Building Air Leakage Test Protocol

Developed December 9, 2011

Updated January 12, 2019

Approved for public release; distribution is unlimited.

TABLE OF CONTENTS

1 Introduction and Applicability

On March 22, 2011 the City of Fort Collins adopted Ordinance No. 031, 2011 amending Chapter 5, Article II, Division 2 of the Code of the City of Fort Collins for the purpose of amending the 2009 International Energy Conservation Code (Ordinance). This protocol shall carry over to current code adoption. This ordinance requires (among other measures) that all new buildings, additions, and those undergoing major renovations shall have an *air leakage rate* that does not exceed 0.25 CFM75/sq ft of the total *building envelope* area when tested in accordance with the City of Fort Collins Air Leakage Test Protocol for Non-Residential Building Enclosures (Protocol).

This Protocol is applicable to those buildings subject to the requirements of the International **Building** Code, as adopted by the City of Fort Collins. This Protocol does not apply to buildings subject to the requirements of the International **Residential** Code, as adopted by the City of Fort Collins.

This Protocol is intended to provide a higher level of detail than the Ordinance and to ensure that air leakage tests are conducted uniformly and that test results are reported consistently with the Ordinance. This document and the accompanying Test Form in Appendix A (normative) contain both mandatory procedures and testing requirements.

Unavoidably, there is an even higher level of detail required to conduct these tests that is beyond the scope of this Protocol. For example, there are detailed and equipment-specific procedures to be followed for generating the airflows and measuring the airflows and pressures. This level of detail is left to the individual manufacturers of such equipment and, in some cases, to the expertise of the test agency.

Appendix D provides context to Ordinance requirements, referencing other national and international standards.

This document does not supersede the Ordinance; it is intended to clarify and not alter the requirements of the Ordinance. When questions arise, the reader should seek clarification from the City of Fort Collins Building Services Department.

2 Requirements for Building Air Tightness

The following sections outline the City of Fort Collins requirements for building *air tightness* and building *air leakage* testing:

2.1 Design Requirements:

The *building thermal envelope* shall be designed and constructed with a *continuous air barrier* that complies with the following requirements to control air leakage into, or out of, the conditioned space. Clearly identify the boundary limits and size of the surface area (floor, walls, and ceiling or roof) of the building air barrier, and of the zone(s) to be tested for building air tightness on the drawings. All *air barrier components* of each *building thermal envelope* assembly shall be clearly identified on construction documents and the joints, interconnections, and penetrations of the *air barrier components* shall be detailed and comply with the following:

1. The *air barrier* shall be continuous throughout the *building thermal envelope* (at the lowest floor, exterior walls, and ceiling or roof), with all joints and seams sealed, and with sealed connections between all transitions in planes and changes in materials and at all penetrations.

2. The *air barrier* component of each assembly shall be joined and sealed in a flexible manner to the *air barrier* component of adjacent assemblies, allowing for the relative movement of these assemblies and components.

3. The *air barrier* shall be capable of withstanding positive and negative combined design wind, fan, and stack pressures on the *air barrier* without damage or displacement, and shall transfer the load to the structure, and shall not displace adjacent materials under full load.

4. The air barrier shall be installed in accordance with the manufacturer's instructions and in such a manner as to achieve the performance requirements.

5. Where lighting fixtures with ventilation holes or other similar objects are to be installed in such a way as to penetrate the continuous air barrier, provisions shall be made to maintain the integrity of the continuous air barrier.

6. Compartmentalize spaces with combustion equipment that are under negative pressure and provide make-up air.

2.2 **Compliance:**

Compliance of the continuous air barrier for the opaque building thermal envelope shall be demonstrated by all of the following:

1. **Materials.** Using air barrier materials that have an air permeability not to exceed 0.004 cfm/ft2 under a pressure differential of 0.3 in. water (1.57 lb/ft2) (0.02 L/s.m2 under a pressure differential of 75 Pa) when tested in accordance with ASTM E2178;

2. **Assemblies.** Using assemblies of materials and components that have an average air leakage not to exceed 0.04 cfm/ft2 under a pressure differential of 0.3 in. water (1.57 lb/ft2) (0.02 L/s.m2 under a pressure differential of 75 Pa) when tested in accordance with ASTM E2357;

3. **Building.** Testing the completed *building* using *both* pressurization and depressurization and documenting that the air leakage rate of the *building thermal envelope* does not exceed 0.25 cfm/ft2 under a pressure differential of 0.3 in. water (1.57 lb/ft2) (0.02 L/s.m2 under a pressure differential of 75 Pa) in accordance with ASTM E779, ASTM E1827, or an equivalent approved method. Testing to be performed by an approved agency with sufficient airflow-producing equipment. Submit the Certification of Compliance (Appendix B) to the City of Fort Collins Building Services Department.

3 Protocol for Roles and Responsibilities, Documentation, Testing, and Reporting

3.1 Designer of Record (DOR)

The Designer of Record (DOR) shall:

1. Design the boundary limits of the air barrier to be tested to meet the applicable provisions of the Ordinance, excerpted above.

2. Define the test boundary and calculate the associated surface area to be used in the normalized air leakage calculation. The location and surface area of the test boundary shall be clearly defined in the project documents.

3. Design garages, maintenance bays, and loading docks which have overhead coiling doors that open to outdoors to be outside of the air barrier test boundary.

4. Design the following rooms to be outside of the air barrier test boundary: all heating, ventilating, and air-conditioning (HVAC) rooms with large louvers, electrical rooms, and laundry facilities with mechanical ventilation and dampers oriented to the outside of the building. Design the interior walls of these spaces to be part of the thermal and air barrier of the building to the same level of detail as other parts of the thermal and air barrier that face the outdoor elements.

5. Design multi-unit dwellings such that each dwelling is designed as a separate, individually testable zone.

6. Include Testing Agency Responsibilities as a section in the construction specifications as identified in 3.3 Items 1 through 10 below.

3.2 Contractor Responsibilities

1. Construct the air barrier system to meet the applicable provisions of the Ordinance, excerpted above.

2. Retain the services of a qualified Testing Agency to perform testing as described in Appendix C.

3. Coordinate with the Testing Agency to determine roles and responsibilities for preparing the building in the “closed” envelope condition, as further described in the Testing Agency Guide.

4. Provide responsible HVAC technician and electrician support for the Testing Agency in order to properly isolate the HVAC system from the test and provide appropriate power sources for test equipment.

