Air Leakage Testing of High Rise Buildings: Limitations and Alternate Approaches

Denali Jones

RDH Building Science

abaa EDUCATION

Air Barrier Association of America (ABAA) is a Registered Provider with The American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of Completion for non-AIA members are available on request.

This program is registered with the AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

air barrier
abaa
association of
america

CONTINUING EDUCATION
AIA

Overview

- Seattle & WA code background
- Limitations of current testing standards
- Stack effect & wind
- Guarded testing
- Case studies

air barrier
abaa
association of
america

Not covered

- Why air barriers are important
- Why air leakage testing is important

air barrier
abaa
association of
america

Seattle & WA energy codes

Paraphrased…

- 2006 – you have to have an air barrier
- 2009 – you have to test the air barrier (0.4 cfm/sf target)
- 2012 – you “have to” pass the test (0.4 cfm/sf)
- 2015 – you “have to” pass the test (0.3 cfm/sf)

If the tested rate exceeds that defined here, a visual inspection of the air barrier shall be conducted and any leaks noted shall be sealed to the extent practicable. An additional report identifying the corrective actions taken to seal air leaks shall be submitted to the building owner and the code official and any further requirement to meet the leakage air rate will be waived.

air barrier
abaa
association of
america

C406 Additional Efficiency Options

- Pick 2 of the following:
  - Better HVAC
  - Better lighting
  - Better lighting controls
  - On-site renewables
  - DOAS
  - Better service water heating
  - Better thermal envelope
  - Increased airtightness
- Have to meet 0.25 cfm/sf
  - For SEC, 0.25 for group R & 0.22 for all others

air barrier
abaa
association of
america

Lots of testing since 2009 SEC/WSEC

- RDH testing since 2009 code
  - 100+ buildings
  - From single story office to 40 story apartments
  - 10,000,000+ sq ft of enclosure area tested
- # of buildings above 0.40 cfm/sf
  - 7
- All 7 are mid-rise multifamily with mechanically fastened sheet applied air barrier

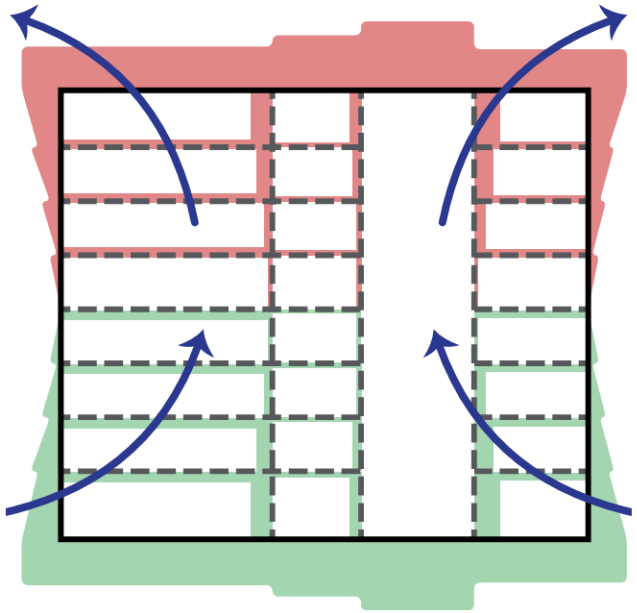
air barrier
abaa
association of
america

Whole building testing standards

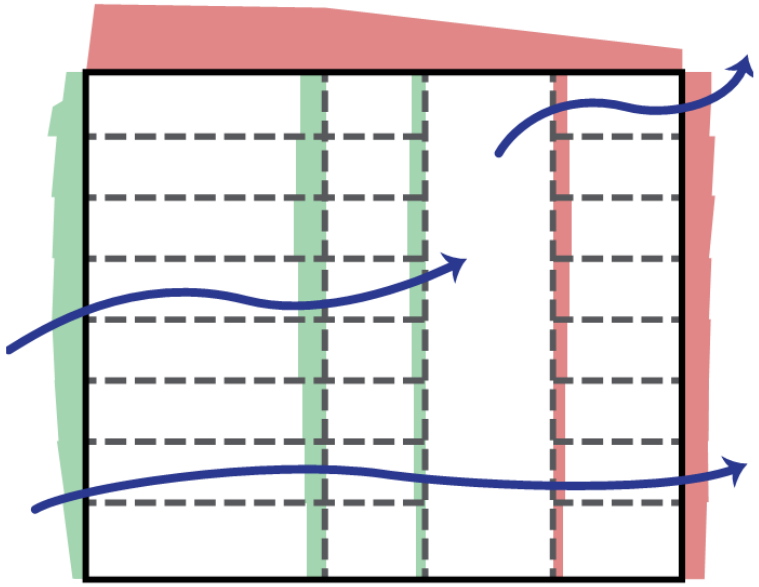
- Theory
  - Pressurize entire building to achieve a uniform interior pressure (single zone, big open box)
  - Measure airflow during pressurization to define relationship between pressure & airflow
  - Limits on baseline pressure (wind, stack)
  - If there was no stack pressure & no wind we should be able to test a building of any size/height

air barrier
abaa
association of
america

Weather Limitations



Stack Pressure



Wind

air barrier
abaa
association of
america

Weather Limitations

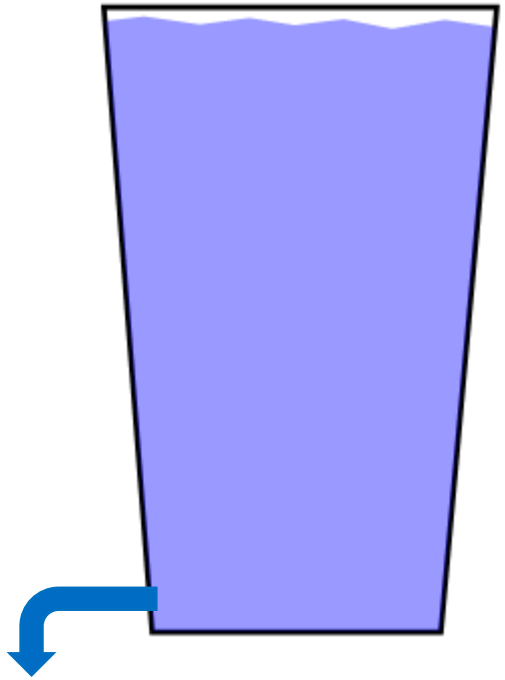
- ASTM E779
  - Height x ΔT must be less than 1180ft°F (200m°C)
  - Wind speed must be reported (only applicable at “low” wind speeds)
- USACE Protocol
  - Baseline must be less than 30% of lowest induced pressure
- ABAA standard
  - Uses formula to determine min induced pressure based on baseline readings

air barrier
abaa
association of
america

$$P_{induced,\ min} \geq Max\ (|P_{base,pre}| + 10xSTDev(P_{base,pre}),\ P_{stack}/2,\ 10\ Pa)$$

