abaa2024 building enclosure conference

Building Envelope Airtightness Quantification

Challenges applying sectional, sampling, or wall assembly testing methods

Stephen Wong, P.Eng.
Principal, Building Science Engineer
Morrison Hershfield

AIA Continuing Education Provider

abaa EDUCATION

Overview

- Current standards - building as a **whole**
- Approaches for **portion** of the building
  - Impacts from variations of approaches
  - **Awareness** (or lack of awareness) to these impacts
    - False positives
  - **Variables** leading to inaccurate and widely misleading building envelope (BE) airtightness results
    - Understanding these variables - different for every building *and* every test.

Overview

- Regression Method
  - Understanding **validity** and **repeatability** of data measurements
  - Understanding conditions leading to **high uncertainties** and **inaccuracies** of the true building envelope airtightness.
  - Avoid misinterpretations and misrepresentations the BE airtightness performance of a building
- What’s at stake - impact to design and construction of buildings
- Research

Building Envelope Airtightness

- What is the goal and purpose of tests?
- How are we applying and interpreting these tests results?
- Is this the right testing approach for this project? (Specs, SOR, Memos)
- Understanding can help avoid:

  -Liability of misrepresentations (assemblies represents BE)
  -Risk of misinterpretation (false passes/fails)
  -Costly re-testing
  -Losing faith on test approach

Stakeholders

- Who needs to understand?
  - Developers, owners
  - Designers, architects, engineers, consultants
  - Builders, Contractors
  - Commissioning Agents
  - Testers
  - Authorities Having Jurisdictions, Building/Code Officials

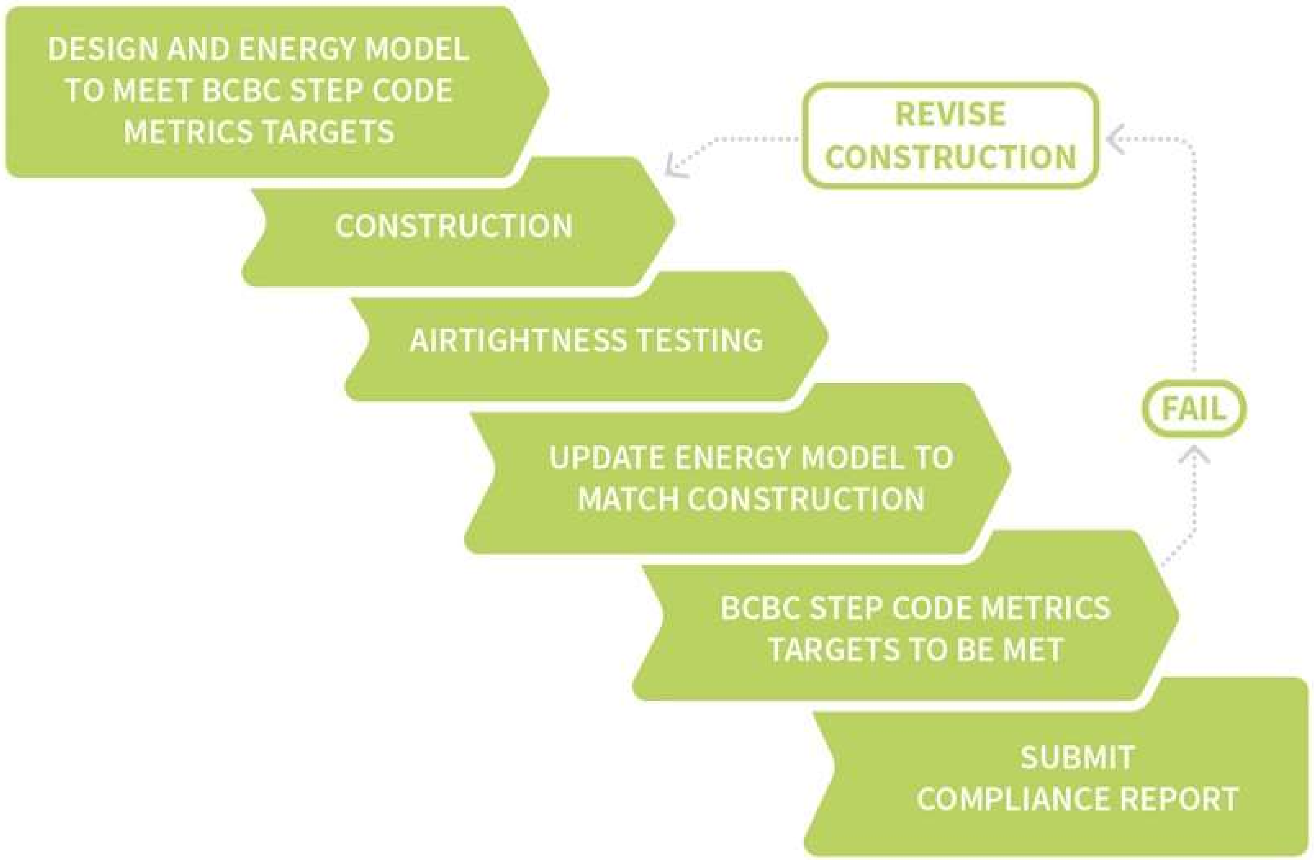
Energy Efficiency and Higher Performance

Building Envelope

BC Energy Step Code

Energy Efficiency and Higher Performance

Building Envelope



BC Energy Step Code

Standards:
Building Envelope Airtightness

ASTM E-779

US Army Corps of Engineers (USACE)

ASTM E-3158

Building Envelope Airtightness testing

Whole Building Envelope

- Fans pressurize/depressurize the entire building
- Measure **pressures**
  - (at multiple pressure setpoints)
- Calculate **airflows**
- Calculate **air leakage rates** based on building enclosure area (or volume)

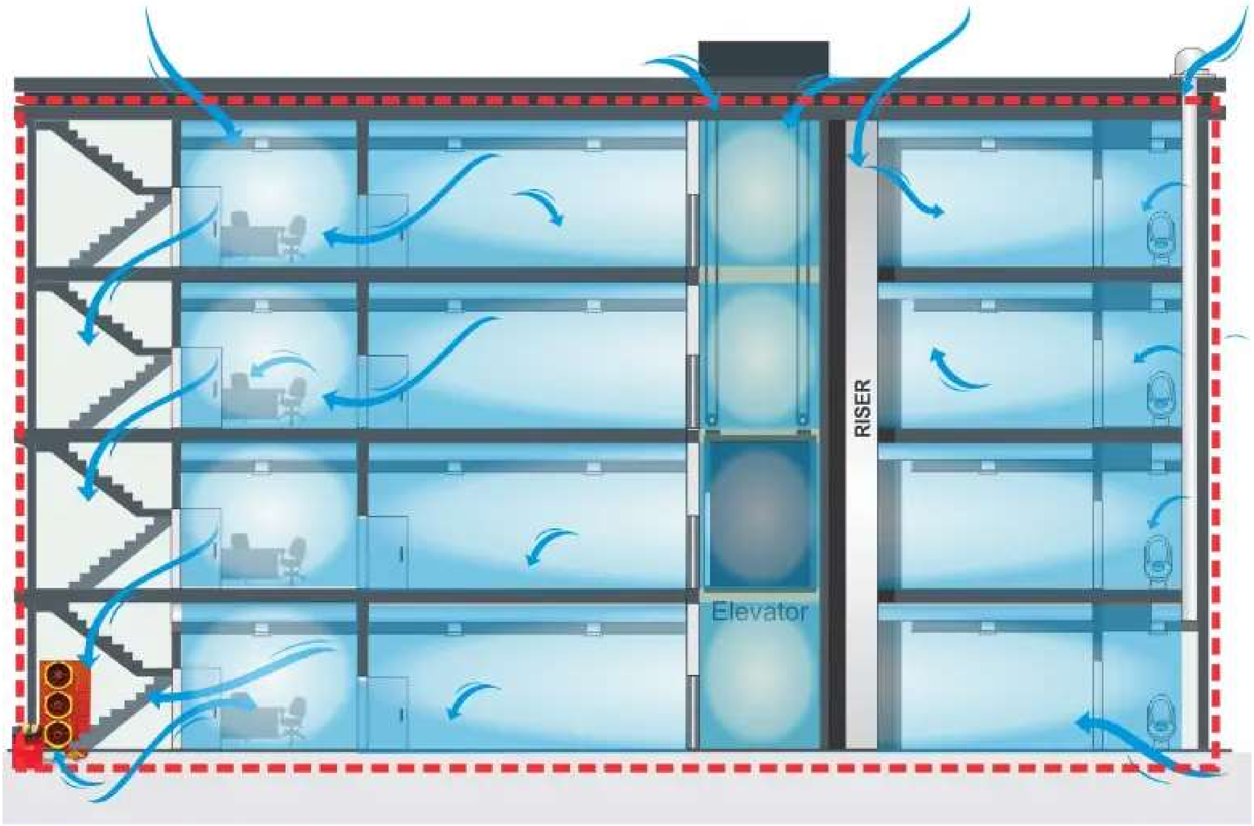
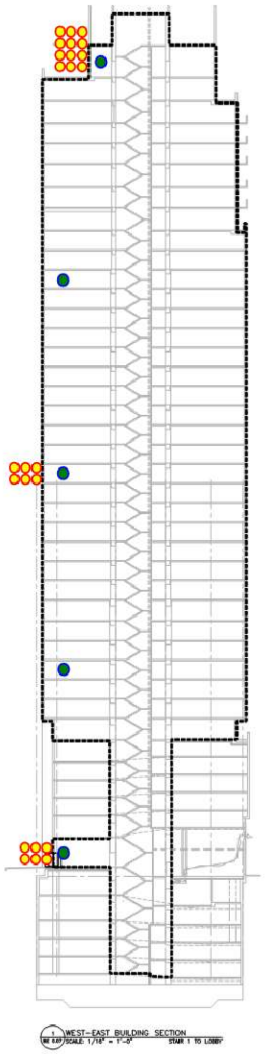


photo: Efficiency Matrix

Whole Building

The high-rise is treated as one zone

- Entire Envelope Airtightness is Quantified
- No pressure neutralization
- Data is repeatable
- Data is valid



Standards:
Wall Assemblies' Airtightness

ASTM E-283

Fenestrations
(Laboratory)

ASTM E-783

Fenestrations
(Field)

ASTM E-2178

Materials

Photo: The Construction Specifier

Wall Assembly Airtightness?

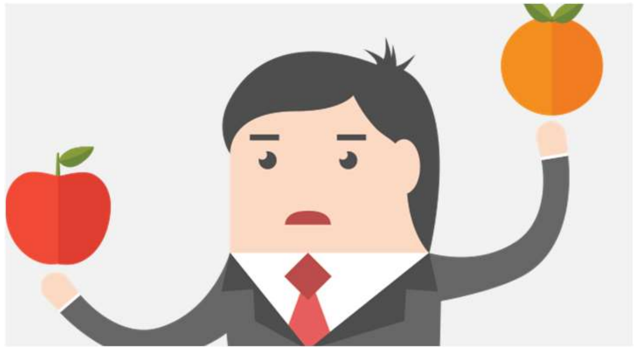
Can we make a direct interpretation on *Envelope* Airtightness based on measuring an *Assembly* Airtightness?

