GSA

U.S. General Services Administration

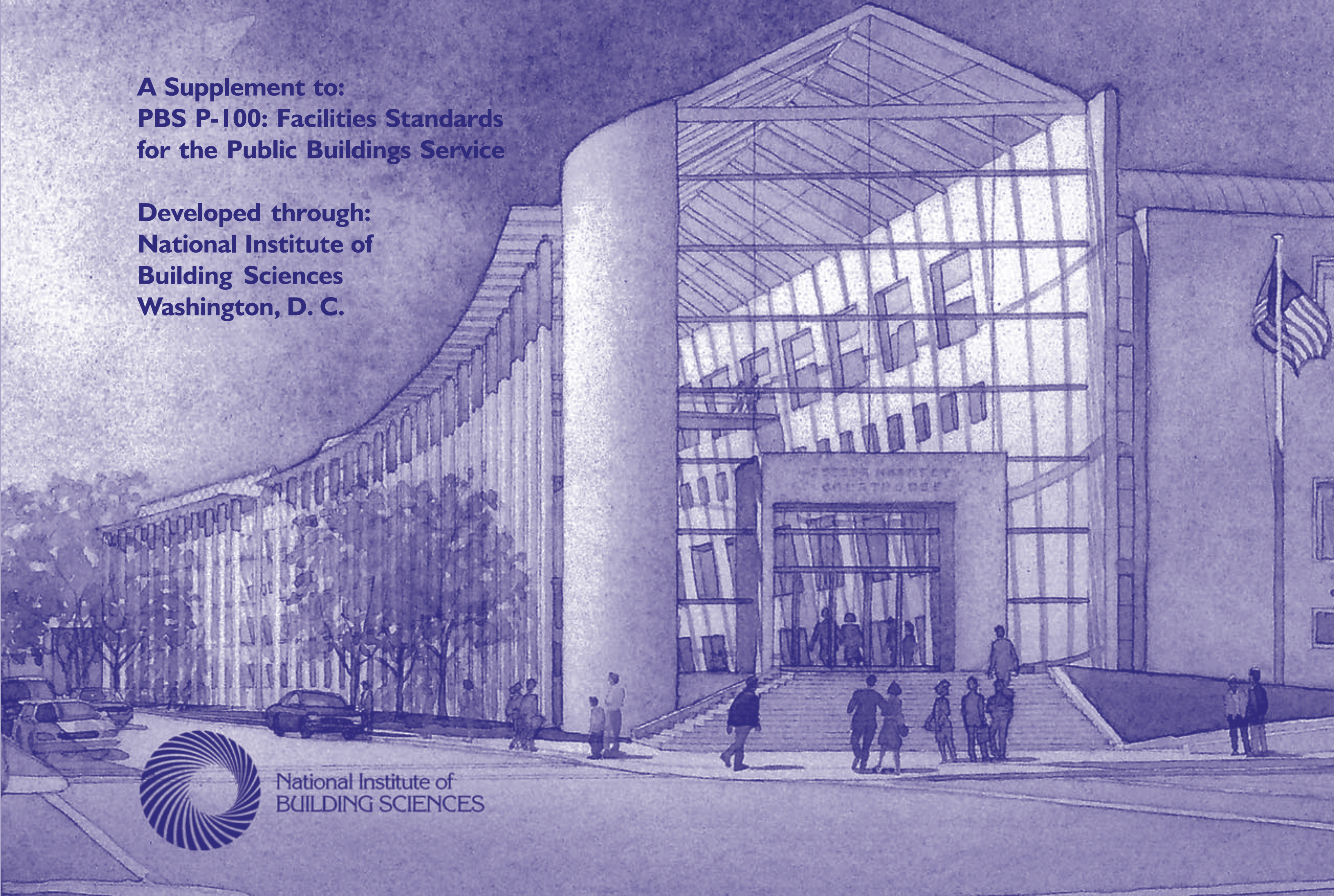
PBS Guideline for

# RAISED FLOOR SYSTEMS

## With and Without Underfloor Air Distribution

**A Supplement to:**
**PBS P-100: Facilities Standards for the Public Buildings Service**

**Developed through:**
**National Institute of Building Sciences**
**Washington, D. C.**



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**U.S. General Services Administration**
**Public Buildings Service**
**Office of the Chief Architect**
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Washington, D. C. 20405

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## Federal Building, San Francisco, California