5. Ensure that all windows and doors along the test envelope are kept closed. Schedule subcontractors to ensure that there is no entry and exit through doors in the test envelope during the test. Ensure that no subcontractors are working in the area of the test fans during their operation.

6. Perform corrective work as necessary to achieve the whole building air leakage rate specified in the Ordinance.

3.3 Testing Agency Responsibilities

1. Test the completed building air barrier system and demonstrate that the air leakage rate of the building envelope does not exceed 0.25CFM/sq ft at a pressure differential of 0.3 in. wg (75 Pa) in accordance with ASTM E 779 or ASTM E 1827 and with additional direction provided in the Testing Agency Guide and Appendix A herein.

2. Provide direction to the General Contractor (or their designate), or self-perform, preparation of the building as follows in order to isolate "intentional" holes in the test boundary:

   - Disable the HVAC system and exhaust fans.
   - Mask, seal, or close dampers to outside air and makeup air intakes.
   - Mask, seal, or close dampers to ventilation and exhaust outlets.
   - Close and lock all windows and doors on the limits of the test boundary.
   - Fill all plumbing traps with water.
   - For suspended ceiling plenums, remove one tile for every 500 sq ft of ceiling area.
   - Disable vented and non-sealed combustion equipment or place in the "pilot" position.
   - Prop open all interior doors within the test boundary.
   - Open windows or doors of interior spaces that are beyond, but adjacent to, the test boundary to introduce ambient conditions to non-exterior walls on the test boundary.

3. Record the exact building preparation and equipment set up conditions. Include photo documentation of representative setup conditions, including fan, pressure gauge, and pressure monitoring station type and location, to be included in the final report.

4. Test the whole building as a single space (single zone), unless one of the conditions noted below exists and prevents single-zone testing:

   A. The test zones identified in design are separate and compartmentalized. In this case, each zone must be tested with each subject to the criteria included in the Ordinance.

   B. The building consists of multi-unit apartments, separated and not joined by a common corridor or other common space. In this case, refer to the *City of Fort Collins Building Code Protocol for New Multifamily Building Air Tightness Testing*.

   C. The building requires test airflow in excess of 125,000 CFM at 75-Pascals (Pa) and cannot be tested as a single zone. In this case, accomplish testing by one of the following means (reference the Testing Agency Guide noted in the table of contents for further discussion):

      i. Separate the building into multiple temporary test zones using boundary pressure neutralization.

      ii. Erect temporary walls to create multiple test zones.

      iii. Use the installed building HVAC system to induce the test pressure.

   D. The building is five (5) stories or taller and the floor-to-floor pressure differential requirements of 3.3.9 cannot be satisfied. In this case, floor-by-floor testing may be necessary.

5. The building HVAC system may be used for testing, in lieu of portable equipment, if the building requires 125,000 CFM or more to induce an envelope pressure of 75-Pa. Test in accordance with CAN/CGSB-149.15. (Note that the preferred testing method is with portable equipment, which has been shown to be more accurate than testing with the HVAC system.) The following requirements apply if the HVAC system is used:

   A. There must be sufficient outside air supplied through installed air handlers to induce a pressure of 75-Pa.

   B. Airflow measurement devices shall be documented to measure air flows within 5-percent of actual airflows.

C. Pressure gauges must be digital with a resolution of 0.1-Pa and accurate to within +/- 1-percent of reading or +/- 0.25-Pa, whichever is greater, and must have means of adjustable time averaging to compensate for wind.

6. Accomplish tests using BOTH pressurization and depressurization. If an airflow in excess of 125,000 CFM @ 75-Pa is required to perform the test, one or the other can be used to accommodate the type of pressure inducing equipment utilized.

7. Record measured flow rates required to establish a minimum of 12 positive and 12 negative induced envelope pressures spanning at least a 25-Pa range. Induced envelope pressure test points shall be averaged over at least 20 seconds and shall be no lower than 75-Pa. If the 75-Pa pressure (induced) differential cannot be achieved and the maximum allowable flow (in CFM) is exceeded, than the building is insufficiently air tight to pass the test. If the 75-Pa pressure (induced) differential cannot be achieved and the maximum allowable flow (in CFM) is NOT exceeded, then the testing agency did not provide sufficient equipment to induce the required pressure.

8. Verify that pressures in the extremities of the envelope and between the floors do not differ from one another by more than 10-percent of the average induced envelope pressure.

9. Record baseline pressures prior to and immediately after each test (pressurization and depressurization). Baseline pressure points shall be taken across the envelope where each point is an average taken over at least 120 seconds. The initial baseline pressure point must not exceed 30-percent of the minimum induced envelope pressure test point used in the analysis. (Reference Part 4 for further guidance.)

10. Divide the average measured air leakage flow rate in both directions (positive and negative) in CFM @ 0.3 in. wg (L/s @ 75 Pa) by the surface area of the envelope enclosed by the continuous air barrier of the building, including roof or ceiling, walls, and floor to produce the air leakage rate in CFM/sq ft @ 0.3 in. wg (L/s.m2 @ 75 Pa).

11. Report the equivalent leakage area @ 75-Pa (EqLA75) as identified in the referenced ASTM Standards.

12. Report the correlation coefficient (r2) and 95-percent Confidence Intervals (95%CI) to determine the accuracy of the data collected and the quality of the relationship between flow and pressure that was established during the test. Calculate the 95-percent CI in strict accordance with the methodology contained in ASTM E 779 and the r2 from log-linear regression analysis of collected and plotted data. For the collected data to be statistically significant, the 95-percent CI must not exceed 0.02

for mean values of 0.25 or less, which equates to approximately 8-percent. The r2 value must be above 0.98 for the data to be statistically significant.

13. Perform the test only when it is verified that the continuous air barrier is in place and installed without failures in accordance with installation instructions. Coordinate the testing schedule with the General Contractor to coordinate testing with air barrier, cladding, and fenestration installation.

14. Use test fan measurement equipment calibrated at least every four (4) years in compliance with ASTM E1258-88. Calibration certificates must show the deviations from the calibration equations that must not exceed ± 5-percent of the flow reading for a range of airflows and backpressures (the pressure across the fan). For each test fan flow range configuration used in a test, the calibrations shall include the minimum and maximum airflows allowed by the manufacturer for that range plus at least one intermediate flow. For each flow rate, calibrations shall include data at backpressures within +/- 10-percent of 25, 50, and 75-Pa. Digital pressure gauges and test fans may be calibrated separately and used interchangeably as long as they meet the requirements of this section.

