What Real-World Experience Says About The UFAD Alternative

What can we learn from recent UFAD field experiences, as reported in the literature? This 12-page article provides objective and measurable criteria with which the performance of UFAD and conventional air distribution systems can be evaluated and compared—in the real world—during design and occupancy.

By James E. Woods, Ph.D., P.E., Fellow ASHRAE

Within the last few years, underfloor air distribution (UFAD) systems have become popular design alternatives to conventional air distribution (CAD) such as overhead, sidewall, unit ventilator/fan coil and packaged unit systems for thermal and ventilation control. A summary of types and variations of current UFAD systems is shown in Table 1.

UFAD systems and concepts are not "new" or "cutting edge." Systems that supply air through plenums to floor grilles and registers have been designed, installed, and operated in residences, public assembly buildings, concert auditoriums, and other commercial buildings for nearly two centuries. Notable buildings incorporating UFAD include Thomas Jefferson's Monticello (late 1700s), Houses of Parliament (1800s), Louis Sullivan's Auditorium in Chicago (1890), and the Metropolitan Opera House prior to its destruction by fire in 1890 (see note 1 on page 14).

Moreover, raised floors in computer rooms and data processing facilities have served as plenums and floor cavities for ducted and unducted supply air to computer cabinets for more than 30 years (see note 2).

Thus, historic experience has guided designers, contractors, and operators of these facilities regarding UFAD system benefits—and limitations.

Recently, underfloor systems have been the subject of renewed interest. This

continued on page 4

Table 1

Types and Variations of Current UFAD Systems

Supply Air	Return Air
Positive Pressure Plenum Unducted, "Push" Type ✓ Diffusers & Grilles ✓ VAV Units	**Ceiling Plenum** ➢ Ducted ➢ Partially Ducted ➢ Unducted
"Neutral" Pressure Plenum ➢ Ducted to VAV or FC Units ➢ Unducted, "Pull" Type ✓ Fan-powered VAVs ✓ Fan Coil Units ✓ Fan-powered Diffusers and Grilles	**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

UFAD Alternative *continued from page 3*
development has come to the fore in an almost-indirect manner. Employers and workers seek more flexible work environments. Rapid changes in the ways power and telecommunication services are provided to workspaces—and the frequent moves, adds, and changes to systems already in place—enhanced the market for accessible raised floor systems.

With this underfloor space newly made available, the opportunity for using it for thermal and ventilation control has piqued the interest of designers, contractors, and HVAC manufacturers. Basic schematics of UFAD and CAD systems are shown in Figure 1.

Revisiting UFAD

Reports of UFAD benefits in published laboratory findings, publicized case studies, and suppliers' marketing literature have stimulated a new popularity for these systems. As a result, the design of millions of square feet of office space in the U.S. and elsewhere includes underfloor air systems, according to estimates assembled late in 2002 (by this researcher—see acknowledgements).

However, designers, contractors, facility managers, and others are also expressing concerns regarding the long-term performance of these systems.

Is UFAD "the answer"—or are there legitimate questions about this air distribution approach that are yet to be fully explored? This article seeks to provide an overview of recent field experience, as reported in the literature. Details on the approach used:

1. A preliminary literature search sought to identify physical characteristics of facilities with UFAD systems in place. *Note*: The search also sought to identify issues that could be pursued in subsequent research;

2. A basic set of evaluation and classification criteria used in building diagnostics (see Table 3) was defined. These criteria would be used in comparison with real-world UFAD system performance (see page 8 sidebar for details).

3. Based on a procedure used previously (see note 4), a keyword list was developed. This list was employed—via a Web search engine—to do an extensive search of the technical and marketing literature. The goal was to uncover real-world comparative performance of UFAD and CAD systems during occupancy.

4. These results were analyzed and compared with the evaluation criteria, discussed and interpreted, and conclusions were drawn and recommendations presented.

James E. Woods, Ph.D., P.E.., is an ASHRAE Fellow and the Executive Director of the Building Diagnostic Research Institute (www.buildingdiagnostics.org). Recognized as one of the nation's most knowledgeable engineers and scientists on indoor environmental equality, Woods chaired the ASHRAE Presidential Study Group on Health and Safety Under Extraordinary Incidents.

BRDI and Woods work frequently with the National Energy Management Institute (www.nemionline.org) and the Testing, Adjusting, and Balancing Bureau (www.tabbcertified.org).

Research Findings

Preliminary Search

The preliminary search yielded 13 facilities built over the past 15 years in which UFAD systems were installed (see notes 5, 6, and 7). Roughly half had UFAD systems installed during new construction; all but one of the 13 were owner-occupied. The facilities ranged in size from 20,000 to 290,000 square feet.

However, information on what percentage of each building's floor area that was served by UFAD systems was not readily available. In one case, the percentage was determined to be approximately 33%; in another, only interiors had UFAD systems installed; and in another, 80% of the floor area had UFAD systems (see notes 5 and 6).

A preliminary conclusion based on the preliminary search: Facility floor area is *not* a sufficient characteristic to estimate UFAD system impact on total building performance (i.e., energy efficiency or cost effectiveness).

Gaps In Available Data

Further, the 13-building sample assembled in the preliminary search was not representative of North American climatic conditions and thermal loads. Nine buildings were located in western United States and southwestern Canada—areas without high summer dew-point temperatures or latent loads.

Perhaps as a result, neither external nor internal sensible or latent loads were reported for these facilities; nor were humidity and moisture control identified as an issue.

