Commissioning and Envelope Leakage: Using HVAC Operating Strategies to Meet Design and Construction Challenges

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The Building Envelope …

… Making a Statement about the Building and its Owner

- Aesthetics and visual appeal are key drivers
- Origins in the early phases of design

The Building Envelope …

… An Essential Component of the Building Environmental Control System

- Resist energy transfer
- Resist mass transfer
  - Water
  - Air
- Allow occupant access

These functions evolve later in the design process

Envelope Details …

…Impact HVAC Performance

- Thermal implications
- Humidity implications
- Pressure implications

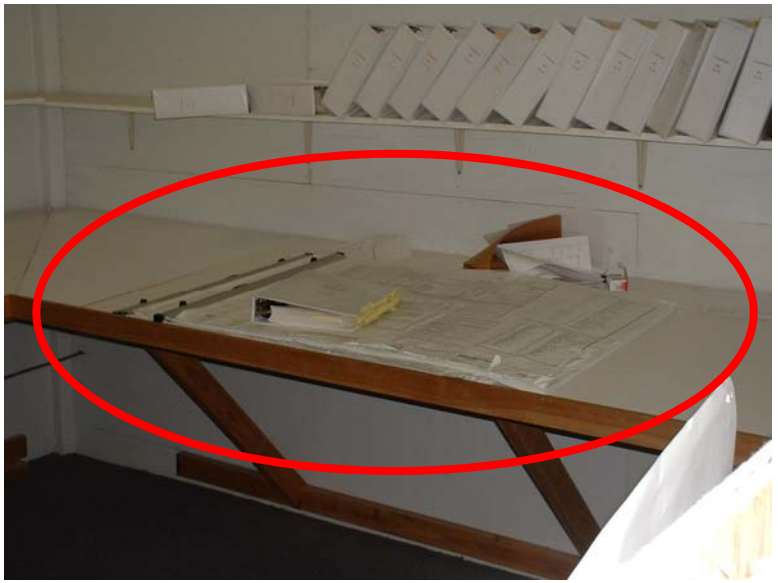
It Takes A Lot of Detail ….

… to Assemble a Building Envelope

Shop drawing sets that define the curtain wall and window system for a 400 foot tall high-rise

The Contract Documents for the Same Project

The Architectural Contract Documents



The Mechanical Contract Documents

Perhaps a clue about why there may be a few problems and where they are going to occur?

Envelope Design Realities

- Multiple panels = Multiple joints
- Different materials = Different physical characteristics
- Different characteristics = Joint movement
- Building movement = Joint movement
- Entrances and exits = Envelope breaches
- Building height = Stack effect

Envelope Fabrication Realities

- Construction timeline = Seasonal variations
- Different materials = Multiple trade specialties
- Architectural features = Hidden joints and construction
- Plenums = Heightened performance requirements from standard construction techniques
- Special products = Special handling
- Special products = Special installation processes in a less than optimal environment

