Underfloor Air Distribution Systems: Design and Operational Lessons Learned

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James E. Woods, Ph.D., P.E.,
Fellow ASHRAE
Executive Director, BDRI

John Hamilton
Chief Operating Officer
Testing, Adjusting and Balancing Bureau
www.tabbcertified.org

The Building Diagnostics Research Institute, Inc.
www.buildingdiagnostics.org
jewoods@buildingdiagnostics.org

Purpose

To present lessons learned from evaluations of Underfloor Air Distribution (UFAD) systems as alternatives to Conventional Air Distribution (CAD) systems.

Fundamental Objectives of Environmental Control

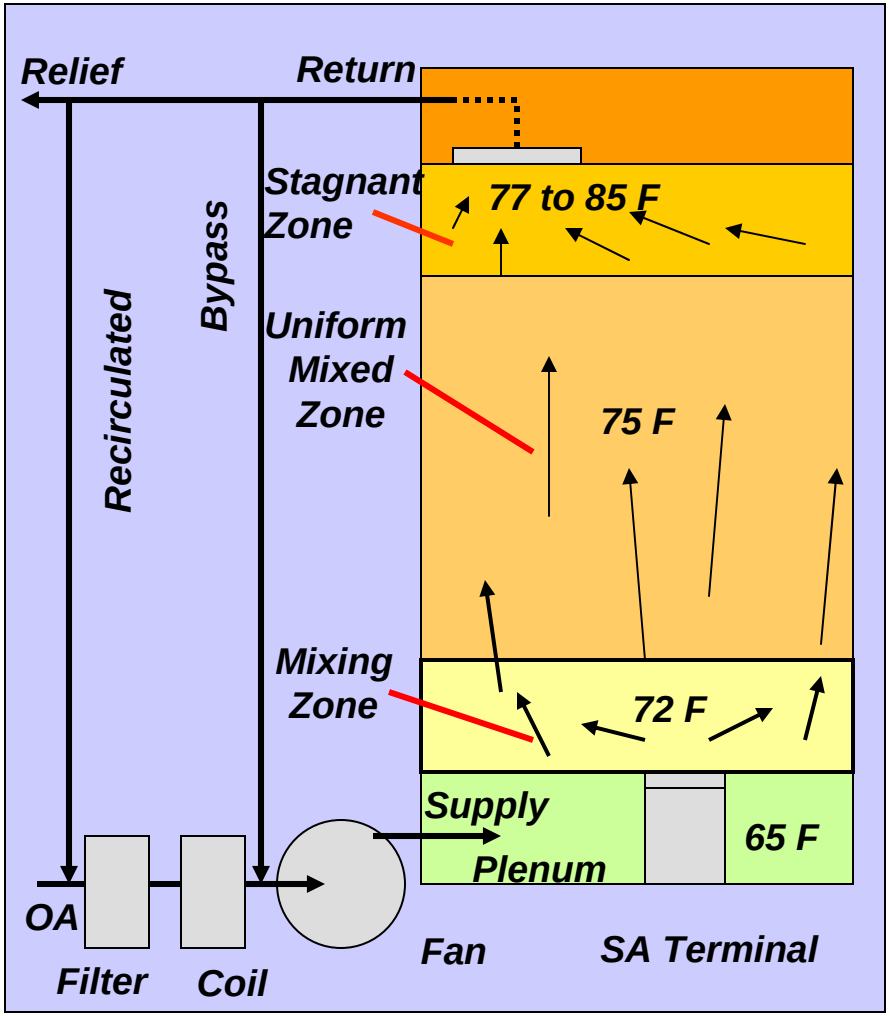
- ***Prevent adverse health and safety effects during Normal and Extraordinary Conditions***
- ***Provide for desired conditions:***
  - ***Human Response***
  - ***Occupant Performance***
  - ***Productivity***
- ***Achieve by simultaneous control of exposure parameters:***
  - ***Thermal***
  - ***IAQ***
  - ***Lighting***
  - ***Acoustics***

