclusive to one floor can be quickly spotted.

Fan power and control are one issue; another issue is fan stability. Typical house-testing fans use PSC motors that do not stay on a fixed speed very well. Their speed varies slightly but constantly, which destabilizes readings when fixed, neutralizing pressures from floor to floor are necessary to get accurate readings. An internal clock inside a variable-frequency drive—a drive that is free of outside interference—regulates the speed of Retrotec fans. The motor will run at the same speed regardless of input voltage and regardless of frequency. The variable-frequency drive changes both the frequency and the voltage of its output waveform to adjust speed. This three-phase motor-and-drive combination is designed to offer fine speed adjustment; the motors used in residential fans offer only crude speed adjustment. This crude speed adjustment is somewhat unstable, and it produces a lot of heat when speed is adjusted downward, causing the motor to overheat and pop its thermal overload breaker in a half hour or so. The Retrotec motors can be run at any speed for 24 hours.

Another problem with measuring leaks in multifamily buildings is the limited time available to perform tests, as people move about the building.

Pressurizing and Depressurizing



Pressurize Eo + Du =	6,600 CFM
Depressurize Eo + Du =	5,400 CFM
Average Eo + Du =	6,000 CFM

Our rapid setup panels, which install quickly and can be removed in seconds, solve this problem. The panels allow operators to pass through a 24-inch port without removing the panel.

Leakage from most high-rise buildings can be simplified to one leak to the outdoors and one leak to the floor above. Flow from a floor must either end up outdoors, or move to other floors or stairwells. Using this simplified model, you can measure the major leakage pathways in an apartment building, using three blower doors.

Building Setup and Testing Operation

Normally, when a pressurization test is performed, an extra tube must be connected to the gauge to ensure that the flow pressure is referenced to the front of the fan, showing that the pressure drop across the flow device was correct. This is not necessary with the Retrotec digital gauge, because when it sees a positive building pressure on channel A, it automatically subtracts room pressure from flow pressure. Measurements can be made in either direction, with any number

of the fans running, and the results will be correct every time.

Preparations for this air leakage test are the same as those for any door fan test. Extra care must be taken to ensure that all openings to the outdoors are closed, and that nobody uses the elevators. Best results are achieved after hours, when all the tradesmen have left, since the more often doors are opened, the longer it takes to get accurate results. Continuously operating exhaust systems should preferably be shut down and sealed off, but if this is not possible, reasonable results can be achieved so long as the test is performed in both directions—pressurized and depressurized (see "Which Direction to Measure? p. 35").

All three digital gauges must be set up on one floor in order to make sense of the results. Setting up the gauges in a stairwell has the added advantage that the operator can change fan ranges and flow direction faster without needing to use the elevator or the stairs. All ports of the gauges must be connected to areas outside the stairwell; otherwise, the high air velocities will skew the readings.

If the building is occupied, post at least one person on each floor to ensure that no one tampers with the fan, or is endangered by it. Make sure that no one opens an elevator door, a window, or a hallway door. Check these openings before taking final readings to ensure that they stay closed.

Measure Leakage with Multiple Fans

In order to illustrate how to measure air leakage in a multifamily building, here is an example (also, see "Testing a Building in California," as an example of a real building that achieved LEED certification.) In the following example, doorfan 1 is set up on floor E to pressurize and then depressurize the floor to 50 Pa (see Figure 2). Air moves outdoors through a hole that we call Eo and to

Testing a Building in California

My company, Indoor Environmental Engineering, a ventilation and indoor air quality consulting firm located in San Francisco, performed building envelope air leakage tests in a four-story multifamily building. The first floor is an unconditioned parking garage. Floors 2, 3, and 4 include 36 apartments. We installed a Retrotec 2 hp fan in the stairwell door opening to the common hallway on each of the three residential floors. We propped open a door from the stairwell to the outdoors and doors at the bottom and top of the stairwell. All apartment doors to the common hallway were propped open. All the windows and doors to outside were closed, and the ventilation Z-ducts that provide a sound-attenuated opening to the outside were closed. All the intermittent operating fan systems were turned off, and all the constant operating fan systems (such as the kitchen and bathroom central exhaust fans) were kept operational.

We tested the building in both the pressurization and the depressurization directions. During the pressurization test we were able to achieve a pressure of 24 Pa. The air flow rates at this pressure were adjusted for a 50 Pa building pressure as follows: Flow, Q, is equal to the pressure to the power of n, times a constant, C. When a series of test points are taken and curve fit to calculate the values of n and C, we discover that n is usually about 0.65. In this test, where one point was taken, n was assumed to be 0.65, allowing for the calculation of C, which then allows us to calculate air flow at 50 Pa. For example, using the above equation, a measured air leakage flow of 5,000 CFM at a pressure of 24 Pa is extrapolated to a flow of 8,060 CFM at 50 Pa. It is easy then to calculate ACH using the leakage air flow at 50 Pa divided by the volume of the tested building.

The average ACH_{50} was 5 (it was 5.3 on the second floor, 4.7 on the third floor, and 4.8 on the fourth floor). During depressurization, we were able to achieve a pressure of 34 Pa. The flow rates of air at this pressure were adjusted for a 50 Pa building pressure, again assuming a flow exponent of 0.65. The average ACH_{50} was 3.3 (5.7 on the second floor, 1.4 on the third floor, and 2.7 on the fourth floor). The average of the pressurization and depressurization ACH_{50} tests was 4.1 (5.5 on the second floor, 3.0 on the third floor, and 3.7 on the fourth floor).