Detection By Inspection is Increasingly Difficult as Construction Progresses

Elevation makes assessment from the exterior difficult

Detection By Inspection is Increasingly Difficult as Construction Progresses

Finishes make assessment from the interior virtually impossible

Complex Geometry Compounds the Problem

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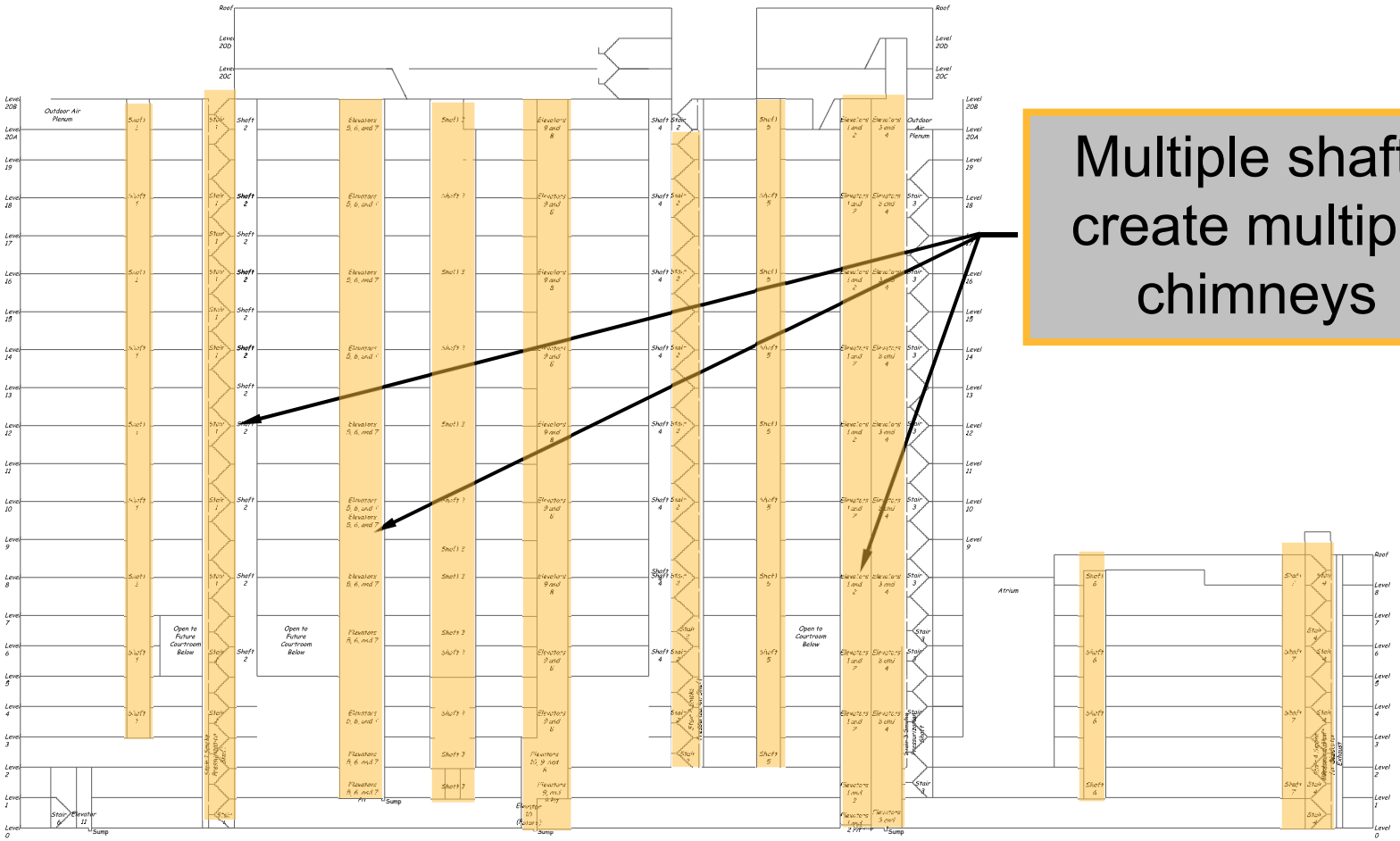
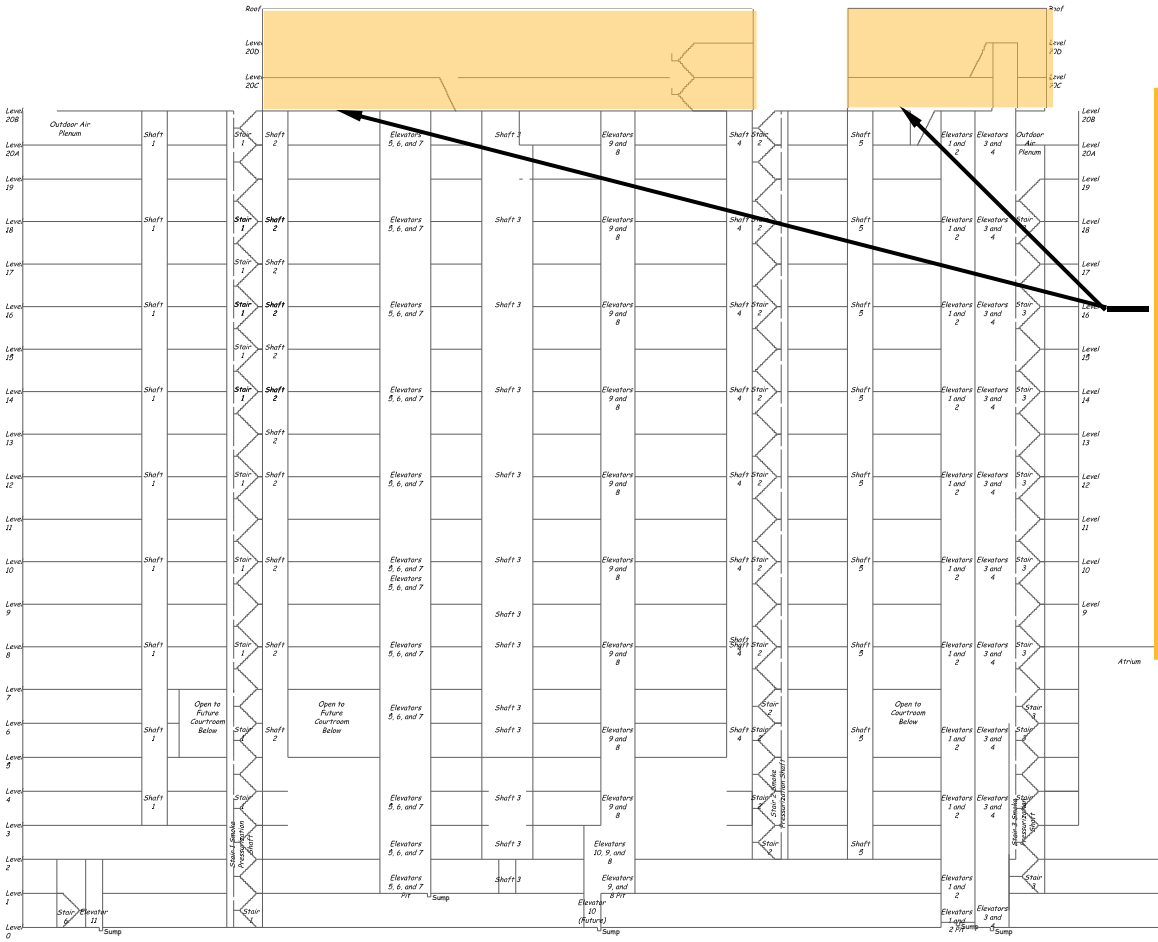
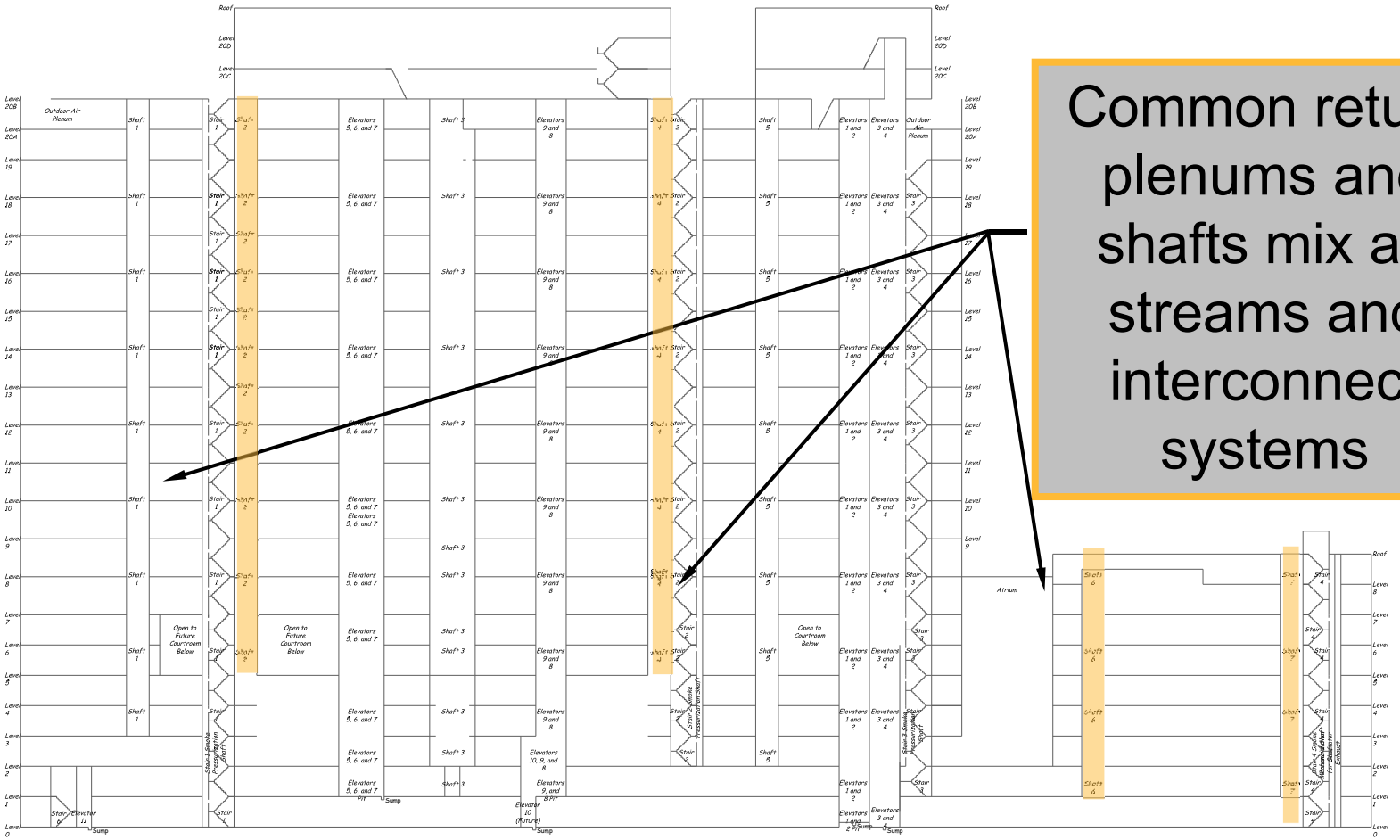