Brief History of UFAD Systems

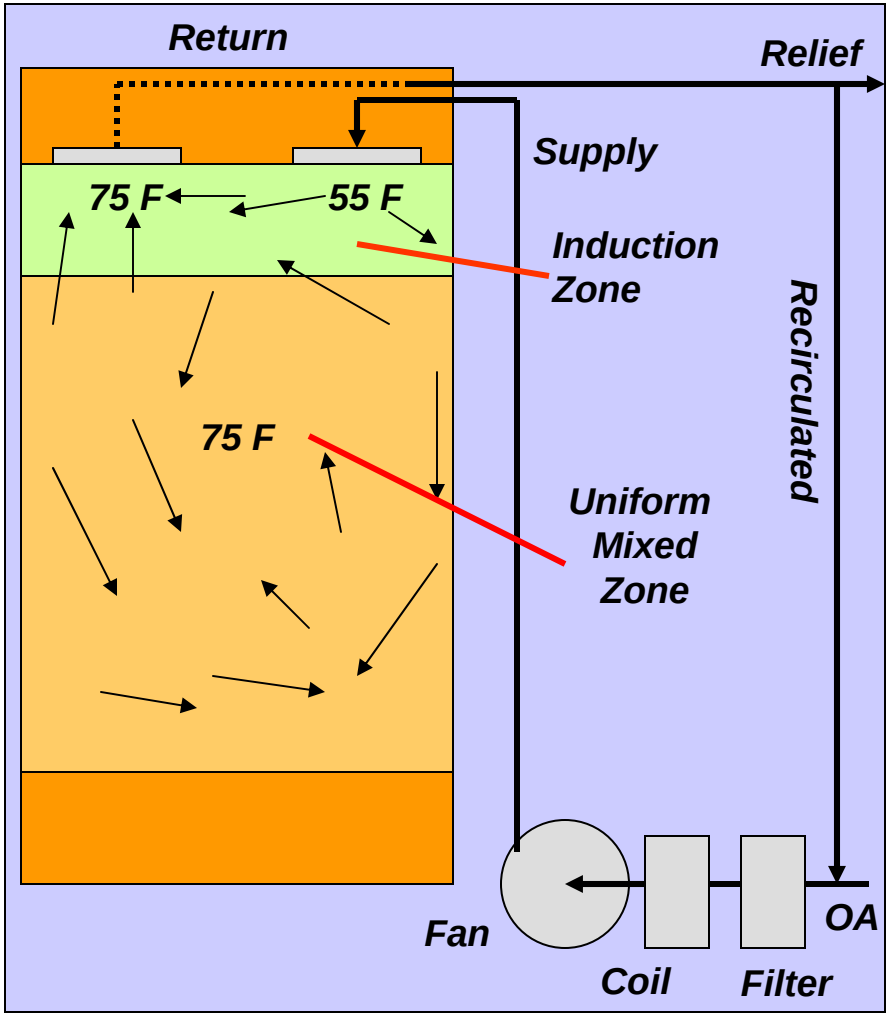
- **Prior to 1900s**
  - *Heating and ventilation (Monticello, Houses of Parliament, Chicago Auditorium, Metropolitan Opera House).*
- **Cleanrooms and Computer Spaces (1960s - current)**
  - *Cooling of single-zone, constant sensible loads (floor return for contamination control, floor supply for thermal control).*
- **Flexible Workspaces (1990s - current)**
  - *Heating, cooling, and ventilation of multiple interior and perimeter zones with various loads.*

UFAD and CAD Systems

UFAD (TM or VD)



CAD



Types and Variations of Current UFAD Systems

Supply Air

Positive Pressure Plenum

- Unducted, "Push" Type
  - ✓ Diffusers & Grilles
  - ✓ VAV and FPVAV Units

"Neutral" Pressure Cavity or Plenum

- Ducted to VAV or FC Units (C)
- Unducted, "Pull" Type (P)
  - ✓ Fan-powered VAVs
  - ✓ Fan Coil Units
  - ✓ Fan-powered diffusers & Grilles