ASTM E-783

Intended for Windows and Doors

Wall Assembly Airtightness?

Can we make a direct interpretation on *Envelope* Airtightness based on measuring an *Assembly* Airtightness?



ASTM E-779

Intended for Whole Building Envelope Airtightness

e.g. 0.4 CFM/ft^2 @ 75 Pa

ASTM E-783

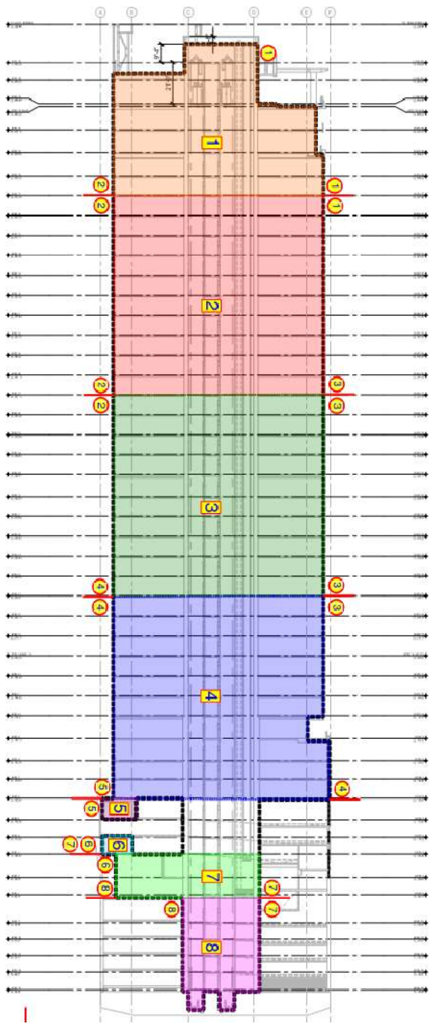
Intended for Windows and Doors

e.g. 0.1 CFM ft^2 @ 300 Pa (NAFS AW performance)

Compartments

<u>**Sectional** method </u>(vs Whole Building)

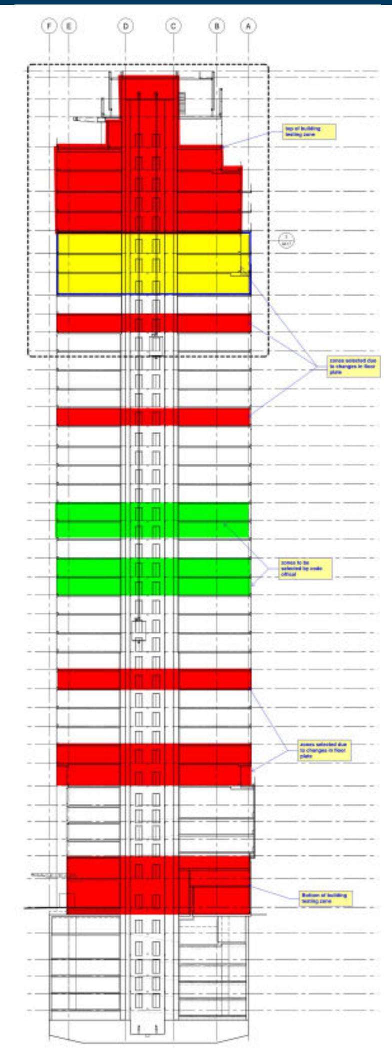
Multiple mobilizations (vs Single mobilization)



Compartments

<u>Sampling</u> <u>method</u> (vs Whole Building)

Multiple mobilizations (vs Single mobilization)



Partial Building Airtightness?

"Compartmentalized" test

– How is this compartment airtightness being quantified and evaluated?

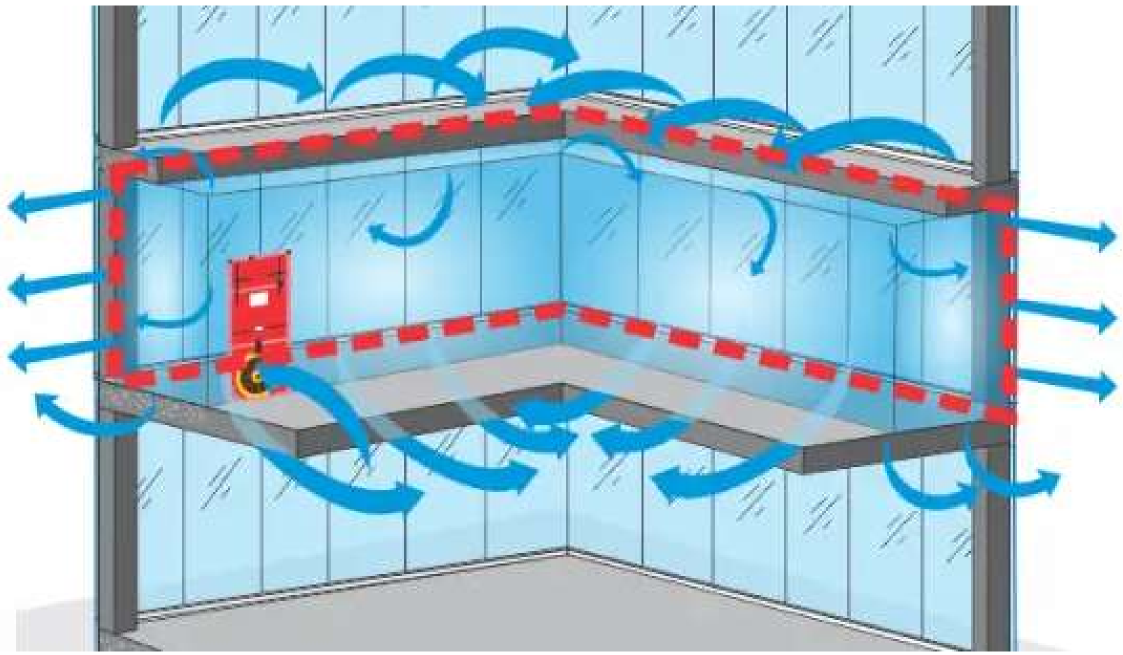


photo: Efficiency Matrix

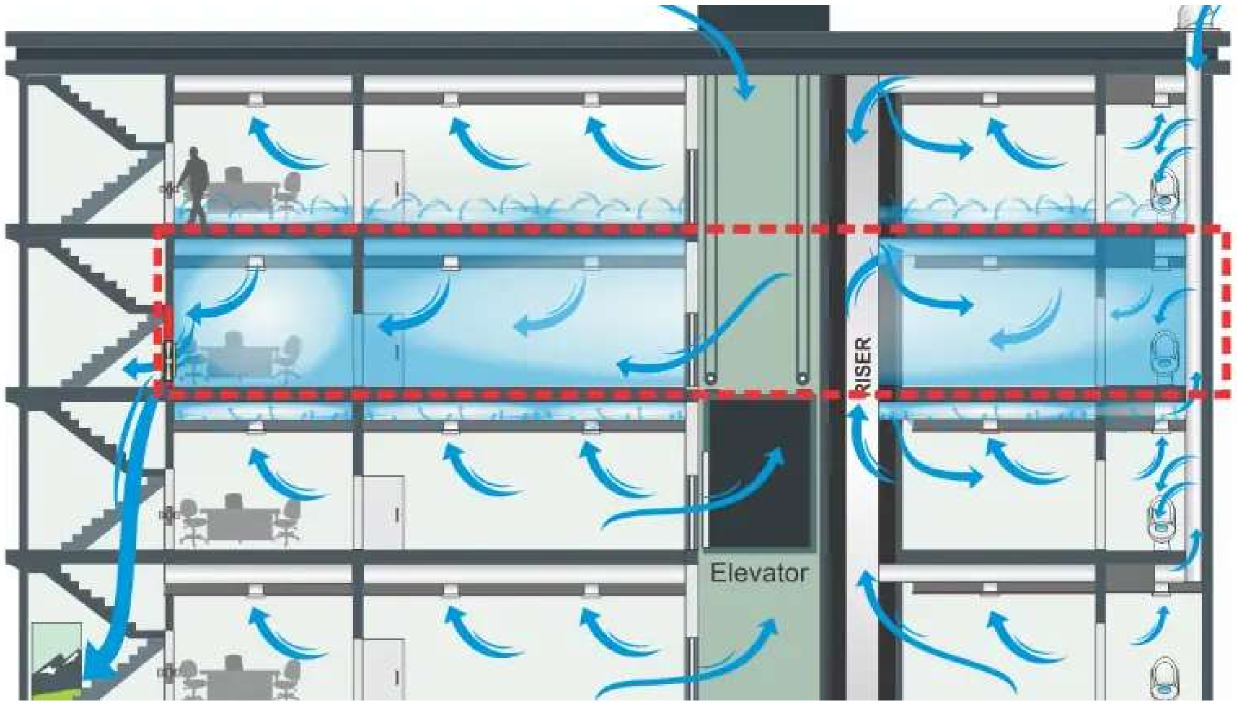
Wall

Airtightness Test

Partial Building Airtightness?

"Compartmentalized" test

– How is this compartment airtightness being quantified and evalulated?



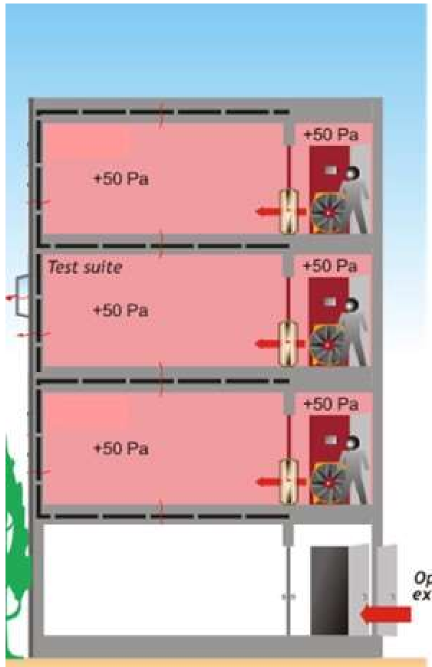
Single Floor (alone)

Airtightness Test

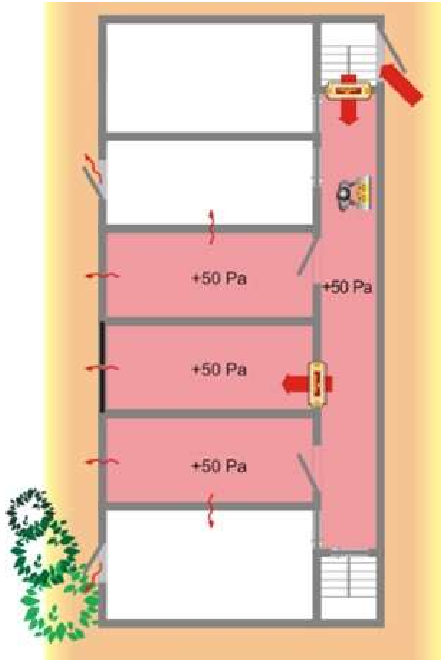
photos: Efficiency Matrix

Pressure Neutralization

Theory:
Leakage is only measured across areas with pressure differential – True or False?



