# High Rise Energy & IAQ Envelope Testing

Exterior Shell &

Individual Apartment &

Individual Surface Leakage

# Real problems in high rises

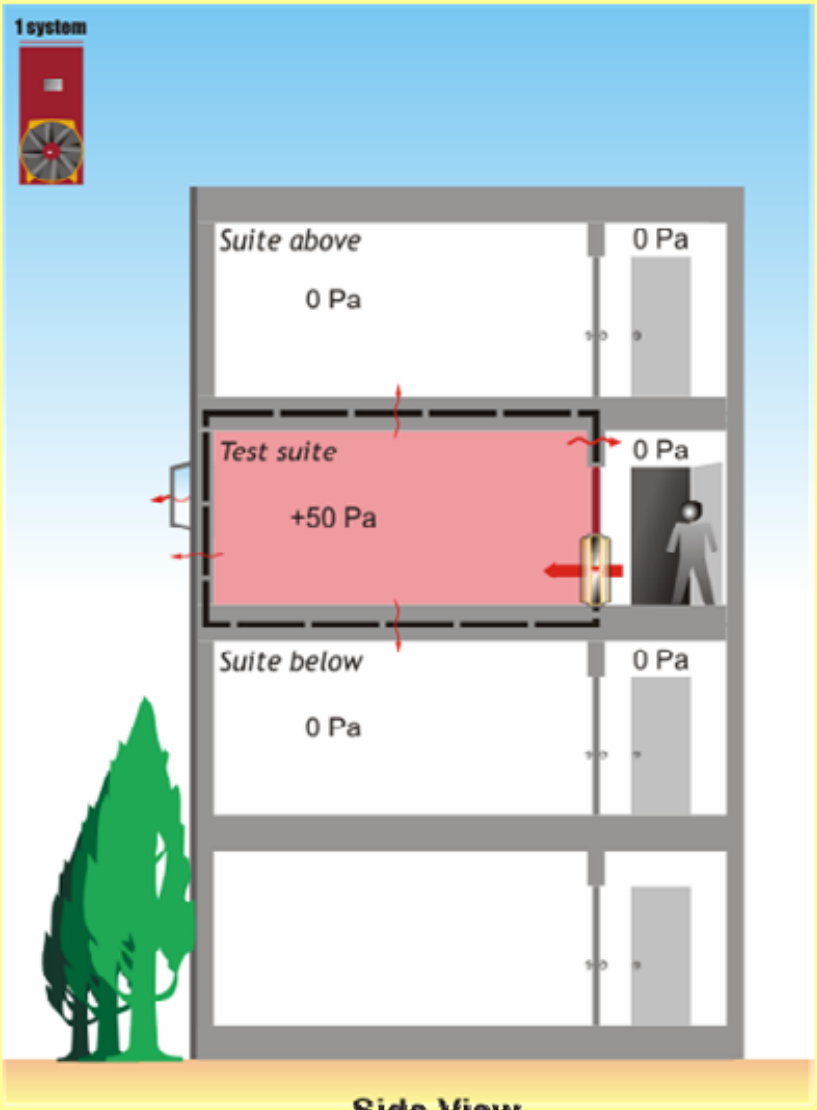
# Various Standards Converted to: $cm^2$ EqLA per $m^2$ envelope @ 50 Pa

| n=0.6 for an **apartment**, 120 x 110 x 8 ft, 4 stories | house | Apt. |
|---|---|---|
| Canadian R-2000 1 $in^2$ EqLA @10 Pa /100 $ft^2$ envelope | **0.9** | **0.8** |
| Canadian R-2000 house 1.5 air changes/ hour | **0.8** | **2.4** |
| US Army standard is 0.25 cfm/ $ft^2$ at 75Pa | **1.8** | **1.8** |
| UK 3 $m^3/h/m^2$ at 50 Pa Best practice, House | **1.5** | **1.5** |
| LEED,1.25 $in^2$ EfLA @ 4 Pa / 100 $ft^2$ envelope | **2.1** | **1.9** |
| UK 5 $m^3/h/m^2$ at 50 Pa Best practice, Commercial | **2.5** | **2.5** |
| Danish House Standard 1.5 $l/s/m^2$ floor @ 50 Pa | **2.7** | **2.7** |
| IECC standard is 0.4 cfm / $ft^2$ at 75Pa | **2.8** | **2.9** |

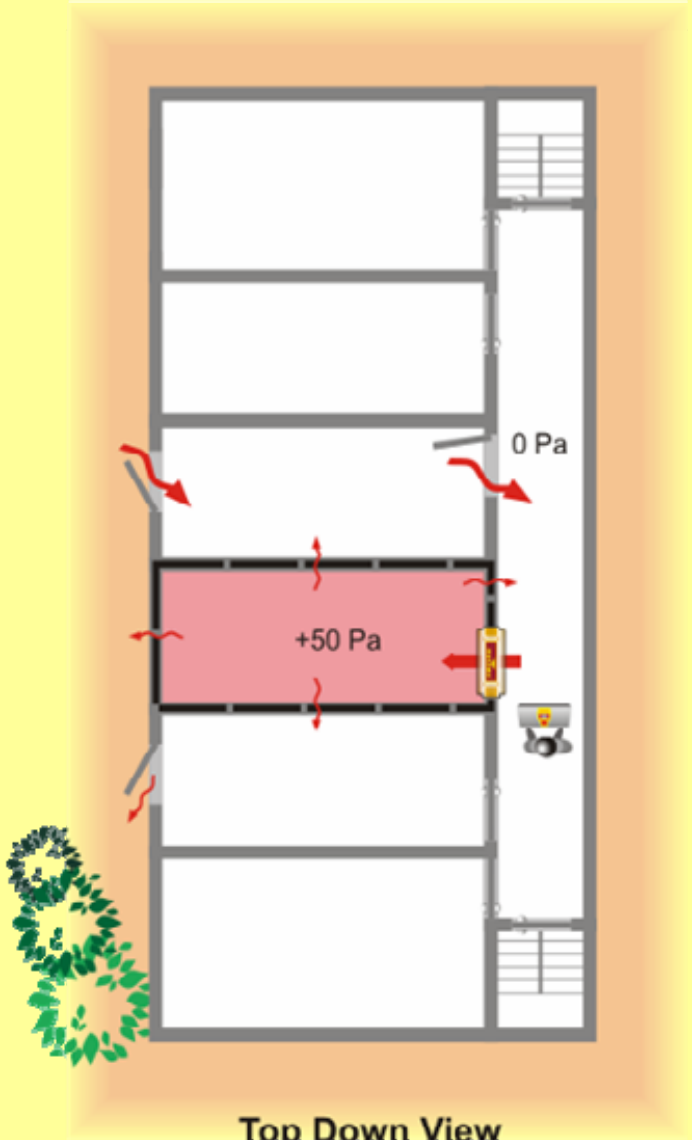
# Leakage Standards

| Standard | Leakage | $cm^2/m^2$ EqLA at 50 Pa |
|---|---|---|
| ASHRAE standard for tight buildings | 0.10 cfm / sq.ft. at 75 Pa | 0.7 |
| Canadian R-2000 for houses | 1.0 sq.in /100 sq.ft. at 10 Pa<br>0.7 sq.cm / sq.m. | 0.9 |
| Canadian Building code for assemblies | 0.15 l/s/sq.m. at 75 Pa<br>0.05 l/s/sq.m. | 0.2<br>0.07 |
| UK Section L for tightest Commercial | 2 cu.m /h/sq m. | 1.0 |

# Total Unit Leakage - All 6 Sides, 1 Door Fan



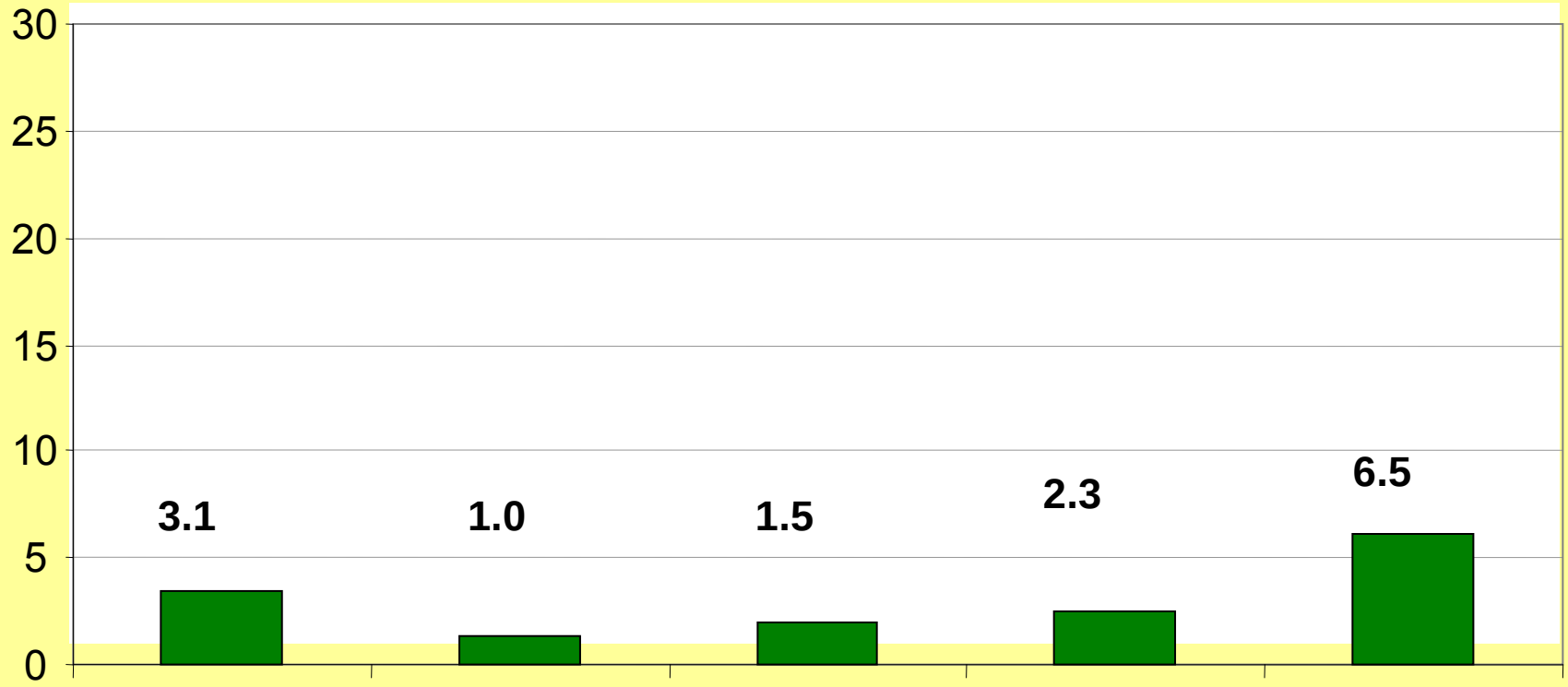

Side View



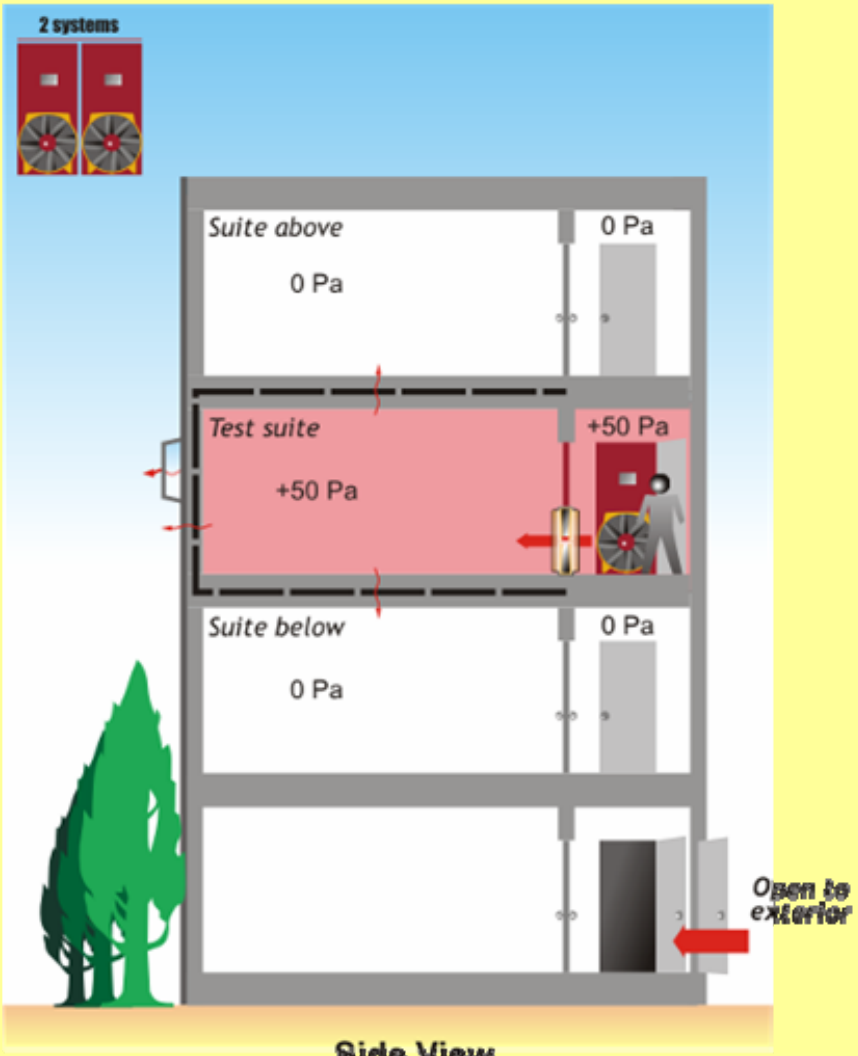

Top Down View

# Numerous Apartment Buildings Tested

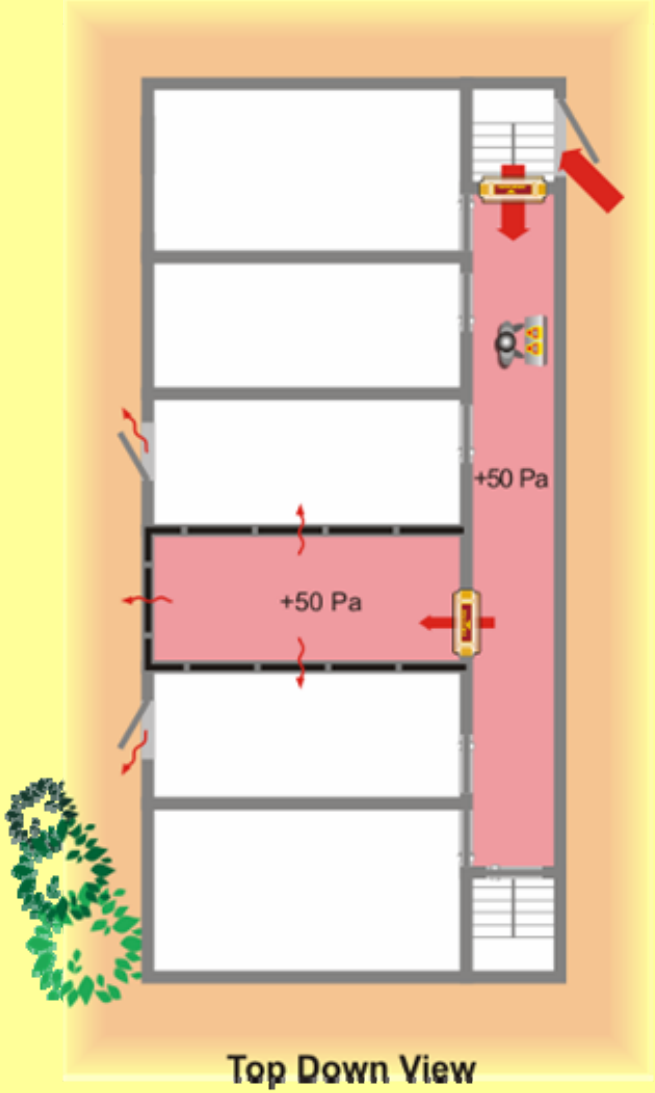
# Leakage on all 6 sides
# $cm^2/m^2$ @ 50 Pa



