Morrison Hershfield

Airtightness in Buildings

A Canadian History

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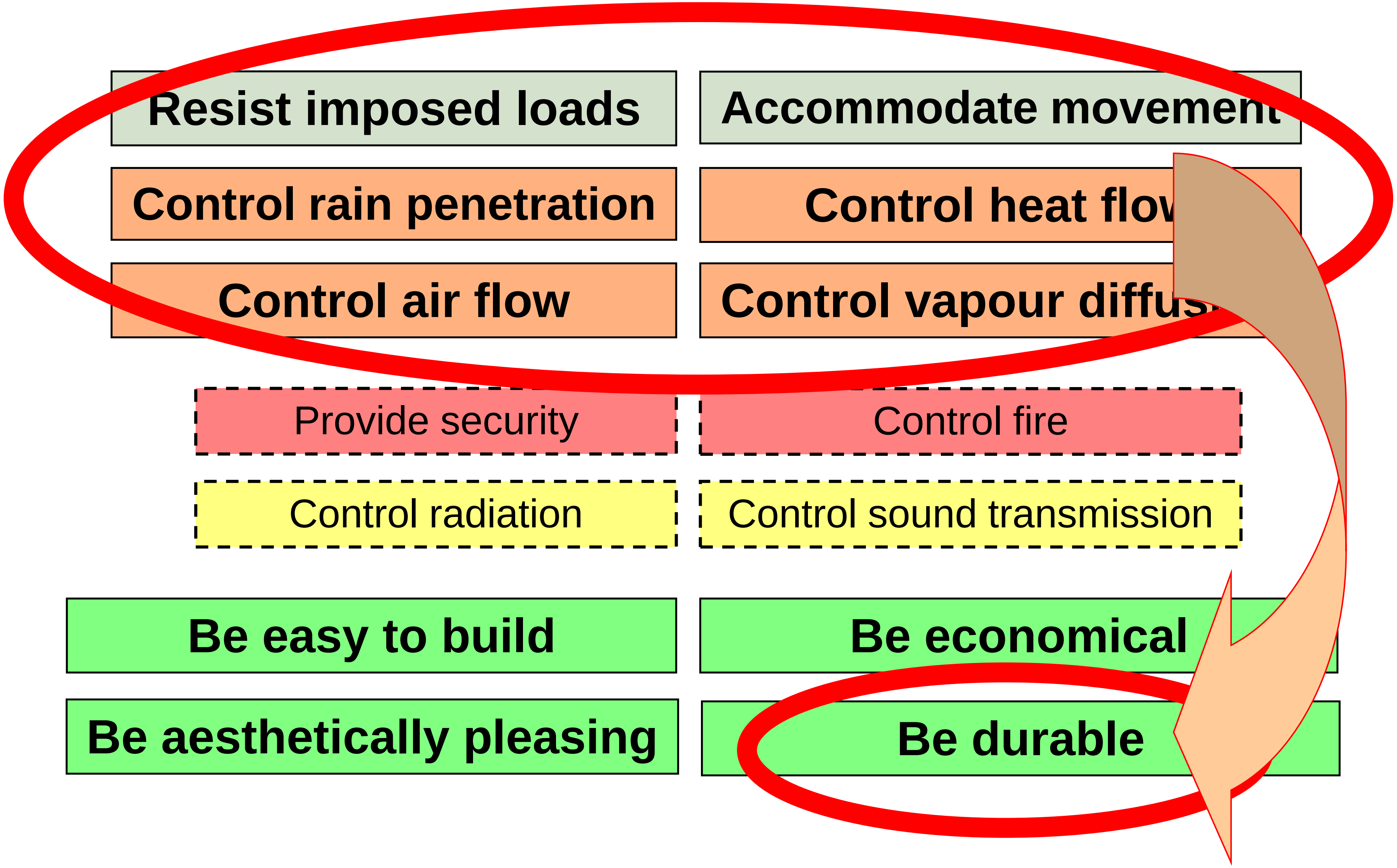
History of What?

- Understanding
- Measurement
- Implementation

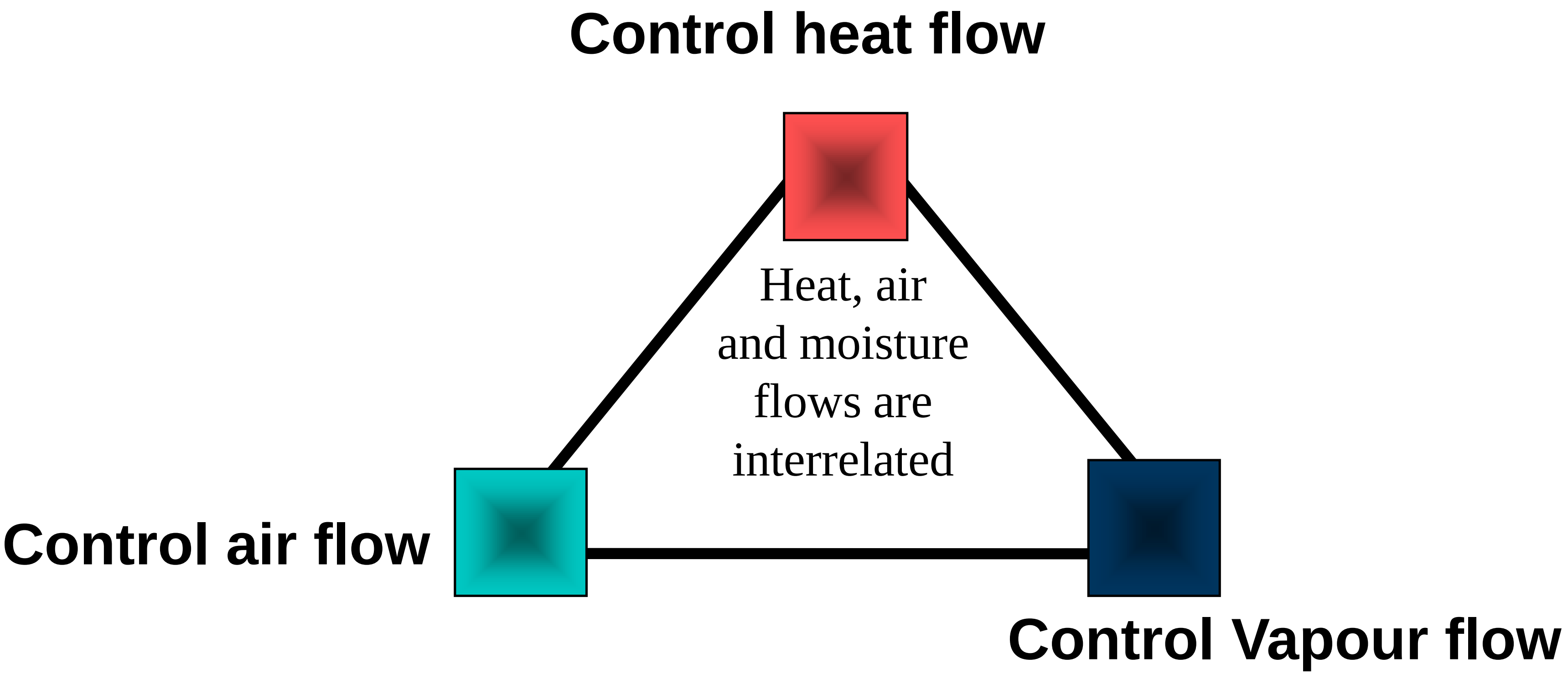
Air in Buildings

- Carries **moisture** to cold surfaces where condensation can occur.
- Carries **energy** (sensible and latent); so air exchange implies energy costs .
- Dilutes **contaminants** generated inside a building, and carries them out of the building.
- Carries **exterior generated contaminants** into the building.