In one case, perimeter zones on each floor were served by separate single-zone variable air volume (CAD) systems to offset heat loss through exterior walls (see note 7).

All cases identified in the search had ducted supply air to floor plenums. In three cases, pressurized air from the plenum was discharged at 63 F through floor diffusers in the interior zones and two-pipe fan coils delivered thermostatically controlled supply air to floor diffusers in perimeter zones (see note 5).

One case had thermostatically controlled VAV boxes supplying the unducted plenum at 65 F in perimeter and interior zones. In three cases, the plenum was pressurized and provided supply air temperatures that ranged from 55 to 70 F through reheat coils.

Note: For the other cases in the preliminary search, information was not found on methods for supplying air to the plenums or for controlling supply air temperatures.

As psychrometric processes were not reported for any of the 13, psychrometric comparisons with CAD systems were precluded.

Field Investigations

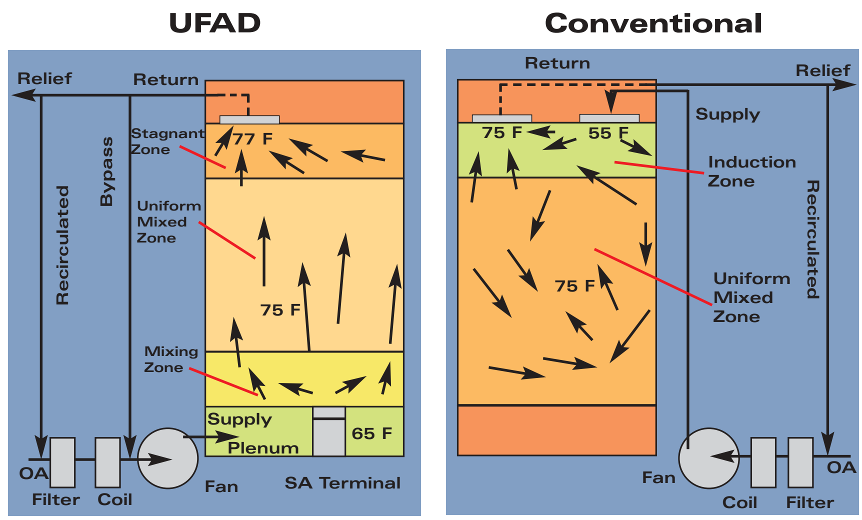
Field investigators (see Note 5) evaluated seven of the 13 cases—buildings occupied for up to five years. Findings include:

- thermal and draft complaints were reported in four of the seven cases;
- noise complaints (due to exposed ceilings) were reported in one case;
- underfloor dirt was reported as a problem in one case, especially in the processing area; and dirt in the diffusers was a reported problem in two cases (i.e., occupant complaints and sticking dampers in the floor diffusers); and
- air distribution and TAB (i.e., testing, adjusting and balancing) problems were noted in six of the seven cases.

Additionally, while energy and cost savings were one reason for the inclusion of UFAD in these buildings, the field investigations did not reveal *any* evaluations of energy usage or actual operating costs. Moreover, neither exposure conditions nor occupant responses were correlated by the field investigators to intended or actual energy savings or cost-effectiveness in these cases. The dearth of energy use and cost information precluded a valid determination in this preliminary search of UFAD system energy and cost effectiveness.

Figure 1

Underfloor & Conventional Air Distribution Systems



In three cases, wiring and cabling within the plenums were required (by code) to be contained in hard or flexible conduits—restricting the potential flexibility of the raised floor systems. Code compliance was not mentioned in the other cases in the preliminary literature review.

Subsequent Search

With the use of Google.com, 2,990 citations were found on UFAD systems. These citations included scientific and technical papers, system manufacturer Web sites, and many citations that were of little value.

Analysis of more than 500 citations yielded ***nine*** general review articles on UFAD and related systems that provided a balanced representation of benefits and concerns.

Of the total 4.7 million non-residential, non-industrial buildings in the U.S. (see note 8), the number of buildings with UFAD or task air systems has been estimated to range from 130 (see note 9) to more than 200 (see note 10). From the larger list, 65 occupied installations were explicitly identified as having ducted or unducted UFAD systems.

Here's a brief analysis of the 65-building sample:

- they ranged in size from 2,000 to 3 million square feet;
- approximately 30% of their UFAD systems were installed during new construction;
- eight were associated with industrial, rather than office-type work; and
- seven were among the 13 facilities found in the preliminary search;
- 33% were located in the U.S. West and Northwest, areas with light to moderate latent heat loads;
- 33% were located in the Midwest and 14% on the East Coast, areas with large sensible heat losses in winter and large sensible and latent heat loads in summer; and
- 18% were located in the Southeast, an area with light to moderate sensible heat losses in winter and large sensible and latent heat loads in summer; and
- initial occupancy dates range from 1984 to 2002.

continued on page 6

UFAD Alternative *continued from page 5*

Unfortunately, the percentage of each building's floor area served by UFAD systems was—once again—not available. A comparison of the facility characteristics found in the preliminary and subsequent literature searches is shown in Table 2.

Evaluation of Occupant Responses

None of the literature reviewed addressed the prevalence in these UFAD-served buildings of sick building syndrome (SBS) or building-related illnesses (see classifications P1 or P2 in Table 3). However, notable perceptions of occupant discomfort (see classification P3) in UFAD systems were reported pertaining to:

- thermal discomfort (see notes 5, 10, 11, and 12);
- lack of air movement or drafts (see notes 5, 10, 11, and 12);
- noise (see notes 5 and 10); and
- dust and dirt (see notes 5 and 10).

