# Airtightness Testing in Large Buildings: NESEA 2016

**Dr John Straube, P.Eng.**

Associate Professor, University of Waterloo

Principal, RDH Building Science

# This session:

- why would one invest in airtightness testing for a large building,
- how the testing is done,
- how the results are interpreted, and
- how this information can be used

# Why airtightness?

- Comfort
- Health
- Moisture
- Energy
- Code
- Standards (e.g. ASHRAE, PassivHaus)

# Enclosure – HVAC interaction

- Without estimate of airtightness:
  - How to size equipment?
  - How to predict energy use?
- Pressurization / depressurization
  - Significant operational implications

- Old buildings were leaky and this did not matter ….

# Measuring Airtightness

- Usually use ASTM E779 /E1827 (in North America)
- May use building airhandler if flow can be measured accurately (e.g. CGSB)
- Buildings over 800 000 sf and 30 stories have been tested to date
- USACE has best protocol IMHO, supported by best ASHRAE research

# Excellent Reference.

http://www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf

US Army Corps of Engineers®
Engineer Research and Development Center

air barrier
abaa
association of america

**U.S. Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes**

**Version 3 - May 11, 2012**

| | CGSB<br>149.10 - M86 | CGSB<br>149.15 - 96 | ASTM<br>E 779 - 10 | ASTM<br>E 1827 - 11 | ISO<br>9972:2012 | USACE | ATTMA Technical Standard<br>L2 | ABAA (unreleased) |
|---|---|---|---|---|---|---|---|---|
| **Origin of Standard** | Canada | Canada | USA | USA | International | USA | United Kingdom | USA |
| **Intended Building Type** | Small detached but adaptable for larger buildings | Buildings with air handling systems | Single zone buildings | Single zone buildings | Single zone buildings | All buildings | Non-Dwellings | All buildings |
| **Recommended Test Conditions** | Wind < 20 km/hr (5.6 m/s) | Wind < 20 km/hr (5.6 m/s)<br>Temperature limit depending on building height | ΔT x Height < 200 m°C | Wind < 2 m/s<br>5°C ≤ T ≤ 35°C | Wind at Ground < 3 m/s<br>Wind at Station < 6 m/s<br>Wind < 3 on Beaufort Scale<br>ΔT x Height < 250 m·K | Max. Baseline Pressure < 30% of minimum induced pressure difference | ΔT x Height < 250 m·K<br>Baseline < ± 5 Pa | None, but minimum pressure determined based on baseline or stack presures. |
| **Baseline Pressure Measurement** | Before and After<br>(no duration provided) | Before and After<br>(no duration provided) | Before and After for min. 10 s | Before and After<br>(no duration provided) | Before and After | Before and After<br>(12 measurements each time for min. 10 sec each) | Before and after for min. 30 sec | Before and after for 120 sec |
| **Range of Test Pressure Differences** | 15 Pa to 50 Pa | Not provided | 10 to 60 Pa | Single-Point: 50 Pa<br>Two-Point: 50 Pa & ≈12.5 Pa | At least one > 50 Pa, with allowance for 25 Pa in large buildings<br>(Recommend 10 Pa (or 2 x baseline) to 100 Pa at maximum 10 Pa increments) | Min. Range of 25 Pa<br>One-Sided: > 50 Pa to > 75 Pa<br>Two-Sided: > 40 Pa to > 75 Pa<br>Max ≤ 85 Pa | Min. is greatest of 10 Pa or 5 x Baseline<br>Max. is > 50 Pa<br>Range > 25 Pa | Min is greatest of "Baseline + 10 x baseline std. dev.", "Stack pressure / 2", and 10 Pa.<br>Max. is < 100 Pa<br>Range > 25 Pa |
| **Number of Test Points & Duration** | 8<br>(duration not provided) | 4<br>(duration not provided) | > 5 for min. 10 sec | Single-Point: 5 at 50 Pa<br>Two-Point: 5 at each of 50 Pa & 12.5 Pa<br>(no duration provided) | > 5<br>(duration not provided) | 10 for min. 10 sec | 7 at < 10 Pa in…<br>(no durati… | > 10 |
| **Preferred Test Direction** | Depressurize | Either | Both | Either | Both | Both | | Either |
| **Acceptable Test Direction** | Depressurize | Either | Both Required | Either | Either | Both<br>(either for v… | Either | Either |
| **Reporting Metric(s)** | C, n, EqLa, NLA | C, n, $Q_5$, $Q_{50}$, $Q_{75}$ | C, n, EfLA (or other) for both pressurization, depressurization, and average | Single-Point: $Q_{50}$<br>Two-Point: C, n, EfLA, $Q_{50}$ | C, n for both pressurization and depressurization | | C, n, $Q_{50}$ | |
| **Preparation of Intentional Openings** | Schedule provided | Limited guidance | Close operable dampers | Schedule provided, with options | Schedule provid…<br>op… | …escription provided | Description provided | Schedule provided, with options |
| **Acceptable Ranges** | 0.50 ≤ n ≤ 1.00<br>R > 0.990<br>$(Q_{regression} - Q_{measured}) / Q_{measured}$ < 0.06 L/s for all pressures<br>Standard Error at 10 Pa < 0.07 L/s | 0.50 ≤ n ≤ 1.00<br>R > 0.990<br>$(Q_{regression} - Q_{measured}) / Q_{measured}$ < 0.06 L/s for all pressures | 0.50 ≤ n ≤ 1.00 | None provided.<br>(Single and Two-Point tests do not provided sufficient information for detailed precision analysis) | 0.50 ≤ n ≤ 1.00<br>$R^2$ > 0.98 | 0.45 ≤ n ≤ 0.80<br>95% CI + $Q_{75}$ < Requirement or $Q_{75}$ < Requirement &<br>95% CI < 0.02 cfm/ft² at 75 Pa.<br>$R^2$ > 0.98 | 0.50 ≤ n ≤ 1.00<br>$R^2$ > 0.98 | 0.45 ≤ n ≤ 1.05<br>$R^2$ > 0.98<br>Max test pressure > 0.9 specified target pressure<br>Various 95% CI requirements for determination of pass or fail. |
| **Other** | Includes allowance for pressure equalizing adjacent zones which is intended for attached buildings, but could be adapted for zones within a building | Because calibrated fans are not used in this method, flow rate must be measured using alternative methods. | Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 5% of the test pressure. | Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 5% at the maximum test pressure and 2.5 Pa at 50 Pa. | Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% of the measured test pressure. | Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% at test pressure of 30 Pa. Contains allowance for testing zone within a building, but does not pressure equalize. | Indicates that a check of single zone conditions should be performed for buildings > 20 m tall to ensure that the interior pressure differs by no greater than 10% at test pressure of 50 Pa. Allowance for equalized testing of tall or complex buildings. | Indicates that a check of single zone conditions should be performed to ensure that the interior pressure differs by no greater than 10% of the measured test pressure. |

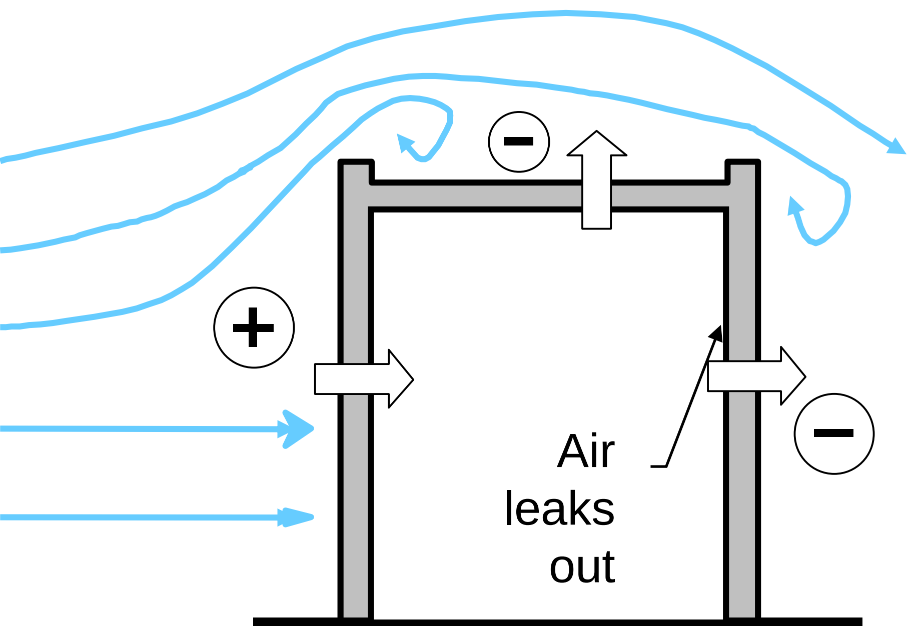
**Many available standards**

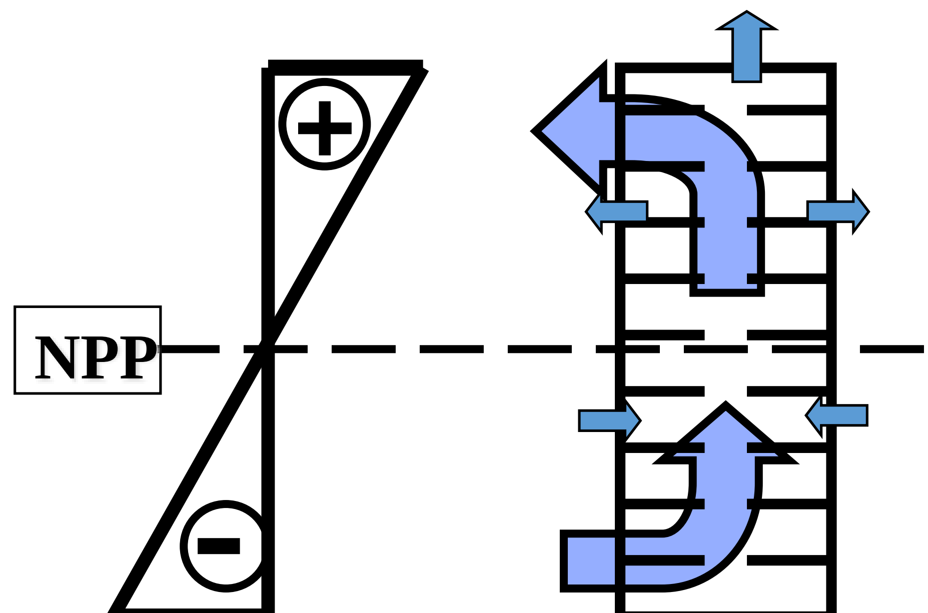
# How to measure?