Building Envelope Design Factors



Hygrothermal Design Factors



Consequences of Poor Air Leakage Control

- Interstitial condensation
  - corrosion / rot
  - mold
  - freeze/thaw damage
- Poor thermal comfort (winter and summer)
- Higher energy cost
- Larger forces for rain penetration
- Uncontrolled indoor environment (humidity, outdoor contaminants)
- Increased sound transmission
- Possible fire/smoke movement

Evolution of Codes

NBC Year	Part 5	Part 9
1977	Under **Control of Condensation** “continuous vapour and air barrier...on high vapour pressure side of material that has the major thermal resistance.”	“vapour barriers shall be installed in warm side of insulation” Measures to provide continuity of VB and prevention of air leakage into attic but no use of term of “air barrier”.
1980	Clarifications	Clarifications
1985	New section on **Control of Air Leakage** and Subsection on **Air Barriers** “an effective barrier to air exfiltration and infiltration...through materials…joints…and junctions”	Clarifications in sealing cuts and holes to maintain integrity of VB.
1990	No change	Requirement for a “barrier to air leakage”

Evolution of Codes - Objective Based Codes

NBC Year	Part 5	Part 9
1995	Introduction of "system properties" Material 0.02 L/s/m^2, continuity at joints, junctions and penetrations, transfer of full wind load to structure. Appendix has "Recommended Maximum Air Leakage Rates" depending on RH (and energy).	Some redefinition to "air barrier system which will provide a continuous barrier to air leakage" to protect against interstitial condensation from exfiltration and interior surface condensation from infiltration. Additional prescriptive requirement for continuity and commentary in appendix.
2000		
2005	More clarity on purpose of an air barrier system. Requirements for structural support relocated to section on Loads.	
2010	Reference to CAN/ULC S741 Air Barrier *Materials.*	Articles to address masonry walls and below grade assemblies (soil gas control).

Recommended Maximum Air Leakage Rates

Warm side RH	Maximum System Air Leakage Rates $l/s/m^2$
< 27%	0.15
27 to 55%	0.10
>55%	0.05

- Related to “insulated portion of envelope” not whole building.
- Values based on judgement and third party standards rather than great science.
- Code framers wanted to include in code document but relegated to appendix on compliance concerns.
- The 0.15 value was capped based, in part, on energy analysis.

- Codes are not “leading” documents, they react to research and experience - with a time lag of about ten years.
- The NBC addressed air leakage control for durability and moisture control, not energy conservation.

Who recognizes this?

Saskatchewan Conservation House

- 1977
- R40 double frame wall, R60 ceiling, no basement, insulated floor
- 0.8 ACH @ 50 Pa
- Fabricated HRV
- No furnace

- Launched in 1982.
- Directed to builders not architects.
- Promoted as a market differentiator.

Requirements

- Trained and licensed builders.
- Annual energy target by computer simulation (based on 50 kwh/m^2 factored by DD and number of units in building).
- Post construction air tightness tests
  1.5 ACH @ 50 Pa or NLA 0.7 cm^2/m^2 @ 10 Pa.
- Continuous ventilation.
- Backdraft resistant combustion appliances.
- Consideration of replacement air for exhaust devices.

Why 1.5 ACH?

- Because we could
- Forced attention by builders

Prerequisites

- Training courses
  - Builders
  - HRV installers
- Simulation tools, (HOT-2000)
- Tools and procedures to measure airtightness
- Production HRVs
- Better windows

Issues to be addressed

- Air quality concerns.
- Thermal degradation of poly air barriers.
- Durability of air barrier system performance.
- Ventilation standards (F326).
- Performance certification of HRVs.
- Cold weather performance of HRVs.
- Backdrafting appliances.
- “Almost R-2000” houses.

Demonstration

- Analysis of airtightness test results
- Monitoring
  - Energy use
  - HRV efficiency
  - Indoor air contaminants
    - Humidity
    - Formaldehyde
    - CO_2
    - VOC
    - Radon
- Retesting to confirm airtightness over the years

Concurrent Programs

- CMHC Research Division
- CMHC builder training courses
- Homebuilder associations and building research committees
- NRC Research
  - Durability
  - Energy Conservation
- US weatherization programs
  - LBL (Sherman)

Outcome

- General acceptance, in Canada, of the "Build Tight - Ventilate Right" philosophy.
- A homebuilding industry that could deliver tight houses.
- An understanding in the building community of the importance of airtightness based on the physics of small buildings.

Air Flow Control – Energy Costs

"Air infiltration can account for 30% or more of a home's heating and cooling costs and contribute to problems with moisture, noise, dust, and entry of pollutants, insects and rodents. Nearly 45% of this uncontrolled air infiltrates through openings in ceilings, walls, and floors, as well as plumbing penetrations."

- U.S. Department of Energy

Beyond Houses – Larger Buildings

- Both design and construction “distributed”.
- Key party: architect rather than builder.
- Lower surface to volume ratio.
- In many commercial buildings, fan driven air change overwhelms natural force driven airflow.
- With height, stack forces more dominant.
- Many different construction systems, in general, and even on same building.

Existing Buildings

In Canada

- Ample evidence that air leakage causes harm.
- Limited information on how tight existing buildings were.
- Focus on identifying and correcting air leakage points rather that average level of tightness.

In US

- Less concern.
- More emphasis on energy and average air leakage.