# Executive Summary

This *PBS Guideline for Raised Floor Systems with and without Underfloor Air Distribution* has been developed as a supplement to the *Facilities Standards for the Public Building Service* (PBS P-100), which provides design standards and criteria for new buildings, major and minor alterations, and work in historic structures. To realize space flexibility and cable management benefits, the PBS P-100 requires incorporation of Raised Access Flooring (RAF) in all new construction where "office functions will take place," and in "appropriate areas of courthouses." The PBS P-100 also recognizes that additional benefits might be realized if the RAF in those areas is adapted to incorporate underfloor air distribution (UFAD) for heating, ventilating, and air-conditioning (HVAC). To address the special issues involved in RAF with or without UFAD, the PBS P-100 refers to this Guideline for design and construction details.

Over the past decade, GSA has been incorporating RAF/UFAD systems into the design of U.S. Courthouses, Federal Office Buildings, and special applications facilities throughout the country. Extending the use of UFAD systems from special applications, such as single-zone computer rooms, to multi-zone applications in general building spaces is a reasonably new concept when compared to the more "conventional air distribution" (CAD) methods of overhead distribution, fan-coil systems, etc. Therefore, this Guideline has been published to assist architects and engineers in the selection and design of these systems that provide the functional requirements in GSA facilities, in accordance with PBS P-100. In addition to the design professionals, the Guideline is intended for use by the construction industry (e.g., construction managers, contractors and tradesmen) and by building managers and other management personnel. This Guideline is based on lessons learned from review of actual designs and operations of GSA and private sector facilities that incorporated RAF, with or without UFAD; from published research, and from manufacturers' information on RAF and UFAD components.

A fundamental lesson learned is that the primary purpose for raised access flooring in new or renovated GSA facilities is to provide horizontal pathways that enhance the flexibility of power, data, and communications systems, and that this purpose can be realized with or without the potential secondary benefits of UFAD. However, 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.

Another fundamental lesson learned is that adapting RAF for UFAD systems to achieve the HVAC performance requirements in the PBS P-100 also demands supplemental design and construction coordination regarding multi-discipline and multi-trade resolution of incremental effects on the RAF requirements, as well as air leakage, thermal loads, moisture detection, fire and smoke management, and indoor environmental control issues. Moreover, 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 (throughout the life of the building) 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, and energy efficiency. The pressurized plenum design also involves many general construction materials not normally considered to perform in an airtight configuration. In fact, numerous trades and associated components and products have been identified as being instrumental in ensuring a quality pressurized plenum design, including: concrete, masonry, gypsum drywall systems, joint sealants, curtain wall systems, raised access flooring, insulation, vapor barriers, expansion joints, firestopping, waterproofing, millwork, carpet and other floor finishes, electrical conduits and power wiring, plumbing and ductwork. With this in mind, the need to integrate structural, mechanical and electrical performance requirements with the architectural features of the facility during the earliest stages of the design and construction processes becomes obvious.

Recognition of excessive air leakage in pressurized underfloor plenums as a main obstacle to assuring excellence in UFAD design has led to the stipulation within this Guideline of designing and testing a mockup of any UFAD system proposed for use within a federal facility. Traditionally, conventional overhead air supply ducts are constructed, insulated and tested (limiting air leakage rate to 1 to 3 % of supply airflow rate) according to strict industry standards such as those provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the Sheet Metal and Air Conditioning Contractors' National Association (SMACNA). However, in the case of UFAD systems, where the plenum - which is essentially an assembly of architectural components - often functions as an air supply duct, no credible industry standards or testing techniques exist to assure such plenums achieve and maintain air-tight status. Thus, designing and testing of a mockup will assure the highest available standard of performance from our UFAD systems.

One of the main reasons for installing RAF is the efficient re-location and management of power, data, and telecommunication cables beneath the floor: this inevitably involves the moving of floor components, which has the potential for compromising the structural integrity and efficiency of UFAD systems operating with pressurized plenums. Thus, along with the construction and testing of an initial mockup, use of RAF and UFAD systems involve a serious commitment to the continuous air-leakage testing and maintenance of these systems' components over the life of the building. It is also recommended that warrantees related to RAF/UFAD systems be increased from the usual one-year period to a period of five years, to ensure the proper functioning of these systems over time.