Complaints about poor air quality or lighting discomfort—two major contributors to occupant dissatisfaction in the workplace—were not revealed in this literature search.

Evaluation of Occupant Exposures

As reported in the literature reviewed, non-compliance with exposure criteria in UFAD systems (see classification M1 in Table 3) focused on thermal conditions, including

- excessive temperature ranges (see note 5);
- vertical temperature gradients (see notes 10 to 13);
- high relative humidities (see notes 10 to 12); and
- excessive or insufficient air movement (see notes 5, 10, 11, 12 and 13).

Concentrations of particulate and gaseous contaminants in occupant breathing zones were reported as typically less in UFAD than found in CAD systems and within acceptable exposure criteria (see notes 10 to 13).

However, occupant exposure to concentrations of contaminants emitted from sources *below the breathing zone*—including emissions from the floor plenum—were more likely to be elevated within UFAD compared to CAD systems (see notes 10, 12, and 13). These findings have important implications with regard to control of moisture and mold, precursors of fire/smoke (e.g., fumes), liquid and particulate spills, and intentionally released chemical, biological, or radiological agents (notes 10, 15, 16, and 17).

An overview article (Stanke—see note 14) also expressed concerns with these exposure parameters. Other concerns:

Noise levels were reported both higher and lower in UFAD compared to conventional systems—varying with diffuser placement and characteristics, and the presence of sound-absorbing materials such as acoustic ceiling tiles (see notes 5 and 10).

Although ***lighting designs*** and associated thermal loads may well—as claimed—be an advantage for UFAD over CAD systems, lighting level and quality measurements were not reported in the literature reviewed.

Table 2

Characteristics of Occupied Facilities with UFAD Systems, as found in the Preliminary and Subsequent Searches.

Characteristic	Preliminary Search	Subsequent Search
Number of facilities	7 [5]	65 (including 7 of the 13 from the preliminary search) [10]
Size range of facilities (10^3 ft^2)[a]	20 – 290	2 – 3,000
Geographic Location (% of total)		
West	69	33
Midwest	15	33
Northeast	15	14
South	-	18
Age range of facilities	1990 – 2000	1984 – 2002
Percent new construction	50	30

Notes: **a.** Percentages of floor area in each building served by UFAD systems are not known.

Evaluation of System Performance

Two difficult issues regarding non-compliance with system performance criteria (see classification M2 in Table 3) were revealed in the literature reviewed. Unfortunately, quantitative measures were not available. These issues were:

Insufficient Capacities—UFAD systems tend to have insufficient capacities to remove the latent heat loads, and to have difficulty in controlling relative humidity without causing thermal discomfort complaints—especially in hot humid climates (see notes 10 and 12). One of the reasons for this insufficiency is the lack of real-world experience in calculating the appropriate components of sensible and latent loads in the two compartments in the occupied spaces of UFAD systems (i.e., "uniformly mixed" and "stagnant" compartments) as compared to the one compartment (i.e., uniformly mixed) in CAD systems (see notes 13 and 18).

Insufficient Controllability—the installed systems' control of supply air temperatures and flow rates tended to have insufficient control flexibility and sensitivity to simultaneously provide acceptable thermal and air quality exposures in occupied zones during various part-load conditions (see notes 5 and 10).

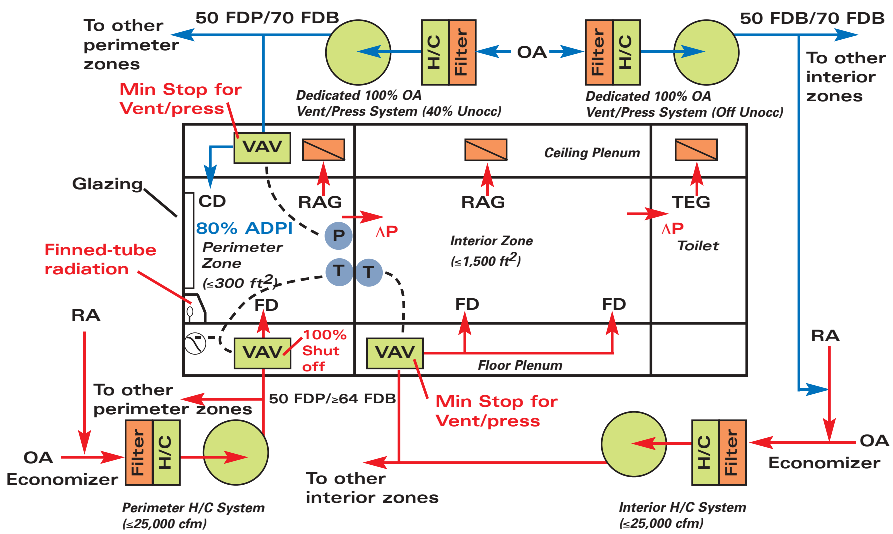
To overcome the sensible and latent heat- deficiencies in some cases, separate dehumidification systems were installed for UFAD systems—as were supplemental heating systems in perimeter zones (see notes 10 and 12). Stanke's overview article (note 14) also expressed concern with these system parameters. An example schematic of UFAD systems specified by GSA (see note 16) to provide acceptable thermal, air quality, and energy efficient control is shown in Figures 2 and 3.