Science

Canada

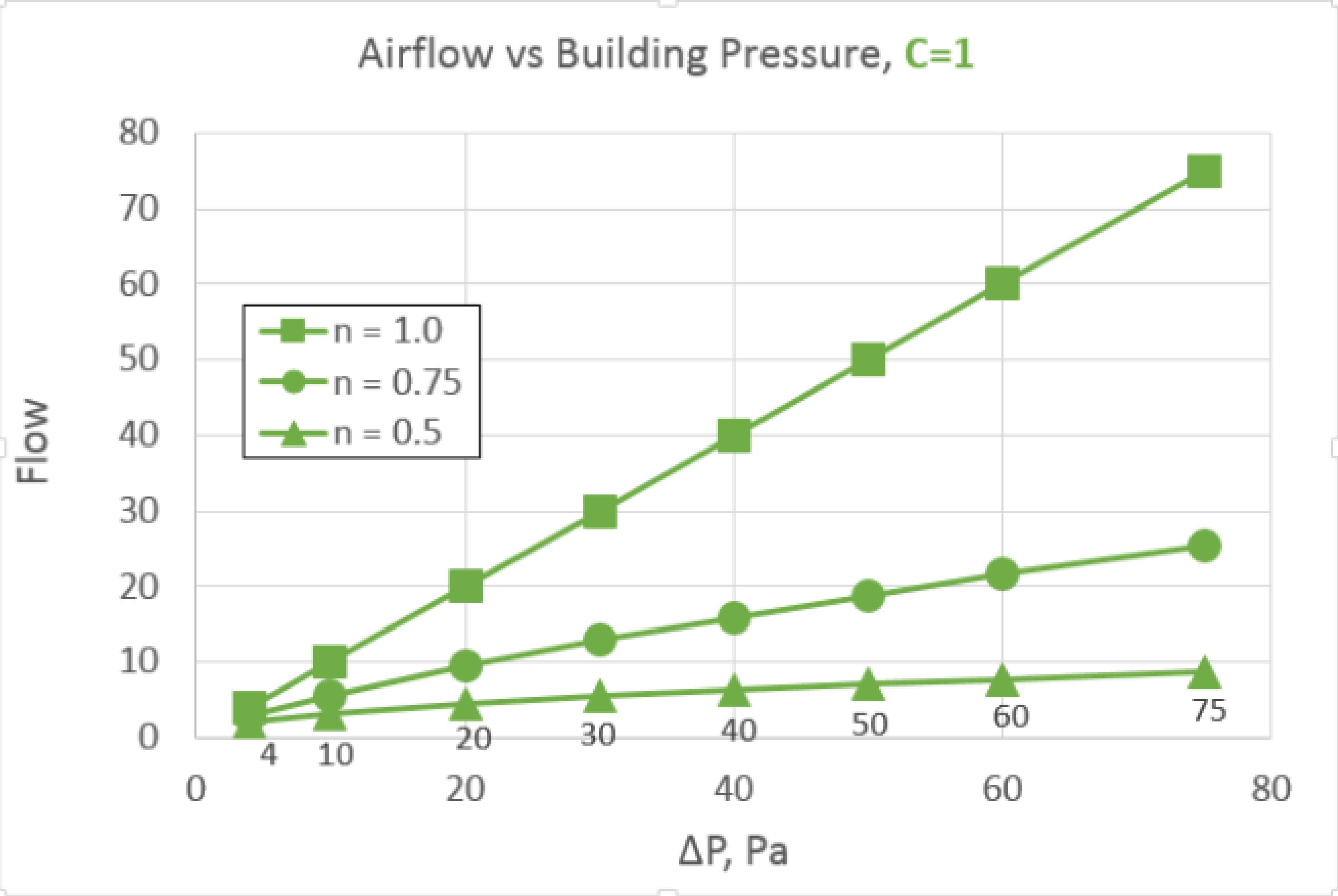
- NRCC (Wilson, Quirouette, Perreault, Handegord)
- CMHC for residential
- EMR/NRCan
- Several Universities