Return Air

Ceiling Plenum or Cavity

- Ducted (C)
- Partially Ducted (P)
- Unducted (P)

High Sidewall Grilles

- Ducted or unducted to Ceiling
- Ducted to VAV or FCU in Floor

Floor Plenum

- Ducted from Kiosk to VAV or FCU
- Ducted from Grille to VAV or FCU
- Membrane to separate floor plenum for supply and return

Basis for Lessons Learned

- ***From TABB series of interactive seminars with architects and engineers:***
  - ***~50% of the 600 participants were design engineers.***
  - ***UFAD comprised ~ 2% of current design work.***
  - ***Hundreds of buildings with UFAD now exist (several million ft^2).***
  - ***Performance of UFAD highly dependent on close communications with the design architect from earliest conceptual stages of design.***
  - ***Concerns included:***
    - ✓***Thermal loads in occupied spaces and plenums.***
    - ✓***Air leakage in plenums and potential consequences.***
- ***From observations of operational facilities.***

Two Fundamental Principles

1. **The Maslow Hierarchy of Needs (1968):**
    1. Physiological
    2. Safety and security
    3. Belonging
    4. Esteem
    5. Self-actualization

Health and Safety Outcomes
Learning and other Performance Outcomes

2. **The WHO definition of Health (1946):**

    "A state of complete physical, mental, and social well-being, and not merely the absence of disease or infirmity."

What physiological, psycho-sociological, physical, and performance outcome measures are related to these two Principles?

Evaluation Criteria

- ***Human Responses:***
  - ***Frequency or number of discomfort or dissatisfaction complaints.***
- ***Exposures:***
  - ***Thermal, Lighting, Acoustic, Air Quality and values expected to result in acceptable human responses.***
- ***System Performance:***
  - ***Capacities and control strategies to ensure acceptable exposures during normal and extraordinary conditions.***
- ***Energy and Economic Performance:***
  - ***Energy consumption rates, first costs, life cycle costs and benefits to achieve acceptable system performance.***

Characteristics of Facilities

- ***7 Site Visits with UFAD***
  - *1 Educational Facility*
  - *4 Private Sector Office Buildings*
    - *3 Owner Occupied (designer leasee in 1)*
    - *1 Speculative (resold once)*
  - *2 Public Sector*
    - *1 Federal Courthouse*
    - *1 Federal Office Building*

What are the Performance Issues?

Architectural and Structural:

- *Incremental RAF heights and clearances*
- *Cable Management and Flexibility*
- *Structural and seismic impacts*
- *Vibrations and acoustics*
- *Air leakage and water control in plenums*
- *Fire, safety and security*

Thermal and Operational:

- *Thermal and IAQ zoning*
- *Psychrometrics (dew pt control)*
- *Plenum pressure control*
- *Control strategies for energy efficiency (night set back)*
- *Construction Quality*
- *TAB and Commissioning*
- *Long-term Performance*

Findings (1)

- *Objective data difficult to obtain:*
  - *Owners and designers are vested*
  - *Operators may share fixes*
- *Air leakage is problematic: up to 70% of supply airflow.*
  - *In the private sector offices, air leakages were reduced by remediation after initial occupancy, but data that quantified the resultant air leakage rates were not available.*
  - *Even after remediation, discomfort complaints associated with cold air were reported, especially at the floor level during light thermal load conditions.*

Findings (2)

Thermal loads were different than expected:

