

Blower Door Applications Guide: Beyond Single Family Residential

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And

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Foreword

This document has been developed by the hard work of the authors based on their years of experience and research testing buildings that are beyond single family residential units. We have tried to provide a basic understanding of the steps involved with testing larger and more complicated buildings.

This book is divided into three basic sections. Chapters 1, 2 and 3 describe all of the information and preparation needed before a test can be performed. Chapter 4 provides information on testing buildings using equipment from The Energy Conservatory (TEC) of Minneapolis, MN, USA. Chapters 5 and 6 concern work after the test is done such as finding leaks and writing the report. The Appendices provide some working terminology and hazard analysis.

The authors intend that this document will be periodically updated as more information is gathered and more test procedures are defined.

We ask you to comment on this material. If you have additional insights or you see something that raises a question or has not been explained thoroughly, please let us know.

We have added a page at the end of the document for you to place notes that may help you and may help the authors. Please forward your comments and questions to TEC. You may email your comments to editor@energyconservatory.com.

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Introduction

The need to achieve high-performance buildings has prompted design changes that incorporate efficient use of energy and resources. One of these changes, the design, installation, and testing of the building air barrier has driven a dramatic increase in the demand for blower door testing of large buildings.

The 2012 International Energy Conservation Code (IECC) requires testing of multifamily buildings less than 3 stories. The General Services Administration (GSA) requires testing of new government buildings. Washington State requires that commercial and multifamily residential buildings of greater than five stories have the completed air barrier tested. The United States Army Corps of Engineers (USACE) has an airtightness requirement and all new buildings and major renovations must be tested for air leakage. The Army Corps has found that when consultants work with the contractors through the design and construction phases they are able to pass the blower door test at levels greater than 50% tighter than the standard. As more consultants learn these techniques, this emerging technology will move more quickly from the public sector to the private sector.

Until recently, most blower door testing was performed on small non-residential and residential structures. However, there is now a demand for consultants with the knowledge and equipment necessary to test large facilities, usually using multiple-fan blower door systems. The primary objective of this manual is to introduce experienced Energy Conservatory blower door users to proven techniques for:

- planning a blower door test,
- preparing a building for the test,
- setting up the equipment,
- performing the test,
- finding air leaks, and,
- writing a report

The manual is designed for Energy Conservatory blower door users that are already at intermediate to advanced level, but is extremely valuable for people considering doing this kind of testing, architects, code officials and product specifiers. It will be helpful for the users to have a working knowledge of big building mechanical systems, be able to read drawings and identify the envelope, and be able to set up the equipment and run the software.

The manual will step you through the process from beginning to end to help give you a clear understanding of what is involved in preparing for and performing the test. We

will attempt to introduce you to a few building types and mechanical system types, but the possibilities are endless and cannot all be covered in this manual.

Chapter 1 What does a blower door test tell us?

1.1 Blower Door Basics

The blower door is a tool designed to measure the airtightness of an envelope and help locate air leakage sites. Blower door tests are conducted for several reasons, including:

- To check for compliance with an airtightness specification or regulation and to evaluate air-sealing effectiveness

Typically results are reported at 50 or 75 Pascals. This pressure is called the reference test pressure. Results must include a calculated uncertainty interval.

- To measure air leakage characteristics for use in infiltration modeling

Accurate estimates of airflows at pressures representative of normal operating building conditions are needed. Typical reference pressures for ordinary operating conditions are 4 and 10 Pascals.

- To design a pressure management solution or resolve a problem caused by unplanned airflows in a building.

Typical interior building pressures used to control air flow direction are between 4 and 10 Pascals. In taller buildings in cold climates the pressure differences may be much greater – a hundred Pascals or more. Repeatability, reproducibility and accuracy at the desired pressure difference are needed.

- To find air leaks in existing buildings or during the installation of air barriers in buildings under construction.

This includes mock-up QA testing, energy audits or building forensics. Zonal diagnostics (test methods beyond the scope of this manual) are conducted to detect and measure leakage between spaces (attics, crawlspaces, garages, neighboring apartments, etc.). Air leakage sites may be located using methods such as theatrical fog, infrared thermography and hot wire anemometers.

The blower door consists of a variable speed fan with a built-in flow measuring sensor. One or more fans can be temporarily sealed into a single exterior doorway. The fan blows air into or draws air out of the building to induce an air pressure difference between inside and outside. The induced pressure difference forces air through all holes and penetrations in the exterior envelope. If the induced pressure is high enough, the air moving through the building holes and penetrations equals the air moving through the blower door fan. If the interior of the building is a single zone then according to

Pascal's principle the pressure difference between inside and outside changes by the same amount everywhere. However, bottlenecks between different sections of the building could cause pressure imbalances between the sections. More on this in Section 1.2.a.

A conceptual model of a blower door test using a simple, single zone box to represent a building envelope is shown in Figure 1.1. The airtightness of the test enclosure is measured by simultaneously measuring the air flow through the test fans and the induced air pressure across the test enclosure. The airtightness is usually described by an airflow and a pressure difference. For example, 5000 cfm at 75 Pascals. The tighter the building (e.g. the smaller the total leakage area), the less air you need to move through the blower door fans to induce a predetermined change in the differential pressure across the test enclosure.

The example illustrated in Figure 1.1 is the simplest form of a blower door test. It assumes that the interior is wide open, with no interior partitions or floors dividing it into smaller boxes (therefore, Pascal's principle applies). It also assumes that the indoor-outdoor pressure difference with the building closed up and the test fan off and covered is zero.

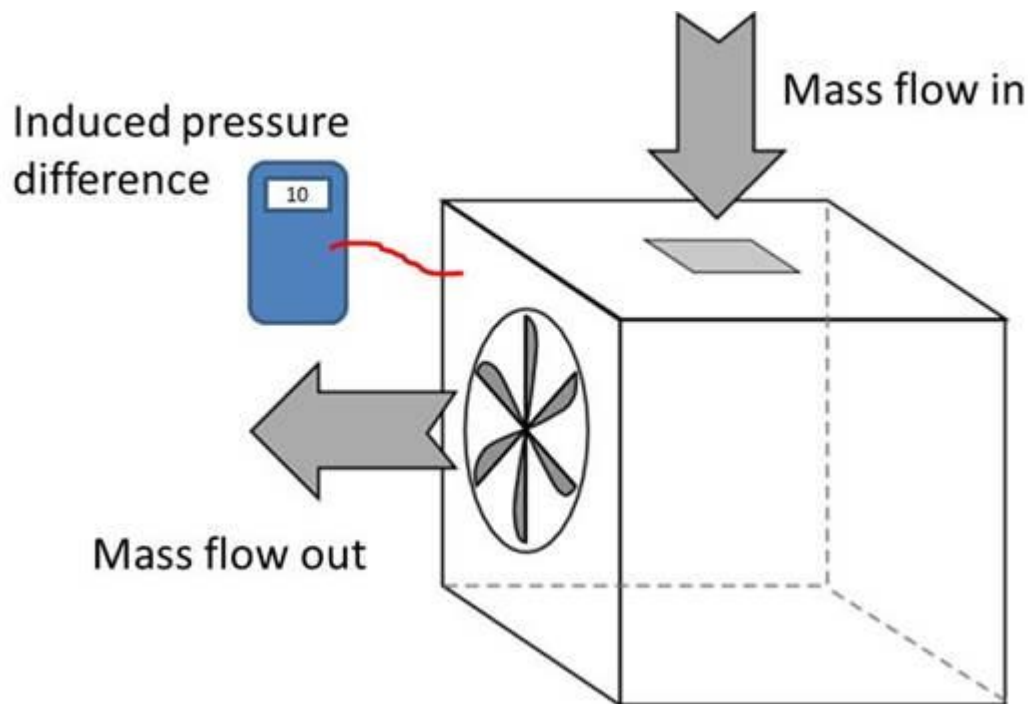


Figure 1.1. A simple example of a blower door test. A fan exhausts air from an otherwise airtight box with a single hole in the box.

1.2 Testing is a little more complicated

Blower door tests at most buildings are more complicated. Often interior partitions and floors divide up the interior space so establishing a single zone condition takes some planning and effort. More often than not, when a building is closed up for a test there is a measureable pressure difference between inside and outside. In this manual, the pressure difference between inside and outside when the building is closed up and the test fans are off and sealed is called the baseline building pressure. We want to measure the change in pressure caused when a test fan is turned on. This is called the induced pressure. The baseline pressure difference is subtracted from the pressure measured across the building envelope when a test fan is operating to give the induced pressure. For example, the baseline building pressure is measured to be -2 Pascals. A test fan is then turned on and adjusted until -50 Pascals is measured across the building envelope. The change in pressure is $-50 - (-2) = -48$ Pascals. If a test fan is then turned on and adjusted until +50 Pascals is measured across the building envelope, the change in pressure is $+50 - (-2) = +52$ Pascals.

1.2.a Single zone conditions

Big buildings come in all shapes, layouts and sizes. It is important to locate the fans so the induced pressure on the building envelope is uniform. If the building is a warehouse with no interior partitions, then fans can be set up anywhere in the envelope and a single zone will be established. The same is true of a tall building with an open, interior atrium that extends the height of the building. If the building has many rooms, interior partitions and multiple stories, the simplest way to establish a single test zone is to open interior doors. Open doors, interior partition air leaks and HVAC equipment ductwork often connects interior spaces well enough to create a single test zone.

Sometimes an interior partition separates two sections of the building with only a passage door or no door at all connecting them. In this case test fans may need to be placed on both sides of the partition. This is often referred to as a guarded blower door test or a multi zone test. Buildings with more than one floor may have the same problem with the upper floors acting as air barriers to uniform pressure distribution. The orifice equation can be used to help determine the extent of the bottle neck. The equation is:

$CFM = 1.07 \times A \times \sqrt{\Delta P}$ where:

A = area of the opening in square inches

ΔP = pressure difference in Pascals across the opening

For example, when using the Army Corps of Engineers standard your lowest test pressure may be 25 Pa and you need to ensure that no two locations differ in pressure by more than 10% of the induced envelope pressure. Other standards have different pressure requirements to meet single zone conditions. If all of the air flow from the blower door fan is moving through one 3'x7' door opening and the pressure is 2.5 Pa

(10% of 25 Pa) across the door, you can calculate the flow that will induce this pressure in the following way:

$$1.07 \times 3024 \text{ square inches} \times \sqrt{2.5} = 5116 \text{ CFM}$$

In other words, if you move the entire 5116 CFM across a single door opening, you will have a pressure drop of 2.5 Pa across the door opening and the single zone test condition is not met. If a building has spaces that are connected by door openings and only one model 3 or 4 fan is needed, a single zone condition will almost always be met.

1.2.b Handling baseline building pressures

There are three major sources of baseline building pressures. They are handled in different ways.

Stack Effect

Temperature differences between the indoor air and the outdoor air will cause pressure differences between inside and outside of a building. During cold weather buoyant warm air rises and leaks out the top of a building while colder, denser outdoor air is pressed in at the bottom (**note:** when outside air is warmer than inside air, this process is reversed). In winter, the stack effect creates positive pressure at the top of the building and negative pressure at the bottom. This is called stack effect. Stack effect pressures are a function of the temperature difference between inside and outside and the height of the building.

The greater the temperature difference and the taller the building, the greater the stack effect will be. For example, if a building is 100' tall, and the temperature difference between inside and outside is 30 degrees and the air leaks are evenly distributed throughout the height of the building; the pressure at the top will be about +10 Pa and at the bottom of the building will be about -10 Pa. The middle floors of the building will be near the neutral pressure level of the building and will see very little stack effect pressure. The pressure differences caused by stack effect must be accounted for when conducting a blower door test. If you want to directly measure stack effect pressure at a certain elevation, the pressure tubing must exit the building at that elevation.

A quick estimate of stack pressure in a single zone building near sea level can be calculated using this equation:

$$\text{Stack pressure (in Pascals)} = 0.0067 \times D \times \Delta T$$

Where

D is distance from neutral pressure level in feet

ΔT = temperature difference in degrees F

Wind Pressure

Wind blowing on a building causes outside air to enter on the windward side of the building, and inside air to leak out on the leeward side. With tall buildings in high winds, wind pressure can be a major driving force for air leakage. Wind pressure is a function of the wind speed squared. Wind pressures can affect the accuracy of a blower door test. Fluctuating pressures due to wind are usually more troublesome for blower door testing than the steady-state wind induced pressures. See Section 4.1.h of this manual for suggestions on dealing with wind during a blower door test.

Mechanical Effect

Operating fans and chimneys can affect the baseline building pressure. Air leaving the building from these devices causes a negative pressure in the building which draws outside air into holes and cracks in the building envelope. Outdoor air and makeup air fans (e.g. positive pressure ventilation fans) deliver air into the building creating a positive pressure which pushes inside air out of the building through holes and cracks in the building envelope. Turning these fans off eliminates the baseline building pressures they cause. Depending on the purpose for the test you may leave the exhaust outlet or outdoor air intakes for these fans open, close their dampers or temporarily seal them to make them airtight. See Section 3.4 for additional information on sealing intentional openings.

1.2.c Tubes, Cables and Wireless, oh my!

One of the major challenges with setting up for this testing is the potential distance between your fan systems and the centrally located computer. In a large building this distance can be hundreds of feet. You then have to decide between running hundreds of feet of multiple tubes, running hundreds of feet of a single cable or using wireless connections. Not only is it easier to run a single cable, but there are problems associated with running long lengths of tubing. Here are a few of the problems:

- Stepping on tubes can result in pressure spikes.
- Tubes of longer than 100' will cause measurement errors.
- Tubing of a smaller diameter will cause larger measurement errors.
- Sun shining on long lengths of tubing will cause errors, as will anything that causes tubing to change temperature.
- Tubing running vertically through a space at a different temperature than the rest of the building causes errors due to stack effect.

The DG-700 gauge has both USB and 9-pin RS232 communication ports. For cable lengths longer than 15', the RS232 port should be used. We have successfully used CAT5 cables up to 4,000 feet in length. A DB-9 RS232 to CAT5 adapter can be installed on top of the gauge. The DG-700 only uses three of the 9 pins on the connector, so a splitter kit can be used to combine the signals of 2 DG-700's to a single CAT5 cable. The TECLOG3 software allows you to configure each channel as a pressure or fan flow, so

only two DG-700's are needed for a three fan system (one envelope pressure and three fan flows). An Eight-Port DB-9 RS232 to USB Adapter Hub can be used to read the signals from eight DG-700's through a single USB connection to your computer. The TECLOG3 software allows you to connect to up to 16 DG-700's and therefore control up to 28 blower door fans and measure 4 building pressures from one computer and using multiple computers allows you to control an unlimited number of fans.

TEC WiFi Link™ adapters are now available for DG-700 gauges and have obvious advantages. They have been shown to be a real time saver in many cases. However, large buildings are filled with concrete and metal assemblies that limit the effective range of wireless adapters. Watch out for buildings with shielded rooms or areas of the building that are designed to block WiFi signals. Over long distances, cable connections may be required. Using routers, repeaters and additional access points is still being investigated and is expected to provide a good solution for typical buildings. It is a good idea to bring cables as a backup.

Large building testing is still in its early stages, but the breakthrough of the TECLOG3 software makes it easier to have control over the test from a central location and to have clear, accurate documentation and reporting of the test. The tech support for the software makes it easier for consultants to get up to speed using it. There are obvious advantages to using one CAT5 cable versus multiple tubes and fan control cables to control a three fan system. We expect that this industry will continue to grow for years and new technologies will continue to make this testing more efficient and accurate.

1.3 Basic Test Results

During a blower door test the following measurements are made:

- The pressure difference between inside and outside air
- The pressure difference between the flow sensor in a test fan and the air the fan draws air from (inside when depressurizing and outside when pressurizing). This pressure difference is then converted to an air flow in cubic feet per minute (CFM)
- Pressure differences between the core of the building and other interior locations. These are used to monitor and maintain single zone test conditions.
- Indoor air temperature and outdoor air temperature. In combination with elevation above sea level, the temperature measurements are used to convert the test fan airflows to airflows at Standard Temperature and Pressure.

Test results have historically been reported in units of airflow (e.g. CFM or air changes per hour (ACH)) and associated induced building envelope pressure differences or in terms of leakage areas.

1.3.a Two basic test methods

There are two basic methods used in testing:

- **Multipoint regression tests:** regression analysis on the results of a series of flow and induced envelope pressure test points. This yields a building leakage curve.
- **Single point test:** flow and induced envelope pressure measurements made at (or close to) the reference test pressure. This measurement is often repeated multiple times in order to calculate measurement uncertainty.

Either of these may be done by pressurizing, depressurizing or both.

Multipoint regression tests

Coefficient (C) and Exponent (n)

Once a multi-point automated airtightness test sequence has been completed using the TECLOG3 software, a best-fit line (called the Building Leakage Curve) is drawn through the collected blower door data. The Building Leakage Curve can be used to estimate the leakage rate of the building at any pressure. If you conduct a single point test, the program assumes an exponent (n) of 0.65 in its calculation procedures.

The Building Leakage Curve is defined by the variables Coefficient (C) and Exponent (n) in the following equation:

$$Q = C \times \Delta P^n$$

where:

Q is airflow through the building leaks (in CFM).

C is the Coefficient (CFM airflow needed to change the building pressure by 1 Pascal).

ΔP is the induced pressure difference between inside and outside of the building.

n is the Exponent (theoretically between 0.5 and 1.0).

C and n are calculated so that Q is the flow that would occur with air at standard temperature and pressure (STP).

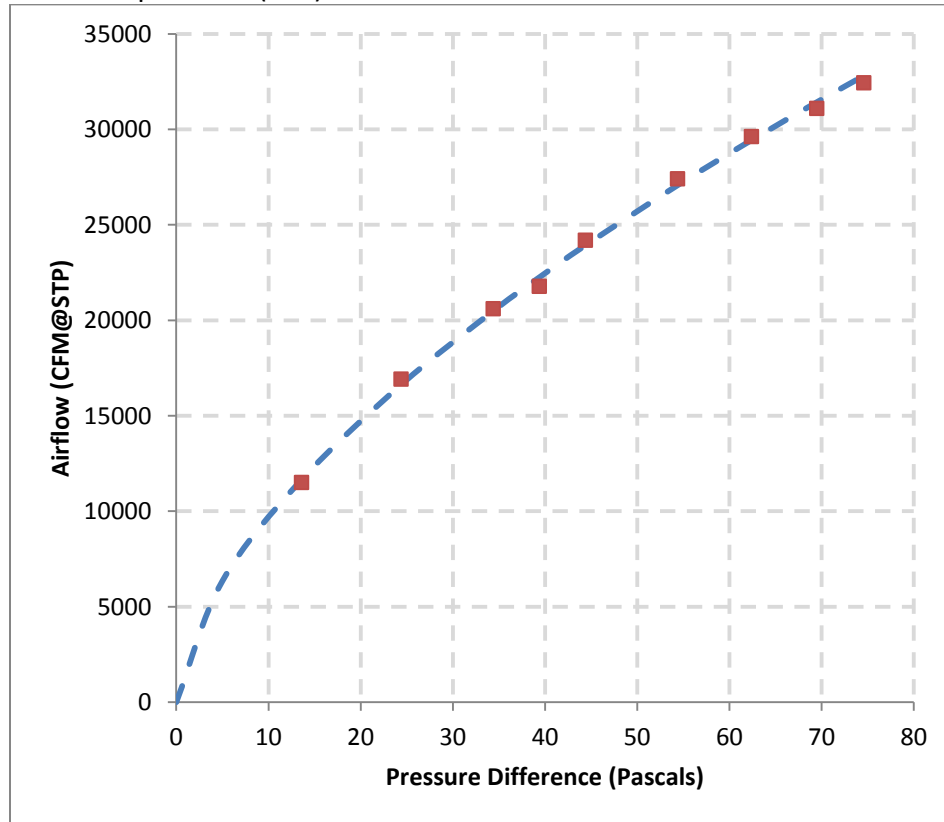


Figure 1.2 building leakage curve in linear scale format. Notice the data really form a curve.

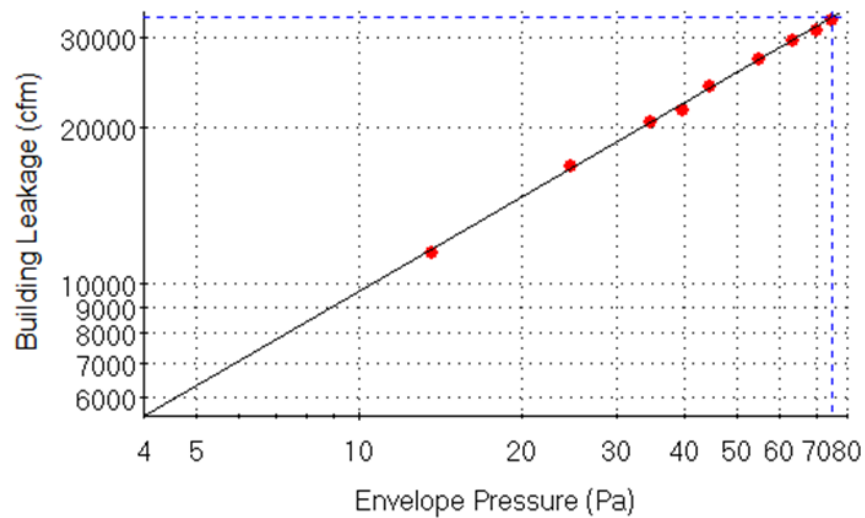


Figure 1.3 The same data as Figure 1.2 in a logarithmic scale format.

Example: Use the Building Leakage Curve in figures 1.2 and 1.3 to estimate the exhaust fan airflow in a building needed to create a 5 Pa negative pressure. From our blower door test software (TECTITE or TECLOG) we determined the following Building Leakage Curve variables: $C = 2430$ $n = 0.601$

From the equation above:

Airflow (at 5 Pa) = $2430 \times 5^{.601} = 6390$ CFM. In other words, we estimate from the Building Leakage Curve that it would take exhaust fans with a combined capacity of about 6000 CFM to cause a 5 Pa pressure change in this building (starting out at zero).

Correlation Coefficient

The TECLOG3 software will also calculate the correlation coefficient. The correlation coefficient is a measure of how well the collected blower door data fit onto the best-fit Building Leakage Curve. The closer all data points are to being exactly on the Building Leakage Curve, the larger the calculated correlation coefficient (note: the largest possible value for the correlation coefficient is 1.0). Under most operating conditions, the correlation coefficient will be at least 0.990 or higher and some standards require the correlation coefficient to be higher than 0.990. Testing in very windy weather can sometimes cause the correlation coefficient to be less than 0.990.

CFM50 is the airflow (in cubic feet per minute) through the blower door fan needed to create a change in building pressure of 50 Pascals (0.2 inches of water column). CFM50 is the most commonly used measure of building airtightness of single family residential homes in the US. However, big building testing in the US is often done at 75 Pa to account for higher baseline pressures experienced by bigger buildings.

Repeated single point tests

In order to determine compliance with an airtightness test specification at a high pressure such as 50 or 75 Pascals, it may be more efficient to conduct repeated single point tests than multipoint regression tests. In this type of testing, all of the effort is concentrated on inducing pressures near the reference test pressure and the result is a better determination of the air leakage at that pressure. The primary disadvantage is that nothing is learned about the pressure versus flow characteristics at lower building pressures. Below is a graph of the envelope pressure during repeats within a repeated single point pressurization test.