Complex Geometry Compounds the Problem



Common mechanical room/relief plenum interconnects shafts and systems

Complex Geometry Compounds the Problem



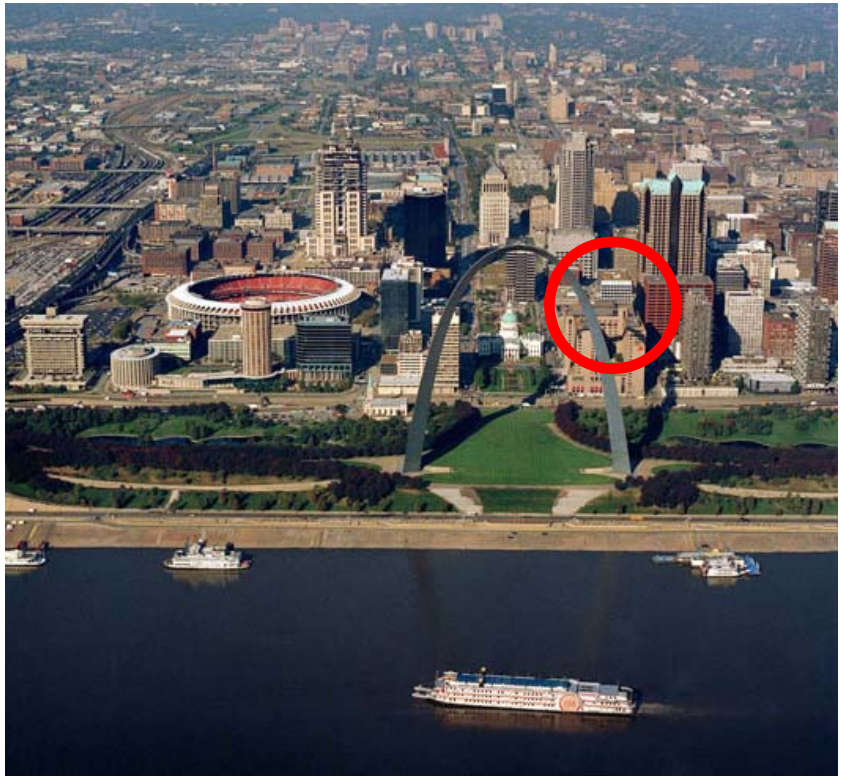
Common return plenums and shafts mix air streams and interconnect systems