# Leakage from Apartment to Hallway

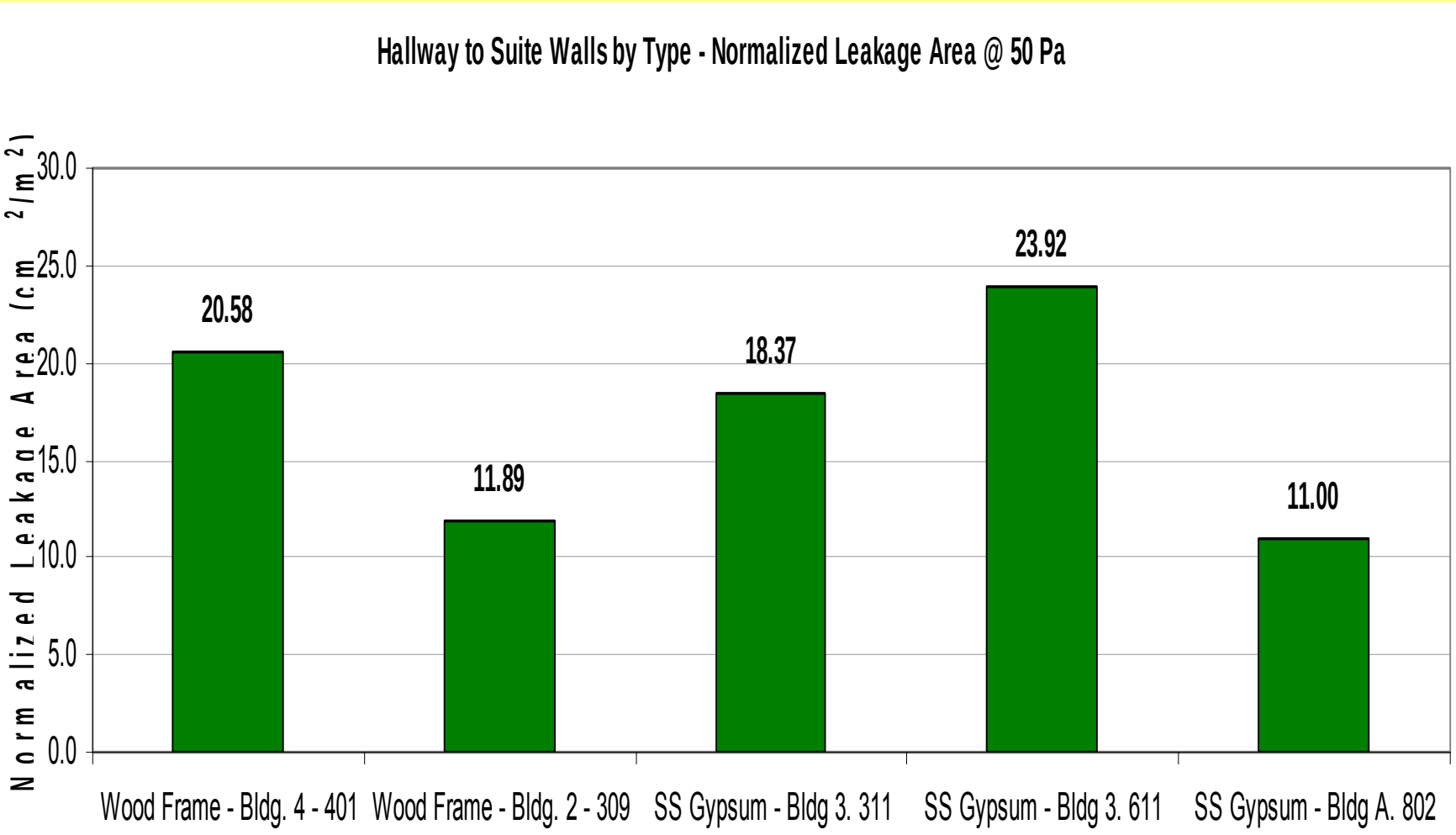



Side View

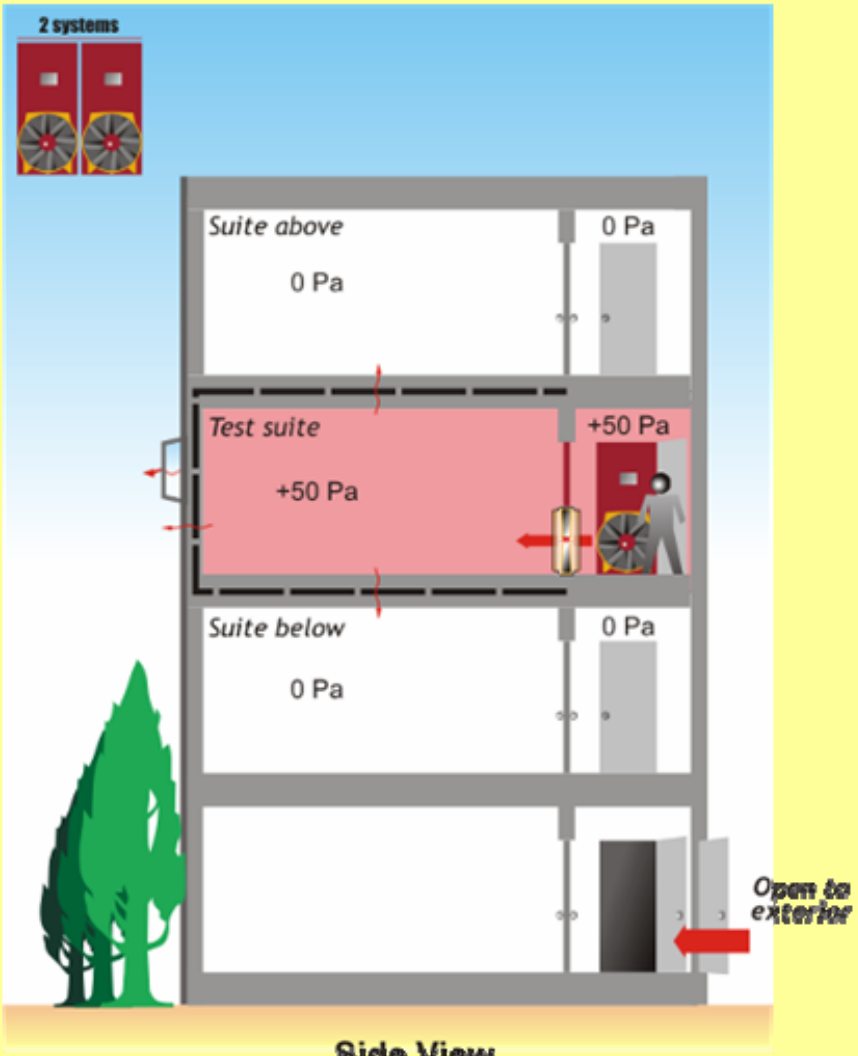



Top Down View

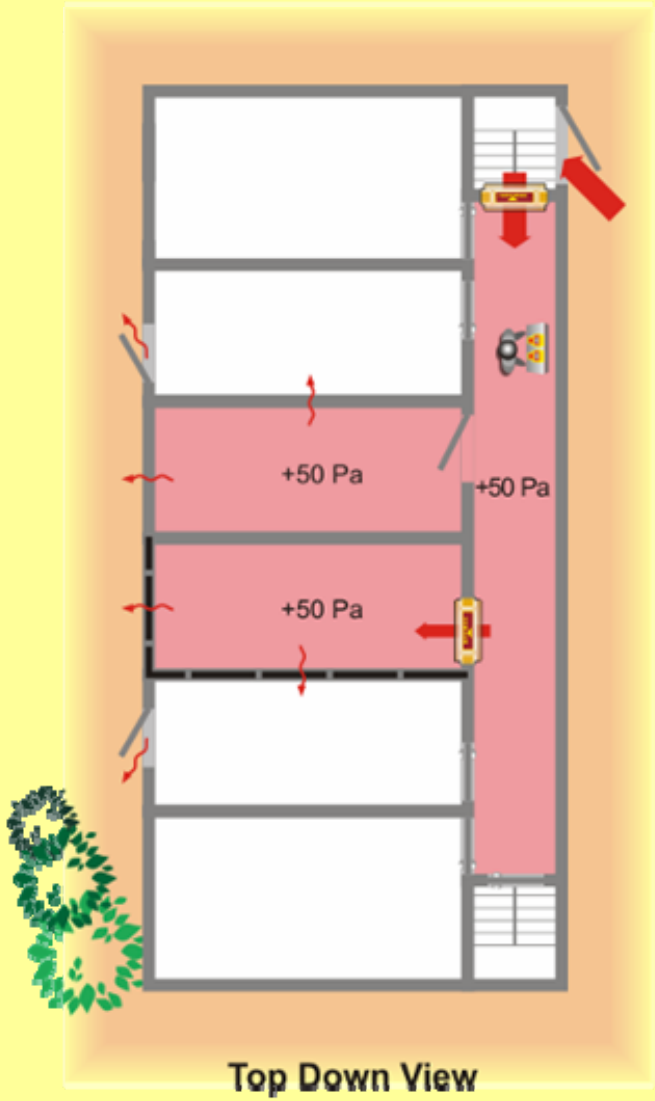
# Hallway Walls



# Leakage across 1st Party Wall

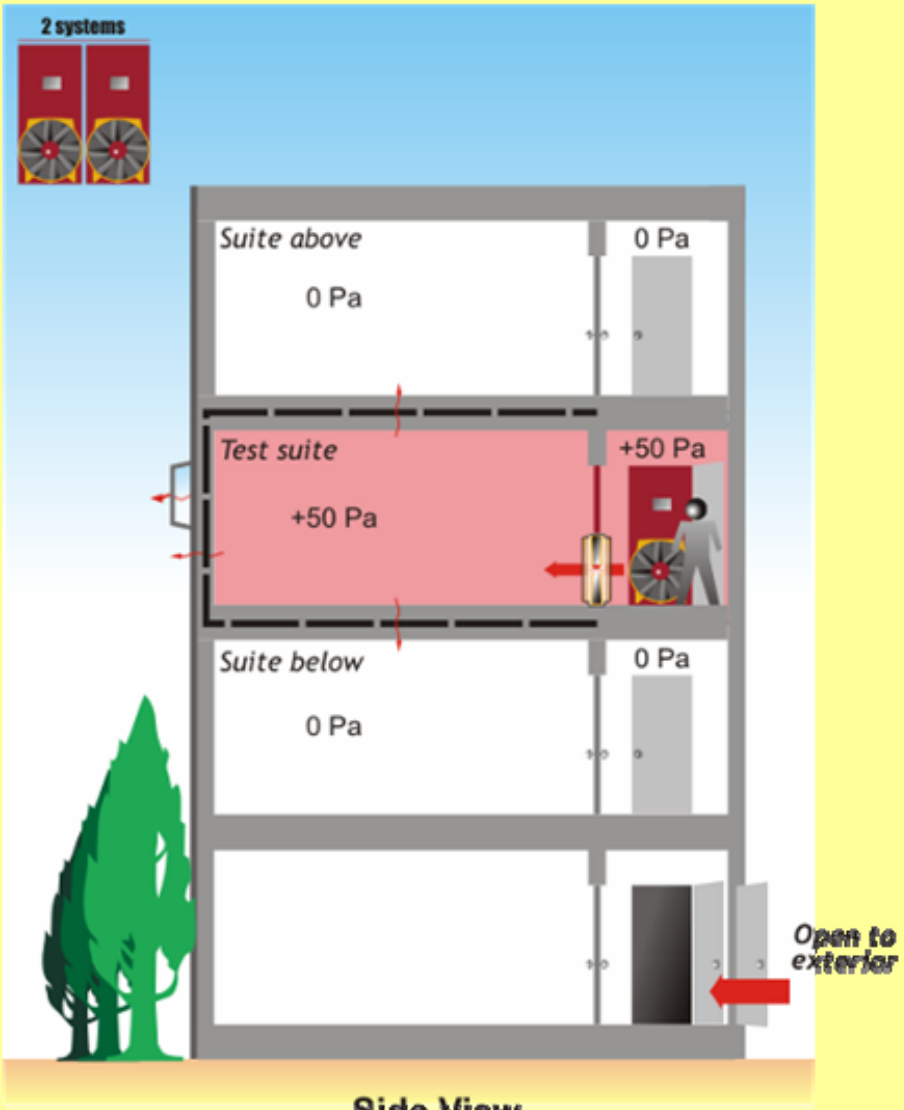



Side View




Top Down View

# Leakage across 2nd Party Wall

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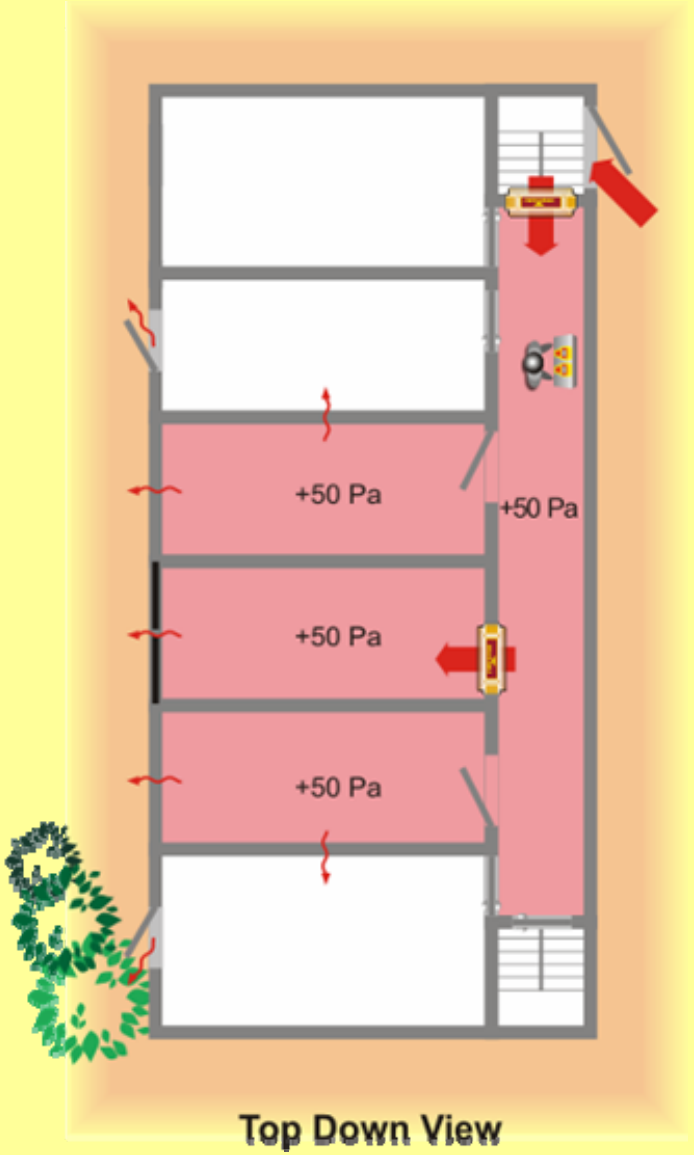
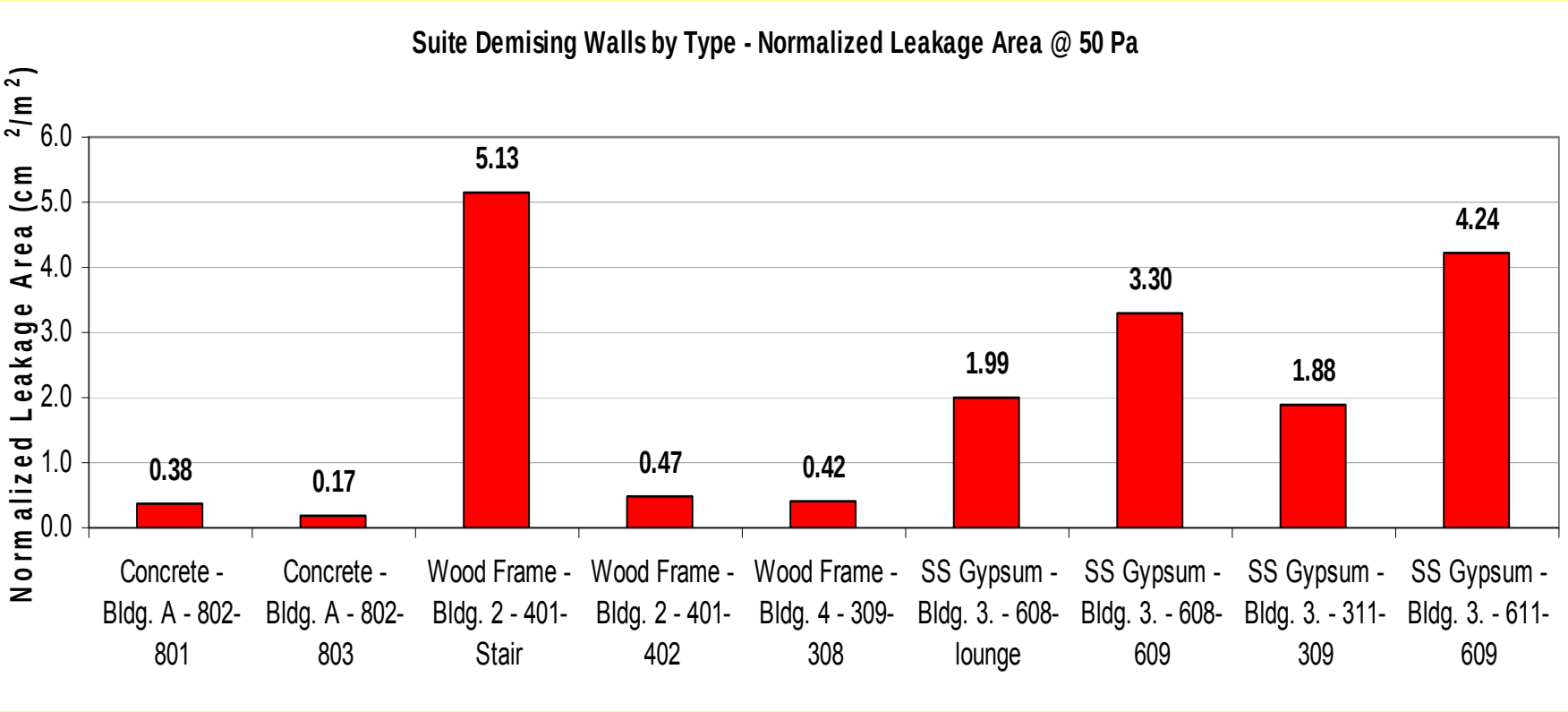
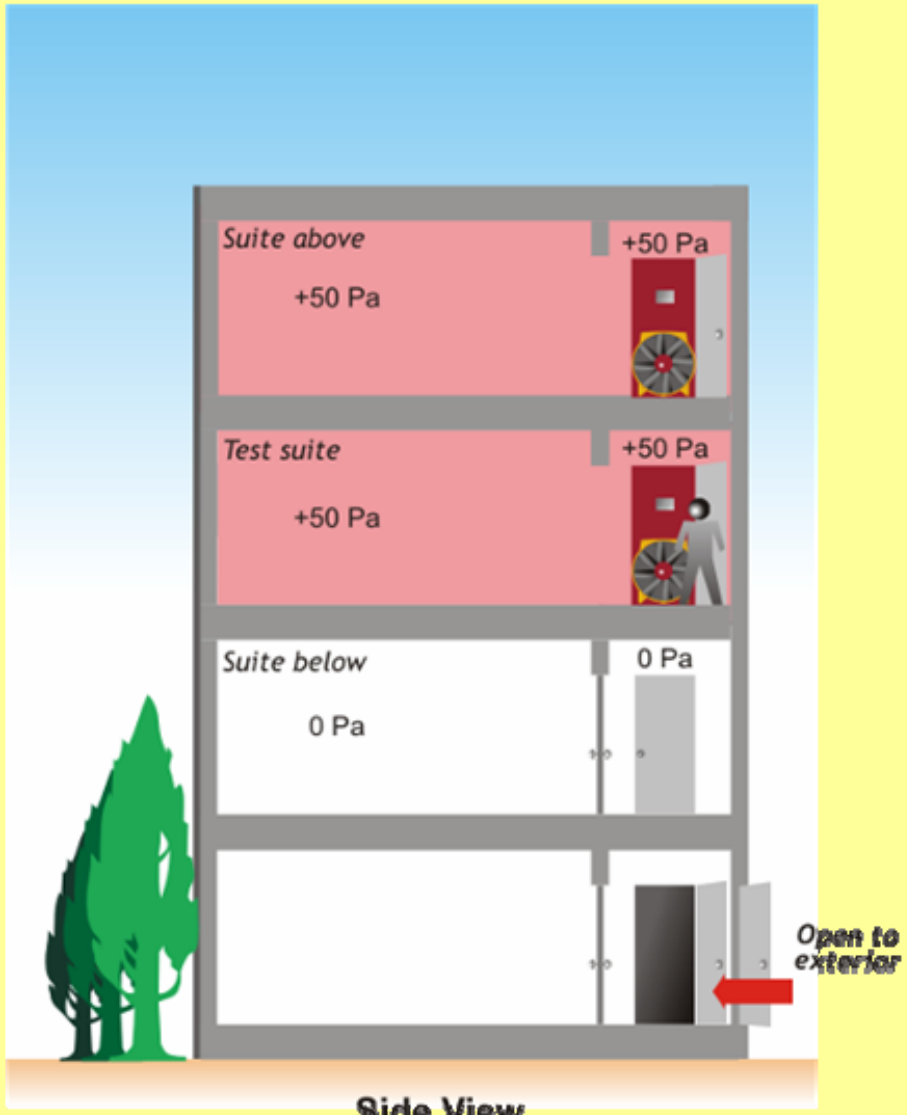