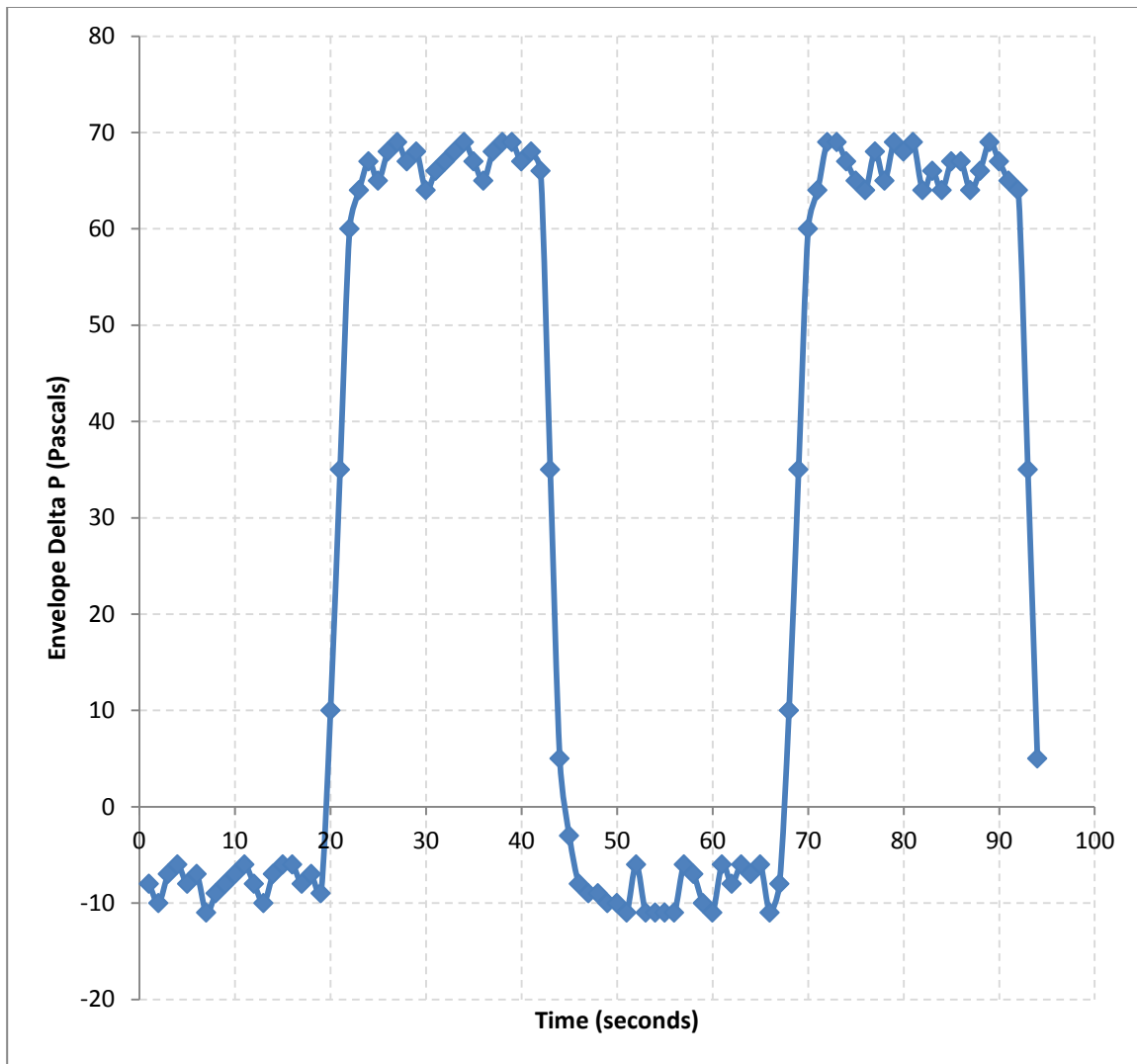


Figure 1.4 A repeated single point test with a baseline before each test. The reference test pressure is 75 Pa for this test.

1.3.b Normalizing Air Leakage for the Size of the Building:

In order to compare the relative tightness of buildings, it is useful to adjust (normalize) the results for the size of the building. This allows easy comparison of various size buildings with each other, or with program standards. There are many aspects of building size which can be used to normalize including volume, floor area and surface area of the building envelope.

Air Changes per Hour at 75 Pascals (ACH75):

One way to compare different size buildings is to compare the measured *Air Leakage at 75 Pascals* (e.g. CFM75) to the conditioned interior volume of the building. *Air Change per Hour at 75 Pa* or (ACH75) is calculated by multiplying CFM75 by 60 to get air flow per hour, and dividing the result by the volume of the building. ACH75 tells us how

many times per hour the entire volume of air in the building is replaced when the building envelope is subjected to a 75 Pascal induced pressure.

$$ACH75 = (CFM75 \times 60) / \text{Building Volume (cubic feet)}$$

Air Leakage at 75 Pascals per square foot of Envelope Area:

This metric is used by the Army Corps of Engineers in their standard and is the measured *Air Leakage at 75 Pascals* (abbreviated as CFM75) divided by the total area (e.g. 6 sides) of the building envelope. It is a useful method of adjusting the leakage rate by the amount of envelope through which air leakage can occur. The Army Corps standard is 0.25 CFM75 / square foot of envelope area.

1.4 Test standards and protocols

There are many test standards and protocols currently in use. Here are some examples:

ASTM E779-10 Standard Test Method for Determining Air Leakage Rate by Fan Pressurization

This standard requires pressurization and depressurization testing and an adjustment for temperature and elevation. It is referenced by many other testing standards and protocols. This test method is intended to be used for measuring the airtightness of building envelopes of single-zone buildings. Multi-zone buildings can be treated as single-zone buildings by opening interior doors or by inducing equal pressures in adjacent zones, though the latter is an advanced technique. This standard was designed to calculate an effective leakage area that is based on the flow for an induced envelope pressure of 4 Pa and therefore has some stricter requirements than other standards. One of the requirements limits the ability to test taller buildings during cool weather conditions.

ASTM E1827- 11 Standard test method for determining the airtightness using an orifice blower door.

This standard requires making repeated airflow measurements at either one or two reference test pressures. Uncertainties are calculated using ordinary statistical methods. The 2 point method can be used for calculating flow for an induced envelope pressure of 4 Pa while the 1 point test cannot, unless a flow exponent (n) value is assumed.

U.S. ARMY CORPS OF ENGINEERS Air Leakage Test Protocol For Measuring Air Leakage In Buildings.

This standard requires continuous air barrier systems design, installation, pressure testing, identifying air leakage sites and remediation if needed. The air leakage rate normalized to the surface area of the envelope must be ≤ 0.25 cfm/ft² envelope at 75 Pa. This is one of two test protocols that includes a method of determining pass-fail for

a specified airtightness target that accounts for uncertainty in the measurements (the RESNET protocol is the other). This standard is quickly becoming the primary standard for big buildings in the United States.

CGSB-149.10-M86 *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method*

This is a multi-point test that only requires depressurization testing and an adjustment for indoor and outdoor temperatures. This standard has not been updated in decades. Temperature corrections result in significantly different answers than more modern standards. This standard was designed to calculate an equivalent leakage area that is based on the flow for an induced envelope pressure of 10 Pa and therefore has some stricter requirements than other standards.

RESNET Chapter 8 2011 *Envelope and Air Distribution Leakage Testing*

This protocol allows single point, repeated single point and multipoint regression methods of data collection and analysis. Either pressurization or depressurization tests are allowed. RESNET includes a detailed description of building test setup. RESNET is one of two methods that includes a method of determining pass-fail for a specified airtightness target that accounts for uncertainty in the measurements (the Army Corps of Engineers protocol is the other). It allows two levels of accuracy:

- **Standard level of accuracy:** This is the level of accuracy that is normally attained unless there are adverse testing conditions such as high winds, an extremely leaky building or very large baseline pressure adjustments.
- **Reduced level of accuracy:** during adverse testing conditions or in certain applications where testing time and costs are a factor, a test with a reduced level of accuracy may be used.

ISO 9972 *Thermal performance of buildings-Determination of air permeability of buildings –Fan pressurization method (EN 13829)*

This standard is used in EU countries. This standard is very similar to ASTM E779.

ATTMA Technical Standard L2. *Measuring the Air Permeability of Building Envelopes (Non-Dwellings)*

This standard is used in the UK for large buildings. It is similar to ASTM E779. It includes significant guidance on building setup. It specifically allows guarded tests.

CAN/CGSB-149.15-96, *Determination of the Overall Envelope Airtightness of Buildings by the Fan Pressurization Method Using the Building's Air Handling Systems*

In order to achieve the same level of confidence obtained using blower doors a significant level of mechanical engineering expertise and experience in measuring airflows through mechanical systems is needed. Knowledge of calculating the uncertainty of flow and pressure measurements is required.

LEED Multifamily ETS PR 2012

This is an Indoor Environmental Quality prerequisite for all LEED Multifamily buildings and is intended to reduce Environmental Tobacco Smoke transfer between units. The standard requires testing individual units and leakage must be less than 0.23 CFM50/ ft² unit envelope (all six sides). It does not address setting up the building for the test.

Other related references include, but are not limited to:

- NIBS Guideline 3 recent update (337 pages)
- Recent California Title 24 rules (2014)
- Seattle and State of Washington Rules
- NEBB, ABAA/ASTM, ASHRAE 189

Chapter 2 Planning a blower door test

To plan a blower door test you must coordinate with the building owner or their representative. If the building is still under construction the general contractor is the owner and you will likely be working with the QA officer, site supervisor, or construction manager. If it is an existing, occupied building you may be working with the owner, facilities personnel or a building management company.

There are several steps that must be taken to conduct a blower door test.

- Preparations
- Building set-up
- Equipment set-up
- Data Collection and analysis
- Returning building to operational status
- Preparing report

A test plan addresses each of these steps.

2.1 Preparations

A fair amount of work must be done before packing the truck and heading to the site.

2.1.a Review the test specifications and drawings

Determine whether they:

- Identify the purpose of the test – e.g. a whole building test to determine whether it meets an airtightness target or to qualitatively identify air leaks in a portion of a building under construction
- Identify a test method – e.g. ASTM E779, ASTM E1827, EN13829 or the Army Corps of Engineers Test protocol
- Specify an airtightness target that must be met – e.g. 0.25 CFM75/ft² envelope or 0.6 ACH50
- Identify the volume or area to be used in the calculation.
- Specify how the building is prepared for the test. (mechanical rooms in / out, etc.)
- Identify the location of the test envelope.
- Define how to determine whether a building passes the test
- Define what happens if the building fails the test
- Contain requirements beyond those required by the identified test method

Note any additional requirements that need clarification.

A number of reasons for conducting a test are discussed in Chapter 1. Often a test is being used to determine whether or not a building meets an airtightness specification. In this case the target airflow rate and induced envelope pressure difference must be clearly stated. For example 0.25 CFM per square foot of test envelope at 75 Pascals is a commonly used airtightness specification. While the air flow target and induced envelope pressure difference is clearly stated it is only half of the specification. Because the target includes the test envelope area a procedure for calculating the area of the test envelope must be included as part of the specification or better yet, it should be calculated for you. A typical specification may state “the area of the test envelope includes the combined surface area of the air barriers in the walls, floors and ceiling or roof assembly that bound the test envelope”. A clear definition of passing the test must be included because any test result will have associated precision and bias errors. It must be clear whether or not a building passes a test if the airtightness specification falls within the uncertainty of the test. For example if a test result is 0.24 ± 0.02 CFM/ft² envelope it is not clear whether that is a pass or a fail because 0.25 CFM/ft² at 75 Pascals lies between 0.22 and 0.26 CFM/ft² at 75 Pascals and is within the uncertainty of the measurement. Last, the consequences of failure must be spelled out. For example, if the building fails the test then it must be air sealed until it passes; or if the building fails the test it must be air sealed until it is within 10% of the airtightness specification. If all these things are explicitly defined in the testing specifications then interpreting the result is straightforward.

If there are no formal test specifications or the ones you have are insufficient to plan the test then work in cooperation with the client to clarify the purpose of the test, appropriate test method, method of determining whether the building passes and what happens if it does not.

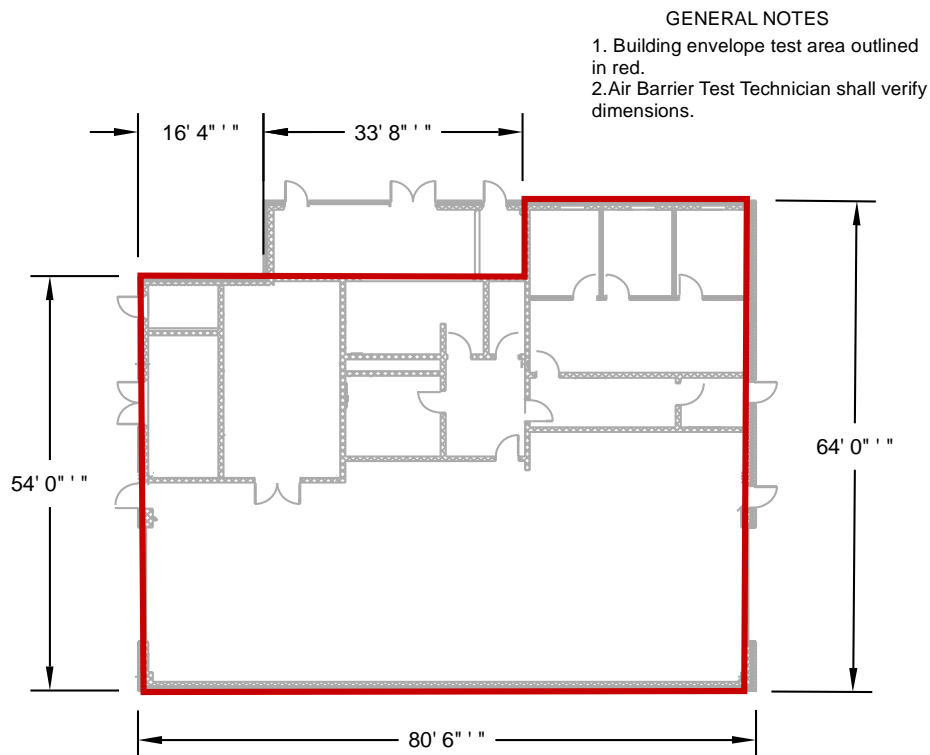
2.1.b Identify the test envelope boundaries

The walls, floors and roof assemblies that form the test envelope must be clearly identified. Everyone should agree before the day of the test. All doors and windows in the test envelope must be closed and latched during the test. Doors and windows with test fans set up in them will be secured in the open position. If, as in the example above, the test is being done to determine whether or not a building meets an airtightness target there are two important reasons for being certain of the area:

- The number of blower door fans you need to conduct the test depends on the envelope surface area.
- The area is part of the calculation used to determine whether or not the building passes. A 20% error in the calculation of the envelope area will result in a 20% error in the normalized result.

Always double check the area of the envelope before you test. Unless otherwise specified the envelope areas are calculated using outside dimensions. Make sure there have been no changes and the designer has calculated the area correctly. If the calculated area is different from the specified area by more than 4% reconcile the differences with the designer of record.

If the boundaries have not been clearly defined in the specifications or drawings work with your client to clarify them. Figure 2.1 illustrates an example of a clearly defined test boundary on a floor plan and building section.



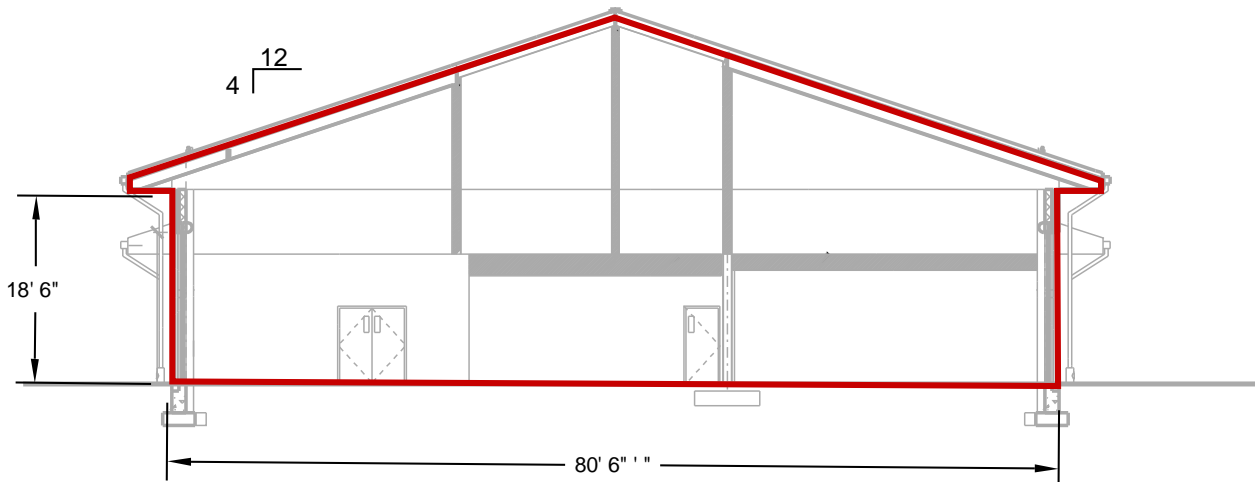


Figure 2.1. Example floor plan and building section designating the test envelope boundaries.

2.1.c Number of test fans needed

If a building must meet an airtightness specification bring enough fans so that if the building just passes the induced pressure will equal or exceed the specified pressure. For a new building an airtightness specification may be part of the construction documents, a code requirement or may be something agreed to by the owner, designer and builder.

Some examples showing how to use an airtightness specification to calculate the number of test fans needed:

- If the specification is in terms of CFM/ft² of envelope at a reference induced envelope pressure (Pa), the required fan flow rate is the envelope area (ft²) times the maximum allowable flow per square foot of envelope (ft²). If a building with an envelope area of 90,000 ft² must meet an airtightness specification of 0.25 CFM/ft² at 75 Pascals induced envelope pressure then bring $90,000 \times 0.25 \text{ CFM} = 22,500$ of fan capacity at a pressure drop of 75 Pascals. Dividing this flow rate by 4,900 CFM (the flow rate of a single Model 3 fan at 75 Pascals) yields 4.6 fans. Rounding up, take at least 5 test fans. It is a good idea to take 6 test fans. Six provides a back-up fan in case something goes wrong. It is not much more work to set up two three fan doors than to set up a three fan door and a two fan door.
- The airtightness specification may express the flow rate required. For the previous example, it would specify that the air leakage rate of the test envelope cannot exceed 25,000 CFM at 75 Pascals. In this case simply divide the flow by 4,900 CFM to calculate the number of fans.
- If the flow rate is given in air changes per hour ACH at a reference test pressure difference then the ACH value must be converted to CFM and the result divided by 4,900 CFM. For example, if a building with a volume of 250,000 ft³ has an airtightness specification of 0.6 ACH at a reference test pressure difference of 50 Pascals then the largest flow needed for a test is $0.6 (\text{ACH}) \times 250,000 \text{ ft}^3 / 60$

(min/hr) = 2,500 CFM at 50 Pascals induced envelope pressure difference. One Model 3 test fan is all you'll need.

If there is no airtightness specification for the building use the following guidance to determine how many test fans to bring.

- Really leaky building – if the building is known to have air leakage problems – e.g. it is experiencing condensation in the envelope, freezing pipes, draft complaints, high fuel use or ice dam problems use 0.80 to 1.20 CFM/ft² at 75 Pascals (0.63 to 0.94 cfm at 50 Pascals) to estimate the needed flow. How many fans you take depends on how much uncertainty in the measurement is acceptable.
- Typical building – if the building appears to be of typical construction use 0.40 to 0.80 CFM/ft² at 75 Pascals (0.31 to 0.63 cfm at 50 Pascals) to estimate the needed flow.
- Tight building – if the building was designed with the intention of making it airtight and the construction included a QA program for the air barrier systems (e.g. the Air Barrier Association of America Quality Assurance Program) use 0.25 to 0.40 CFM/ft² at 75 Pascals (0.20 to 0.31 cfm at 50 Pascals) to estimate the needed flow.

2.2 Building and Equipment Setup

2.2.a When the weather allows

Specifications for some jobs may require certain weather conditions during the test. For example, “the wind speed during the test shall not exceed 10 mph”. This is an issue you really do not have much control over. If the test dates are flexible you may be able to check the weather forecast and pick a time when the weather looks like it is going to meet the conditions required for the test. Sometimes you may not have that opportunity because the test must be done on a specific date. You schedule the test, arrive on site and find it too windy to do the test. You may need to do it in the middle of the night when the wind may not be blowing so hard. The worst case is you have to come back when the weather moderates. Have you made provisions in your scope of work to cover that possibility?

2.2b Windows and doors

The position of doors and windows in the test envelope and those in the interior of the test envelope may be detailed in the specifications of the test method. If they are not, use the following guidance:

- Windows and doors in the test envelope boundary will be closed and latched for the tests. Windows and doors that contain test fans are exceptions and will be secured in the open position during the tests.

- Doors inside of the test envelope will generally be open during the tests. It will require a lot of shims or door wedges to assure that the doors remain open during the test.

Exceptions:

- There are times when interior doors must be left closed for security reasons. If it is determined that the position of the door has no significant impact on the test results interior doors may be left in the closed position during the test. To determine whether or not interior doors can be left closed set up the building for the test, depressurize or pressurize the building core to induce 50 to 75 Pascals envelope pressure difference. Measure the pressure drops across the doors or walls separating the building core and these rooms. If the pressure drop across a door is less than 10% of the induced envelope pressure the room behind the closed door is well connected to the building core and the door may remain closed for the test. Make a table of all interior doors tested in this way and record the pressure drop and whether the door was left in open or closed position. Doors with large pressure drops are of interest because this may indicate a large leak to the exterior in the area they isolate.
- Selected interior doors may be left in the closed position to help achieve single zone pressure conditions during a test.

2.2.c HVAC equipment that must be turned off during the test

Identify all mechanical equipment that must be turned off during the test. This may be spelled out in the test method used as the basis of the test. Make a table that can be used as a check list.

2.2.d HVAC related penetrations

There are a number of intentional openings in building envelopes. Windows and doors have already been addressed. Most of the remaining intentional openings are related to HVAC equipment. Typical HVAC related penetrations include outdoor air intakes, make-up air intakes, relief dampers, exhaust louvers and rooftop or wall mounted exhaust fans. HVAC related openings will be equipped with motorized dampers, gravity dampers or no dampers. Test specifications may spell out how dampers should be positioned during a test. If the specifications do not address damper positions follow this guidance:

- All exhaust and makeup air fans are turned off
- Motorized outdoor air, makeup air, exhaust air and relief air dampers are cycled to the closed position.
- Gravity dampers are left in the closed position. Optionally they may be blocked closed so they do not open from pressures induced during the test. If blocked closed make certain they are on the list of items to be returned to operating conditions before leaving the site.

In addition to closing dampers HVAC related openings may also be temporarily air sealed. Whether none, some or all are sealed should be spelled out in the test specifications or in the test protocol. If it is not use this guidance to determine whether or not to air seal the opening:

- If the test is clearly intended to *only* measure the air leakage through the opaque and fenestration portions of the envelope temporarily air seal all HVAC related openings.
- Otherwise
 - Leave the opening unsealed if it is connected to a fan that operates less than 8000 hours per year.
 - Temporarily seal all other HVAC related openings.