Side View



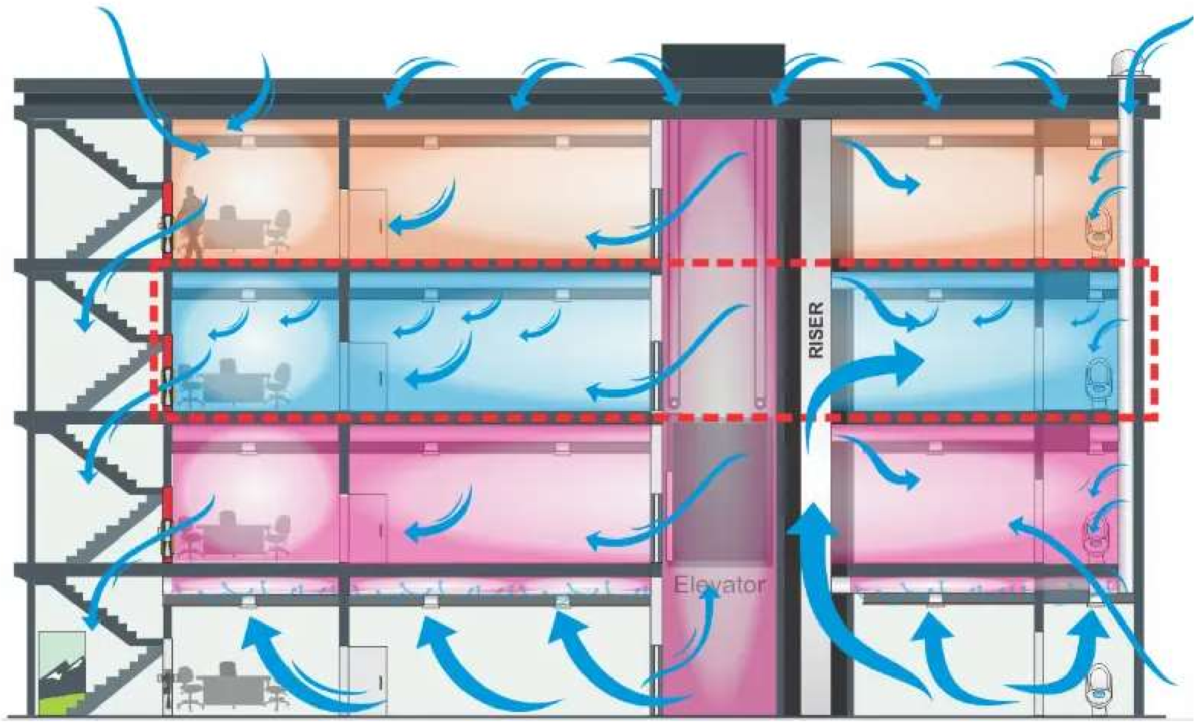
Top Down View

photos: Retrotec

Partial Building Airtightness?

"Compartmentalized" test

– How is this compartment airtightness being quantified and evalulated?



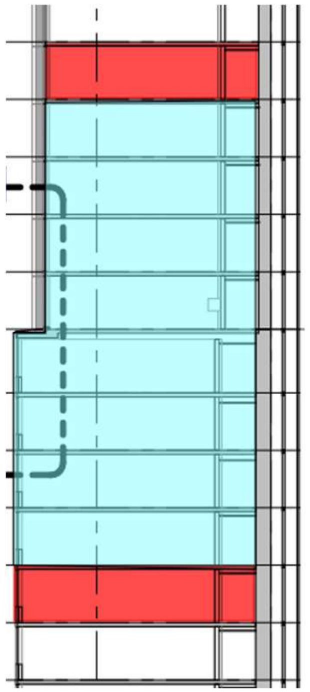
Single Floor (pressure-neutralized)

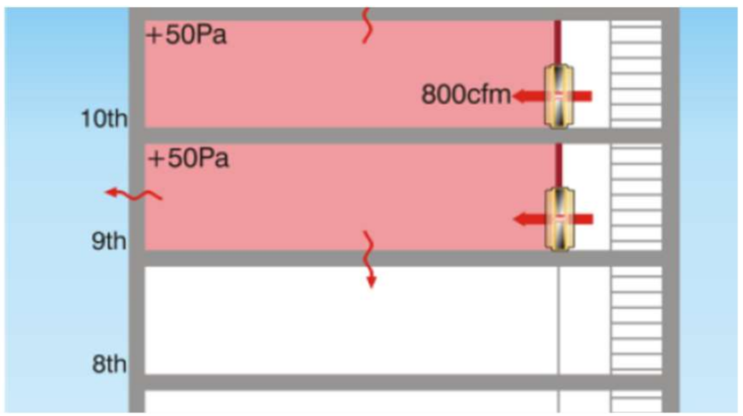
Airtightness Test

photos: Efficiency Matrix

Partial Building Airtightness?

Reality Vs Theoretical/Expectation





Floor-by-Floor Approach

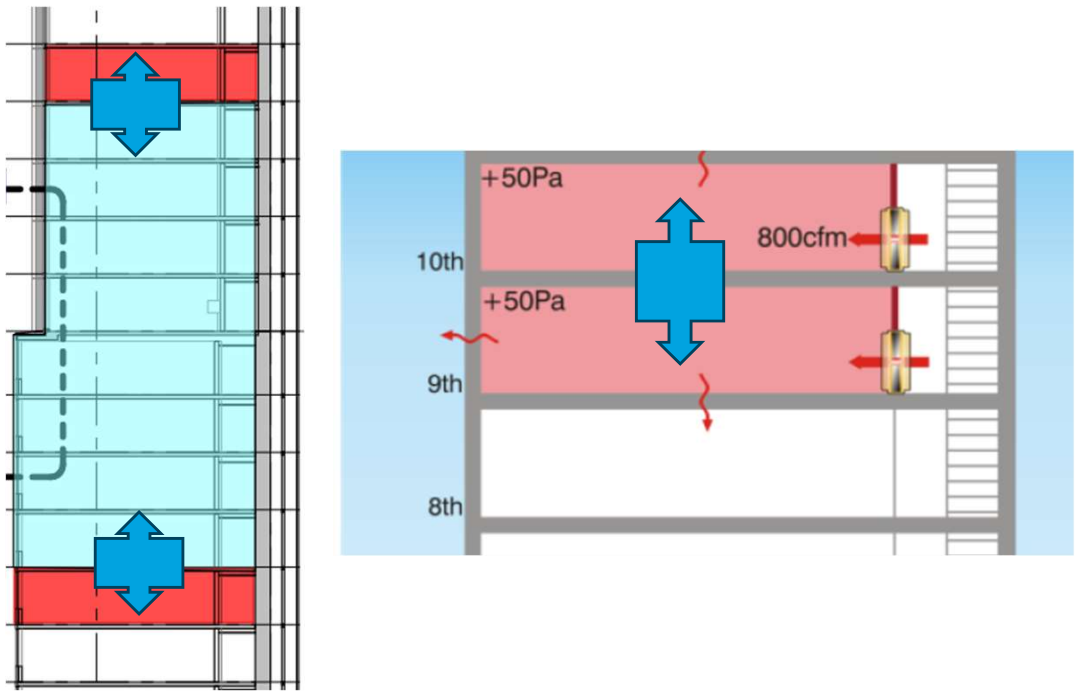
Unit-to-Unit Approach

photos: Retrotec

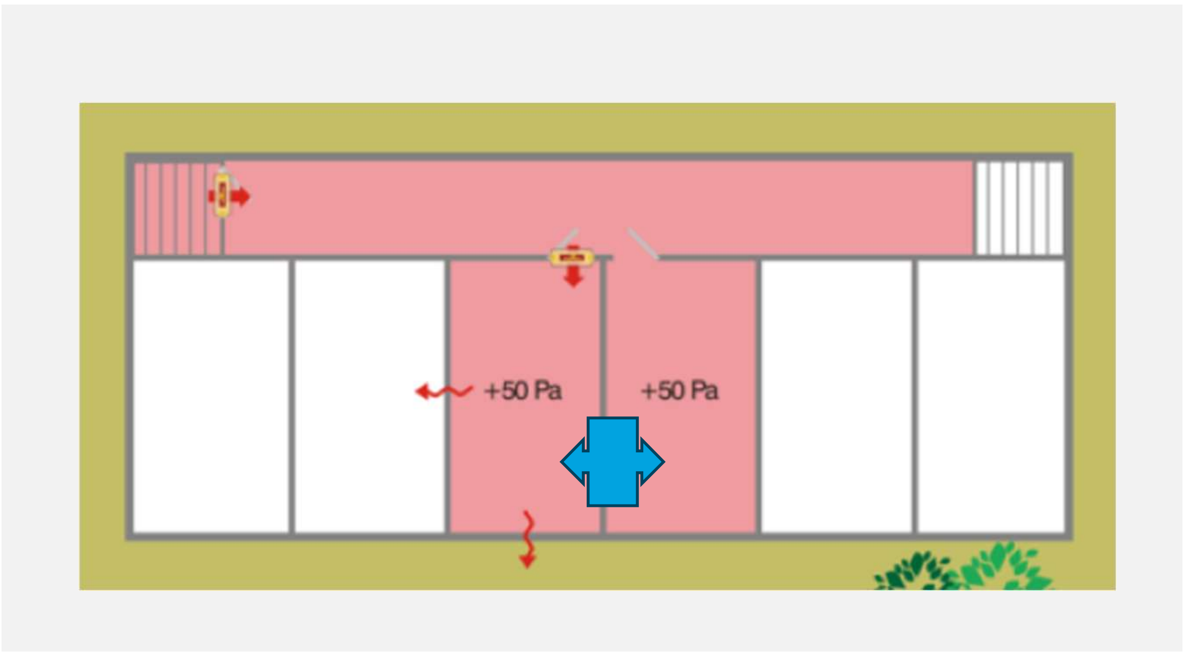
Partial Building Airtightness?

Theory – Pressure Neutralization Testing Approach

– Are testers' non-standardized approaches becoming more innovative? Or becoming misleading?



Floor-by-Floor Approach



Unit-to-Unit Approach

photos: Retrotec

Partial Building Airtightness?

Data uncertainties and inaccuracies largely unrecognized - ASHRAE research paper (RP-4275)

4275 (RP-935)

Protocol for Field Testing of Tall Buildings to Determine Envelope Air Leakage Rate

William P. Bahnfleth, Ph.D., P.E.
Member ASHRAE

Grenville K. Yuill, Ph.D., P.E.
Fellow ASHRAE

Brian W. Lee
Student Member ASHRAE

ABSTRACT

The objective of this project was to develop a relatively simple, accurate method for testing the overall envelope leakage rate of tall buildings. Two fan pressurization test techniques, the floor-by-floor blower door method and the air-handler method, were developed and tested on two buildings. Criteria for conducting accurate tests were developed, including limitations on outdoor air temperature and wind speed. The floor-by-floor blower door method permits isolation and measurement of the leakage flow rate of a single floor, but it is difficult and time-consuming to apply. The air-handler method uses building air distribution fans for pressurization. It is most easily applied on a system-by-system level rather than floor-by-floor. Fan airflow techniques including orifice plate, pitot traverse, and tracer gas dilution were considered. The tracer gas method was found to be relatively easy to apply and highly accurate. Fan airflow rate measurement uncertainty by tracer gas was estimated to be 5.4% to 8.8% for the cases considered, assuming a 5% uncertainty in interzonal leakage.