Top Down View

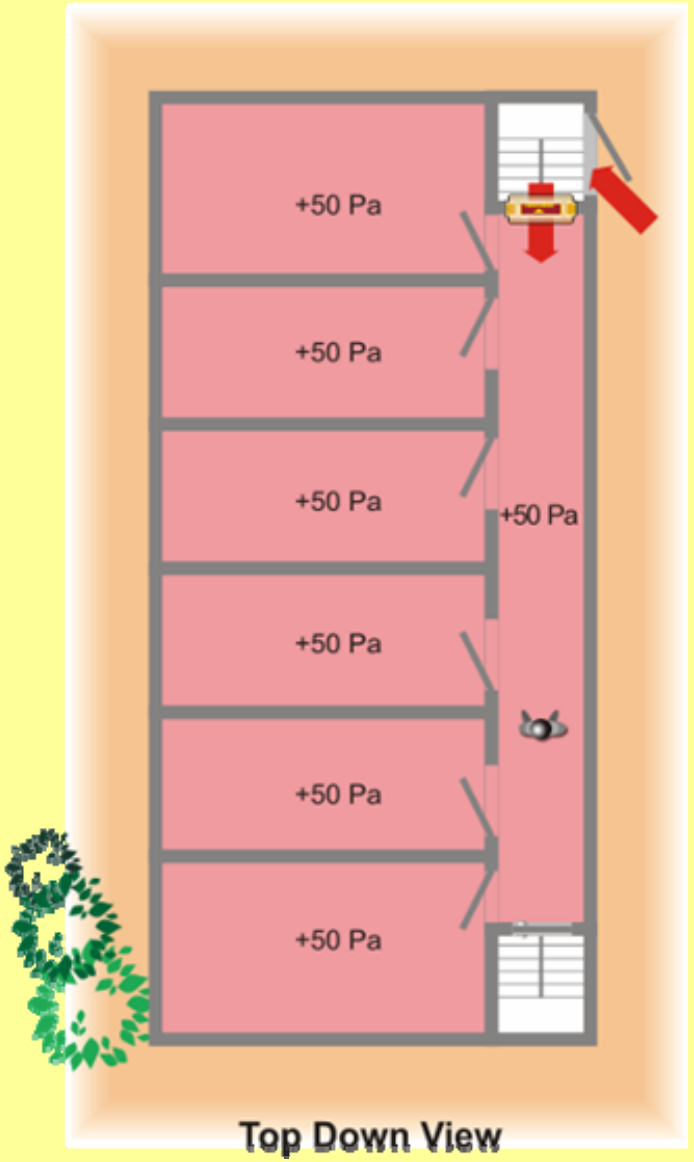
# Party Walls



# Pressurizing the Floor Above

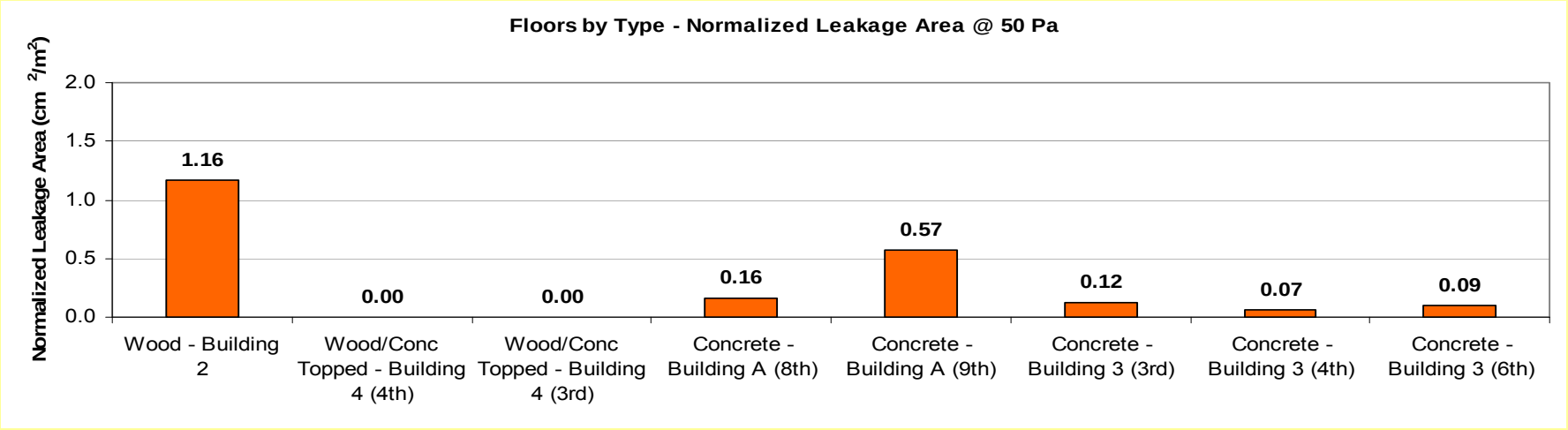



Side View

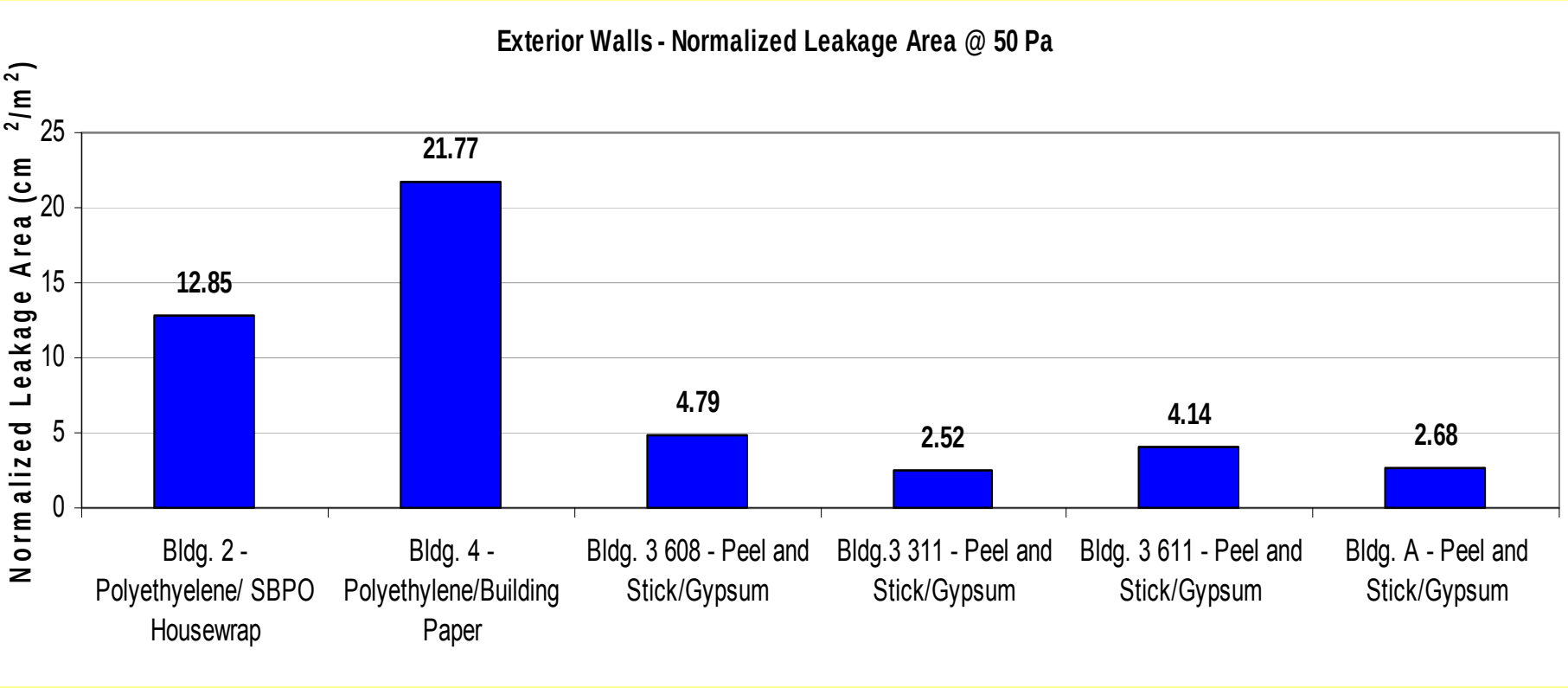



Top Down View

# Floor Leakage



# Exterior Walls



# Elevator Shaft test in Dam

# Lobby Test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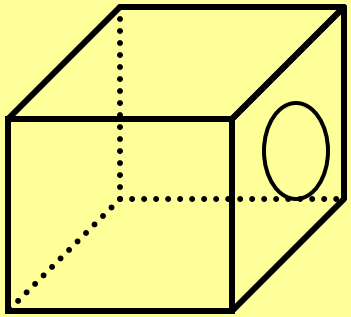
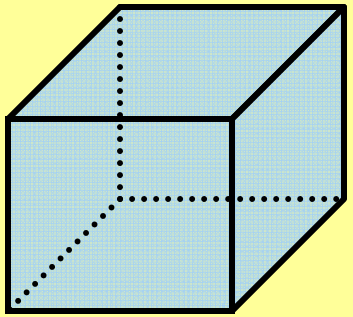
# Why/how do buildings leak?

Level 1 Training

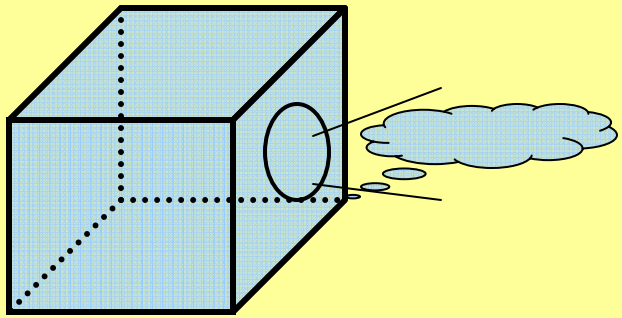
# Pressure + Hole = Leak



No pressure, no flow

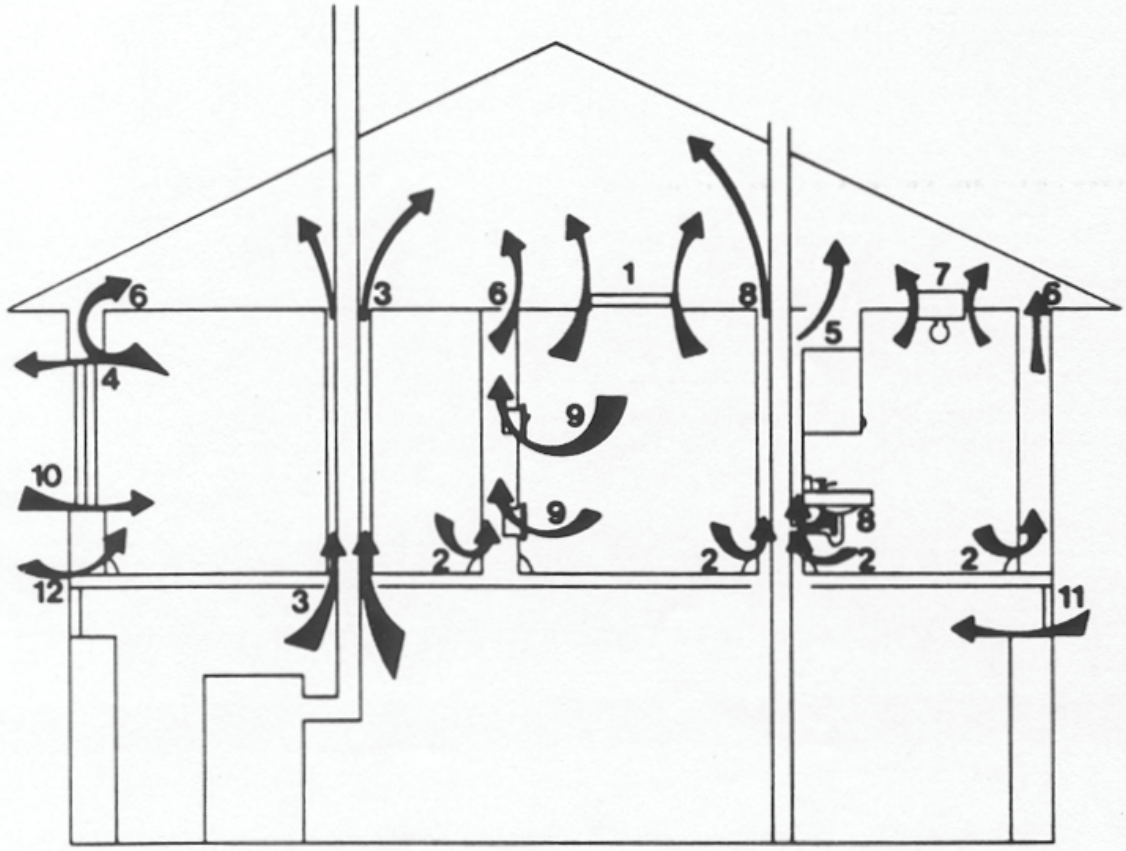


No hole, no flow



It takes BOTH pressure and a hole
for there to be flow.

# Buildings are full of holes




**Warm air escapes around:**

1 attic hatch
2 baseboards and molding
3 chimney flue
4 doors and windows
5 dropped ceilings
6 exterior and partition walls
7 lighting fixtures
8 plumbing penetrations
9 wall switches and electrical outlets

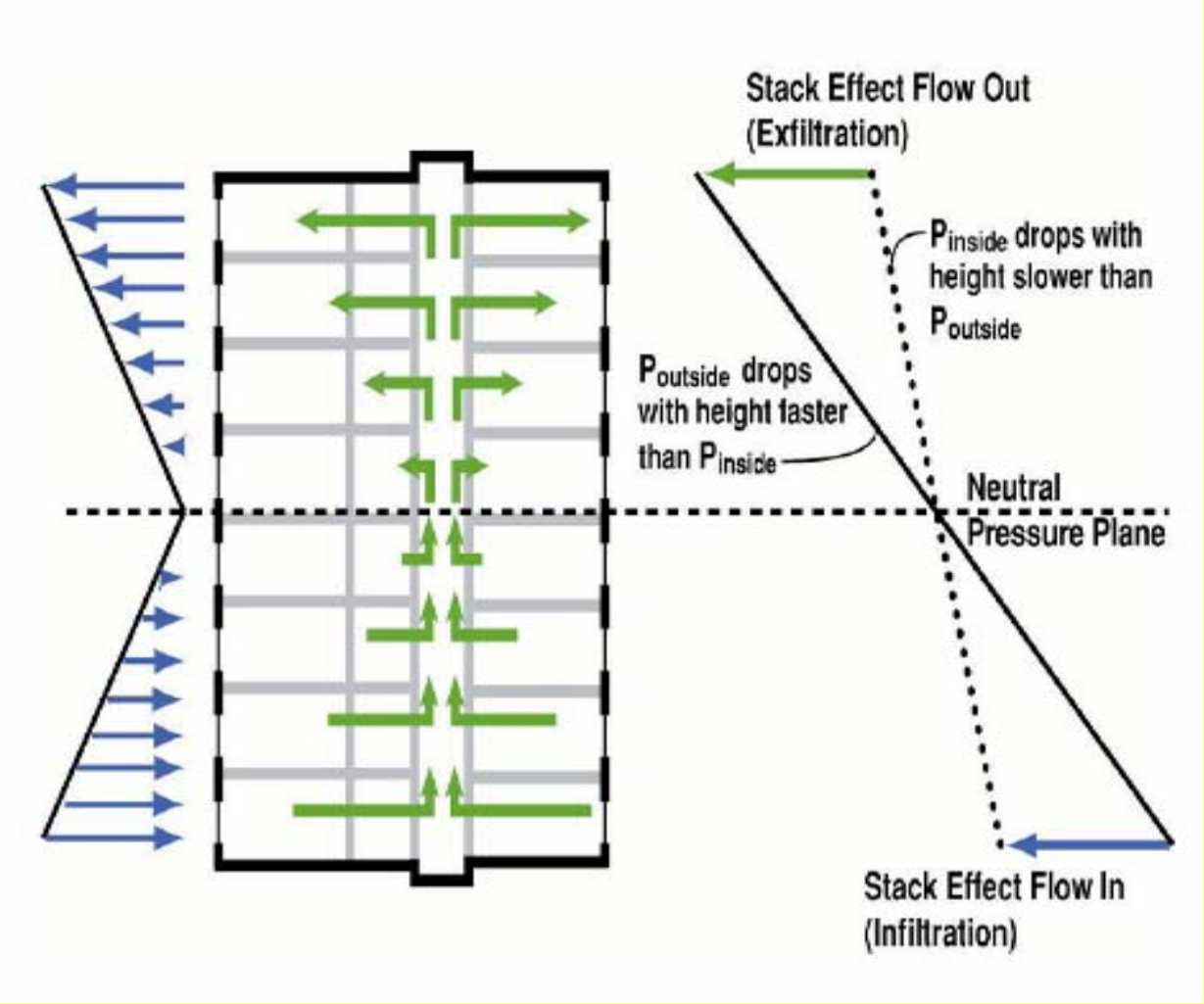
**Cold air infiltrates around:**

10 doors and windows
11 rim joists
12 other cracks and holes

# Sources of Pressure

- Stack effect
  - Hot air rises, cold air falls
- Wind pressures
  - Pressure ≈ $mph^2$ / 10  (20 mph = 40 Pa)
- Mechanical equipment
  - Ventilation fans, HVAC, etc
- Elevators
  - Pistons pumping air around building