*By far the most important and overarching lesson learned is that incorporation of RAF, with or without UFAD, for the purpose of achieving performance in accordance with PBS P-100 requires an early commitment to integrated design, beginning at planning and preliminary concept stages, and extending through the construction and commissioning phases.*

It should be noted that this Guideline provides the "what to do" regarding RAF/UFAD systems in federal buildings; the "how to do it " is, in many instances, still being "discovered" by the building industry. However, it is GSA's hope that this Guideline will be seen as a step forward in promoting excellence in the design, construction and long-term maintenance of RAF/UFAD systems, leading ultimately to improved operations and maintenance, energy efficiency, thermal comfort, and customer satisfaction, not only within the federal government, but within the building industry as a whole.

## Summary of the Guideline

Part 1 presents design considerations and criteria for the selection of Raised Access Flooring products and how they must interface with the facility. In **Sections 1.0 and 4.2**, RAF products are noted to consist of proprietary modular panels and understructure that vary widely in terms of construction and cost. As supplemental information to the PBS P-100, Section 1 lists areas that are most suitable for RAF; areas that are suitable but require special design features, and areas that are generally inappropriate for RAF.

**Section 2** points out that economic considerations of RAF alternatives are needed, even for those areas where PBS P-100 specifies its application. Therefore, Section 2 states that a benefit-cost method, which recognizes the value of RAF benefits as well as its costs, shall be used for two applications:

1) In the areas where RAF is required, the features and characteristics shall be selected to optimize the benefits and costs of RAF for cable management; and
2) In other areas being considered for RAF, the benefits and costs of RAF shall be compared to those for conventional flooring and horizontal pathways for wiring and cabling distribution above suspended ceilings.

Some of the issues to be considered in the benefit-cost analyses are discussed in Section 3, *Cable Management Technology and Planning*, and additional information is provided in the Appendix.

**In Sections 4 – 7**, architectural and electrical design conditions and criteria are addressed that are supplemental to those in the PBS P-100:

- Section 4.1 identifies additional soil and climatic conditions and corresponding criteria that must be addressed to minimize water and contaminant incursions into the RAF cavities for protection of the wire and cable management systems, and to minimize the risks of fire and adverse health effects.
- Section 4.2 addresses structural conditions and specifies minimum criteria for uniform, point, impact and rolling loads for RAF products. In addition, guidance is provided for specifying stringer loading, pedestal axial loading, and

overturning resistance, in response to analyses of seismic, acoustic and vibration requirements that are also addressed in this Section.

- Section 4.3 addresses supplemental issues related to the proximity in the RAF cavities of potential fire, smoke, and other hazards to the occupants, and specifies minimum supplemental criteria to reduce risks to the occupants, first responders, and property assets.
- Sections 4.4 and 4.5 address supplemental interfaces with adjacent finishes in new and existing buildings, and the issues regarding interfaces with the Planning Grid in PBS P-100, panel edging, and cavity heights as they impact clear ceiling and building heights.
- Section 5 highlights and supplements the basic requirements in Chapter 6, Sections 10 –14 of PBS P-100 for normal and emergency electrical power wiring distribution, for communications cabling beneath the RAF, and for grounding.
- Section 6 addresses supplemental requirements for documentation and drawing details for RAF.
- Section 7 addresses supplemental inspection, testing and commissioning issues associated with the design and construction of RAF systems.

**Part 2** presents supplemental design considerations and criteria for the selection of UFAD systems and how they must interface with the architectural, structural, mechanical and electrical systems. Section 8 addresses the similarities and differences between UFAD and CAD systems and increments the listed areas in Section 1 that are most suitable for UFAD; areas that are suitable but require special design features, and areas that are generally inappropriate for UFAD.

**Section 9** explains that economic consideration of UFAD alternatives is needed, although the PBS P-100 identifies UFAD as one of the four types of acceptable HVAC Baseline systems. Therefore, a benefit-cost method, which recognizes the value of UFAD benefits as well as its costs, is required for two applications:

1) In areas where RAF has been previously selected for cable management in accordance with Part 1, benefits and costs of providing UFAD with RAF, modified in accordance with Part 2, shall be compared with CAD and RAF that is

in accordance with Part 1 but not modified in accordance with Part 2; and

2) In areas where RAF has not been previously selected in accordance with Part 1, benefits and costs of providing UFAD with RAF, which is in accordance with Parts 1 and 2, shall be compared to CAD with conventional flooring and horizontal pathways for wiring and cabling distribution above the suspended ceiling.

