LESSONS LEARNED FROM PRESSURIZED UNDERFLOOR AIR DISTRIBUTION SYSTEMS

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What is Building Performance?

Based on control theory and the assumption that a building is a system:

Building Performance may be defined as:

A set of measured responses of a building, as a system, to anticipated and actual forcing functions

where:

- ***Measured responses are valid and reliable parameters and values of human response, occupant exposure, system performance, and economic performance***
- ***Forcing functions are known physical or social forces that are likely to perturb the building system, to which the response functions occur.***

Background

- ***Why is UFAD Popular?***
  - ***If power, communications and other systems are floor based, placing HVAC under the floor seems a logical additional step.***
  - ***Using the space under the floor as a pressurized plenum rather than using overhead or underfloor ductwork seems attractive:***
    - ***Lower cost of sheet metal.***
    - ***Easier coordination between HVAC and other systems.***
    - ***Less labor to change supply air distribution when changes are made to the occupied space.***

Background

- *Why is design for UFAD an issue?*
  - *Concerns include:*
    - *Latent cooling capacities*
    - *Accumulation of particulate matter and moisture*
    - *Air leakage in pressurized floor plenums*
    - *Testing and Balancing (TAB) difficulties*
    - *Compartmentalization and Isolation during incidents*
    - *Transient heat transfer through plenum surfaces*
    - *Energy consumption*
    - *Lack of Commissioning Procedures for UFAD*

Background

- ***Why is Design for UFAD an Issue?***
  - *GSA has over 8,000,000 square feet of space in use, in use and under construction using UFAD.*
    - *In recently completed GSA buildings, the UFAD has not performed as expected.*
  - *The private sector has approximately 100,000,000 square feet in use, in design, and under construction using UFAD.*
    - *In a recent survey of private sector buildings, mixed reactions to the performance of UFAD systems was reported (in NCEMBT report to DOE).*

Need for Air Tightness

- *UFAD Plenum typically at 0.05 – 0.10 in. wg (12 – 25 Pa)*
- *CAD typical leakage of 1.5% @ 0.5 in. wg (125 Pa)*
- *Both systems provide ~ 1.0 cfm/ft^2 floor area*
- *Air Leakage affects comfort, energy, materials, safety, security*
- *Goal is ≤ 10% air leakage at design s.p.*

View of Courthouse Library with diffusers taped for testing

Two Categories of Air Leakage

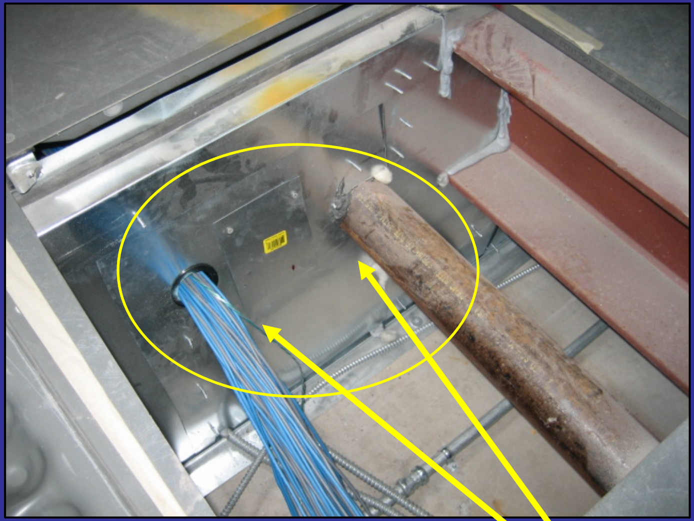
- ***Category 1: General Construction Leaks***
  - *From plenum into other building cavities*
  - *Air is wasted or short cycled to Return Air or to Conditioned Spaces*

- ***Category 2: Product Leaks***
  - *Through RAF into Conditioned Spaces*
  - *Pathways include:*
    - *Panel and edge joints*
    - *Diffusers losses*
    - *IT/Power Boxes in Floors*

Category 1 Examples

- *Leakage around and in annular spaces in conduit:*

Conduit through floor slab to Space below UFAD



Conduit through plenum bulkhead

Category 2 Examples

Leaks of conditioned air from the plenum through components of the raised access floor system:

- Floor panel seams and edge closures
- Electric power connection and outlet service units
- Communications and data service units
- Air diffusers that do not close tightly

Methods of Air Leakage Testing

- **Mockup Test** – Prior to permanent construction
- **Permanent System Test** – (Substantial Completion)
- **Smoke Test** – to locate air leakage pathways

