# Characterizing Air Leakage in Large Buildings: Part I

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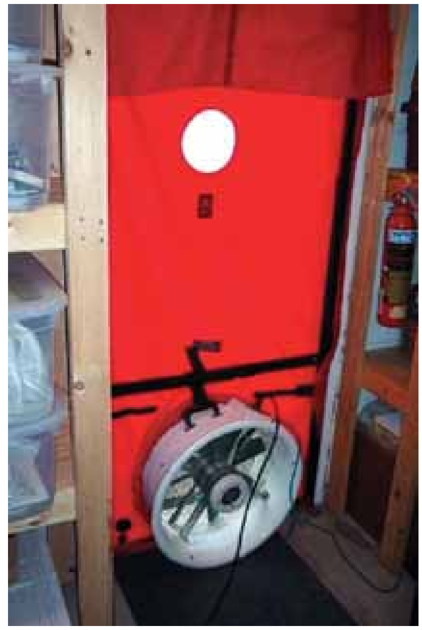


*Figure 1 - A calibrated blower door.*

## THE FAN PRESSURIZATION TEST

Pressure testing to determine the air tightness of a building's enclosure is conceptually simple. A variable speed fan is used to either exhaust air from a building or supply air to a building. This changes the building's air pressure relative to the outdoors—hence the name Pressure Testing. To some, this name may be a little confusing because most tests are done by exhausting building air.

When a mass of air is exhausted or supplied to a building, the indoor/outdoor pressure relationship changes until the same mass of air enters or exits the building through leaks in the building enclosure. Once this mass balance is reached, the induced pressure difference stabilizes. The magnitude of the pressure difference between inside and outside depends on the size and shape of the leaks in the building. The smaller the leaks the greater the pressure difference has to be to reach this balance.

Measuring the two variables—the air flow rates and the induced air pressure differences—provides data that can be used to characterize the building's air tightness. The quality of the resulting data depends on how well these two variables are measured. This is where the conceptual simplicity of the test meets real world complexity. Wind, occupants, equipment limitations, and the skill and knowledge of the person doing the test impact the test's overall accuracy.

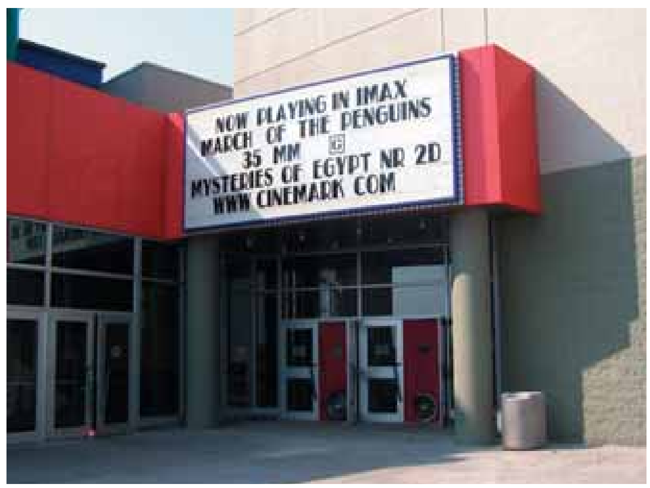
## WHY PRESSURE TEST A BUILDING?

Besides having fun doing weird things in buildings if you are a building science geek, or making some money if you are a businessperson, there are many reasons for conducting fan pressurization tests, such as:

- To determine whether a building enclosure (or a zone within a building) meets tightness specifications (Potter 2007). Airtightness may be specified to conserve energy (Emmerich 2007) or to reduce water vapor migration (Brennan 2002).
- To compare the tightness of a building to other tested buildings (Emmerich 2007).
- To determine whether air pressure control can reasonably be expected to solve a problem in an existing building. For example pressurizing wall cavities to prevent the entry of hot, humid outdoor air or depressurizing a crawlspace to prevent the entry of radon-laden air (Brennan 1997).
- To develop a "calibrated" airflow model of an existing building. Airflow modeling software (example, CONTAM) can be used to predict the effect of changes in the enclosure or mechanical systems on airflows through the building. Such a model can be tested against measured airflow and induced pressure data.