Design and Fabrication Realities Lead to Operating Realities

- A weather tight building is not air tight
- Uncontrolled, unanticipated air leakage leads to:
  - Comfort problems
  - Energy waste
  - Catastrophic events
    - Indoor air quality failures
    - Piping failures
    - Damage to finishes

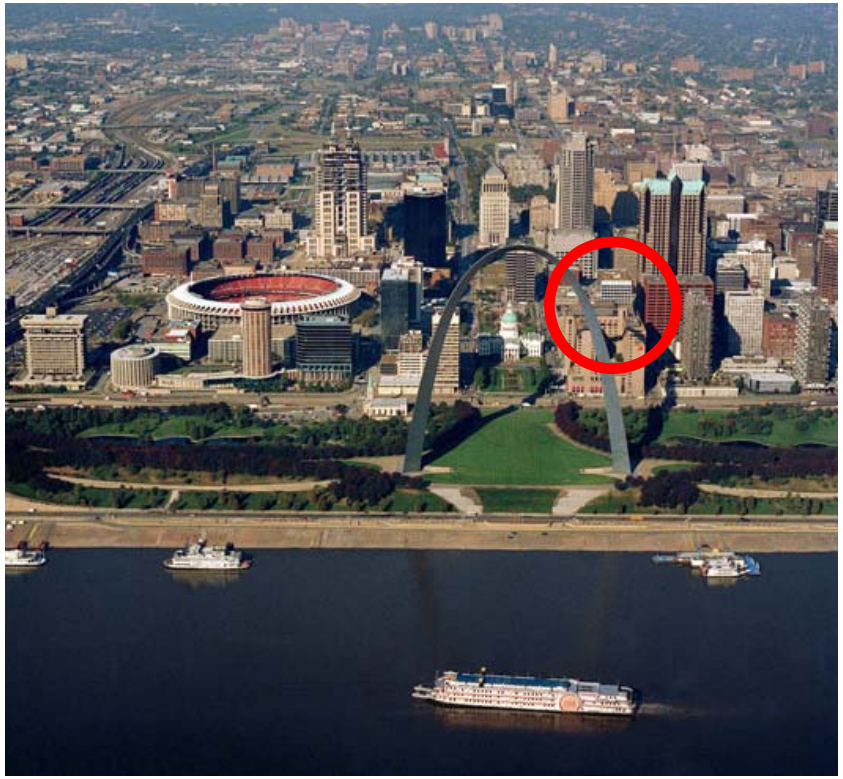
A 1960's Vintage Mid-West High Rise Experience *circa 1978*

- Energy crisis driven costs result in lobby air curtain shut down
  - Stack effect results in:
    - Elevator shafts = Chimney
    - Lobby = Hearth



A 1960's Vintage Mid-West High Rise Experience *circa 1978*

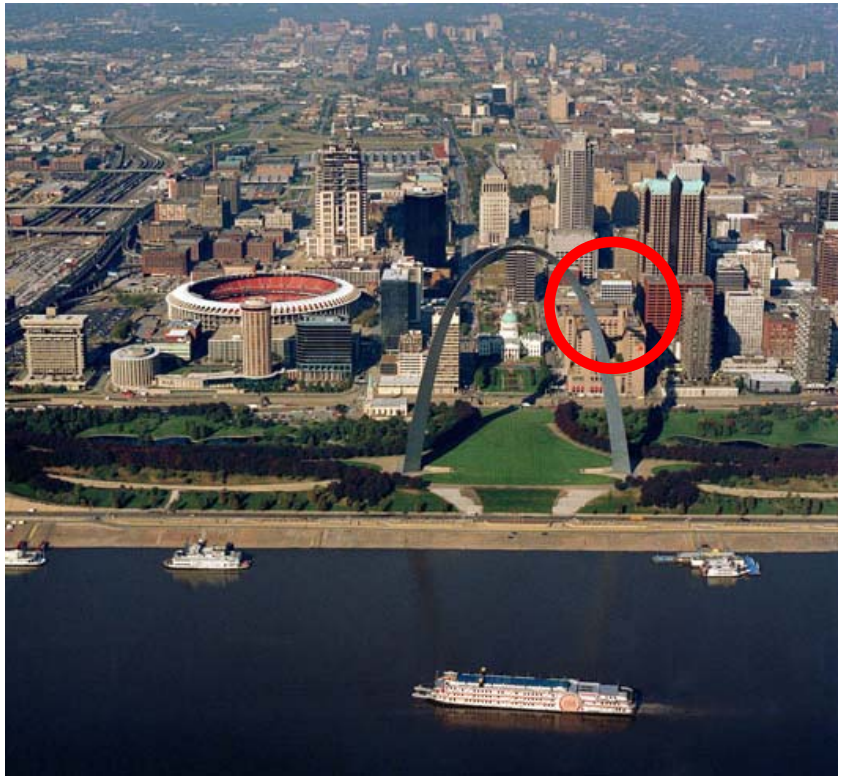
- Energy crisis driven costs result in evening and weekend HVAC shutdown
  - Stack effect results in:
    - Humid air infiltration
    - Perimeter induction unit drain pan overflow