Optionally after conducting the required tests, remove the temporary air seals while maintaining the envelope pressure at the specified test pressure. Record the results with TECLOG3 so that air leakage through the masked HVAC related openings can be estimated. Use TECLOG3's Event Markers to record the times when the seals are being removed.

Make a table of all HVAC related openings. For each one record whether it has motorized dampers, gravity dampers or no dampers; the damper position during tests; whether it was temporarily air sealed and include a photo of it in the test condition.

2.2.e Plan blower door locations

Examine the floor plans of the test envelope. Identify locations to set up test fans that are likely to provide effective pressure distribution throughout the test zone. Good locations include large open areas with many corridors and doorways to the rest of the building and fire egress stairwells with exterior doors at the top, bottom or both. Note if the doors that you plan to use are larger than the commercial blower door frame size (4' x 8') since some additional labor and materials will be required when using larger doors.

One blower door fan will move roughly 5,000 CFM at 75 Pa. If 5,000 CFM is going through a single door opening of 3'x7', it will result in a pressure drop of about 2.5 Pa across the door. A flow of 10,000 CFM across a single 3'x7' will result in a pressure drop of about 10 Pa and a flow of 15,000 will result in a pressure drop of about 20 Pa. The same flows across double doors will result in a pressure drop of about 0.5, 2.5, and 5 Pa respectively. See section 1.2.a for more information.

Identify walls and floors that divide the test zone into subsections with only a small number of doors connecting them. Place test fans in each subsection to obtain single zone conditions. Sometimes fire egress stairwell doors can be used as balancing devices to improve floor to floor single zone conditions.

2.2.f Material and Equipment Needs

This section will provide you with information concerning the equipment and materials you may need to conduct a test. You won't use all of the equipment and materials described here on every job but you should have most if not all of these items available.

Before we discuss the equipment and materials in detail, let's describe a basic test setup. Essentially, your computer controlling the fan speeds and recording the air flow volumes and building envelope pressures (a.k.a. indoor/outdoor pressure differences) is connected to one or more DG700 manometers with cabling or WiFi. The manometer is close to the fan or near the outdoor pressure location. Tubing is run from the ports on the manometer to the fan or to the outside pressure location. The DG700 manometers measure the air flows and/or pressures and send these data to your computer.

You have three options for connecting the manometers to your computer. The option you use will depend on the equipment you have, the number of fans you need, and the distance from the manometer to the computer. These options are explained in detail in Chapter 5. You can also get more information about this in the TEC publication Setting Up a Three Fan Minneapolis Blower Door System for Automated Testing available for download at:

<http://www.energyconservatory.com/products/blower-door-systems-and-accessories/multi-fan-blower-door-systems>.

Proper preparation before you start out for the job site is crucial. You don't want to be setting up your test equipment and find that you forgot something or that an essential piece of equipment does not work. An ounce of prevention can be worth a pound of money and possibly your good reputation.

If you have planned the job correctly you probably know how many fans, DG700s, etc. you will need. The question is should you bring along spares? The Energy Conservatory equipment is very dependable but stuff happens. This is specialized equipment and you won't be able to replace it by running down to the local hardware or home improvement store. If you have spares bring them along.

Other equipment and materials can be purchased at hardware or home improvement stores but running out and getting it is not very efficient and you eventually end up with far more ladders, extension cords and like equipment than you really need.

The best way to make sure you have the needed equipment is to make a checklist as you are packing. You can also use this to make sure you have collected all of your equipment when the job is done.

The following presents advice on how to make sure you get to the site with the properly operating equipment.

2.2.g Test Equipment: Fans

Before you leave for the job check the fans which you will be using. If the fan housing, guards or blades are damaged, do not operate the fan until repairs have been made. Repairs should only be made by qualified repair personnel. Examine the flow sensor tubing, making sure it is securely fastened to the fan pressure tap and flow sensor. Examine the motor cooling holes for excessive dust build-up. Use a vacuum with a brush attachment to remove dust, or blow out the dust with compressed air. Especially note clearance of blade tips relative to the fan housing. There should be about 1/4 inch of clearance. Test each fan and controller. Make sure they work and listen for unusual noises. Finally make sure you have all of the flow rings and fan caps you need. For further information on issues affecting fan calibration refer to Appendix A of the Blower Door Operation Manual available at

<http://www.energyconservatory.com/support/manuals>.

Fans typically remain calibrated unless damage should occur. Also, some clients such as the Army Corps of Engineers require periodic calibration checks and certificates.

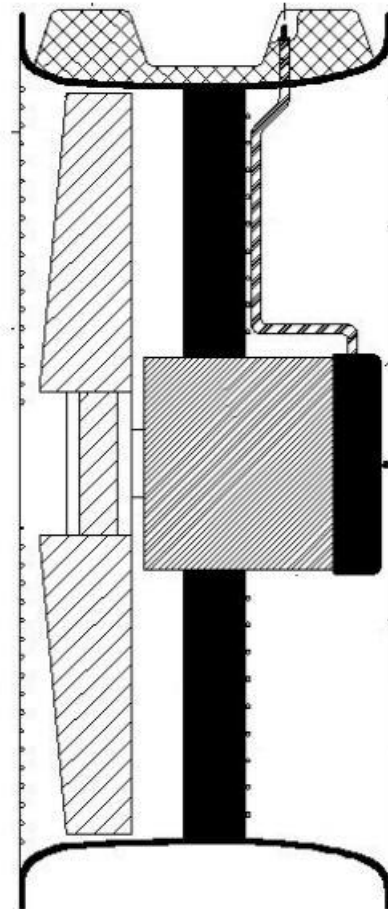


Figure 2.2 Blower door fan

Conditions which could cause the fan calibration to change are primarily damaged flow sensors, movement of the motor and blades relative to the fan housing, and leaks in the sensor or tubing running from the flow sensor to the fan pressure tap. These conditions are easily detected and should be tested for on a regular basis.

Model 3 fans (both 110V and 230V) use a round white plastic flow sensor. The flow sensor is permanently attached to the end of the fan motor opposite the fan blades. First visually confirm that the sensor is not broken or deformed due to impact. Check that the sensor is firmly attached to the motor. Next, perform a test for leaks in the sensor or the tubing connecting the sensor to the fan pressure tap (this test is easier if you first place the fan in an elevated position such as on a bench top or table.) Attach a piece of tubing to the pressure tap on the blower door fan electrical box. Leave the other end of the tubing open. Find the four intentional pin holes in the flow sensor; they are evenly spaced around the outside rim of the sensor. Temporarily seal the holes by covering them with masking tape. Don't forget to remove the tape when you are done.

Next, create a vacuum in the fan pressure tubing by sucking on the open end. A vacuum in the tubing assures that the flow sensor does not leak. There is a vacuum, if by placing your tongue over the end of the tubing, the tubing sticks to your tongue. Make sure that the vacuum persists for at least 5 seconds. If a vacuum cannot be created, contact The Energy Conservatory to further diagnose the sensor leakage problem.

If a fan has been dropped, the motor may have shifted from its proper position in the motor mount. This can degrade the fan calibration. To test the motor position, lay the fan on its side with the flow sensor facing up and all Flow Rings removed. Place a straightedge (such as a heavy yardstick on edge) across the inlet of the fan. Use a ruler to measure the following distance and compare this measurement to the appropriate specification.

Measure the distance from the bottom of the straightedge to the face of the flow sensor. This distance should be in the range of 3/16th to 5/16th of an inch. If the motor is not in the proper position, call The Energy Conservatory for further instructions.

It is certainly helpful to bring carts, or have access to carts, to move the three fan systems from the staging area to the area where you will be setting them up.

Controllers. Check your controllers as you are packing. Look for frayed cords, bent contacts, loose or missing speed control knobs, etc. Plug the controller into a receptacle and make sure the cooling fan runs. Note: older model controllers will not have a cooling fan.

Get in the habit of making sure the switch is in the off position before you connect the controller to the fan and electrical power. This prevents the fan from coming on unexpectedly.

Flow Rings. The blower door fan can accurately measure airflow over a wide range of flow rates using a series of calibrated flow rings which are attached to the inlet of the fan.



Attaching a flow ring lessens the area of the inlet. This creates a higher pressure for a lesser volume of air as compared to a fan with no ring installed (open fan). This provides accurate air flow volume measurements at low volumes. The tighter (or smaller) the building being tested, the smaller inlet opening you need.

Configuration	Flow Range (cfm)
Open Fan – no ring	2,435 - 6,100
Ring A	915 – 2,800
Ring B	300 – 1,100
Ring C	85 – 330
Ring D	30 – 115
Ring E	11 - 45

The standard system comes with 2 flow rings (A and B) capable of measuring flows as low as 300 cubic feet per minute (cfm). Optional rings C, D and E are available. The table below shows the approximate flow range of a fan with the six different flow rings attached. When using a flow ring make sure all of the black fasteners are secure or you may get air leakage around the ring.

Frames and Nylon Panels. You can easily determine how many frames and nylon panels you will need for a job, but before you go, check to make sure you have all the frame parts and have the correct nylon panel: one, two or three fan panels. Also, and we can't stress this enough, job site realities can make your best laid plans a shambles. If you think you will need a three fan panel, bring it and a one and two fan panel and extra frames. You may need to set up two systems to get equal pressures throughout the building or maybe there isn't enough power close by to run three fans in one location. Be prepared.

DG700 Manometers. Inspect each DG700 before you leave the office. Bi-annual calibration is recommended and may be required by some clients. The date of the last calibration can be found on a sticker on the back of the gauge.



Frame and 3 fan nylon panel

Also check the batteries. A DG700 uses 6 AA batteries. Before you leave turn the on the DG700. When the DG700 is first turned on the battery voltage will be displayed on the Channel B (right) side of the LCD. Fully charged batteries should read around 9 volts. If the display reads 7 volts or less it is a good idea to change the batteries before starting the test. When the battery voltage drops to less than 6 volts the **BAT** icon will begin to flash. The DG700 will still provide reliable data for a short time. Once the voltage drops to a point where reliable data is no longer provided, the words **LO BAT** appear and the batteries must be changed. Although battery life with alkaline batteries is over 100 hours of continuous use you probably won't be keeping track of the DG700 usage so bring along plenty of extras. Use of the WiFi Link during testing will shorten battery life to less than 30 hours. When using WiFi Links, If the display reads 7 volts or less with the Wifi Link powered on it is a good idea to change the batteries before starting the test. You can also use the optional AC power adapter which can be purchased from TEC.

The DG700 was designed to work with either rechargeable or non-rechargeable batteries. The AC adapter for the DG700 will not charge the rechargeable batteries. A separate charger will be needed.

DB9 to USB Adapter Hub The Eight-Port DB-9 to USB Adapter Hub provides 8 separate RS-232 serial communication ports through a single USB connection to your computer. This allows you to take advantage of the very long cable lengths available with RS-232 communication ports when connecting multiple DG700 gauges to your computer.



Make sure you have the correct cables. Bring along spares. Check the pins on the connectors to make sure they are not bent.

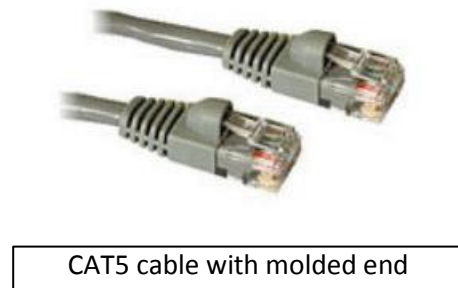
On some jobs you may have a nice environment with a desk or table where you can set up your command center. On others you will need to make do as shown in the photo to the right.

Notice the USB hub is taped to the tool box. This is a lesson learned the hard way; if someone pulls on or trips over a cable the adapter box may go flying and break. As an added precaution consider NOT securing the USB/DB9 adapters to the hub. If someone pulls on a CAT5 cable it will come off the hub.



CAT5 Cables, Signal Splitters, Couplers and CAT5 to DB9 Adapters. We recommend using CAT 5 cables made with stranded wires. The stranded wire rolls up much easier on an extension cord spool and better resists breaking when flexed many times than does solid cable. In a pinch, you can easily find CAT5 with solid conductors and end connections pre-installed at a local hardware or home supply store. There are many online sources

for inexpensive stranded CAT5 cable. You can get cables in different colors. Try using a different color for each different cable length. We recommend having an assortment of cable lengths of 5 feet, 50 feet, 100 feet, and 250 feet available.



To keep the cables from tangling store them on an extension cord reel. Otherwise, eventually the cables will become twisted and will not lay flat on the floor. This is a trip hazard. Make it a habit to run the cables full length and work out the twists when you roll them up.

Inspect the cables regularly. Look for tears in the insulation. Remember, some CAT5 cables are not designed to be connected and disconnected as often as you will be doing. Check the connectors closely because they often get damaged by someone stepping on them. Use CAT5 cables with the connectors molded to the cable as shown in the photo. They resist damage from being pulled. If you don't have molded cables use electrical wire shrink tubing to reinforce the connections.

Signal Splitters are handy pieces of equipment that allow you to connect two DG700s to the USB hub using a single CAT5 cable running from the DG700s to the USB hub in the control center. This saves set up and tear down time.



Couplers are used to mate the CAT5 connector in the splitter to the CAT5 cable running to your computer. They are also needed to connect two lengths of CAT5 cabling together. You can find these at home improvement stores, hardware stores and office supply stores.

CAT5 to DB9 Adapters are needed to connect the CAT5 cabling to the USB hub (needs a female adapter) and to a manometer (needs a male adapter). These adapters are available from The Energy Conservatory.



CAT5 to DB9 adapters

Tubing and Connectors. How much tubing you will need for a particular job is difficult to determine before you leave the office. If you have dimensioned building plans you can make a rough estimate of how much you will need but you can't count on always laying out your equipment as planned. Job site realities often get in the way of the best laid plans so if you estimate how much tubing you need bring twice as much. Better yet, bring all you have or all you can carry.



Cord wrap for storing tubing

Tubing easily becomes tangled and unsnarling it can be time consuming and frustrating. A good way to prevent this is to store it on extension cord wraps such as the one shown.

You will also need a good selection of Tee's, splices and 4-way connectors. Those are difficult to find in the correct size so don't forget them. A good way to ensure you have what you need is to place a bag containing spares in your vehicle. Leave them there and don't take them out unless you really need them.

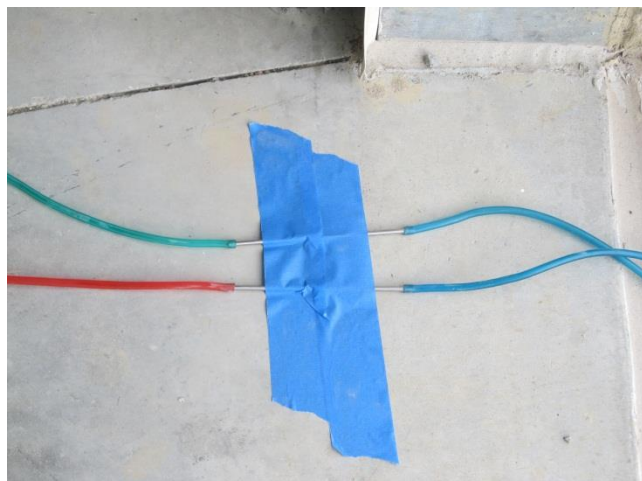
Get in the habit of inspecting the tubing for blockage, kinks or holes. A tube may become blocked by moisture or dirt. This may or may not be easy to see as you deploy the tubes.

Kinks are not an issue with the 1/8" i.d. tubing provided by TEC. This tubing is very flexible and does not permanently kink. However, you may be using tubing from another source that can develop a permanent kink. The best time to check for blockage and kinks is when you are picking up after the previous job. Check your tubes as you are stowing them. Also check them again as you are deploying them on the next job.

Holes are another matter and are difficult to visually detect. Leaky tubing can seriously degrade the accuracy of the airtightness test. These leaks can be small enough to go undetected for years but large enough to affect fan calibration. Perform the following:

- After you have checked for blockage as previously described, inspect both ends of the tubing to make sure they are not stretched out to the point where they will not make a good seal when attached to a gauge. If so, trim a short piece off to remove the damaged end.
- Seal off one end of the tubing by doubling it over on itself near the end. Create a vacuum in the tubing by sucking on the open end. Let the end of the tubing stick to your tongue due to the vacuum. The tubing should stick to your tongue indefinitely if there are no leaks. Waiting for 5 seconds or so is a good enough test. A syringe also works well as a source of pressure to check tubes. If there are no leaks the syringe will spring back from the pressure in the tubing after you stop pushing on it.
- If the tubing has a leak, it should be replaced immediately. Mark the bad tube with tape as having a hole. When you get a chance, locate the hole and cut it out. Now you will have two shorter pieces of tubing. Check both of those for leaks. Don't assume the original tube had only one hole.

Metal Tubing is necessary when you need to run a plastic pressure tube out through a closed door or window. In many cases you won't be able to close the door or window without crimping off the tube. Spanning the door threshold or window sill with a length of metal tubing prevents the pressure tube from getting crimped. You can use 1/8" diameter copper or stainless steel tubing for this purpose. Longer lengths of tubing make it easier to measure the pressure under closed interior doors (less bending over) and above T-bar ceilings (less ladder climbing).



An overhead door will be lowered on this tubing before the test begins. The metal tubing prevents the door from crimping the tubing.

You can buy the copper tubing on-line or at many hardware stores. Ask for refrigeration tubing. In a pinch you can also buy the tubing at most auto parts supply stores.

Extension Cords. You should plan on bringing at least one extension cord for each fan you will use. Remember, Model 3 fans are rated at 15 amps. Make sure you use the right extension cord. For a 15 amp fan you can use a 14 gauge cord for distances up to 50 feet. Use a 12 gauge cord for distances between 50 and 100’.

Each fan should have its own circuit. Sometimes circuits are labeled or a building staff person knows which outlets in a building are on various circuit breakers. But often it is up to the testing team to decide where to plug in fans and being conservative might mean using lots of long extension cords. A process for determining separate circuits for powering fans using an inexpensive volt meter such as a *Watt’s Up* or *Kill-a-Watt* plug-in meter is described in Chapter 4, section 4.1.g.

On a construction site many of the trades will be using extension cords. It is a good idea to mark your cords as yours so there will be no confusion as to who owns a cord.

Inspect each cord before you use it. Better yet, inspect each cord before you leave the office. All extension cords, and also any other electrically powered tools, should be checked for frays, broken insulation, cuts, separation from either end, missing ground prong, etc. Any tools or cords with flaws should not be used until repaired or replaced.

Construction and electrical contractors have developed a common color coding for electrical inspections. They use the "seasonal color" scheme for quarterly inspections: white for winter (January, February and March); green for spring (April, May and June); red for summer (July, August and September); orange for autumn (October, November and December). If a company desires to use a monthly inspection frequency, a second color may be added. An example would be to add yellow for the second month of any quarter and blue for the third month in any quarter. A monthly inspection color for May would be green and yellow, or for December would be orange and blue.

A Ground Fault Circuit Interrupter (GFCI) should be used in conjunction with each cord or tool. Plug the GFCI into the receptacle and then plug the extension cord or tool into the GFCI. Active construction sites may require GFCIs.

Cable Testers

A cable tester is a handy tool to have when you cannot establish communications between the central computer and your DG700s. Plug one end of the CAT5 cable into the tester and the other end into the remote. It will indicate if the cable is good or if there is a short or open. Low-



Cable Testers

cost cable testers can be bought at most home improvement stores or online at places like amazon.com, mouser.com, digi-key.com, etc. You can also buy very expensive testers but if you are only going to use it for the few occasions that you have a communications problem during a test, save your money and buy the low-cost model.

2.2h Miscellaneous Tools and Supplies

Ladders are needed for a variety of tasks such as masking louvers, exhaust fans, etc. and also for removing ceiling tiles. Make sure your company name is on each ladder to prevent arguments with other contractors.

Everyone knows how to use a ladder but falls are the leading cause of death in construction. According to OSHA, there were 264 fall fatalities (255 falls to lower level) out of 774 total fatalities in construction during 2010. There are very specific rules for the safe use of ladders. For more information concerning the use of ladders refer to OSHA publication “Stairways and Ladders – A Guide to OSHA Rules”. This can be obtained, in PDF format at <http://www.osha.gov/Publications/osh3124.pdf>.

The United States Army Corps of Engineers provides a handy ladder safety checklist. If you are working on a Corps project you will be required to follow this. On other projects it is still a great way to make sure you are using safe ladder practices. Getting caught using unsafe ladder practices is a quick way to get thrown off the job. The checklist can be found at:

<http://www.usace.army.mil/Portals/2/docs/Safety/CESO%20Checklist%2024-01%20Ladders.pdf>

Door Wedges These are needed to make sure the interior doors stay open during the test. They may also be needed to make sure the exterior door where you have your fan located does not swing open or shut during the test.

Wedges can be bought at most hardware or home improvement stores but it is more economical to make your own out of wooden 2x4's or have a shop make them for you. If you are making your own, make sure to cut with the grain and not across it. Wedges made by cutting across the grain will fall apart quickly.

Sealing Materials. It is best to take an inventory of everything that needs sealing, note how you will seal it and note what materials you will use to seal it. Always bring extra materials of each type.

Duct Mask is an essential for sealing supply dampers and return grilles, exhaust fans and many other intentional openings in the building envelope that require sealing. Duct mask is self-adhering so it is much easier to use than pieces of poly and tape. Like tape it does not stick well to very cold surfaces, dirty surfaces, concrete and brick and rock. It does stick well to warm clean metal and gypsum board so be careful when you remove it. Don't damage painted surfaces.

Carpet protector is available in 3' widths and works well for sealing the intentional openings. Be aware that it can be difficult to remove if it has been baking in the sun for a while. Bring along an adhesive remover solvent because it may be needed in these cases. Shrink wrap material also works well.

Tapes. Always bring along a good selection of tapes including painters tape, duct tape and metal tape. Be careful to use the correct tape for the surface you are taping to. Don't damage the paint.

Cleaners. Alcohol or window cleaners and some rags or paper towels can be used to clean smooth surfaces before applying masking materials.

Garbage bags. Sometimes garbage bags are useful for sealing roof top ventilators. Really big ones are available from shipping supply catalogs such as ULINE.

Sheet material. Large openings can be sealed with sheet materials. It is best to use something 1/8" thick or thinner taped to a smooth surface. If the sheet materials are covering a large horizontal surface, it is good to bring ballast to hold it down during pressurization tests.

2.2.i Collect the basic information

Emergency contact information: Ask the client to provide you with a list of people to contact in the event of an emergency. For example you may want contact information for the owner or their representative, the client, contractor, the fire department and emergency medical services.

Dates and times when the test can be conducted: When you test will depend on the reason for the test. You may be tasked with testing the building before it is complete. Typically you would do this to test the design and construction, making sure the building has a chance to even meet the airtightness requirement. This would be done very early in the construction process. You may test a mock-up of a wall section or one room of a building to test the wall and roof sections or their interface transitions and window and door installation details. When you do this type of test you are probably not looking for a number, you only want to know if the design will provide a good effective air barrier and whether it can be put together correctly and in a reasonable sequence.

Other times you may be tasked with testing to determine if the completed building meets the airtightness requirement. You may have to comply with specifications that dictate when the test is conducted. For example, when the air barrier installation is complete but before the finished ceiling (if it is not part of the air barrier) is installed.