- Pressurize/depressurize
  - Unlike in houses, *both* are recommended
- Seal / damper intentional holes
  - Beware operational reality vs test
- Limit testing when pressures imposed
  - Stack effect
  - Wind
  - Important issues for large buildings

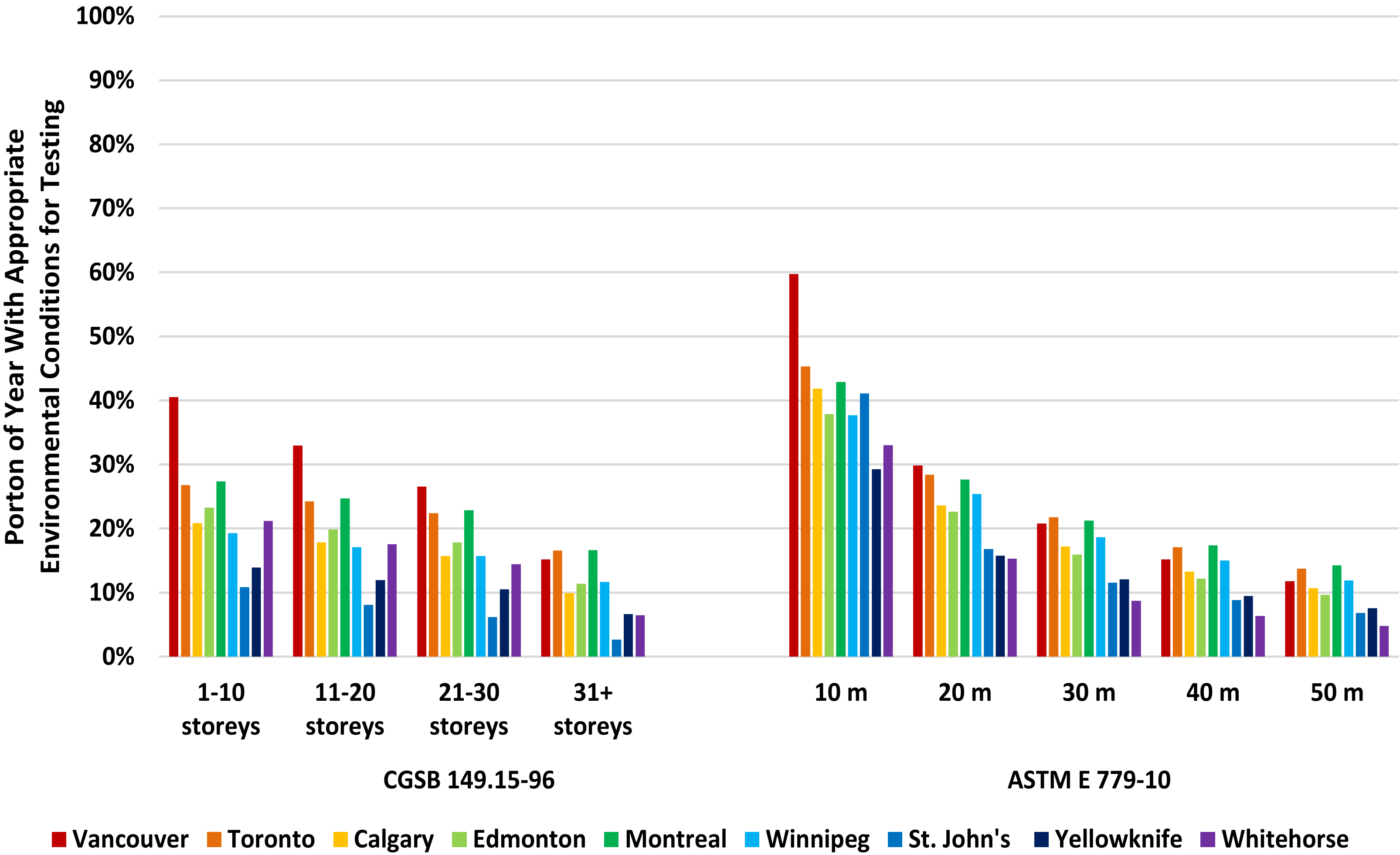
# Pressures During Test

- Wind & Stack
- If too large, can't test



# When can one test?



# Measurement Reporting

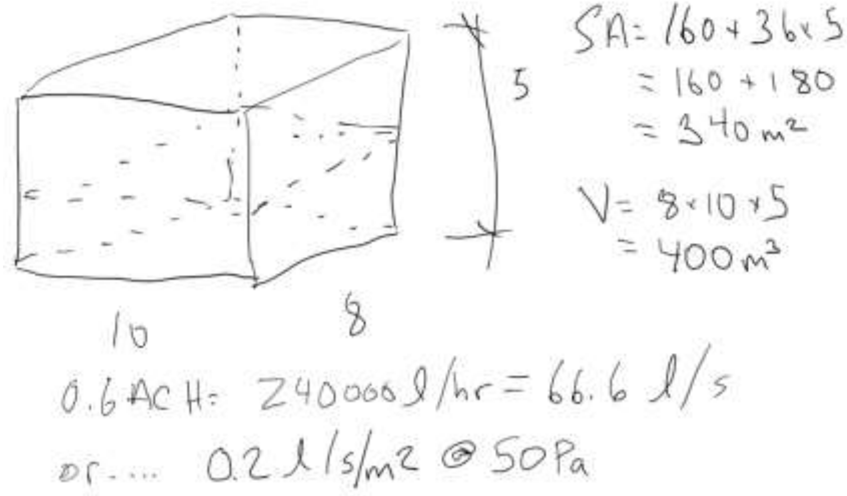
- Common to use ACH@50 for houses
  - This is not a good metric for *enclosures*
- Industry has chosen cfm/sf @ 75 Pa for *commercial* buildings
  - Accounts for enclosure : floor ratio
  - Which test? Pressurization or Depressurization
- Use of total enclosure area is common
  - Check that the area used includes slab
  - Where is conditioned/unconditioned space?

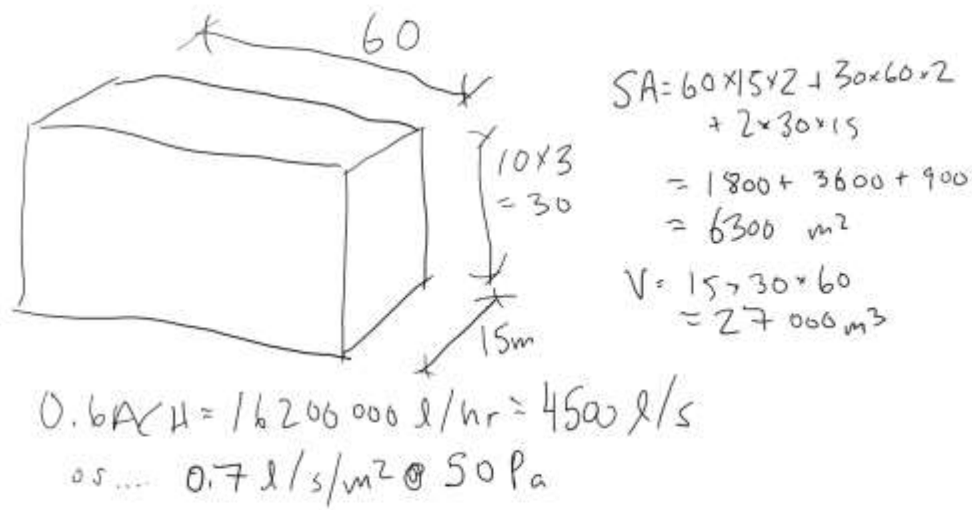
# Reporting Metrics

- ACH @ pressure (usually @50 Pa)
  - Volumetric flow rate / volume
- Permeance (usually @50 or 75 Pa)
  - Volumetric flow rate / area
  - What area?
  - Recommend six sided area
- Higher pressures are both possible and preferable for measurement accuracy

# Why ACH is a poor metric

- e.g. a 2 story house vs hi-rise apt. @0.6ACH
- House 0.2 l/s/m$^2$
  vs
- Apartment 0.7 l/s/m$^2$
- Large buildings can easily meet low ACH targets
- But relation to performance?



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# Targets?

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TABLE 4.1 WHOLE BUILDING AIRTIGHTNESS PERFORMANCE REQUIREMENTS FOR CANADA AND THE UNITED STATES (RETROTEC, 2012)

| Standard | Region | Comments | Requirements |
|---|---|---|---|
| USACE | USA | Large Buildings | 1.27 L/(s·m²) @ 75 Pa |
| | | Large Buildings (Proposed) | 0.76 L/(s·m²) @ 75 Pa |
| GSA | USA | All Buildings | 2.03 L/(s·m²) @ 75 Pa |
| 2012 Washington State Energy Code | Washington State | Commercial Buildings | 2.03 L/(s·m²) @ 75 Pa |
| 2012 Seattle Energy Code | Seattle | Commercial Buildings | 2.03 L/(s·m²) @ 75 Pa |
| IBC/IECC | Model Code | Commercial Buildings in Climate Zone 4 – 8 | 2.03 L/(s·m²) @ 75 Pa |
| IGCC | Model Code | Commercial Buildings | 1.27 L/(s·m²) @ 75 Pa |
| LEED | USA | All 6 surfaces enclosing an apartment. | 1.17 L/(s·m²) @ 75 Pa |
| LEED Canada | Canada | All 6 surfaces enclosing an apartment. | 1.52 L/(s·m²) @ 75 Pa |
| Passive House (Canada | Canada | All buildings | 0.6 $ACH_{50}$ |

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# Targets, e.g. GSA

- Air impermeability
  - Material: 0.02 lps/$m^2$ @75 Pa 0.004 cfm / $ft^2$ @0.3"wg
  - Component: 0.2 lps/$m^2$ @75 Pa 0.04 cfm / $ft^2$ @0.3"wg
  - Building: 2.0 lps/$m^2$ @75 Pa 0.4 cfm / $ft^2$ @0.3" wg
- *Building* requirement most important for energy, interior RH, IAQ
- *Component* requirement *may* matter for air leakage condensation control, comfort

# Practical Issues: A Big Deal

- Occupancy– doors opening, bathroom fans operating, HVAC operation?
- Security/Safety- opening doors to connect interior spaces together
- Control & Power.  How to control many different blowers  How to power same.
- Sealing.  Need to access and seal many HVAC vents grilles, etc.