15. Use pressure gauges that are digital with a resolution of 0.1-Pa and accurate to within ±1-percent of reading or ±0.25-Pa, whichever is greater, and have a means of adjustable time averaging to compensate for wind. Pressure gauges shall have their calibration checked and accuracy verified minimum every two (2) years (or sooner, based on the gauge manufacturer's recommendations) against a National Institute of Standards and Technology (NIST) traceable standard over at least 16 pressures from at least +250 to -250-Pa or to the greatest pressure used during a test.

16. If the building test fails, identify air leakage paths in accordance with ASTM E1186-17 by infrared thermography scanning using an infrared camera with a resolution of 0.1oC or better, by smoke tracer (neutral buoyancy smoke or theatrical smoke) or by other listed methods.

17. Submit written test results, meeting the reporting requirements of ASTM E 779, including all calculated values, to the building official for approval. A computer-generated test report containing all of the information in the air leakage test form in Appendix A is permitted, given that calculations used in the program are in accordance with equations herein and in referenced Standards.

Test fans are generally placed in doors of the test envelope. Other openings in the test envelope may be used. The testing agency must have access to these locations, be able to open them, and be allowed to remove closure hardware that interferes with test equipment set-up.

The *air leakage* test to determine final compliance with the *air tightness* requirement shall be conducted when all components of the *air barrier assembly* have been installed and inspected, and have passed any intermediate testing procedures as detailed in the construction drawings and specifications. The test may be conducted before finishes that are not part of the *air barrier assembly* have been installed. For example, if suspended ceiling tiles, interior gypsum boards, or cladding systems are not part of the air barrier assembly, the test may be conducted before they are installed.

4 Testing Agency Guide

The following sections along with the Air Leakage Test Form in Appendix A define this test Protocol. This test Protocol was developed by the City of Fort Collins with assistance from the private industry using ASTM E779-10 as a basis. In cases where this document differs from ASTM E779-10, this document shall be followed.

4.1 Pre-Test

Test Equipment Airflow Capacity

The minimum *induced pressure* for a valid test is 75-Pa. In planning for a test, the test agency must determine how much test airflow capacity they will need on-site and supply that amount for the test. For whole-building testing in single-zone buildings, and in the absence of any other information, plan for 0.30 CFM/sq ft of flow against a pressure of 75-Pa. Since the true minimum test pressure is only 75-Pa, this allows a comfortable margin to account for *baseline pressures*, reduced on-site voltages, or other effects which could prevent the theoretical *induced pressure* from being attained. For example, if the building had 100,000 sq ft of envelope area, then it would theoretically require 100,000 x 0.25 = 25,000 CFM75 to induce a pressure of 75-Pa. If the test agency brings equipment capable of 30,000 CFM75, they should very easily be able to reach 75-Pa if the building meets the specification; if 0.25 CFM/sq ft is applied to the building and 75-Pa cannot be achieved, the building fails. There are other important considerations, some of which are listed below.

Recirculating Air Handlers

In some cases, recirculating air handlers may also need to be turned off. The building contractor must provide a responsible HVAC technician with the authority to place the HVAC system in the correct mode for the pressure test. The testing agency must have unhindered access to mechanical rooms, air handlers, exhaust fans, and outdoor air and exhaust dampers.

Building Preparation Inspection

A pre-test visual inspection must be performed to determine whether there are any factors that would prevent the test from being completed. For example, all door hardware must be installed and properly adjusted such that the building can be pressurized without opening doors.

Power Considerations

For certain test equipment, due to power quality considerations such as long extension cords, the *test fans* might not deliver their full rated capacity when used on-site. Consult the fan manufacturer for further information. Portable fans manufactured for the purpose of pressure testing buildings often require significant electrical power (e.g., 20 amps) and can trip circuit breakers. Coordinate with the building contractor and their electrical subcontractor to have circuit breakers reset as necessary.

Bottlenecks or Zones without Interior Access

If a building is not well connected internally (relative to its leakage rate) fans may need to be separated from one another, amongst two or more locations in order to achieve pressure uniformity. This may increase the number of fans required for the test as opposed to increasing the total fan capacity. For example, two large areas connected by a narrow corridor may require fans to be located in each of the two large areas, as opposed to in just one area.

4.2 Special Considerations

Interior Pressure Uniformity

Pressure differences within the test zone shall be monitored to confirm that it is uniform within 10-percent of the average induced envelope pressure. *Test fans* must be installed to satisfy this requirement. This may require *test fans* to be widely separated from one another. For example, a building may have a “bottleneck” that would prevent uniform (within 10% of the average) pressure difference within the test zone. As a result, a test that may have been accomplished with all test equipment in one area would require that the equipment be separated to accommodate the “bottleneck.”

Whole Building Testing

When performing a *single zone* test in a building that is not completely open inside, the interior zones in the building need not be interconnected by large openings if they can be tested to demonstrate compliance with the test pressure uniformity requirements in section 3.3.9 and 4.3. For example, a room with an exterior door, but no doors leading to the interior of the building, may be designed to be within the thermal and air boundary if there are enough leaks into it from other building zones. A pressure hose/sensor must measure the pressure difference between this area and the rest of the building to ensure equal pressure between rooms. In this case, the room is allowed to be part of the *single zone* test. As another example, such a zone can be part of the *single zone* test if test-fans can be installed between that zone and *outdoors* and controlled such that the pressure uniformity criterion is met for the building as a whole. In this case all fan airflow rates must be included in the total airflow.

Individual Room or Dwelling Testing

When it is not possible to test a whole building as a *single zone*, the multiple zone tests must include all the surfaces which make up the entire *building envelope*. For example, in a building where doorways of the apartments/offices/rooms/common spaces do not lead to common spaces such as hallways, it would be impractical to simultaneously test all spaces together as a *single zone*, and each apartment/office/rooms/common spaces must be tested individually.

In this case of individual room testing, walls between adjacent rooms are to be treated as part of the envelope in spite of the fact that leakage of the adjacent walls would be to another conditioned space and could therefore be ignored. Common walls will be treated as part of the *test boundary* for the zone and each zone must pass the normalized leakage test criteria, with the following exception. When testing an individual room or dwelling, all adjacent spaces must be open to the *outdoors*.

Exception: When conducting individual room testing in multi-unit apartments subject to this Protocol, at least 20-percent of the apartments must be tested, including all corner rooms, and including at least one of each style of apartment.