The Need For Control

Other control issues associated with unducted or partially ducted UFAD systems have also been reported (see notes 5 and 10) or expressed (see note 14), including:

Figure 2

Example Schematic of UFAD Systems Specified by GSA: Thermal, Ventilation, Pressurization Zones



Condensation and mold growth can occur on concrete plenum floors when the floor plenum's supply air temperature is below 63 F. To control this condensation in one case, the slab temperature was controlled to remain 4 F above the supply air's dew point temperature (see note 10).

Dirt and mold accumulation in floor plenums was associated with inadequate cleanup when a construction project reached the period of "substantial completion." Additionally, reports noted the lack of cleanup after changes were implemented due to churn requirements (see notes 5 and 10). The remedy: More-frequent and more-rigorous plenum inspections and cleanups were necessary (see note 10).

Dirt and liquid accumulation in floor-mounted diffusers can cause their control dampers to cease functioning. Such occurrences are associated with contamination from the occupied zone (see notes 5 and 10). To control this accumulation, catch basins—which hold approximately 5.5 fluid ounces—have been installed in the diffusers (see note 10).

Difficulties in maintaining pressurization control were reported, especially in "push-type" (i.e., pressurized) unducted and partially ducted UFAD systems (see note 10).

Typically, a 0.1-inch W.G. static pressure was recommended in the plenum to provide the required airflow rates through the floor diffusers (see note 10). Note that literature of more recent vintage recommends a maintained static pressure of 0.05 in. W.G.; however, performance under occupied conditions has not been reported (see note 18).

Seal all surfaces—in connection with the above pressurization problem, it is important to emphasize the need to seal—diligently—all surfaces in contact with the plenum. This not only maintains the static pressure, but also minimizes moist air exfiltration from the

continued on page 8

UFAD Alternative *continued from page 7*
floor plenum into wall cavities…where mold growth can occur.

Smoke control & environmental security—zoning and compartmentalization for fire and smoke control and for environmental security can be problematic with unducted and partially ducted UFAD systems (see notes 10 and 17).

Why? Floor plenum areas are as large as 15,000 square feet; plenum depths range from a minimum of 7 inches to more than 24 inches (see notes 9 and 10). For plenum depths of more than 18 inches, sprinklers in the floor plenum have been required (see note 10).

Further, some jurisdictions impose fire safety codes requiring placement of wiring and cabling in unducted or partially ducted UFAD systems in hard or flexible conduits (see notes 5 and 10).

Evaluation of Energy and Economic Performance

As indicated in Table 3, M3 classification indicates that the system does not comply with energy and economic criteria established before design and construction. The criteria are defined together with the building owner or other accountable person (see notes 3, 15, 16, and 17). Included in these criteria are:

- energy requirements, consumption rates, and costs;
- first costs for new construction and renovation; and
- operational and maintenance costs.

Absolute values for energy and economic criteria were not discovered in this review of the literature. Rather, relative costs of UFAD and CAD systems were ***projected . . . but not quantitatively substantiated*** (see notes 5, 6, and 10). Moreover, the types and performance characteristics of the UFAD and CAD systems being compared, *were not defined*.

For example, Loftness et al (see note 10) speculated that if the raised floors are cost-justified for "connectivity" or other reasons, the first costs of UFAD systems in ***new construction*** should not be more than for CAD systems.

Comment: This opinion was apparently derived from analysis of projected costs and **not** from actual cost analyses of the specific facilities. Moreover, this opinion omitted the following real-world costs (see notes 5, 19, and 20):

- callbacks to determine the nature of occupant complaints;
- the cost of the time needed to move furniture and furnishings before one can gain access to equipment in the floor plenum (for maintenance or troubleshooting);
- modifying and rebalancing the systems; and
- costs associated with impacts on occupant performance and productivity

Additional economic issues include:

Retrofit construction—the first costs of UFAD systems in retrofits were projected to be 5% to 20% higher than for CAD systems (see note 10). The literature review found no details or descriptions of retrofits or the types and performance characteristics of the compared UFAD and CAD systems.

Churn cost savings for UFAD compared to CAD systems were projected to range from $100 to $500 per person moved (see note 10). However, these projections neither described nor detailed the specific types and performance characteristics of the systems being compared or the accompanying code compliance issues—such as movement in plenums with wiring and cabling or fire and smoke control modifications (see notes 5 and 17).

Energy savings for UFAD compared to CAD systems were projected to range from 20% to 35% (see notes 10 and 18). However, these reports of such savings:

- did not account for the energy required to simultaneously maintain acceptable thermal and air quality exposure criteria;
- provided no actual energy consumption details or estimates for the dissipation of thermal and contaminant

continued on page 10

To Compare HVAC System Performance, Start With Classification Criteria

In the past decade, a series of published papers introduced and explored a useful concept. A relational set of evaluation and classification criteria could be, it was demonstrated, an integral part of a diagnostic procedure to evaluate building performance of buildings (see notes 3, 18, and 19).

In this relational set of criteria, objective and measurable parameters and corresponding values are defined in terms of *distinguishable connections* between human response, exposures, system performance, and economic performance.

With this study's goal of comparing UFAD and conventional air distribution system performance, the evaluation criteria set was modified. Specific parameters and values were added based on findings in the preliminary literature search (see notes 5, 6, 7, and 13).