# Stack Effect

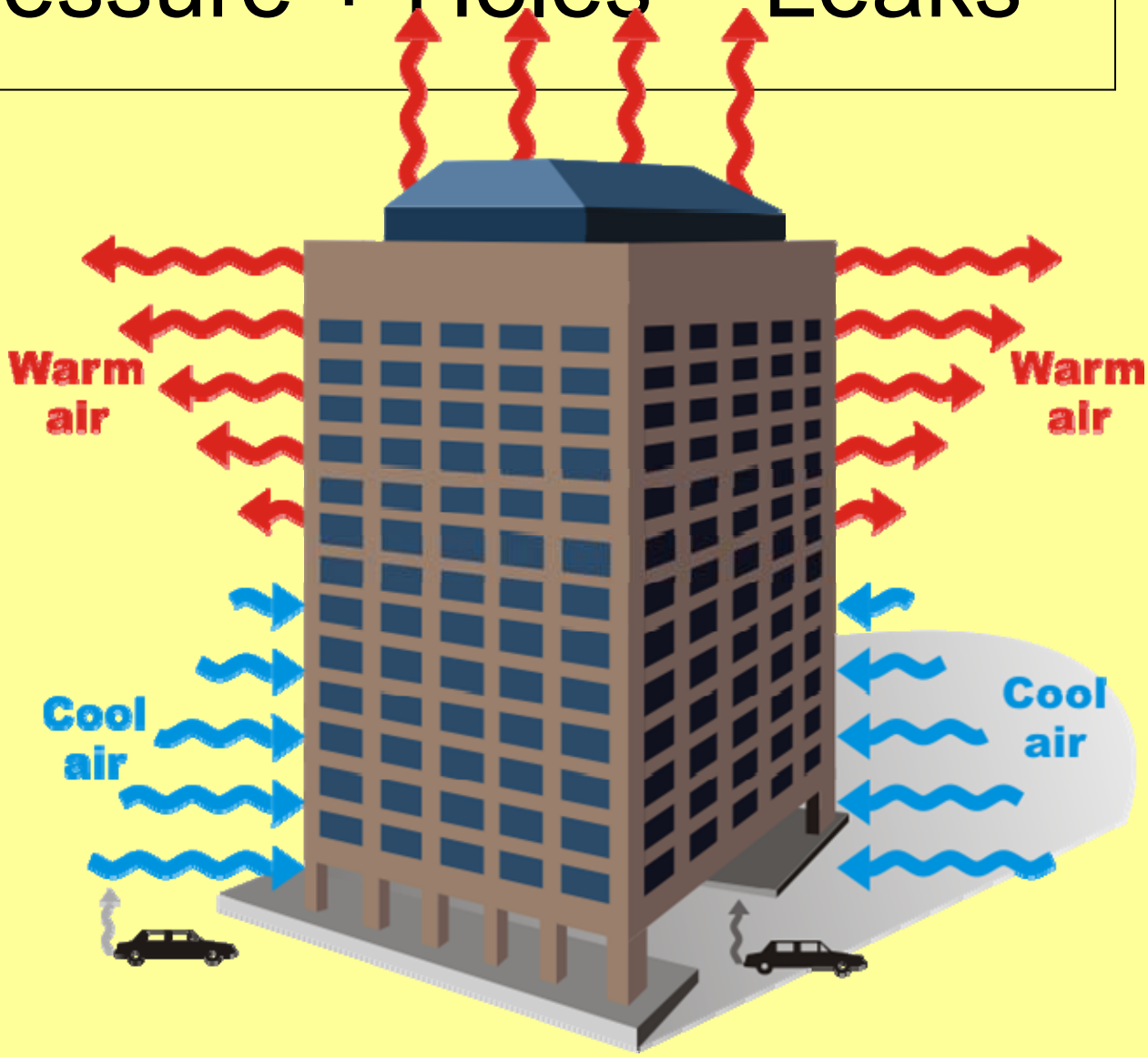


# Stack Pressure + Holes = Leaks

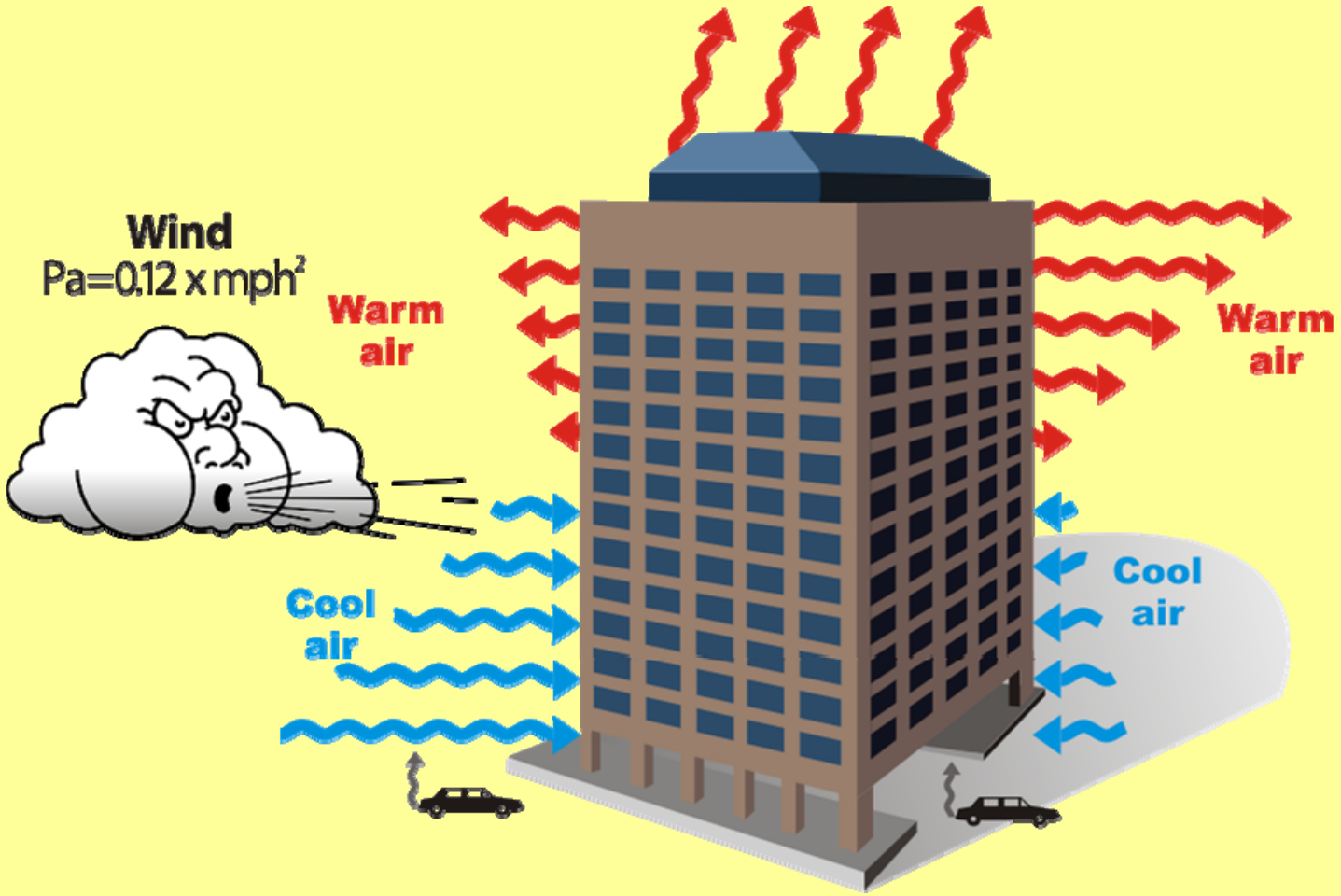

**Stack Effect**

Warm air rising

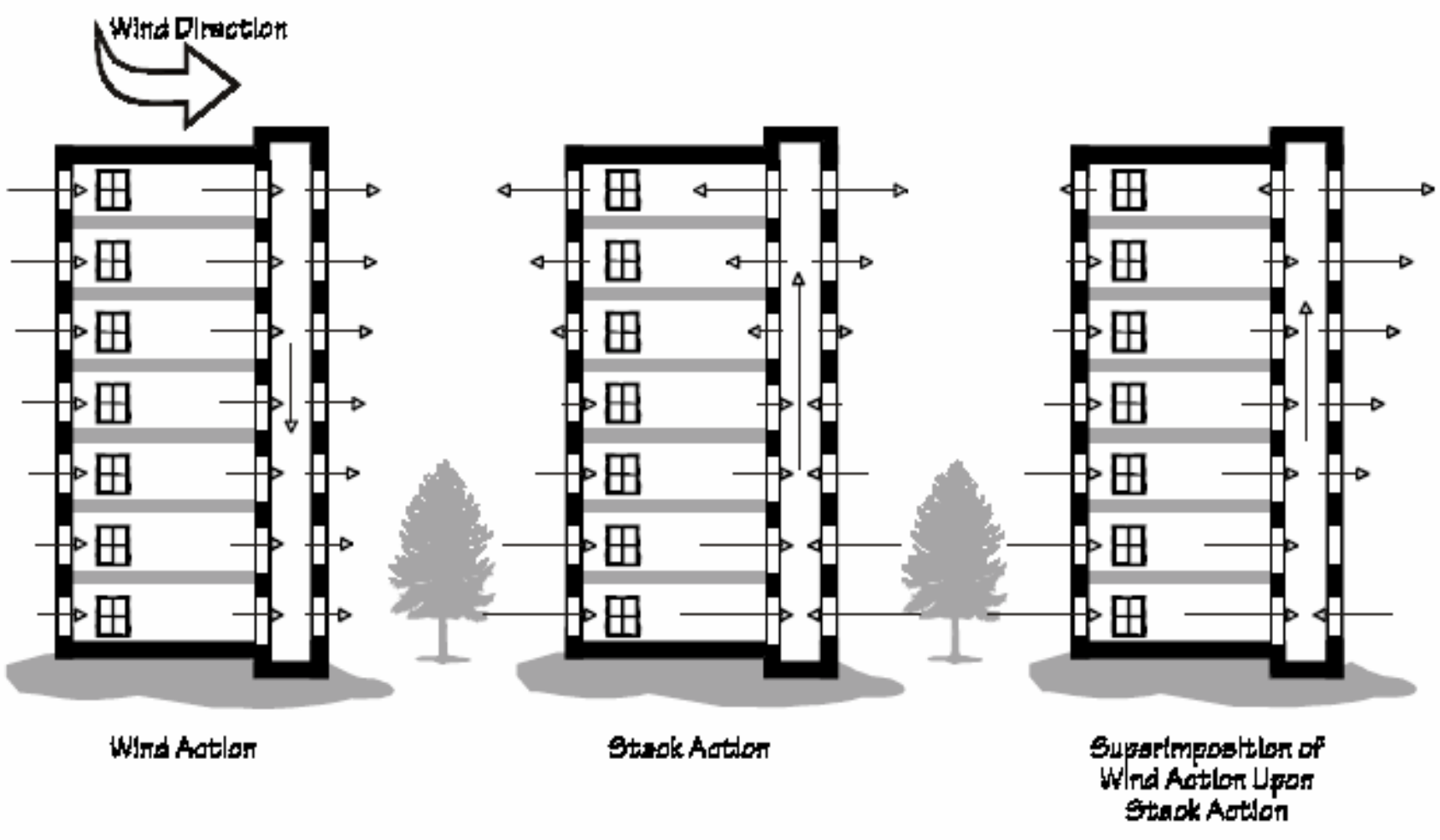
Cold air falling



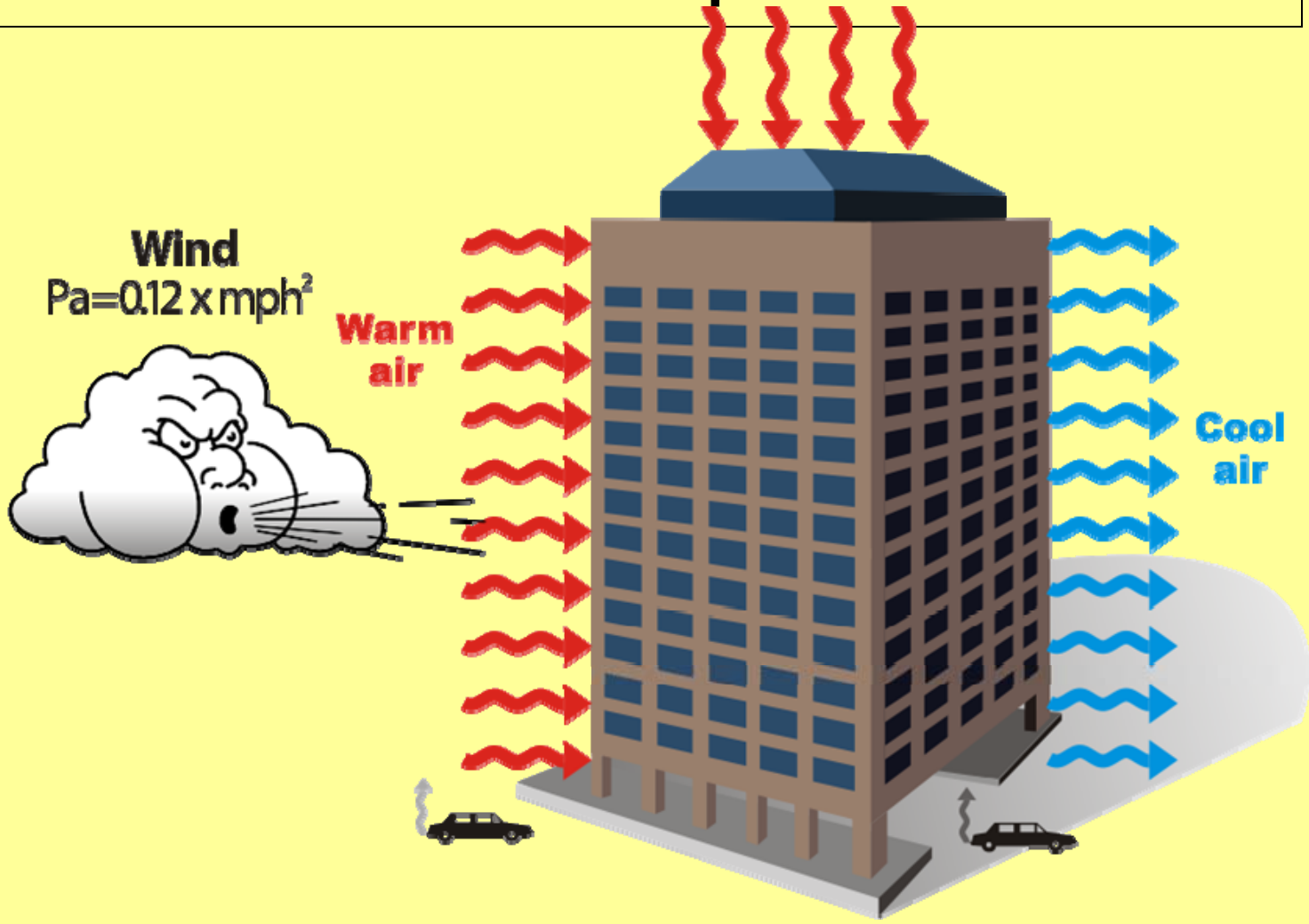
# Stack Pressure + Wind Pressure + Holes = Bigger Leak



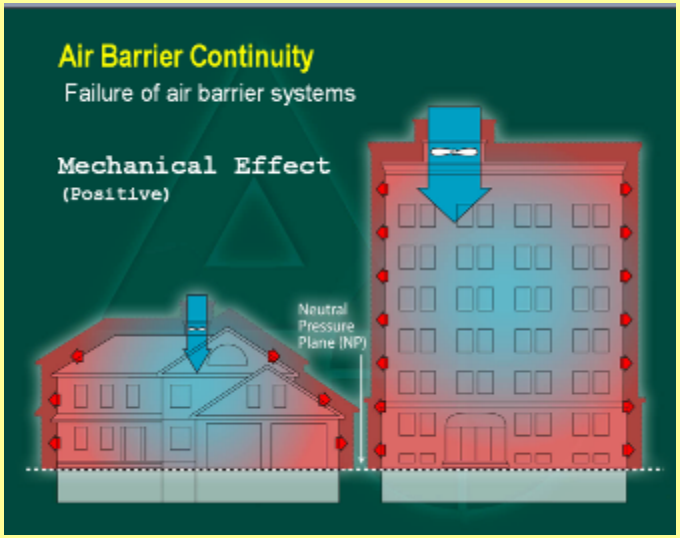
# Wind + Stack Effect



# Hot climates
# - walls more important



# Flues & Mechanical Systems also create Pressures




**Flues**

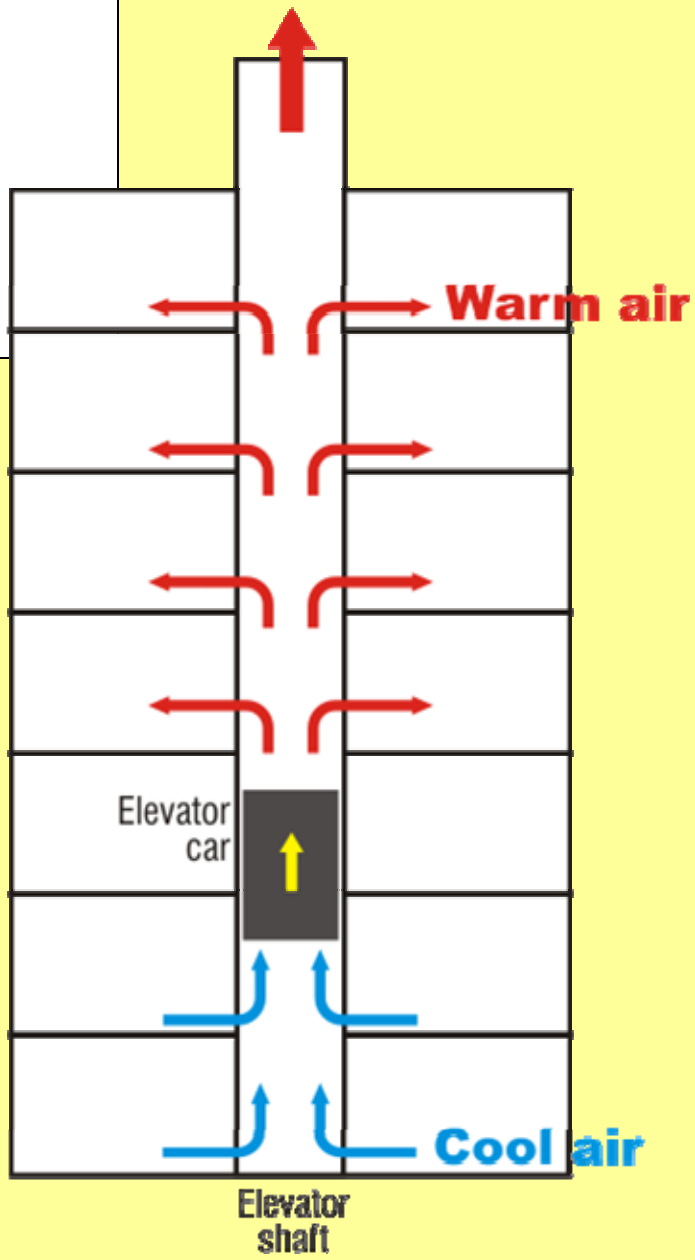
Air flows out

**Mechanicals**

Force air in and/or out

# Elevators create pressure

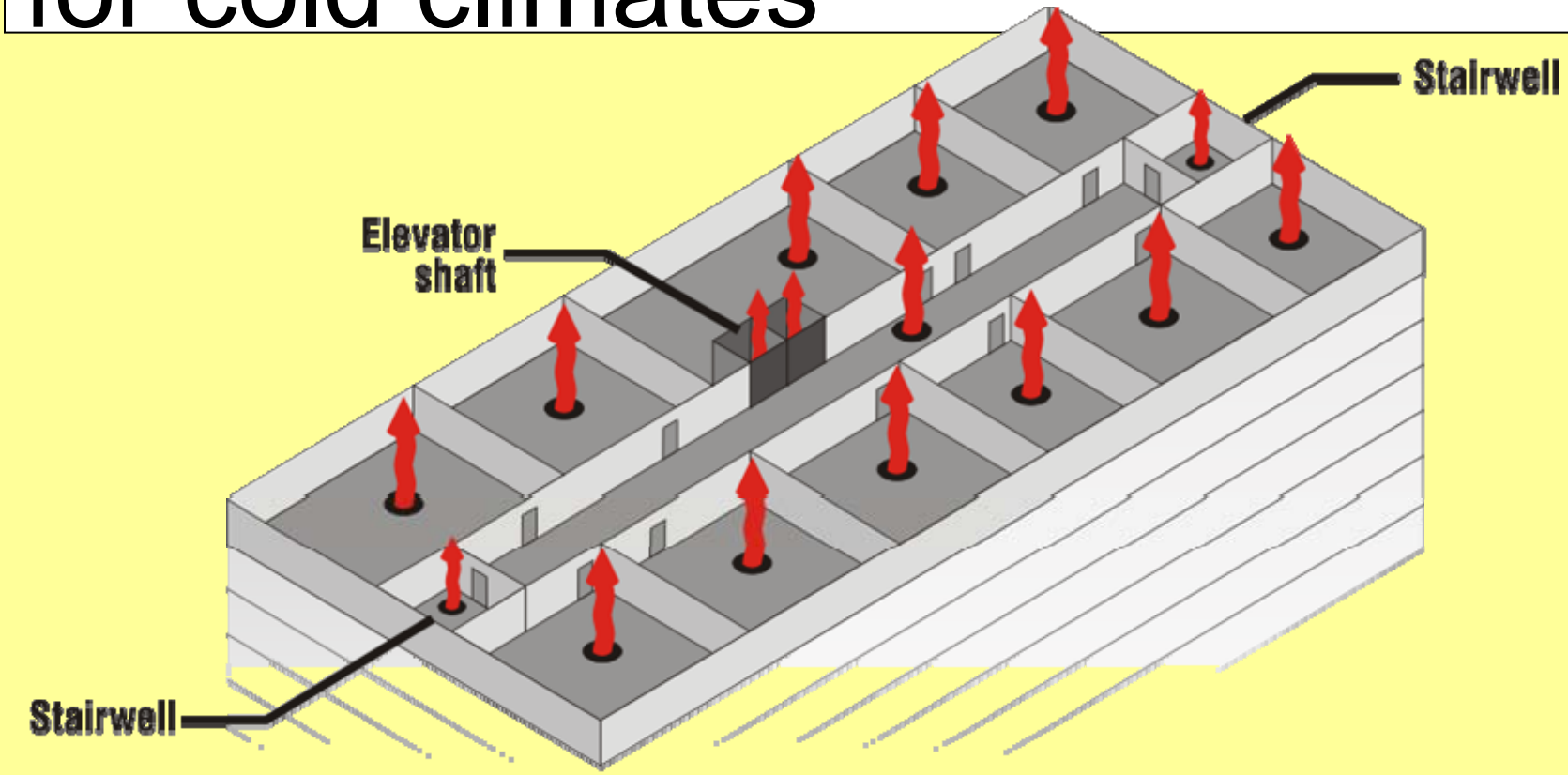
Elevator piston effect



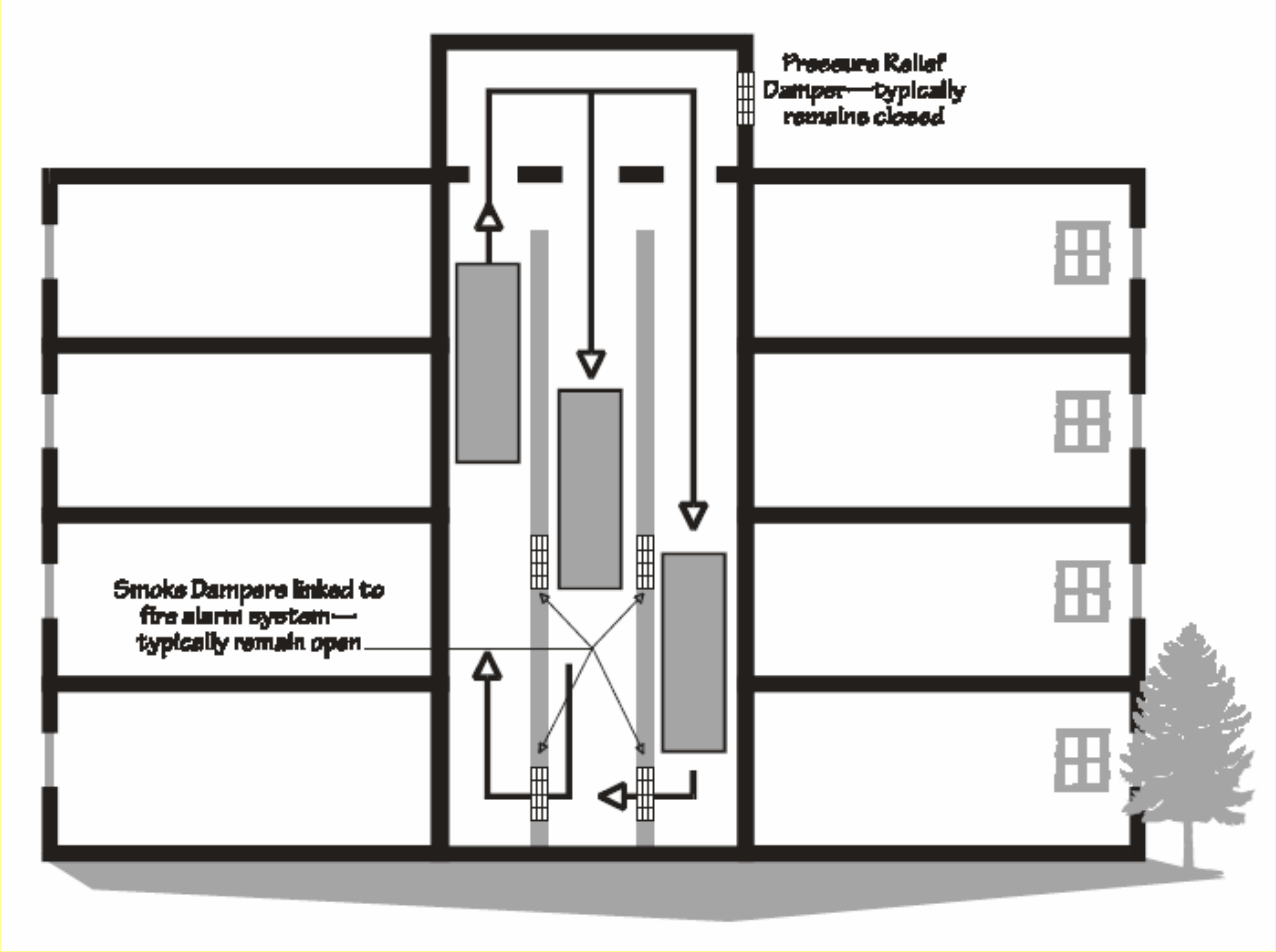
# Needed, Design

- Minimize slab leakage
- Elevator lobbies
- Elevator Shaft seal
- Stairwell seal
- Exterior wall not as important

# Primary Boundaries for cold climates



# Improved Airtightness in Elevator Shafts

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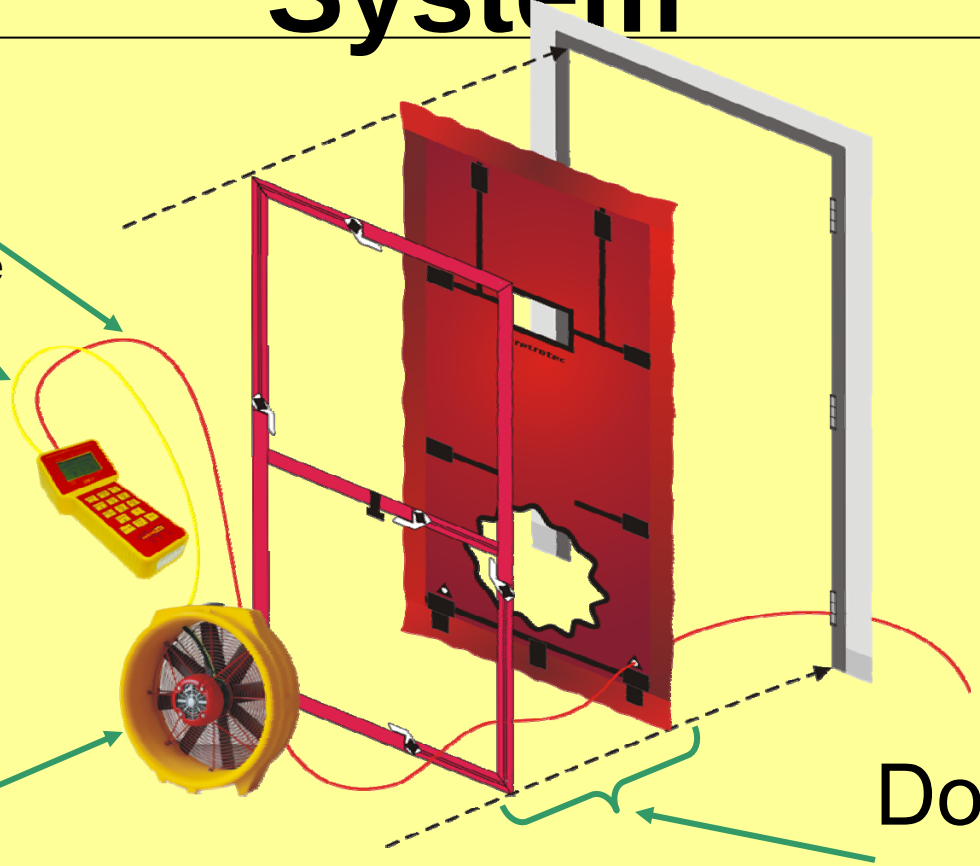
# What is a Door Fan?