Weather Limitations – Stack Effect

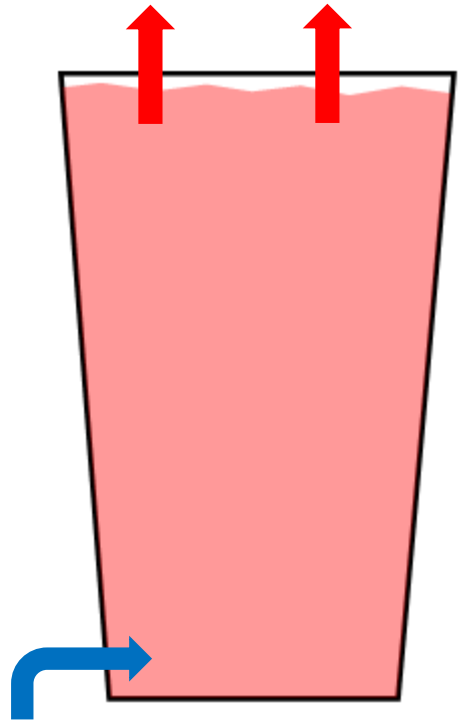
- Cup full of water
- Put a hole in the bottom
- Flow is a result of size of hole & pressure difference
- Pressure difference is a function of height (head pressure) & density of fluid (water)



air barrier
abaa
association of
america

Weather Limitations – Stack Effect

- Warm air is less dense than cold air
- Building = column of warm air
- Outdoors = column of cold air
- Cup of water in reverse



air barrier
abaa
association of
america

Weather Limitations – Stack Effect

- Bigger height = bigger stack pressure
- Bigger temperature difference = bigger stack pressure
- Formula assumes open top (think chimney)
- Buildings do not have open tops

$$\Delta P = Cah\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

SI units:

where:

ΔP = available pressure difference, in Pa

C = 0.0342, in K/m

a = atmospheric pressure, in Pa

h = height or distance, in m

T_o = absolute outside temperature, in K

T_i = absolute inside temperature, in K

U.S. customary units:

where:

ΔP = available pressure difference, in psi

C = 0.0188, in °R/ft

a = atmospheric pressure, in psi

h = height or distance, in ft

T_o = absolute outside temperature, in °R

T_i = absolute inside temperature, in °R

air barrier
abaa
association of
america

Neutral Pressure Plane

- Height at which there is no stack pressure in the building
- More leakage at the top shifts the NPP up
- More leakage at the bottom shifts the NPP down
- Amount of leakage does not change overall stack pressure

air barrier
abaa
association of
america

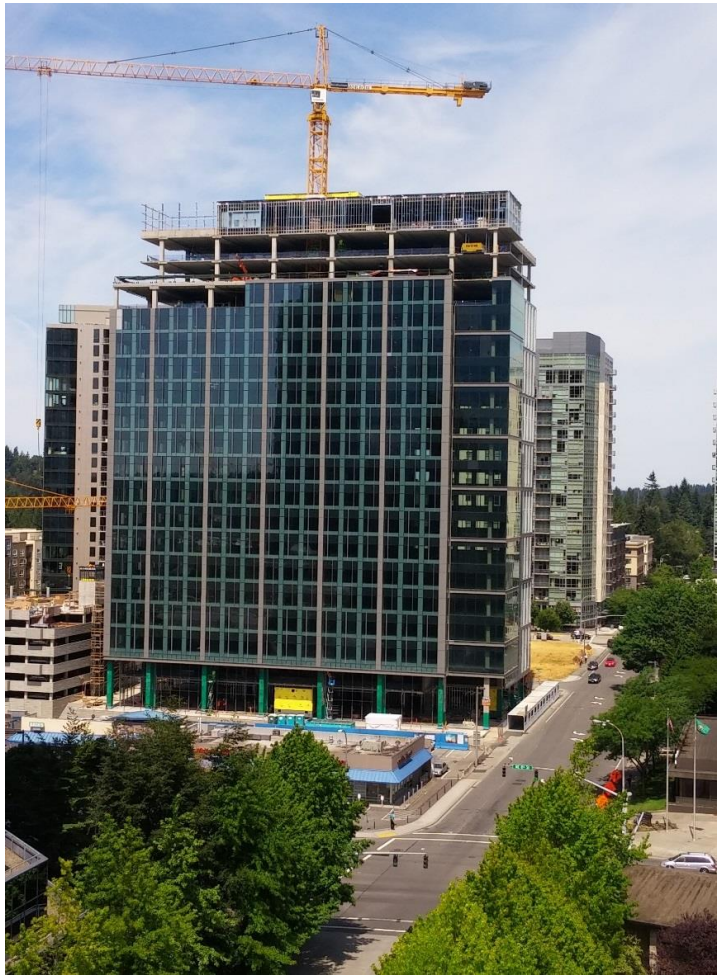
Stack Effect – Real World Example

- Height: 283ft (23 floors)
- Indoor temp: 60F
- Outdoor temp: 52F (in December!)
- Total stack pressure should be 16.2Pa
- Assuming even distribution of leakage we should measure -8.1Pa at the bottom of the building and +8.1Pa at the top

air barrier
abaa
association of
america

Stack Effect – Real World Example

- Actual measurement at ground level: -9.65Pa
- ASTM E779: height * ΔT must be less than 1180ft°F (200m°C)
- This building would require a indoor-outdoor temperature difference of less that 4°F



air barrier
abaa
association of
america

Problem

- Really tall buildings rely on good weather for whole building test
- Need to test after air barrier is complete
- Need to test before occupancy
- Cannot practically wait for good weather

air barrier
abaa
association of
america

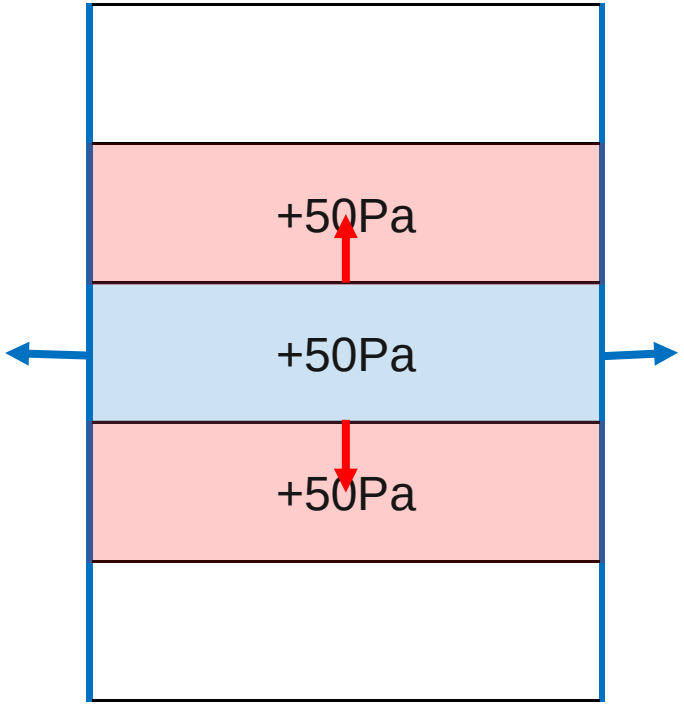
Solution

- Most really tall buildings have repeated floor plans
- Most of the leakage is at transition floors
  - Unitized glazing with reasonable QA/QC should be far below 0.4 cfm/sf
- Test smaller portions of the building
- Guarded testing…