If the test is being conducted to compare the results to a target airtightness, as the British Part L energy code requires (Potter 2007), or to compare the building airtightness to other buildings, specific details of the test must be standardized. Weather conditions, the state of windows and doors, treatment of intentional HVAC openings through the building shell, and the location and setup of test fan equipment must be considered.

*Figure 2 - Multiple blower doors used in buildings with leakage areas too large for a single blower door.*




You will need to carefully measure air flows and pressure differences and conduct uncertainty analysis to ensure the accuracy of the result. There are a number of protocols that can be followed in conducting the test:

- The British Air Tightness Testing and Measurement Association (ATTMA) Standard 1: Measuring Air Permeability of Building Envelopes (contains guidance for large buildings);
- CGSB 149.15-96 Determination of the Overall Envelope

*Figure 3 - Infiltec G-54 trailer mounted calibrated blower for testing large buildings.*

*Figure 4 - Measuring total exhaust flows by summing flow through exhaust grilles (NOTE: This misses air leaks in the ductwork).*

Airtightness of Buildings by the Fan Pressurization Method Using the Buildings Air Handling Systems (contains guidance for large buildings);

- E 779 – 03 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization (does not specifically address large buildings); and
- E 1827 – 96 (Reapproved 2002) Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door (does not specifically address large buildings).

If, however, you want to know how many cubic feet per minute of exhaust air it would take to depressurize a crawlspace by 4 Pascals, the test would need to be conducted differently and the results are likely to be used to design an intervention in a building related problem. There are no published protocols for conducting a diagnostic test of this kind.

This article focuses on pressure testing the entire enclosure of a large building ("large" meaning "not single family residences"). Most of the building tightness data collected in the United States has been for single family residences. A much smaller number of other building types have been tested. For non-residential buildings tightness data has been reported for low-rise, mid-rise and high-rise buildings: for offices, banks, restaurants, food markets, theaters, schools, warehouses, rowhouses and apartment buildings. They have ranged in size from several thousand to several hundred thousand square feet. Many of these buildings present issues that do not occur while pressure testing single family buildings (Emmerich 2007).

## PLANNING THE TEST

The purpose of the test, how you are going to conduct it, and what equipment you will use should be well understood and planned well before going into the field. For example, are you going to use a blower door, the building's air handler or some other method of providing the air flow needed for the test? Where are you going to measure the pressure differences and with what instruments? Not that the plan won't change once it encounters the reality of field measurements, but come prepared or failure is likely.

The purpose of the test determines how much of the building you are going to test. To determine if the building meets airtightness specifications the entire exterior shell of a building—defined by the thermal or air pressure boundary of the building would be tested. For other purposes a smaller enclosure within a building may be tested (example, a special use area like a swimming pool or a fruit ripening room). In apartment buildings air sealing each apartment reduces transport of air contaminants and odors to neighboring units, reduces accidental outdoor airflows through the building and improves the distribution of intentional ventilation air. In this case it may be as important to pressure test each apartment as the entire building enclosure.

Collect background information. You need information on the building itself—the enclosure and the HVAC systems. Architectural and mechanical drawings are very helpful. The people who maintain the building, the HVAC equipment and controls are a wealth of information. They are needed on the day of the test to answer questions, open doors and set the HVAC systems to the state you would like during the testing (without setting off fire alarms or sprinklers, freezing coils or otherwise damaging equipment or controls). It is best to schedule the test when the fewest people are likely to be in the building opening doors and windows, turning exhaust fans on and off, or doing other things that interfere with your test.

Identify the pressure boundaries of the zone to be tested. The pressure boundaries may be well defined and implemented. Possibly they were not clearly defined in the design documents during the design of the building. The location of the actual pressure boundary can be determined during a pressure test by making pressure drop measurements across each layer of the enclosure. This is an advanced topic and is not covered in this article. When the boundaries of the zones to be tested have been identified, the surface area of the enclosing walls, ceilings and floors and the enclosed volume can be calculated. This information will be needed so the results of the test can be normalized. Normalizing leakage to the surface area of the enclosure allows comparison to target tightness levels or to the normalized tightness of other buildings.