Conducting the test when no one else is in the building is the best situation for the test team (the test team includes the testing agency and also everyone else needed to do an

effective test). No one else in the building means no one interferes with the test. Doors remain closed, pressure tubes do not get stepped on and no one asks annoying questions. HVAC equipment does not get turned on.

Unfortunately that is often not possible, particularly when you are testing a newly constructed building. The builder may be under the gun, having to meet a completion date. That usually means you and other trades are trying to finish their tasks at the same time. It is particularly difficult to do the blower door test when the furniture is being delivered, when the floor tile is being installed or when the test and balance crew needs the HVAC system operating and you need it off. You need to make this clear to the builder and have them coordinate with the other trades, but even then expect interference. As much as you would like, the construction process does not revolve around you.

When you have to test the building with other people around, there are some steps you can take to minimize interference. Attending the weekly trades meeting and talking to all the foremen may help get their cooperation. Taping signs asking building occupants to close a door behind them (or leave the door open if it is an interior door) sometimes works. Posting people at each exterior door may be required.

2.2.j Security issues

In cooperation with the client determine what level of security may be needed at the test building. Security issues revolve around protecting people and property in the test building.

Some buildings may have established security measures in place such as:

- Access to the building. The measures may require exterior doors to remain locked. This actually helps during the test because people cannot enter the building. However, it is also frustrating when you lock yourself out or activate alarms that you can't turn off.
- Access to sensitive areas such as vaults, confidential record file rooms, etc. If you can't get into an area that is within the test area there are methods to determine if there is enough air being transferred from these areas to the main test area. More on this in the discussion on single-zone conditions in Chapter 3, section 3.1.a. Always check the mechanical plans for these rooms to make sure you are not omitting something that should be sealed during the test.

2.2.k Official witnesses

At times the airtightness specification requires that one or more designated parties witness the test or at least have the opportunity to witness the test. Witnesses will need to be given advanced notification of testing dates and times.

2.2.l Personnel provided by the client

The client must provide:

- A person authorized to provide access to all interior spaces including basements, crawlspaces, attics, mechanical rooms, custodial closets, offices, toilets and all exterior spaces needing sealing such as roofs (excepting spaces identified by the owner as security or health hazard areas)
- A person authorized to safely place HVAC and combustion equipment into test mode (off with motorized outdoor air intake and exhaust dampers closed) and return them to operational status:
 - All ventilation systems
 - All major air handling units
 - All combustion equipment
- A person who can turn circuit breakers back on in the event a circuit breaker is tripped

2.2.m Electrical Power

You are going to need electrical power for your fans, and also for your computer. Each fan will require its own 20-amp circuit. Keep in mind someone else may also be using this circuit. You don't want to pop a circuit breaker and find out you cut power to someone's computer. Make sure you know where the circuit breakers are and have access to them. A voltage drop method for determining separate circuits is discussed in Chapter 4, Section 4.1.g. During construction, temporary power may be located in one or two locations or there may be sections of the building without power. Confirm the status of power before test day.

2.3 Safety and Health

When you are on the job you don't want to get hurt, you don't want your co-workers to get hurt, and you don't want to hurt anyone else. Being safe on the job, working in a healthy job environment and not creating a hazardous environment is the goal, but safety is no accident; it doesn't happen by chance. A hazard is the potential for harm which, if not recognized or left uncontrolled, can result in an injury or illness. You must be aware of the potential hazards associated with your particular job and how they can affect you and others around you. You also must be aware of the hazards others working in the building create. Take steps to eliminate or reduce risks. The following sections present a brief and certainly not all-inclusive list of some of the considerations for on-the-job safety and health. We highly recommend you visit the Occupational Safety and Health Administration (OSHA) web site for more information regarding your responsibilities.

2.3.a Company Safety and Health Policy

Develop one, follow it and enforce it. You may want to include items such as requiring workers to wear steel-toed safety shoes and eye protection when testing. Maybe you will prohibit wearing shorts while on the job. Look at what is involved with conducting a test, from the time you leave the office to the time you return. Identify the hazards associated with completing your job, don't forget hazards others in the building may create, and use that information to develop your company Safety and Health Policy.

Activity Hazard Analysis (AHA)

Identifying hazards and eliminating or controlling them will help prevent injuries and illnesses. An activity hazard analysis, also called a job hazard analysis, is a technique that focuses on tasks of a specific job as a way to identify hazards before they occur and provides avoidance methods. It focuses on the relationship between the worker, the

OSHA

Even though many federal laws are restricted to companies that have 15 or more employees, this is not true with OSHA regulations. The Occupational Safety and Health (OSH) Act applies to every business that operates within the United States, regardless of size. This federal law was passed in 1970 and specifies that all employers are responsible for providing a workplace that is free from recognized hazards that are causing - or have the potential to cause - death or serious injuries or occupational illnesses.

Business owners and managers are responsible for familiarizing themselves with the aspects of the OSH Act that apply to their companies and to ensure that their organizations are compliant with all of applicable standards and regulations established by OSHA. It is also necessary for businesses to provide employees with copies of the OSHA requirements that affect their workplaces upon request. Ignorance of the law is not an acceptable excuse for noncompliance, and companies that do not operate in a manner consistent with the OSH Act can be required to pay significant fines, and the amount can vary greatly depending on the severity of violations discovered.

<http://www.osha.gov/>

task, the tools, and the work environment. Ideally, after you identify uncontrolled hazards, you will take steps to eliminate or reduce them to an acceptable risk level.

While many construction companies will require an AHA, others do not, and if you are testing an existing building it is likely an AHA will not be required. Develop an AHA whether it is a requirement or not and when you arrive on the job site make sure all of the test team members read it. A sample AHA is included in Appendix B. There are on-line pay services that help you create an AHA. Search on Activity Hazard Analysis or Job Hazard Analysis.

For more information on this subject refer to OSHA publication 3071 “Job Hazard Analysis”. This can be obtained by following this link:

<http://www.osha.gov/Publications/osha3071.pdf>

2.3.b Training

If you are testing a building still under construction the general contractor will likely require any worker on their site have some level of safety and health training. They may provide this training themselves, charging their Safety Officer with providing the training, usually a 20-30 minute safety orientation. Others may require more formal training such as the OSHA 10 or 30 hour Construction Safety and Health course.

The OSHA courses are available on-line from many providers. At a minimum consider having all your workers (and yourself) take the 10 hour course. It covers job safety issues most of us who are testing buildings will face. The 30 hour course is much more inclusive and covers issues we as testers will not encounter. However, general contractors may require at least one person on the test team to have completed the 30 hour course. It is best to look closely (and early) at your contract to determine what is required and plan accordingly. Don't be surprised at the last minute and find out your test team will not be allowed on the job site.

2.3.c Safety Equipment

You should always bring safety equipment to a job site. At a minimum have a first aid kit and a fire extinguisher on every job or know where they are located at the job site. Make sure the test team has and uses the required personal protective equipment (PPE) as specified in your company Safety and Health Policy. Other items that are not always needed on all jobs but are necessary for certain tasks include safety harnesses and lanyards for fall protection, respiratory protection, gloves, protective clothing, hearing protection and lock-out/tag-out kits. Having this equipment available when it is needed is much more efficient (and safer) than having to leave the job to get what you need or not using it.

Chapter 3 - Prepare the building

3.1 Review the plan for building setup

During the planning stage, you will have determined the purpose of the test and the test protocol needed to achieve the desired results. This will in large part determine the complexity of setting up the building.

3.1.a If the whole building can be tested as one open zone

In this case, setting up the building can be pretty straightforward. All exterior doors and windows will be closed and all interior doors will be opened. Take a walk around the outside of the building to confirm that all windows are closed. Make sure that all occupants of the building are aware that they should not open windows during the test. It is good practice to have one of your team members walk around the outside of the building during the test to verify that windows have not been opened and that doors have not blown open. Between the depressurization test and the pressurization test verify that seals are holding and that the building conditions have not changed. You should also walk around to make sure someone has not done something else that invalidates your test.

Plan on bringing a bag full of wedges to prop open the interior doors and to firmly prop open exterior doors containing the blower door fans to prevent the wind from slamming the exterior door against the blower door fan assembly or damaging the exterior finish of the building. For security and other reasons, it will not always be possible to open all interior doors and you may need to monitor or at least take a measurement of the induced pressure in those spaces.

3.1.b If the test zone is a portion of the whole building

In this case there will be additional things to consider. Adjacent parts of the building that are unconditioned should be opened as much as possible to the exterior and doors will be closed between adjacent space and the test zone. Pressures in these adjacent spaces should be monitored during the test to confirm that they are truly outside.

Often buildings have adjacent zones that are conditioned and have very little or no openings between those spaces and the main section of the building. An example of this type of space could be a mechanical room. When testing new buildings there are often workers still doing work in the mechanical rooms, even when your planning had discussed this. You will need to improvise and adapt. These adjacent zones can be treated in one of two ways. Blower door fans can be set up in those sections of the building and the building can be tested as one zone by bringing both zones to the same induced pressure at the same time. You also have the option of testing one zone at a time. In this case, you will have exterior doors and windows closed and doors closed

between the adjacent space and the test space. Tape off any supply diffusers and return grilles in the test zone that connect to ducts or equipment outside of the test zone. Pressures in the adjacent zone should be monitored during the test. The test results will include air leakage between the test zone and the adjacent conditioned spaces. The amount of air leakage between the test zone and the adjacent spaces can be determined using zone pressure diagnostics techniques and software, which is beyond the scope of this guide.

Garden style apartments or row houses are examples of test zones with adjacent conditioned spaces. With these types of buildings you have the option of setting up blower doors in adjacent zones and using them to keep the adjacent zones at the same pressure as the test zone. Only the flow through the blower doors in the test zones are used in the test results. This is often referred to as guarded testing.

Compartmentalizing apartment units

The goal of certain airtightness standards is to compartmentalize individual units of an apartment building to reduce the transfer of pollutants, such as tobacco smoke and odors, between the units. This will require setting up a blower door fan or Duct Blaster® fan in the apartment unit's window or door and testing units one at a time. The protocol may call for opening a door between the hallway and the outside or opening windows or doors in adjacent spaces to the outside.

Compartmentalizing floor by floor

Testing several floors at a time of tall buildings is not recommended because vertical shafts such as elevators and mechanical shafts connect the test zone to other sections of the building and can result in inaccuracies in the testing. But there are times where this may be necessary. The test will likely overestimate the actual leakage due to the path leakage of the shafts.

3.2 Turn off mechanical systems for the test

Work with the building management to gain access to and turn off all combustion appliances and all HVAC system controls. Make sure all domestic hot water systems and boilers are adjusted so they do not come on during the test and remember to get them turned back on at the end of the test. The chimneys for these appliances should not be sealed. Exhaust fans and HVAC systems should be turned off. Door alarms will need to be addressed at the locations where the blower doors will be set up. If you are using smoke to find air leaks you may need to address smoke alarms and fire sprinklers.

3.3 Intentional holes in the building

Most test protocols will include some level of sealing of intentional holes in the test boundary. The Army Corp's standard has specific requirements pertaining to masking HVAC openings. Air leaks around windows and doors are not considered intentional holes. Also remember that chimneys for combustion appliances should **not** be sealed as part of the test. Mechanical dampers may be sealed or left unsealed; however, mechanical damper leakage may be significant and you may choose to do some level of diagnostic testing with dampers sealed and unsealed. Preparing the building by sealing all of these openings and unsealing them after the test will often be the most time consuming part of the entire test process. When testing a new building, this may be the responsibility of the builder; however, you will want to make sure that their sealing technique will withstand the pressures that will be applied to the building. You may want to also confirm that all dampers are working properly.

The table below refers to Air Barrier Association of America (ABAA) section 10.12.3 for guidance of what on what should be sealed during the test if it is not already spelled out in your test specifications. The table below may no longer be current – refer to the table in the current edition of the ABAA test method.

Intentional Openings	Air barrier systems envelope test (HVAC-related openings excluded)	Operational envelope test (air barrier systems and HVAC-related openings included)
Doors, hatches and operable windows inside the test envelope	Open	Open
Windows, doors, skylights and hatches in the bounding envelope	Closed and latched	Closed and latched
Dryer doors and air handler access panels	Closed and latched	Closed and latched
Vented combustion appliance	Off, unable to fire	Off, unable to fire
Pilot light	As found	As found
Chimney or outlet for vented combustion device in a separate mechanical room	As found	As found
B-vent or other insulated chimney serving a vented combustion appliance located within the test space	Sealed	As found

Solid fuel appliances (fireplaces, wood burning stoves, pellet stoves)	No fires; dampers closed; chimney sealed	No fires; dampers closed
Exhaust, outdoor air, make-up air fans, air handlers that serve areas inside and outside the test envelope	Off	Off
Clothes dryers	Off	Off
Air intake inlet with motorized dampers	Dampers closed and sealed*	Dampers closed
Air intake inlet with gravity dampers	Dampers closed as found and sealed	Dampers closed as found
Air intake inlet with no dampers	Sealed	Open unless fan(s) serving inlet is operated >8000 hours per year, then sealed
Exhaust or relief air outlet with motorized dampers	Dampers closed and sealed	Dampers closed
Exhaust or relief air outlet with gravity dampers	Dampers closed as found and sealed	Dampers closed as found
Exhaust or relief air outlet with no damper	Sealed	Open unless fan serving outlet is operated >8000 hours per year, then sealed
Clothes dryer outlets	Sealed	As found; sealed if there are no gravity or motorized dampers or if dryers are not yet installed
Exhaust, outdoor air or make-up air fan that runs > 8000 hours per year	Sealed	Sealed
Ductwork that serves areas inside and outside the test envelope	Sealed at supply and return	Sealed at supply and return
Floor drains and plumbing	traps Filled	traps Filled
*Sealed means that an opening has been temporarily masked airtight (e.g. covered with self-adhering plastic film , taped polyethylene film or rigid board stock)		

TABLE 3.1 Default Conditions for Building Preparation

3.4 Sealing the intentional holes

Basic sealing techniques

Shapes and size of the openings will vary greatly. Products like Duct Mask™ or adhesive backed carpet protectors will often be the only products you will need. Most surfaces will require cleaning with Windex or rubbing alcohol to allow good adhesion of the tape. Some openings like a roof top ventilator can be sealed with a garbage bag and tape. Some larger openings can be sealed with plastic, tarps or light weight rigid sheet goods and tape. If you are testing under pressurization and depressurization, keep this in mind when developing your sealing strategies. You may need to weigh down the sheet goods to prevent them from moving during a pressurization test. 75 Pa of pressure is equal to about 1.6 pounds per square foot. If your sheet goods weigh less than this they may move during the tests.

Where you seal depends on issues such as safety and access and the location of the air barrier. If you can't get to the roof to seal a roof-mounted exhaust fan for example, you will probably need to seal it indoors.

The location of the air barrier is also an important consideration when sealing intentional openings. For example, consider a bathroom exhaust fan. You can't get to the roof so you seal it in the bathroom. The air barrier is the gypsum board bathroom ceiling. The duct work and the fan itself are likely to be pretty leaky so sealing in the bathroom may not accomplish much. Whenever possible you will want to seal the intentional opening in line with the plane of the envelope.

3.5 Examples of Intentional Holes

The size and types of intentional holes are as varied as the type of building or type of mechanical systems you might come across. Each building will have its own set of new challenges that you will need to be prepared for. We have included some examples of sealing techniques to give you a general idea of the process. All of the examples shown were sealed to withstand pressurization and depressurization at 75 Pa.

3.5.a Outdoor air intakes

Outdoor air intakes are louvered grilles that draw air into the building to ventilate or condition interior spaces. These openings are essentially a direct hole into the building envelope covered by insect screen with a fixed louver to prevent rain from entering the opening. They usually have dampers and are usually motorized. When viewed from the outside, the louvered area may be one story tall and 40' long, but when viewed from the inside it may have multiple openings that have a much smaller surface area. The interior openings may go into a large section of ductwork that in turn has multiple

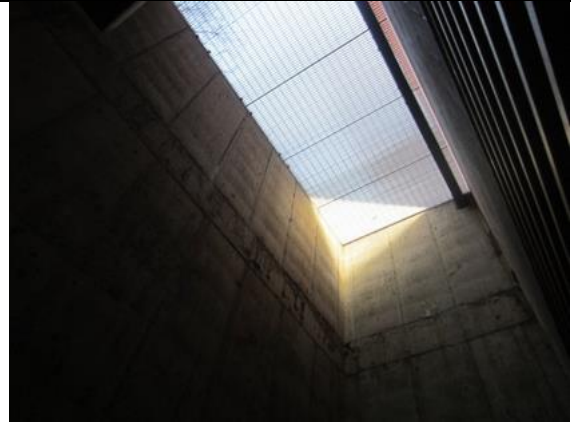
dampened openings. It is often easier and more practical to seal the multiple smaller openings.



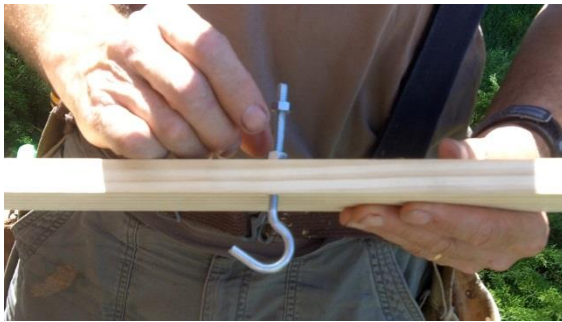
Often it is easier to close the dampers and seal it from the inside.



In this example, sealing from the inside will be easier.



In this example, sealing from the exterior will be easier.



J-hooks can be used with 1x4s to hold tarps down to metal grates. Sill sealer foam material at the edges helps make an airtight seal.



1x4s are cut to length and held down to the grate below using J-hooks



Blower door frames can also be used to hold the tarps down over metal grates. Short pieces of 1x4 with J-hooks were used as an extra protection to keep frames in place during the pressurization blower door test.



Large openings up high can be difficult to seal from the exterior.



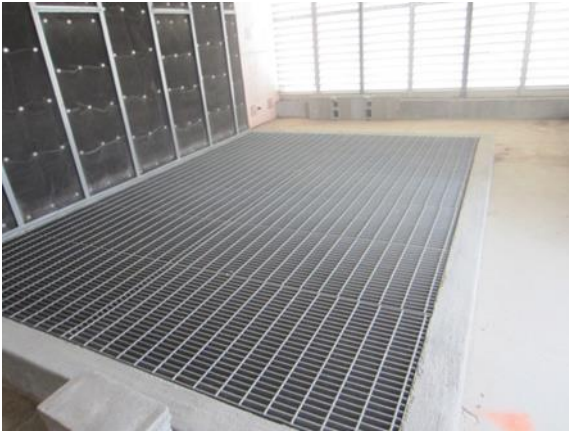
This is a view of those openings from the interior. Rolls of 3' wide sticky back carpet protector tape work great for sealing large openings.



Those openings lead to this ductwork, which is smaller and easier to access.



Sometimes renting a hoist is the best solution to seal exterior intentional openings. Training and safety harnesses are required here.



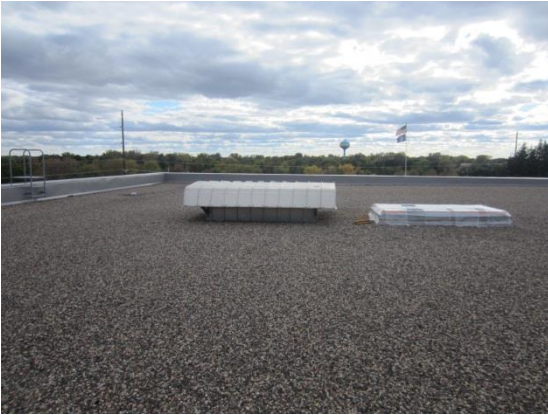
Adding weight helps hold the tarps in place on a large opening.



This is another example of sealing a large duct opening using strapping behind and in front of the sticky backed plastic.

3.5.b Metal rooftop hoods

These hoods protect a ventilation shaft so rain water, birds and insects do not enter. Verify that any mechanical fan connected to the shaft has been turned off before you begin sealing it. The hoods are typically fastened to the roof curb with four or more screws. If the hood is small enough, you can simply put a garbage bag over it and secure it with tape. If the hood is larger than 3'x3', it is often easier to seal the opening by first removing the hood. Make sure to secure the hood so it will not become airborne in the wind. The opening can then be sealed using carpet protector tape or Duct Mask.



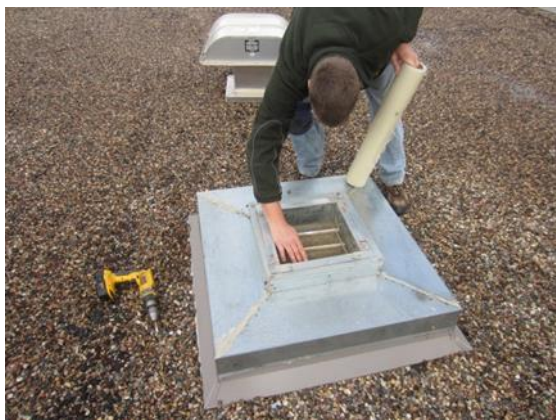
It was easier to remove the hood and seal a flat surface. Straps were used to secure the plastic.



Removing the hoods, installing a tarp, and then reinstalling the hoods works well.



The connection to the curb is often leaky and you may want to test it with it sealed and unsealed. Straps with tarps were used to seal the top opening.



Removing the hood made this one much easier to seal. Make sure to secure the hood or reinstall it over the opening.



Make sure dampers are in the closed position before sealing a roof top unit hood.

3.5.c Exhaust systems

Exhaust systems can be roof top exhaust fans or wall hung fans. If the fan is inside the building and is ducted, it may look like an outdoor intake except the dust will be on a different side. There is a wide variety of exhaust systems.

Kitchen exhaust will typically not contain a damper because of the possibility of a grease fire. The duct running from the hood to the fan outside is required to be welded seam so there should be no leaks in the duct. Commercial kitchen exhaust fans will typically have air intake fans also. The exhaust and intake may need to be sealed, although this could easily be considered a building leak.

Bathroom ventilation will typically consist of a grille on the wall or ceiling that is ducted into a shaft with a roof top ventilator at the top.

Garbage chutes will typically have a roof top ventilator fan at the top. Makeup air for the room at the bottom of the chute may be provided by louvered openings or by air intake fans.

Clothes dryers may be vented into a duct with a roof top ventilator at the top. Makeup air from the outside may be provided by a mechanical or gravity damper.

Fans that run continuously are not acting like a leak, so they should be masked. They are typically not dampered. Do not seal these fans until they are turned off.

Fans that run intermittently may be on a schedule when the building is occupied or may simply be controlled with an on / off switch.

Garage exhaust may not need to be sealed if the garage is determined to be outside the conditioned space.



Kitchen hoods are typically not dampered. These dryer vents were sealed on the inside.



Kitchen exhaust fan. The make-up air intake on the front and the exhaust on the rear of the hood have been sealed. You may find a large quantity and a wide variety of openings on a roof.

3.5.d Roof Top Air Handler Units (RTU)

RTUs come in a variety of shapes and sizes. These might have no dampers, gravity dampers or powered mechanical dampers. Before sealing them you should turn off equipment, verify that the dampers are closed to reduce the pressure on the masking tape and then mask the dampers or the opening. You will find that about 5% of the dampers are not operating properly. Relief dampers prevent the building from being over pressurized. They may have motorized or gravity dampers. The gravity dampers may open due to building pressure, being sucked open by wind or due to stack effect.