air barrier
abaa
association of
america

Guarded Test

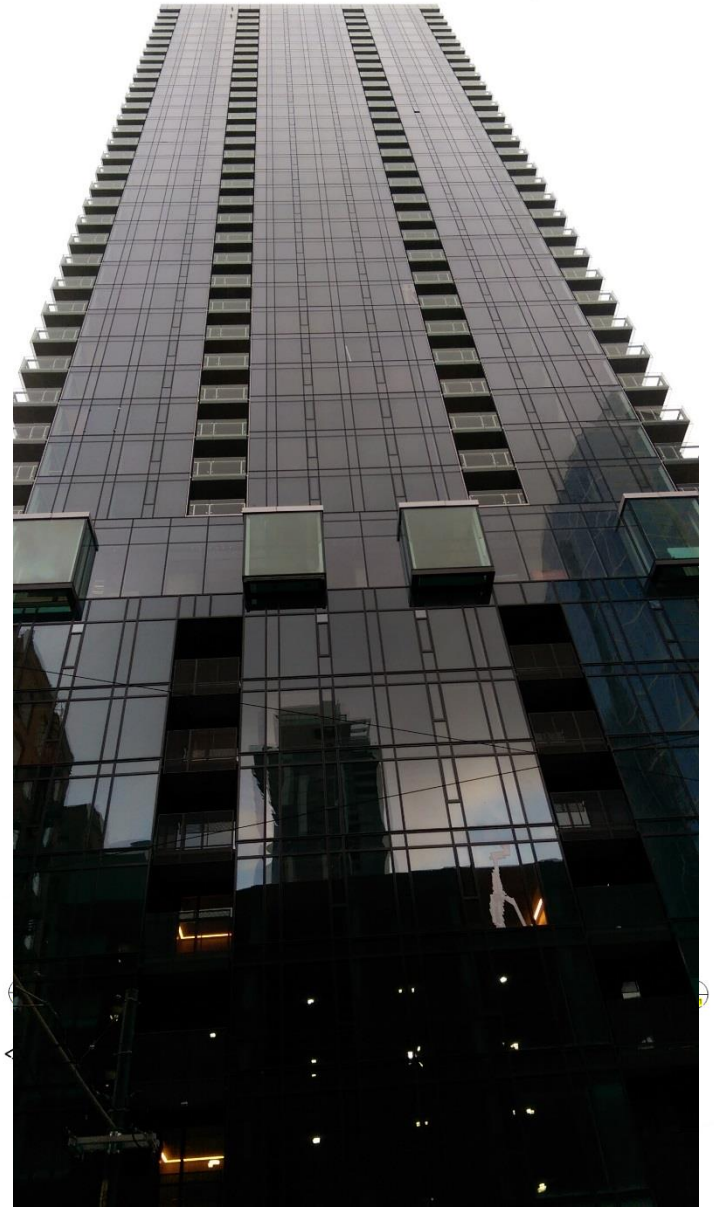
- Intent: measure leakage of a portion of a building through exterior surfaces only
- Need to neutralize (guard) pressure across interior surfaces
- No pressure difference = no flow
- Measure only exterior leakage
- Simple in theory…



air barrier
abaa
association of
america

Case Study

- 40 story apartment building
- Street level retail
- L8 restaurant space
- 415ft tall
- Temperature difference of just 10F could result in stack pressure of 15-20Pa



air barrier
abaa
association of
america

Strategy

- Test one 2-floor section per 10 common floors
- Test top floor & bottom floor
- Test other unique floors (L8)
- 7 tests total, conducted over a 4-month window
- Need buy in from SDCI, Owner, Contractor

air barrier
abaa
association of
america

Contractor pitched the idea!

- Schedule
- Swing shifts doing interior work 24-7
- Prepping roughly half of the units
- Work can continue during all testing

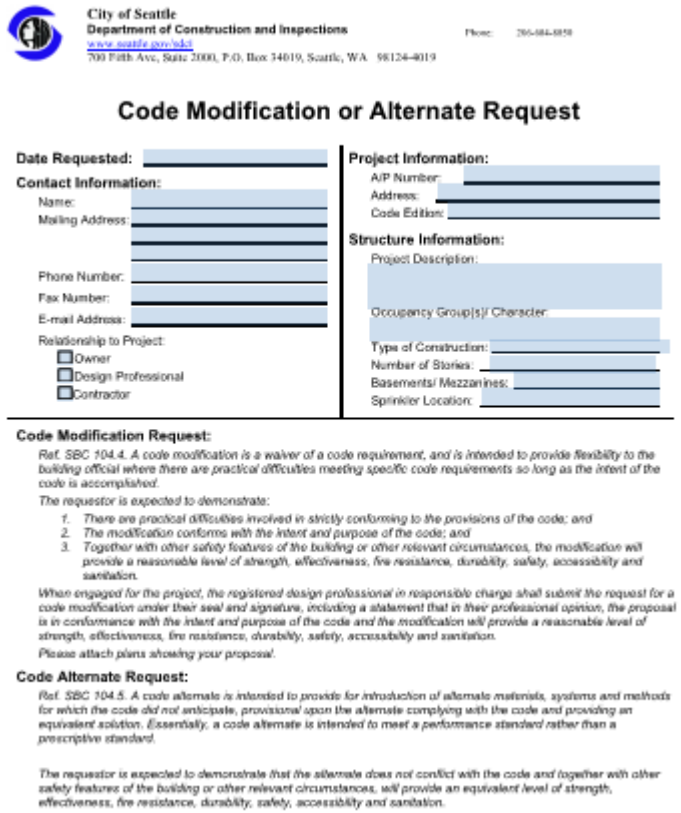
air barrier
abaa
association of
america

Coordination

- Work is ongoing during testing
- 200+ people on site
- Controlling access to test floors & guarded floors is critical
- Temporary masking strategy can change from 1 floor to the next
- Pre-test meeting & walkthrough before every test

air barrier
abaa
association of
america

Code Alternate Request



City of Seattle
Department of Construction and Inspections
www.seattle.gov/sdci
700 Fifth Ave, Suite 2000, P.O. Box 34019, Seattle, WA 98124-4019

Code Modification or Alternate Request

Date Requested:

Contact Information:
Name:
Mailing Address:
Phone Number:
Fax Number:
E-mail Address:
Relationship to Project:
- Owner
- Design Professional
- Contractor

Project Information:
A/P Number:
Address:
Code Edition:

Structure Information:
Project Description:
Occupancy Group(s)/ Character:
Type of Construction:
Number of Stories:
Basements/ Mezzanines:
Sprinkler Location:

Code Modification Request:

Ref. SBC 104.4. A code modification is a waiver of a code requirement, and is intended to provide flexibility to the building official where there are practical difficulties meeting specific code requirements so long as the intent of the code is accomplished.