Level 1 Training

# Anatomy of a Door Fan System

## Gauge

1. House Pressure
2. Fan Flow Pressure



## Fan

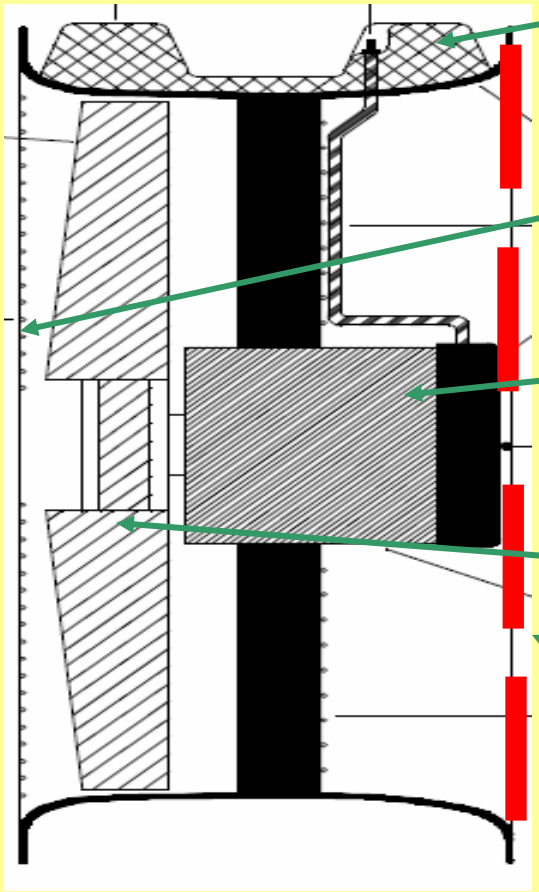
Calibrated for accurate flow

## Door System

Mounts fan(s) in opening

Seals around fan

# Anatomy of a Door fan



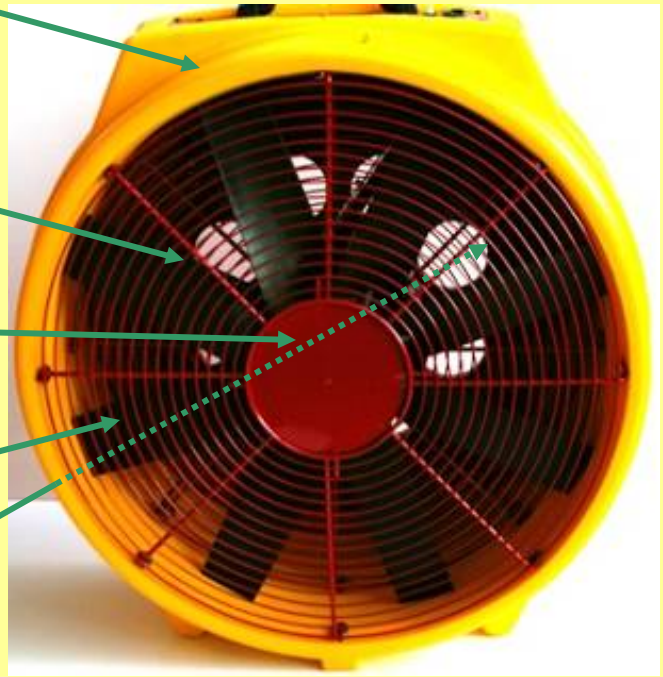
Fan shell

Screen

Motor

Blades

Range Plates

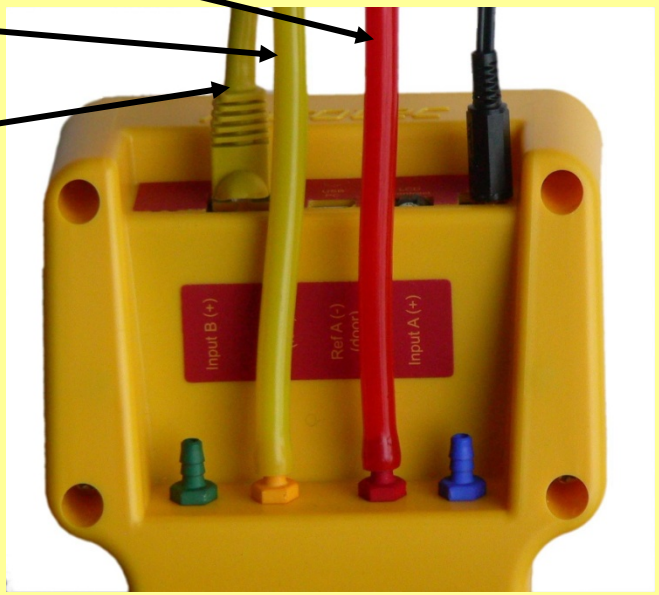


# Anatomy of a Gauge

Building Pressure

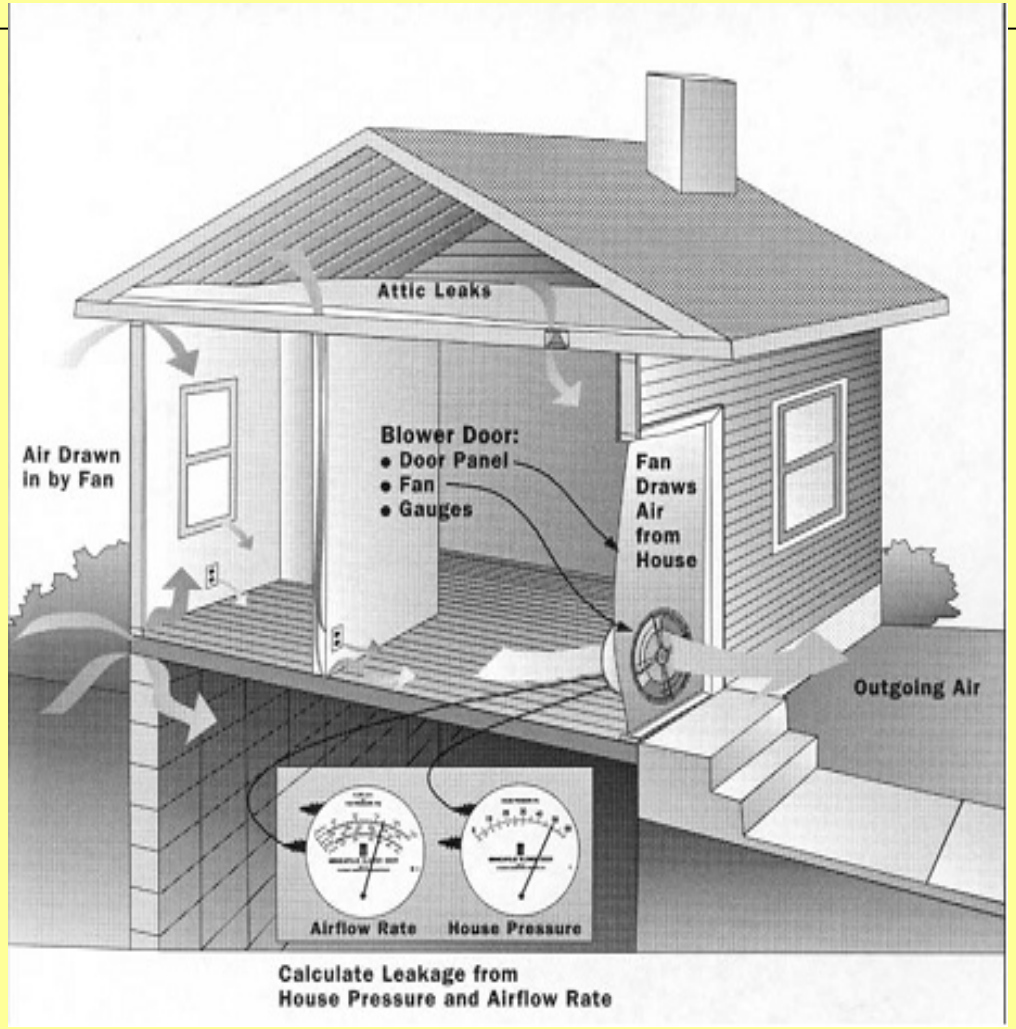
Flow Pressure

Fan Speed Control

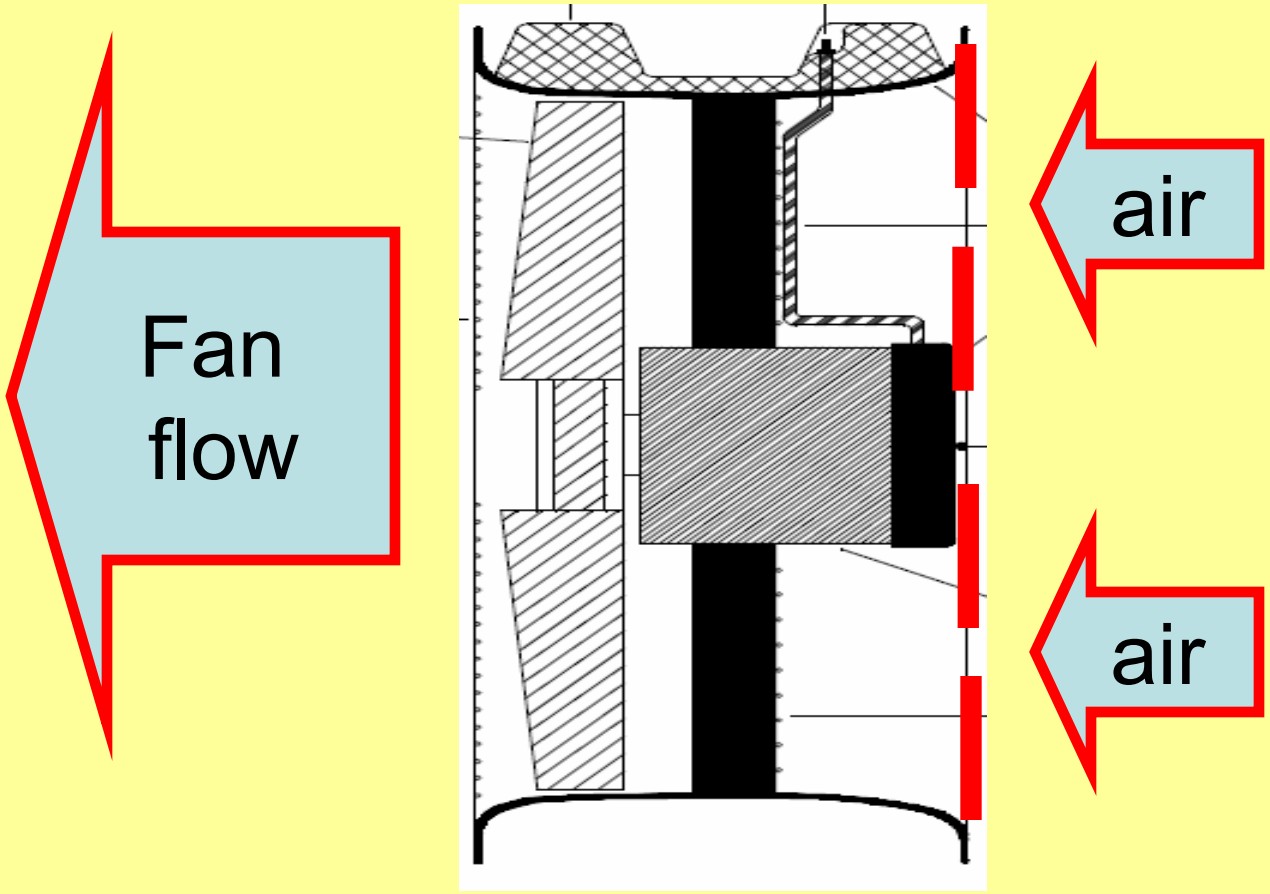
# Door fans measure:

- Pressure, Pa
- Flow rate, cfm, l/s
- Hole size, $cm^2$, $in^2$

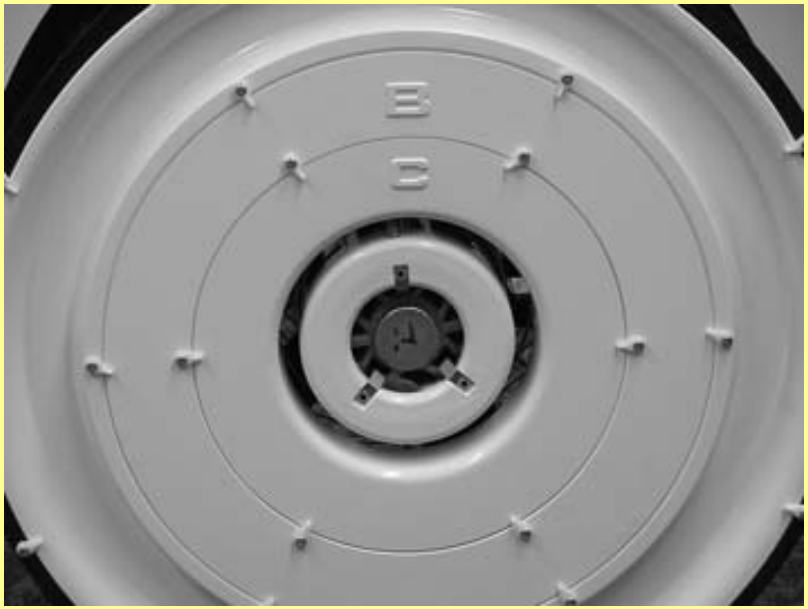


# How a Door Fan Works

**1. Fan pulls air through calibrated holes**

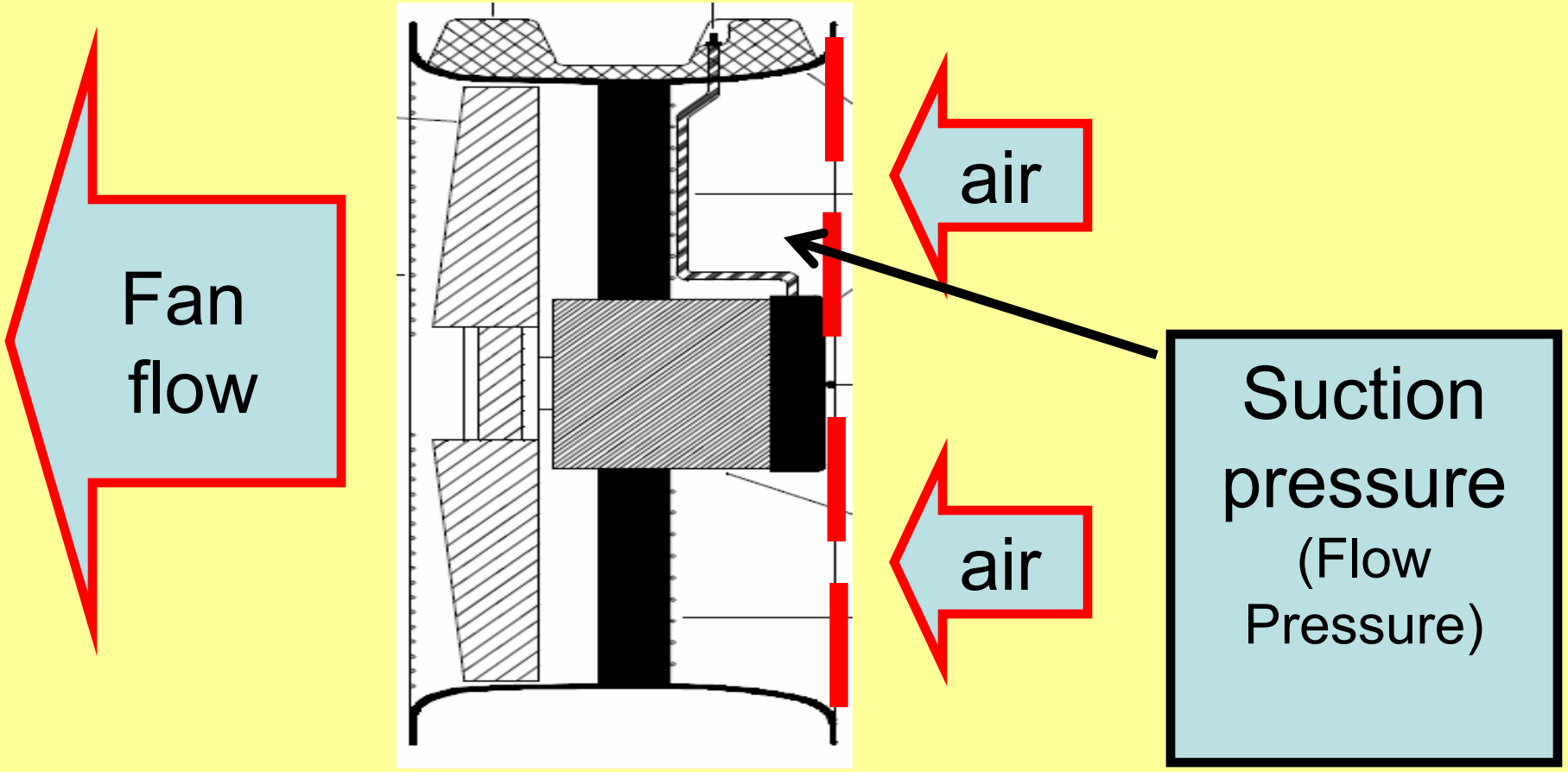


# Holes look like this



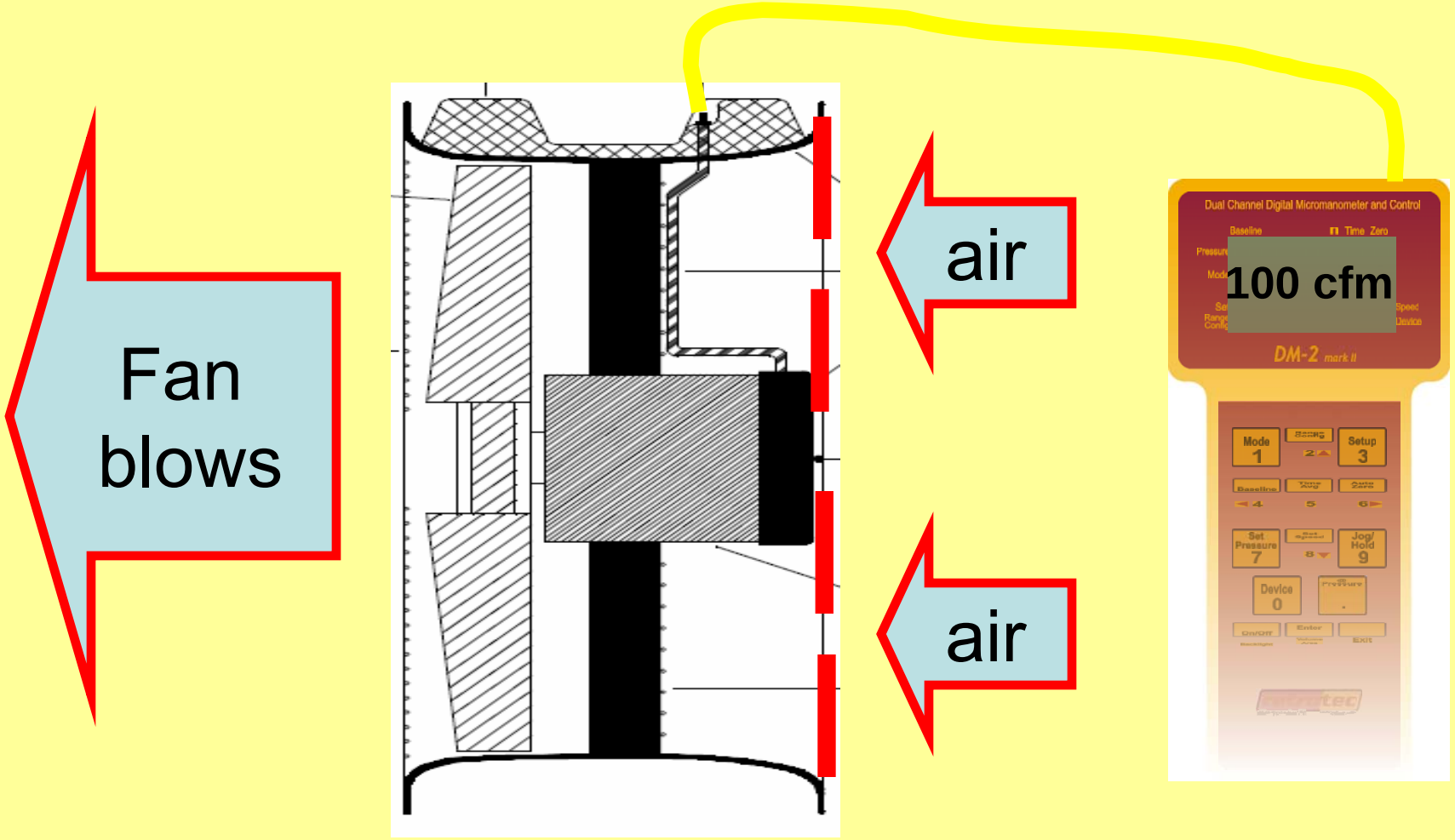
# How a Door Fan Works

**2. Measure “suction” pressure between blades and holes**



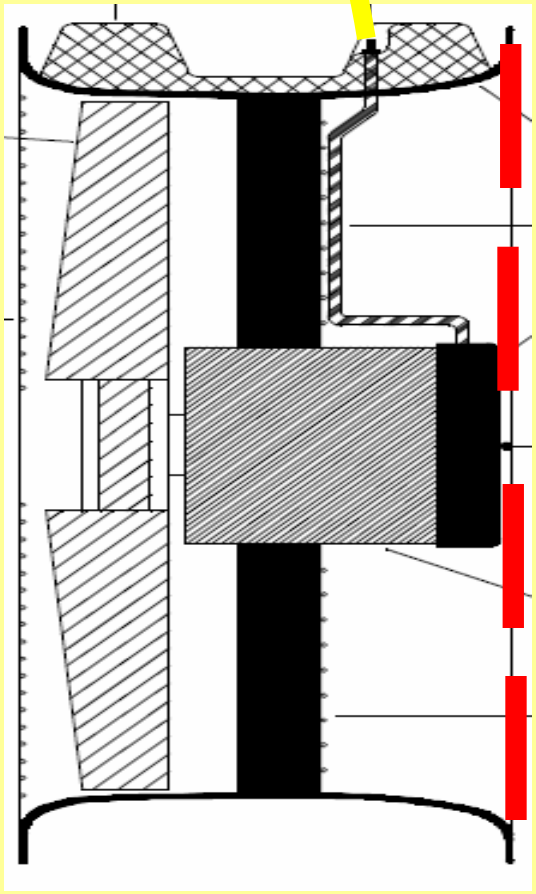
# How a Door Fan Works

**3. Flow Pressures is used to calculate flow**



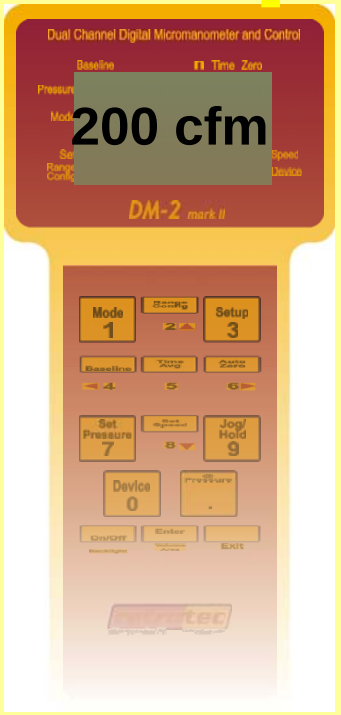
# More suction = more flow

More fan flow



air

air



# Types of Door Fan Tests

- Single Point
  - House is pressurized to single test pressure
  - Typically 50 Pa
- Multiple Points
  - House is pressurized to multiple test pressures
  - Typically between 20 Pa and 50 Pa
  - Line of best fit

# Types of Door Fan Tests

- Manual Test
  - Equipment adjusted by hand
  - Data recorded by hand, entered into computer
- Automatic Test
  - Computer controls system thru test
  - Automatically gathers all data
  - Typically multiple point tests

# The Right Fan for the Job

Things to consider

- Maximum & minimum flow
- Cost
- Set-up time
- Number of ranges
- Accuracy
- Ability to test in both directions

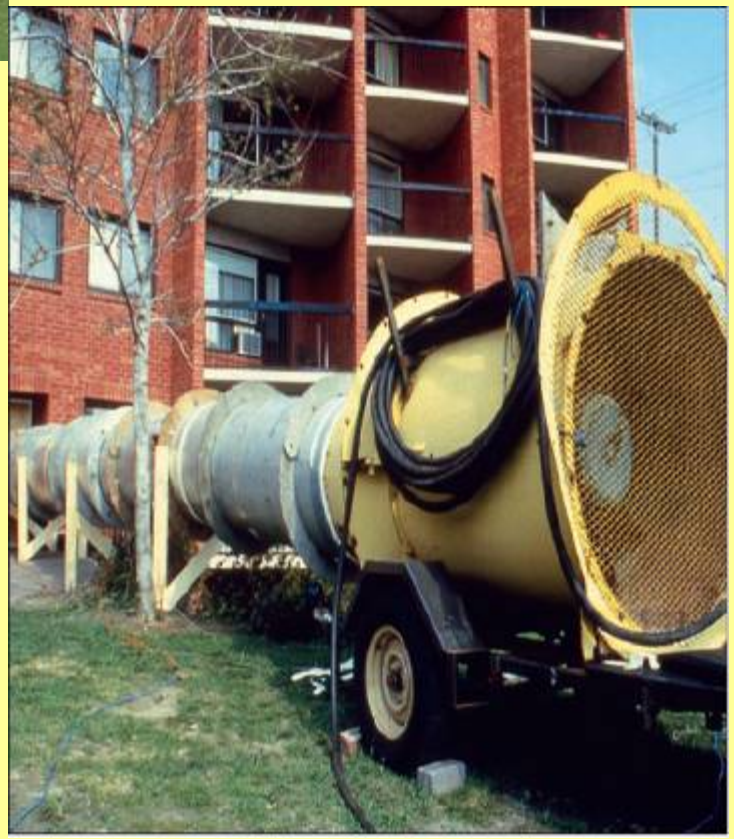
# The Right Fan for the Job

## Maximum Flow Rates

- Residential 5,000 cfm at 75 Pa
- High-power 8,000 cfm at 75 Pa
- QMG 24,000 cfm at 75 Pa
- QMG-2x 48,000 cfm at 75 Pa
- Trailer/Truck 25,000 cfm at 75 Pa and up





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# Measuring Leakage with a Door Fan

Level 1 Training

# Overview of a Door Fan test

- Set up the building
  - Close exterior doors and openings
  - Open interior doors and openings
  - Control occupants
- Set up the door fan
- Test
  - Single or multiple pressures
  - One of both directions
- Pack up and return building to normal

# How long does it take?

- Residential home
  - Setup: 10 min to 1 hour
  - Test: 15 min
- Large building
  - Setup: hours to days
  - Test: minutes to hours

# Door fan safety

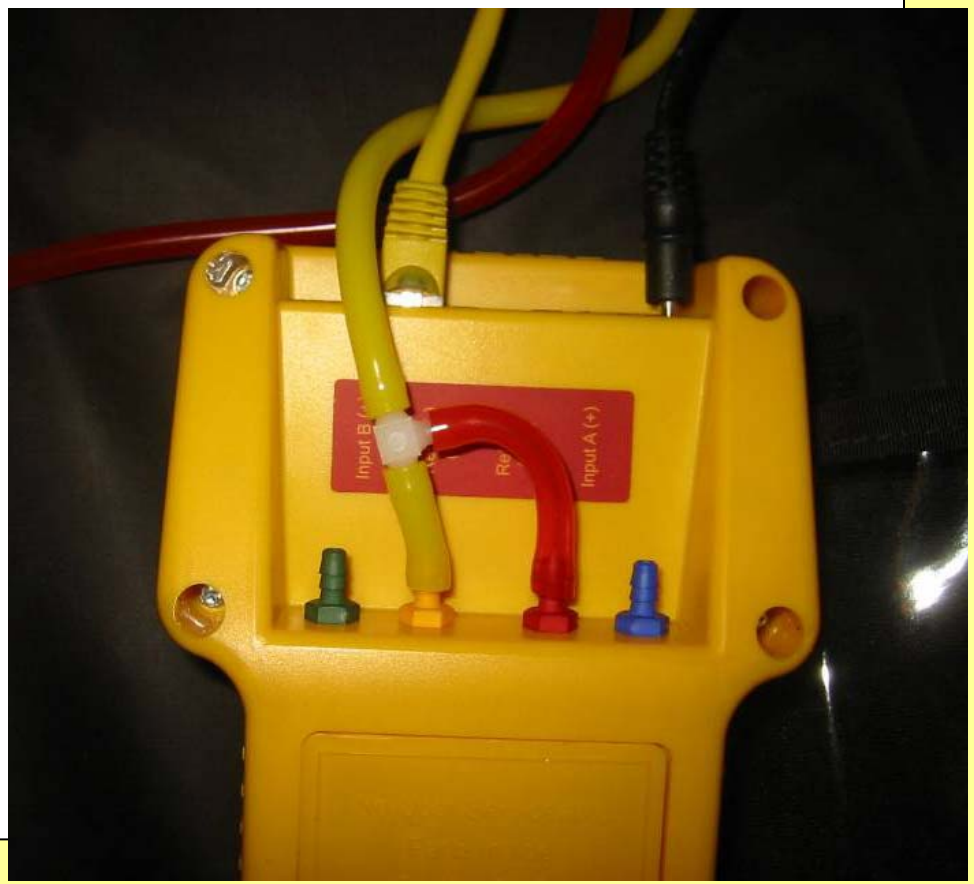
- exposed fan blade
- high velocity flows
- soot down chimneys
- back-draft appliances
- pulling in dust & mold from attic or outdoors
- security with open door

# Equipment accuracy

- Measure pressure ± 5%
- Measure flow ± 5%
- Check gauge and system regularly
  - Before every test
  - Return for service if problems
- Calibrate
  - Gauge – every 2 years
  - System – every 5 years

# Gauge calibration check

- Tee channels to fan flow pressure
- Run fan
- Free air
- Compare readings
- Within 5%



# System calibration check

- Measure a knows hole
- Catches most problems
  - Pinched blocked tubes
  - Correct tubing connections
  - Fan calibration
  - Gauge calibration
  - Operator error
- Add known hole, use EqLA on gauge

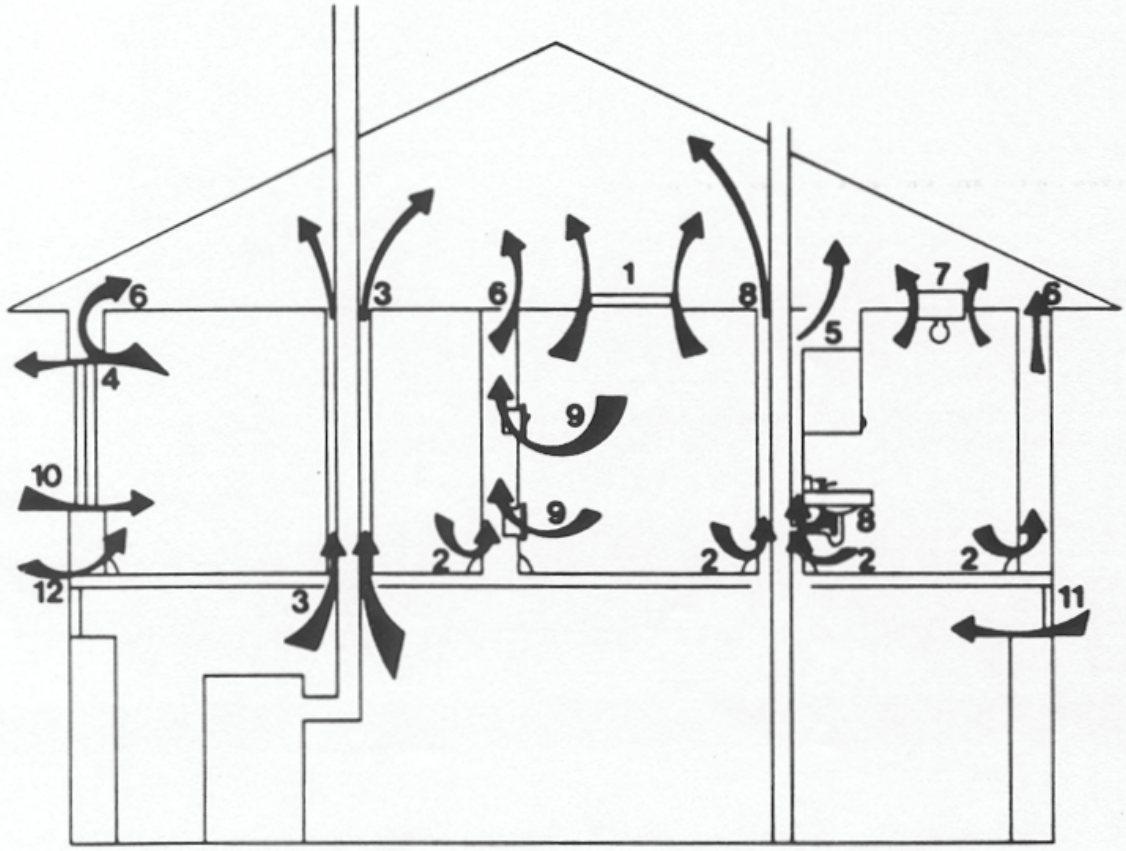
# Test in Both Directions

- Example: leaky HVAC 1000 cfm 1 Pa bias
- At 10 Pa
  - Pressurization only: 34% error
  - Depressurization only: 20% error
- At 50 Pa
  - Pressurization only: 11% error
  - Depressurization: 9% error
- Testing both directions and averaging
  - 0% error

# Locating leaks

Level 1 Training

# Locating Air Leaks
## where are they?

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7 lighting fixtures
8 plumbing penetrations
9 wall switches and electrical outlets

**Cold air infiltrates around:**

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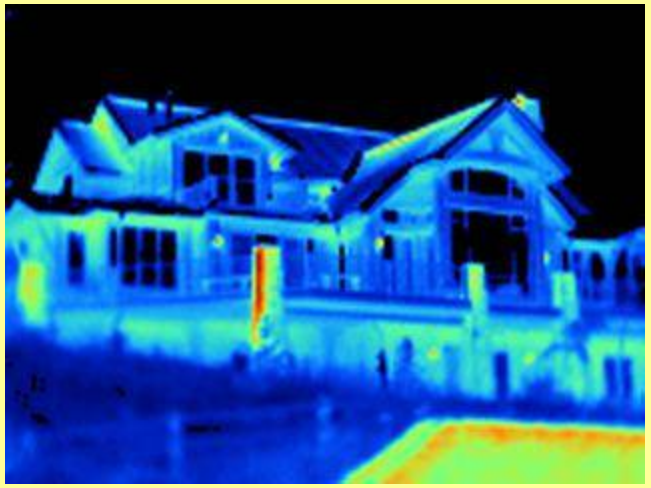
11 rim joists
12 other cracks and holes

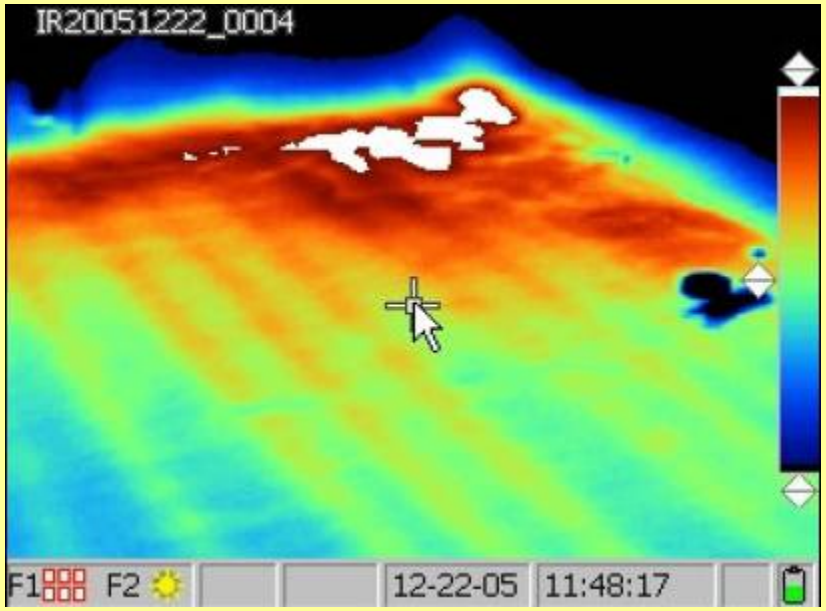
# Locate leaks with:
# smoke, infrared, hand, cobwebs



# Locating leakage sites with a door fan & smoke

# Door fan and theatrical smoke

# Door fans and infrared camera

# Sealing air leakage sites

- Use a door fan
  - Increase effectiveness of air seal crew
  - Identify leaks
  - Monitor progress
  - Train air-sealers
- Use spray rubber
- Seal during construction

# Sealing

- Places to focus
  - Wall to floor joints (flexible rubber)
  - Partition walls
  - Inter-floor penetrations
- Cheap during construction
  - Cost 10 to 1000 times more afterwards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# Development of the US Army Corp Testing Protocol

# US Army Corp Protocol

0.25 cfm per $ft^2$ envelope @ 75 Pa

=

1.27 l/s per $m^2$ envelope @ 75 Pa

# How does it compare?

| | | | cfm/ ft$^2$ at 75Pa |
|---|---|---|---|
| UK | TS-1Commercial Best Practice | 5 m$^3$/h/m$^2$ at 50 Pa | **0.36** |
| US | LEED | 1.25 in$^2$ EfLA @ 4 Pa / 100 ft$^2$ | **0.30** |
| US | ASHRAE 90.1 Average | | **0.30** |
| | **US Army standard is 0.25 cfm/ ft$^2$ at 75Pa** | | **0.25** |
| UK | TS-1Commercial Tight | 2 m$^3$/h/m$^2$ at 50 Pa | **0.14** |
| CAN | R-2000 | 1 in$^2$ EqLA @10 Pa /100 ft$^2$ | **0.13** |
| US | ASHRAE 90.1 Tight | | **0.10** |