US

- DOE
  - LBL
  - Brookhaven
  - Oakridge

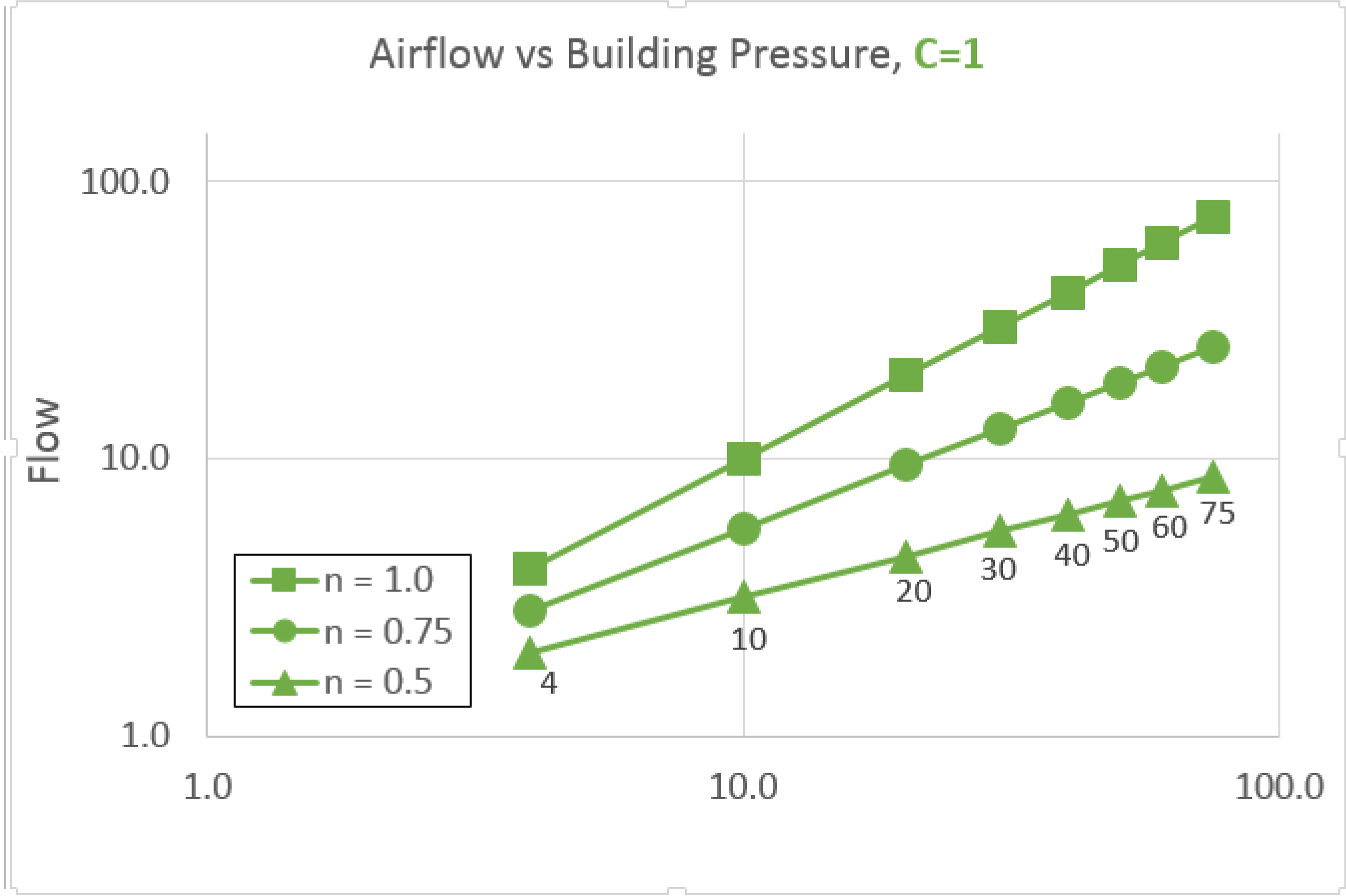
Generalized Flow Equation

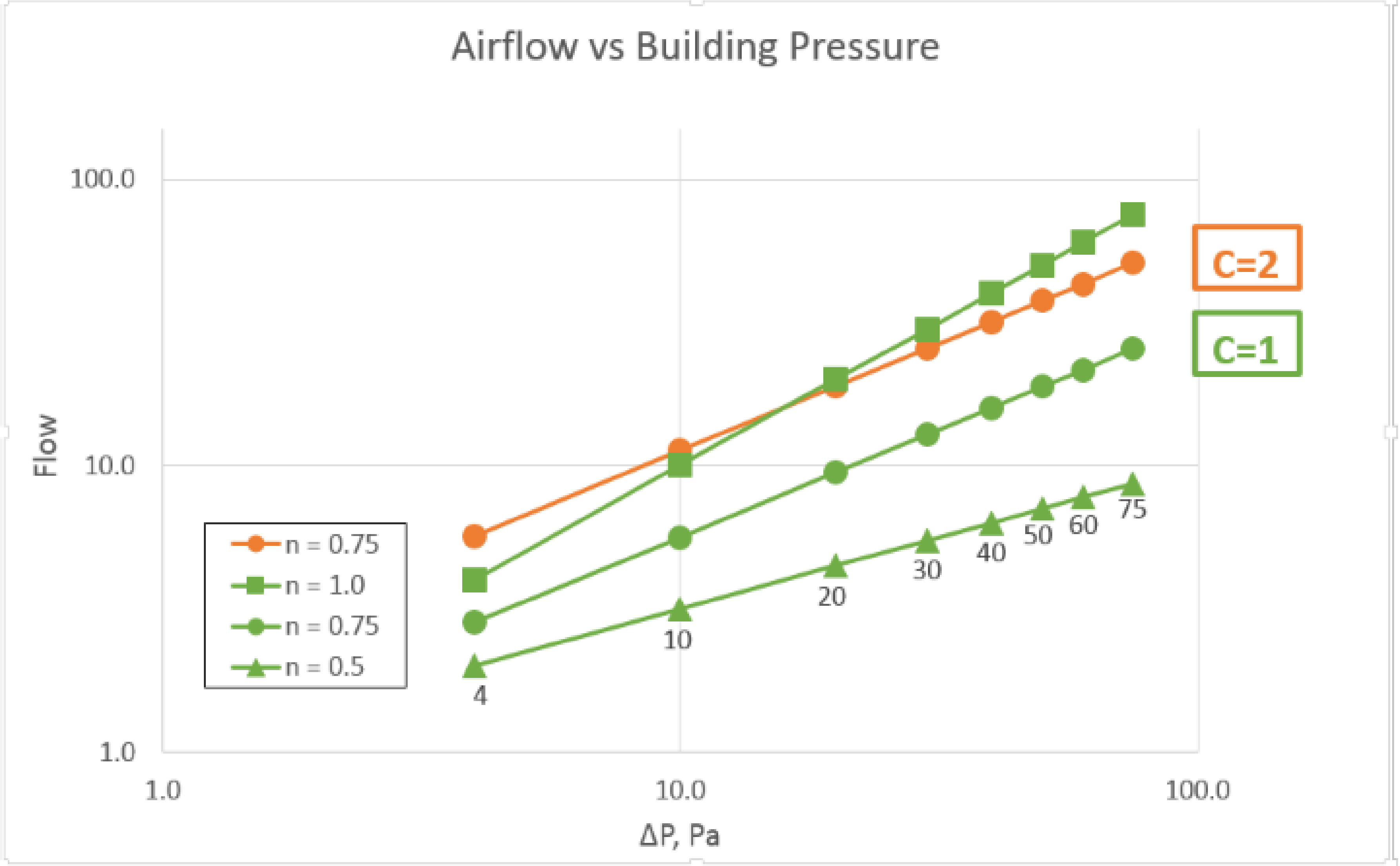
$$Q = cA\,\Delta P^n$$



Airflow vs Building Pressure, C=1
Flow
80
70
60
50
40
30
20
10
0
0
20
40
60
80
ΔP, Pa
n = 1.0
n = 0.75
n = 0.5
4
10
20
30
40
50
60
75