The requestor is expected to demonstrate:

1. *There are practical difficulties involved in strictly conforming to the provisions of the code; and*
2. *The modification conforms with the intent and purpose of the code; and*
3. *Together with other safety features of the building or other relevant circumstances, the modification will provide a reasonable level of strength, effectiveness, fire resistance, durability, safety, accessibility and sanitation.*

When engaged for the project, the registered design professional in responsible charge shall submit the request for a code modification under their seal and signature, including a statement that in their professional opinion, the proposal is in conformance with the intent and purpose of the code and the modification will provide a reasonable level of strength, effectiveness, fire resistance, durability, safety, accessibility and sanitation.

Please attach plans showing your proposal.

Code Alternate Request:

Ref. SBC 104.5. A code alternate is intended to provide for introduction of alternate materials, systems and methods for which the code did not anticipate, provisional upon the alternate complying with the code and providing an equivalent solution. Essentially, a code alternate is intended to meet a performance standard rather than a prescriptive standard.

The requestor is expected to demonstrate that the alternate does not conflict with the code and together with other safety features of the building or other relevant circumstances, will provide an equivalent level of strength, effectiveness, fire resistance, durability, safety, accessibility and sanitation.

When engaged for the project, the registered design professional in responsible charge shall submit the request for a code alternate under their seal and signature, including a statement that in their professional opinion, the alternate is equivalent to the code provisions.

Please attach plans showing your proposal.

Washington State Seal and Signature

Seattle DCI Use Only
- Approved
- Approved with Amendment
- Denied

Reasons:

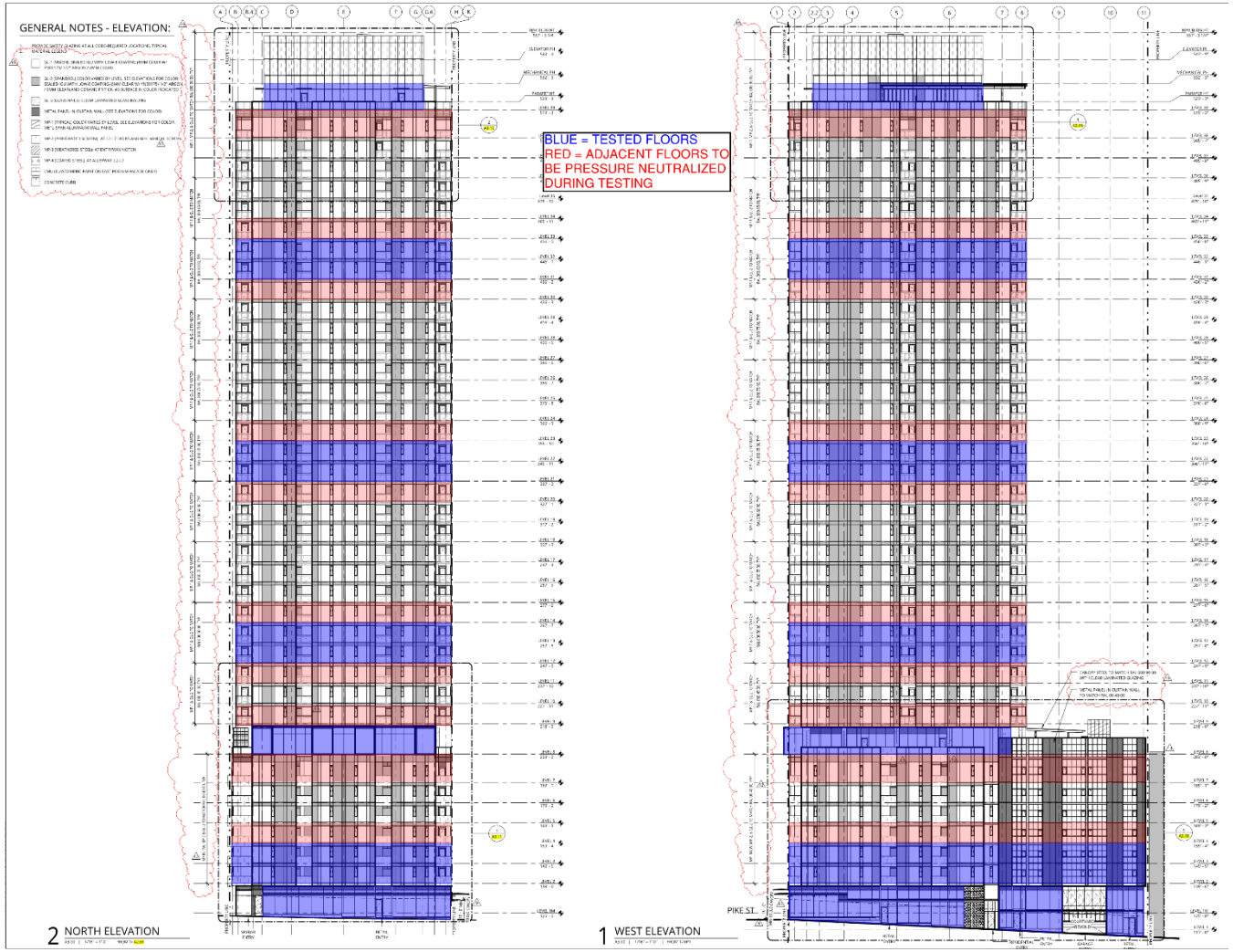
Description of Alternate/ Modification (include reason for request):

Description of Code Requirement (include section):

Justification (attach copies of any reference, test reports, expert opinions, etc.):