Testing of Spaces within Zones That Do Not Require Testing

Buildings may include spaces that require testing which are partially or wholly located within unconditioned zones that do not require testing. For example, office and break room facilities located within an unconditioned maintenance facility require air barrier testing, but the maintenance facility envelope does not. In such cases the air barrier test boundary is the envelope of each conditioned space that requires testing. The spaces requiring testing may be adjacent or detached, have some exterior walls, or may be entirely within the unconditioned enclosure. Testing should be conducted with the unconditioned zone open to the outdoors. Each of the detached spaces may be tested separately; adjacent, but unconnected spaces will require separate test fans or temporary, intentional openings between the adjacent zones in order to maintain constant pressures during testing. Multiple spaces may be tested simultaneously provided that the building pressure in each space is consistent and that the leakage amount and envelope area is totaled from each of the tested spaces.

Larger Buildings

Some larger buildings (typically those requiring a test airflow in excess of 125,000 CFM75 – cubic feet per minute at 75 Pascals) may require special test techniques not covered in this document primarily because of test equipment limitations. One option is to separate the building into multiple temporary test zones using boundary pressure neutralization techniques. A second option is to erect temporary walls to create multiple test zones. A third option may be to use the building *HVAC* system to establish test pressures (see next paragraph). These three special techniques will require a higher level of experience and engineering to establish useful results. It is up to the DOR to establish conformance criteria and test procedures for these unique buildings with the help of the testing agency. In summary, the importance of *air tightness* testing must not be lost on buildings with envelopes requiring a test airflow in excess of 125,000 CFM75. Tests of these buildings should be performed, even if some adaptations to the standard test procedure are necessary.

Use of Building HVAC System for Testing

HVAC systems may be used to conduct the building *air tightness* tests. For *single zone* tests on very large buildings, (typically requiring a test airflow in excess of 125,000 CFM75) this technique may be the practical option. Currently, there is not an ASTM or ISO standard that adequately addresses this issue. Canada uses the CAN/CGSB-149.15 standard for very large buildings. In the hands of experienced personnel, reasonable results may be achieved, but note that accuracies have been reported to be no better than ± 20-percent when 75-Pa was achieved.

Floor-by-Floor Test Method for Tall Buildings

The floor-by-floor method is a testing option for buildings greater than five stories in height. It may be possible to isolate and test individual floors for buildings in excess of five stories, if the testing agency's equipment is not capable of achieving a uniform pressure within the building due to the geometry of the interior partitions and limited shaft and stairwell interconnections. However, the floor-by-floor method requires exceptional preparation and knowledge of airflow characteristics within chases, shafts, and wall cavities in addition to the difficulty of maintaining an identical or balanced pressure between the floors above and below. Refer to the ASHRAE study, 'Protocol for Field Testing of Tall Buildings to Determine Envelope Air Leakage Rate 935-RP (Bahnfleth 1998)' for additional information on the floor-by-floor method of testing. It is recommended that the whole building achieve a uniform pressure to avoid the uncertainty inherent in the floor-by-floor method.

Additions and Renovations

If it is practical to isolate the addition from the original building, an air tightness test shall be performed on the addition per this protocol. Where it is impractical to isolate the addition, the building air barrier shall be inspected for continuity and integrity at the following locations.

1) Roof-wall intersections
2) Fenestration flashing
3) Fenestration installation
4) Bottom of wall (wall-to-foundation connection)
5) Connection of dissimilar wall and roof assemblies
6) Isolation of interior rooms such as mechanical and paint rooms
7) Wall and roof penetrations

It will be necessary to define wall-assembly material serving as the air barrier in the existing building and ensure that there is a continuous plane of air tightness between it and the addition air barrier.

4.3 Performing the Test:

Complete the test sequence as outlined in the Air Leakage Test Form (Appendix A).

There are additional details to be observed which are specific to the test equipment used and beyond the scope of this document. The test agency is required to abide by the test equipment manufacturer's instructions to ensure proper application of test equipment.

Since this test is performed by pressurizing and depressurizing the *building envelope*, *baseline pressure* effects are minimized, yielding more accurate results. This is the required test method since it is not only more tolerant of test conditions, but it also gives a more accurate representation of the *building envelope* leakage under ambient conditions, where pressures can be either positive or negative in direction. *Baseline pressures* may be up to 30-percent of the lowest induced envelope pressure, allowing this method to be used in a wider range of weather conditions. For example, if the average measured *baseline pressure* is 10.5-Pa, then the lowest induced envelope pressure the testing agency must achieve is 35-Pa (30% of 35 Pa is 10.5 Pa). This ensures that the lower induced envelope pressures are not overly influenced by those factors affecting the baseline pressure, primarily wind.

The testing agency must achieve at least 75-Pa provided the building is sufficiently air tight to pass the *building envelope air leakage* requirements. The agency is encouraged to achieve the highest building pressure possible, but should not exceed 85-Pa.

Care shall be taken to install interior pressure difference measurement equipment to ensure that it is unaffected by velocity pressure created by the test equipment airflow. As an example of the uniformity criterion, for an induced envelope pressure of 75-Pa, the maximum difference between any two locations within the test zone must be 7.5-Pa or less. The number of indoor pressure difference measurements required to prove uniformity will depend on the presence of airflow bottlenecks that could create significant pressure drops (e.g., doorways and stairwells).

Several common conditions which will cause results to be much *higher* than they should be include:

- Intentional openings that have not been properly sealed or have opened during the test (i.e., pressure relief dampers, plumbing traps).
- Windows or exterior doors left open.
- HVAC equipment not properly disabled.
- If the gauge is set on a higher range than the fan, then the measured flows will be much higher than the actual flow.

Several common conditions that will cause test results to be much *lower* than they should be include:

- Interior pressure monitoring stations placed too close to direct airflow; condition typically produced by the *test fans*.
- Usually tests are conducted with the fan inlet fully open, allowing maximum airflow. For testing tighter *building envelopes* that require smaller test flows, the fan manufacturer provides a flow restriction device such as a plug or plastic ring that can be installed on the fan. When limiting the fan airflow, some systems require that the *digital gauge's* configuration be adjusted. If the gauge is incorrectly set on a lower range than the fan, then the measured flow will be much lower than the actual flow.
- Interior doors left closed.

4.4 Reporting of Results

The testing agency is required to report results including all calculated values, in accordance with ASTM E 779. The information below provides further guidance on the content of the report.