INTRODUCTION

Building envelope tightness is of importance to owners, operators, and tenants of tall buildings for operational, indoor environmental quality and financial reasons. Airflows through envelope leakage paths caused by pressure differential due to stack effect and wind have several undesirable effects. Uncontrolled entry of unconditioned outdoor air into occupied spaces may adversely affect comfort. Movement of air within a building as a result of envelope leakage may transfer contaminated air. Leakage also adds to air-conditioning peak loads and total energy consumption. The movement of air through the envelope can cause serious moisture problems if air is cooled to its dew point while within an exterior wall. Stack effect pressure differential across building shafts can generate objectionable noise that is particularly evident at stairwell and elevator doors. In view of the negative consequences of envelope leakage, construction methods to limit leakage and testing procedures to verify their efficacy should be a part of building design and commissioning.

Measurement of the envelope leakage of houses and other small buildings through pressurization and depressurization testing is a common procedure (Shaw et al. 1990). The typical test method utilizes a temporarily installed fan to pressurize or depressurize the building to a series of desired indoor-outdoor pressure differentials. The airflow rate into or out of the building is measured at steady state for each differential. Data from these tests are used to establish a correlation between airflow and pressure differential. In principle, this approach is also applicable to tall buildings. However, stack and wind effects and the large flow rates required for standard leakage tests make the application of these techniques to tall buildings less than straightforward.

The objective of ASHRAE Research Project 935 (Bahnfleth et al. 1998) was to develop a method to evaluate the airtightness of the envelope of tall buildings that represents the best compromise between simplicity and accuracy. Two leakage test procedures were developed for tall buildings by extension of established pressurization test procedures. Criteria for accurate application of these methods to tall buildings were developed. The procedures were tested in two different buildings and evaluated according to criteria including the value of the information acquired, ease of use, and degree of disruption of building operations.

William P. Bahnfleth is an assistant professor in the Department of Architectural Engineering, Pennsylvania State University, University Park, Pa. **Grenville K. Yuill** is director of Architectural Engineering at the University of Nebraska, Omaha, Neb. **Brian W. Lee** is a health facilities officer at the U.S. Air Force Health Facilities Division, Atlanta, Ga.

RESULTS

Floor-by-Floor Blower Door Method

Testing was conducted first at the university library site, beginning with the floor-by-floor blower door method. Numerous attempts were made to execute this procedure, but adequately sealing a single floor to isolate it from its neighbors was found to be impossible. Elevators, doors, ducts, and other apparent leakage paths were carefully and completely sealed, yet a large amount of additional, inaccessible floor-to-floor leakage remained. This was evident because, with the test floor sealed and adjacent floors pressurized by additional blower doors, high pressures were recorded on the test floor when the blower door fan was off. The inability to adequately seal the test floor is perhaps more significant in view of the fact that a crew of four workers spent nearly three hours in the effort on each occasion that the procedure was tested. Extrapolating this level of effort very roughly to the larger office building, one obtains an estimate on the order of 500-1,000 person hours simply to seal interfloor leakage paths.

Further efforts to find hidden leaks did not substantially reduce interzonal leakage. Numerous holes and cracks that could not be reached and sealed were found in return risers and elevator shafts. Further, the return air shaft was found to be constructed of 16 in. concrete masonry unit (CMU) blocks that offer only a small resistance to airflow. Sealing this return shaft leakage was not feasible. It was concluded on the basis of these discouraging experiences that the floor-by-floor blower door test method is impractical for general use and it was not tested further.

Partial Building Airtightness?

Empirical data - High Degrees of Data uncertainties and inaccuracies can be largely unrecognized

Test #1	Date	Levels	Primary System	Target	Result	Result
1	9/29/2023	20-21	Window wall	0.25 cfm/ft2	0.35 cfm/ft2	Fail
2	10/6/2023	20-27	Window wall	0.25 cfm/ft2	0.35 cfm/ft2	Fail
3	10/13/2023	20-27	Window wall	0.25 cfm/ft2	0.147 cfm/ft2	Pass

Floor Re-tests

(varying interior compartmentalization and preparation)

Mobilization	MOBILIZATION 1 (3/25/2022)		MOBILIZATION 2 (4/08/2022)		MOBILIZATION 3 (4/15/2022)	
Test	1	2	1	2	1	2
Direction	Pressurization	Depressurization	Pressurization	Depressurization	Pressurization	Depressurization
Start Time	1:43:15 PM	1:56:37 PM	12:05:27 PM	3:13:59 PM	1:28:42 PM	1:48:18 PM
Enclosure Area	8381	8381	8381	8381	8549	8549
Neutralization Floors	9 & 11	9 & 11	18 & 21	18 & 21	28 & 31	28 & 31
Tested Floors	10 & 11	10 & 11	19 & 20	19 & 20	29 & 30	29 & 30
Flow per envelope area at 75 Pa	0.331	0.167	0.292	0.111	0.182	0.096
Combined	0.249		0.202		0.139	
Correlation	0.999	0.999	0.989	0.991	0.996	0.994
Slope	0.805	0.586	0.792	0.600	0.725	0.668
Notes	No changes in floor-plate of test levels		No changes in floor-plate of test levels		No changes in floor-plate of test levels	

Various Floors, but same Floor Plate

(pressure –neutralizing repeatability issues)

Partial Building Airtightness?

Empirical data - High Degrees of Data uncertainties and inaccuracies can be largely unrecognized

* Compartment/facade testing should NEVER actually ever be considered, due to some extra additional works that need to be undertaken to achieve a targeted leakage rate.

Case study of a building air tightness tested in Melbourne

Level 1 Compartment 3 Fan *	3.7m3/h/m2@50Pa	Building/floors in fire mode, bathroom ventilation taped up
Level 2 Compartment 3 Fan *	18.1m3/h/m2@50Pa	Building/floors in fire mode, bathroom ventilation taped up
Level 3 Compartment 3 Fan*	19.8m3/h/m2@50Pa	Building/floors in fire mode, bathroom ventilation taped up
Level 4 Compartment 3 Fan*	18.4m3/h/m2@50Pa	Building/floors in fire mode, bathroom ventilation taped up
Level 5 Compartment 3 Fan *	5.3m3/h/m2@50Pa	Building/floors in fire mode, bathroom ventilation taped up
Average Whole building Testing with compartment testing *	13m3/h/m2@50Pa	Average Leakage rate in a case study
Whole Building Blower Door Test, 5 Fan Test	5.2m3/h/m2@50Pa	Building in fire mode, all dampers closed off

^ The table above shows a recent actual case study of a commercial building air tightness test in Melbourne. Note the huge difference in leakage rate from overall leakage from a compartment test compared to a whole building airtightness test.

source: Efficiency Matrix

Floor tests vs Full Building

Partial Building Airtightness?

What do standards say about testing a portion of a building?

Larger Buildings

Buildings requiring flow in excess of 200,000 cfm at 75 Pa have been successfully tested using standard techniques. Some larger buildings may require special test techniques not covered in this document primarily because of limitations in *test fans*. 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. These three special techniques will require a higher level of experience and engineering to establish useful results. It is up to the specifier to establish conformance criteria and test procedures for these unique buildings with the help of the testing agency. The Canadian General

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 a bad test, but in practice, tests outside the range of 0.45 to 0.80 would generally indicate an inaccurate

USACE Air Leakage Test Protocol for Building Envelopes – Version 3: 2012-05-11

separate test envelopes and tested separately. While testing isolated subsections, monitoring must be conducted for any extraneous/flanking air movement between the different zones.

USACE

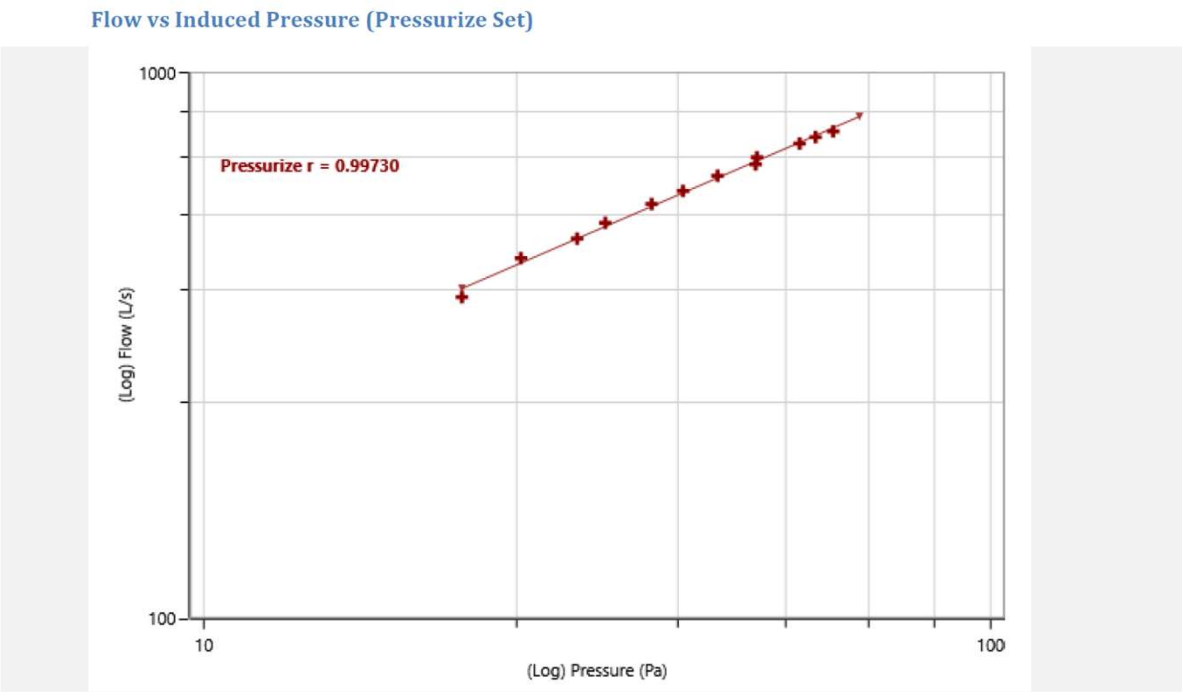
Keywords: “**require higher level of experience and engineering**” which on the surface appears to suggest it could be possible, until you truly understand the requirements and caveats:

ASTM E-3158

- Keywords: “**monitor**” and avoid “**any extraneous air movement between different zones**”, which ASHRAE research paper (RP-4275) claims “isolating [floor] from its neighbor was found to be impossible” (attached)