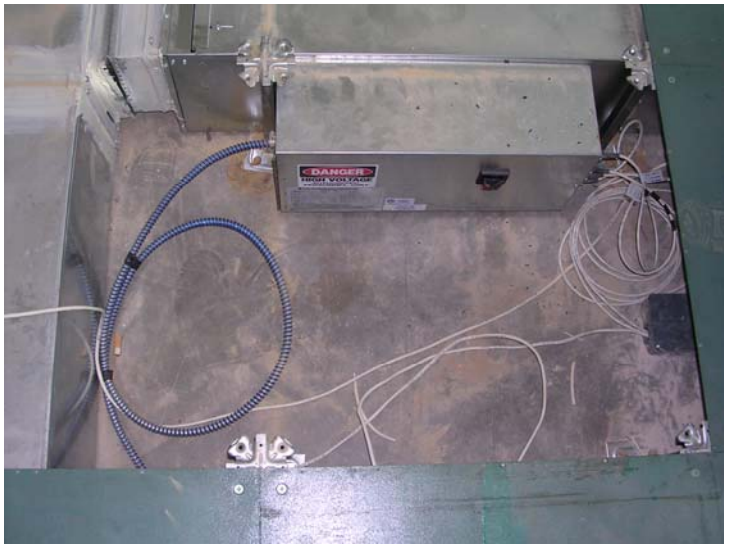
- ***In the occupied spaces, stratification did not develop:***
  - ***Temperature differences as low as 3 F between air diffusers at the floor and return air grilles at the ceiling of interior zones.***
  - ***Resultant subnormal room temperatures under minimum load conditions manifested in cold discomfort complaints.***
- ***In the supply air plenums, the transient heat transfer rates through the massive concrete slab floors and perimeter walls were not considered:***
  - ***Large deviations in plenum air temperatures of as much as ± 5 F and static pressures of ± 0.10 in. w.g.***
  - ***Loss of control especially after night set-back, and energy waste.***

Findings (3)

- Fire, safety, security, and smoke management issues not considered:
  - Detectors located in Return Air to AHU.
  - No Emergency Power-Off Switches.
  - Egress issues not considered.
  - First-response safety issues not considered.

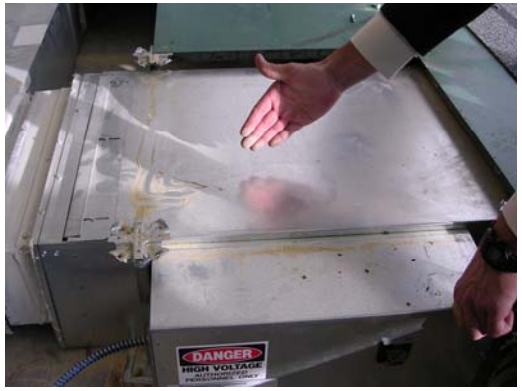
Findings (4)

- Moisture, mold and other contaminants within the supply air plenums were apparent.
  - At two of the sites, signs of rodent infestation were found in the supply air plenums
  - At one of the sites revealed moisture and suspected mold stains on the inside surface of a perimeter wall of the plenum.



Findings (5)

- *Energy consumption is problematic:*
  - *Utility bills not available at 3 of 4 private sector and 1 public sector buildings*
  - *Annual consumption 2-3 times higher than expected at 1 private sector and 2 public sector buildings (e.g., 80 – 120 KBtu/ft^2-yr)*
  - *Major contributing factor is need for reheat.*
- *First costs vary widely from private sector offices to monumental governmental buildings.*



Fundamental Lesson Learned: RAF

The primary purpose for RAF in new or renovated facilities is to provide horizontal pathways that enhance the flexibility of power, data, and communications systems:

- ***This purpose can be realized with or without the potential secondary benefits of UFAD.***
- ***The selection of RAF as an alternative to conventional flooring and suspended ceiling systems demands supplemental design resolution regarding structural, acoustic and vibration, fire and smoke management, safety, and security issues.***

Fundamental Lesson Learned: UFAD

Adapting RAF for UFAD systems to achieve HVAC performance requirements demands supplemental design and construction coordination regarding multi-discipline and multi-trade resolution of:

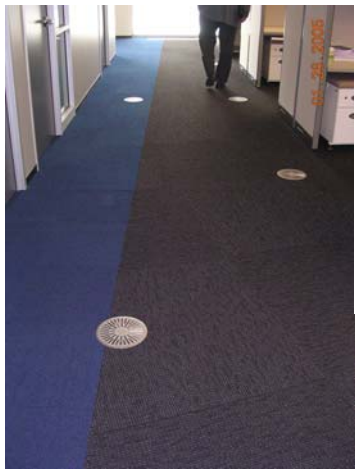
- ***Incremental effects on the RAF requirements on structural conditions; fire and smoke management; safety and security.***
- ***Additional effects of air leakage, thermal loads, moisture detection, room air distribution, and indoor environmental control issues.***

Overall Lesson Learned: Design Integration

- *Incorporation of RAF, with or without UFAD, to achieve overall performance requires an early commitment to integrated design, beginning at planning and preliminary concept stages.*
- *If a pressurized plenum design is to be used rather than a cavity design with ducted supply air, the plenum must be designed, constructed and maintained as an airtight enclosure that also provides for horizontal cable management; occupant satisfaction with thermal, air quality, and acoustic conditions; structural stability; fire and smoke management; security and physical safety.*
  - *The pressurized plenum design involves many general construction materials not normally considered to perform in an airtight configuration.*
  - *Therefore to achieve the performance integrity, the design and construction processes must integrate the structural, mechanical and electrical performance requirements with the architectural features of the facility.*

What are the Resolutions?

- *Early Commitment to Integrated Design:*
  - *Major Decisions by Final Conceptual Design*
  - *UFAD requires integration of architectural and HVAC decisions*
- *Construction Integration of 8-10 trades:*
  - *masons, steel, drywall, carpenters, sheet metal, pipe fitters, electricians, fire protection, controls contractors*
- *Scheduling and Quality Control*
- *TAB and Commissioning*
  - *Testing for Air Leakage in Mockup*
  - *Testing for Air Leakage before TAB*
- *Training of O & M Personnel*



What are the Conclusions? (1)

- **Functional Areas determine Appropriateness of UFAD:**
  - **Generally suited for areas such as:**
    - General open office areas, computer rooms and other information technology spaces, training and conference areas, exhibit spaces with light rolling loads.
  - **Generally not suited for areas such as:**
    - Toilets, showers, kitchen and food prep areas, child care centers, public lobbies and atria, wet laboratories, secured areas, response spaces, fire stairs, central equipment rooms, central storage and trash rooms, and loading docks.

What are the Conclusions? (2)

- Plenums are complex architectural elements that must provide long-term performance:
  - Wire and cable management
  - Owner flexibility
  - Air distribution for thermal, pressurization and IAQ control
  - Structural, vibration and acoustic requirements
  - Safety and security requirements

What are the Conclusions? (3)

- **Two fundamental performance issues must be addressed:**
  - **The slabs have significant thermal inertia that affect control strategies and energy efficiency.**
  - **Plenum air leakage must be minimized (i.e., to within 10% of supply airflow at operational static pressure for the total of Category 1 and 2 leaks):**
    - ✓ **Category 1 Leaks through general construction.**
    - ✓ **Category 2 Leaks through raised floor products and accessories.**

What are the Conclusions? (4)

- **Plenum safety issues must be addressed:**
  - **Water detection and drainage**
  - **Early smoke detection in the plenum**
  - **Emergency Power Off (EPO) station**
  - **Structural damage or collapse**
    - ✓ **Seismic zones**
    - ✓ **Rolling and other "live" loads**
  - **Physical protection of occupants when panels are open**

What are the Conclusions? (5)

- ***Economic analysis must include a <u>Benefit-Cost</u> analysis compared to CAD:***
  - ***Benefits (e.g., thermal and IAQ, flexibility, sustainability)***
  - ***Risks (e.g., health, safety, security)***
  - ***Costs (e.g., first costs, life-cycle costs)***

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Specing TABB Benefits

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- HVAC system running at the optimum performance level