# Sealing Openings

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# Whole-Building Testing

- Test early if you **must** hit a target
- Design enclosure for **testability**
  - Construction sequencing!
- Test before most of air barrier system is covered by other layers
- Do mockups
- Confirm trades are executing early


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# Large Building Air Leakage Testing


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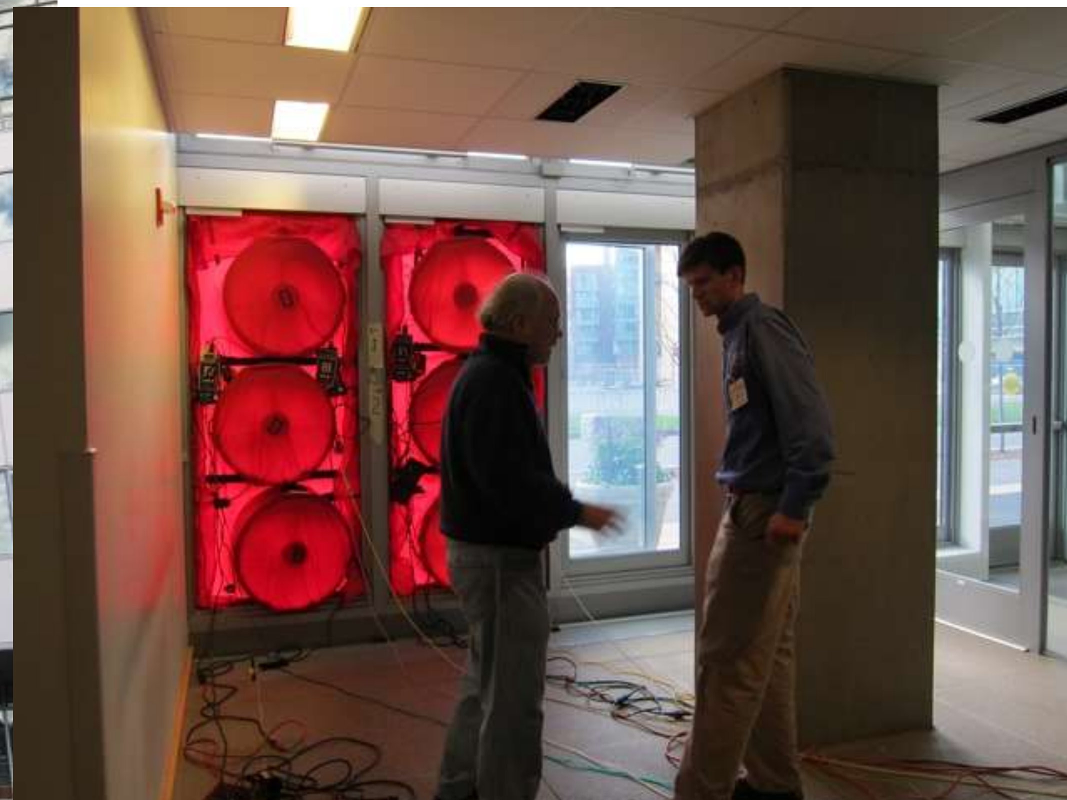
# Air Leakage Testing

- Power Supply: 15A-20A per door

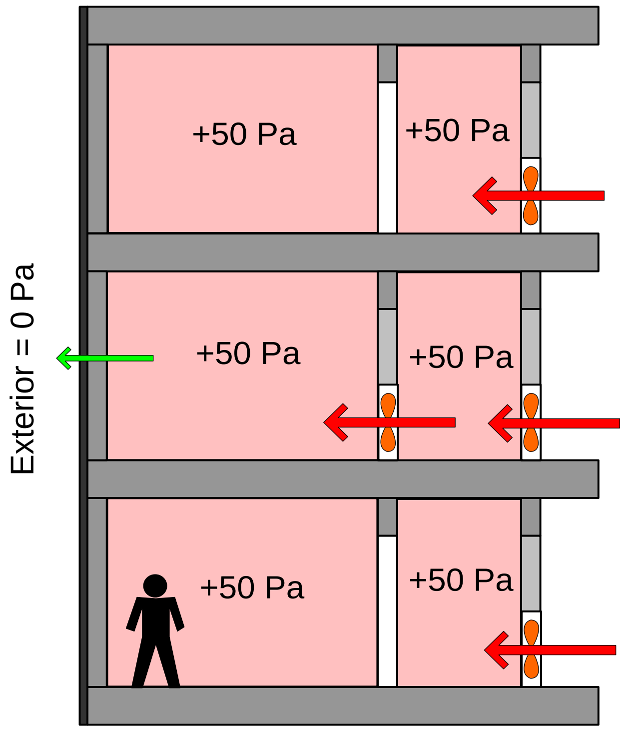
# HVAC Systems

- Grills, louvers, dampers, vents are all penetrations of the air barrier system
- Become one of the largest sources of leakage in “good” buildings
- Typically these are excluded from targets, but should be measured if you can

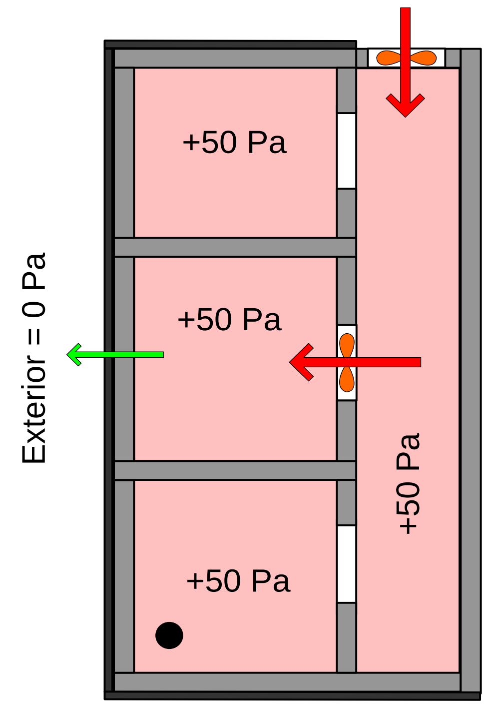
# Compartmentalization

- Construction sequencing
- Managing size
- Research

Test # 6 – Pressurize Suite and All Adjacent Interior Surfaces



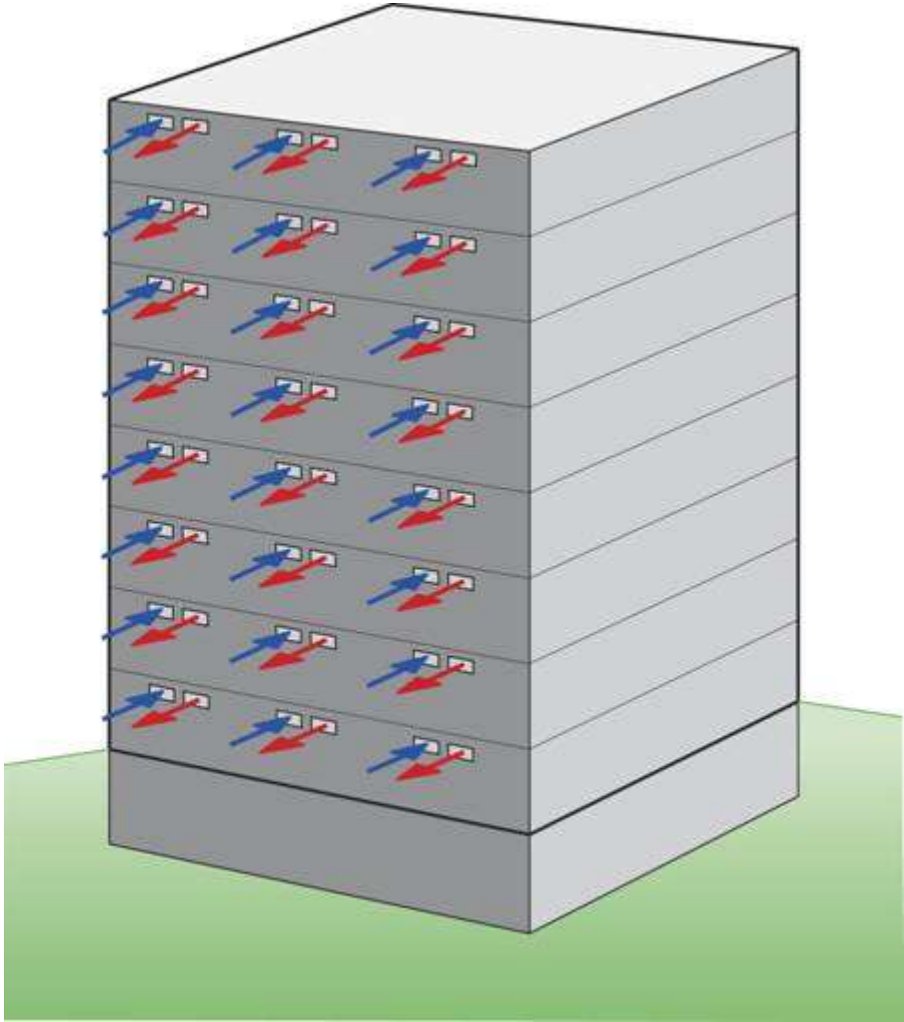

*Section View – Floor Above and Below*




*Plan View – Test Floor*

# Many suites / many holes

- Significant effort required for multi-unit buildings…..
- Depressure easier



# What to do with results?

- First, find the leaks
- Commonsense/experience is helpful
- ASTM E1186 *Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems*
- IR camera, smoke, hand

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# IR Camera

- Requires skilled operator
- Temperature difference
- Flow inward, then outward


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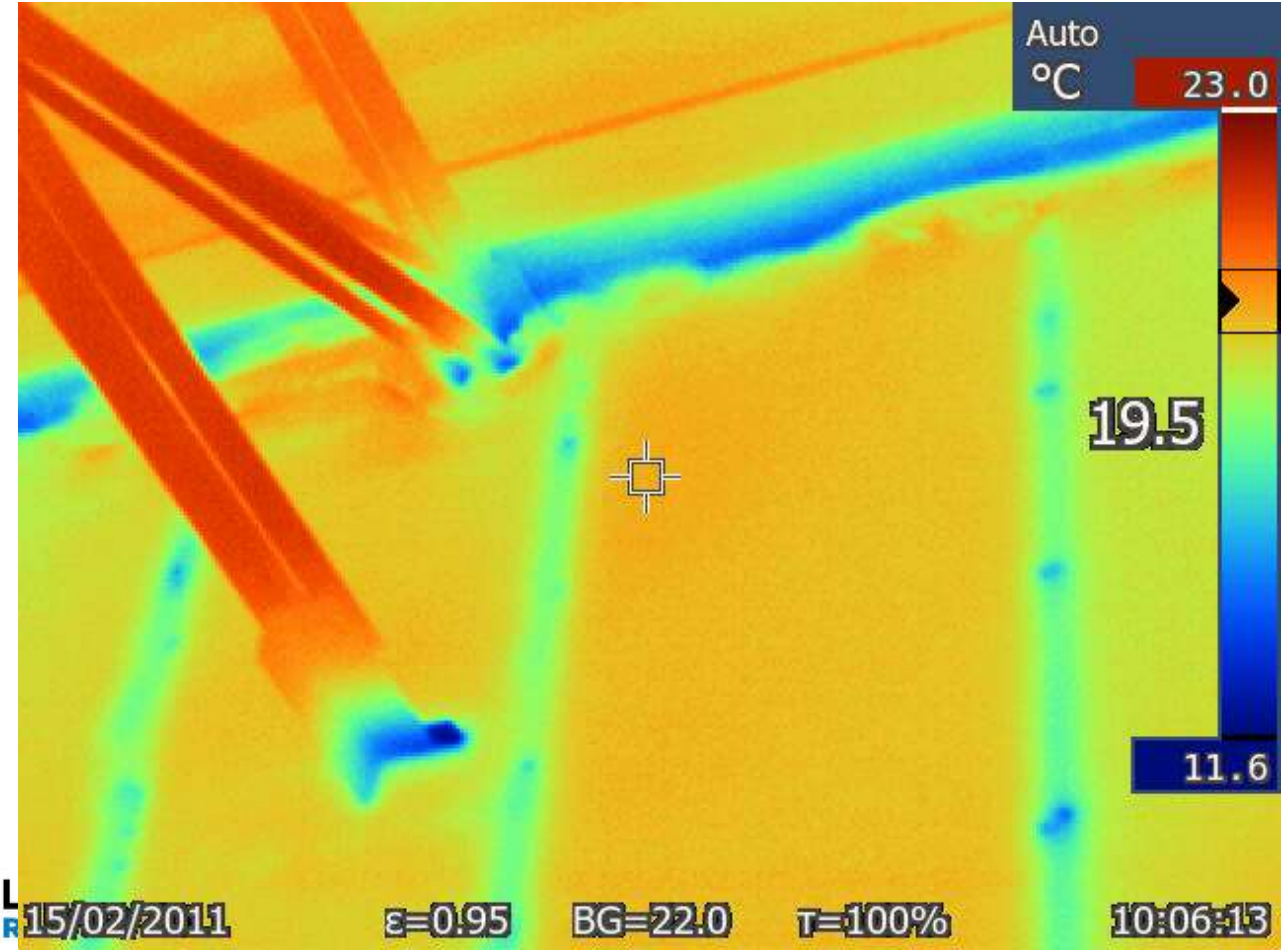
# Air leak or thermal bridge?