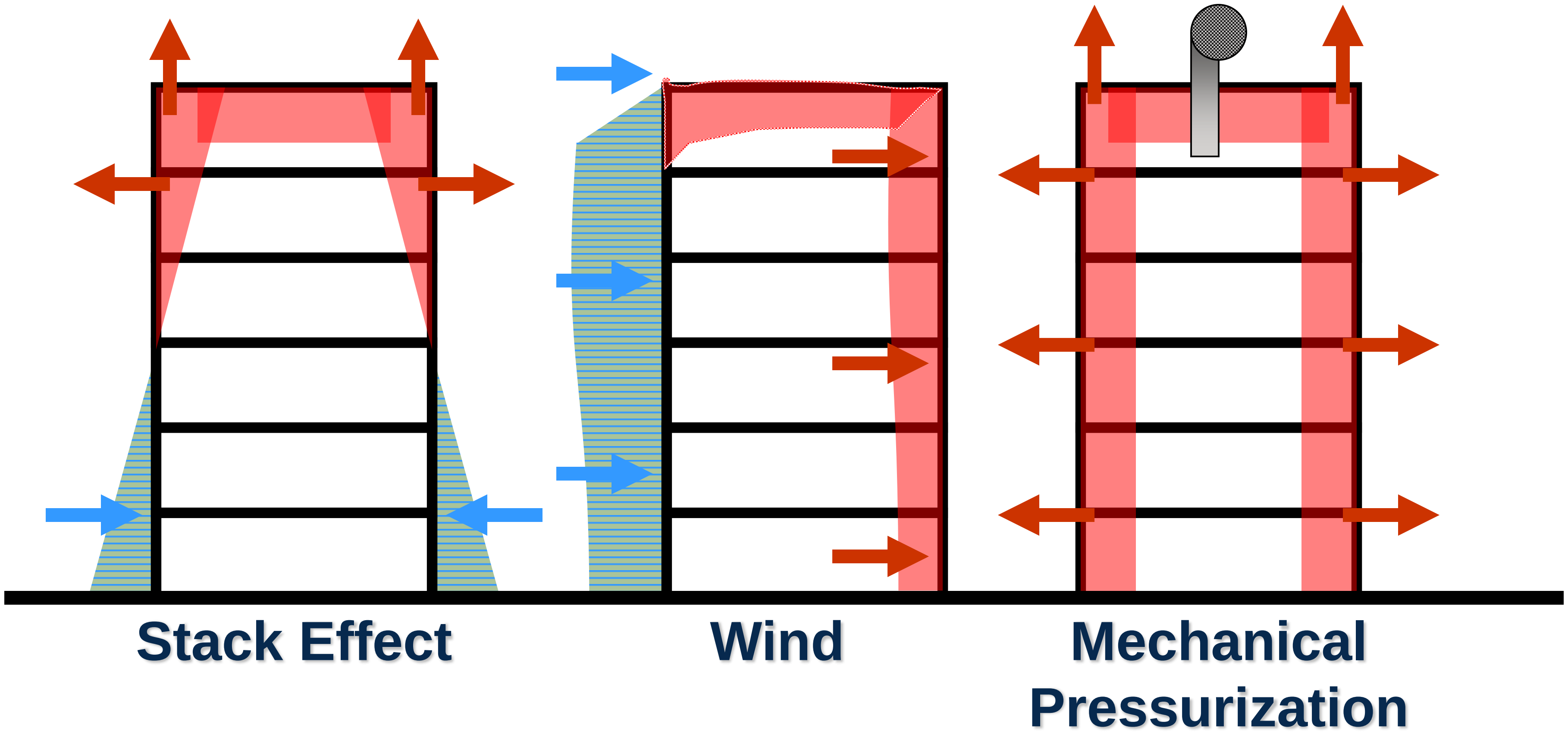
Graphic Representation



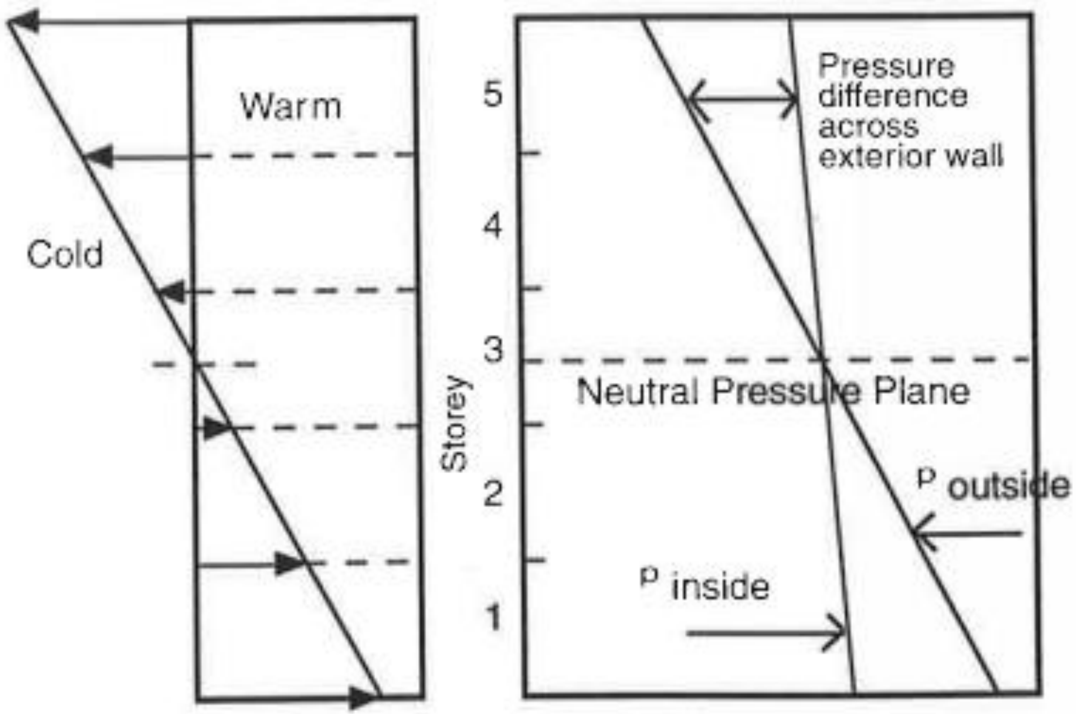


Airflow vs Building Pressure
100.0
10.0
1.0
Flow
1.0
10.0
100.0
ΔP, Pa
C=2
C=1
n = 0.75
n = 1.0
n = 0.75
n = 0.5
4
10
20
30
40
50
60
75