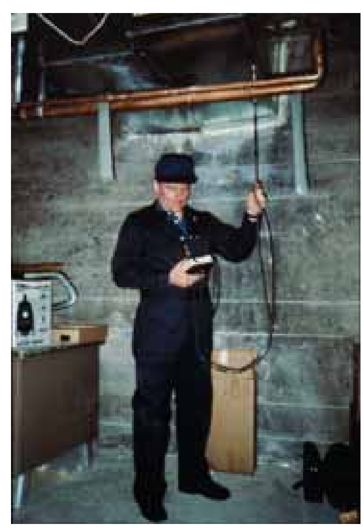


*Figure 5 - Measuring air flow through an outdoor air duct by pitot tube traverse.*

Get an understanding of the HVAC systems. Locate each exhaust outlet and outdoor air inlet. Locate each air handler. Trace supply and return ducts and plenums. Identify outlets, inlets, ductwork and air handling equipment that breaches the boundaries of a test zone. Plan to air seal the HVAC openings that will compromise the test enclosure. The HVAC inventory may also be useful if it turns out that using the ventilation equipment in the building is the best way to pressure test the enclosure.

Estimate the amount of air flow that will be needed to achieve the required pressure difference. An estimate can be made by calculating the area of the enclosure and multiplying that area by measured or target normalized leakage rates for buildings of the type under consideration (ATTMA 2007, CGSB 1996). An on-line calculator for estimating the amount of airflow needed to pressure test a building can be found at www.infiltec.com/inf-ukstd.htm. Determine how the airflows will be provided and measured—see the next section.

### MAKING THE TEST

On the day of the test you will need to be able to close all the intentional openings in the enclosure, open all the interior doors and turn off all the ventilation equipment. In many buildings the buildings and grounds personnel will be needed to get these things done. An HVAC controls contractor may be needed to turn off the ventilation system.

You will also have to prepare the building:

If the whole building is one test zone

- Close exterior doors and windows
- Open interior doors

If the test zone is a portion of the whole building

- Close exterior doors and windows
- Isolate test zone from surrounding building
- Close doors
- Tape off supply diffusers and return grilles that connect to ducts or equipment outside the test zone
- Determine whether adjacent zones should be open to outdoors or closed
- Close outdoor air intakes and exhaust outlets
- Dampers
- Gravity dampers
- Plastic, foam board and tape

### MEASURING AIRFLOW

There are three basic strategies for providing known airflow rates to depressurize or pressurize the building:

- Blower doors: variable speed, calibrated blower doors are available from two U.S. companies (the Energy Conservatory and Infiltec) and one Canadian company (Retrotec). Blower doors are available in a range from 5000 to 8000 cfm. Airflow through blower doors is easily and accurately measured with these units. They are easy to install in a door opening. With a little effort and creativity they can be installed in windows, access hatches or more unusual openings. Multiple blower doors can be used on one building to achieve higher airflows and to distribute the induced pressure differences throughout a building. Distributing the air pressure becomes more important as the size and the number of rooms and floors in a building increase. **Figure 1** shows a photo of a single blower door used in a research project on unplanned airflows in small commercial buildings in New York State (NYSERDA 2006). **Figure 2** shows two blower doors being used to test a movie theater in the same project.
- Trailer mounted fans: Infiltec manufactures a trailer mounted calibrated, variable speed fan that produces flows between 20,000 and 60,000 cfm. This unit is ideally suited for large buildings with few interior floors or partitions. Problems producing uniform indoor/outdoor pressure differences can occur in more complex buildings. For example, consider a trailer mounted fan depressurizing the first floor of a six story building, that has two fire egress stairwells open into the lobby. All the air depressurizing the top five floors must be drawn through the open stairwell doors. The first floor may be depressurized to a significantly greater extent than the upper floors because the stairwell doors may form a bottle neck, creating a two or three zone problem. Additional smaller fans depressurizing the upper floors using windows or rooftop access can be used to even out the depressurization.