As shown in Table Three, these criteria are classified in three categories:

healthy, which is the desired level of performance from the time of conceptual design, through detailed design, construction, and operations;

marginal, in which compliance with evaluation criteria is *not* achieved, but this non-compliance does not have direct health consequences to the occupants; and

problematic, in which compliance with evaluation criteria that have direct health consequences to the occupants is not achieved.

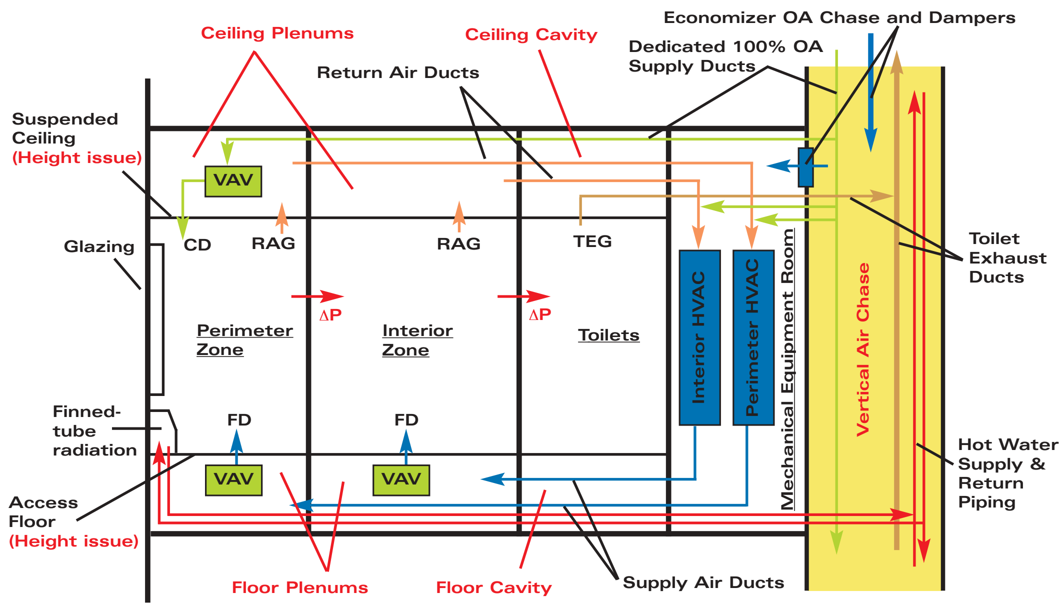
Table 3

Classification and Evaluation Criteria—Summary (adapted from sources presented in notes 3, 19 and 20)

Category	Classification Criteria	Evaluation Criteria
Healthy: A facility or area within it is considered healthy if it complies with all Evaluation Criteria. For this Protocol, *transparency* is considered a necessary but not sufficient criterion for a healthy classification.	**H2:** Compliance with all Evaluation Criteria in H1 plus compliance with occupant performance, environmental security, and productivity criteria (Enhanced Performance).	Occupant performance criteria should be similar for UFAD and Conventional systems. Preparedness of facilities to respond to an extraordinary incident should be similar for UFAD and Conventional systems. Benefit/Cost Ratios should be similar for UFAD and Conventional systems.
	H1: Compliance with all Evaluation Criteria, including M3 (Transparent Performance).	See M3 evaluation criteria.
Marginal: A facility or area within it is considered to have marginal performance if compliance with human response criteria is achieved, but non-compliance with exposure, system performance or energy and other facility cost criteria is detected.	**M3:** Compliance with all Evaluation Criteria except Energy and Economic Performance Criteria.	Building Energy Efficiency ≥70%, calculated in enthalpy units; and annual costs of operations and maintenance should be similar for UFAD and Conventional systems.
	M2: Compliance with all Evaluation Criteria except System Performance Criteria.	The *system capacities* shall match the peak or design loads to within ±10%, and shall maintain the set of exposure values within the specified limits at peak or design load conditions (e.g., approximately 10% of the year). And, the *system controls* shall reduce the part-load capacities to match the minimum or partial loads to within ±10%, and shall maintain the set of exposure values within the specified limits at minimum and partial load conditions (e.g., approximately 90% of the year).
	M1: Compliance with all Evaluation Criteria except Exposure Criteria.	***Thermal:*** 74 ±4F Operative Temperature, ≤5F vertical temperature gradient, 45 ±15% RH, ≤50 fpm in room. ***IAQ:*** ≤500 μg/m³ TVOC, ≤800 ppm CO_2, ≤50 μg/m³ PM10, Indoor to outdoor bioaerosol ratios ≤0.5 with similar I/O taxa. ***Lighting:*** 500 ±100 lux, 0.8 ±0.1 contrast ratio. ***Acoustics:*** 45 ±5 dB Room Criteria Curve.
Problematic: A facility or area within it is considered to have problematic performance if non-compliance with human response criteria is detected.	**P3:** Compliance with Personal-objective and Personal-perceptual Criteria, but non-compliance with Environmental-affective Criteria.	At least 80% of both short term and long term occupants (i.e., assigned occupants and visitors) in the area being evaluated shall consider the overall environment in the space as "acceptable."
	P2: Compliance with Personal-objective Criteria, but non-compliance with Personal-perceptual Criteria.	Not more than 20% of the occupants being evaluated shall report more than two symptoms characteristic of SBS that are alleviated upon leaving the area being evaluated, that recur upon re-entry, and that persist for more than two weeks.
	P1: Non-compliance with Personal-objective Criteria.	Not more than one occupant in the area being evaluated shall be documented to have building related disease or illness.