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# Smoke / visualization

- Especially useful diagnostically
- Demonstration to trades

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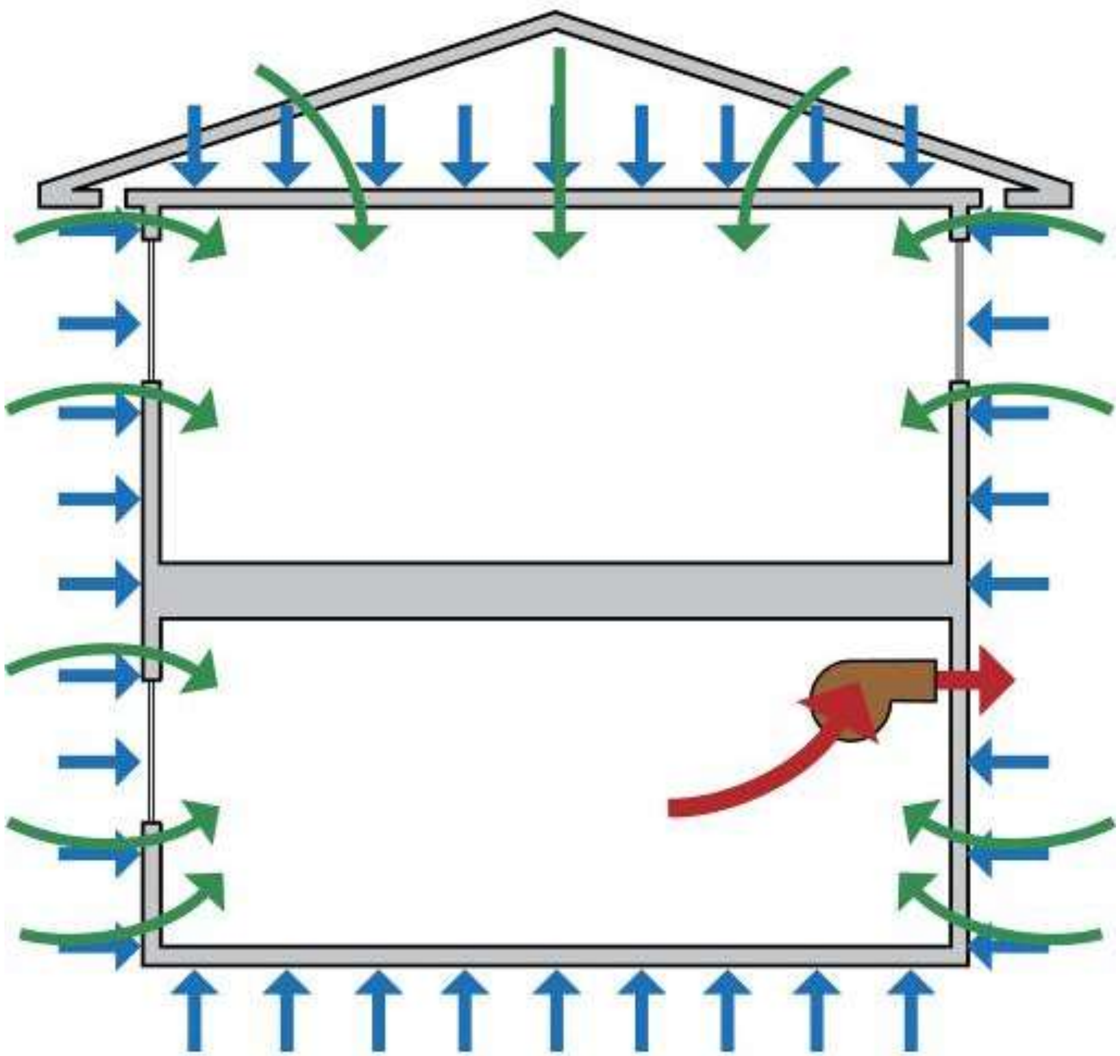
## Blower doors…

- Imposes Uniform Air pressures
- Real life is not uniform

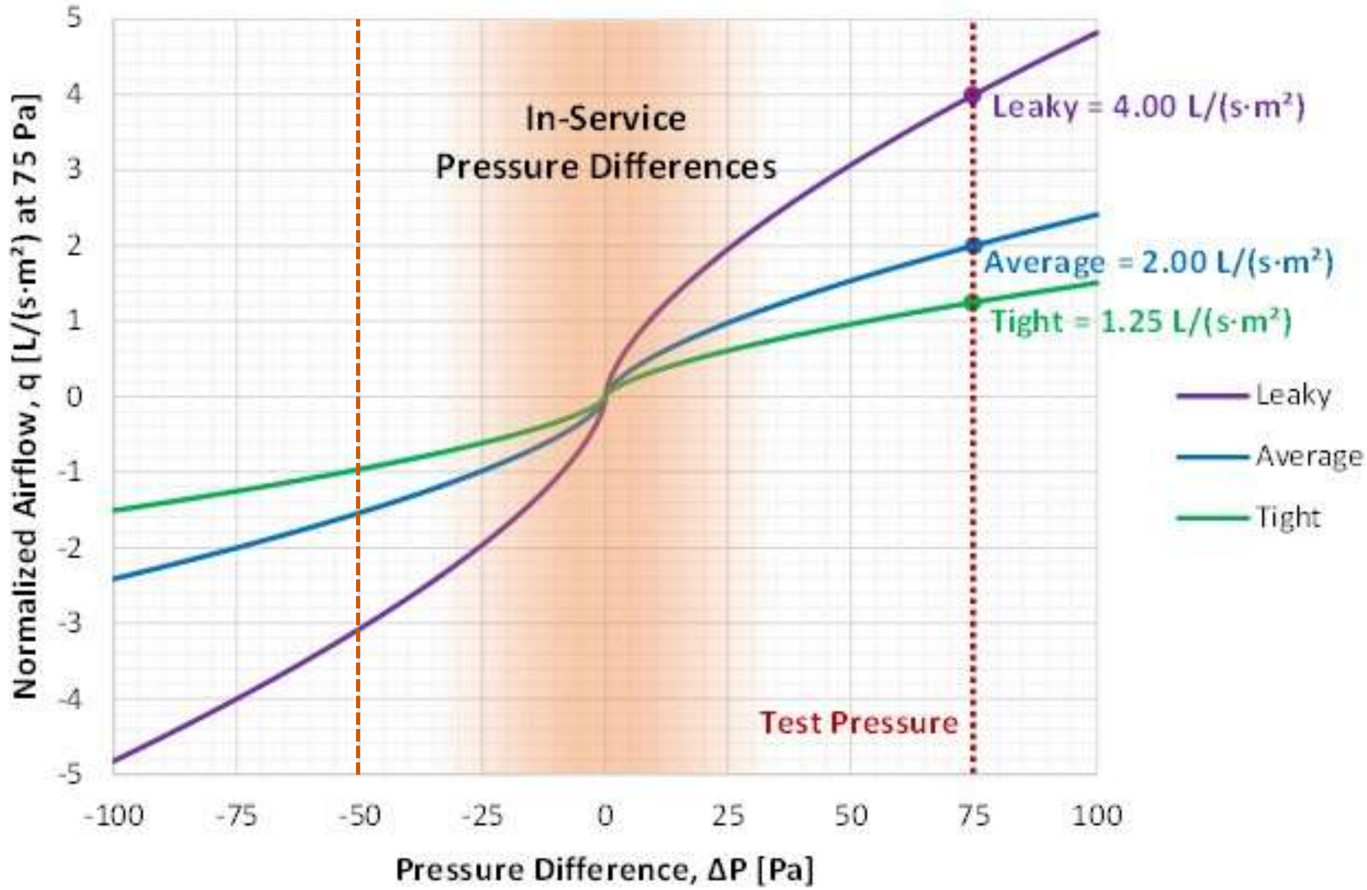
## Test results therefore…

- Cannot directly or accurately predict in-service air leakage
- HVAC pressurization can begin to approach leakage of test



# Test vs Service pressure

- 



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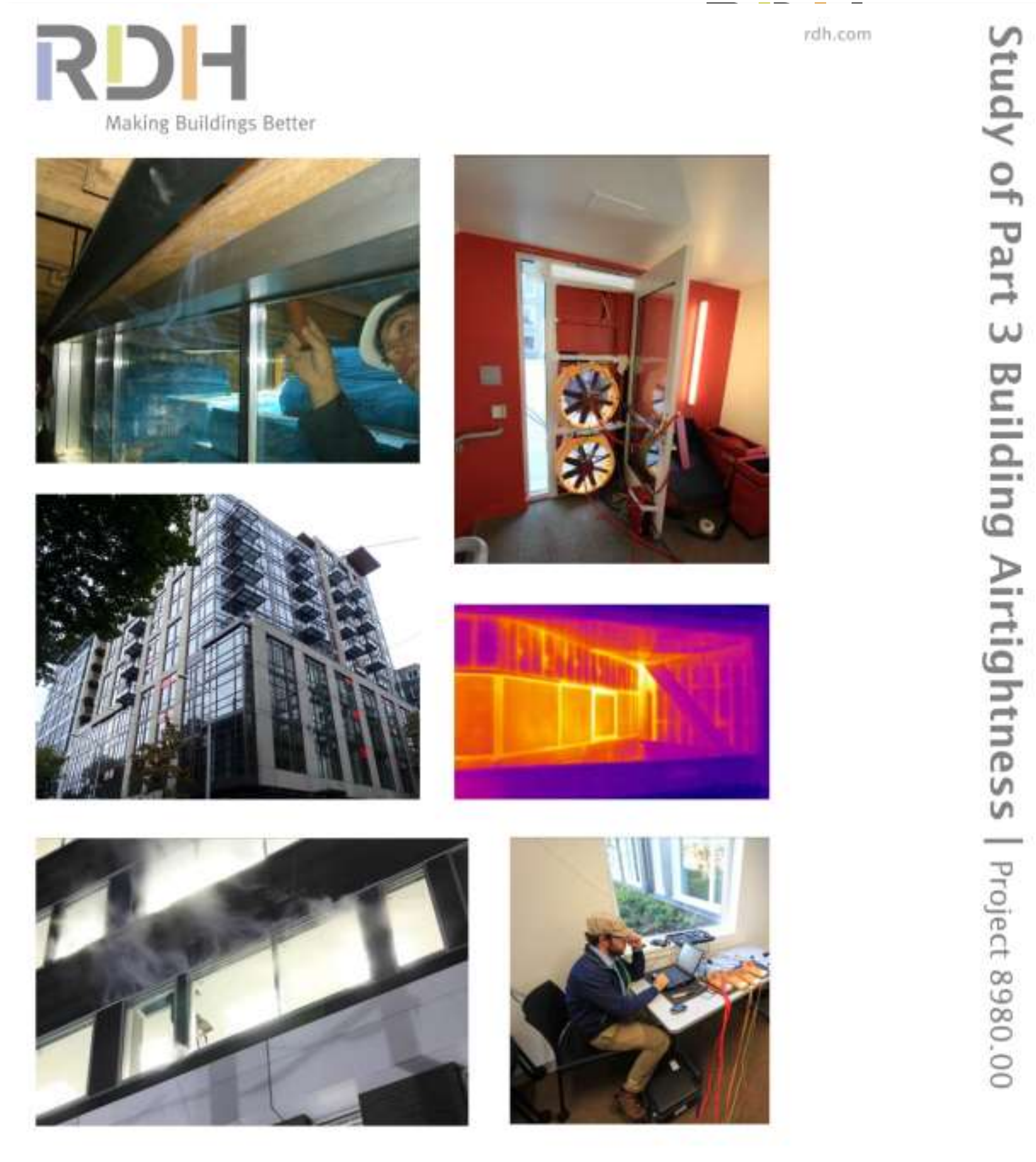
# Verification Testing