The requirements for LEED for Homes (V1.11A, EA 3. Air Infiltration in IECC Climate Zones 5–7) are

- Good Envelope (prerequisite), equal to or less than 5 ACH_{50}.
- Better Envelope (2 points), equal to or less than 3.5 ACH_{50}.
- Best Envelope (3 points), equal to or less than 2 ACH_{50}.

Thus, this multifamily residential building earned the prerequisite Good Envelope rating. These data also indicate that there is significantly more envelope air leakage on the second floor than there is on the other floors.

—Francis J. (Bud) Offermann

Bud Offerman is president of Indoor Environmental Engineering (www.IEE-SF.com), where he directs an interdisciplinary team of environmental scientists, chemists, and mechanical engineers in indoor air quality building investigations and healthy building design projects.

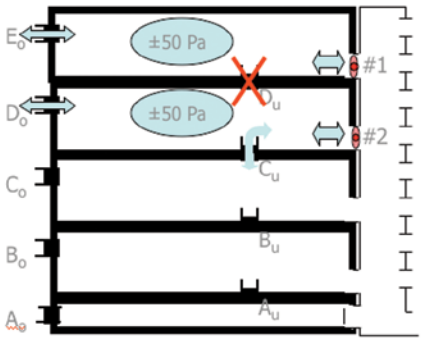
the floor below air leaks out through a hole we call Du. In this example, air flow through Eo + Du equals 6,600 CFM at 50 Pa under pressurization but only 5,400 CFM at 50 Pa under depressurization. The average is 6,000 CFM at 50 Pa. When results are averaged at the same test pressure, most errors drop out, allowing us to measure the net pathways. (In this example, all further results are shown for testing in both directions.)

Adding door fan 2 allows us to measure the leakage from floor E to the outdoors as well as the leakage from floor E to floor D (see Figure 3). The same 50 Pa static pressure is established on floors E and D, neutralizing the flow between floors. Now door fan 1 measures an average air flow of 5,000 CFM between floor E and the outdoors. Slab leakage, Du, is calculated by subtracting Eo (5,000 CFM) from the previously measured Eo + Du (6,000 CFM), yielding 1,000 CFM for Du. This is the leakage between floors D and E.

Using three fans makes it dramatically simpler to measure envelope leakage to the outdoors. Instead of having to make many measurements and then subtract floor-to-floor leakage to arrive at this value, we can measure leakage to the outside for floors E and D directly, using door fans 1 and 2 respectively, while we use fan 3 to eliminate the flow between floors C and D (see Figure 4). Repeating this process, we move door fan 1 to floor B to eliminate the air flow between floor C and floor B. Then door fan 3 is used to measure leakage to the outside on floor C (see Figure 5). The final step is to move door fan 2 to floor A and make measurements there. In this way, both leakage to the outdoors on each floor and floor-to-floor leakages can be quickly measured. Measuring whole-building leakage to the outdoors is a simple matter of adding Ao + Bo + Co + Do + Eo in the this example.

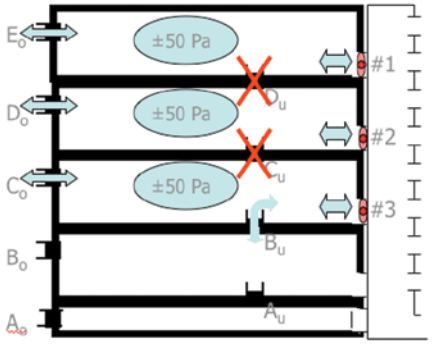
Currently, LEED certification requires that only envelope leakage to the outdoors be measured, but leakage through the slab affects both indoor air quality and the stack pressures that increase energy loss. It is extremely valuable to be able to measure this leakage easily, and with no extra effort. If one floor is leaking more air than the others, it may indicate a problem peculiar to that particular floor. We also learn the floor-to-floor leakage, which helps us identify indoor pollution transmission routes. This is useful for solving cigarette smoke and cooking odor problems so prevalent in high-rise buildings.

Adding a Second Fan



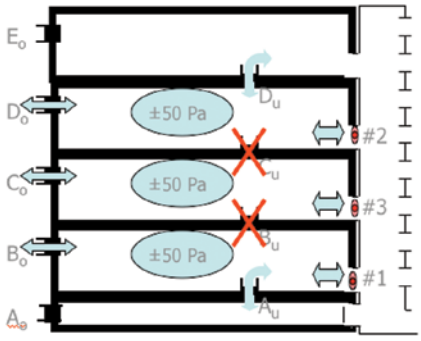
Eo =	5,000 CFM from Fan #1
Du = (Eo + Du) - Eo	= 6,000 – 5,000 = 1,000 CFM

Adding a Third Fan



Eo =	5,000 CFM from Fan #1
Do =	3,000 CFM from Fan #2

Final Step



Co =	1,800 CFM from Fan #3

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For more information:

Visit www.retrotec.com or phone (604)732-0142 for more details about the equipment and procedures used to measure air leakage in high-rise apartment buildings.