Figure 3

Example of plenums, cavities, and chases that are specified by GSA (see note 16).



UFAD Alternative *continued from page 8*
loads from the stagnant zones to the HVAC cooling coils;

• did not define the specific types and performance characteristics of the UFAD and CAD systems being compared; and

• did not appear to be based on *actual fuel consumption data.*

Interpreting The Findings

Comparing Apples & Artichokes?

The "Findings" section's results and analyses indicate that UFAD systems have become an attractive alternative to CAD systems, but that their application may be more limited than market literature might suggest.

Additional note: Field investigations of occupied facilities with UFAD systems and interviews with design professionals indicate that UFAD system performance is not always as beneficial as anticipated in the design phase; a situation that also occurs with CAD systems.

Part of the failure to meet these design expectations is due to the assumed oversimplified and mischaracterized performance of UFAD systems. *How so?* As reported in the literature, UFAD systems may:

• be ducted to floor diffusers or to desk outlets;

• consist of unducted floor plenums supplied by positively pressured ducts to damper-controlled floor diffusers or VAV boxes (i.e., "push-type" systems—see note 10);

• be supplied by neutrally pressured plenums to fan coil units or fan-powered VAV boxes in the floor plenums (i.e., "pull-type" systems—see note 10);

• be supplied by dedicated outside air-handling systems or conventional recirculation air handling systems(see notes 5, 10, 14, 16, and 18);

• be provided with "swirl," linear, or directional diffusers (see notes 5, 10, 14, and 18);

• be designed to provide only ventilation air (i.e., displacement ventilation) or supply air for ventilation and thermal control (see notes 5, 10, 14, and 18); and

• return air from through ceiling, sidewall, kiosk, or floor grilles (see notes 5, 10, 14, 16, and 18).

Each of these configurations has advantages and disadvantages. This adds up to the following conclusion:

An overall claim of generic superior performance by UFAD in comparison with CAD systems (which also have many variations)…is probably *meaningless.*

The findings from the field investigations revealed that occupant complaints (i.e., see P3 in Table 3) in buildings with a UFAD system are likely to be similar to those received from facilities with *any other system* that has been functional for a comparable period.

Further, while the literature review did not discover reports of building-related illnesses or symptoms associated with SBS (i.e., see P1 and P2 in Table 3), this author and others have investigated such complaints in UFAD systems. These findings also indicate that non-compliance with exposure (M1), system performance (M2), and economic performance (M3) criteria are *no less likely* to occur in various types of UFAD systems than in various types of CAD systems.

Redesigning HVAC Guidance

Recent modifications to design guidance documents for office and other non-residential buildings reflect the need to be more specific when analyzing available HVAC options.

Example: The LEED Rating System, Version 2.1, continues to encourage use of underfloor HVAC systems with individual diffusers for "non-perimeter spaces" (1 point); but no longer assigns points for this application for "perimeter spaces" (see note 15).

A detailed look at the current version of Chapter 5 of the "Facilities Standards for the Public Building Services"—from the U.S. General Services Administration includes these options (see Figure 2 and note 16):

1. It allows the use of ducted VAV systems or UFAD systems as design alternatives but requires 100% dedicated outside air systems for both alternatives.

2. It permits—for perimeter systems—an underfloor VAV air distribution system for cooling . . . supplemented with two-pipe, below-floor or above-floor perimeter hot water fin-tube systems for heating . . . or supplemented with above-floor or below-floor four-pipe fan coil unit (FCU) system for heating and cooling.

3. For interior systems, an underfloor Variable Air Volume (VAV) air distribution system or air displacement system with swirl diffusers is permitted.

4. Chapter 5 notes that perimeter and interior systems must be separated.

Designing Without Hard Data

In undertaking UFAD system design, today, the designer must depend on results from analytical studies, as real-world experiences in occupied UFAD systems are very limited. As noted in the "Findings" section, only seven field studies that provided details from investigations of occupied facilities were discovered in the literature review. There is a large information gap here—quite sim-

continued on page 12

Commitments needed for Continuous Accountability

Accountable person must be:

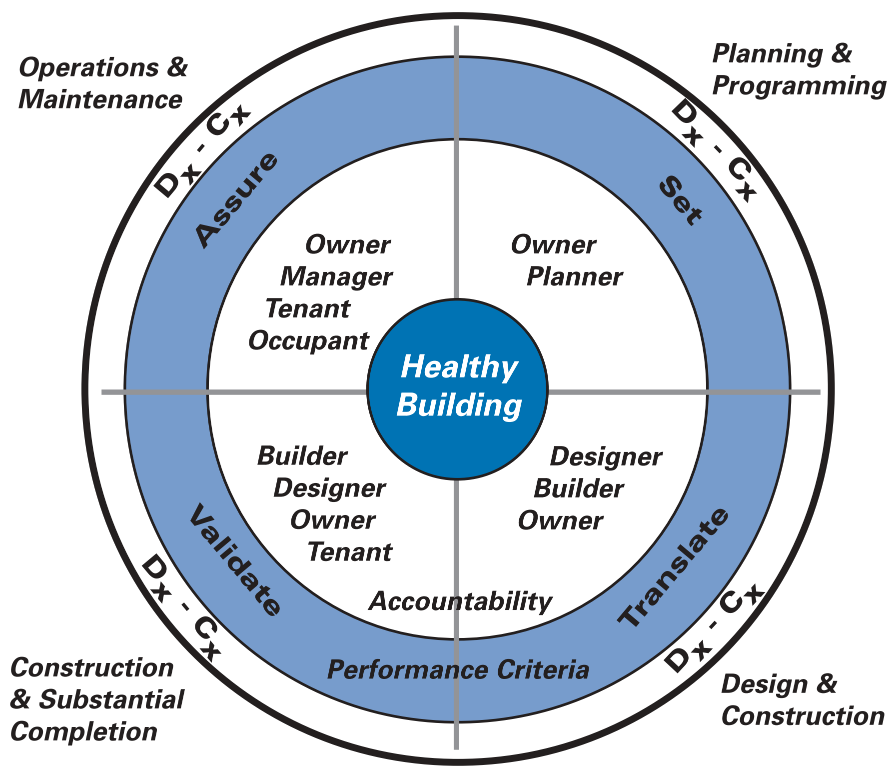
—Explicitly identified for each phase in building's life