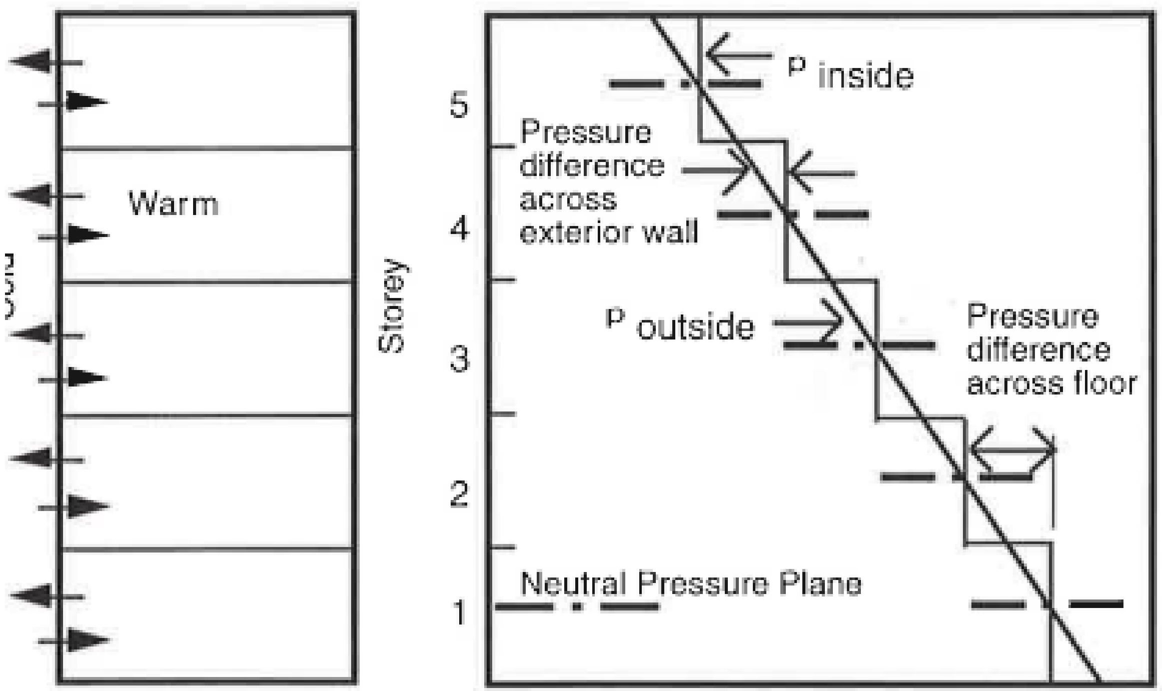
Cold Climate Air Leakage



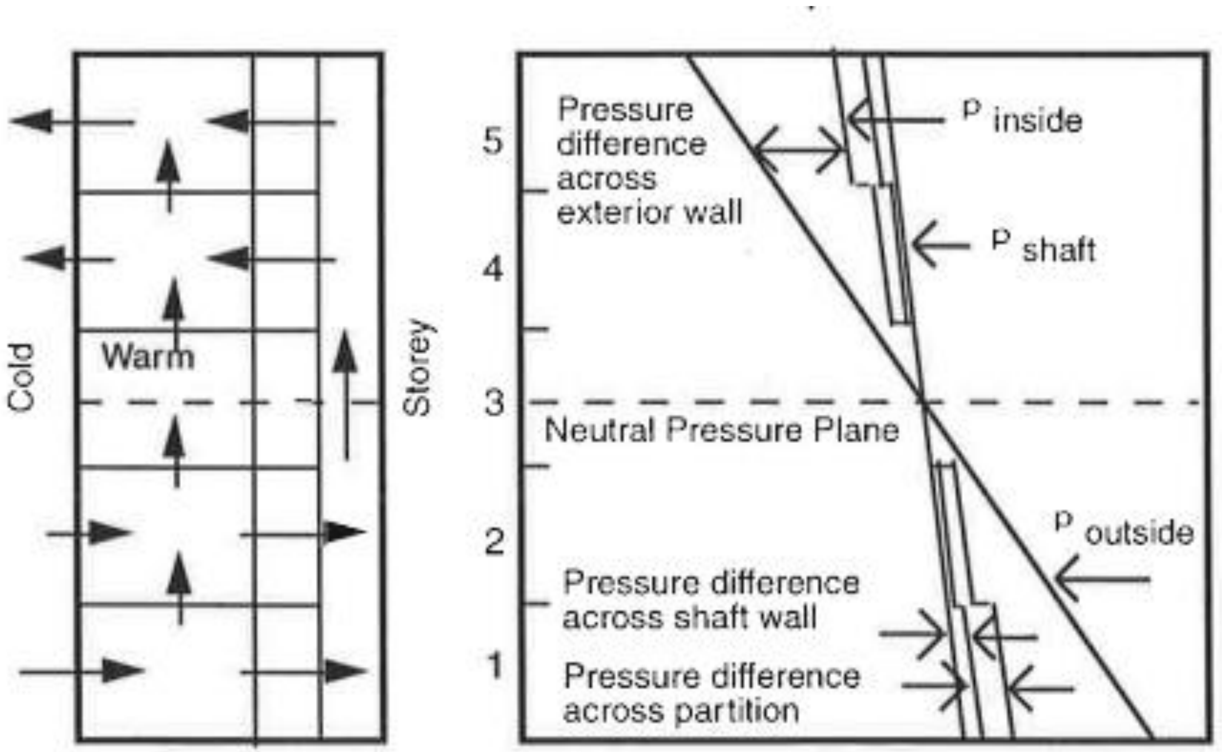
Stack forces in multi-floor buildings



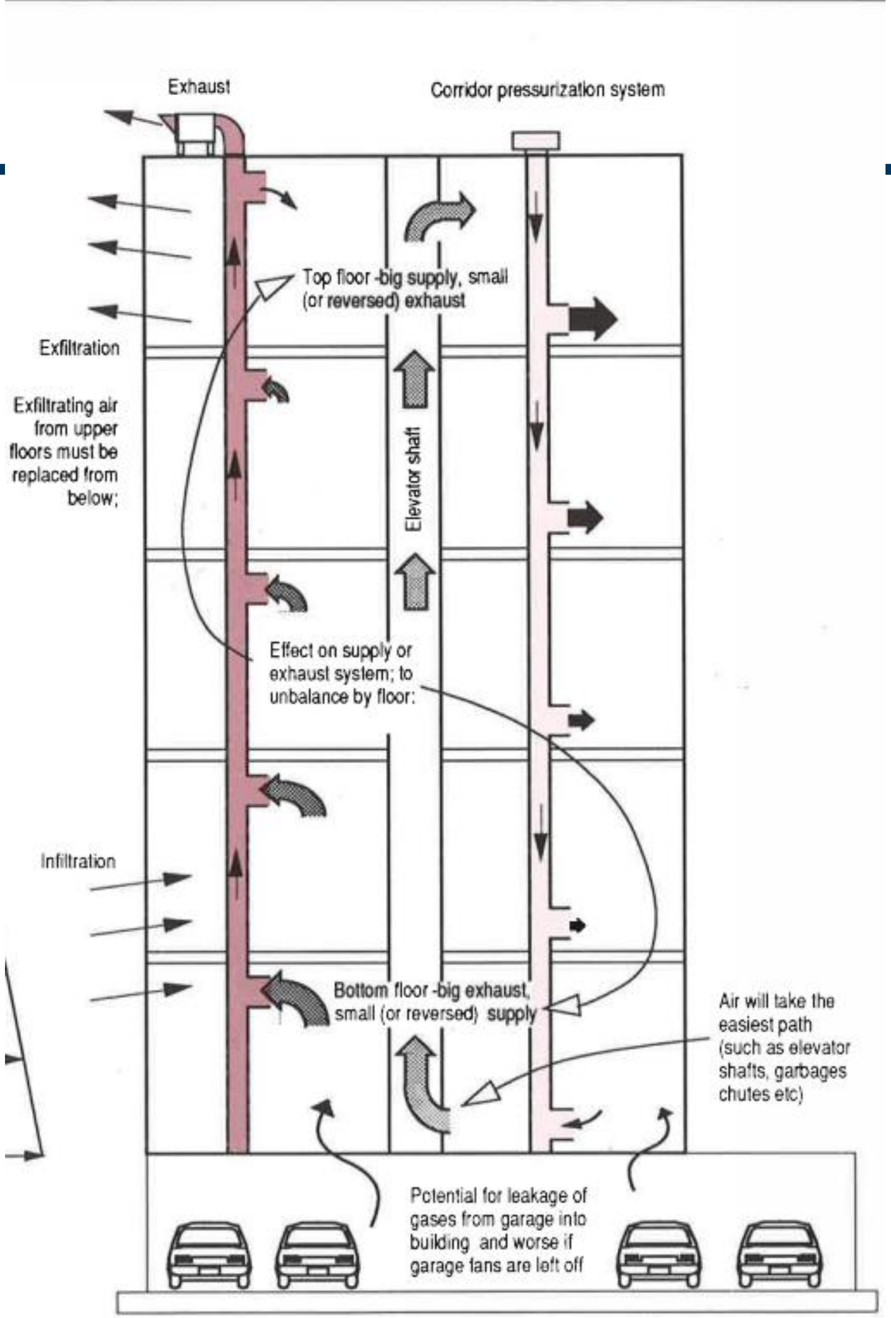
Stack forces in single zone building



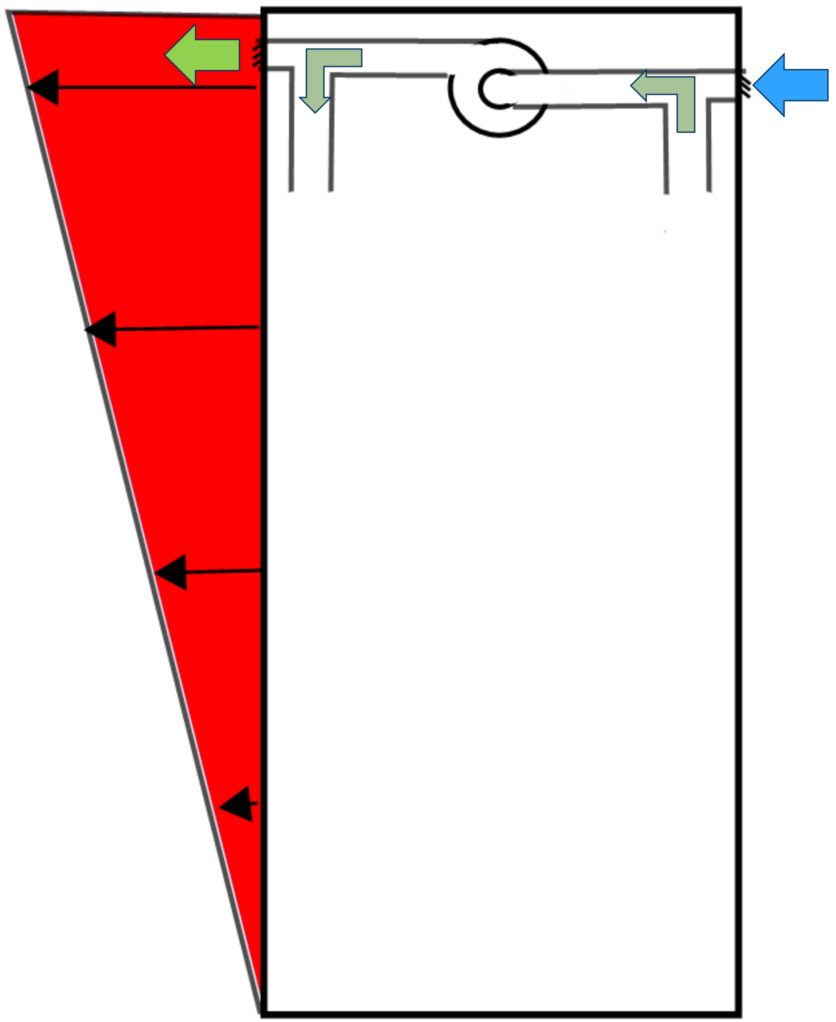
Stack forces in building with airtight floors



Stack forces in an apartment building



Building Pressurization



- Done to control infiltration at lower floors.
- Can be achieved by restricting exhaust rather than increasing supply.
- Limits air change to design ventilation (when operating).

Compartmentalization

- We cannot eliminate stack pressures, but we can design which surfaces take them.
- In an ideal case, one would isolate suites so access to fresh air does not impact other suites.
- It is difficult to seal interior separations.
  - Big vertical transfer paths that that are tough to deal with (think elevators)
  - Consequences of high pressures across internal partitions
- Envelope tightness dictates vertical air movement under stack force.

Measurement

- NRCC (Shaw)
- CMHC for residential
- NIST (Persily)

Field Testing Standards

Quantitative:

- ASTM E 783 – Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors
- ASTM E 2357 – Standard Test Method for Determining Air Leakage of Air Barrier Assemblies
- CAN CGSB 149.10 Determination of Airtightness of Building Envelopes by the Fan Depressurization Method
- CAN CGSB 149.15 ….”Using the Building's Air Handling Systems”
- ASTM E 779 – Standard Test Method for Determining Air Leakage Rate by Fan Pressurization
- US Army Corp of Engineers – Air Leakage Test Protocol for Measuring Air Leakage in Buildings

Output

- CFM @ 50 Pa
- AC/hr @ 50 Pa
- l/s/m^2 @ 75 Pa
- Equivalent Leakage Area (ELA @10 Pa)
- Normalized Leakage Area (ELA per m^2)
- CFM @ 4 Pa

How tight is tight?

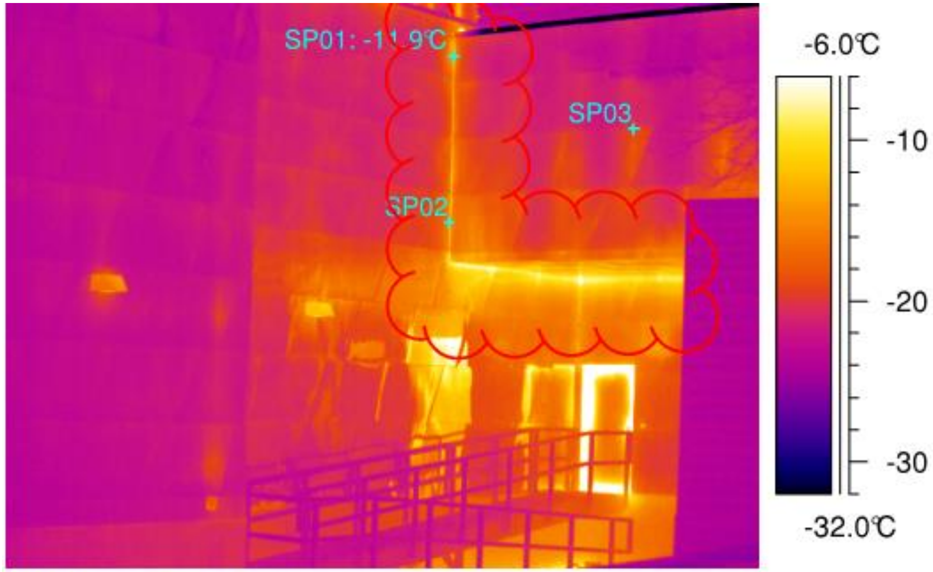
- Test of an insulated wall
  $0.1\ l/s/m^2$ to $0.3\ l/s/m^2$ @ 75 Pa (ref NBC, AAMA)
- R 2000 Standard
  - 1.5 Air change per hour @ 50 Pa
  - $0.7\ l/s/m^2$ @ 75 Pa
- Passive House
  - 0.6 ACH @ 50
- US Army Corp of Engineers criteria for whole building air leakage test
  - $1.27\ l/s/m^2$ @ 75 Pa
- British Standard
  - $2.77\ l/s/m^2$ @ 50 Pa
- Test result from existing large buildings
  - 2-6 $l/s/m^2$ @ 75 Pa (NRC, CMHC)