**Mockups: Confirm design can be built and perform**
**In-situ testing: Verify that enclosure is built as per design=mockup**

# Air Leakage Testing

- Recent study for the Canadian code development

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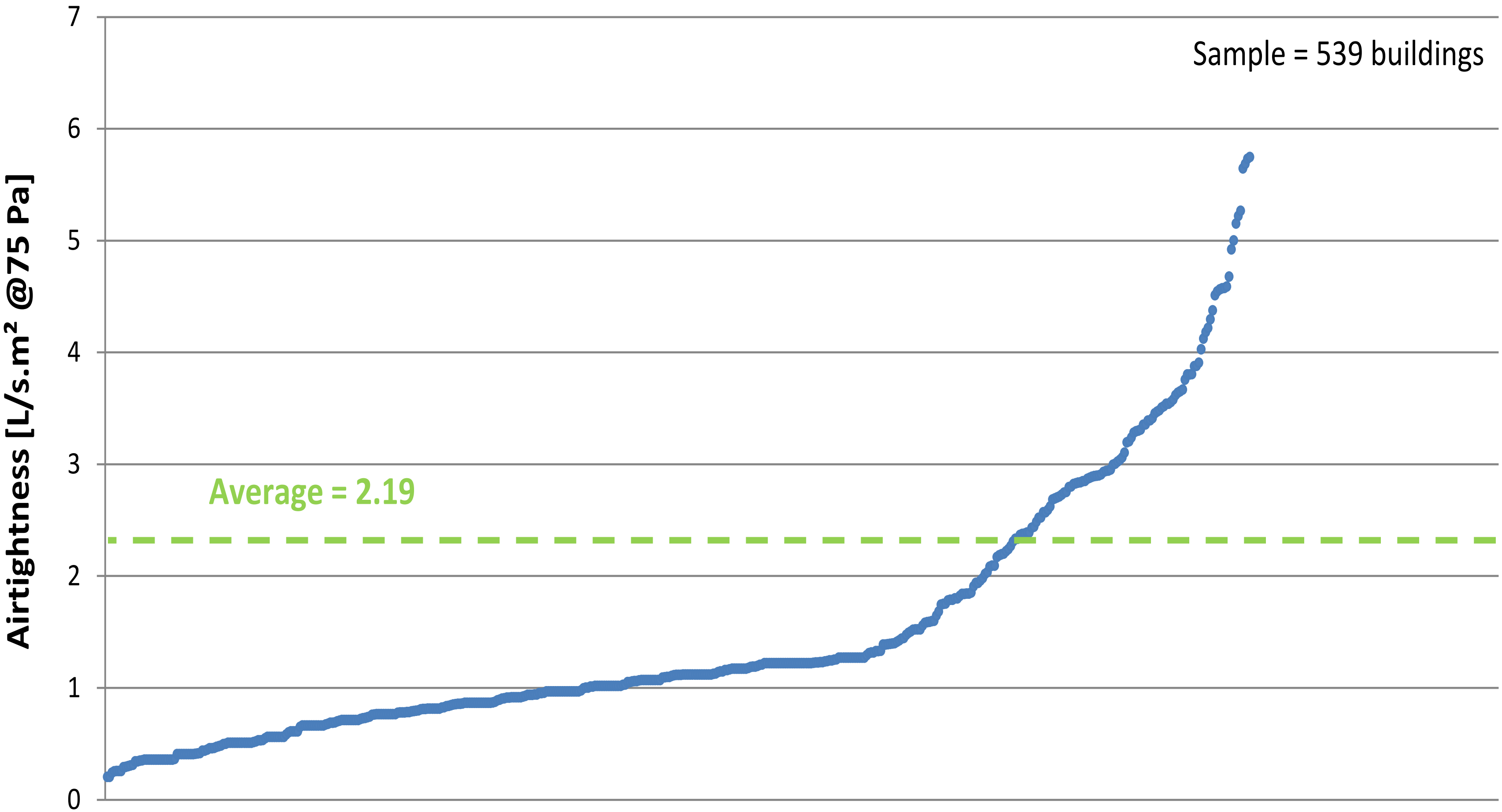
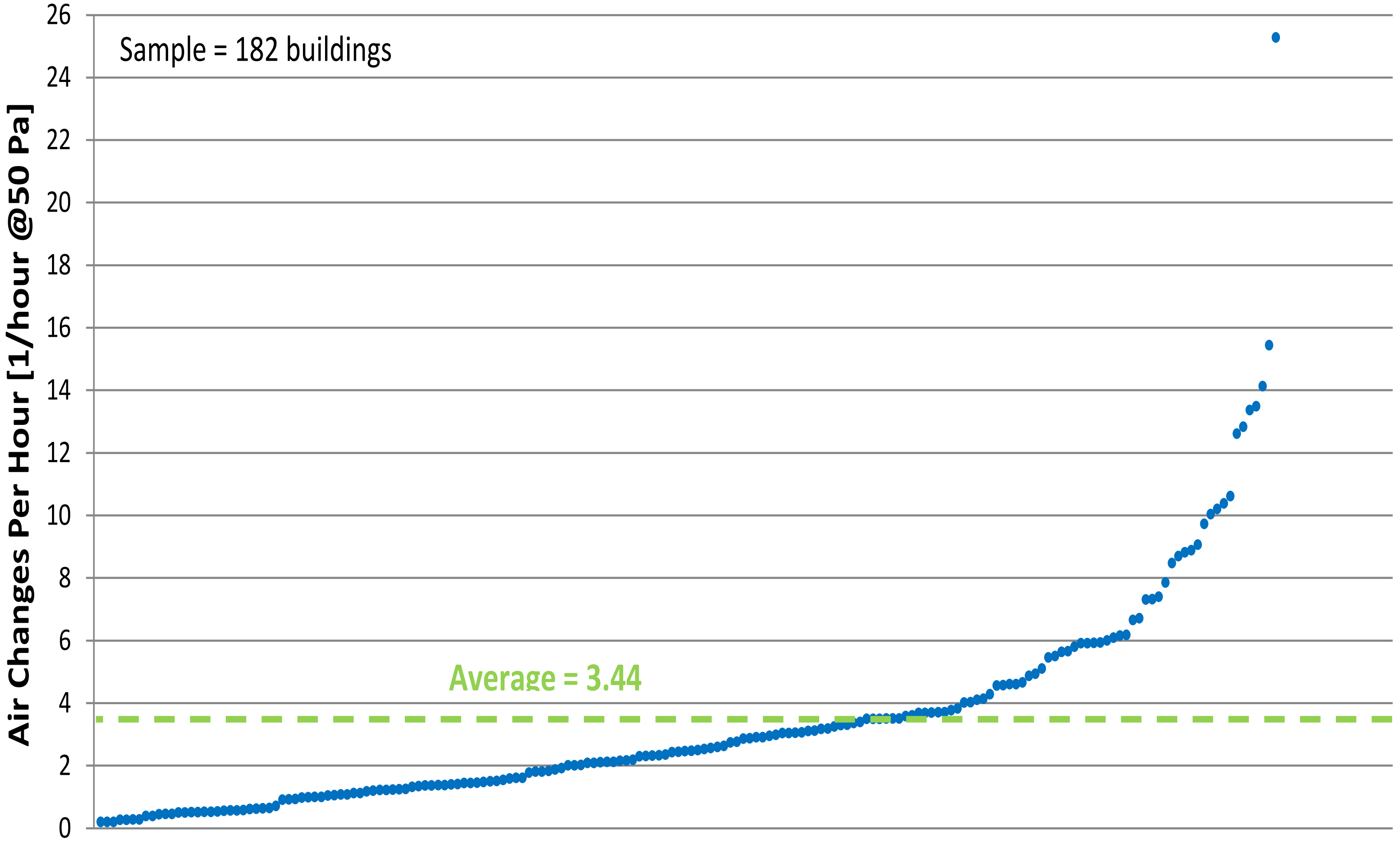
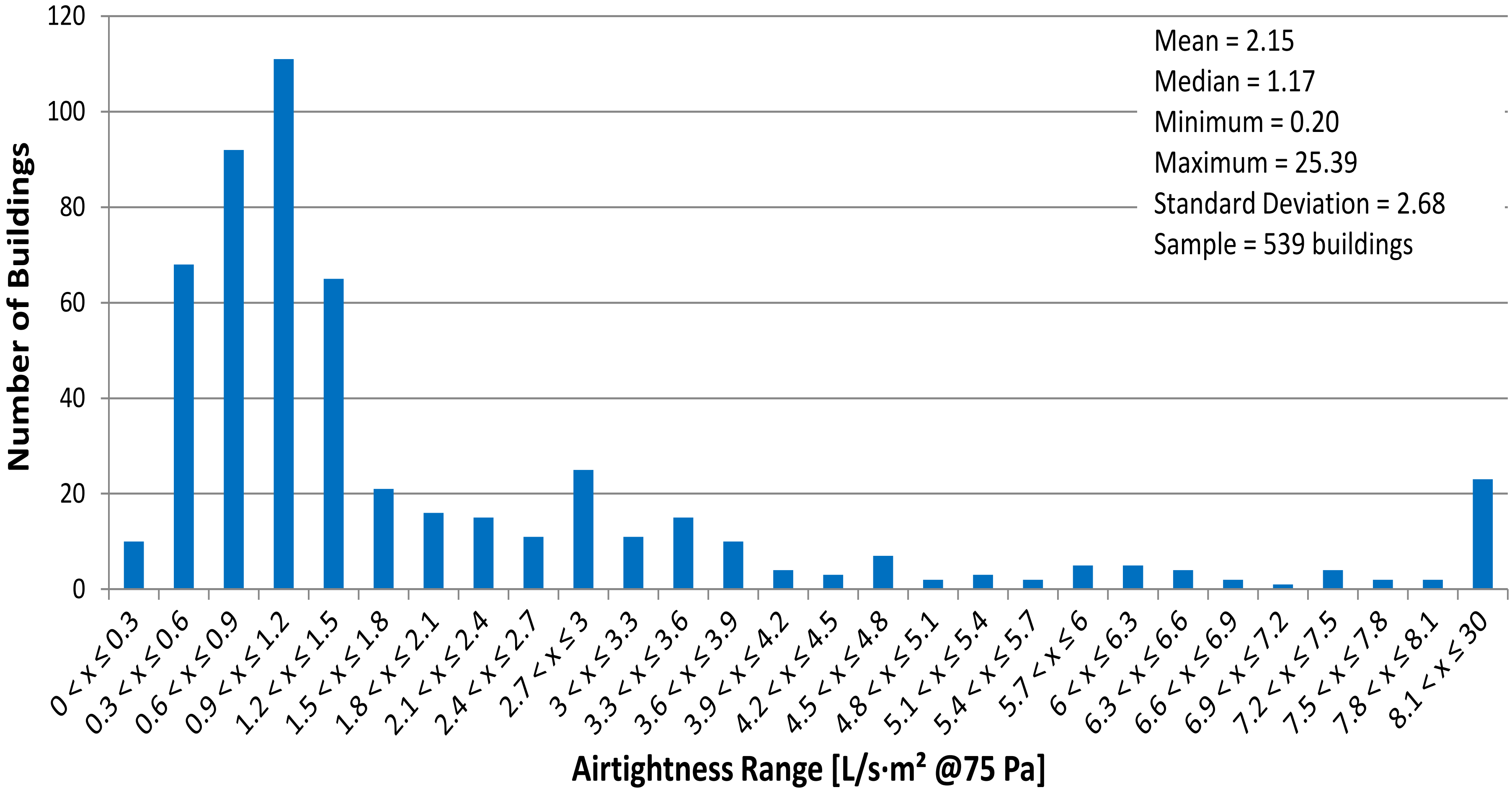
# Air Permeance