Mockup Tests

- Prior to Permanent Construction
  - 1,000 – 4,000 ft^2 area
  - Determine Cat 1 and 2 air leakage rates at design s.p.
  - Use separate fan
  - Establish steady-state s.p. before obtaining data

Permanent Systems Tests

- Substantial Completion of Zone
  - AHU Zone – up to 25,000 ft^2
  - Verify Mockup tests results or
  - Determine Category 1 and 2 leakage rates
  - Use actual AHU with VFD at design s.p.
  - Establish design steady-state s.p. before obtaining data

One of several Thermostatic zones Served by AHU

Typical AHU With VFD and Coil bypass for UFAD

Smoke Tests

- *Purpose: to locate air leakage pathways*
  - *Conduct during Mockup Tests*
  - *For Permanent Systems Tests, conduct and purge during unoccupied periods*
  - *Use “theatrical” smoke generator (non-toxic)*

Theatrical smoke generator

Smoke induced into calibrated fan inlet

Plenum Air Leakage

- Results of Air Leakage tests showed plenum leakage rates of 30 – 200% of design airflow rates at plenum static pressures of 0.07 in. w.g. (17 Pa)

View of Library in FCH-1 with diffusers taped for testing

Cat 1 Air Leakage (FCH-2)

- *First Mockup (22-24 Feb 06):*
  - *70% Air Leakage in Initial Tests*
  - *35% after first mitigation*
  - *16% after second mitigation*
- *Second Mockup (subsequent date):*
  - *35% Air Leakage in Initial Tests*
- *Third set of tests were report at approximately 20%*

Category 1 and 2 Air Leakage (FCH-1)

- ***First Series of Tests (Oct-Dec 05):***
  - *Initial range of Cat 1+2 air leakage rates was 34% (AHU 6 – 4th floor) to 68% (AHU 5 – 3rd floor)*
  - *After remediation, range was 26% (AHU 1 - 1st floor) to 59% (AHU 7 – 4th floor)*
- ***Second Series of Tests (May 06):***
  - *AHUs 2 and 3 – Second Floor*
  - *Cat 1+2 was 43% of design airflow rate at 0.07 in. wg*
  - *Cat 1 was 32% of design airflow rate at 0.07 in. wg.*

Taped floor diffuser on carpet

Sealed pipe and cable penetrations through RAF

Column and piping penetrations through RAF

*Summary of Air Leakage Findings**

Type of Facility	Dates of Tests	Cat 1	Cat 2	Cat 1+2
FB-1	7-06	52	8	60
FB-2	7-06	43	2	45
FB 3	8-06	40-200	NA	NA
FB-4	11-06	44-48	NA	NA
FCH-1	11-05 to 9-06	NA 32	NA 11	34-68 43
FCH-2	11-05 to 5-06	70-16 35	NA NA	NA NA

*Percentage of design airflow rate at 0.07 in. w.g.

GSA Air Leakage Criteria for UFAD Plenums at design static pressure (e.g., 0.07 in. wg or 17.5 Pa)

Test	∑ Air Leakage (Category 1 + 2)	Category 1
Mockup	0.1 cfm/ft^2 floor area	0.03 cfm/ft^2 floor area
Building Floor Plenums	0.1 cfm/ft^2 floor area or 10% of design supply airflow rate, whichever value is smaller	0.03 cfm/ft^2 floor area or 3% of design supply airflow rate, whichever value is smaller

Conclusions (1)

- Air leakage consequences are significant:
  - ✓ Air leakage is an architectural design and general construction Issue.
  - ✓ Construction of an airtight plenum requires strict coordination of ten to twelve trades, and special construction techniques that have not been developed
    - ✓ Concrete
    - ✓ Masonry
    - ✓ Drywall
    - ✓ Millwork
    - ✓ Sealant and joint specialists
    - ✓ Carpenters
    - ✓ Sheet Metal
    - ✓ Plumbing
    - ✓ Electrical
    - ✓ Communications
    - ✓ Etc.
  - ✓ Predictions of air leakage are unreliable: testing is required at this time.
  - ✓ Air leakage testing results indicate GSA goal has not been met.

Conclusions (2)

- *Thermal mass of slab is a major issue for energy and control*
- *Heat and moisture transmission/condensation in the plenum is also a major issue*
- *Life safety codes need to address UFAD systems*
- *Drainage of water from piping leaks or fire sprinkler discharge is a major issue*
- *Access to underfloor equipment is difficult at best*

Conclusions (3)

- ***Integrated design is essential between architects, engineers***
- ***Testing procedures must be developed by coordinated effort among building code officials, and Standards writing organizations, such as ASTM, ASHRAE, NFPA, ASCE, IEEE, UL, SMACNA, ETC.***