Looser

Tighter

For a 4 story building, 120 x 110 x 8 ft, n=0.65

# Problems considered

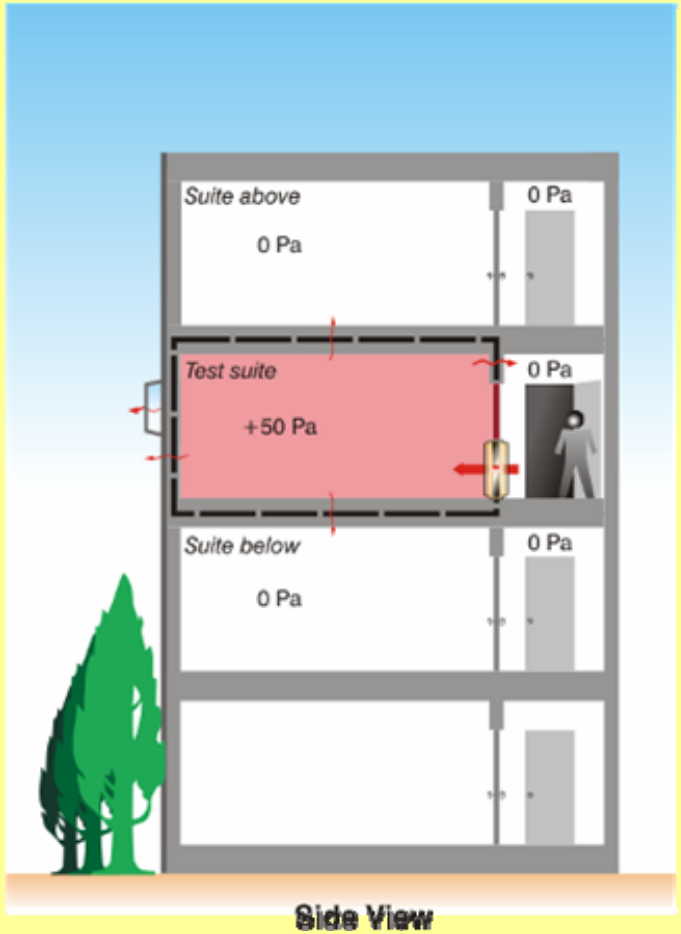
| **Problem** | → | **Solution** |
|---|---|---|
| Stack | | Test both ways |
| Exhaust flows | | Test both ways |
| Wind | | Time average |
| Can't reach 75 Pa | | High power fan<br>Multiple fans |
| Too much data | | Automatic control |

# Keep it simple

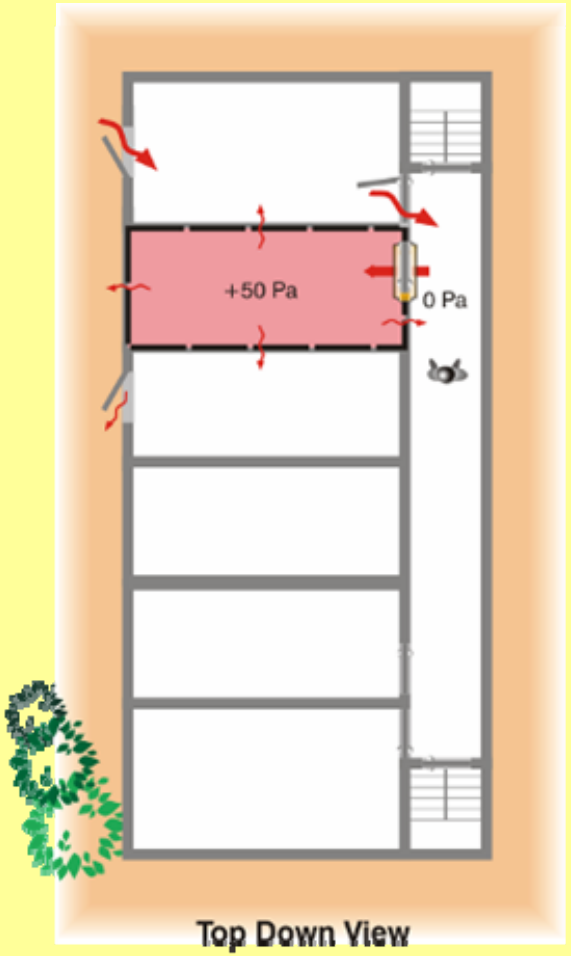
- Simple = Repeatable
  - Ideally:
    - Test in both directions
    - Ignore bias pressures
    - Ignore temperature, barometric, humidity
  - Focus on:
    - Building setup
    - Equipment setup
    - Test procedure

# Apartments with internal access

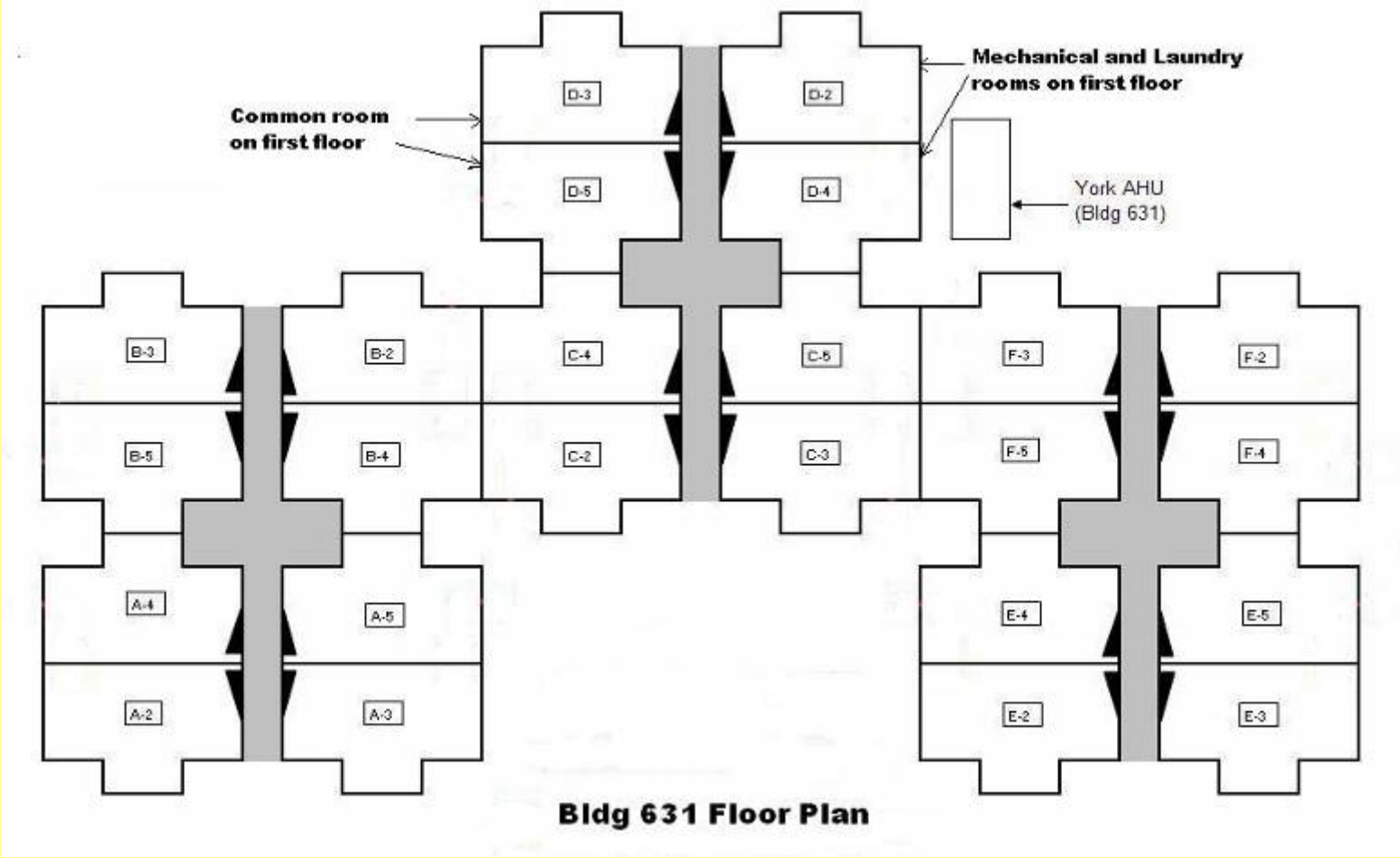
# Protocol
# Apartments with external doors



Side View



Top Down View




**Bldg 631 Floor Plan**

# Use Test Form

Airtightness Test Form Example

for U.S. Army Corp Buildings

rev. 2008-10-14

Building name: ____XYZ Barracks_____

Building address:_____

Contact person: _____ Phone: _____

Testing company name: ____Big House Tester Inc._____

Address:_____

Contact person: _____ Phone: _____

Testing technician: _____ Phone: _____

Test date: _____ Time: _____

| Step | Description | Result | Units |
|---|---|---|---|
| | | | |
| 1 | Calculate total exterior envelope area including walls, floor and ceiling from plans | 60,000 | sq. ft. |
| 2 | Estimate the worst case door fan flow in cfm. Divide area by 4<br>60,000 sq. ft. / 4 = 15,000 cfm | 15,000 | cfm |

# 1. Calculate envelope area

- Designer supplies envelope area
  - Surface area of pressure boundry

(if you have to measure it)

- Total exterior envelope area
  - Include walls, floors and ceiling from plans

# 2. Determine flow

- Estimate the worst case flow in cfm
- Use:  Total Area / 4

For example, 60,000 $ft^2$ building

60,000 $ft^2$ / 4 = 15,000 cfm

# 3. Pre-test inspection

| | | | |
|---|---|---|---|
| 3 | **Pre-test inspection** | | |
| 3.1 | Can all air exhaust to outdoors (fans, dryers and mechanicals) be shut down? | Yes | |
| 3.2 | Can all fresh air supply be shut down? | Yes | |
| 3.3 | Is the building free of any large un-closable openings? | Yes | |
| 3.4 | Is the building free of any discontinuities in the envelope? | Yes | |
| 3.5 | Will you be able to get access on the day of the test to prepare all residential and office units? | Yes | |
| 3.6 | Can all interior doors be opened for the test? | Yes | |
| 3.7 | Will door alarms prevent doors from staying open? | Yes | |
| 3.8 | Will exterior doors and closable openings stay shut when subjected to a 2 lb. per square foot pressure? | Yes | |
| 3.9 | Select the doorway(s) to be used for the test and measure their size | 3 x 7 ft. | |
| 3.10 | Is there sufficient power to run the door fan equipment? | Yes | |
| 3.11 | Is there at least 1 square foot of opening per 200 cfm to allow door fan flow to enter building without excessive losses? | Yes | |
| | | | |

# 3. Pre-test inspection

- Site Requirements
  - Access,
  - Interaction with Other Site Activities
  - Existing Pressure Differentials
- Define tested zones

# 4. Required equipment

| | | | |
|---|---|---|---|
| **4.** | **Test equipment needed** | | |
| 4.1 | Add up door fan system flow rates:<br>Model 3, R43, Q46 = 5,000 cfm each<br>Model Q4E, Q5E = 8,000 cfm each | 2 x Q5E<br>2 X 8,000 | cfm |
| 4.2 | Ensure door widths and heights match the doorways to be used.<br>Model 3, R43, Q46, Q4E = 40 inches wide<br>Model Q5E = 48 inches wide | ok | |
| 4.3 | Measure tubing and cable lengths required | 50 | ft. |
| 4.4 | Tools: 2 inch tape, Plastic, measuring tape, smoke puffers, grille mask, flashlight, ladders, test forms, thermometer, thermographic camera | √ | |
| Notes | | | |

# 4. Required equipment

- Required flow rates
- Door options, widths and heights
- Measure tubing and cable lengths required

# 4. Test equipment

(Obviously each of these will require different installations)

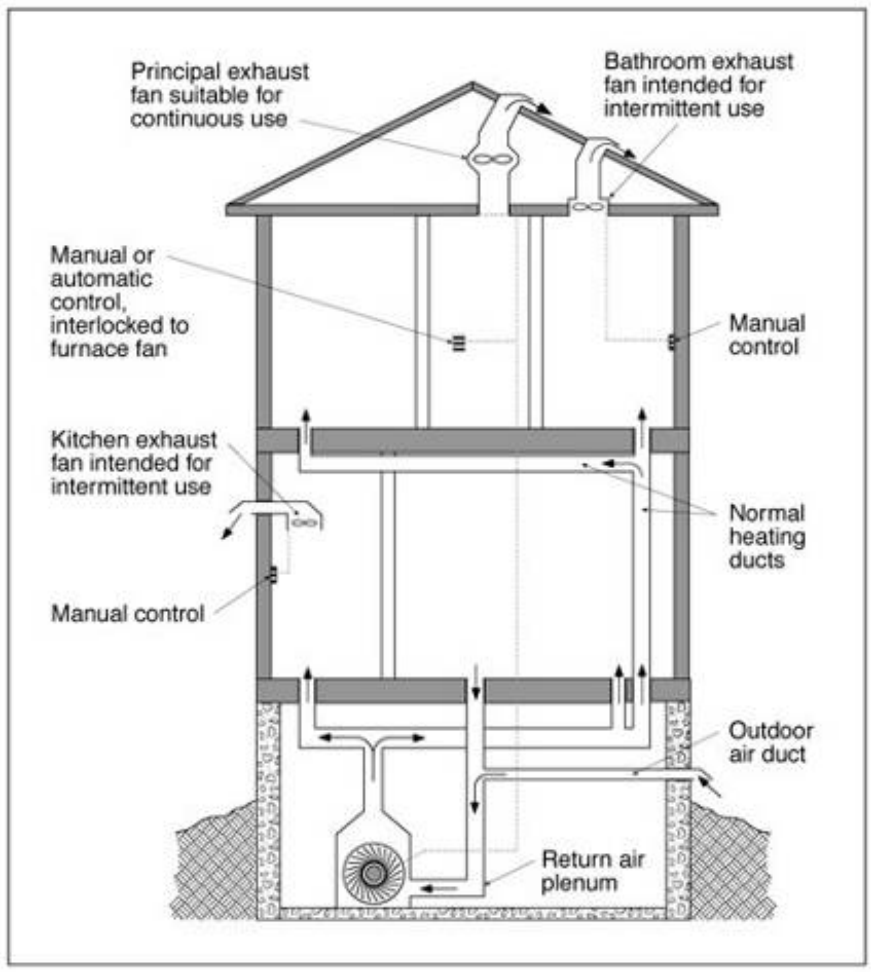
# 5. Record setup conditions

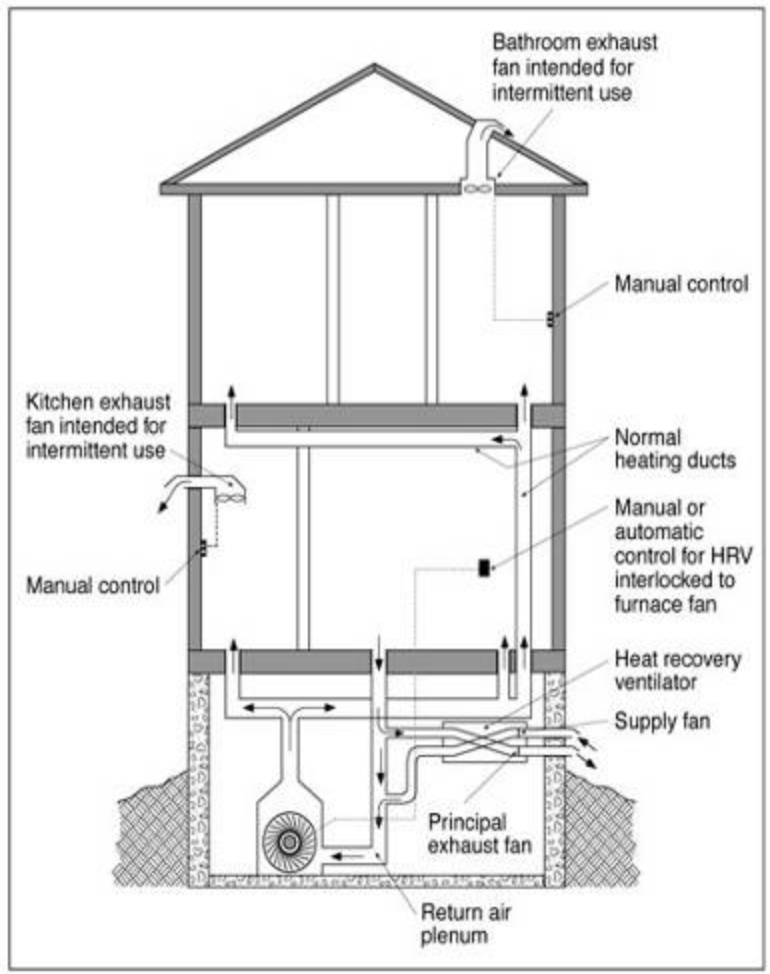
| 5. | Preparing the building - record set up conditions | | |
|---|---|---|---|
| 5.1 | Shutdown HVAC | Yes | |
| 5.2 | Turn exhaust fans and dryers off | Yes | |
| 5.3 | Seal air inlets | Yes | |
| 5.4 | Seal air outlets | Yes | |
| 5.5 | Shut exterior doors | Yes | |
| 5.6 | Open interior doors | Yes | |
| 5.7 | Close dampers | Yes | |
| 5.8 | Turn gas fired hot water heaters to pilot | None | |
| 5.9 | Wind Speed | 10 | mph |
| 5.10 | Raining? | No | |
| Notes | | | |

# 5. Seal these

# 5. Open interior doors

# 5. Seal inlets and outlets



# 5. Setting up the building

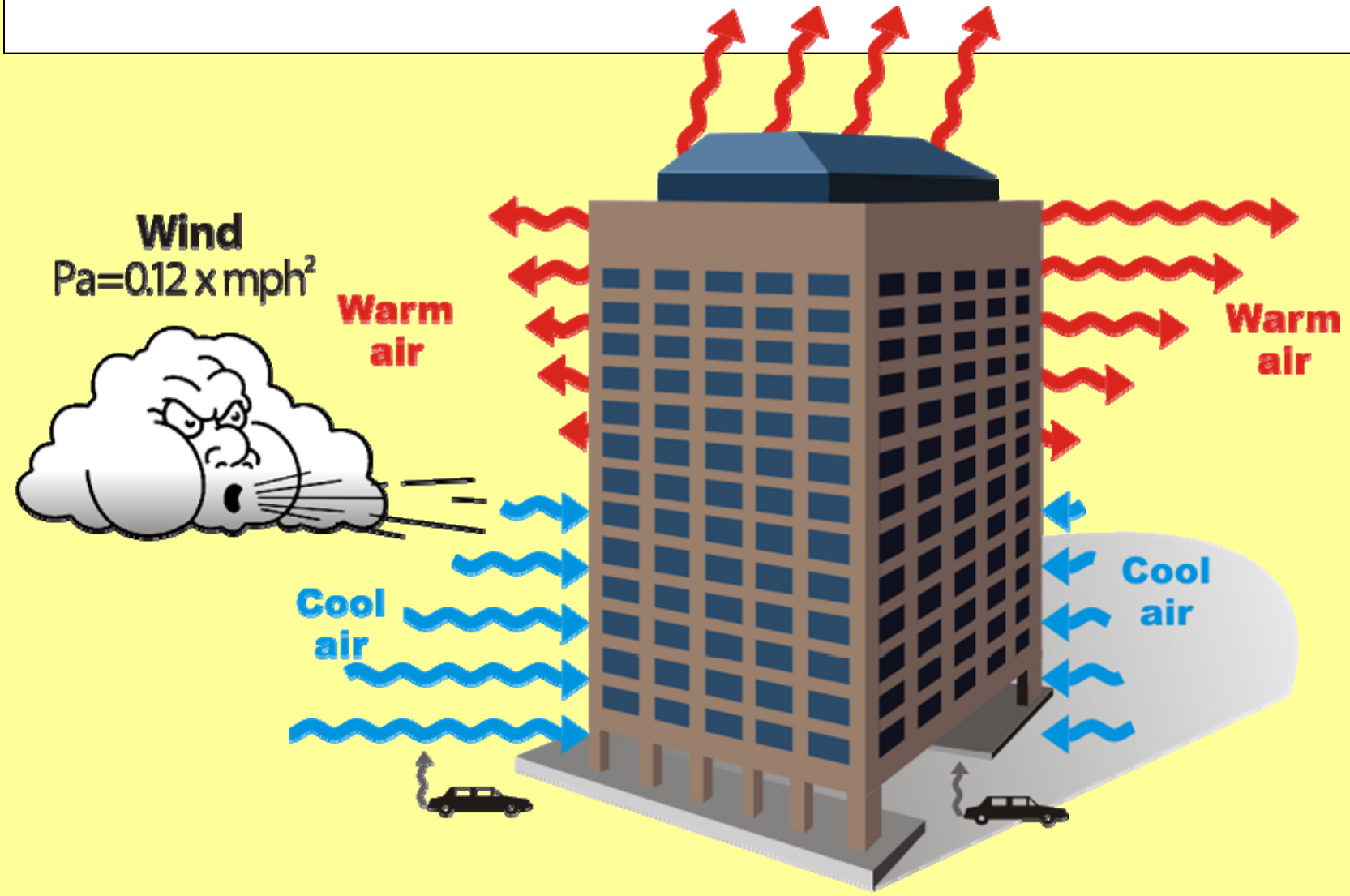
- Awkward situations
  - fireplace burning
  - kids and pets
- Problems to avoid
  - doors slamming shut and blowing panels out of door way
  - elevator operation
  - door openings
  - water in tubes