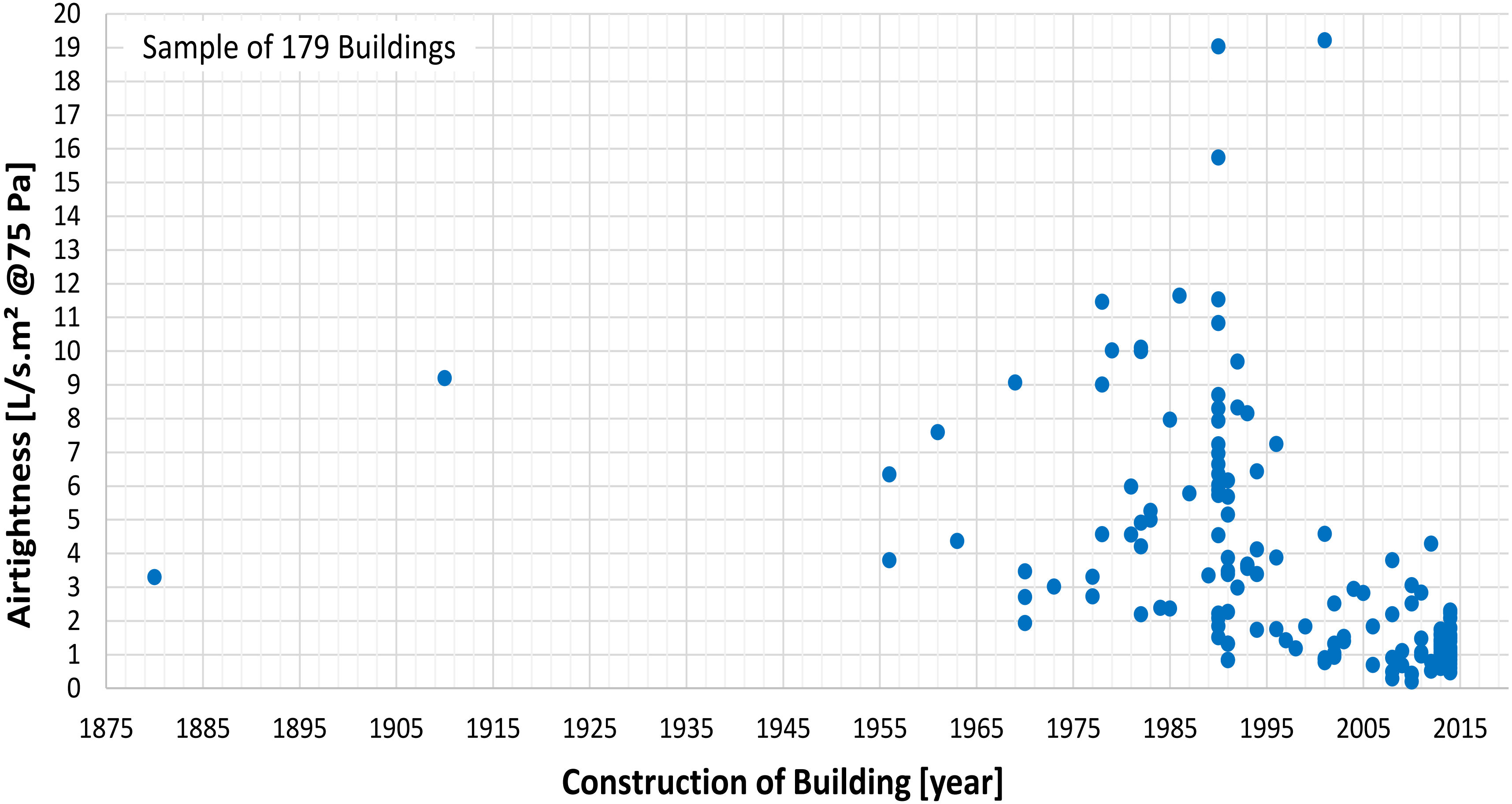
# Air Change per Hour



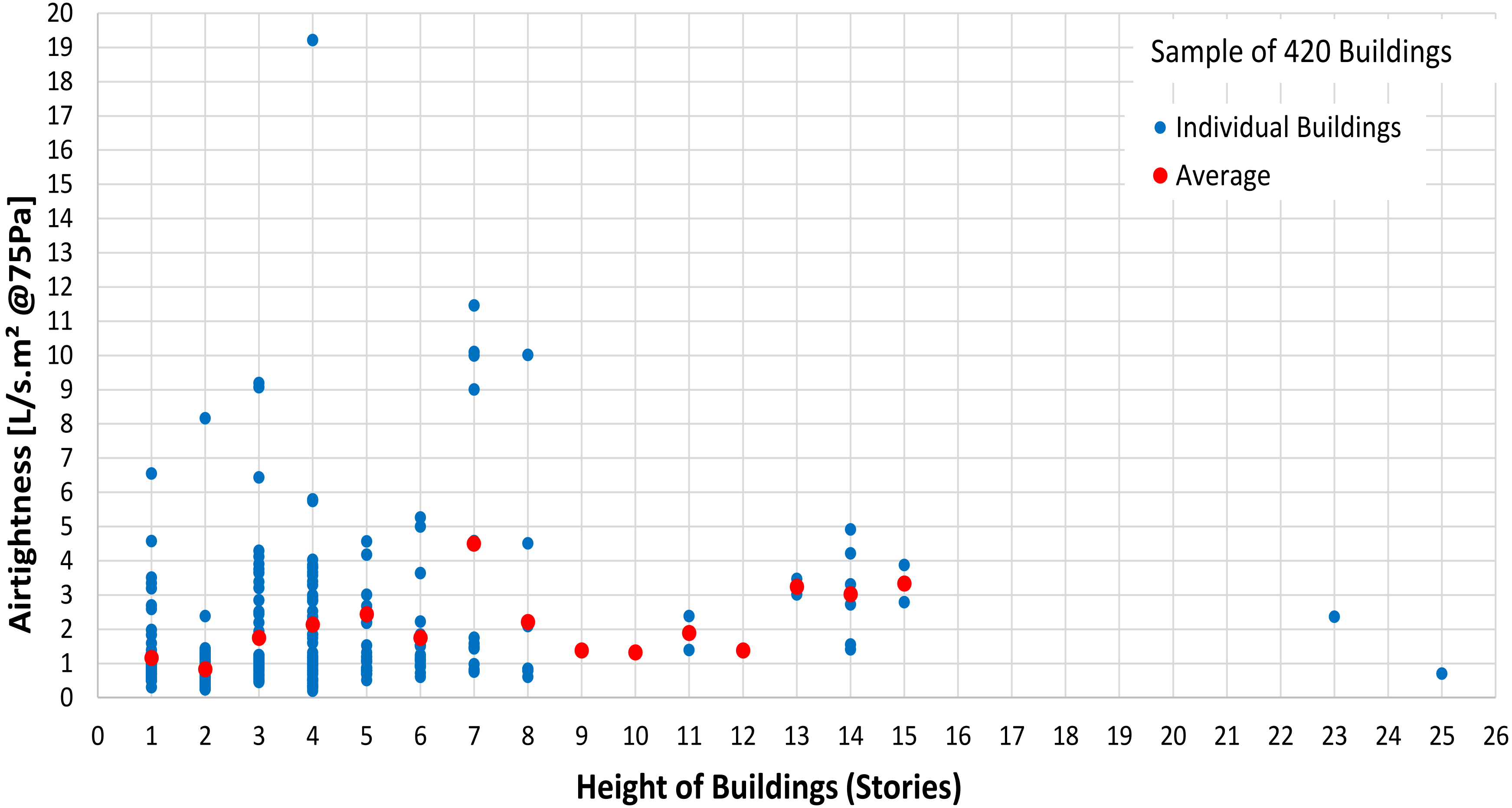
# Airtightness distribution



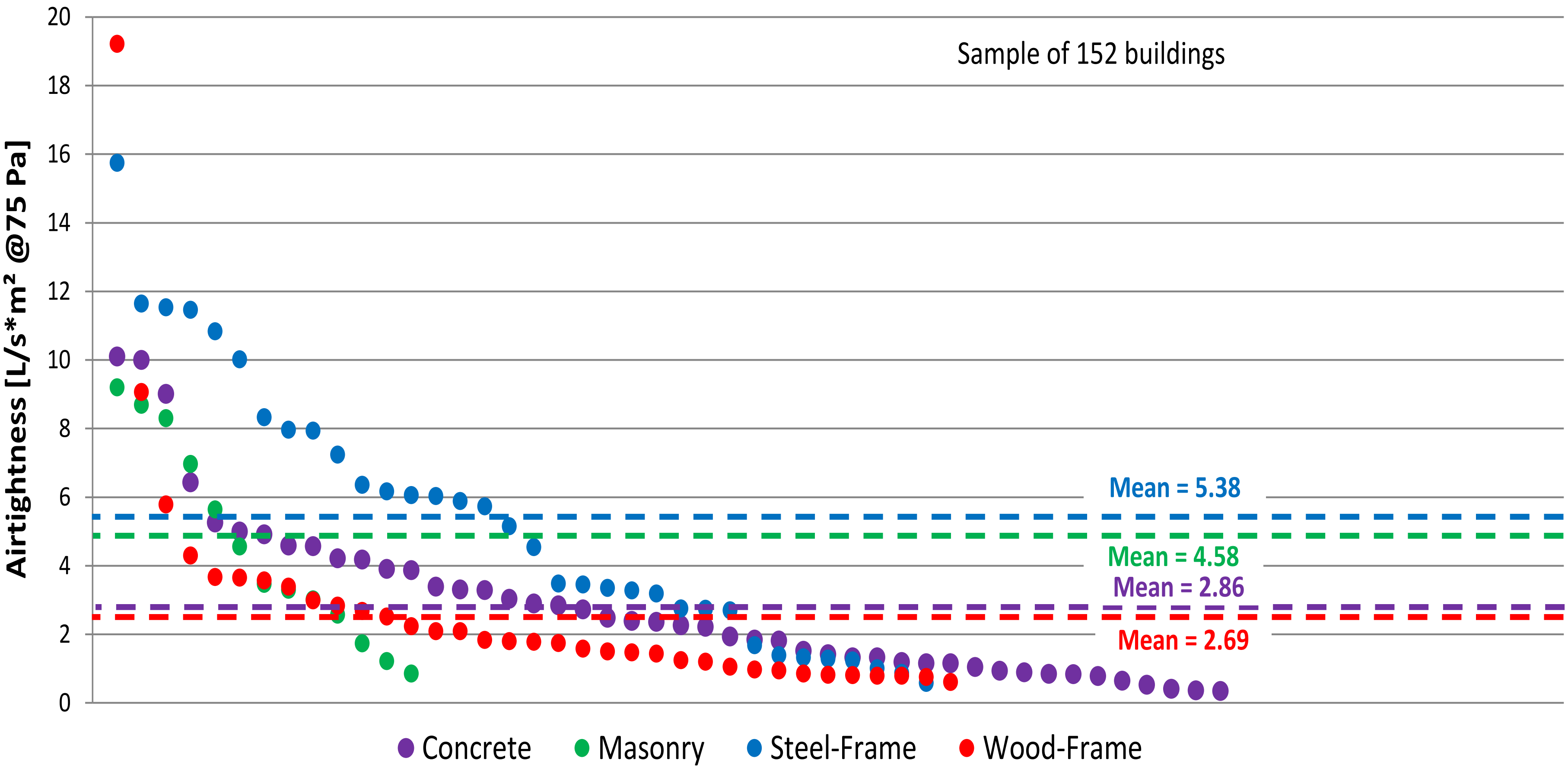
# Age


Sample of 179 Buildings
Airtightness [L/s.m² @75 Pa]
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1875
1885
1895
1905
1915
1925
1935
1945
1955
1965
1975
1985
1995
2005
2015
Construction of Building [year]

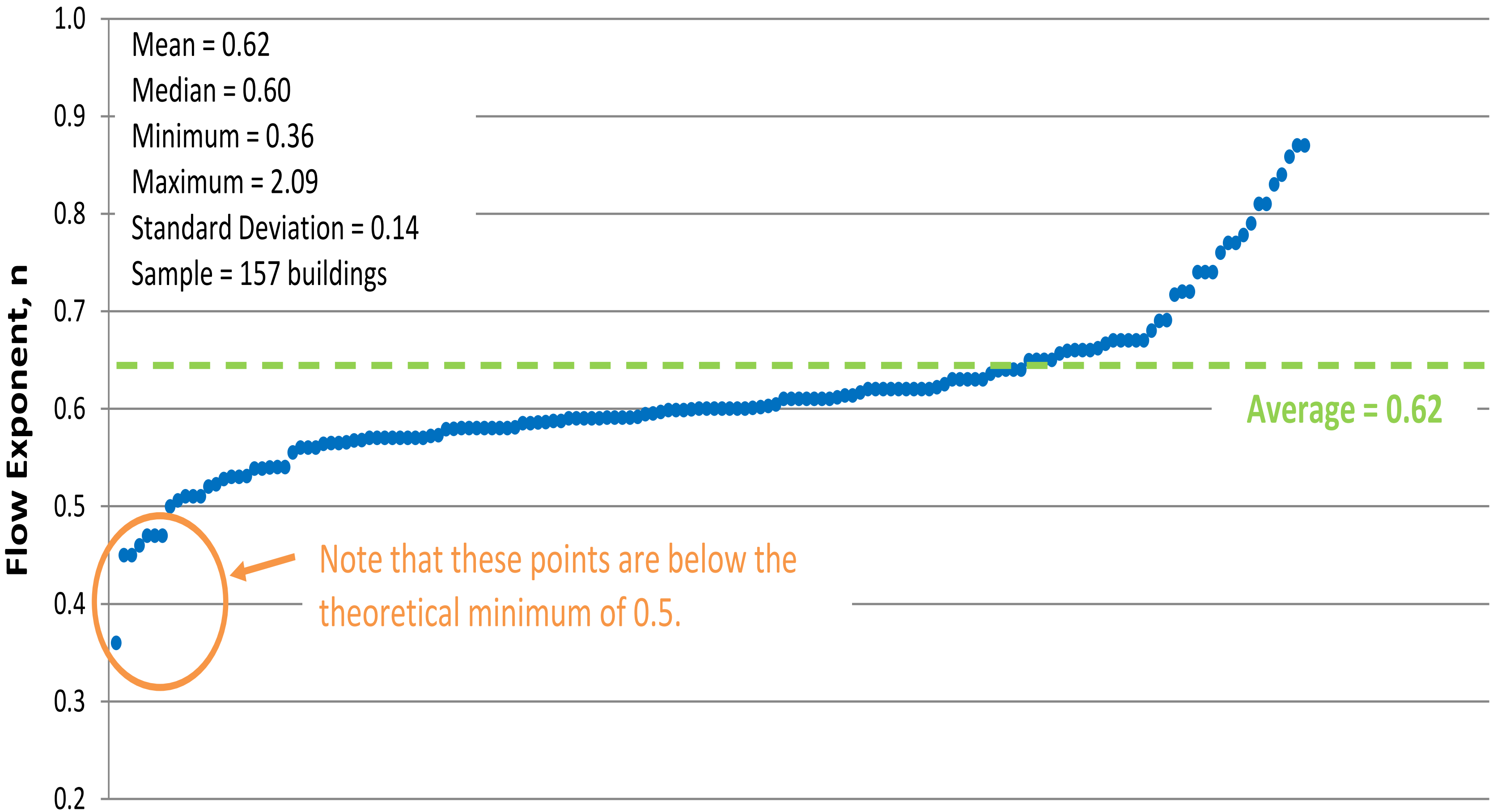