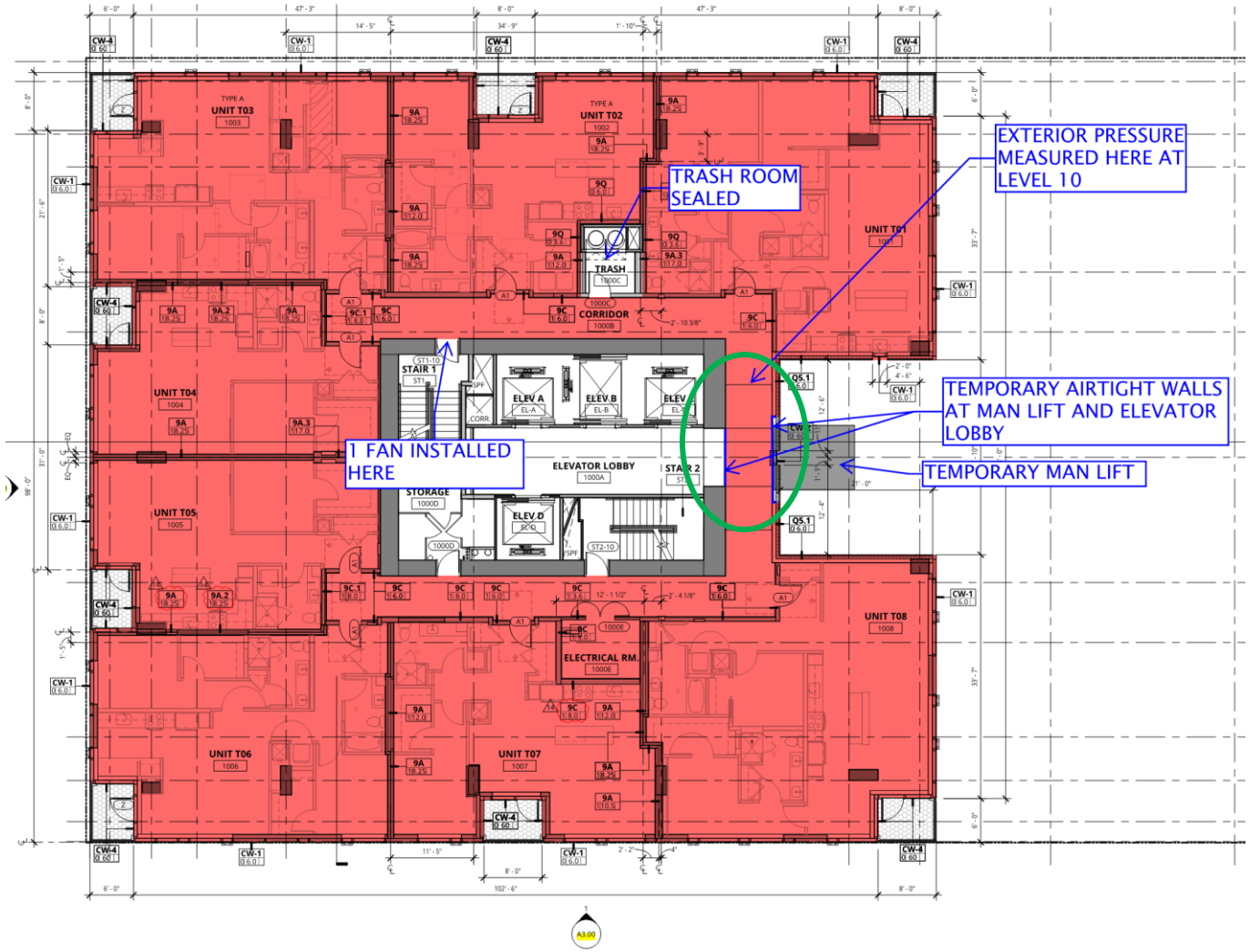
air barrier
abaa
association of
america

Test Plan



air barrier
abaa
association of america

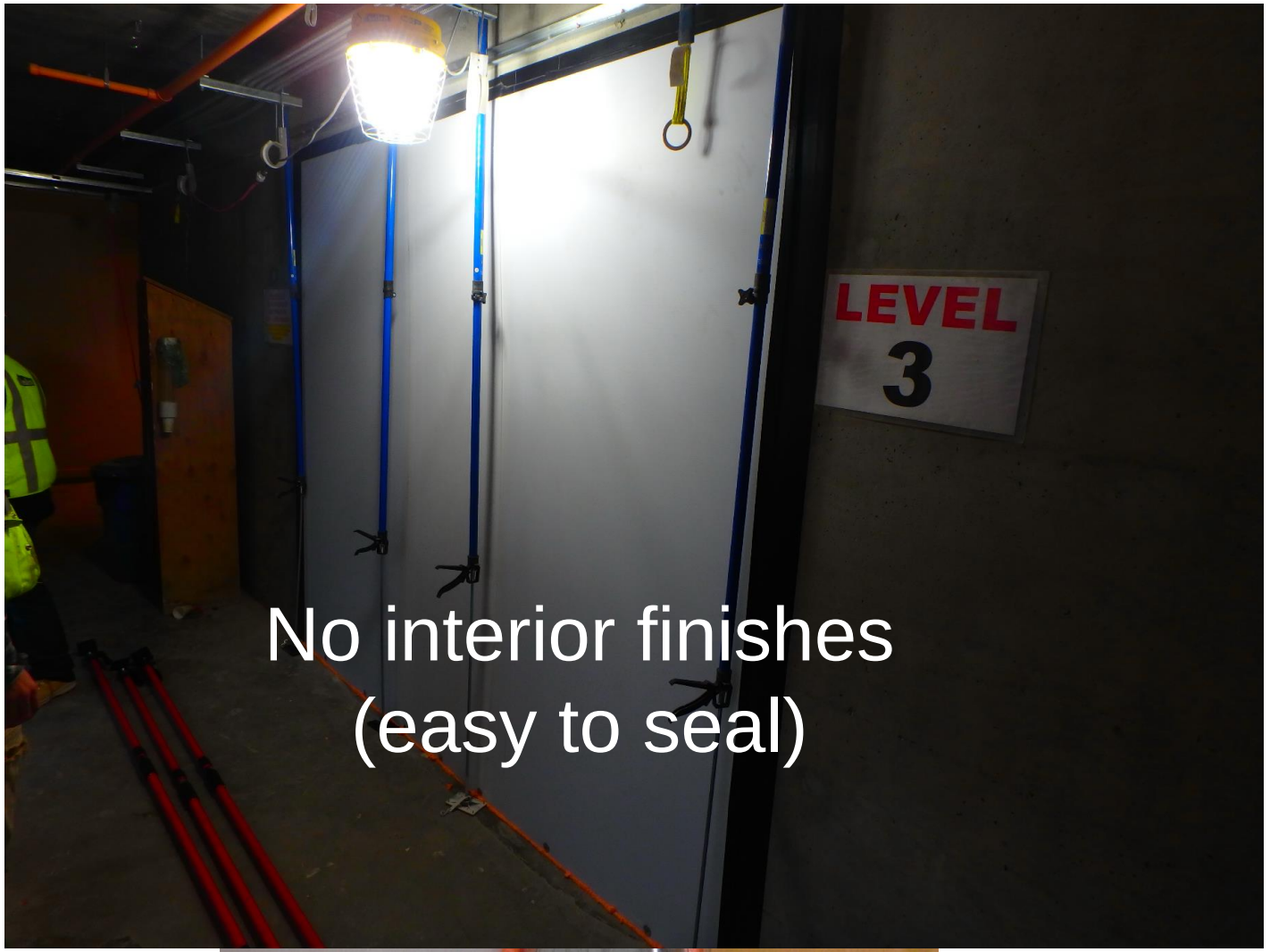
Test Plan – Typical Tower Floor



LEVEL 11&14 SETUP

air barrier abaa association of america

Temporary Walls

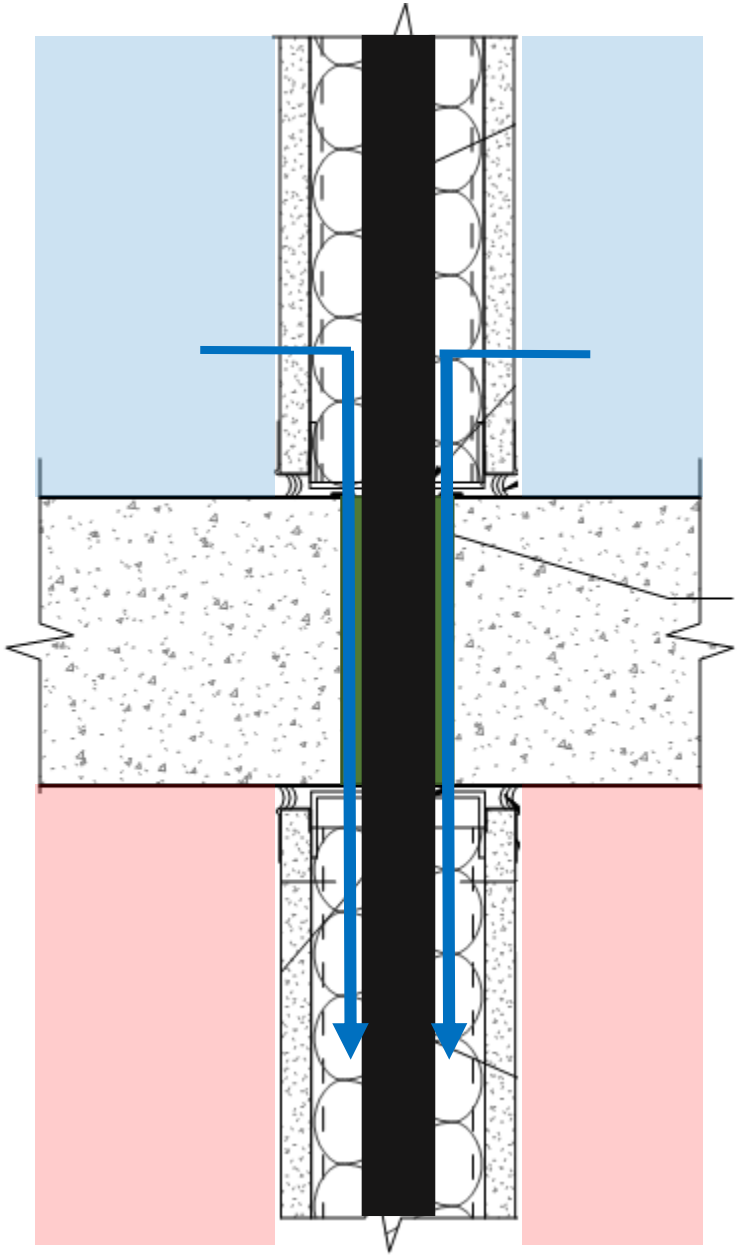


No interior finishes
(easy to seal)

air barrier
abaa
association of
america

Floor Penetrations

- Plumbing stacks penetrate each floor through intumescent sleeves
- Sleeves are not airtight until heat is applied