The data collected during the multi-point tests will be corrected for standard conditions (elevation, inside and outside temperatures) and used to determine the *air leakage* coefficient, *C*, and the pressure exponent, *n*, in accordance with the referenced Standards and this document:

$$CFM = C * \Delta P^n$$

The values *C* and *n* in the above equation are calculated using a linear regression of the natural log of the flow (in CFM) versus the natural log of the baseline-adjusted *building envelope* pressures (in Pa). The testing agency must take data at a minimum of 12 *building envelope* pressures for each test, but is not limited to the maximum number of *building envelope* pressures measured during the test. It is recommended to record data at additional *building envelope* pressures so in the analysis the "outliers" will not materially affect the calculation procedure. Outliers are pressure and flow data points that do not fit the linear regression well, and can be caused by wind gusts, changes in wind direction, door openings, etc. Data gathered while exterior doors are open shall not be included in the analysis.

Flow rates in CFM/sq ft @75-Pa (CFM75/sq ft) must be calculated for the linear regressions for both the pressurization and the depressurization data sets. The average of those two flow rates will be divided by the *building envelope* area in square feet provided by the DOR to determine the final CFM75/sq ft. This average value will be used as the basis for determination if the building meets or does not meet the requirement for maximum *building envelope air leakage* requirements in the Ordinance. The value is to be rounded to the nearest hundredth. For example, a value of 0.255 would be rounded to 0.26.

In addition to reporting the *normalized air leakage* in units of CFM75/sq ft, the testing agency is also required to report the squared correlation coefficient (r^2) and the 95-percent confidence intervals (95% CI) of both the pressurization and depressurization test to demonstrate the accuracy of the data collected and the quality of the relationship between flow and pressure that was established during the test. The 95-percent CI and r^2 must be calculated in strict accordance with the methodology contained in this document, and the data used in these calculations must correspond to the data used for the linear regressions.

In general, a narrower 95-percent CI to the mean value and higher r^2 value indicates a clear relationship for the building's *air leakage* characteristics was established. Regardless of the magnitude of the final result, the r^2 value must be above 0.98.

The testing results will be expressed in terms of the *equivalent leakage area* @ 75-Pa (EqLA75, see definition in Glossary). EqLA75 is the equivalent area, in square feet of a flat plate that leaks the same amount as the *building envelope* @ 75-Pa. This information helps those responsible for further sealing the envelope to know the approximate size of total leakage area they should be seeking. Air leaks can consist of many small cracks, or a few very large openings or a combination of both. It is not unusual for large buildings to have an EqLA75 of up to 100 sq ft. It is also common for air sealing efforts to be focused on the small cracks while large holes that are a major contributor to failing the test go unnoticed. Even if the building achieves the required *air tightness* requirement, a thorough diagnostic evaluation is recommended to help the construction team identify additional areas of leakage that could be sealed on the current building or similar future buildings.

The pressure exponent, *n*, will also provide some insight as to the validity of the test and relative tightness of the *building envelope*. Exponent values less than 0.50 or greater than 1.0 in theory indicate errors in the test, but in practice, tests outside the range of 0.45 to 0.80 would generally indicate an inaccurate test or calculation methodology. This range is dictated by basic fluid dynamics and the characteristics of developing airflow through leaks, an explanation of which is beyond the scope of this Protocol. Except for very rare circumstances, n values should not take on values less than 0.45 and not greater than 0.80. If the n value is outside of these boundaries, the test must be repeated.

The testing agency is required to produce the data used in the analysis and results in tabular and graphical form, including the curve fitted coefficients and correlation coefficient.

4.5 Locating Leakage Sites with Pressurization and Depressurization

If the building fails the air leakage test, it is important to determine the source of the leakage. It is also beneficial for the Owner / Architect / Contractor team to understand the locations and details that are susceptible to leakage. For these reasons, if the building fails the testing agency is required to perform a diagnostic evaluation in accordance with ASTM E1186-17. The testing agency can use additional methods to discover leaks.

The use of neutral buoyancy smoke, theatrical smoke, and infrared thermography are effective means to find leakage sites. When testing equipment pressurizes the *building envelope*, air leaks can be seen from *outdoors* (provided exterior walls have not been heated by radiation from the sun) using infrared thermography or large scale smoke generation. When testing equipment depressurizes the *building envelope*, air leaks can be observed from the inside using infrared thermography or smoke generation. When the building interior temperature is close to the outdoor temperature, then cooling or heating of the building by the HVAC system may be required to perform an effective infrared thermography scan.

In general, when locating leaks, the airflow equipment should be adjusted to establish a minimum pressurization of +25-Pa pressure differential to use smoke or infrared thermography while viewing the building from *outdoors*. A depressurization differential of -25-Pa should be used when using infrared or smoke from the interior. Additional guidance for the diagnostic evaluation should be in accordance with ASTM E1186-17.

5 Glossary and Acronyms

5.1 Glossary

Term	Definition
air barrier assembly	A combination of air barrier materials and building components that are designated and designed within the building envelope to act as a continuous barrier to the movement of air.
air barrier material	A building product designed and constructed to provide the primary resistance to airflow through the building envelope.
air barrier system	The combination of assemblies used in building construction to create a plane of air tightness throughout the building envelope and to control air leakage. Includes, at a minimum, opaque walls, fenestration, roof/ceiling, and floor/foundation.
air leakage	The movement/flow of air through the building envelope, which is driven by either or both positive (infiltration) or negative (exfiltration) pressure differences or test pressures across the building envelope. See also air tightness.
air leakage rate	The volume of air movement/unit time across the building envelope.
air tightness	Property of a building envelope which will inhibit air leakage, air tightness is determined by measuring the airflow rate required to maintain a specific induced test pressure. In this Protocol air tightness is measured and reported in units of CFM/sq ft of air leakage at a uniform test pressure of 75-Pa.
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.
boundary neutral pressurization	A process of separating a building into multiple temporary test zones. A non-tested space adjacent to a tested space is pressurized / depressurized along with the tested space to prevent space-to-space leakage not intended to be measured.
building envelope	The boundary or air barrier separating the interior conditioned space of a building from the outside environment including below-grade exterior walls and floors.
CFM/sq ft @ 75-Pa or CFM75/sq ft	CFM75/sq ft is the flow rate, in CFM, required to pressurize or depressurize the building by 75-Pa.