A 1960's Vintage Mid-West High Rise Experience *circa 1978*

Solutions:

- Live with the cold lobby and whistling
- In hot and humid weather:
  - Run the chiller plant around the clock
  - Keep one core air handling system running in full recirculation



A 1980's Vintage Mid-West High Rise Experience *circa 1988*

- Complex building geometry makes envelope closure assessment difficult during construction
  - First cold snap results in:
    - 55°F office space
    - Irate tenant
    - Questioning of Engineer's competence

      (among other things)

A 1980's Vintage Mid-West High Rise Experience *circa 1988*

- Field inspection by the Engineer:
  - Identifies a 4 foot by 40 foot hole to the exterior above the ceiling in the affected area
  - Provides vindication

A 1980's Vintage Mid-West High Rise Experience *circa 1988*

Solution:

- Fix the hole
- Buy the Engineer a beer

A 1990's High Tech Experience *circa 1998*

- Critical clean room pressurization requirement results in the following design:
  - Two parallel, 100% redundant fans:
    - Only one fan runs normally
    - Provides 27,000 cfm at 3.5 inches w.c.

A 1990's High Tech Experience *circa 1998*

- Clean room leakage resulted in running both fans to achieve pressurization required
  - 14,000 extra cfm of outside air to move and condition
  - Static requirement increased to 7 in.w.c.

Duct pressure class was 4 in.w.c.!!

A 1990's High Tech Experience *circa 1998*

Solution:

- Run scared!
- Find and fix the leaks as time and money permit
  - Repair work in an active clean room is difficult and expensive
  - Looking for hundreds to thousands of small leaks not one large leak

Two 1990's Health Care Experiences

circa 1995

- Two Hospital renovations involving new entry lobbies
  - Reception staff and visitor seating located near the entry
  - Large, complex buildings constructed over a number of years
  - Pressurization issues tended to make entry areas negative

Two 1990's Health Care Experiences

circa 1995

- Lobby HVAC designed to meet the challenges
  - Vestibules
  - Independent air handling system
  - Floor to desk top enclosure of reception work area
  - Occupant controlled radiant heat under the reception desktop

Two 1990's Health Care Experiences

circa 1995

Project 1 included the features in the base bid

- Design goals met after commissioning
- Well trained motivated staff ensures that the design intent persists

Two 1990's Health Care Experiences

circa 1995

- Project 2 VE'd the features out due to budget issues
  - Site work problems ate a big chunk of contingency
  - Provisions made to add the features if operating experience indicated they were desirable
  - Operating experience indicated they were desirable
  - Implementing the features made vast improvements in lobby comfort

HVAC Modifications May Or May Not Be Able To Mitigate Air Leakage Problems …

… Understanding the problem is the key first step to developing a solution

Assess air leakage:

- Magnitude
- Location
- Significance relative to other openings
  - Entrances
  - Loading docks
  - Relief systems

Assessing Air Leakage

- Procedures and Data Available
  - *Standard Test Method For Determining Air Leakage Rate By Fan Pressurization*
    - ASTM Standard E 779 (ASTM 1992)
    - Rigorous

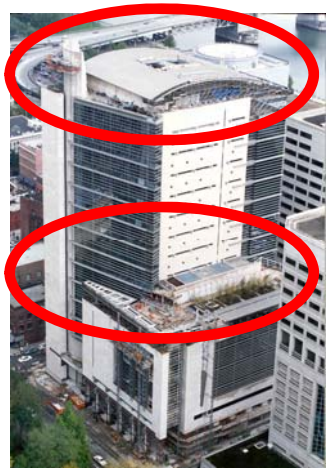
Assessing Air Leakage

- Procedures and Data Available
  - *Myths About Building Envelopes*
    - March 1999 ASHRAE Journal
    - Documents DOE study results using ASTM E 779

Assessing Air Leakage

- Procedures and Data Available
  - *A Test Procedure for Assessing Envelope Leakage in Commercial Buildings: The Issues, the Process and the Results*
    - NCBC 2004 (download at www.PECI.org)
    - Overview of other procedures and data
    - Abbreviated procedure based on ASTM E 799 discussed and included as an appendix