- Depending on level of completion – guarded floor may not neutralize pressure through plumbing chase



air barrier
abaa
association of
america

Exterior Pressure Measurement

- For whole building test, typically measure at grade
- Impractical to run tubing down stairwells to grade
- Measure at floor below bottom guarded zone
- Need to ensure that floor is at exterior conditions

air barrier
abaa
association of
america

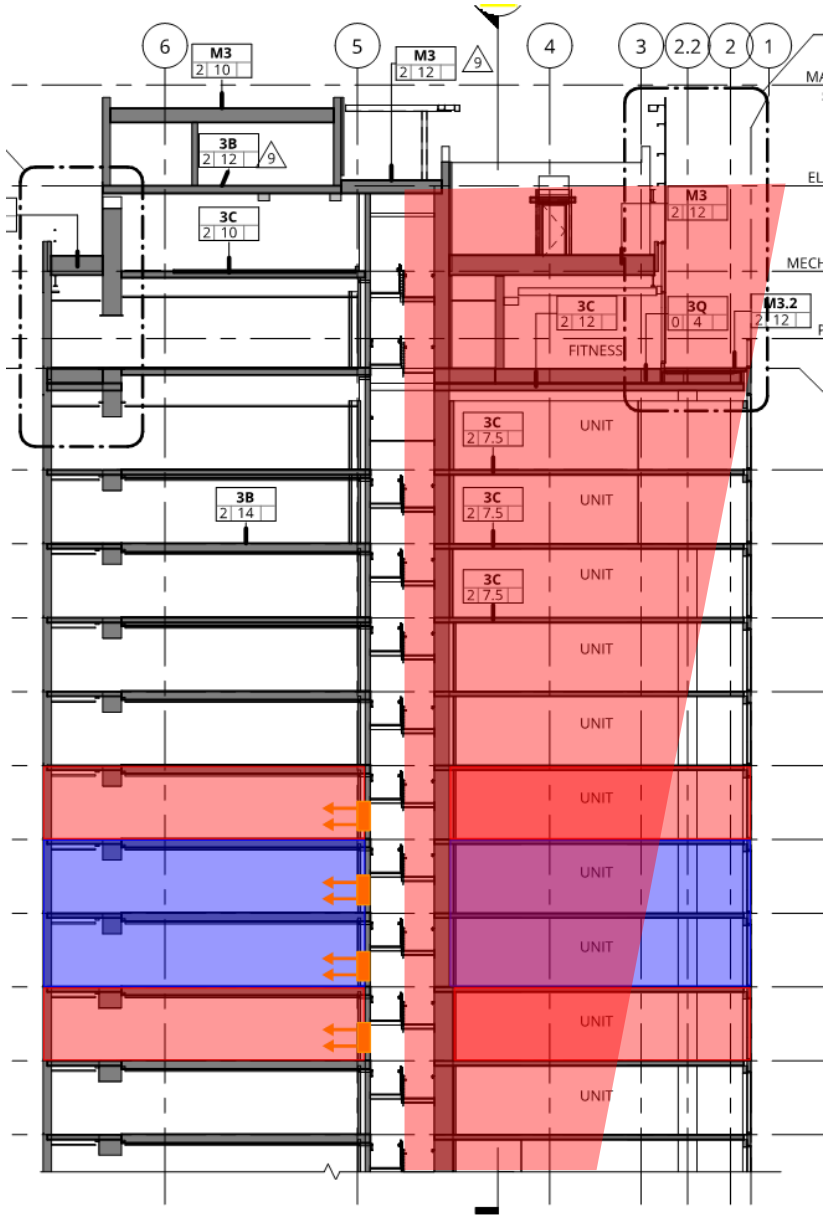
Dealing With Stack

- Not a significant issue at lower floors
- Building not heated
- Temporary lift still in place
- Upper tower tests required adjustment