The large intake on the left will be sealed for this test. The gravity relief damper on the right was overlooked until it popped open during pressurization.



Layers of plastic were run diagonally to add strength to the seal. Wasps are a common sight on roof tops. Always have some spray handy.

3.5.e Smoke evacuation systems

These will have large roof top ventilators and dampers that open to provide makeup air. Elevator shafts may have louvered openings at the top or mechanical vent dampers that open in case of a fire. Some of these are very tall and are a challenge to seal on a roof top.



3.5.f Roll up (coiling) garage doors

These typically have flaps that can blow open during the blower door test when the pressure reaches a certain level.



3.5.g Additional diagnostic testing

Additional diagnostics may be done to quantify air leakage. Here a site-built cardboard orifice was used to measure damper leakage with the blower doors running..



3.5.h Elevator vents

Vents at the top of an elevator shaft may have no dampers or may have a motorized damper that will open when a smoke alarm goes off and should default to open position if power is lost. Whether or not to seal these openings will depend on the purpose of the test. Above all it is important to document and report on the status of these openings during the test.

3.5.i Plumbing traps

Plumbing traps are a direct opening to the sewer system if the traps are not filled with water. The water may evaporate from traps that have not been used for extended periods of time. If traps are not filled, sewer odors may be pulled into the building during the depressurization test. Some precaution should be taken to ensure that the traps are filled.

Chapter 4 – Setting up Equipment and Performing the Test

4.1 Confirming Equipment Setup Locations

The first step in setting up the equipment is to refer to your predetermined layout plan to confirm that site conditions allow the blower door fans and the control center to be set up in those locations. Here is a list of recommendations that will help your setup go smoothly.

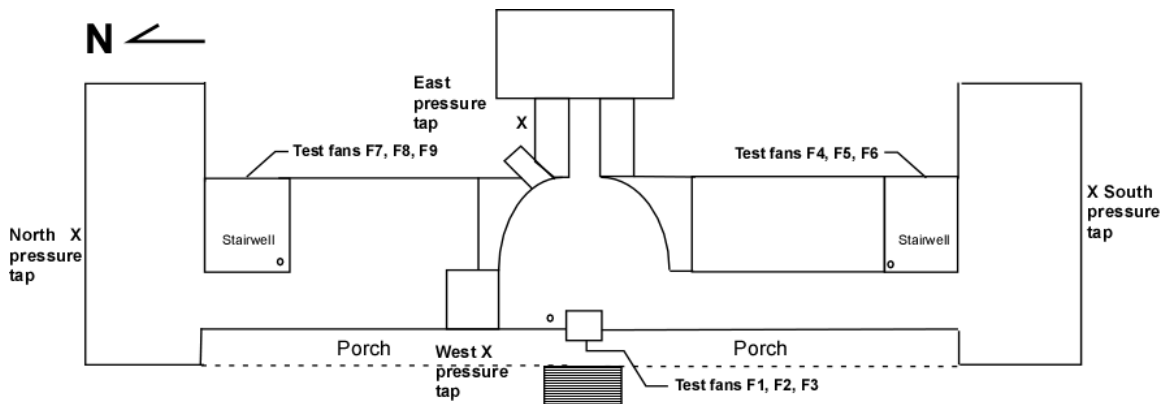


Figure 4.1 An example of a predetermined fan layout plan

4.1.a. Locate fans and gauges to minimize tubing lengths

It is much easier and better to run long lengths of CAT5 cable back to the central control center. One of the major challenges with setting up for large building testing is the potential distance between your fan systems, gauges and the centrally located computer (control center). In a large building this distance can be many hundreds of feet. You then have to decide between running hundreds of feet of multiple tubes, or running hundreds of feet of a single CAT5 cable from each measurement location. Not only is it easier to run a single CAT5 cable, but there are problems associated with running long lengths of tubing.

The DB9 serial port on the DG-700 along with a set of DB9 to CAT5 adapters allows the use of CAT5 cable in virtually any length (up to 4,000 feet) which greatly simplifies test

setup. CAT5 cable is readily available in various lengths with end connectors already attached or you can purchase bulk lengths and attach the cable ends.

Using one or more 8 Port DB9 to USB hubs is a preferred communication option in large buildings using multi-fan systems. Each 8 port hub allows the control software (TECLOG3) to communicate with up to eight separate DG700 gauges through a single USB connection to the computer. The CAT5 cables from the various measurement locations will be routed to the central computer and connected to the hub using DB9 to CAT5 adapters. A modular wiring splitter such as the 10BaseT/ 10 BaseT by L-com can also be used in pairs to allow a single CAT5 cable to be run from the two gauges of a 2 or 3 fan system to the 8 port hub. This is especially helpful when running cable over long distances. Note: Stranded CAT5 cable is more durable than single wire (solid conductor) cable. Single wire cable is not intended for repeated rolling and unrolling. Energy Conservatory sells these splitters in kits which each allow connection to 2 DG-700s over one long CAT5 cable.



4.1.b. Avoid installing fans in doors needed for traffic

Workers need certain doors for fire or safety egress. Confirm with your building contacts which doors should not be used for blower door setup.

4.1.c. Confirm the door opening size.

It is possible to install a 3 fan system in a 6'8" door opening, but it is better to use a taller door opening whenever possible. A standard blower door frame will expand to 45" x 96" and the commercial frame will expand to 48" x 96". Some older frames will only expand to 40" wide.

When the door openings are taller than 96", you can cut a piece of XPS foam (recommended is 1 ½" or 2" thickness) to fit in the door opening above the blower door frame. The foam can be temporarily taped in place or held by a shim.

Double doors can present their own set of issues. Some will have no center post. If one of the doors can be secured to make it stationary, a blower door frame can be set up on the operable side. If one side cannot be secured you may be able to set up two blower door frames side by side in the opening if the opening is at least 55" wide (or 58" wide if you are using a commercial sized blower door frame). Make sure the top and bottom of the frames are aligned, so the



2x4 in center with shims at bottom.

forces of the cross bars are properly transferred. A clamp should be installed in the middle of the two adjoining vertical sections to hold them firmly together. If the door opening is wide enough, it is best to install a vertical 2x4 in the center of the opening, held in place with wedges. The two frames can then be installed against the 2x4.

4.1.d. Door closers will need to be dealt with

Door closers are typically in the way when setting up the blower door frame. In older buildings, the closer may be rusted in place and not easily removed. An impact driver may help to remove rusty screws. Make sure you are using the right sized bit. A time saving solution is to leave the door closer in place and use 3/4" foam pipe insulation to seal the opening above the blower door frame. You may need to also use tape to make an airtight seal.



4.1.e. The doors may have security alarms

Check with your building contact to make sure the security alarms have been disabled for the test and enabled once the test is complete.

4.1.f. Doors will need to be secured in the open position

When propping open a door to install a blower door frame, make sure it is securely held in place with shims or wedges at the bottom to keep it from swinging into the blower door fans or the exterior finishes in case a wind gust catches the door. Block the door from swinging either direction by placing shims from both sides.



4.1.g. Each blower door fan must have its own 15 or 20 Amp circuit

Availability of enough power may affect your choice of fan location. Sometimes circuits are labeled or a building staff person knows which outlets in a building are on various circuit breakers. But often it is up to the testing team to decide where to plug in fans and being conservative might mean using lots of long extension cords. The following is the recommended process for determining separate circuits for powering fans using an inexpensive volt meter such as a *Watt's Up* or *Kill-a-Watt* plug-in meter:



Before fan is turned on the meter reads 125 volts

- Plug your first fan into the closest outlet that you would like to use. Plug an extension cord into an outlet that you want to test to see if it's on the same circuit. Plug the Watt meter into the other end of the extension cord. Set the Watt meter so that it displays AC Voltage. With the meter in one hand, walk over to the speed controller for the first fan. While watching the voltage reading on the meter, quickly turn the fan to maximum speed and back off. You don't need to let the fan reach full speed. If the voltage reading on the meter goes down noticeably (more than a Volt), the 2 outlets are probably on the same circuit. If the voltage reading stays nearly the same or goes up when the fan is turned on the 2 outlets are on separate circuits. Repeat this process for additional fans.
- Although it is best to have a separate circuit for each fan, it is often possible to run 2 fans on a single 20 amp circuit if there is nothing else drawing power from that circuit and both fans are running at full speed. A Model 3 fan on maximum speed draws a maximum of about 9.1 amps. Surprisingly, at about half speed the fan can draw up to about 11.5 amps due to motor efficiency, controller efficiency, and power factor all decreasing at part load. To run two fans on the same circuit first turn one fan on to full speed and then quickly (over 5 seconds or so) turn the second fan to high speed. If there is nothing else connected to that circuit you should be able to run both fans indefinitely this way. Don't do this without knowing where to locate the circuit breakers if one trips. Two fans on one circuit is really only practical if controlling fan speeds manually, and even then is a last resort. When using computer control, always avoid putting two fans on the same circuit.



After fan is turned on the meter reads 122.3 volts, indicating that both outlets are on the same circuit

4.1.h. Envelope pressure measurement locations

For outside terminations and where tubing will be run into the building, consult your predetermined plan for the location and number of envelope pressures and confirm that these are still appropriate based on site conditions. These locations are largely determined by the geometry of the main floor of the building. It is recommended to use four envelope pressure measurement locations, one on each side of the building, to reduce wind fluctuations and provide redundancy. If there is no or slight wind during the test (calm), using a single envelope pressure measurement on the leeward side of the building is a reasonable alternative. The TECLOG3 software has



If tape does not stick to the wall, you will need something to hold the tubing up off the ground

the capability to record multiple envelope pressure locations and will average the envelope pressure readings.

In most cases, the installation location for a multi-fan blower door system makes a good choice for one of the envelope pressure measurement locations because you already need to run cabling from that spot back to the central control computer. Sometimes you will need to locate a single gauge on one side of the building simply to measure an envelope pressure. Remember to try and keep tubing lengths to less than 100 feet.

Tubing terminations should be located at a ground / wall intersection and should be taped or held in some fashion with the tubing end pointed down to protect it so rain will not enter the tube. If rain is likely, a larger diameter tube connected to the end of the envelope tube will prevent water from getting into the bottom of the tube by capillary action.

4.1.i. Interior building differential pressure measurement locations

Consult your predetermined plan for the location and number of interior pressures and confirm that these are still appropriate based on site conditions. These measurements are made in remote locations in the building with reference to the main body to determine if the building pressures meet single zone conditions or to verify that an adjacent unconditioned zone is truly outside. You should locate the manometer to optimize tubing length so the longest length does not exceed 100'. If you must use longer tubes, keeping them out of direct sun and away from hot or cold air streams will reduce errors in the pressure readings.

4.1.j. Confirm the control center location

Confirm where the computer will be set up to control the blower door fans. After any needed adjustments are made to your predetermined fan locations, you will need to confirm that your predetermined control center location is still appropriate. It is best to find a place on the main floor which will not be in a high traffic area. You will need to run data cables and sometimes tubing to this area. It is convenient, but not necessary, to have it be within line-of-sight to some or all of your blower door fans. Avoid having the control center too close to the direct path of airflow to or from the test fans because it will be quieter and also more comfortable, especially when you are pressurizing the building during extreme outdoor conditions. It is helpful to have a large table, counter or desk for setting up the computer and data hubs.



If you are using an 8 port DB9 to USB hub, it is good practice to secure the 8 port hub to the table but not screw the DB9 to CAT5 adapters to the hub. This will help prevent damage to the hub in the event that someone trips on the CAT5 cables that are routed to the central control center.

4.2 Distribute Equipment

Once the final decisions are made about fan locations and the control center location, it is time to start unloading the equipment. It is often best to have a centrally located staging area, with easy access and lots of room, to unload all of the equipment. Before this point, you will have already come up with a strategy on how to pack and transport equipment. The two strategies for packing equipment are typically either:

- Pack like items in boxes, such as all of the red nylon panels in one box and all extension cords in another box, etc., or,
- Pack all of the items needed for your two or three fan system in one duffle bag; something about the size of a Duct Blaster® bag. This method saves time at the setup and tear down stages because everything, except for the fans and frame, is kept together in the one bag.

It is certainly helpful to bring carts, or have access to carts, to move the blower door fan systems from the staging area to the area where you will be setting them up. Once all of the equipment is distributed, it is time to start the setup.



There are a lot of logistics to consider on these projects. Combining all items needed for a 3 fan system in one duffle bag has its advantages.



Carts with fans above with bins below. Scaffolding / cart serves many purposes and folds into a small package for transport.

4.3 Setting Up the Frame and Panel

Installation of the commercial aluminum frame and 2 or 3 hole panel is very similar to installation of the standard Minneapolis blower door frame and panel (see instructions in Chapter 3 of the blower door operation manual). It is best to initially install the frame and panel into the opening with only the lower cross bar installed. To orient the panel, be sure the green patch containing a bulkhead for attaching tubing is located in the lower right corner when the panel is installed on the frame. Older panels will have two holes at the bottom corners of the panel to slip the tubing through.

Because the frame and panel will be holding 2 or 3 fans, it is very important that the frame be installed very tightly into the door opening.

If the frame does not fit tightly enough, disengage the cam levers, re-adjust the frame (using the adjustment knobs) to fit tighter in the opening, and then re-engage the cam levers. Remember that over-tightening the knobs will not help hold the frame in place any tighter and can lead to damage to the frame assembly.



After the frame and panel are tightly installed into the opening, install the upper cross bars. The top cross bars should be centered in the fabric space between the fan holes. Securely tighten the upper cross bars using the adjustment knobs and engage the cam

levers. The frame should be installed tight enough that it would be very difficult to pull the frame and panel out of the door opening.

Installing a frame against a surface that does not have a door stop can be problematic, especially if it is a smooth, polished, or curved surface. **Make sure the blower door frame is installed firmly in place.** Having a 2 or 3 fan system pop out of an opening under 75 Pa of pressure is not something you want to happen. The blower door frame is most likely to pop out under negative pressures with a typical setup, but in some cases you will be set up in an opening with no door stops and it could pop out during a pressurization test also. Here are a couple of tips to help prevent this from occurring:

- Use a pencil or a pen or a dowel that is about that diameter and some tape to create a temporary door stop. The temporary stop should be placed tight against the blower door frame.
- Tape a U-shaped piece of metal to the edge of the door jamb to keep the blower door frame from slipping out of the opening.
- Either device should be installed at approximately the height of the middle cross bar to prevent the top of the frame from popping out.



Install tape around the opening about the height of the middle cross bar. Install blower door frame and red nylon panel into the opening.



Pull back the tape and install the dowel, pencil or pen tight against the blower door frame. Re-install the tape.



Another option is to use a U-shaped piece of plastic and some shims.

4.4 Installing the Fans (2 or 3 fan system)

4.4.a. Complete a field calibration check on each blower door fan

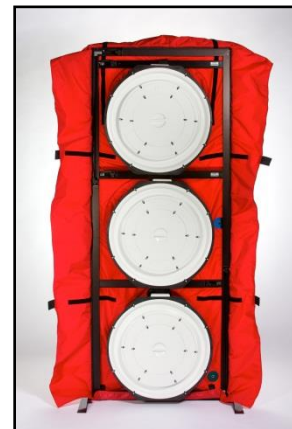
Fans can get jostled around during shipment and it is good practice to inspect the fans before installing them. Check Appendix A of the blower door manual for issues affecting calibration. With a field calibration check you are essentially verifying the integrity and location of the flow sensor and verifying the integrity of the tubing that goes from the flow sensor to the brass tap on the fan.

4.4.b. Are you are setting up for pressurization or depressurization?

Consult your predetermined plan to see which test will go first. This will determine if the side of the fan with the Flow Rings and Flow Sensor is facing out of the building (pressurization) or facing into the building (depressurization).

4.4.c. Flow rings with 'no flow plates' or fan caps?

It is common practice when testing single zone big buildings with more than 3 fans to only use fans in the open configuration (e.g. without flow rings installed). Instead of adding rings when the fan pressure drops below 30 Pa, you will turn off the speed controllers to one of the fans and cap it off. This will avoid the confusion of determining which fan has a ring installed. If you are following this procedure you may find it easier to use fan caps to seal off a fan instead of installing the flow ring sets. Using fan caps also makes sealing the fans easier during the pressurization test because you can install the fan caps from inside the building, whereas you would need to install the flow rings from the outside.



4.4.d. Install the fans

Once the frame and panel are securely installed in the door opening, install the fans in the holes in the red nylon panel. Start with the lower fan and work your way up. Secure each fan to the cross bar just above it by slipping the Velcro strap from the cross bar through the fan handle and looping it up and back around the cross bar. Pull the strap tight and engage the Velcro.

4.5 Installing the Speed Controllers (2 or 3 fan system)

Slide the fan speed controllers for the multi-fan system onto the commercial mounting board using the clips on the back of the controller envelopes. Use the C-clamp on the back of the mounting board to attach the board to the left side of the lowest cross bar. Be sure the speed control knobs are set to off.



Plug the fan connect cord from each of the controllers into the fans. Connect the lower controller to lower fan, middle controller to middle fan, and upper controller to upper fan.

Plug each of the controller's power cords into separate wall circuits that are compatible with the power requirements of the fan and speed controller. Power extension cords should be #14 gauge or lower. See section 4.1.g for an explanation on finding separate circuits.

4.6 Installing the DG-700 Gauges (2 or 3 fan system)

Attach each of the DG-700 gauges to one of the black gauge boards using the Velcro strips found on the back of the gauge.



Attach the first gauge and board to the left side of the middle cross bar using the C-clamp on the board. Attach the second gauge and board to the right side of the middle cross bar.

4.7 Connecting the DG-700 Gauges to Your Computer for Automated Testing

For automated testing using the TECLOG3 software, you have the option of communicating to a computer via Wifi, via cable, or a combination of both.



To connect via WiFi using multiple DG-700 gauges, you will attach a WiFi Link to the top of the DG-700's and use the TECLOG3 software to configure the WiFi Link to Router Mode. All of the DG-700's will connect to a router via WiFi and the router will then connect to the computer via WiFi.



To connect via cable, attach a male DB9 to CAT5 adapter to the RS-232 port on top of both gauges. You can either run a length of CAT5 cable from each DG-700 to the computer or run two short lengths of CAT5 to a modular wiring splitter and run a single CAT5 cable to the computer.

If you have additional gauges that will be used to separately measure envelope pressures or interior building pressure differentials, the location of these gauges will be determined by which pressure signals they are measuring. Each additional gauge can be connected to the computer via WiFi or via cable.

4.8 Attaching the Fan Control Cable (2 or 3 fan system)

The commercial fan control cable uses the fan control output jack on a single DG-700 to control 2 or 3 fans via the TECLOG3 software. When using this setup, all fans for this multi-fan system are controlled together and cannot be independently adjusted (this works well for large building testing). Install one end of the commercial fan control cable into the left side DG-700 gauge. We now need to need to insert the 3 remaining plugs on the cable into the fan control input jacks on the side of the fan speed controllers (the order in which they are connected does not matter).



Controllers are activated by turning them to the “just on” position (turning the controller knob on and then turn the knob fully counter clock wise, just before it clicks off). If you do not need all installed fans, simply turn the appropriate controller(s) to the off position.

4.9 Tubing Connections (2 or 3 fan system)

For multi-fan blower door systems, we recommend that all ports on the DG-700 gauges have tubing connected at all times to protect from noisy readings caused by air currents at the gauges. The colors and lengths of tubing suggested below are included with new two and three fan systems. Other colors and lengths can be substituted. *** the tubing connections outlined below assume that you will be using the location of this multi-fan blower door system for one of the envelope pressure measurements.*

Note: TECLOG3 allows any channel to measure any pressure, but we normally use channel A of the left gauge to measure envelope pressure and the other channels for fan pressures.

Red tubing (three 4' lengths)

- On the left gauge, connect one of the red tubing lengths from the **Channel B Input** tap to the pressure tap on the lower blower door fan.
- On the right gauge, use the remaining two lengths of red tubing to connect the **Channel A Input** tap to the middle fan, and the **Channel B Input** tap to the top fan. (if you are using a two fan system, simply leave the **Channel B Input** tap open).

Green tubing (one 7' length and one 15' length)

- On the left gauge, connect the 7' green tube from the **Channel A Reference** tap to the indoor side of the pressure tap on the green patch, located at the lower right corner of the red nylon panel.
- Connect one end of the 15' green tube to the outdoor side of the pressure tap on the green patch. The other end of this tube should be placed on an outside wall of the building, away from the air flow of the blower door fans. Longer lengths of the exterior tube can be used in place of the 15' green tube, but they should be less than 100' and should be placed in a way that they are not likely to be driven over or stepped on. Longer lengths of lighter colored tubing will be less affected by pressure fluctuations caused by the sun shining on the tubing. See section 4.1.h for additional details on envelope pressure measurement locations.
- If you have an older nylon panel, you may have a hole at each of the bottom corners of the panel instead of the pressure taps on the green and blue patches. If this is the case, simply extend your outside envelope pressure tube through the left hole and connect it to the Channel A Reference tap on the left gauge.

White tubing (one 15' length)

- On the left gauge, connect one end of white tubing to the **Channel A Input** tap and run the other end to an inside location away from the turbulent air streams near the blower door system. If the building is a single zone, this inside location should be at the same pressure as all of the other envelope pressures.

Blue Manifold (one 18' length with two T's)

- The blue manifold is used to connect the fan pressure reference taps together. The end of the blue manifold with the two short tubing pieces should be connected to the **Channel A and B Reference** taps on the right gauge. The remaining short tubing piece should be connected to the **Channel B Reference** tap on the left gauge.
- When conducting a depressurization test of the building, run the remaining end of the blue manifold to an inside location away from the turbulent air streams near the blower door system. If there is a vestibule, extend the tube into the main body of the building away from turbulent air streams.

- For a pressurization test of the building, connect the remaining end of the blue manifold to the indoor side of the pressure tap on the blue patch, located at the center right side of the red nylon panel.



Tubing Connections – Depressurization Test

Typical Set-Up of a Three Fan Minneapolis Blower Door System For an Automated Depressurization Test Using the TECLOG3 Software

Left Side Gauge:

- **Channel A** measures the building envelope pressure.
- **Channel B** measures flow from bottom fan.
- Commercial fan control cable plugged into the fan control jack.
- DB9/CAT5 adapter plugged into RS-232 port.

Right Side Gauge:

- **Channel A** measures flow from middle fan.
- **Channel B** measures flow from top fan.
- DB9/CAT5 adapter plugged into RS-232 port.



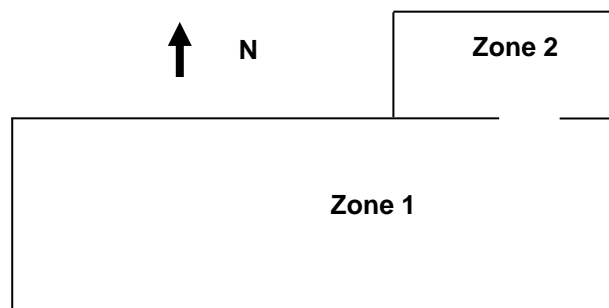
- Three fan speed controllers on one mounting board clamped to the lower cross bar.
- 3 plugs from commercial fan control cable inserted into fan control jacks.
- Each fan speed controller is plugged into a separate

- CAT5 Splitter Kit being used to combine CAT5 cables from the two gauges into a single CAT5 cable run.