# Airtightness vs Height



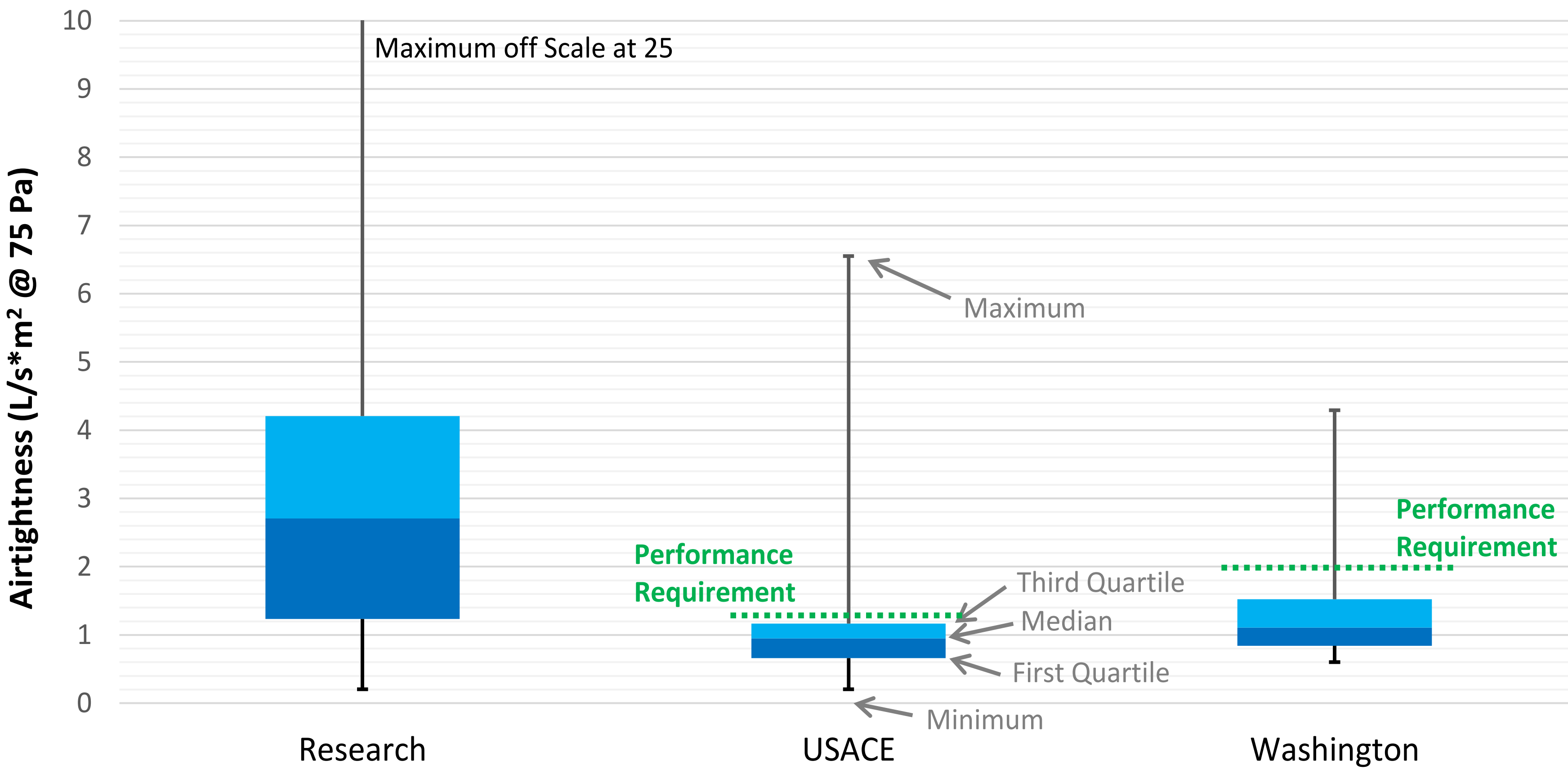
# Building “Construction”



# Flow Exponent



# Influence of requirements

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# Conclusions

- Many reasons to measure
- Testing large buildings is possible
- But, some potential challenges
  - Wind and stack
  - Many HVAC penetrations
  - Different protocols
- Usually worth it, and will be done more
- Follow ASHRAE / Brennan / Energy Conservatory / USACE protocols