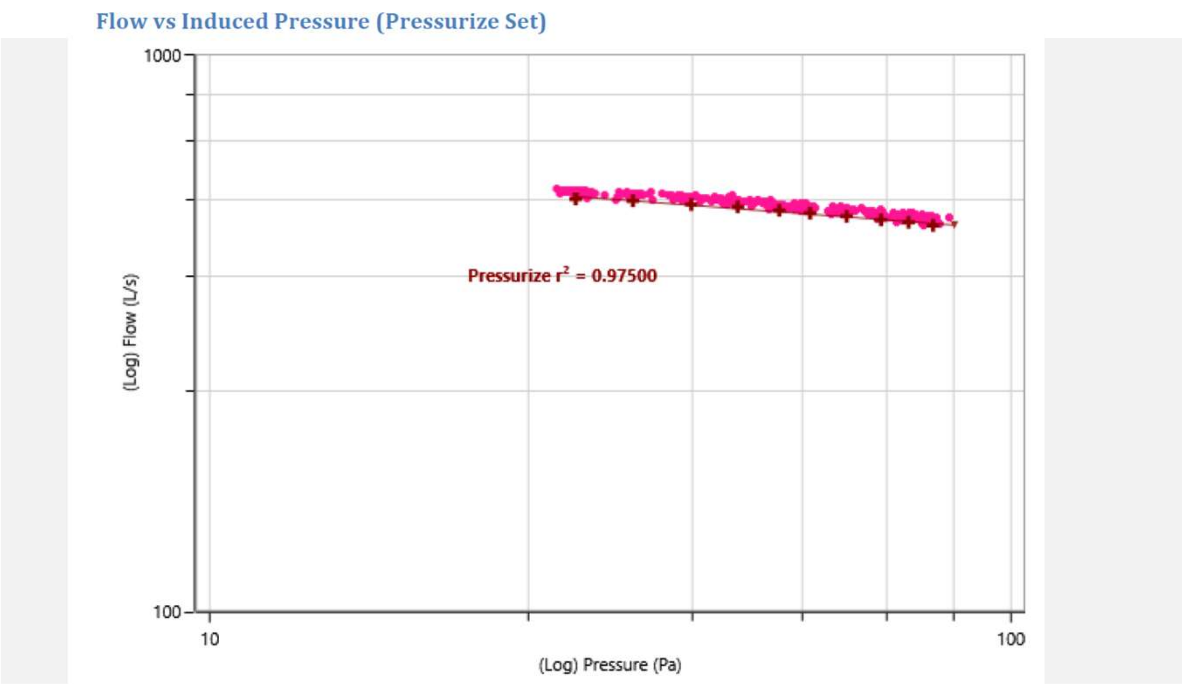
Partial Building Airtightness?