# 6. Setting up the door fan

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6. | **Setting up the door fan** | | | | | | | | | | |
| 6.1 | Run tubing to building pressure gauge and install door fan panels | | | | | | | | ✓ | | |
| 6.2 | Record 10 bias pressures every 5 seconds with 2 second averaging | | | | | | | | | | |
| | 1.4 | -2 | -3 | +2 | -2.2 | -0.5 | +0.6 | -0.9 | +0.3 | +0.3 | |
| 6.3 | Run additional exterior tubes if needed to reduce bias pressure | | | | | | | | ✓ | | |
| 6.4 | Building pressure with 1 fan at full speed | | | | | | | | 25 | | Pa |
| 6.5 | Number of additional fans needed = 75/25 /3 = 1 | | | | | | | | 1 | More fan(s) | |
| 6.6 | Install additional fans | | | | | | | | ✓ | | |
| 6.7 | List equipment and range used: 2 Q5E with 200 feet of tubing, Open 22 | | | | | | | | | | |

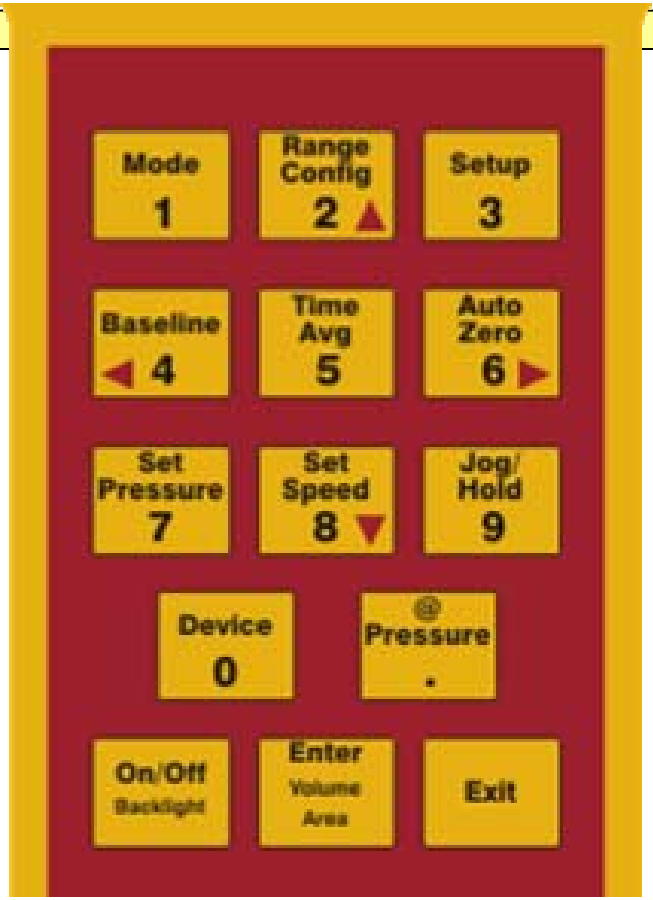
# Setting up the door fan

# Stack and wind effects



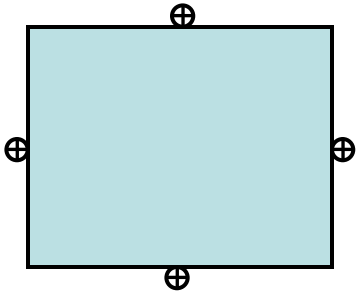
# Testing in unstable conditions

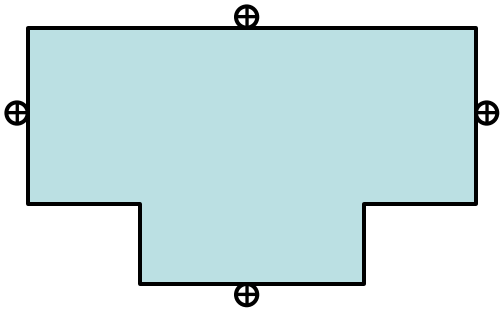
- Use @50 (@75)
- Increase TimeAvg 20s
  - (wait 40s)
- Cover end of tube
- Tee in analog gauge

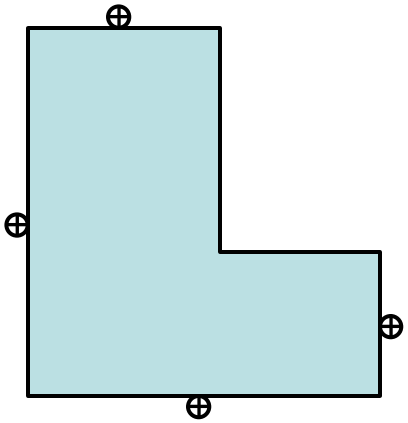


# Dealing with bias pressure

- Run additional tubes
- Manifold tubes together







# 7. Perform single-point test

- Try to achieve 75 Pa with your door fan setup

| | | | |
|---|---|---|---|
| **7.** | **Performing a single-point door fan test** | | |
| 7.1 | Establish a building pressure of +75 Pa (maximum) or highest attainable | +70 | Pa |
| 7.2 | Record flow measured at pressure from Step # 7.1 | 14, 509 | cfm |
| 7.3 | Flow at 75 Pa | 15, 234 | cfm |
| 7.4 | If you can achieve 50 to 75 Pa and can test in both directions, go to Step #8. This is the preferred test method | √ | |
| 7.5 | If you can achieve 75 Pa but can only test in one direction, go to Step #9 | √ | |
| 7.6 | If you cannot fulfill Step 7.4 or 7.5 requirements, go to Step # 10. The test is not in compliance with the US Corp requirements but the result is a useful +/- 25% estimation | | |

# 7. Perform single-point test

- Taking Readings -  test form
- Test pressure
- Test direction
- @75 pressure extrapolation modes
- Basic airtightness test results

# 8. Both directions: 50 to 75 Pa

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **8.** | **Performing a six-point door fan test in both directions starting at +/- 50 to 75 Pa** | | | | | | | |
| 8.1 | + pressure | +75.5 | +69.8 | +64.2 | +61.0 | +54.2 | +49.8 | Pa |
| 8.2 | + Flow | 15, 225 | 14,600 | 13,000 | 13,300 | 12,600 | 11,900 | cfm |
| 8.3 | Curve fit average pressurization flows in Step 8.8 and 8.9 in compliance with ASTM E779 | | | | | | | |
| 8.4 | Flow constant $C_p$ = | 1,274 | Flow exponent $n_p$ = | 0.5704 | Correlation = | 99.8% | | |
| 8.5 | Calculate CFM at +75 Pa using: Q = 75$^n$ X C | | | | | 14,957 | | cfm |
| 8.6 | Turn the fan around and repeat at same positive pressures | | | | | | | |
| 8.7 | - depressure | -74.5 | -71.2 | -65.2 | -59.6 | -55.0 | -50.2 | Pa |
| 8.8 | - Flow | 15, 401 | 14,770 | 14,100 | 13,400 | 12,700 | 12,100 | cfm |
| 8.9 | Curve fit depressurization pressures and flows in Step 8.2 and 8.3 in compliance with ASTM E779 | | | | | | | |
| 8.10 | Flow constant $C_d$ = | 1152.1 | Flow exponent $n_d$ = | 0.5999 | Correlation = | 99.9% | | |
| 8.11 | Calculate CFM at -75 Pa using: Q = 75$^n$ X C | | | | | 15,358 | | cfm |
| 8.12 | Average flows in Step 8.5 and 8.11 | | | | | 15,158 | | cfm |
| 8.13 | Average flow in previous step must be within +/-5% of the flow in Step # 7.3. 15,158 - 15, 234 = 76 / 15,158 = 0.5% | | | | | 0.5% | | |
| 8.14 | **Go to Step #10** | | | | | | | |

# 8. Multi-point tests

- Taking Readings - test form
- Test pressure range
- Test direction(s)
- Taking sets of building pressure and corresponding flow readings
- Averaging readings

# 9. Single direction: 75 to 50 Pa

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **9.** | **Perform a six-point door fan test in one direction starting at + 75Pa** | | | | | | | |
| 9.1 | Record indoor and outdoor temperature | | | | | | 72 78 | F |
| 9.2 | Record Baseline bias pressure for 50 seconds | | | | | | +0.64 | Avg.Pa |
| 9.3 | Establish a building pressure of + 75 Pa (maximum) or highest attainable. Reduce magnitude of pressures in 5 Pa increments | | | | | | | |
| 9.4 | Test direction ? | | Pressurize ✓ | | | Depressurize | | |
| 9.5 | Pressure | +75 | +70 | +65 | +60 | +55 | +50 | Pa |
| 9.6 | Flow | 15, 401 | 14,770 | 14,100 | 13,400 | 12,700 | 12,100 | cfm |
| 9.7 | Curve fit average flow results in compliance with ASTM E779 | | | | | | | |
| 9.8 | Flow constant C = | 1,170.8 | Flow exponent n = | 0.5967 | Correlation = | 99.9% | | |
| 9.9 | Calculate CFM at 75 Pa using: Q = 75$^n$ X C | | | | | | 15,394 | cfm |
| 9.10 | Must be within 5% of the flow in Step # 7.3. 15,394 - 15, 234 = 160 / 15, 394 = 1% | | | | | | 1% | |
| | **Go to Step #10.** | | | | | | | |

# 10. Restore building

- Return the building to its pre-test condition

| | | | |
|---|---|---|---|
| **10.** | **Restoring building to pre-test condition** | | |
| 10.1 | Remove all sealing materials applied to penetrations prior to test | *yes* | |
| 10.2 | Set HVAC back to pre-test conditions | *yes* | |
| 10.3 | Turn gas fired hot water heaters back on | *yes* | |
| 10.4 | Open any dampers closed for test | *yes* | |
| | | | |

# 11. Pass/fail results

| | | | |
|---|---|---|---|
| **11.** | **Pass/Fail requirement** | 0.25 | cfm/ sq. ft. |
| 11.1 | Air flow per Step # 7.3___ # 8.15_√_ or # 9.9__ | 15,157 | cfm |
| 11.2 | Air flow at 75 Pa divided by the envelope area in square feet | 0.2526 | cfm/ sq. ft. |
| 11.3 | Building passes if it has a leakage rate of 0.25 cfm/square foot at 75 Pa or less | Fail | |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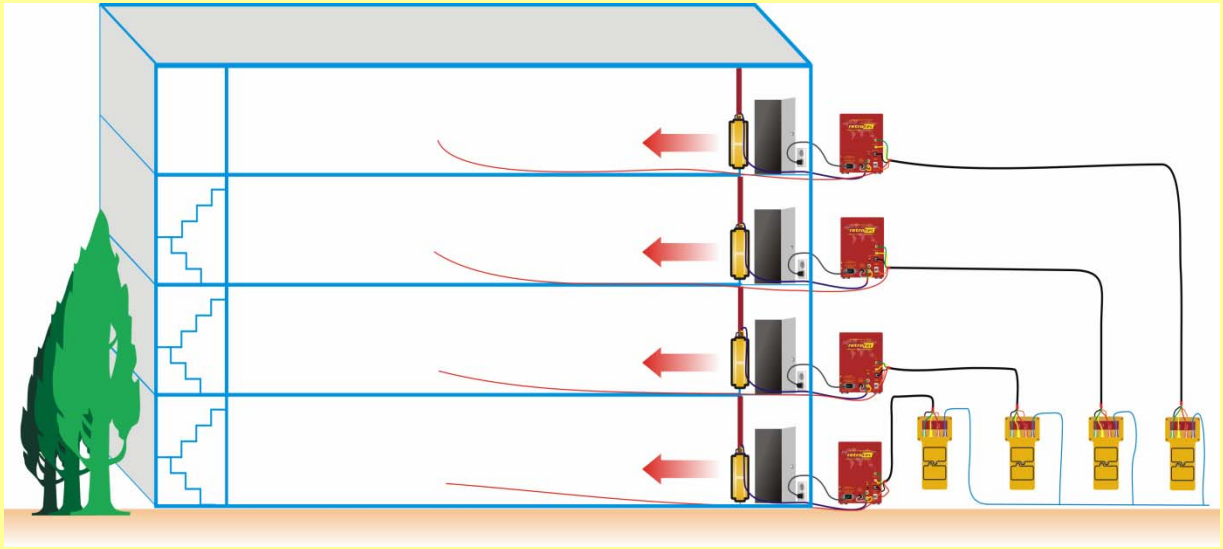
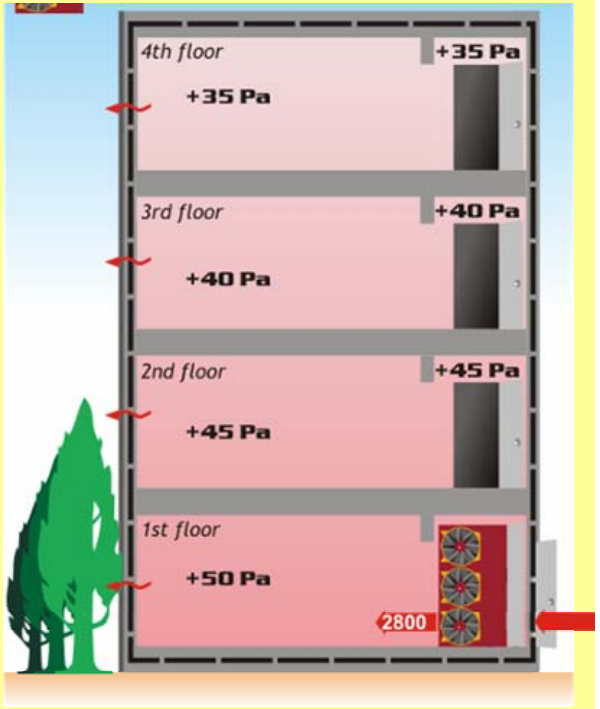
# Problems and Challenges

# Problem: Pressure drop






## Solution: Multiple doorways

- Install systems in multiple doorways

# Problem: Multiple fans

## Solution: Central control

- Control all fans from a central location

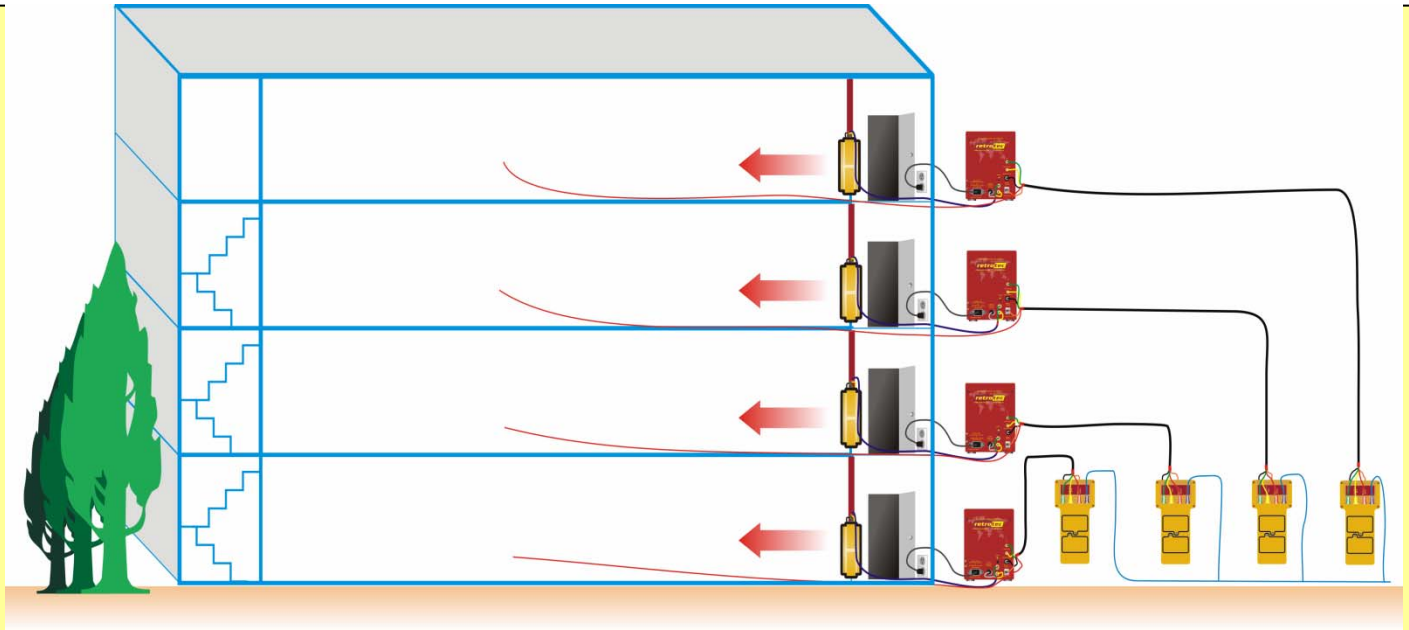
# Problem: Multiple fans



## Solution: Cruise control

- Use Set Speed and Set Pressure

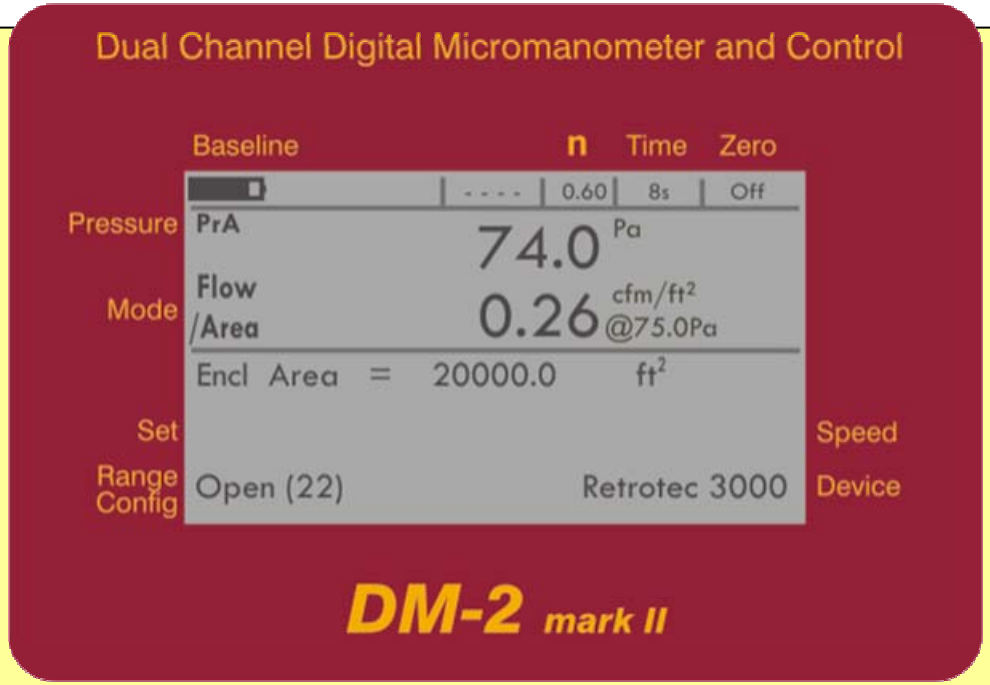
# Problem: Building pressure



## Solution: Average location

- Choose an average, central location
- Each gauge controls to its own pressure

# Problem: Computer setup time




# Solution: Direct readings

- Read cfm / $ft^2$ directly from gauge

Problem:
Door setup time

**Solution:**
**Rapid setup panels**

# Problem: Insufficient flow


## Solution: High-power fans

- 2 hp fans with variable frequency drives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# Room Pressurization, Venting & Retention Time

Solutions for Clean Agent Enclosures

by Colin Genge colin@retrotec.com