Term	Definition
conditioned space	Any mechanically heated and/or cooled space.
effective leakage area	A common term used to describe airflow at a pressure by equating it to an equivalent size hole in an elliptical nozzle that would pass the same airflow at the same test pressure. It is usually taken at 4-Pa and incorporates a 1.0 discharge coefficient. It is typically about half the size of an equivalent leakage area that describes the same airflow rate. See ASTM E779-10, eq. (5).
equivalent leakage area	A common term used to describe airflow at a pressure by equating it to an equivalent size hole in a flat plate that would pass the same airflow at the same test pressure. It is usually taken at 10-Pa and incorporates a 0.611 discharge coefficient. For the purposes of this document, it is taken at a reference pressure of 75-Pa and is referred to as EqLA75. It is typically about twice the size of an effective leakage area that describes the same airflow rate. See ASTM E779-10, eq. (5).
envelope pressure	Differential pressure between the interior of the building being tested and the outdoors, measured with the outdoors as the reference.
fan pressurization method	Method defined in ASTM E779-10. Even though this term contains the word "pressurization" this does not indicate that exclusively positive pressures are to be used.
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.
induced envelope pressure test point	Each point consists of the average induced envelope pressure and the average test fan flow reading required to induce that pressure.
normalized air leakage	Total leakage air flow divided by test boundary surface area, with temperature and elevation corrections.
outdoors	Outside the building in the area around the building.
single zone	For this Protocol, a space in which the pressure difference between any two places differs by no more than 10-percnet of the inside to outside pressure difference. Not to be confused with the ASTM E779-10 definition in which the pressure differences may be no more than 5- by the same measure.
test boundary	Boundary of the portion of the building which is actually tested. The area of this boundary is used in the results calculation.

Term	Definition
test fan	For this document, this term is used to represent a calibrated variable speed fan that is typically temporarily mounted in an opening in the envelope for the purpose of providing a test pressure and for measuring the flow rate required to establish that test pressure. Other commonly used terms are "blower door" and "door fan".
time averaging	Refers to the digital gauge display or other means of averaging pressures over a time interval. Time averaging can be block averages that will update for the length of the average or non-overlapping rolling (moving) averages that will update continuously by displaying the average over the past time period.
zero flow pressure	ASTM E779-10 terminology for baseline pressure.

5.2 Acronyms and Abbreviations

Term	Spelled-out
ACH	air changes per hour
AOR	Architect of record
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
CD	Compact disk
CFM75	cubic feet per minute at an induced building envelope pressure of 75-Pascals
CGSB	Canadian General Standards Board
CI	Confidence Interval
US DOD	U.S. Department of Defense
US DOE	U.S. Department of Energy
DOR	Designer of Record
EqLA75	Equivalent leakage area @ 75-Pa assuming a discharge coefficient of 0.611. This is a special case of EqLA.
EqLA	Equivalent leakage area; usually referenced to 10-Pa, commonly called ELA but EqLA is used to avoid confusion.
HVAC	Heating, ventilating, and air-conditioning
IR	infrared

Term	Spelled-out
ISO	International Organization for Standardization
NIST	National Institute of Standards and Technology
sq ft	Abbreviation for "square feet"
STP	Standard temperature and pressure conditions of 14.696 psi (101.325 KPa) and 68F (20°C).

Appendix A (Normative) – Test Form

This test form includes mandatory procedures and requirements

Building Air Leakage Test Protocol – Test Form

(Note: this test form is procedural and results can be reported in alternate formats.)

Building name: _____

Building address: _____

Prime contractor:____

Contact: ____

Testing agency: ____

Address: ____

Testing agency contact: ____

Phone: ______________________________ Email: ______________________________

Lead on-site personnel: ___________________________ Phone: __________________________

Test date: ____

Additional information: ____

____

____

Witnesses:

Name:	Organization:	Telephone/Email:
______________________	______________________	______________________
______________________	______________________	______________________
______________________	______________________	______________________
______________________	______________________	______________________
______________________	______________________	______________________
______________________	______________________	______________________

INSERT PHOTOGRAPHS OF SUBJECT BUILDING:

Testing agency to provide digital photographs of subject building, setup, test procedures, and diagnostic evaluation to the client.

1. Test Boundary Dimensions

1.1. ___ Record the total test boundary surface area in square feet including walls, floor and ceiling from design plans as supplied by the Designer of Record (DOR). ________sq ft

1.2. ___ Verify the building envelope square footage used by the DOR is reasonable.

1.3. ___ Attach a description of the building characteristics, including intended use, wall, roof, and floor construction, fenestrations, HVAC system, air barrier system, and any additional information that may be relevant to the air leakage test.

1.4. ___ Record elevation of building above sea level in feet. __________ ft

1.5. ___ Record the height of the building above grade. __________ ft

2. Set Up Checklist

2.1. ___ Confirm HVAC shutdown/disabling.

2.2. ___ Confirm all dampers in the envelope perimeter are closed and/or isolated.

2.3. ___ Confirm exhaust fans & dryers are off and isolated at the air barrier.

2.4. ___ Confirm combustion appliances are on pilot or are disabled.

2.5. ___ Confirm all air inlets at the envelope perimeter are sealed or isolated.

2.6. ___ Confirm all interior doors are propped open.

2.7. ___ Confirm all air outlets at the envelope perimeter are sealed or isolated.

2.8. ___ Note rain or snow conditions that may cause leakage rate to be less than in dry conditions.

____

____

2.9. ___ Confirm exterior doors and windows are closed and latched.

2.10. ___Confirm all areas outside of air barrier envelope being tested are at ambient conditions.

2.11. ___ Confirm all plumbing traps are filled with water.

2.12. ___ Confirm dropped ceiling tiles are removed at specified rate.

2.13. ___Confirm uniform **interior** pressure distribution by inducing an envelope pressure of at least 30-Pa. Measure interior pressure differences to ensure no two locations differ in pressure by more than 10-percent of the induced envelope pressure. Document uniform interior pressure distribution by recording the locations and values of interior pressure differences in tabular or graphic form. Data may be collected by hand or acquisition equipment.

Location	Pressure (Pa)
(Use as many as necessary)	

Maximum Pressure Difference, as a % of induced ___________%

2.14. ___ Document the approximate locations of the **envelope** pressure measurements in tabular or graphic format including the interior and exterior locations for each envelope pressure tap/monitoring station.

____

____

2.15. Exterior pressures are:

_______ manifolded together, _______ electronically averaged or, ________manually averaged

2.16. Record additional set up notes.

____

____

____

3. Testing Equipment Used

3.1. ___ List gauge(s):

model	serial #	accuracy	calibration date

3.2. ___ Confirm the gauge has an accuracy of ± 1-percent or 0.25-Pa, whichever is greater and has had its calibration checked against a National Institute of Standards and Technology (formerly National Bureau of Standards, or NIST) traceable standard within two (2) years.