Data uncertainties and inaccuracies largely unrecognized – **Empirical data**



Expectation

n = 0.45 to 0.8

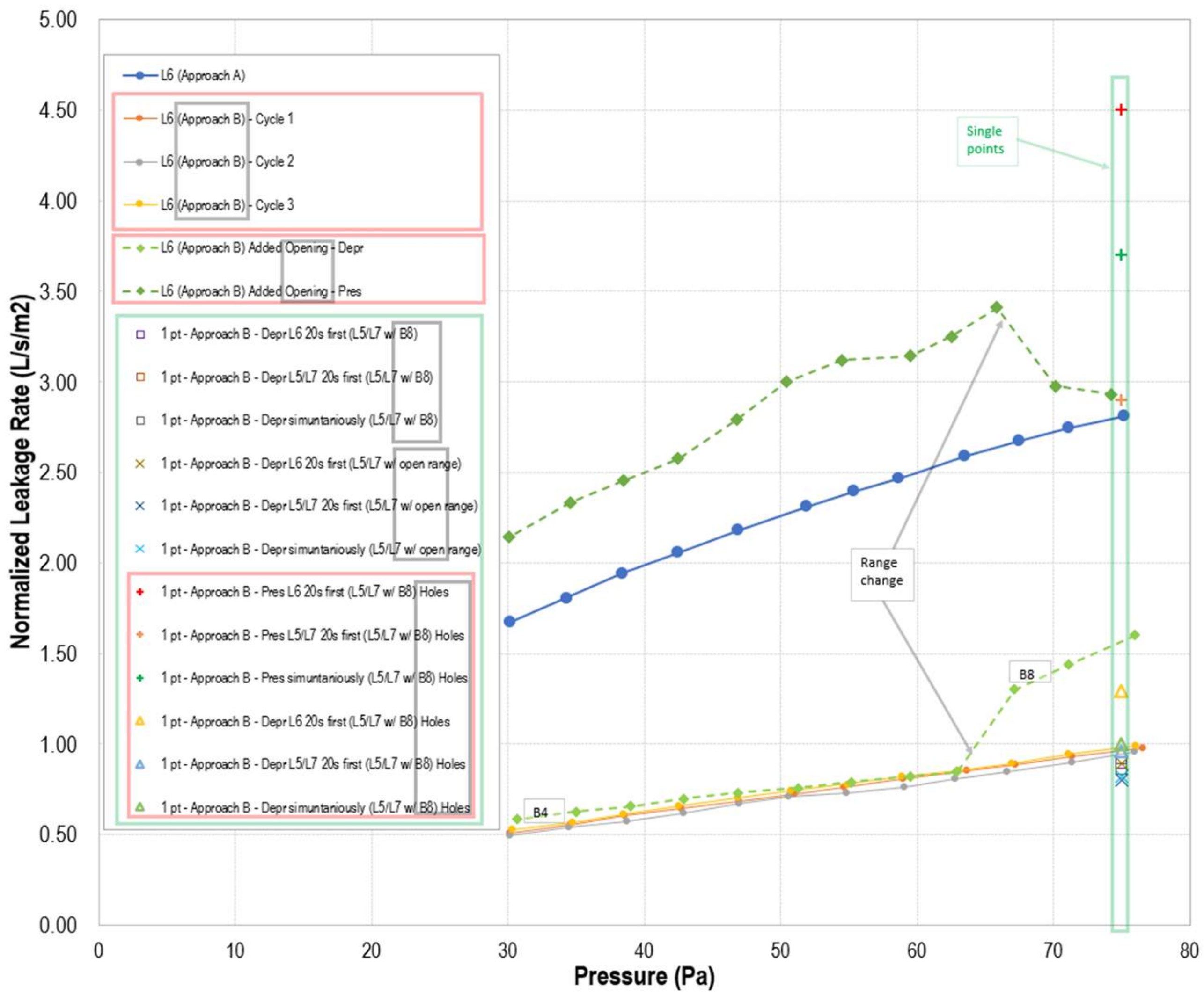


Reality

n = -0.11

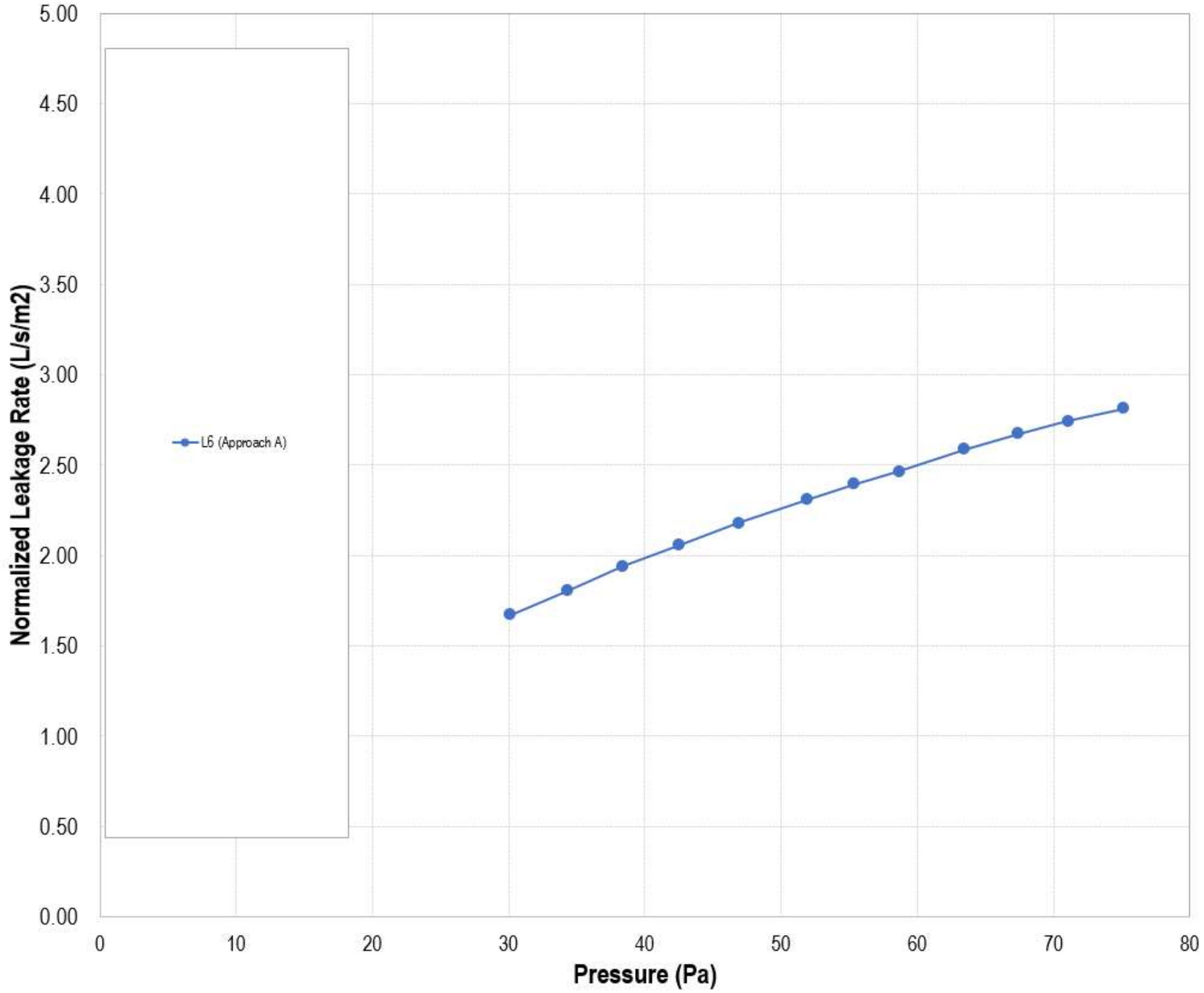
Research Data

Airtightness result variances on tested area



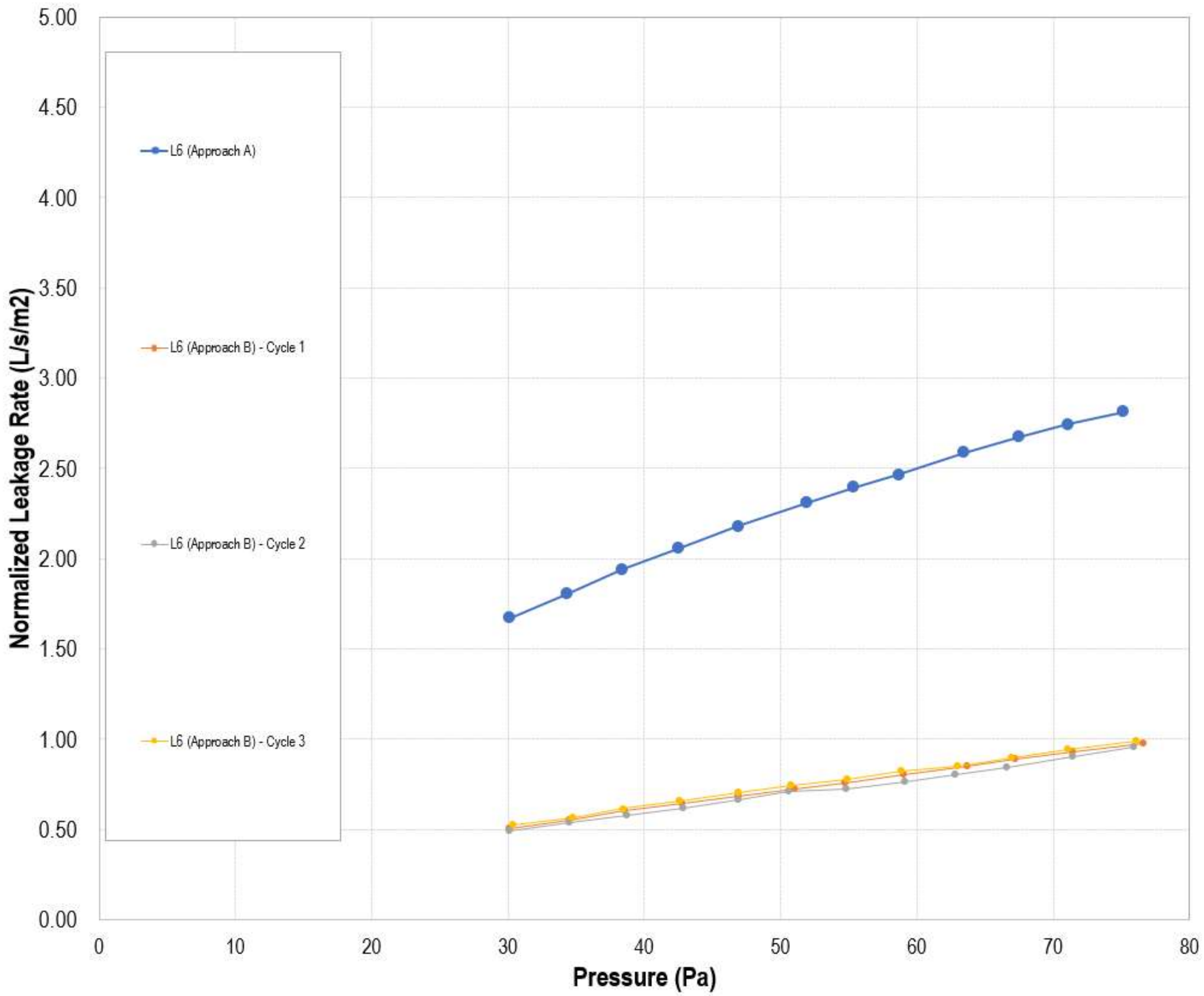
Research Data – Approach B variables

Approach A



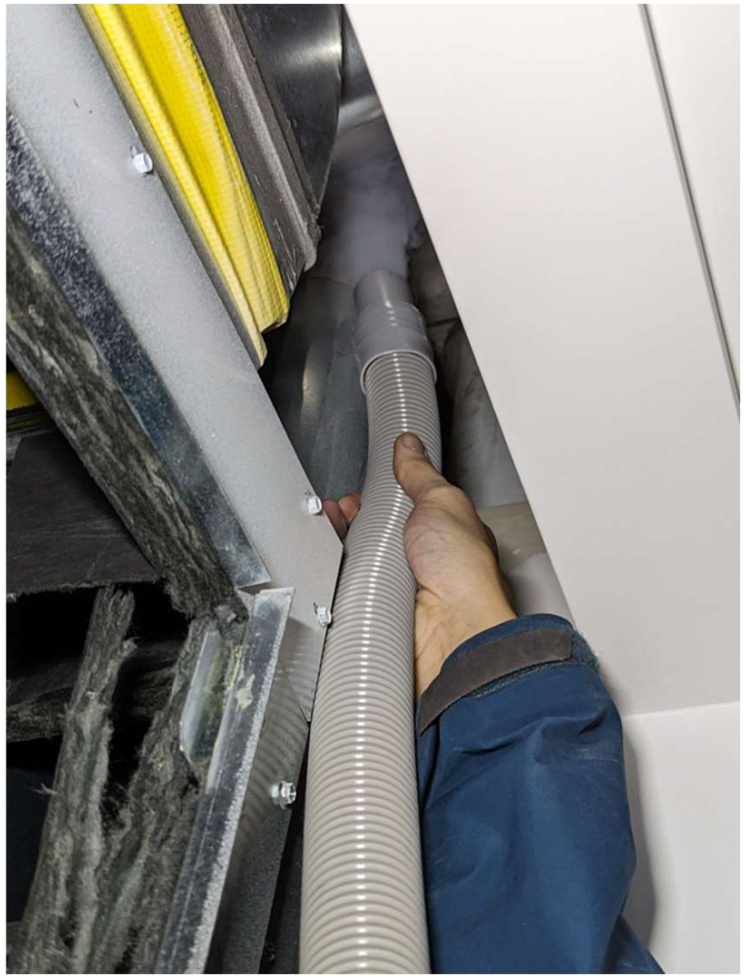