4.10 Example Multi-Fan Airtightness Test with TECLOG3

Setting up and Conducting a Test

This paper documents how TECLOG3 was used to conduct a multi-fan blower door airtightness test on a commercial building using the building envelope test protocol developed by the U.S. Army Corps of Engineers (Ver. 3). The building tested consists of one large (Zone 1 - offices) and one small (Zone 2 - warehouse) connected spaces. The two spaces are separated by a sheetrock wall which includes double doors allowing access between the office and warehouse spaces. The entire structure has an airtightness level that required 4 blower door fans to induce a change in building envelope pressure of approximately 75 Pascals.



Example Building

TECLOG3 is The Energy Conservatory's (TEC) data logging program. TECLOG3 is designed to work with up to 16 DG-700 digital pressure gauges to monitor and store data from differential pressure channels, and to provide computerized control of multiple Minneapolis blower door fans. The program provides easy control of data acquisition parameters and includes a feature to calculate multi-fan airtightness test results. TECLOG3 continuously records pressure and fan flow data during an entire airtightness test sequence, from beginning to end. The user selects time periods on the graph that will be used in the final airtightness test results.

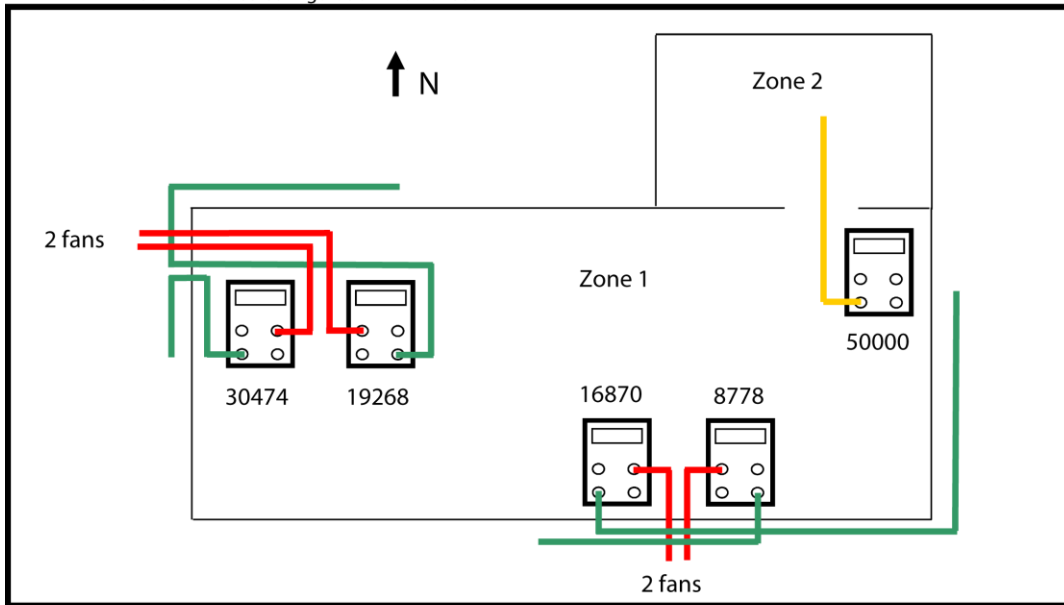
Step 1: Document the Floor Plan, and the Locations of Blower Door Fans and Pressure Measurements.

For complicated buildings and especially when using TECLOG3 for the first time, it is helpful to fill in the TECLOG3 configuration worksheet before entering the configuration settings into the program. A blank copy of this worksheet is found under the TECLOG3 help menu.

The top of the configuration worksheet contains space for a simple building floor plan. It is always helpful to mark down the approximate locations of fans and pressure gauges, as well as the tubing connections and outdoor terminations. For this test, we used a total of 4 blower door fans and 5 DG-700 gauges (10 total pressure channels). We installed two 2-fan blower door systems in exterior doors in the office space. The fans were initially set up to depressurize the building. We also measured the building envelope pressure with reference to (WRT) outside on all 4 sides of the building. TECLOG3 allows us to average the 4 building envelope pressure measurements into a single pressure reading. We have found that this technique greatly reduces envelope pressure fluctuations from wind. Finally, we measured the differential pressure between the office and the warehouse to check for pressure uniformity during the test. **Note:** For this test all 5 gauges were communicating wirelessly with TECLOG3 using TEC WiFi Links. The bottom portion of the configuration worksheet is used to record the serial numbers of the DG-700 gauges being used, to document what each pressure channel is being used to measure (i.e. channel label), and to provide a label for each gauge (i.e. gauge label). In this test, a total of 9 pressure channels were used (4 for fan flows, 4 for building envelope pressure WRT outside, and 1 for the pressure uniformity between the two building zones). One of the DG-700 pressure channels was left unused.

Completed Configuration Worksheet

TECLOG3 Device Configuration Worksheet



Serial <u>16870</u> Label <u>South 1</u>	Serial <u> </u> Label <u> </u>
Chan A <u>East - Env</u> Chan B <u>Fan 1 - South</u>	Chan A <u> </u> Chan B <u> </u>

Serial <u>8778</u> Label <u>South 2</u>	Serial <u> </u> Label <u> </u>
Chan A <u>Fan 2 - South</u> Chan B <u>South - Env</u>	Chan A <u> </u> Chan B <u> </u>

Serial <u>30474</u> Label <u>West 1</u>	Serial <u> </u> Label <u> </u>
Chan A <u>West - Env</u> Chan B <u>Fan 1 - West</u>	Chan A <u> </u> Chan B <u> </u>

Serial <u>19268</u> Label <u>West 2</u>	Serial <u> </u> Label <u> </u>
Chan A <u>Fan 2 - West</u> Chan B <u>North - Env</u>	Chan A <u> </u> Chan B <u> </u>

Serial <u>50000</u> Label <u>Interior</u>	Serial <u> </u> Label <u> </u>
Chan A <u>Int Z1 to Z2</u> Chan B <u>unused</u>	Chan A <u> </u> Chan B <u> </u>

Step 2: Edit the TECLOG3 Configuration Settings.

Once the configuration worksheet is completed, we are ready to enter the configuration settings into TECLOG3. Choose **Settings** from the **Configuration** menu at the top of the TECLOG3 screen.

If this is the first time you have used TECLOG3 on this particular building, it is a good idea to click on **Restore Factory Settings (U.S.)**. This puts TECLOG3 into a known condition and provides a basis for the following discussion. The Factory Settings (U.S.) are shown in the screen below. **Note:** If you have tested this same building before and will be using the exact same equipment setup, you can load all of the configuration settings by loading a previously stored TECLOG3 data file, or by loading a previously saved TECLOG3 configuration file.

Configuration Settings (Saved when Storing Configuration File)

Acquisition

Sample Interval: 1.0 seconds
Pressure Autozero Interval: 1.00 minutes

Graph

Graph Memory during Recording: 18000 points
Auto Time Interval: 10.0 minutes
Auto-scroll Mode: 25% Scroll
☐ White Background
☒ Horizontal Grid
☐ Vertical Grid
Event Marker Color: ■ Period Of Record Color: ■
Baseline POR Length: 120 seconds Fan-On POR Length: 30 seconds

Advanced

Startup y-max value: 100.0
Startup y-min value: -100.0
☐ Automatic File Capture ☒ Dynamic Time Scrollbar
☐ Daily File Save
Skip this port during device search: None

Device Settings

Device Type	Serial #	Device Label	link
<input checked="" type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>
<input type="checkbox"/> select			<input checked="" type="checkbox"/>

Scan for Ports/Devices View and Edit Channel Settings Configure WiFi Settings

Airtightness Test Settings

Test Standard: ☒ ASTM E779 ☐ EN 13829 ☐ CGSB
☐ USACE Compliant ☒ Weighted Regression
Flow Units: ☒ CFM ☐ L/s ☐ m³/hr
Temperature Units: ☒ Degrees F ☐ Degrees C
Length Units: ☒ Feet, inches ☐ Meters, cm

☐ SAVE AS DEFAULT CONFIGURATION

Changes made to this screen will be applied to the already running program if you click OK. All of the configurable settings are on this screen. If you would like these settings to also be automatically applied next time you run Teclog click on SAVE AS DEFAULT CONFIGURATION before clicking OK.

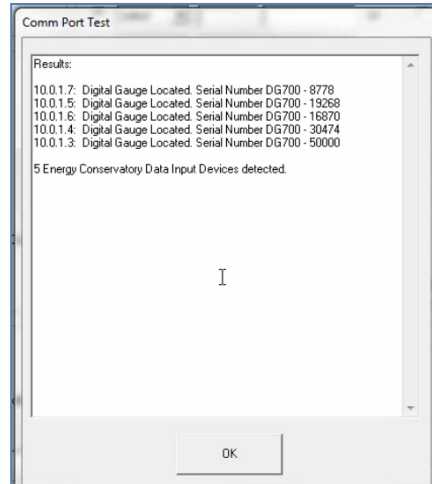
Restore Factory Settings (U.S.) Restore Factory Settings (Europe) OK Cancel

a. Device Settings.

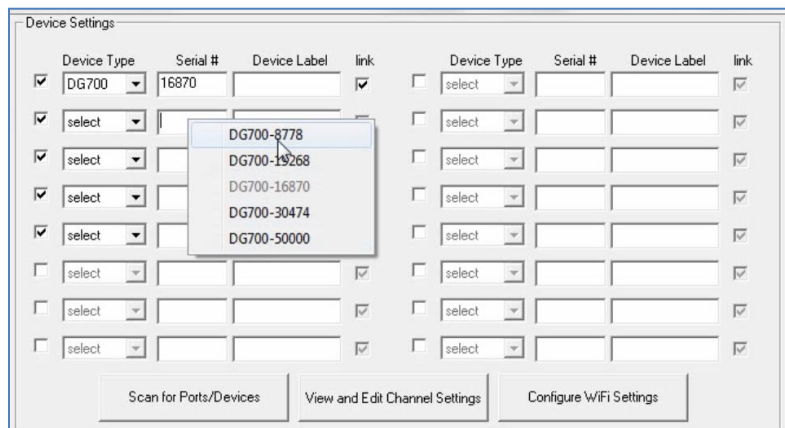
The first step is to enter the device settings for the DG-700 gauges that will be used during the test (5 in this example). Before entering the devices it is often useful to click on the **Scan for Ports/Devices** button. The scan feature conducts a complete scan of COM ports 1-255 plus wireless network connections, and provides a listing of all TEC devices and device serial numbers that are currently connected to the available ports and wireless networks. This confirms that TECLOG3 can establish a communication link with each device you are planning to use for the test. In addition, whenever a scan is undertaken, TECLOG3 stores a temporary table of serial number and device types that it finds, which makes completing the **Device Settings Table** easier.

Note: TECLOG3 can communicate with gauges through the computer's USB and serial ports, and wirelessly through a TEC WiFi Link (using the computer's wireless network adapter). All TEC devices must be properly connected to the computer and turned on in order to be detected during the scan.

Completed Scan for Ports/Devices



Each gauge (device) gets entered on a separate line in the **Device Settings Table** (the left check box must be checked in order to activate each line). Gauges can be entered manually by choosing the device type from the drop down list, and then entering the serial # and a device label of your choice. If you have performed a scan, you can simply double click in one of the activated serial number fields and a table will appear showing all of the gauges and serial numbers discovered during the most recent scan. Click on the gauge you wish to enter and the device type and serial number will be automatically entered into the **Device Settings Table**. Move down to the next activated row and repeat the process. Once all gauges have been entered, add an appropriate label for each gauge to document your test setup.



The **link** checkbox refers to the device's relationship to the **Master Fan Control Slider** and **Master Cruise Control** (see below). Selecting this option causes the DG-700's fan control port to be linked to both of the Master Fan Controls. This linked or unlinked status can be changed during recording. For each DG-700 fan control port that you want to be controlled by the Master Fan Controls, check **link**. For each DG-700 fan control port that you would like to be under independent control (for example to facilitate the balance of interior pressures) uncheck **link**. **Note:** In this example we linked all 5 gauges even though only two of the gauges were used to control fans - we did not use the fan control ports on the other 3 gauges.

b. View and Edit Channel Settings

Once you have entered the device settings, you need to configure the channel settings for each of the gauges. Click on **View and Edit Channel Settings**. The **Channel Settings Window** appears with tab(s) at the top of the window for each of the gauges entered. The figures below show the channel settings entered for each of the gauges used in the test.

Device Settings				Device Settings					
	Device Type	Serial #	Device Label	link		Device Type	Serial #	Device Label	link
<input checked="" type="checkbox"/>	DG700	16870	South 1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input checked="" type="checkbox"/>	DG700	8778	South 2	<input checked="" type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input checked="" type="checkbox"/>	DG700	30474	West 1	<input checked="" type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input checked="" type="checkbox"/>	DG700	19268	West 2	<input checked="" type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input checked="" type="checkbox"/>	DG700	50000	Interior	<input checked="" type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input type="checkbox"/>	select			<input type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input type="checkbox"/>	select			<input type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>
<input type="checkbox"/>	select			<input type="checkbox"/>	<input type="checkbox"/>	select			<input type="checkbox"/>

Channel Settings for Each Gauge

Channel Settings

16870 | 8778 | 30474 | 19268 | 50000

DG700-16870 South 1

	Color	Label	On	Channel Type	Fan SN	Cal Date	# Dec	Sensor	Plot Format	Plot Style
A	Green	East	<input checked="" type="checkbox"/>	Envelope Pressure			1	settings	Symbol and Line	style
B	Red	Fan 1 - S	<input checked="" type="checkbox"/>	Model 3 Fan Flow	3455	01/20/2013	0	settings	Symbol and Line	style

Cruise Settings...

Channel Settings

16870 | 8778 | 30474 | 19268 | 50000

DG700-8778 South 2

	Color	Label	On	Channel Type	Fan SN	Cal Date	# Dec	Sensor	Plot Format	Plot Style
A	Red	Fan 2 - S	<input checked="" type="checkbox"/>	Model 3 Fan Flow	3899	01/20/2013	0	settings	Symbol and Line	style
B	Green	South	<input checked="" type="checkbox"/>	Envelope Pressure			1	settings	Symbol and Line	style

Cruise Settings...

Channel Settings

16870 | 8778 | 30474 | 19268 | 50000

DG700-30474 West 1

	Color	Label	On	Channel Type	Fan SN	Cal Date	# Dec	Sensor	Plot Format	Plot Style
A	Green	West	<input checked="" type="checkbox"/>	Envelope Pressure			1	settings	Symbol and Line	style
B	Red	Fan 1 - W	<input checked="" type="checkbox"/>	Model 3 Fan Flow	7667	01/20/2013	0	settings	Symbol and Line	style

Cruise Settings...

Channel Settings

16870 | 8778 | 30474 | 19268 | 50000

DG700-19268 West 2

	Color	Label	On	Channel Type	Fan SN	Cal Date	# Dec	Sensor	Plot Format	Plot Style
A	Red	Fan 2 - W	<input checked="" type="checkbox"/>	Model 3 Fan Flow	3226	01/20/2013	0	settings	Symbol and Line	style
B	Green	North	<input checked="" type="checkbox"/>	Envelope Pressure			1	settings	Symbol and Line	style

Cruise Settings...

Channel Settings

16870 | 8778 | 30474 | 19268 | 50000

DG700-50000 Interior

	Color	Label	On	Channel Type	Fan SN	Cal Date	# Dec	Sensor	Plot Format	Plot Style
A	Yellow	Z1 to Z2	<input checked="" type="checkbox"/>	Interior Building Pres			1	settings	Symbol and Line	style
B	Brown	P2(Pa)	<input type="checkbox"/>	Pressure			1	settings	Symbol and Line	style

Cruise Settings...

Color Convention: TECLOG3 defaults to the following recommended color convention; - **Green** for channel type set to Envelope Pressure, **Red** for channel type set to Model 3, Model 4 or Duct Blaster Fan Flow, and **Yellow** for Interior Building Pressure. You may choose other colors by clicking on the color box.

Channel Label: Enter the channel label from the configuration worksheet.

On: Check the **On** box to activate the channel (**Note:** one channel has not been activated in this example because we only need 9 total channels).

Channel Type: Select the appropriate channel type from the pull down menu.

Pressure: This is the default channel type and is a generic differential pressure channel.

Interior Building Pressure: When conducting an airtightness test, this channel type is used to measure pressures between various constricted zones in the building to monitor if there are unacceptably large pressure differences occurring during the test.

Envelope Pressure: When conducting an airtightness test, you must choose at least one channel to be your building envelope pressure channel. If you choose more than one, then the average of these channels will be used. The use of multiple building envelope pressure channels can help mitigate the effects of wind on the airtightness test results.

Model 3 Fan Flow, Model 4 Fan Flow and Duct Blaster Fan Flow: If you are conducting an airtightness test you need to have at least one of the channels set to be a fan flow. When one of these channel types is selected, the corresponding channel will be split into 3 channels on the main TECLOG3 readouts and graph (displaying fan pressure, fan ring and fan flow). If you select a fan flow channel type, you also have the ability to enter and record a fan serial number and calibration date.

Dec: Select the number of decimal places you want displayed for each channel.

Sensor Settings: Do not change – leave factory defaults

.

Plot Format: Select a plot format, or leave factory defaults.

Plot Style: Select a plot style, or leave factory defaults.

When you have finished entering the channel settings, return to the main **Configuration** screen and click on **USACE Compliant** (in the **Airtightness Test Settings** section) because

we are performing the test according to the US Army Corp of Engineers test standard. You can keep the default **Baseline POR Length** and **Fan-On POR Length** to 120 and 30 seconds respectively as these values comply with the current USACE standard. Press **OK** to return to main TECLOG3 screen.

The screenshot shows the TECLOG3 configuration window. At the top, there are two color selection buttons: 'Event Marker Color' (blue) and 'Period Of Record Color' (green). Below these are two input fields: 'Baseline POR Length' set to 120 seconds and 'Fan-On POR Length' set to 30 seconds. To the right of these are three buttons: 'Scan for Ports/Devices', 'View and Edit Channel Settings', and 'Configure WiFi Settings'. The main area is divided into several sections. The 'Advanced' section on the left includes 'Startup y-max value' (100.0), 'Startup y-min value' (-100.0), checkboxes for 'Automatic File Capture' and 'Daily File Save', a checked checkbox for 'Dynamic Time Scrollbar', and a dropdown for 'Skip this port during device search' set to 'None'. The 'Airtightness Test Settings' section in the center has a 'Test Standard' dropdown with 'ASTM E779' selected, and radio buttons for 'EN 13829' and 'CGSB'. Below this is a checked checkbox for 'USACE Compliant' and an unchecked checkbox for 'Weighted Regression'. The 'Flow Units' section has radio buttons for 'CFM' (selected), 'L/s', and 'm^3/hr'. The 'Temperature Units' section has radio buttons for 'Degrees F' (selected) and 'Degrees C'. The 'Length Units' section has radio buttons for 'Feet, inches' (selected) and 'Meters, cm'. At the bottom right, there is a checkbox for 'SAVE AS DEFAULT CONFIGURATION'. At the bottom left, there is a note: 'Changes made to this screen will be applied to the already running program if you click OK. All of the configurable settings are on this screen. If you would like these settings to also be automatically applied next time you run Teclog click on SAVE AS DEFAULT CONFIGURATION before clicking OK.' At the bottom right are four buttons: 'Restore Factory Settings (U.S.)', 'Restore Factory Settings (Europe)', 'OK', and 'Cancel'.

Step 3. Connecting the DG-700's to Your Computer

When conducting an airtightness test with TECLOG3, you will operate the program from a single laptop computer located in a central location in the building. The DG-700 gauges used in the test are located throughout the building. The gauges associated with the blower door systems are generally attached to the adjustable aluminum frames, while the other gauges are located wherever they are needed to make the necessary pressure measurements. **Always locate the gauges to minimize tubing lengths. Tubing runs over 100 feet should be avoided because of numerous problems associated with using long lengths of tubing when conducting airtightness tests.**

The two most common ways to connect the DG-700 gauges to your laptop computer for a large building airtightness test include:

- Wirelessly connect multiple DG-700 gauges to your laptop using a wireless Router and TEC WiFi Link modules (***this is the method used in this example***).
- Run long lengths of CAT5 cable from the gauges to the laptop computer using sets of DB9 to CAT5 adapters and a DB9 to USB hub.

You can also use a combination of both wireless and wired connections.

a. Wirelessly Connecting the Gauges to the Computer.

The TEC WiFi Link adapter attaches to the DG-700 gauge and creates a wireless network that can be directly accessed by any computer or mobile device with WiFi capability. In addition, the WiFi Link can be configured to search for a specific wireless access point

(e.g. Router) and automatically connect to it. If multiple gauges with WiFi Links are configured to connect with the same Router, and the laptop computer is accessing that same Router, then TECLOG3 can communicate wirelessly with all the connected gauges.

Router and DG-700 Gauge with TEC WiFi Link



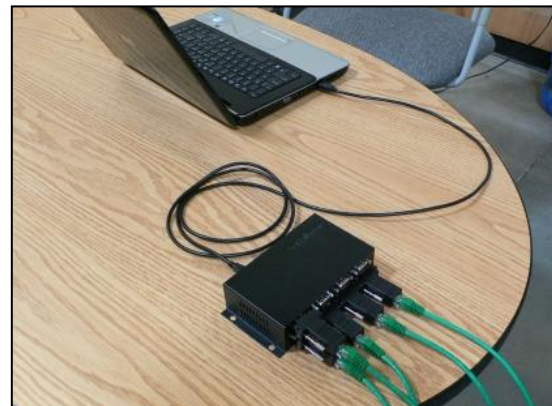
For this test we used an Apple Airport Express Router and 5 TEC WiFi Links, each attached to one of the DG-700 gauges. All 5 WiFi Links were configured to Router Mode and instructed to connect to the Airport Express Router (by entering the Router's SSID and Password into the Wi-Fi Link configuration). The WiFi Links were configured using the **Configure WiFi Settings** button in the **Device Settings** section of the Configuration screen (see pdf file *How to Configure Multiple TEC WiFi Links to Router Mode* in TECLOG3 Help menu).

Once the WiFi Links were configured properly, the laptop computer was set to access the wireless network being broadcast by the Airport Express Router. The Router was placed in a central building location so that it could easily communicate with both the laptop computer and the WiFi Links.

b. Using Wired CAT5 Connections Between the Gauges and the Computer.

In order to create wired connections between the 5 DG-700 gauges to the laptop computer, we would typically use the following hardware option.

- 1 Eight-Port DB-9 RS232 to USB Adapter Hub (available from TEC). This device provides 8 separate RS232 communication ports through a single



USB connection to the laptop. While the DG-700 gauge has both USB and RS232 communication ports, we choose to use the RS232 ports on the gauges because RS232 communication allows for much longer cable lengths (we have successfully used cables up to 4,000 feet in length). This is very useful in large buildings.

- Sets of DB9 to CAT5 Adapters (a set includes one male and one female adapter – available from TEC). These adapters allow the use of standard CAT5 cable between the gauge and the serial ports, rather than using a long serial cable. CAT5 cable is readily available in many lengths, and 2 lengths of cable can be easily connected together with a CAT5 coupler. The male DB9 to CAT5 adapter is plugged into the DG-700 gauge (pictured at right) while the female DB9 to CAT5 adapter is plugged into the hub (pictured below). CAT5 cable is then plugged into the top of the adapters.



Step 4. Method of Fan Control.