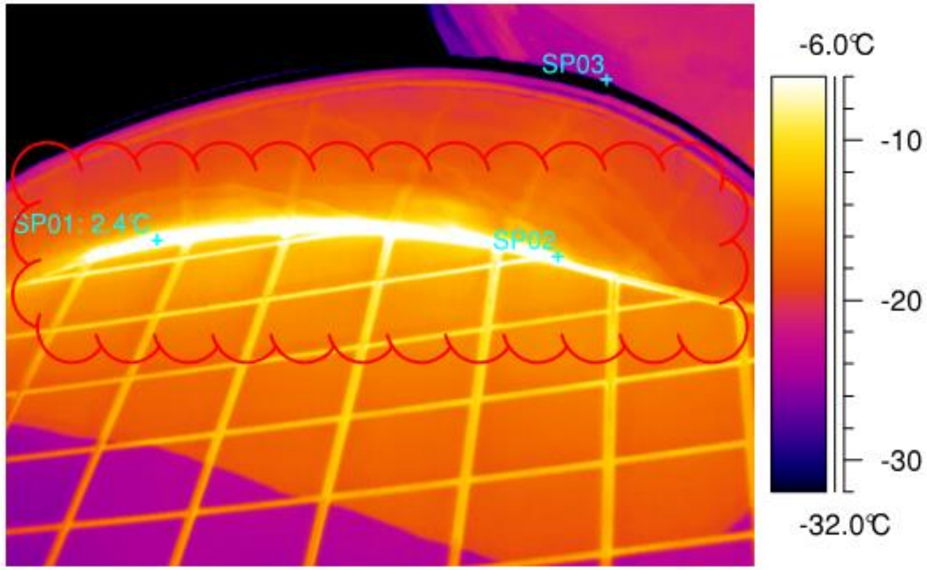
Qualitative Tests

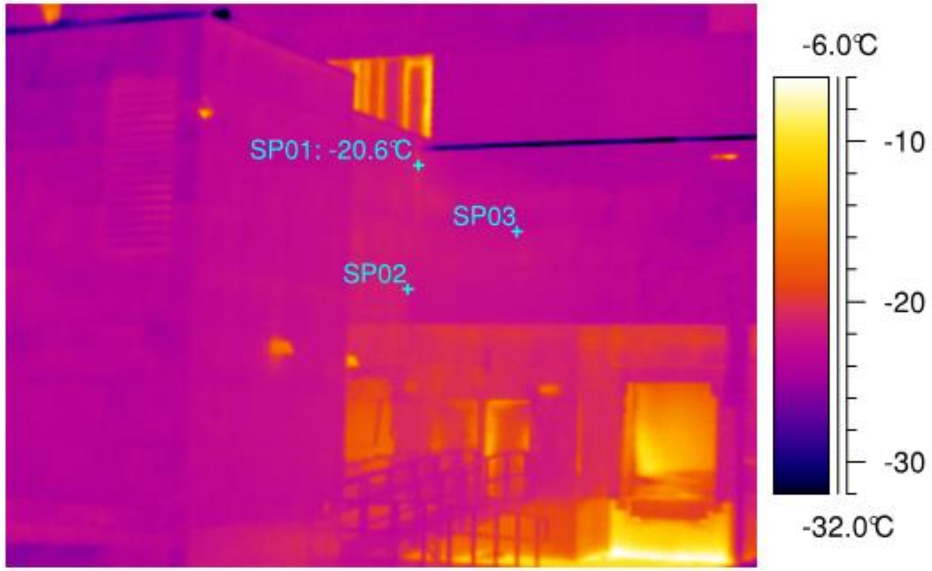
ASTM E1186 – Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems

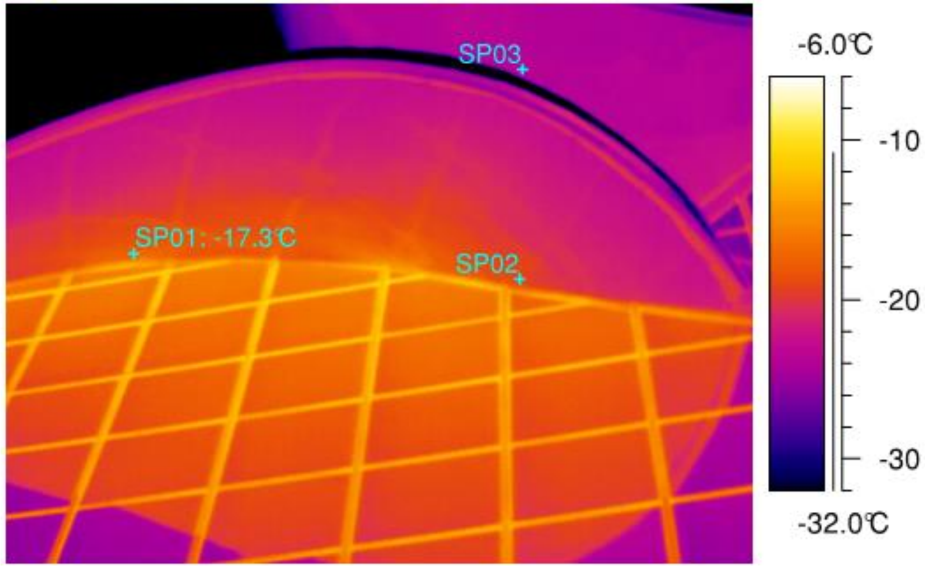
Generally identify leak locations with judgement of how big the leak is.

Thermography









Smoke Testing

Air Flow Control – Energy Costs

2005 Study for the US DOE predicted that improvements to air leakage control in commercial buildings can achieve an estimated average annual heating and cooling energy costs savings of 3% to 36%.

- Greatest savings in heating dominate climates.

Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use – June 2005

Impact of the USACE

- Presidential mandate for military to reduce energy consumption - with targets.
- Air leakage identified as a major factor in energy use.
- USACE decide to require quantitative proof of air tightness in its new facilities.
  - Air leakage became major focus of research in the US
  - Post construction testing “educated” designers and builders
  - It has become accepted that the benefits would not have been achieved without the test requirement

The Big Questions for Enclosure Professionals

- How airtight do building enclosures need to be?
  - Leakage of small quantities of humid air into colder confined spaces can be harmful.
  - Air leakage directly from one side of the enclosure to another is seldom harmful.
  - Where does the Law of Diminishing Returns kick in for energy
- Are building enclosures ever “too tight”?
  - We can’t rely on accidental holes to passively ventilate our buildings.
  - The suction caused by big fans in tight buildings can cause significant problems with combustion appliances.
- Does widespread quantitative air leakage testing provide information worth the cost and effort?