Measuring Leakage in a 1990's Vintage High Rise *circa 2003/2004*

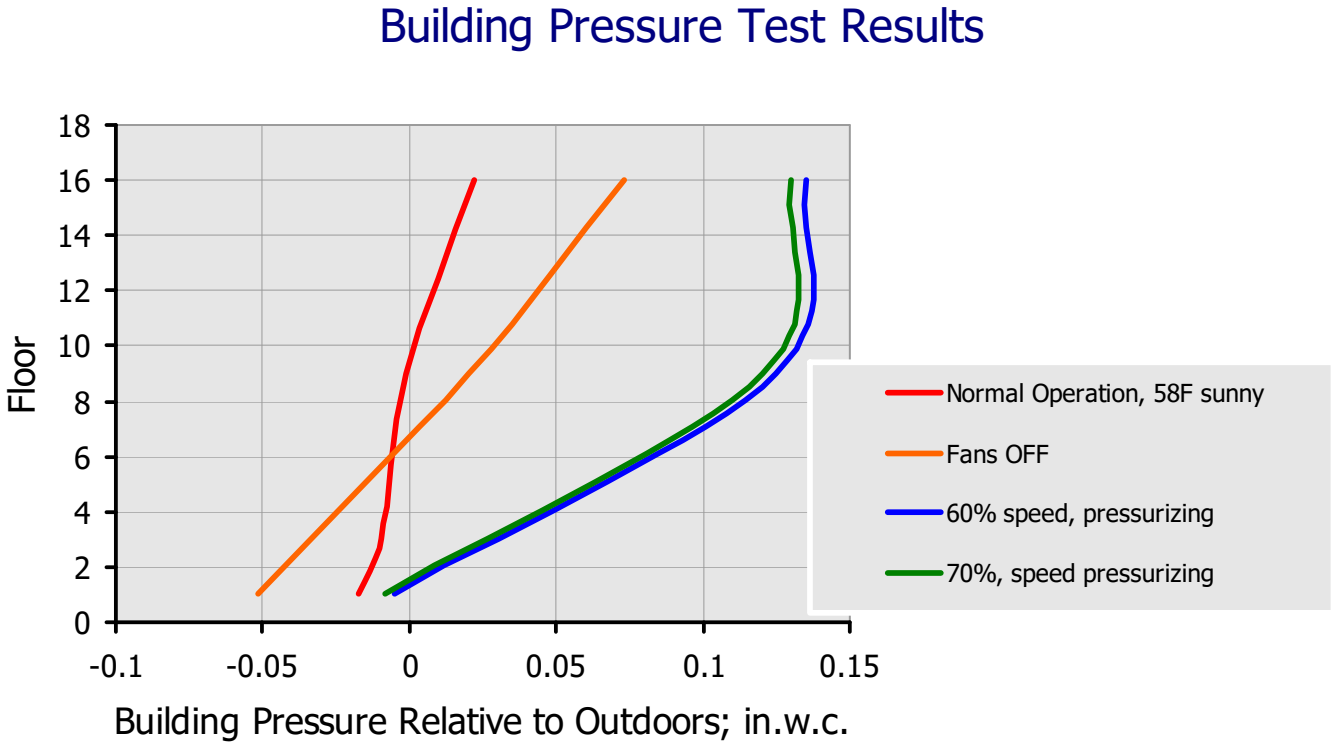


- VAV Double Duct Air Handling systems, nominal 450,000 cfm total capacity
- Structural steel frame with curtain wall system

Nominal 450,000 square foot, 350 foot tall high rise federal court house

Projected leakage rate range from DOE study - 41,597 to 1,918,061 cfm @ 0.10 in.w.c.

Measuring Leakage in a 1990's Vintage High Rise *circa 2003/2004*



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Measuring Leakage in a 1990's Vintage High Rise *circa 2003/2004*

148,000 – 255,000 cfm of outdoor air

- No relief
- No return
- No doors open

No positive pressure at the lobby level!

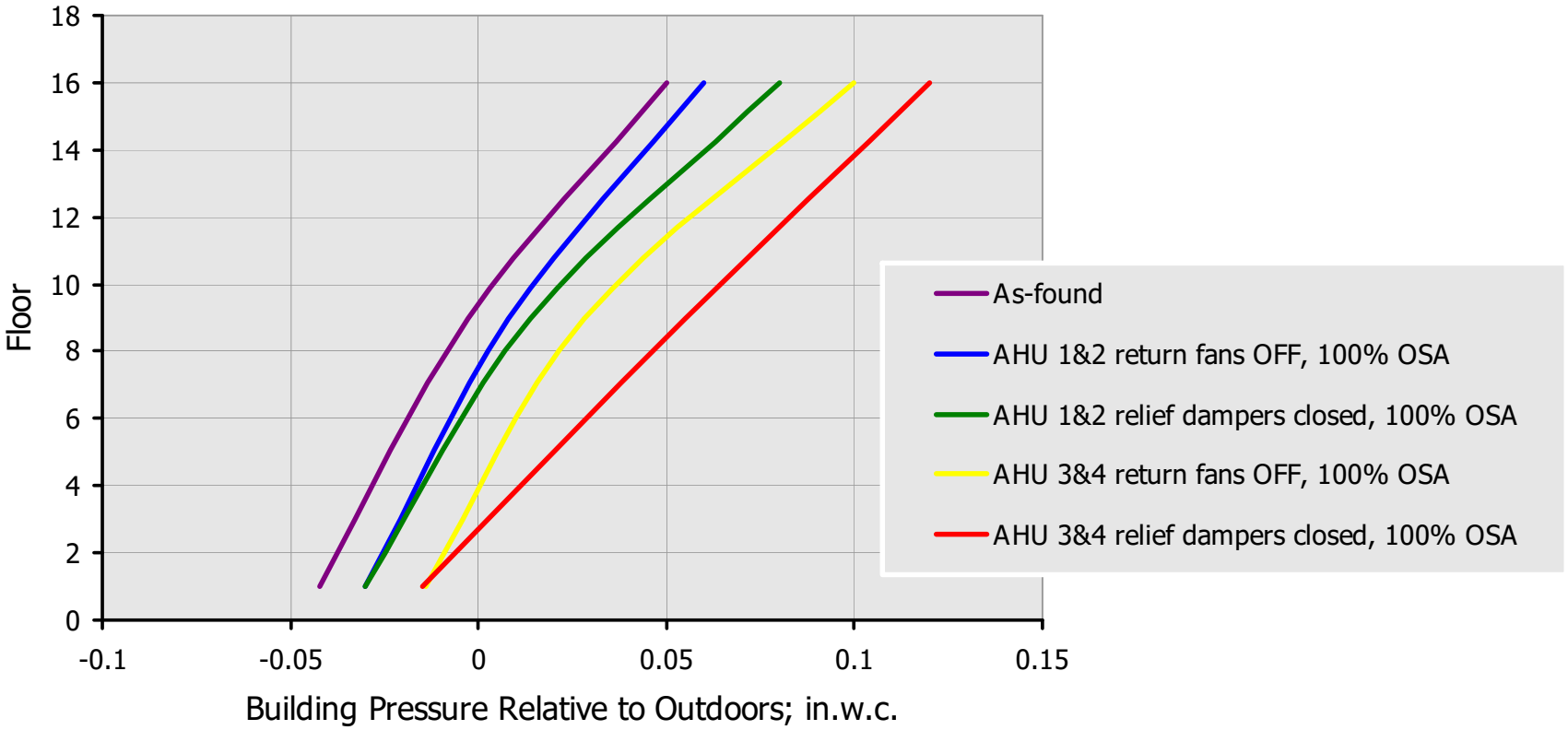
Nominal 450,000 square foot, 350 foot tall high rise federal court house