  Besides the fabled Super Sucker (used for research purposes at the National Research Council of Canada), currently there is one trailer mounted fan in North America owned by Jeff Knutson at A. A. Exteriors in Wisconsin. One interesting aspect of this fan is that it is powered by a gasoline engine rather than an electric motor. This makes the unit more flexible than would be the case

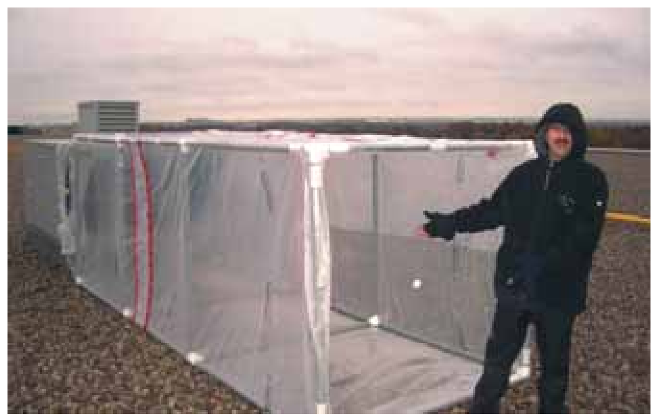


*Figure 6 - Temporary ductwork on outdoor air intake allows pitot tube traverse.*

*Figure 7 - Fan powered capture hood measuring flow from a rooftop exhaust fan. This method provides good accuracy but is limited to flows equal to or less than the flow of the calibrated fan. Photo courtesy of CDH Energy Corporation and New York State Energy Research and Development Authority.*

if a twenty horse power electric motor was used to power the fan. You don't exactly just plug that big an electric motor into the nearest outlet. **Figure 3** shows a photo of the trailer mounted G54 being used to pressure test an 810,000 square foot warehouse. The G54 is ideal for testing large open buildings. Accurate flows are easily measured. Distributing the pressure differences across the enclosure surfaces is not hampered by internal partitions and floors.

- The ventilation equipment in the building (exhaust or outdoor air flows) can be used to pressurize or depressurize the building. In the United States during the late 1980's and early 1990's this technique was used (Persily 1986). The major advantage of this method is that the air handling equipment is already at the building. There are three common difficulties with this method: measuring the airflow through ventilation systems is often time-consuming and tedious; flow measurements made on air handling equipment that is part of the ventilation system are likely to have greater uncertainty than flows measured using a calibrated fan door or trailer mounted fan unit (extra effort is required to ensure data quality); there may not be enough outdoor air or exhaust air capacity to achieve the desired pressure difference or number of flow-pressure data pairs to meet the data quality objectives for the test. The only protocol for pressure testing large buildings using the building air handlers is the Canadian standard CGSB 149.15-96. There are two additional references that are helpful (PECI 2005, Lee 1998). The PECI document is a protocol developed to be part of a commissioning guide. The other document is a Master of Science Thesis. A number of Test and Balance guides provide protocols and methods for measuring outdoor airflow through air handlers and exhaust fans (ASHRAE 2005, SMACNA 2002). Two research projects that studied unplanned airflows in non-residential buildings contain descriptions of additional methods for measuring airflows through air handlers and exhaust fans (Cummings 1996a and 1996b, 1997, Henderson 2006). There are a number of techniques for measuring airflow:
  - Measure the velocity of air in ductwork traversing multiple locations (e.g. using pitot tube, hot wire anemometer or vaned anemometers).
  - Measure airflow through a duct using an orifice (e.g. flow measurement stations built into the system. NOTE: flow station accuracy should be validated using one of the other flow measurement methods).
  - Measure airflow through diffusers or exhaust grilles using calibrated flow hoods.
  - Measure exhaust or outdoor airflow through rooftop intakes or exhaust using a flow compensated shroud and calibrated fan. ■

*Up next issue, Part II: how to measure pressure differences and figuring out what all the facts and figures actually mean, plus a complete reference guide for both Part I and Part II of this series.*

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