air barrier
abaa
association of
america

Dealing With Stack

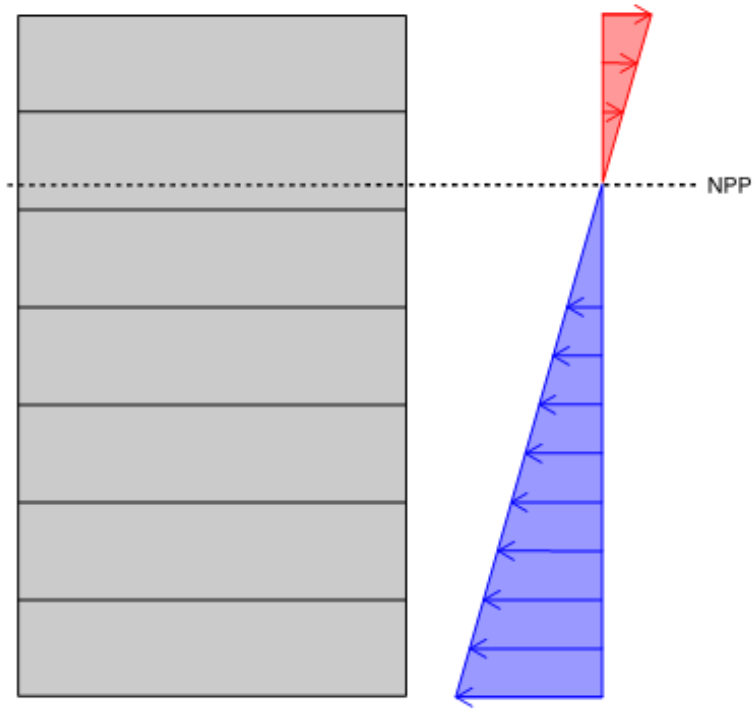
- Theory: each test should be an isolated 4-story box
- Reality: stack pressure measured where exterior tube crosses into stairwell
- Stairwell is a 400ft+ tall column of warm air



air barrier
abaa
association of
america

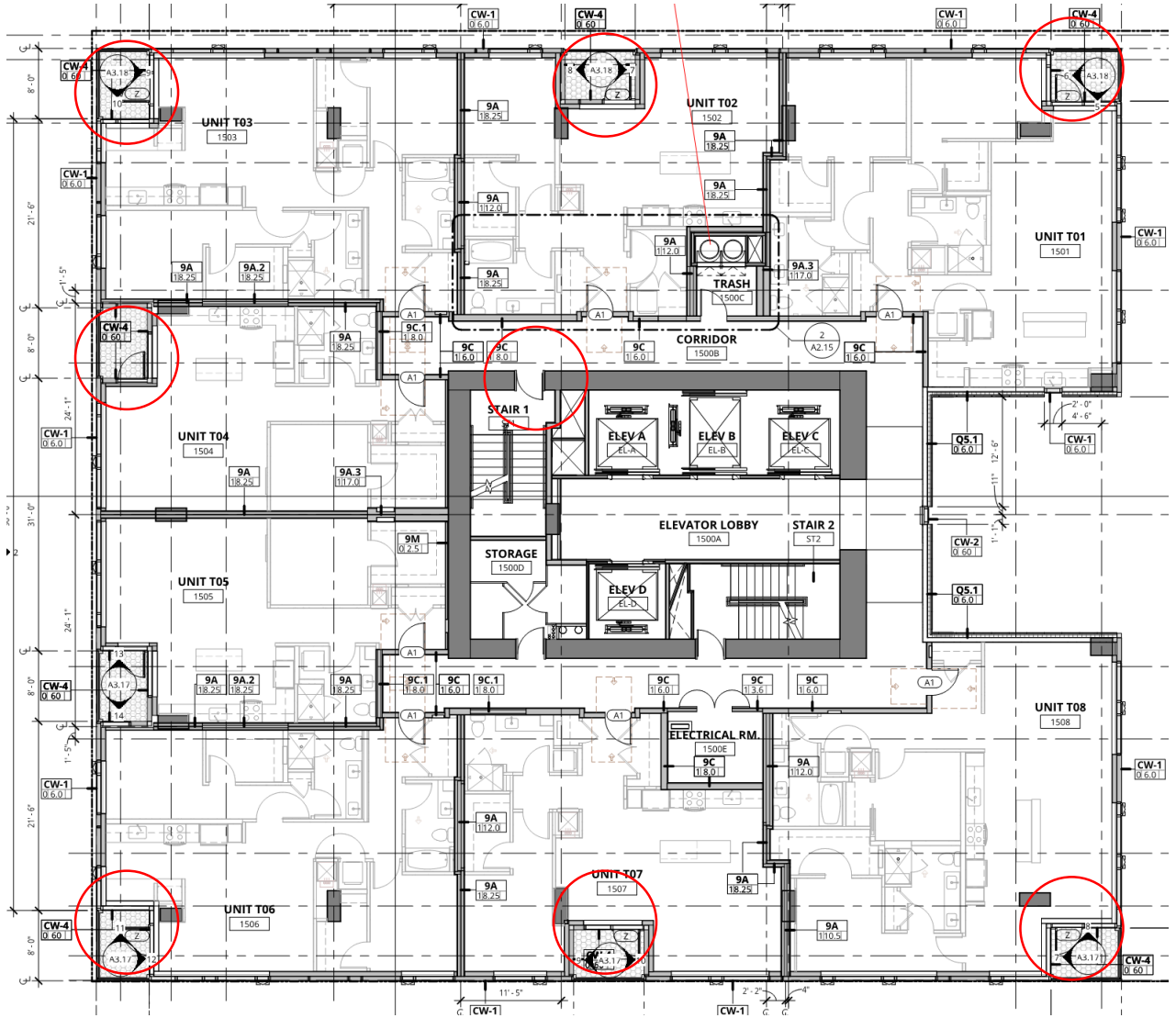
Dealing With Stack

- Need to shift NPP up
- Add leakage below test zone
- Open balcony doors & stairwell doors below test zone