—Empowered with authority to assure building performance

—Educated and trained to assure adequate building performance and occupant protection

Figure 4

Concept of Continuous Accountability



UFAD Alternative *continued from page 11*
ply, we lack UFAD system performance data from occupied facilities.

How does one design without learning from real-world system performance? A first step should be to define the set of criteria, in measurable terms, and a protocol with which the system will be selected, commissioned, and evaluated during occupancy (see Figures 4, 5, 6, and notes 19 and 20).

Evaluation criteria provided in Table 3 might be useful in creating objective and measurable criteria to evaluate and compare HVAC system performance. These criteria can be applied during design *and* occupancy.

Additional steps which might prove helpful include:

A. All conditions for compliance with P1, P2, and P3 criteria should be specified and achieved for UFAD or CAD systems.

B. Additional conditions for UFAD system compliance with M1 criteria should include documentation that predicted concentrations of contaminants at occupant breathing zones comply with evaluation criteria for occupied and unoccupied periods. Issues to be considered include:

- Emissions originating from sources below the breathing zone. These include moist and dirty floor plenum surfaces, which can emit bioaerosols, and heated wiring that can emit ultrafine particulates or fumes—the precursors of combustion.
- Concentrations of gases, vapors and particulates that can accumulate in the stagnant upper layer. This is important for standing or walking occupants, whose breathing zone is near this layer's boundary.

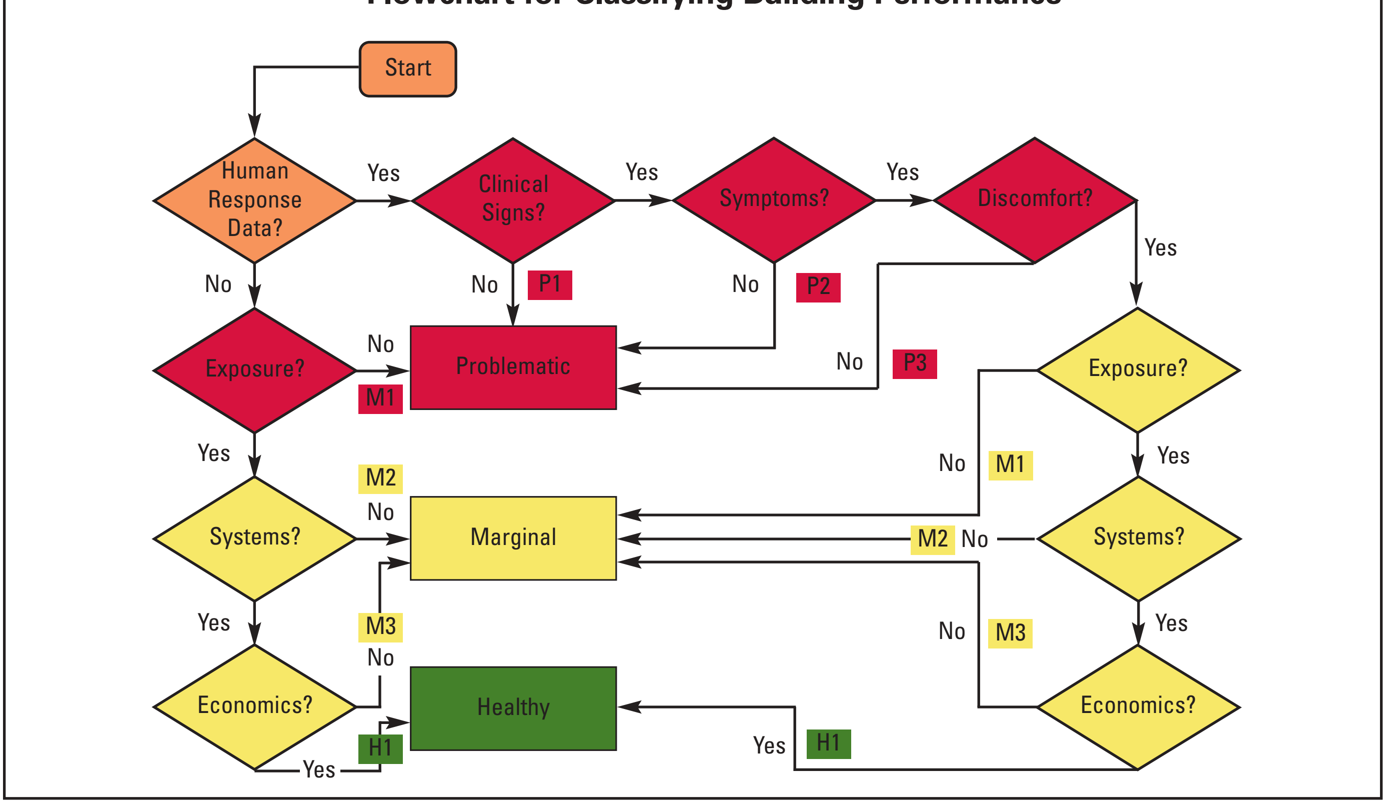
Note that these items can become critical in responses to extraordinary incidents (see note 17).