3.3. ___ List test-fan(s):

model #	serial #	accuracy	calibration date
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________

3.4. ___ Confirm the test-fan has an airflow measurement accuracy of ± 5-percent of the measured flow and has had its calibration checked against an NIST traceable standard within five years.

3.5. ___ List infrared camera(s):

model	serial #	accuracy	calibration date
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________
____________________	____________________	____________________	____________________

3.6. ___ Confirm the infrared camera has a noise equivalent temperature difference (NETD) of +/-0.1°C and has been calibrated within one (1) year of the test date.

3.7. ___ Attach calibration certificates for all equipment listed above to air leakage test form. If additional fans or gauges are used during the test, attach calibration certificates.

4. **Induce Envelope Pressures with Test Fans**

4.1. ___ Both pressurization and depressurization tests performed.

4.1.1. ___ The building target tightness rate is more the 125,000 cfm @75-Pa and may therefore be tested in one direction which will be: _______pressurization **OR** _____depressurization

4.2. ___ Operator will be located inside or outside the tested building. ______ inside **OR** _____outside

4.3. ___ Record indoor and outdoor temperatures before the test. ____°F in ____ °F out

4.4. ___ Record initial 12 baseline envelope pressure points in Pa in accordance with section 3.2. Show positive and negative signs. Data may be collected by hand or acquisition equipment and be reported in tabular or graphic form.

______________	______________	______________	______________
______________	______________	______________	______________
______________	______________	______________	______________

4.5. ___ Average all baseline points from 4.4. ________ Pa.

4.6. ___Record the maximum variation between this average and any one point. ________Pa.

4.7. ___ If greater than 1-Pa, repeat 4.4 for a longer time until 4.6 is 1-Pa or less.

4.8. ___Record the minimum time taken to collect any one baseline envelope pressure point. ________Sec.

4.9. ___ Record the magnitude of the greatest *baseline pressure* point. ________Pa.

4.10. ___Collect a series of at least 12 approximately equally spaced induced envelope pressure test points where each point consists of the average induced envelope pressure and the average test fan flow reading required to induce that pressure over at least the same time in 4.8. The pressure must be the greater of 25-Pa or 3.3 times the value recorded in 4.9. The highest pressure must be 75-Pa and must be at least 25-Pa greater than the lowest pressure.

Pressure (Pa)	Flow (CFM)

4.11. ___Record pressure differentials to demonstrate compliance with the internal pressure uniformity requirement of no two locations differing from one another by more than 10-percent of the induced envelope pressure. Document this requirement at each point.

NOTE: See step 2.13. - Document uniform (within 10%) interior pressure distribution by recording the locations and values of interior pressure differences in tabular or graphic form.

4.12. ___Record at least 12 final baseline envelope pressure points for the time in 4.8.

________________	________________	________________	________________
________________	________________	________________	________________
________________	________________	________________	________________

4.13. ___Subtract the average baseline envelope pressure (obtained from 4.5 and 4.12) from all pressures in 4.10 to determine the induced envelope pressures for use in section 5.

4.14. ___ Record the indoor and outdoor temperature after the test. ____°F in

____ °F out

4.15. ___Calculate the total corrected flow for all test-fans using the range and flow data from 4.10. Use temperatures and altitude to correct to STP using equations from ASTM E779-10.

4.16. Repeat Steps 4.3 through 4.15 in the opposite test direction unless 4.1.1 applies.

5. **Calculate and Report Results**

Curve fit all corrected pressures and flows from the tables and calculate the following values in strict accordance with ASTM E779-10. Attach all data in a tabulated and graphical form and in Appendix B.

Pressurization

5.1. ___The temperature and altitude air leakage coefficient C_P for pressurization.

5.2. ___ The exponent n_p for pressurization. NOTE: if n_p is less than 0.45 or greater than 0.8, test data are invalid and test must be repeated.

5.3. CFM referenced to standard temperature and pressure (STP) at +75-Pa.

5.4. ___ CFM/sq ft of envelope at +75-Pa.

5.5. ___ The correlation coefficient, r^2, of the curve fitted data with a minimum of 10 points.

NOTE: If r^2 is less than 0.98, test data are invalid and test must be repeated.

5.6. If both pressurization and depressurization tests have been completed, go to 5.8.
___If only a pressurization test is completed, calculate the 95-percent confidence interval at +75-Pa for test in pressurization using methods from this document.

NOTE: If the upper confidence limit exceeds 0.27 the test data is invalid and the test must be repeated. If the upper confidence limit is 0.25 or more and the confidence interval (difference between upper and lower limits) is 0.04 or greater, the test data is invalid and the test must be repeated.

Depressurization

5.7. ___The temperature and altitude air leakage coefficient C_d for depressurization.

5.8. ___The exponent n_d for depressurization.

NOTE: If n_d is less than 0.45 or greater than 0.8, test data is invalid and the test must be repeated.

5.9. ___CFM referenced to standard temperature and pressure (STP) at -75-Pa

5.10. ___CFM75/sq ft of envelope at -75-Pa

5.11. ___The correlation coefficient, r^2 of the curve fitted data with a minimum of ten (10) points.

NOTE: If r^2 is less than 0.98, test data are invalid and the test must be repeated.

5.12. If both pressurization and depressurization tests have been completed, go to 6.15.
___If only a depressurization test is completed, calculate the 95-percent confidence interval at -75-Pa for test in depressurization using methods found in this document.

NOTE: If the upper confidence interval exceeds 0.27 the test data is invalid and the test must be repeated. If the upper confidence limit is 0.25 or more and the lower confidence limit is 0.04 lower, the test data is invalid and the test must be repeated.

5.13. ___ Calculate the average CFM75/sq ft from 5.4 and 5.10.

5.14. ___ Calculate the 95-percent confidence interval at 75-Pa for combined pressurization and depressurization using methods found in this document.

NOTE: If the upper confidence interval exceeds 0.27, the test data are invalid and the test must be repeated. If the upper confidence limit is 0.25 or more and the lower confidence limit is 0.04 lower, the test data are invalid and the test must be repeated.

5.15. ___ Determine pass/fail status based on the average of pressurization and depressurization.

5.16. ___ For the purpose of visualizing the magnitude of the air leakage of the enclosure calculate the equivalent leakage area in square feet at 75-Pa.