Research Data – Approach B variables

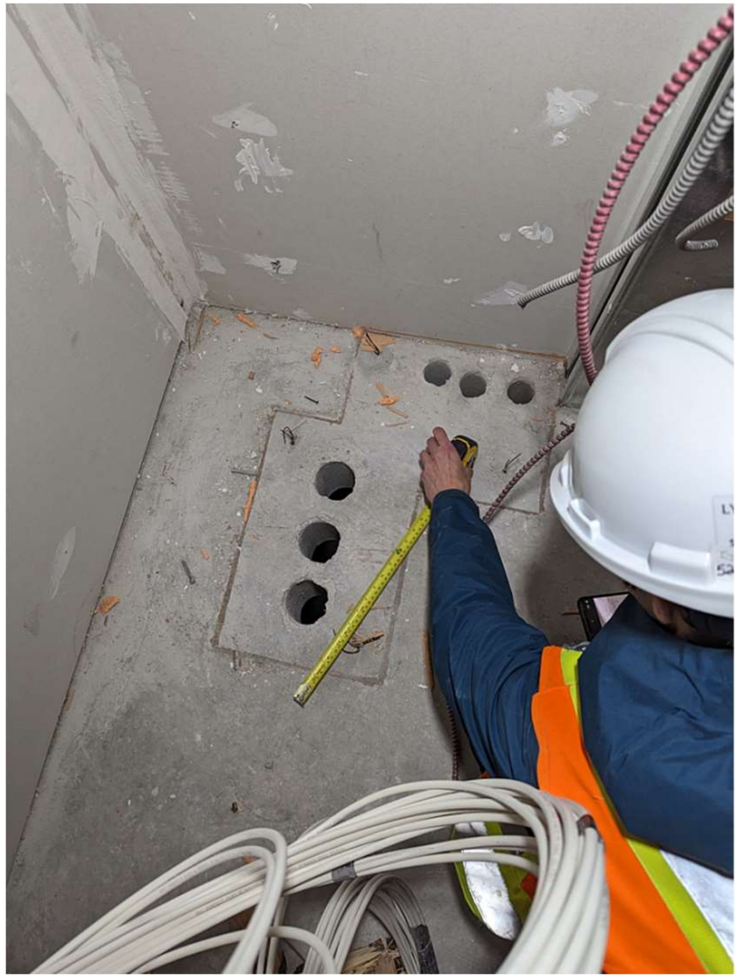
Approach B



Research Data – Approach B variables

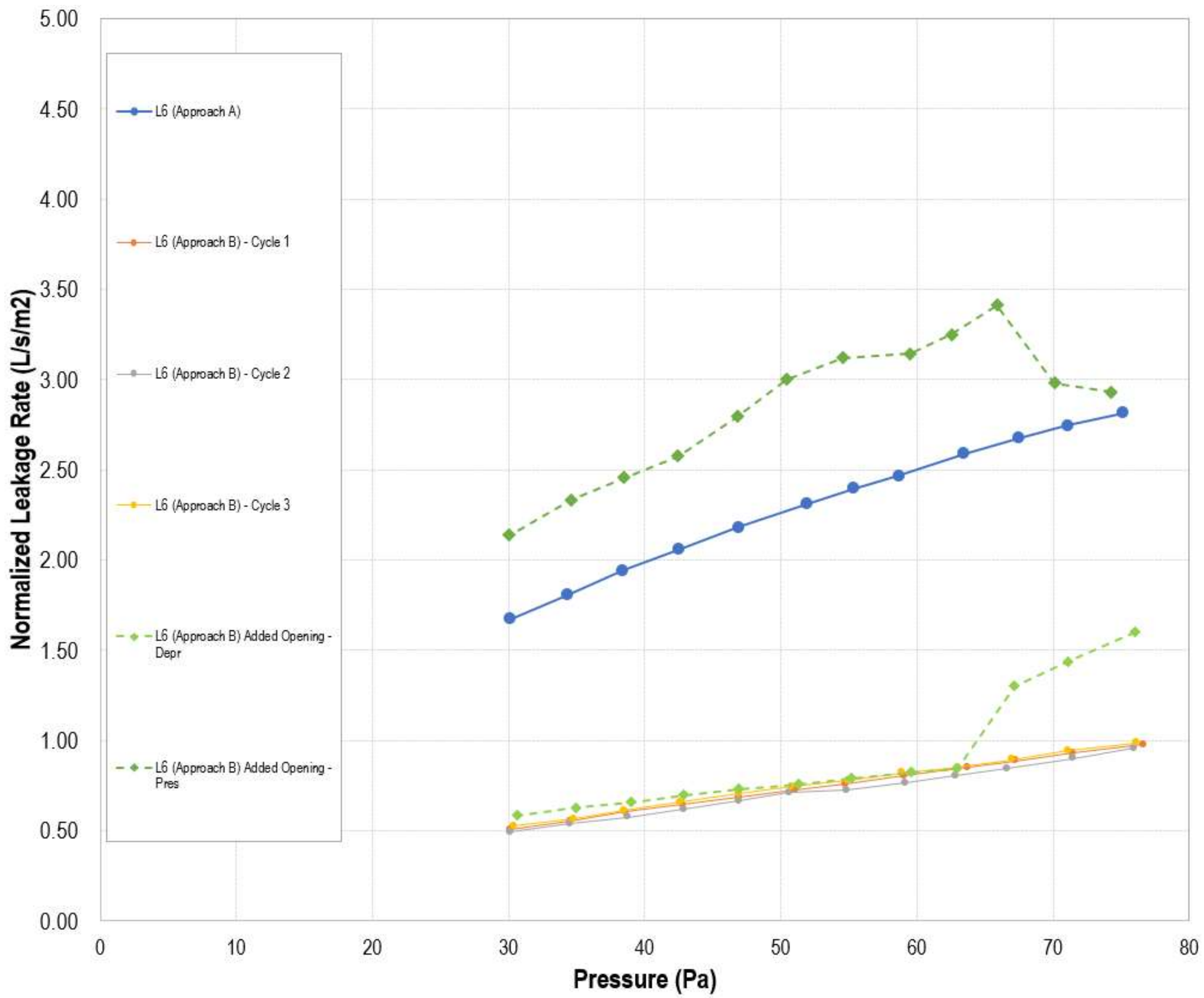
Approach B – with Openings





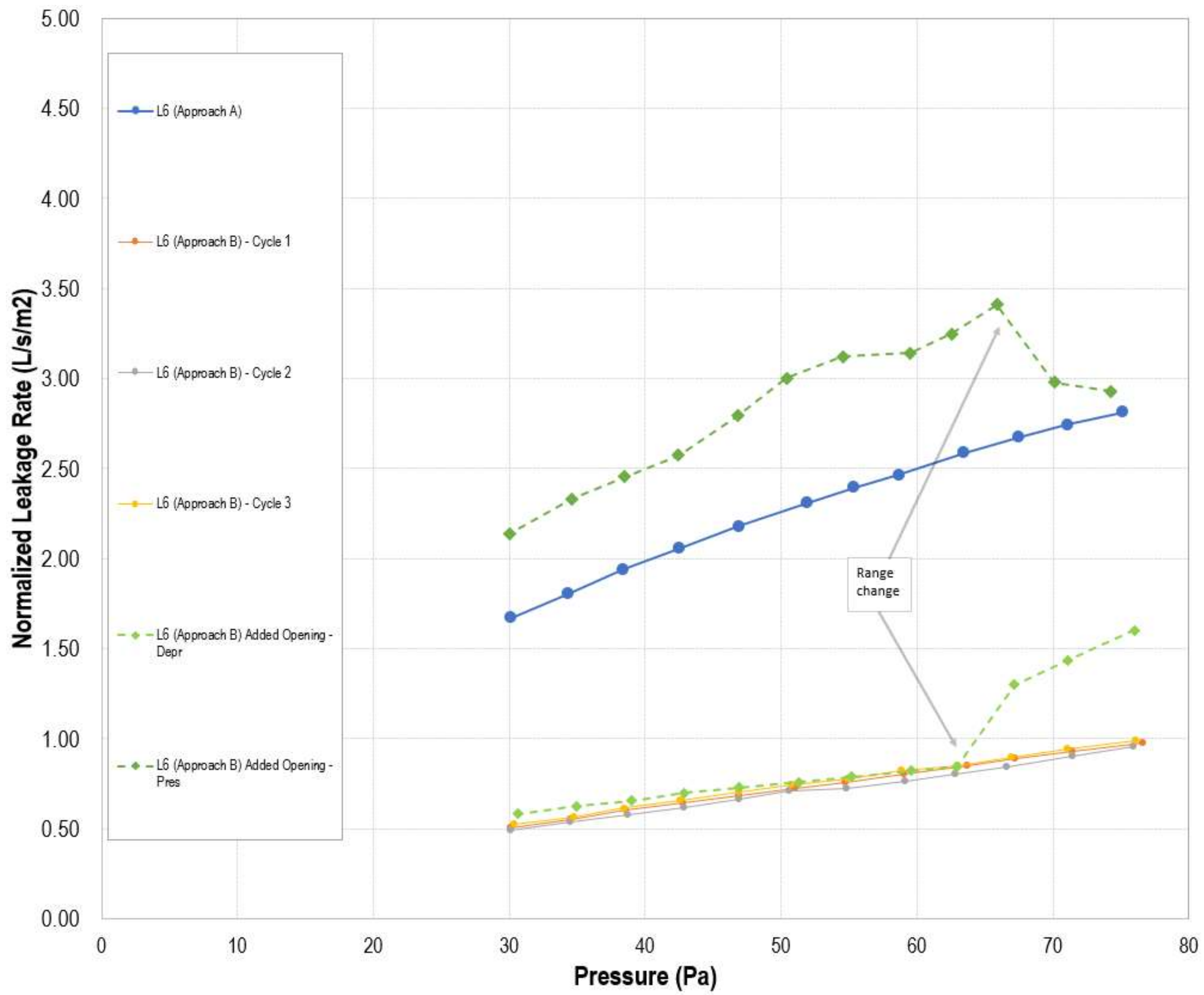
Research Data – Approach B variables

Approach B – with Openings



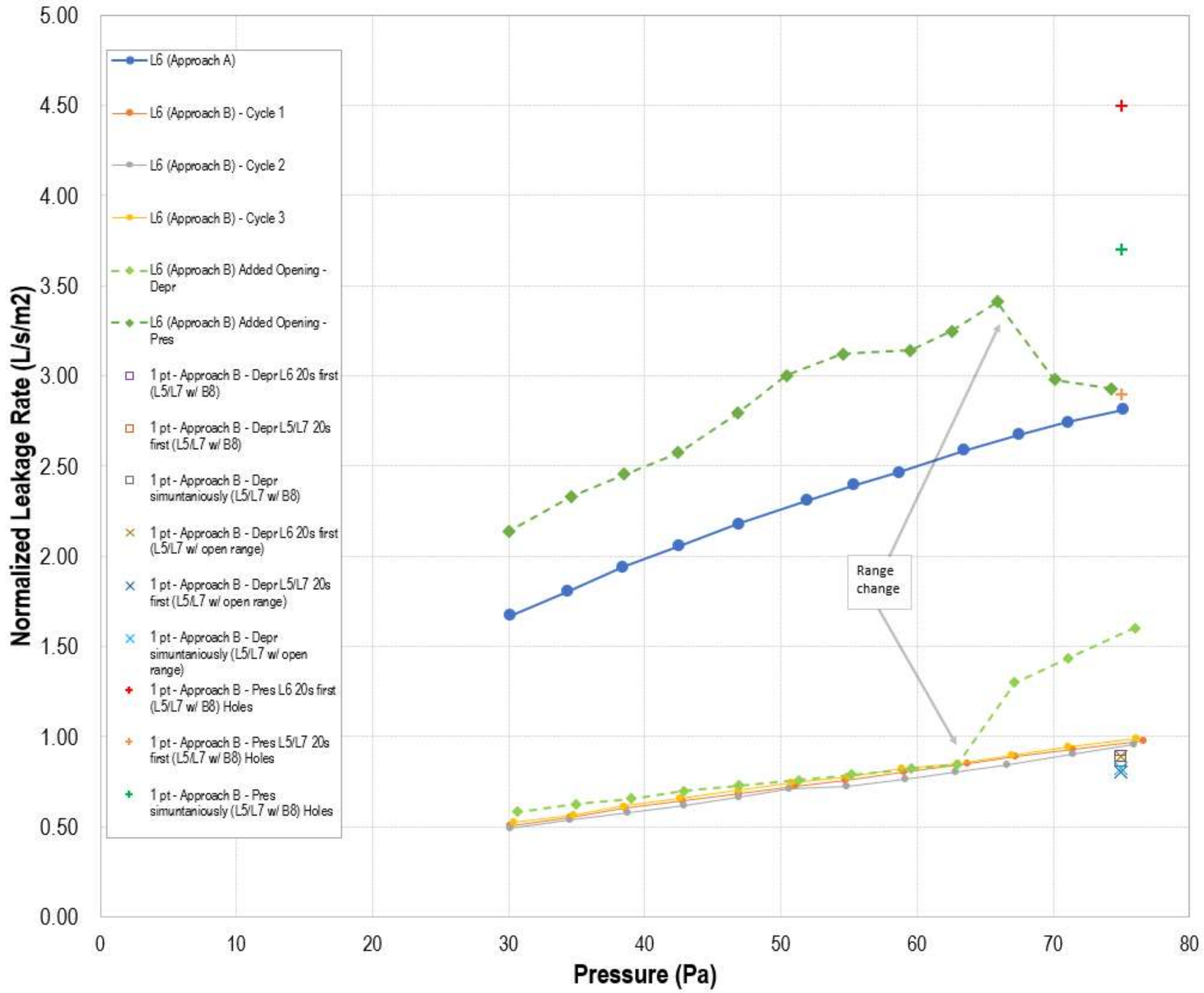
Research Data – Approach B variables

Approach B – with Openings (Range Change implications)