air barrier
abaa
association of
america

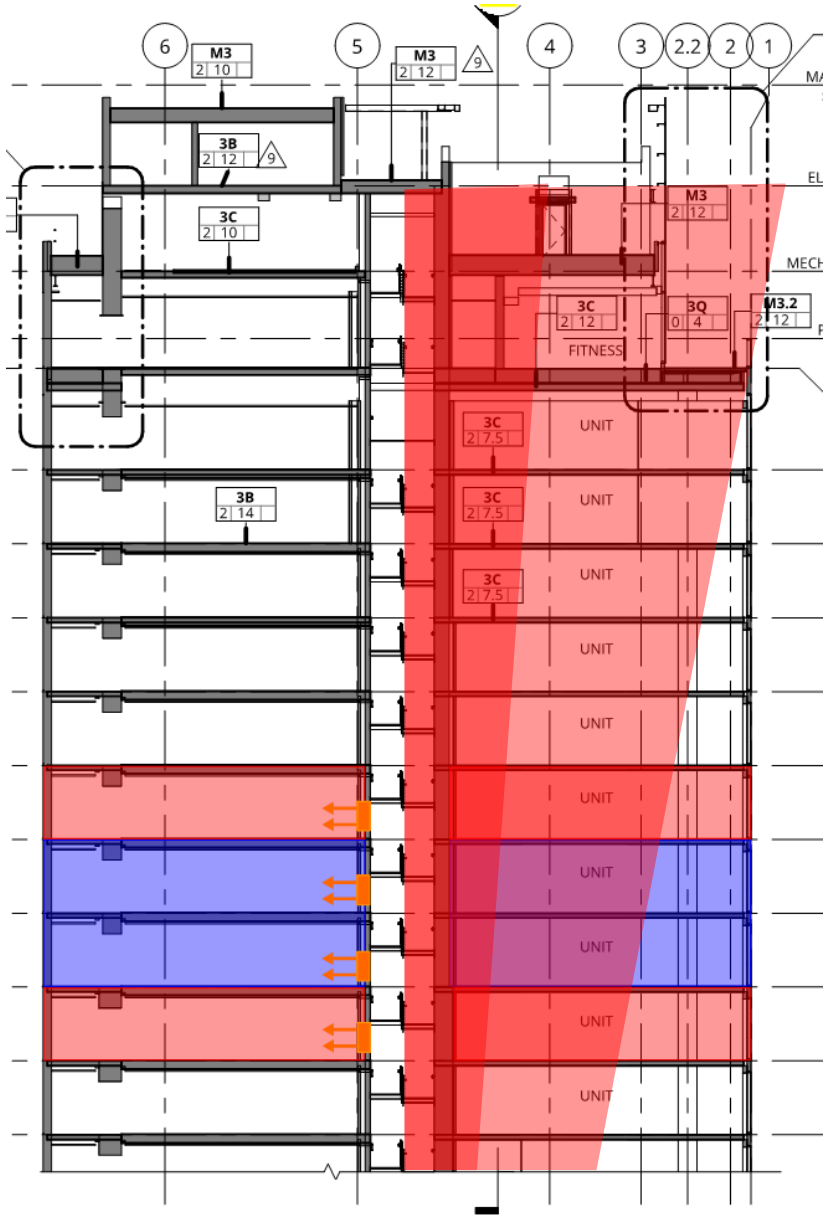
Dealing With Stack



air barrier
abaa
association of
america

Dealing With Stack

- Exterior temp: 47F
- Interior temp: 63F
- Baseline readings dropped from ~25Pa down to ~12Pa



air barrier
abaa
association of
america

Results

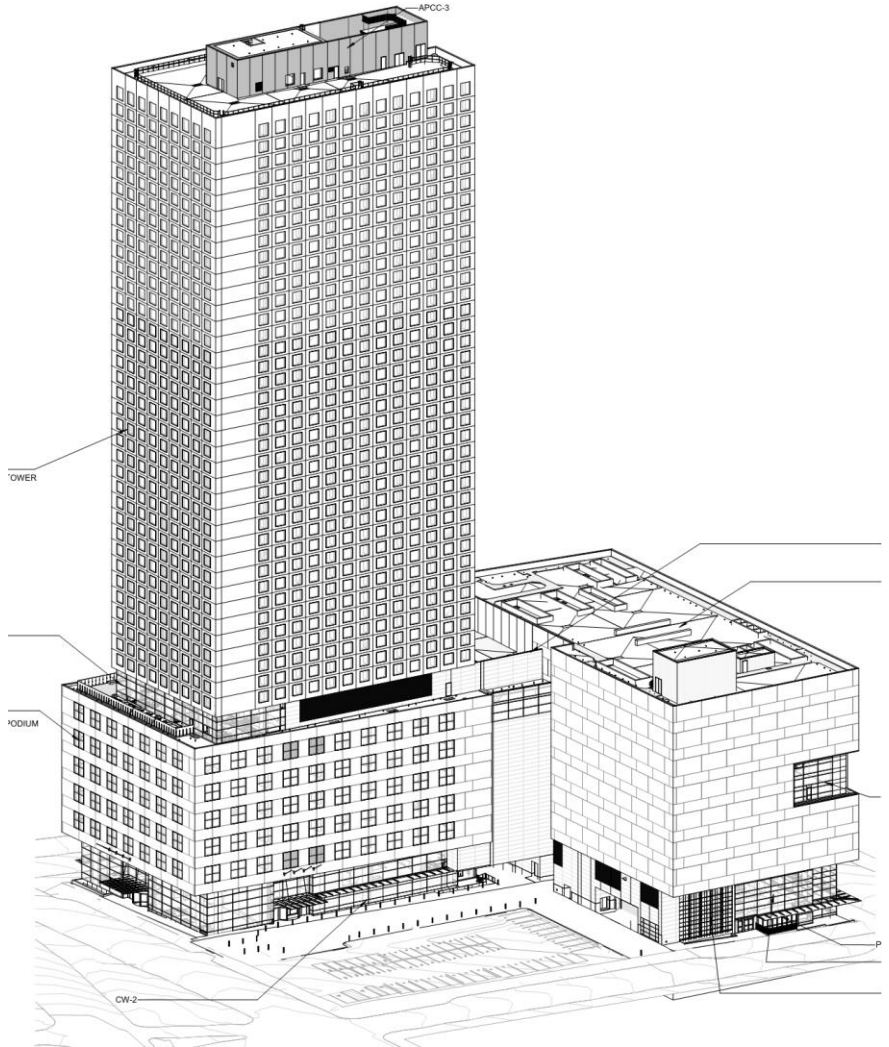
TABLE 2 TOTAL SQUARE FOOTAGE OF THE TEST ZONES AND THE DATE TESTED			
Test Zone	Description	Date Tested	Envelope Area
A	Level 1	1/29/2018	26,696
B	Levels 2-3	10/28/2017	37,066
C	Level 8	12/16/2017	11,350
D	Level 12-13	12/2/2017	14,585
E	Level 21-22	12/2/2017	14,585
F	Level 31-32	12/16/2017	14,585
G	Level 39	1/27/2018	13,232

TABLE 3 SUMMARY AIRTIGHTNESS OF EACH TEST ZONE							
Test Condition	Zone A cfm/ft²	Zone B cfm/ft²	Zone C cfm/ft²	Zone D cfm/ft²	Zone E cfm/ft²	Zone F cfm/ft²	Zone G cfm/ft²
Depressurize:	0.161	0.170	0.271	0.177	0.184	0.132	0.228
Pressurize:	0.167	0.233	0.304	0.259	0.182	0.127	0.254
Average:	0.164	0.202	0.288	0.218	0.183	0.129	0.241

air barrier
abaa
association of
america

Case Study #2

- 45 story hotel
- Ballroom/convention space at podium
- 500ft tall
- No unit balconies
- No operable windows
- Not yet tested (summer/fall 2018)



air barrier
abaa
association of
america

Problem

- Cannot open windows/doors to shift NPP
- Cannot get an exterior pressure tap out of intermediate floors
- Need to keep stack pressure at a reasonable level

air barrier
abaa
association of
america

Solutions

- Follow same strategy as case study #1
  - Test one 2-floor section per 10 common floors
  - Test top floor & bottom floor
  - Test other unique floors
- Complete all tests before temporary lift is removed
- Retain a large hole (from lift) at each floor to mitigate stack pressure & run exterior tubing out of

air barrier
abaa
association of
america

Solutions

- Wait until building is fully enclosed
- Use HVAC systems to cool the building overnight
- Coordinate shutdown & close dampers right before testing starts
- Thermal mass can help – test early morning
- Exact strategy TBD…

air barrier
abaa
association of
america

Takeaways

- Stack/wind rarely a significant limiting factor in most buildings
- Tall buildings present unique challenges – whole building test relies on good weather
- Not always practical/possible to perform whole building test
- Guarded floor testing can be a reasonable alternative
- Early coordination & planning is essential
- Buy-in from construction team is essential

air barrier
abaa
association of
america

Thank You

Denali Jones
djones@rdh.com