6. Infrared or Smoke Leakage Evaluation

If the test fails, perform a diagnostic evaluation in accordance with ASTM E1186-17 'Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems'. Attach results of diagnostic evaluation to this test form.

7. Confirm These Building Components Have Been Returned To Pre-Test Conditions

7.1. ___ HVAC
7.2. ___ All dampers in the envelope perimeter
7.3. ___ Exhaust fans & dryers
7.4. ___ Combustion appliances
7.5. ___ All air inlets at the envelope perimeter
7.6. ___ All interior doors
7.7. ___ All air outlets at the envelope perimeter
7.8. ___ Exterior doors and windows
7.9. ___ Dropped ceiling tiles

Appendix B (Normative) – Certification of Compliance

This test form includes mandatory procedures and requirements

City of Fort Collins Certification of Compliance
Building Air Leakage Test Results

Pressurization

Metric	Requirement	Actual	Requirement Met/Not Met
n	0.45 < n < 0.8		
C	N/A		N/A
r^2	$r^2 > 0.98$		
CFM75/sq ft	Actual < 0.25 CFM75/sq ft		
95% C.I. Upper	N/A		N/A
95% C.I. Lower	N/A		N/A
EqLA75	N/A		N/A

Depressurization

Metric	Requirement	Actual	Requirement Met/Not Met
n	0.45 < n < 0.8		
C	N/A		N/A
r^2	$r^2 > 0.98$		
CFM75/sq ft	Actual < 0.25 CFM75/sq ft		
95% C.I. Upper	N/A		N/A
95% C.I. Lower	N/A		N/A
EqLA75	N/A		N/A

Average

Metric	Requirement	Actual	Pass / Fail
CFM75/sq ft	Actual < 0.25 CFM75/sq ft		

Testing Agency Certified Compliance with the Protocol

1	The test boundary area was obtained from the Architect of Record and was checked on-site for reasonableness.	______Initial
2	Set up was performed according to section 2 of the test form and all deviations and their impact noted here.	______Initial
3	Test equipment used was in compliance with respect to accuracy and calibration date.	______Initial
4	The test procedure used was in compliance except as noted here. ____________________ ____________________ ____________________ ____________________	______Initial
5	The calculations were done in strict accordance with ASTM E779-10 except as noted in this Protocol.	______Initial

6	Provide the value calculated in step 5.15 (or, 5.11 or 5.4 if applicable).	______CFM75/sq ft
7	Determine pass/fail status based on the average of pressurization and depressurization.	Pass/Fail
8	All accuracies, pressure limits, and data correlations and confidence intervals are within the bounds specified in steps 3, 4 and 5 and all deviations are noted here.	______Initial
9	Supporting documentation described in steps 1, 3, 6, and 7 is attached to this test form, including all digital photographs of the building and test procedure.	______Initial

I herby certify that the results above are in conformance with the City of Fort Collins Air Leakage Test Protocol.

Testing agency name:

____

Testing agency authorized representative signature:

____

Testing agency authorized representative printed name:

____

Date: ____________________________

Appendix C (Normative) – Testing Agency Qualifications

Submit a minimum of 3 buildings, each 10,000 square feet or larger (non-residential) that have been tested using the Fort Collins Building Air Leakage test Protocol or ASTM E779. The information submitted must include a building description, building size (SF), address and test results.

Alternative Qualification Method

Firms with commercial building testing experience using other than the above protocols and/or testing buildings less than 10,000 square feet can still qualify as an approved testing agency through a two-step process, as follows:

1. Testing agency shall submit to the Building Official documentation of experience testing three commercial buildings. The information submitted must include a building description, building size (SF), address, test results, and a description testing methodology used.
2. If the Building Official determines that adequate experience has been demonstrated, the firm will initially be approved to test buildings 10,000 square feet or less. The Fort Collins Building Air Leakage Test Protocol must be used for these tests.

Appendix D – Representative Air Tightness Standards

For comparison purposes this appendix lists the air tightness targets for several programs:

- The U.S. Army Corps of Engineers (USACE)
- Government Services Agency (GSA)
- British best practices and normal existing buildings
- Passivehaus US

The USACE and GSA targets are written in the same units – CFM 75/sq ft enclosure. The British targets are also normalized to the enclosure area but are in $m^3/hr/m^2$ enclosure and referenced at 50-Pa. The Passivehaus US target is expressed in air changes per hour at 50-Pa. The targets are not directly comparable due to the following:

- Targets at different reference induced pressure differences depend on the value of the flow exponent measured for each building. An assumption of flow exponent must be made to compare them.
- Targets normalized to building volume rather than surface area varies differently than those normalized to surface area. They vary in proportion to the surface to volume ratio. A specific volume must be assumed to compare them.

The target air tightness values are compared in Table A1 for a two-story, 100 foot x 240 foot x 25 foot building with a flow exponent equal to 0.60. For larger or smaller buildings or for different flow exponents the results will vary. Red numbers in the table are the units specified by the program.

	British best practice $m^3/hr50/m^2$ enclosure	British normal $m^3/hr50/m^2$ enclosure	ACH50	CFM75/ft^2 enclosure
British ATTMA				
Office -Natural Ventilation	*3*	7	1.1/2.5*	0.21/0.49*
Office - mixed ventilation	*2.5*	5	0.89/1.8*	0.18/0.35*
Office -AC/low energy	*2*	5	0.71/1.8*	0.14/0.35*
Factories/ warehouses	*2*	6	0.71/2.1*	0.14/0.42*
superstores	*1*	5	0.36/1.8*	0.07/0.35*
schools	*3*	9	1.1/3.2*	0.21/0.68*
hospitals	*5*	9	1.8/3.2*	0.35/0.68*
museums/ archives	*1*	1.5	0.36/0.53*	0.07/0.11*
cold stores	*0.2*	0.35	0.07/0.13*	0.014/0.025*
dwellings -NV	*3*	9	1.1/3.2*	0.21/0.68*
dwellings -MV	*3*	5	1.1/1.8*	0.21/0.35*
ASHRAE Std 189, GSA	5.7*	--	2*	*0.40*
Army Corps of Engineers	3.6*	--	1.3*	*0.25*
Passiv Haus	1.7*	--	*0.6*	0.12*

NOTE: Numbers in italics are the units used in the standards

* assuming a two story, 48,000 square foot floor area, 100 foot by 240 foot x 25 foot building with flow exponent = 0.60z