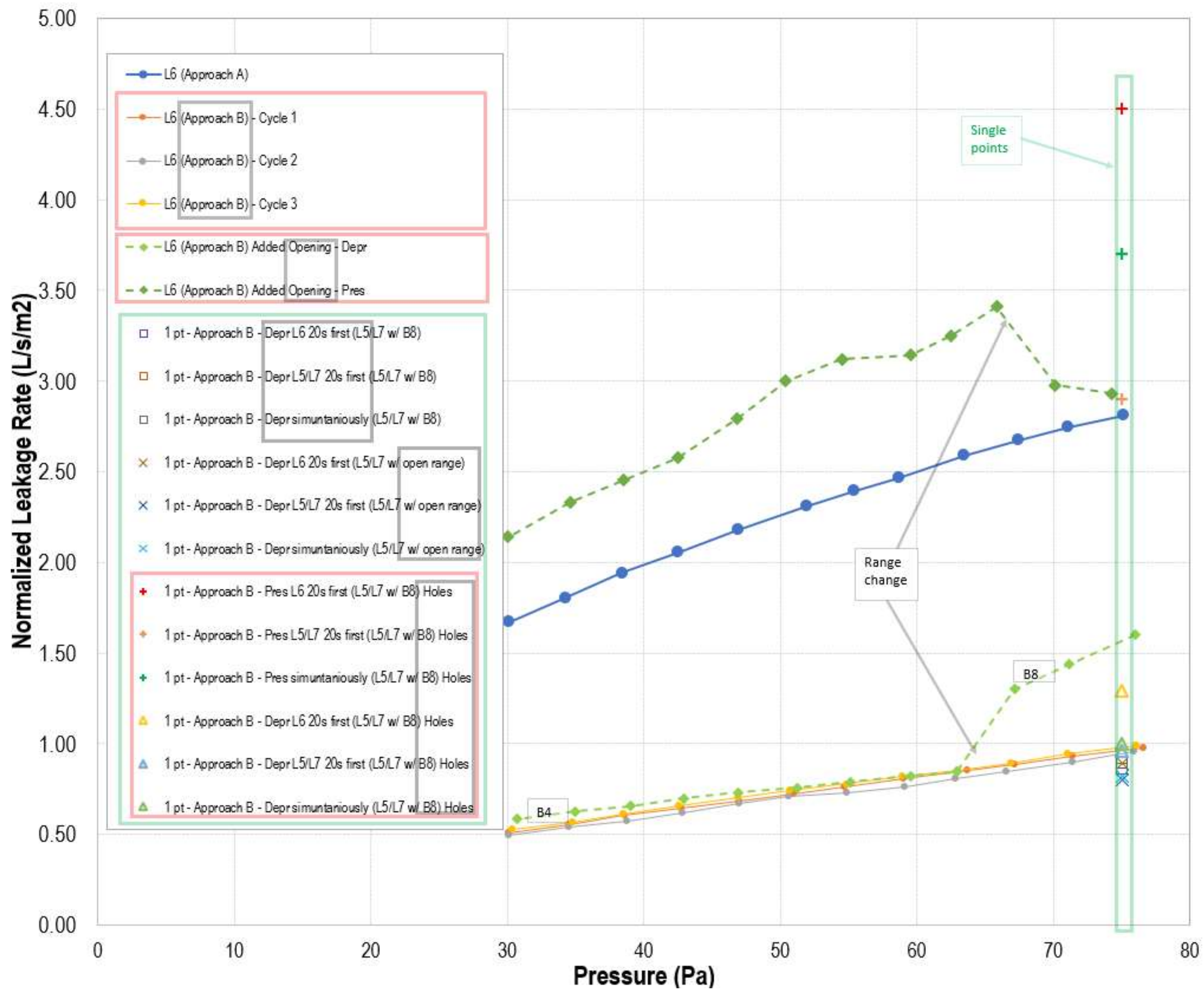
Research Data – Approach B variables

Approach B – with Staggered Fan Starts



Research Data – Approach B variables

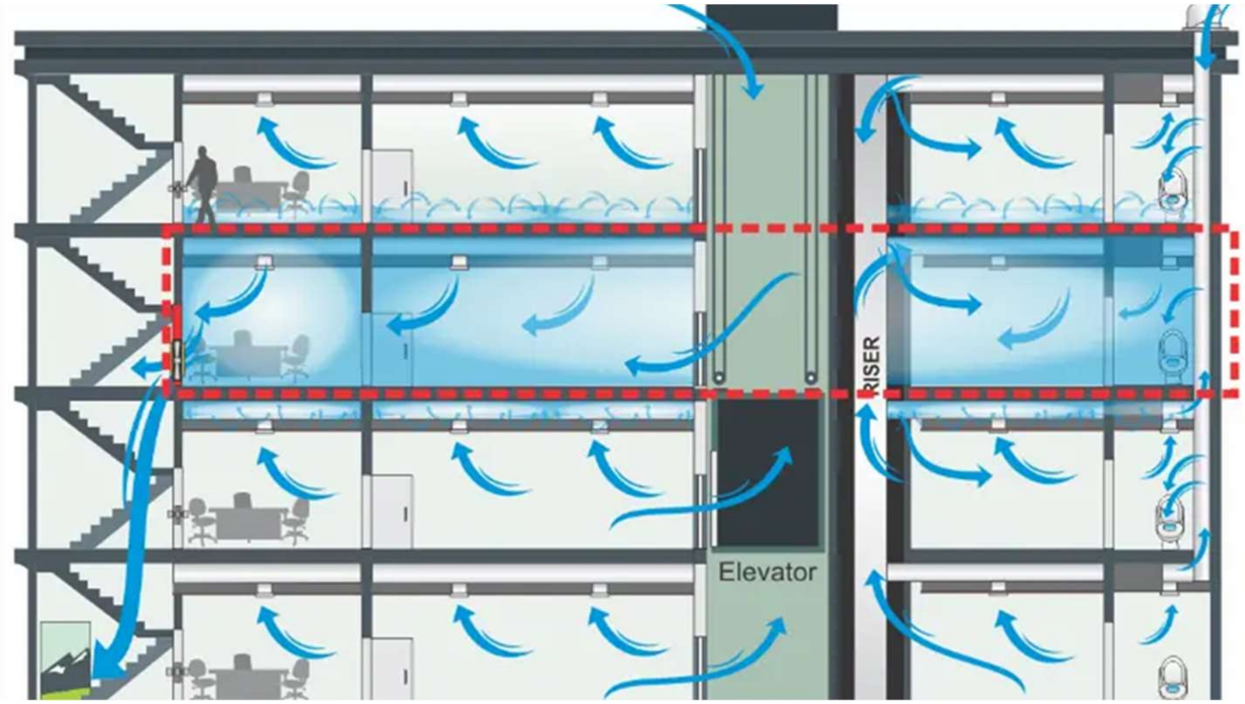
Approach B – with Staggered Fan Starts



Partial Building Airtightness?

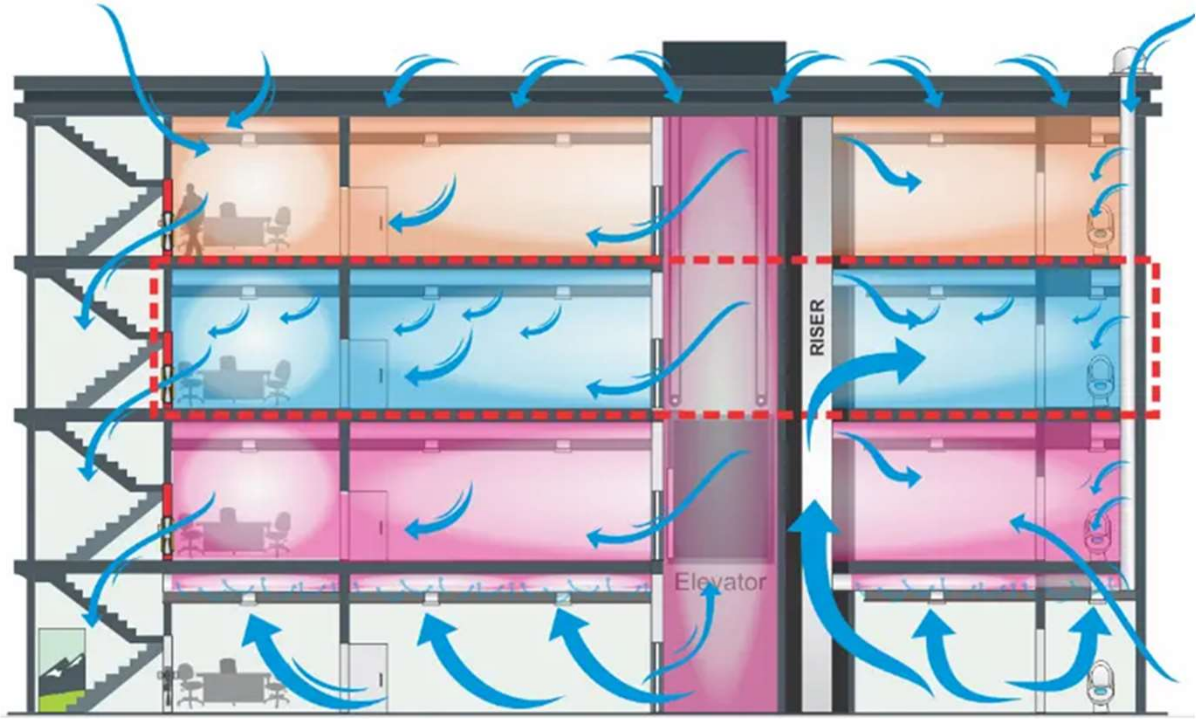
“Compartmentalized” test

– How is this compartment airtightness being quantified and evaluated?



Floors (alone)

Airtightness Test



Floors (pressure-neutralized)

Airtightness Test

photos: Efficiency Matrix

Building Envelope Airtightness Testing

Whole Building Envelope

- Focus on Building Envelope
- Less complicated
- Reproducible test data
- Avoids additional unnecessary work that does not improve building envelope airtightness
- Better to put in extra effort to achieve improvement in airtightness

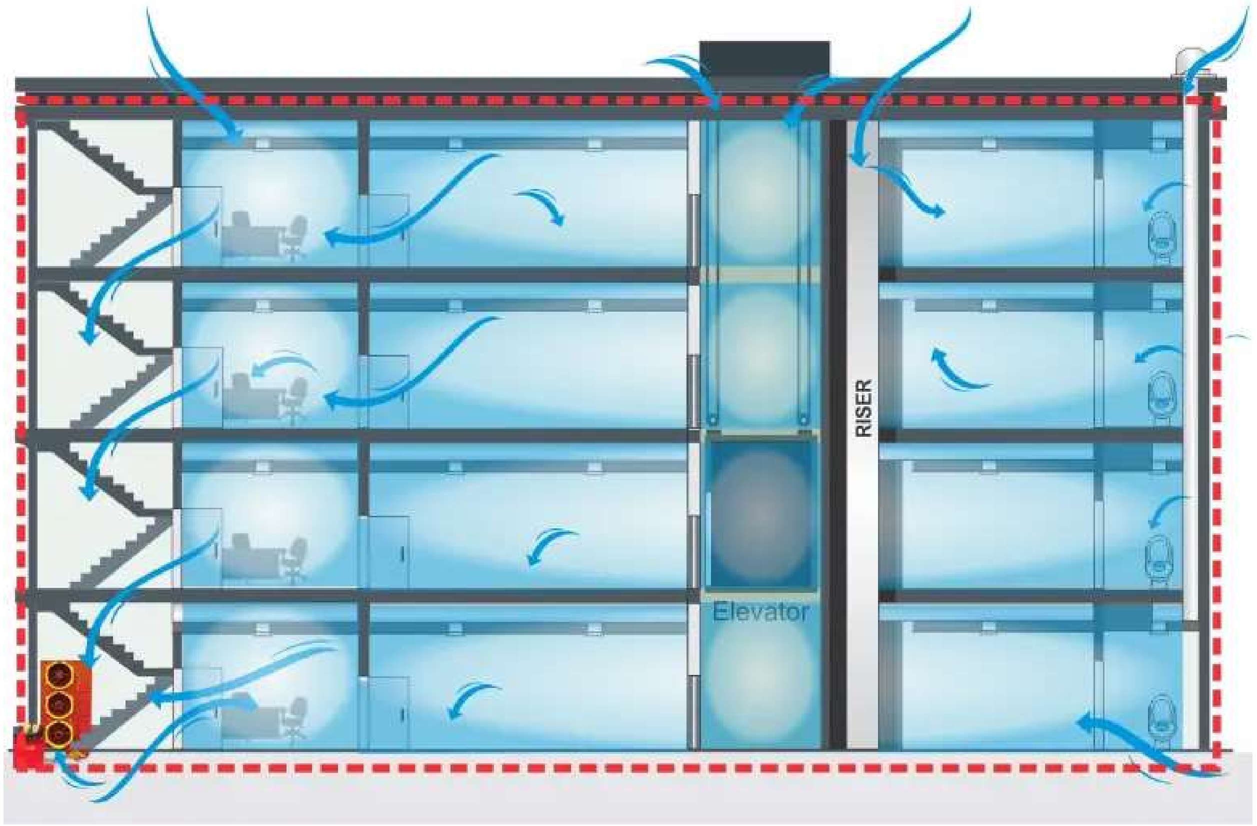


photo: Efficiency Matrix

Partial Building Airtightness Test Results

- Simply checking off a box – just get a number?
  - Are the lines becoming blurred on what's an acceptable standard test approach?
  - Is the number accurate?
  - Is the number misleading?
  - How is this number applied or evaluated?
    - Could the results be misrepresenting the whole building?
    - Could owners, developers, builders be misled on BE issues or lack thereof?
  - Are AHJs, Buidling/Code officials aware of quantification issues?
    - What are the risks and liabilities on design and construction?
  - Does re-testing have to be performed?

- Better understanding and discussions with stakeholders on its limitations
  - Understand the *data* to determine its *validity*
  - Understand the *results* to determine its *accuracy/repeatability*
  - Research

Summary

- Current standards - building as a **whole**
- Approaches - **portion** of the building
  - Impacts from variations of approaches
  - **Awareness** (or lack of awareness) to these impacts
  - **Variables** leading to inaccurate and widely misleading building envelope (BE) airtightness results
    - Understanding these variables - different for every building *and* every test.

- Regression Method
  - Understanding **validity** and **repeatability** of data measurements
  - Understanding conditions leading to **high uncertainties** and **inaccuracies** of the true building envelope airtightness.
  - Avoid misinterpretations and misrepresentations the BE airtightness performance of a building
- What's at stake - impact to design and construction of buildings
- Research

Thank You

abaa2024 building enclosure conference

Stephen Wong, P.Eng.
swong@morrisonhershfield.com

Morrison Hershfield now Stantec