# ASHRAE 1478: Measuring Airtightness of Mid- and High-Rise Non-Residential Buildings

**Terry Brennan**
*Member ASHRAE*

**Wagdy Anis**
*Member ASHRAE*

**Gary Nelson**
*Member ASHRAE*

**Collin Olson, PhD**

## ABSTRACT

*ASHRAE 1478 is a research project designed to measure enclosure airtightness of mid- and high-rise buildings in the United States. Data were collected from 16 non-residential buildings in climate zones 2–7 constructed since the year 2000. The dataset includes buildings with no particular attention to making the building airtight, buildings where some attention was given to airtightness, and buildings where extensive attention was paid to airtightness. Some of the buildings were designed to be sustainable (e.g., receiving LEED status). Buildings ranged from four to fourteen stories. A fan pressure testing protocol based on ASTM E779 was developed by the project team. A number of issues in using E779 to test large building were identified, discussed, and addressed. Building airtightness was reported in CFM per square foot of above grade enclosure at a 75 pascal induced shell pressure difference and CFM per square foot of complete enclosure (including slab and below grade conditioned space walls). The results range from 0.06 cfm 75/ft$^2$ to 0.75 cfm 75/ft$^2$ of complete enclosure (1.10 m$^3$/h/m$^2$ to 13.7 m$^3$/h/m$^2$). Major air leakage sites were identified in the course of testing. Air leakage through HVAC related penetrations was measured in a subset of the buildings. Factors that are associated with the most airtight enclosures include air-barrier continuity detailed in construction documents and precast concrete panel construction. Damper air leakage turned out to be a significant portion of the total enclosure air leakage in some of the buildings. The significance of air leakage by HVAC systems is reviewed in relation to building air tightness.*

# Brennan-Nelson Study

- Avg of all = 0.29 cfm75/ft$^2$
- Green Buildings = 0.32 cfm75/ft$^2$
  - "other" = 0.22 cfm75/ft$^2$
- With air barrier consultant = 0.13 cfm75/ft$^2$
  - "other"=0.39

each building. The mean of the averaged test results is 0.29 cfm 75/ft$^2$ with a standard deviation of 0.20 cfm 75/ft$^2$ (5.3 m$^3$/h/m$^2$ with a standard deviation of 3.6 m$^3$/h/m$^2$).

The air leakage rate of buildings designated a green building is 0.32 cfm75/ft$^2$ (5.8 m$^3$/h/m$^2$). The average leakage rate of all other buildings in the data set is 0.22 cfm 75/ft$^2$ (4.2 m$^3$/h/m$^2$).

The air leakage rates for buildings with an air barrier specified and an envelope expert consulted average 0.13 cfm 75/ft$^2$ total enclosure (2.4 m$^3$/h/m$^2$). If buildings with air barriers and air barrier consultants included in the design of the buildings are removed from the data set, the mean of the remaining buildings is 0.39 cfm75/ft$^2$ total enclosure (7.1 m$^3$/h/m$^2$).

| Build-ing ID | Climate | Test Mode | CFM75 | 95% CI (±%) | CFM75/ft² above grade encl | CFM75/ft² total encl | m³/h | m³/h/m² above grade encl | m³/h/m² total encl | ACH50 | C | n | r² |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2B | 2-dep | 49121 | 0.6 | 0.48 | 0.36 | 81983 | 8.7 | 6.6 | 1.24 | 4479 | 0.56 | 0.9996 |
| 2 | 5A | 1-dep | 112195 | 0.2 | 0.76 | 0.57 | 187253 | 13.8 | 10.4 | 2.01 | 6501 | 0.66 | 1.0000 |
| 2 | 5A | 2-Press | 121958 | 6.9 | 0.82 | 0.62 | 203548 | 15.0 | 11.3 | 2.16 | 6405 | 0.68 | 0.9966 |
| 2 | 5A | ave 1-2 | 117077 | 3.5 | 0.79 | 0.59 | 195401 | 14.4 | 10.8 | 2.08 | 6453 | 0.67 | 0.9983 |
| 3 | 6A | 1-dep | 25537 | 1.4 | 0.18 | 0.13 | 42621 | 3.2 | 2.4 | 0.43 | 1807 | 0.61 | 0.9983 |
| 3 | 6A | 2-Press | 26893 | 2.6 | 0.19 | 0.14 | 44884 | 3.4 | 2.5 | 0.46 | 2346 | 0.57 | 0.9878 |
| 3 | 6A | ave 1-2 | 26215 | 1.5 | 0.18 | 0.14 | 43753 | 3.3 | 2.5 | 0.45 | 2076 | 0.59 | 0.9980 |
| 4 | 6A | 1-dep | 33301 | 2.8 | 0.19 | 0.13 | 55579 | 3.5 | 2.3 | 0.36 | 3157 | 0.55 | 0.9967 |
| 4 | 6A | 2-Press | 36183 | 1.6 | 0.21 | 0.14 | 60389 | 3.8 | 2.5 | 0.40 | 3582 | 0.54 | 0.9981 |
| 4 | 6A | ave 1-2 | 34742 | 1.6 | 0.20 | 0.13 | 57984 | 3.7 | 2.4 | 0.38 | 3370 | 0.54 | 0.9974 |
| 5 | 4C | 1-dep | 31286 | 1.4 | 0.27 | 0.21 | 52216 | 4.9 | 3.9 | 0.61 | 2151 | 0.62 | 0.9980 |
| 5 | 4C | 2-Press | 33552 | 1.4 | 0.29 | 0.23 | 55998 | 5.2 | 4.2 | 0.66 | 2510 | 0.60 | 0.9985 |
| 5 | 4C | ave 1-2 | 32419 | 1.0 | 0.28 | 0.22 | 54107 | 5.0 | 4.0 | 0.63 | 2330 | 0.61 | 0.9982 |
| 6 | 3A | 1-Press | 6440 | 2.1 | 0.08 | 0.06 | 10748 | 1.5 | 1.1 | 0.21 | 601 | 0.55 | 0.9938 |
| 6 | 3A | 2-Dep | 5889 | 3.0 | 0.07 | 0.05 | 9829 | 1.3 | 1.0 | 0.19 | 453 | 0.59 | 0.9932 |
| 6 | 3A | ave 1-2 | 6165 | 1.8 | 0.08 | 0.06 | 10289 | 1.4 | 1.0 | 0.20 | 527 | 0.57 | 0.9935 |
| 7 | 5A | 1-Press | 52604 | 1.0 | 0.40 | 0.31 | 87796 | 7.3 | 5.7 | 0.26 | 3462 | 0.63 | 0.9946 |
| 7 | 5A | 2-Dep | 51442 | 3.4 | 0.39 | 0.30 | 85857 | 7.1 | 5.5 | 0.26 | 3565 | 0.62 | 0.9905 |
| 7 | 5A | ave 1-2 | 52023 | 1.8 | 0.39 | 0.31 | 86826 | 7.2 | 5.6 | 0.26 | 3513 | 0.62 | 0.9926 |
| 8 | 4A | 1-Press | 25330 | 2.7 | 0.36 | 0.32 | 42276 | 6.6 | 5.9 | 1.14 | 1347 | 0.68 | 0.9766 |
| 8 | 4A | 2-Dep | 21649 | 1.6 | 0.31 | 0.28 | 36132 | 5.7 | 5.0 | 1.00 | 1457 | 0.63 | 0.9964 |
| 8 | 4A | ave 1-2 | 23490 | 1.6 | 0.34 | 0.30 | 39204 | 6.1 | 5.5 | 1.07 | 1402 | 0.65 | 0.9865 |
| 9 | 4A | 1-dep | 48605 | 4.2 | 0.77 | 0.56 | 81122 | 14.0 | 10.2 | 1.97 | 3920 | 0.58 | 0.9922 |
| 9 | 4A | 2-Press | 50384 | 2.1 | 0.79 | 0.58 | 84091 | 14.5 | 10.5 | 2.03 | 3968 | 0.59 | 0.9920 |
| 9 | 4A | ave 1-2 | 49495 | 2.3 | 0.78 | 0.57 | 82606 | 14.3 | 10.4 | 2.00 | 3944 | 0.59 | 0.9921 |
| 10 | 6A | 1-dep | 9840 | 1.6 | 0.12 | 0.09 | 16423 | 2.2 | 1.6 | 0.24 | 692 | 0.62 | 0.9978 |
| 10 | 6A | 2- Press | 11609 | 1.5 | 0.14 | 0.11 | 19375 | 2.5 | 1.9 | 0.28 | 699 | 0.65 | 0.9979 |
| 10 | 6A | ave 1-2 | 10725 | 1.1 | 0.13 | 0.10 | 17899 | 2.3 | 1.8 | 0.27 | 696 | 0.63 | 0.9979 |
| 11 | 4A | 1-dep | 53350 | 1.3 | 0.53 | 0.42 | 89041 | 9.7 | 7.7 | 1.34 | 4653 | 0.57 | 0.9967 |
| 11 | 4A | 2-Press | 55729 | 1.4 | 0.55 | 0.44 | 93012 | 10.1 | 8.0 | 1.38 | 4237 | 0.60 | 0.9960 |

Building

RDH BUILDING SCIENCE LABORATORIES

# USACE 2012

The!test!consists!of!measuring!the!flow!rates!required!to!establish!a!minimum!of!ten!(10)!positive! and! ten! (10)! negative! approximately! equally! spaced! induced! envelope! pressures.! Induced! envelope!pressure!test!points(shall!be(averaged!over!at!least!10seconds!and!shall!be!no!lower! Than 40 Pa for a twoGsided!(positive!and!negative)!test!and!50!Pa!for!a!single!sided!test.!The! highest!point!must!be!at!least!75!Pa,!and!there!must!be!at!least!25!Pa!difference!between!the! lowest!and!highest!point.!Pressures!in!the!extremities!of!the!envelope!must!not!differ!from!one! another!by!more!than!10%!of!the!average!induced!envelope!pressure.!Twelve!pre!and!twelve! postGbaseline(pressure!points!must!be!taken!across!the!envelope!with!respect!to!the!outdoors! where!each!point!is!an!average!taken!over!at!least!10!seconds.!The!maximum!absolute!baseline( pressure!point!value!must!not!exceed!30%!of!the!minimum!induced(envelope(pressure(test(point! used!in!the!analysis.!There!are!no!further!restrictions!on!wind!speed!or!temperature!during!the! test.

WATERLOO ENGINEERING

BUILDING SCIENCE LABORATORIES

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The following requirements pertain to masking HVAC openings!other!than!flues:!!
a. The!test!is!conducted!with!ventilation!fans!and!exhaust!fans!turned!off and the outdoor air inlets and exhaust outlets sealed (by!dampers!and/or!masking)
b. Motorized!dampers!must!be!closed!and!may!be!tested!masked!or!unmasked
c. Undampered!HVAC!openings!must!be!masked!during!testing,!and!
d. Gravity!dampers!shall!be!prevented!from!moving!or!can!be!masked

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