Two common fan control methods are described below, along with advantages and disadvantages of each. There are certainly other ways of performing the tests, but a thorough understanding of these two will help you decide how you should conduct your particular tests.

a. Computer Control Using Master Fan Slider and Master Cruise Control.

When using the computer control method, each blower door fan speed controller should be connected to a fan control port on a DG-700 gauge (using a fan control cable) so that all fans can be controlled using the **Master Fan Control Slider**, or the **Master Cruise Control**. It is possible to connect multiple (up to 3) fan speed controllers to a single DG-700 gauge fan control port. The **Master Cruise Control** feature controls the fans to get the average building envelope pressure to the targets which you specify. **This is the fan control method used in this test example.**

Advantages

Easier to get the building envelope pressure to precisely the targets you choose. You may be working with requirements to precisely hit the targets, in which case this may be important to you. (Technically speaking it is not very important precisely which pressures are achieved, as long as the range and even

distribution of pressures is adequate and there are enough points to give you the resolution you need.)

Very easy to stop and restart the fans due to an interruption such as someone needing to enter or leave the building, even when many fans are in use.

Disadvantages

More data is gathered with fans running at less than full speed. This reduces the precision of the flow measurements to some degree. This is really only a problem for positive pressure (pressurization) testing on windy days.

Running the fans at partial speed also leads to higher motor current draw.

For each of the 2-fan blower door systems installed for this test, we used the fan control port on a single DG-700 to control both fans. When using this setup, the two fans are controlled together and cannot be independently adjusted (this works well for large building testing). This setup is accomplished by plugging the single 3.5 mm plug on the commercial fan control cable into a DG-700 fan control port. The remaining plugs on the commercial fan control cable are plugged into communication ports on the side of the fan speed controllers (for a 2-fan system, one of the plugs is left unused). The order in which they are connected does not matter.



b. Manual Control of Fans

With this method, you start up each fan manually, one at a time. When many fans are being used (leakier buildings) you may be running each fan full speed right away. You essentially get one new pressure level for each fan you turn on. You may choose to adjust one fan speed to fine tune the building envelope pressure.

Advantages

Fans are typically running at or near full speed. This leads to lower current draw and somewhat better flow precision. Using this method, it is possible to run two fans off of a single 20 Amp circuit if you avoid running both of them at partial speed at the same time. However it is recommended to have each fan on its own circuit.

You do not need to connect fan speed control cables from the DG-700 gauges to the fan controllers.

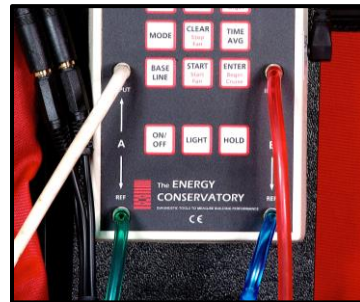
Disadvantages

It is harder (or tedious, at least) to hit specific pressure targets.

Interruptions may be harder to deal with.

Note: When Using a 2 or 3 Fan Blower Door System

For 2 and 3-fan blower door systems, we recommend that all ports on the DG-700 gauges have tubing connected at all times to protect from noisy readings caused by air currents. For example, the gauge pictured to the right is being used to measure one building envelope pressure (Channel A Reference Tap), and one fan flow (Channel B Input Tap). The white tubing connected on the Channel A Input tap is simply run to an inside location near the blower door system that is away from turbulent air flows. For a depressurization test, the blue tubing connected to the Channel B Reference Tap is also run to an inside location to protect from turbulent air flows. When the system is pressurizing the building, the blue tubing will be run to the outside to provide the appropriate reference pressure for the fans.



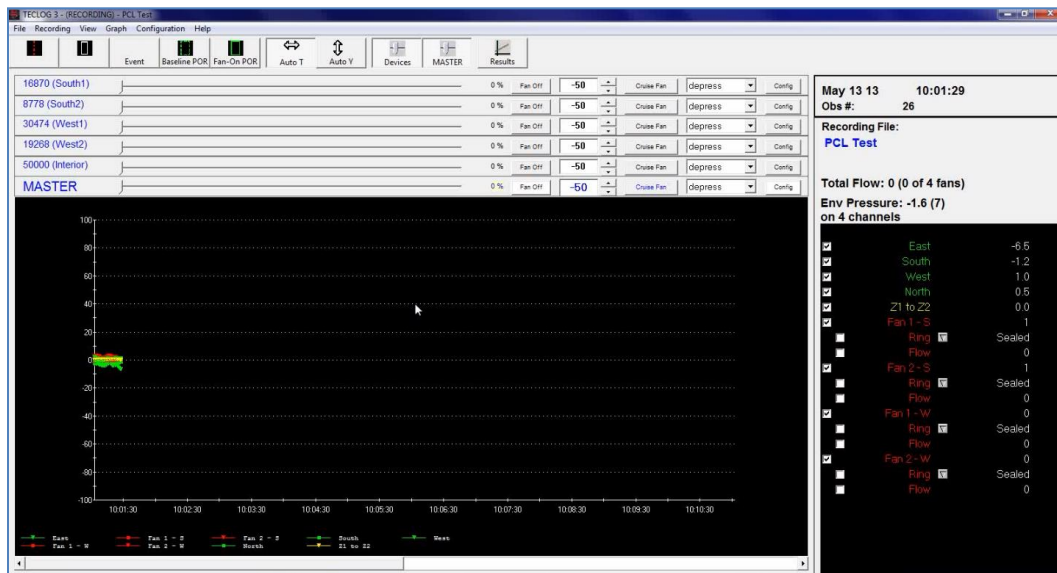
Step 5: Start Data Recording.

To start data recording, click on **Start Recording** from the main **Recording** menu item. At this point, TECLOG3 will search through all available COM ports and wireless networks on the computer to try and find the devices with the specific serial numbers entered into the **Device Settings Table**. If any of your specified devices are not found, recording will not begin and the **Configuration Settings** screen will appear. If any extra devices are found that you have not specified, then you will be warned and given the option to cancel.

Note: If you are having trouble creating a communication link with all of the devices, click on the **Scan for Ports/Devices** button in the **Configuration Settings** screen. The scan feature conducts a complete scan of COM ports and wireless network connections, and provides a listing of all connected TEC devices (the devices must be on to be detected.)

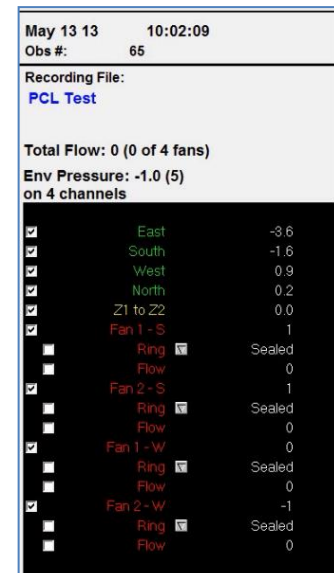
Once a communication link has been established with all the listed devices, you will be prompted to enter a filename for the data that will be recorded. After the filename is entered, the TECLOG3 data recording screen appears.

TECLOG3 Data Recording Screen



The most prominent feature of the data recording screen is the graph displaying the data as it is acquired. The rate at which data points (or observations) for each active channel are added to the graph is determined by the **Sample Interval** from the **Configuration Settings** screen (in this example we used the default setting of 1 second averages). The initial width of the x-axis (time) is determined by the **Auto Time Interval**, and the y-axis limits are determined by the **Startup y max** and **Startup y min** settings, all located in the **Configuration Settings** screen. A time scroll bar, located at the bottom of the screen, allows the user to scroll back and look at data that has scrolled off the screen. **Note:** After using the time scroll bar, click on the **Auto T** button to reset the x-axis scale and display data currently being acquired.

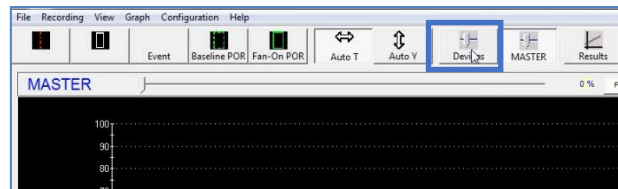
The right side of the data recording screen shows the current date and time (taken from your computer's internal clock), the observation number for the most recent sample interval, and the channel label and channel readouts (corresponding to the current observation number) for all active channels (in this case we have 9 active channels). Channels can be temporarily removed from the graph by clicking on the display button to the left of each channel label. Data for all active channels are stored to the data file even if the display button is turned off. For active channels where the Channel Type has been set to a fan flow, the fan configuration (Ring) and the fan flow are also displayed in addition to the fan pressure and the fans are automatically marked as "Sealed".



The channel readouts are automatically sorted by Channel Type, with all envelope pressures listed first, then interior building pressures, then fan flows and finally generic differential pressure channels.

a. Hiding Device Fan Controls

At the top of the graph are 6 **Fan Control Interfaces** (1 for each DG-700 plus 1 Master control). Because we will be using the **Master Fan Control** interface to control all fans,



we can hide the 5 individual fan controls by clicking on the **Devices** button in the Toolbar menu.

b. Periods of Record (POR)

TECLOG3 is continuously recording pressure and fan flow data for each active channel throughout the entire airtightness test sequence. Periods of Record (POR) are a critical part of conducting airtightness tests with TECLOG3 because they define the time intervals from the test graph which will actually be used in the airtightness calculations.

There are two ways to create a POR for an airtightness test:

1. The most efficient way to create an airtightness test POR is to use the **Baseline POR** and **Fan-On POR** graph control buttons. During **Data Recording** mode, the POR is started at the exact time that the POR button was clicked (assuming the Measurement Line is off). When using the graph control buttons, the length of time for the POR is pre-set in the **Configuration Settings** screen (default of 120 seconds for a Baseline POR and 30 seconds for a Fan-On POR).
2. A POR can also be manually created:
 - Activate the **Region Select Tool**,
 - Drag a rectangle containing the time interval to be included,
 - Right-clicking inside the selected time interval and choosing **Create Period of Record**

TECLOG3 can be used to create POR's for two different airtightness tests within the same TECLOG3 data file. When creating the POR's, you will indicate whether a particular POR is part of Test 1 or Test 2.

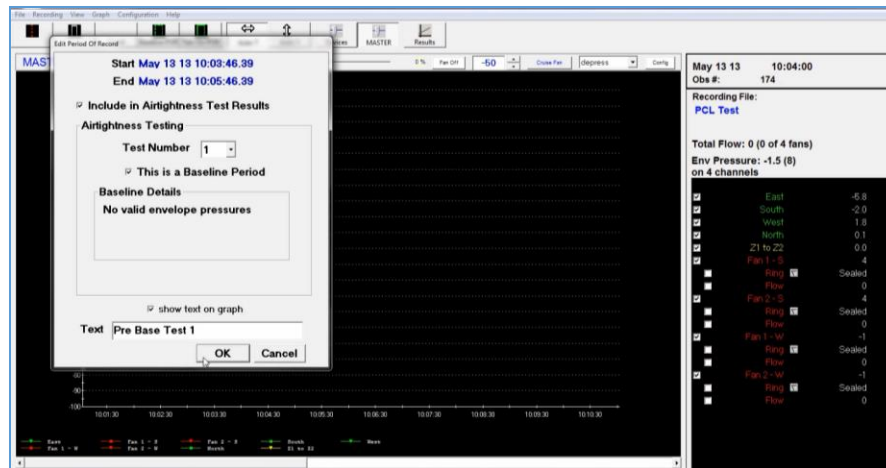
c. Creating the Pre-Test Baseline POR for Test 1 (Depressurization Test)

The first POR you will be creating is the pre-test baseline POR for Test 1. With all the fans off and sealed, TECLOG3 is displaying pre-test baseline data. Click on the **Baseline**



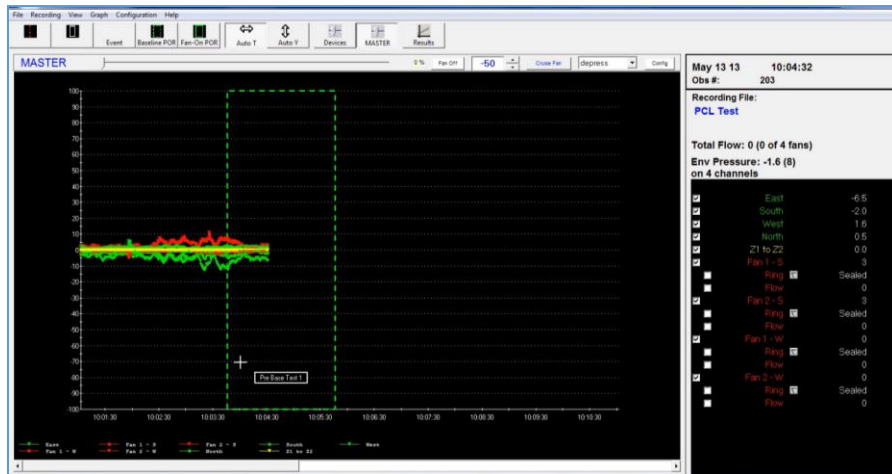
POR graph control button to create a baseline POR.

After pressing the button, an **Edit Period of Record** window appears. Because this POR



is a baseline period, the box labeled **This is a Baseline Period** is automatically checked. Also, because we will be using this POR in our airtightness test results, the box labeled **Include in Airtightness Test Results** is also checked. The text box at the bottom of the window can be filled out identifying the POR that is being created. Click **OK** to finish creating your pre-test baseline POR.

The pre-test baseline POR appears on the graph as a green dashed rectangular box with a default time width of 120 seconds. The POR starting time is the exact time that the **Baseline POR** button was pressed. Simply let TECLOG3 collect enough data to completely fill the width of the baseline POR. **Note:** A POR can be edited or deleted by first clicking within the POR region (this causes the POR box to turn from green to white), then right-clicking within the white box and selecting **Edit Period of Record**, or **Delete Period of Record**.

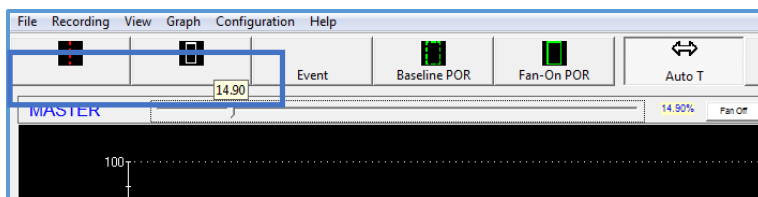
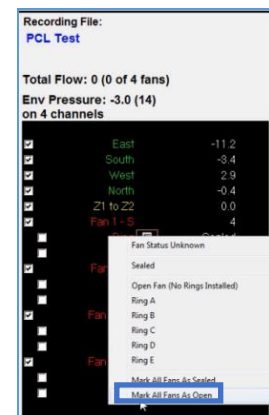


d. Preliminary “Fan-On” Test Using the Master Fan Control Slider.

Before beginning the “fan-on” portion of the airtightness test, it is always a good idea to slowly turn up the installed blower door fans to be sure that the fans and frames are installed properly, and that there is adequate pressure uniformity within the building (by observing the interior building pressure readings). In addition, this allows us to easily determine if we have installed enough fans to achieve the highest desired target building envelope pressure. Because we are using computer control for the fans in this example, the preliminary test is done using the **Master Fan Control** slider. **Note:** For this building we will conduct a depressurization test first, so be sure the fans are initially installed to blow air out of the building.

With the fans remaining sealed and the speed controllers in the off position, click on any of the fan ring pull-down menus and select **Mark All Fans as Open**. Initially after marking the fans as open, the fan channel readouts will be flashing red to indicate low fan pressure (this is normal because the fans have not been turned on). Directly above the graph, find the **Master Fan Control** interface. Manually drag the **Master Fan Control** slider to the right until the slider is calling for approximately 15% to 20% fan speed

At this point the fans are not spinning because all of the speed



control knobs are turned off, even though TECLOG3 is requesting the fans to run. Now go around and for each fan, turn the fan speed control knob to the “just-on” position, and once the blades begin to turn rapidly, unseal the fan (by removing the red fan cover and all flow rings). **Note:** Waiting to unseal the fans until the blades begin turning prevents the fans from spinning backwards due to baseline pressure differences between inside and outside the building.

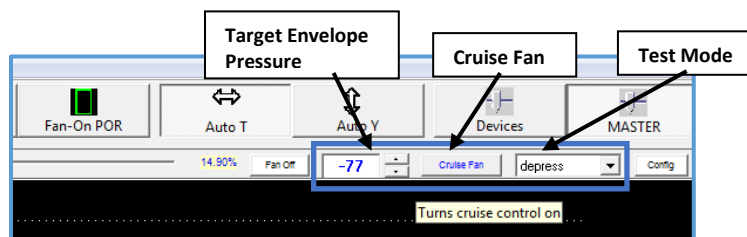
Do this for each fan – all fans should be running slowly once you have turned on all the controllers and unsealed the fans. **Note:** For a Model 3 fan, the “just-on” position means that the controller knob is turned clockwise from the off position only until you feel the click and no further. If the controller knob is turned up more than the “just on” position, TECLOG3 will not be able to control the fan speed.

Once all the fans are unsealed, you can manually drag the slider further to the right and confirm that you will be able to achieve the desired target building pressure, and that there is adequate pressure uniformity within the building. Once you are satisfied, return the slider to the 15% to 20% position (all fans should remain unsealed and running slowly).

e. “Fan-On” Depressurization Test Using the Master Fan Cruise.

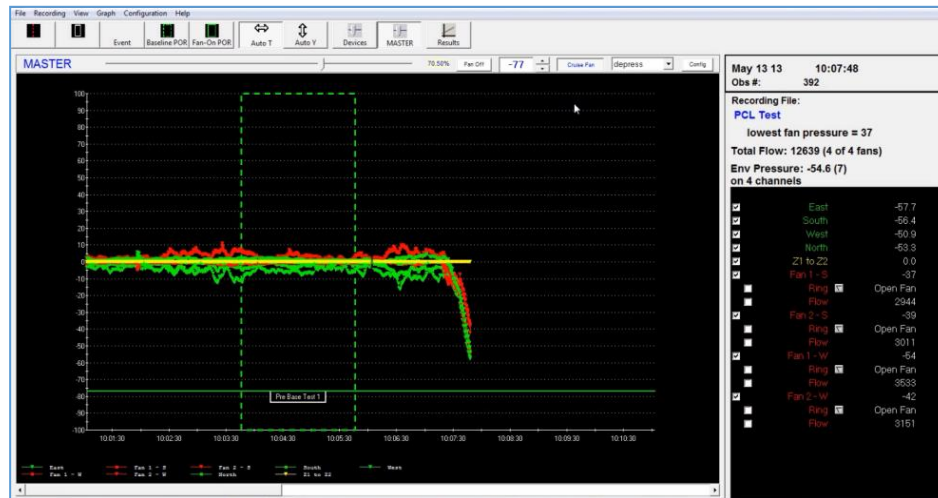
For the “fan-on” test, we will operate all fans in the open configuration, and then when necessary turn one of the fans off and seal it. Use the smallest number of fans that can reach the target building envelope pressure (in this example we needed 4 fans to hit our largest target induced pressure of approximately -75 Pa). In the target envelope pressure box input your first target envelope pressure (in this case we entered -77 Pa rather than -75 Pa in order to account for the initial baseline building pressure of about -2 Pa – we want to change the building envelope pressure by -75 Pa from its initial starting point).

Click on the **Cruise Fan** button and cruise control will begin. All the fans will now begin speeding up at the same time in order to depressurize the building to -77 Pa.



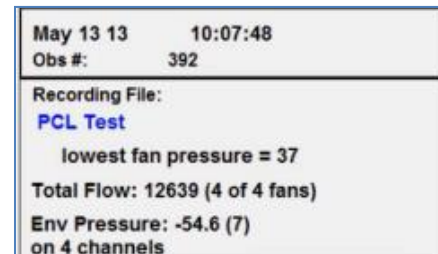
Once the fans turn on high enough to accurately measure flow, the red flashing in the fan channel readouts will go away. A solid green horizontal line represents the target

building envelope pressure. **Note:** You can quickly shut down all fans by either clicking on the **Fan Off** button on the **Master Fan Control** interface, or by simply pressing the **Esc** key on your keyboard.



A key display element is the box in the upper-right corner of the channel readouts. This is where you can see:

- The lowest fan pressure of all of the four unsealed fans (37 Pa). If any of the fan pressures are below the recommended minimum, this line will turn red.
- The total flow rate for the four fans (12,639 cfm)
- The average of all 4 four exterior building envelope pressures (-54.6 Pa). This is the building envelope pressure value that is used by the **Master Cruise Control** interface.
- The difference between the highest and lowest of the four building envelope pressures (7 Pa) – this gives you an idea of the uniformity in the 4 building envelope pressure readings. This test was conducted a fairly windy day causing a difference in building envelope pressures between the four sides of the building.



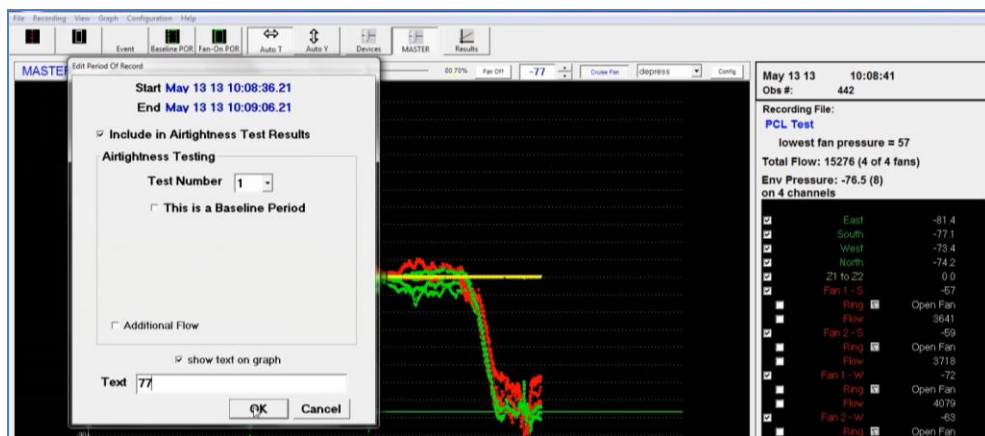
If you need to rescale the y-axis in order to show all of the data displayed on the graph, click on the **Auto Y** button. In addition, if you ever need to rescale the x-axis (time axis) to show the currently collected data, click on **Auto T**.

f. Creating Fan-On POR's for Test 1.

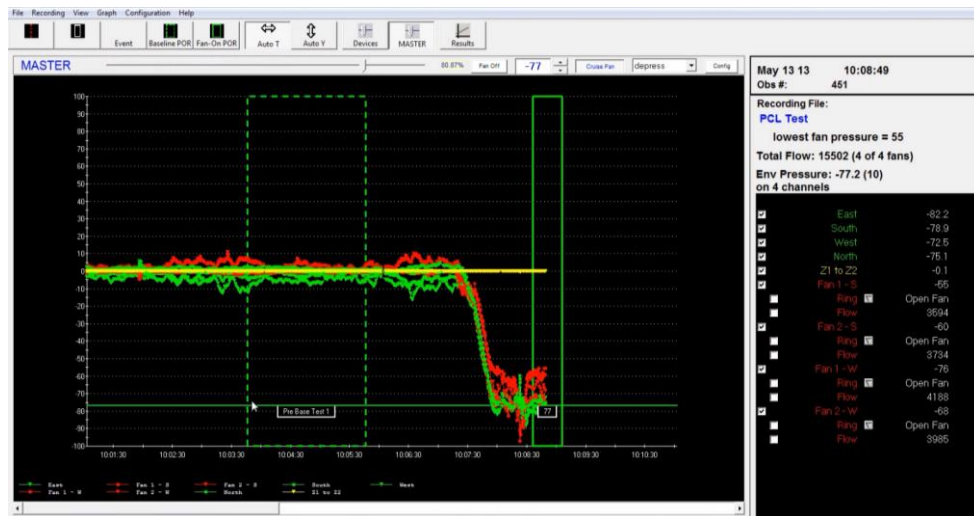
Once the average envelope pressure is close to the first target (-77 Pa), click on the **Fan-On POR** graph control button to create the first fan-on POR for Test 1.