Projected leakage rate range from DOE study - 41,597 to 1,918,061 cfm @ 0.10 in.w.c.

Making Lemonade

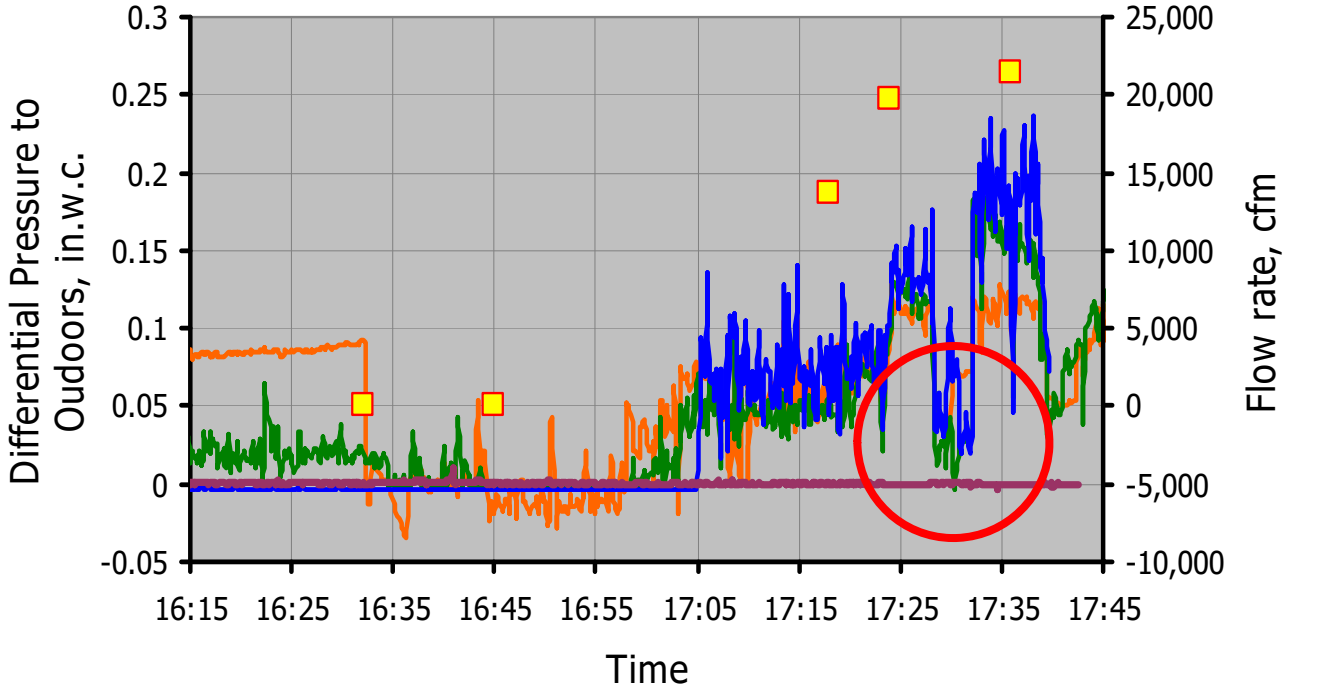
- Opportunity to save fan energy by not running return fans
- Opportunity to shift an exfiltration load to an infiltration load
  - Infiltration must be handled by perimeter system as a heating load
  - Exfiltration handled by internal gains during economizer operation
- Potential to save $14,600 for a $5,000 implementation cost