C. Additional conditions for UFAD system compliance with M2 criteria should include documentation that:

- adequate capacity and control logic has been provided for latent heat removal (e.g., coil "sensible heat ratio") and contaminant removal (e.g., filtration efficiency);
- supply air temperature is at least 65 F;
- airflow rates and velocities provided will dissipate the heat and contaminant loads while avoiding thermal, draft, and noise discomfort complaints.
- the control system prevents condensate formation on plenum surfaces;
- contaminants will not accumulate in the floor plenum or floor diffusers; and

Figure 5

Flowchart for Classifying Building Performance

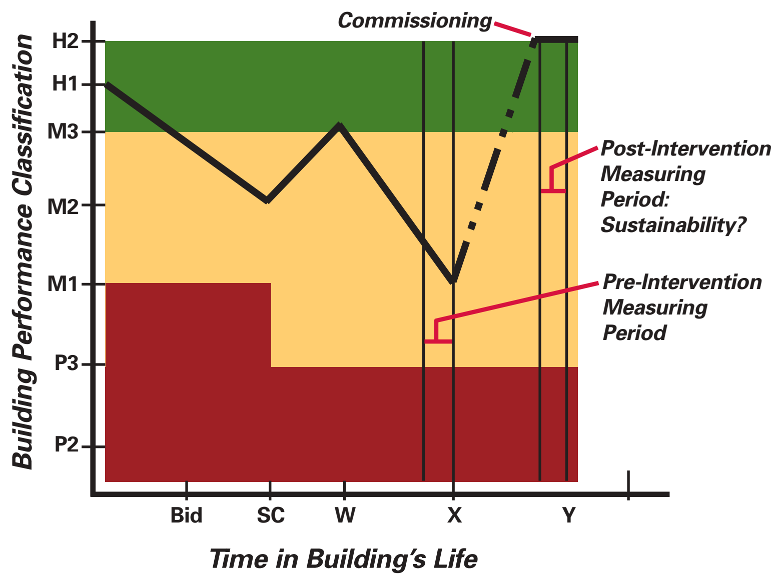


• adequate pressurization control has been provided to prevent exfiltration of moist air or contaminants into wall cavities from floor plenums, and to isolate and compartmentalize zones under fire-safety and other extraordinary conditions (see note 17).

D. Economic performance, including energy efficiency and annualized operating and maintenance costs, should be established with the owner's agreement. Once that is accomplished, conditions for compliance with M3 criteria for UFAD systems should include assurance through design, construction, and operations that the performance complies with evaluation criteria.

Figure 6

Chronology of Building Performance



Legend:
Before Bid = design period
SC = substantial completion
W = warranty
X and Y = operational periods

Bottom-Line Facts

Based on these results, analyses, and interpretations, it is reasonable to make the following statements of fact:

• The quantity of UFAD systems cited in the literature represents a **very small percentage** of the U.S. stock of commercial and institutional buildings in the U.S. However, the rate of penetration into this population is noticeable.

• The literature review revealed that UFAD systems are no more likely to reduce occupant complaints than CAD systems.

• There is no demonstrable real-world difference between UFAD and CAD systems operating over similar periods in compliance or non-compliance with exposure, system performance, and economic performance criteria.

• Sources that emit below the breathing zone and concentrations that accumulate in the stagnant upper layer can become critical issues in the event of intentional or accidental releases of contaminants. Note that concentrations in the upper layer affect building occupants who are standing or walking (putting their breathing zone near the layer's boundary).

Conclusions

These findings and interpretations lead to the following conclusions:

1. Valid and reliable field data from UFAD systems are not available from a sufficient population of existing facilities to conclude, generally, that UFAD performance is superior to—or even much different—than CAD systems.

Note that the lack of data means that we must specifically and especially avoid drawing a conclusion on system superiority with regard to long-term exposures to chemical and microbial contaminants during normal and extraordinary conditions.

2. At this time, UFAD systems provide additional alternatives that can be used by designers to meet owners' needs. In doing so, designers must be made aware that UFAD systems also present special concerns that must be resolved by site-specific analysis.

3. All HVAC—UFAD or CAD—will require more care in design, installation, and operations as awareness of the health, safety, productivity, and environmental security consequences are more explicitly expressed.

Recommendations

Based on these conclusions, it is recommended that before choosing an HVAC system, an objective analysis be made of site-specific conditions. This analysis must use a consistent set of measurable evaluation criteria for design, construction, and operations.

Certainly, HVAC system engineers and designers will continue to choose between UFAD, CAD, and hybrid systems. This supplement was produced in the hopes that facts—not assertions—would be helpful in making such choices.

If this supplement can be summarized in a single short sentence, it is this: The system selection should be made in such a way as to assure the health, safety, and performance of building occupants while simultaneously providing for workplace environmental security and productivity. ■

Notes From Pages 3-13
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—James Woods