After pressing the button, another **Edit Period of Record** window appears. Because this POR is a fan-on period, the box labeled **This is a Baseline Period** is automatically unchecked. Also, because we will be using this POR in our airtightness test results, the box labeled **Include in Airtightness Test Results** is checked. The text box at the bottom of the window can be filled out identifying the POR that is being created. Click **OK** to complete creating your first fan-on POR.



The fan-on POR appears on the graph as a green solid rectangular box with a default time width of 30 seconds. The POR starting time is the exact time that the **Fan-On POR** button was pressed. Simply let TECLOG3 collect enough data to completely fill the width of the fan-on POR



After the first fan-on POR is filled with data, we want to reduce the target envelope pressure by about 5 Pa so that we can create a second fan-on POR at a different building envelope pressure. For this depressurization test, we want to record a total of 12 different envelope pressures (the current U.S. Army Corp Test standard requires 12 target pressures). To easily change the target envelope pressure by 5 Pa, click on the up arrow just to the right of the target pressure field in the **Master Fan Control** interface. **Note:** If you want the target pressure to changes by something other than 5 Pa, then edit the target pressure field manually.

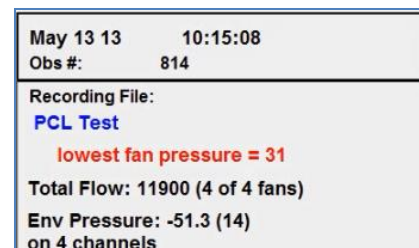
After you have changed the target envelope pressure, the fans will slowly ramp down to achieve the new target pressure. Once the average envelope pressure is close to the new target pressure, click on the **Fan-On POR** button again and create your second fan-on POR.

g. Continue Creating Fan-On POR's - What if you see a red low fan pressure warning?

Continue stepping down through your target pressures, and creating fan-on POR's. Keep an eye on your lowest fan pressure. This label will turn red and start flashing when any operating fan is below a minimum acceptable fan pressure level (it turns red and starts flashing when a fan pressure drops below 35 Pa).

If you see a red low fan pressure warning, follow these steps:

- Seal off one the blower door fans and physically turn off the speed controller for the sealed fan.



- In the channel readout for the sealed fan, mark that fan as **Sealed** using the ring pull-down menu.
- If desired, create an Event Marker that indicates you have turned off the fan.
- Be sure the target pressure field in the **Master Fan Control** interface is set to the next target envelope pressure you wish to achieve.

h. Creating the Post-Test Baseline POR for Test 1.

When you have completed all of your fan-on POR's for the depressurization test, turn off all the fans by clicking on the **Fan Off** button on the **Master Fan Control** interface. Physically seal off all of the blower door fans, and turn the fan speed controllers to the off position. In TECLOG3, use one of the channel ring pull-down menus to select **Mark All Fans as Sealed**.

Click on the **Baseline POR** button to create your post-test baseline POR. Let TECLOG3 completely fill the width of the post-test baseline POR.

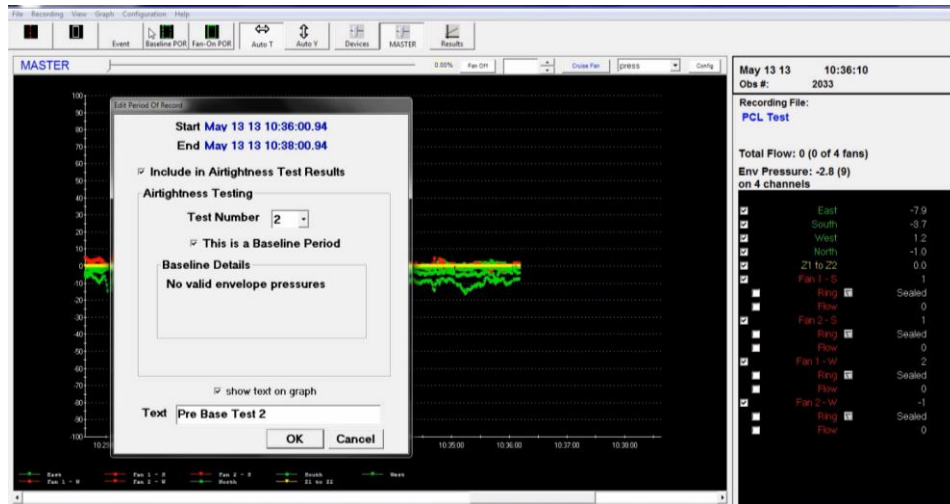
i. Prepare the Fans and Tubing for a Pressurization Test.

Once the depressurization test is completed, let TECLOG3 continue to run while you prepare the fans and tubing for the pressurization test. This will require turning the fans around in the nylon panels so that they are setup to blow air into the building rather than exhausting air from the building. Keep the fans sealed after turning them around. In addition, for all gauge channels being used to measure fan flow, you will need to connect the Channel B reference tap to the outside so that the fan flow channels are properly referenced to the outside space near where the fans are installed. **Note:** If you have an older Model 3 blower door fan with a fan direction switch, do not use the direction switch in lieu of turning the blower door fans around. The fan can only measure airflow in one direction – air must exhausting through the metal exhaust guard in order to measure airflow.

After the fans and tubing are prepared, return to TECLOG3 and change the **Mode** setting in the **Master Fan Control** interface from **depress** to **press**.

j. Creating the Pre-Test Baseline POR for Test 2 (Pressurization Test).

With the fans sealed, TECLOG3 is ready to record the baseline building envelope pressure. Click on the **Baseline POR** button to begin creating the pre-test baseline POR for Test 2.



TECLOG3 will automatically recognize that this is the second test for this file and will fill in the Test Number for this POR and all subsequent POR's with a "2".

k. Create Fan-On POR's for Test 2.

Edit the target envelope pressure field in the **Master Fan Control** interface for your first fan-on POR (approximately 75 Pa, adjusted for the building baseline pressure). Mark the fans as **Open** in TECLOG3 and drag the **Master Fan Control** slider to the right until the slider is calling for approximately 15% to 20% fan speed. Now go around and for each fan, turn the speed controller to the "just on" position and once the blades begin to spin rapidly, unseal the fan (by removing the red fan cover and all flow rings).

After all fans are running slowly and unsealed, click on the **Cruise Fan** button to begin the fan-on pressurization test. Create 12 fan-on POR's at 12 different envelope pressures just like the depressurization test.

l. Create a Post-Test Baseline POR for the Pressurization Test.

When you have completed all of your fan-On POR's for the pressurization test, turn off all the fans by clicking on the **Off** button on the Master Fan Control interface, and then manually turn off the speed controllers. Physically seal off all of the blower door fans. In TECLOG3, use one of the channel ring pull-down menus to select **Mark All Fans as Sealed**.

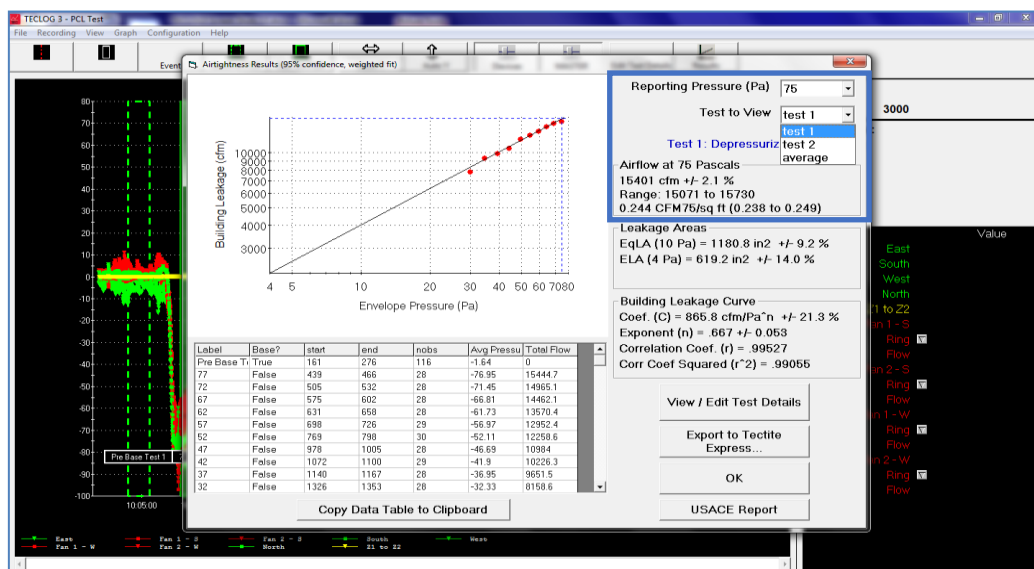
Click on the **Baseline POR** button to create your post-test baseline POR for Test 2. Let TECLOG3 completely fill the width of the post-test baseline POR.

m. Ending the Recording.

Once the testing is completed, it is good practice to view the results of the test (see next section below) to verify that the test results are satisfactory. After you have verified that the results are satisfactory, you can end the recording session using the **Recording....Stop Recording** menu item. TECLOG3 will ask: **Would you like to load the file you just created?** Answer **Yes** to load the complete data file. **Note:** Stored data files can also be loaded using the **File....Load Data File** menu item.

Step 6: Viewing the Results.

While the data file is displayed on the graph, you can view your airtightness test results by clicking on the **Results** button in the toolbar. **Note:** You can also click on the **Results** button during the middle of an airtightness test to see the partial test data.



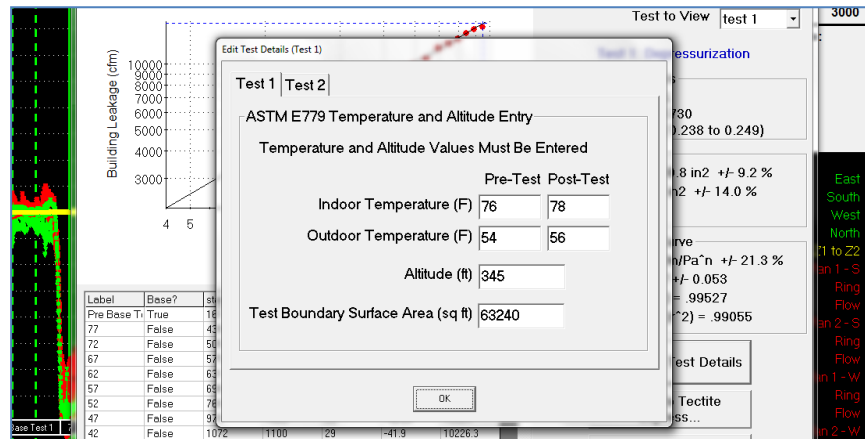
a. Airtightness Results Window.

There are several things to notice in the Airtightness Results window. First, in the **Test to View** field (upper right hand corner) you can choose to see the results of Test 1, Test 2 or the Average of both Test 1 and Test 2. Secondly, a pull-down menu in the upper right hand corner can be used to select the reporting building envelope pressure in Pa (75 Pa in this example). Third, the airflow is reported at the selected reporting pressure along with its 95% precision confidence interval, expressed as a +/- percentage (in this case 2.1) and also as low to high limits (15,071 to 15,730). Finally, if you have input a test boundary surface area in the **Edit Test Details** window (see below), TECLOG3 will report the airflow per square foot of surface area (permeability).

Below the airflow results are the fitted parameters, also with 95% confidence interval information and the correlation coefficient (r) and its square, commonly referred to as the R-Squared.

b. View/Editing Test Details

Test Details including inside and outside temperatures, building site altitude and test boundary surface area can be viewed and edited by clicking on the **View/Edit Test Details** button in the Airtightness Results window. The temperature and altitude data is



used to perform airflow density and viscosity corrections, while the test boundary surface area is used to calculate the measured envelope permeability (CFMXX/ft²).

c. Export Options.

There are two ways to export the summarized airtightness test data.

Copy Data Table to Clipboard will place on the Windows clipboard a copy of the selected results, with one row for each period of record plus a header row. This is in a format that can be easily pasted into a spreadsheet or other program for analysis or into an email.

Export to TECTITE Express will store the selected results in a file which can be loaded by TECTITE Express 4.0 or newer.

d. US Army Corp Report

A test report designed to meet the requirements of the US Army Corp of Engineers test protocol is available by clicking on the USACE Report button at the bottom of the Airtightness Results window.

Chapter 5 – Finding Air Leaks

People want to find and seal air leaks in buildings to solve problems. The most common problems caused by air leaks include:

- Excessive fuel use to heat and cool a building
- Comfort problems
- Condensation in the building envelope in both heating and cooling conditions
- Loss of indoor humidity control in hot, humid climates
- Icicles and ice dams in snow country

As buildings become more airtight the frequency of these problems goes down. However, buildings that meet the GSA or the Army Corps of Engineers airtightness specification may experience one or more of these problems if the leaks happen to be in the wrong place. For example, if there are large air leaks close to plumbing lines, pipes may freeze during cold weather. If there are air leaks close to chilled water lines, mold may grow on the surface of the insulation if warm, humid outdoor air is drawn across the surface of the insulation. Even relatively small air leaks into vented attics or the vent space in vented foam board/roof sheathing panel systems can result in ice dams.

Know where to look

The best way is to have spent 35 years doing building forensics in commercial and institutional buildings and to know where to look. If that's not you, get some geezer to tell you. From geezers we know that air leakage sites are where things come together:

- Roofs and walls
- Soffits and overhangs
- Bump outs and canopies
- One wing meets another part of the building
- Foundations and floors or walls
- Structural elements that pass through the thermal envelope
- The tops of coiling doors
- Elevator room vents
- Kitchen exhaust fans
- Walls, floors and ceilings that separate vented attic spaces or vented mechanical rooms from conditioned spaces
- Penetrations from plumbing, electrical and HVAC

Tools and Methods

Using blower doors to induce an indoor/outdoor pressure difference is a powerful way of finding air leaks. Here's a list of methods that are useful in finding air leaks:

- Use your eyes, ears and brain
- Use blower doors to make a pressure difference (10-20 Pascals is plenty) and:
 - Stand in doors ways to see where the most air is coming from
 - Use smoke pencils and theatrical fog to track air currents and find holes
 - Micromanometers to measure serial pressure drops (e.g. depressurize the corridors and measure under closed doors to see how much pressure drop is across the door)
 - Use tracer gas to track air flows (e.g. CO2 or microwave popcorn)
- Infrared imagers can be used with or without blower doors. It is very helpful to begin scanning before blowers are turned on and rescan suspect locations after they are turned on so that the changes that result from air leaks can be seen. You are not likely to find leakage on the exterior of a brick veneer building. You will normally want to scan from the inside on these type buildings.
- Acoustical methods can be used to find air leakage sites. Blower doors will not be useful with this method.

ASTM E1186 Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems. This standard identifies seven methods for finding air leaks:

- Combined building depressurization (or pressurization) and infrared scanning,
- Building depressurization (or pressurization) and smoke tracers,
- Building depressurization (or pressurization) and airflow measuring devices,
- Generated sound and sound detection,
- Tracer gas detection,
- Chamber depressurization (or pressurization) and smoke tracers, and
- Chamber depressurization and leak detection liquids.

Chapter 6 – Writing a Report

If the test is informal, there may only be a brief report of the results or no report other than verbal. For most paying projects a final report must be written. What is included depends on the needs of the customer and your own needs for documenting the test and results. The test standard being used most likely has specific minimum reporting requirements. These must be followed and inclusion of additional information should be considered.

If the test must be documented well enough that a knowledgeable third party can determine whether or not the test was conducted properly and whether the results were interpreted defensibly then a fair amount of information must be included. For example, a test being conducted to provide documentation that a building has or has not met a specified airtightness target must be well documented. In this case the report should include:

1. Testing company information
2. Reason for conducting the test
3. Test procedure used
 - a) Multipoint regression,
 - b) Single point repeated or,
 - c) Two point repeated
 - d) Test standard or protocol (e.g. RESNET, ASTM E779, ASTM E1827, ABAA, ACE)
4. Elevation above sea level
5. Building dimensions needed to calculate results (e.g. envelope surface area or volume)
6. Test Results
 - a) Metrics needed by customer plus
 - b) CFM50 or CFM75 and
 - c) CFM75/ft² envelope
 - d) Calculated uncertainty
7. Location of test enclosure boundaries.
 - a) As tested (plus as designed if information is available)
8. Status of:
 - a) Windows and exterior doors (open or closed position)
 - b) Mechanical System Related Penetrations (ie. louvers, grilles, rooftop and wall-mounted fans, air distribution ductwork that serves areas both inside and outside of the test enclosure).
 - i. Masked/unmasked
 - ii. Location of masking
 - c) P-traps (filled with water)
9. Status of HVAC equipment: off or running during test

10. Any deviation(s) in the test procedure from standard practice and the specific reason for the deviation(s)
11. Test equipment used
12. Test conditions
 - a) Inside and outside temperature
 - b) Wind conditions and precipitation
13. Measured test results
14. Conclusions
 - a) Test Purpose
 - b) Discussion

Appendix A – Definitions

Air Barrier System: combination of air barrier assemblies and air barrier components, connected by air barrier accessories that are designed to provide a continuous barrier to the movement of air through the building envelope.

Air Barrier System Envelope Test: building envelope airtightness test to determine air leakage through the building envelope excluding HVAC-related penetrations.

Airtightness: property of a building envelope which will inhibit air leakage, airtightness is determined by measuring the air flow rate required to maintain a specific induced test pressure.

Baseline pressure: The building envelope pressure with test fans off and sealed, recorded while the building is in the test condition. The terms bias, static pressure readings and zero-flow pressure difference are used interchangeably with the term baseline pressure in other documents/standards used in the industry.

Building Enclosure – see *Building Envelope*. These terms are used interchangeably.

Building Envelope - The exterior envelope consists of roofs and skylights; above grade walls, windows, curtain walls, and doors; and below grade walls and floors; and connecting flashings, air barrier and moisture control transition membranes, sealants and expansion joints that separate the interior environment from outdoors and adjoining unconditioned spaces.

Correlation Coefficient - The correlation coefficient is a measure of how well the collected blower door data fit onto the best-fit Building Leakage Curve.

Envelope pressure: Differential pressure between the interior of the building being tested and the outdoors, measured with the outdoors as the reference.

HVAC: Heating ventilating air conditioning systems.

Induced envelope pressure: The change in envelope pressure caused by operation of the test fans. Calculated as the difference between the envelope pressure with the test fan(s) on and the average baseline pressure. Induced envelope pressures are positive during pressurization tests and negative during depressurization tests.

Operational envelope test: building envelope airtightness test to determine air leakage through the building envelope including HVAC-related penetrations.

Single-zone: during a blower door test a space in which the pressure difference between any two places differs by no more than 10% of the inside to outside pressure difference. Not to be confused with the ASTM E779 definition in which the pressure differences may be no more than 5% by the same measure.

Appendix B – Activity Hazard Analysis sample

ACTIVITY HAZARD ANALYSIS			
Date Prepared:	9/25/2012	Overall Risk Assessment Code (RAC): L	
Client:	XYZ Construction		
Project Name:	Really Big Building		
Activity/Work Task:	New Facility Envelope Test		
Activity Location(s):	123 Main St. West Ouburn, NY 12345		
Prepared By:	Neil Downes		
Task Start Date:	9/26/2013		
Task Duration:	9/27/2013		
Task Supervisor:	Stan Still		
Reviewed By:	Les B. Safe		

Risk Assessment Code Matrix					
Severity	Frequency	Probability			
		High	Medium	Low	Very Low
Extremely High Risk	Extremely High	Red	Red	Red	Red
High Risk	High	Red	Orange	Orange	Orange
Medium Risk	Medium	Orange	Yellow	Yellow	Yellow
Low Risk	Low	Yellow	Green	Green	Green
Very Low Risk	Very Low	Green	Green	Green	Green

Job Steps	Hazards	Actions to Eliminate or Minimize Hazards	RAC
1. On-Site Arrival	<ul style="list-style-type: none"> - Extreme Weather - General Construction Safety Hazards 	<p>Stay hydrated. Drink plenty of water. Wear appropriate clothing for weather conditions.</p> <p>Mandatory Personal Safety Equipment: Hard Hat Safety Glasses Steel Toes Shoes or Boots High Visibility Safety Vest</p> <p>Get briefing from Safety Officer. Obtain emergency (fire, EMT, etc.) telephone numbers Go over AHA with team members Stay Alert Look up before entering/exiting doorways Obey Safety Signage/Tape Do not wear hearing protection unless the job dictates. Listening to music with earphones is prohibited.</p>	L
2. Equipment Delivery, Set-up, and Tear-down	<ul style="list-style-type: none"> - Heavy manual lifting/moving 	<p>Size up the load Plan ahead making sure of a clear path to carry the load. Bend knees when lifting Place feet close to the object and center over the load. Get a solid hand hold Lift straight up and smoothly letting the legs do the work, not the back. Do not twist or turn the body once the lift is made Set loads down properly, bending at the knees.</p>	M
		<p>Always push objects instead of pulling if possible. Keep the load as close to the body as possible. Split larger loads if possible. Get help if needed.</p>	
3. Building Preparation	<ul style="list-style-type: none"> - Falls/Trip Hazards - Fire - Ladders (portable, fixed) - Unfamiliar Equipment 	<p>Stay alert Obey Safety Signage and tapes. Do not enter until areas without flashlights Make sure shoes are tied.</p> <p>Locate fire extinguishers, alarms and exits.</p> <p>Read and follow ladder label markings. Avoid electrical hazards - always look for overhead lines before handling a ladder. Inspect ladder before use. If damaged remove from service and tag. Do not use a step ladder as a single ladder or in the partially closed position. Do not use the top step/rung of a ladder as a step unless it has been specifically designed for that purpose. Always maintain a three-point contact on the ladder. Use ladders only on stable, non-slippery surfaces. Secure ladder in place as necessary.</p> <p>Do not operate HVAC or other mechanical equipment that does not belong to you. If equipment needs to be turned off on or otherwise adjusted, inform appropriate contractor.</p>	M
4. Building Envelope Test	<ul style="list-style-type: none"> - Electrical Shock - Falling Equipment - Moving Fan Blades 	<p>Inspect electrical cords and fan controller before use. Use GCTI's on all electrical equipment.</p> <p>Ensure fans and blower door frames are secure before operating fan. Check for security before each test.</p> <p>Inspect fan guards. Do not use fan if guard is damaged or missing. Keep fingers out of the fan. Secure long hair in a manner which will prevent it from getting into the fan. Pick-up debris from around fan which may become airborne when fan is operating.</p>	M

Equipment	Inspection	Training
Blower Door	<ul style="list-style-type: none"> - Inspect all electrical cords and fan guards before each test. - Inspect blower door installation security before each test. 	- Qualified Person

Involved Personnel: Neil Downes, Stan Still

Notes