Making Lemonade

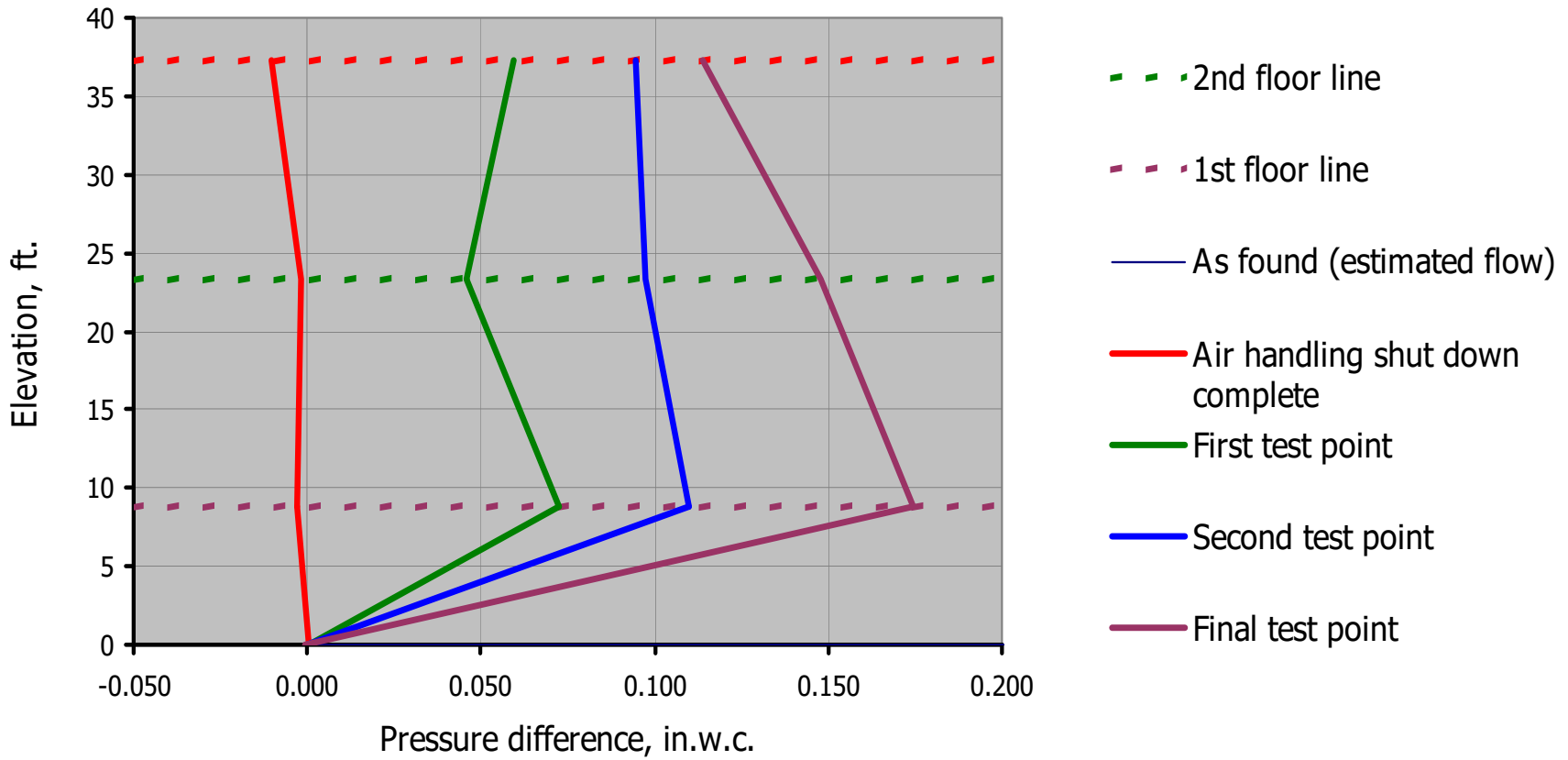


Measuring Leakage in a 1950's Vintage Low Rise *circa 2003/2004*

Building Pressurization Test Results



The PEC Pressure Gradient



The PEC Pressure Gradient

Good News!

- The building leakage rate is about 75% of what might be anticipated from data in the literature
- Anticipated range at .10 in.w.c. – 2,300 to 26,000 cfm
- Measured leakage at .11 in.w.c. – 19,000
- 12,000 – 18,000 cfm of air required to pressurize the lobby for normal operation
- The system spends a lot of time on economizer at 12,000 – 18,000 cfm
- Relief damper control based on building static pressure looks like a good approach

Conclusions

- Buildings are generally not air tight
- Commissioning efforts can mitigate the effect with the HVAC systems in some cases
- In some cases, the leakage can overwhelm any practical HVAC mitigation
  - Target and repair the leaks as a first step
  - Provide additional HVAC based mitigation if necessary as a final step

Key Design Points to Consider

- Consider decoupling the temperature control and building pressure control functions associated with the economizer
- Provide vestibules on lobbies
- Provide supplemental heat and draft protection at workstations located in the lobby
- Provide an independent HVAC system for the lobby in high-rise and complex buildings

Recommendations

- Assume buildings will leak
  - Research and develop design and operating strategies to allow HVAC systems to cope
  - Target leakage during commissioning
    - Design phase
    - Construction observation phase
    - Start up and testing phase
    - Ongoing commissioning
    - Retro commissioning

Recommendations

Endevor to Build Leak Free Buildings!

Support the effort with ongoing research regarding:

- Existing building leakage performance
- Leakage mitigation techniques
- Improved construction techniques