Some of the issues to be considered in the benefit-cost analyses are discussed in Section 10, *Interface between Cable Management and Air Distribution*, and additional information is provided in the Appendix.

**Sections 11 – 15** focus on the architectural, structural, mechanical, and electrical design conditions and criteria that must be addressed due to the introduction of underfloor air distribution through *pressurized plenums* (i.e., RAF with UFAD):

- Sections 11.1, 12.1 and 12.2 address additional conditions to those in Section 4.1 that must be controlled to:
  - Minimize heat transfer, and water and contaminant incursions through slabs and perimeter walls into the pressurized UFAD plenums, which must be maintained at lower values of dry bulb and dew point temperatures than the unpressurized RAF cavities.
  - Minimize the uncontrolled heat and contaminant exchange between the UFAD plenums and the occupied zones.
  - Achieve acceptable values in Table 5.1 of PBS P-100 in terms of Operative Temperatures, defined by ASHRAE Standard 55, in the occupied zones to compensate for higher air velocities at the floor, and increased radiant heat exchange with the floor panels of UFAD systems.
- Section 11.2 identifies pathways of air leakage and water accumulation in UFAD plenums. Section 11.2.1 defines Category 1 (i.e., general construction) and Category 2 (i.e., product) air leakage criteria. In order to reduce Category 2 air leakage rates, *RAF for UFAD shall be provided with stringers or other demonstrably equivalent air-sealing devices, staggered carpet tiles, and floor panel accessories with minimum leakage values.* Criteria for air leakage require that, *as a maximum, the total air leakage from all Category 1 and Category 2 leaks shall not exceed 0.1 cfm/ft$^2$ floor area or 10% of the design supply airflow rate,*

*whichever value is smaller, when the plenum static pressure is maintained at its control value (e.g., 0.1 in. w.g.).* Section 11.2.2 describes methods that must be considered for prevention of water accumulation in UFAD plenums. Sections 14.1 and 15.2 provide additional information on testing procedures.

- Sections 11.3 and 11.4 address incremental structural, acoustics and vibrations issues that must be considered due to RAF modifications required for the UFAD plenums.
- Sections 11.5 and 11.6 address additional issues related to the effect that air movement through the UFAD plenums has on potential fire, smoke, and other hazards to the occupants, and specifies additional minimum criteria to reduce risks to the occupants, first responders, and property assets in facilities with UFAD plenums.
- Section 11.7 addresses supplemental issues regarding the locations of floor diffusers and grilles in perimeter and interior zones, specifies the maximum unducted distance (i.e., 50 ft) from the point of supply air entry into the plenum to the most distant air diffuser or grille in that zone, and reaffirms that the return air pathways from the return air grilles of the UFAD systems to the air handling units shall meet the same criteria as specified for Plenum and Ducted Return Air Distribution of CAD systems (Section 5.8 of PBS P-100).
- Section 13 describes additional electrical requirements to those described in Section 5 that must be implemented for UFAD plenums: 1) compliance with the National Electrical Code (NEC) for wiring and cabling in plenums, and 2) a minimum of 4 in. (100 mm) vertical clearance in the plenum to allow cables to cross above the ducts.
- Section 14 addresses additional requirements to those in Section 6 for documentation and drawing details for UFAD.
  - Section 14.1 focuses on issues that must be addressed in the various divisions of Project Specifications to ensure the air tightness and cleanliness of the UFAD plenum, including the construction of a full-size mockup of the UFAD system, which is to be tested in accordance with procedures provided in Section 15.2.1.
  - Sections 14.2 – 14.6 describe additions that are needed to drawings and to operations, maintenance, and housekeeping documents.

- Section 14.7 requires an extended warranty that must be coordinated with the Contracting Officer to ensure continuous performance after Substantial Completion, including testing in accordance with procedures provided in Section 15.2.3.

- Section 15 specifies methods of inspection, testing and commissioning GSA facilities that have UFAD. Three methods of testing for plenum air leakage are listed:
  - In Section 15.2.1, methods of determining Category 1 and 2 air leakage rates are specified. Preparation of a mockup of the UFAD is also specified.
  - In Section 15.2.2, the lessons learned from 15.2.1 shall be disseminated to: 1) all the trades involved in the construction of the plenums as supplemental information, and 2) all inspection and approval authorities on the project. After the permanent building floor plenums have been completed in accordance with steps 1 – 4, Category 1 and 2 air leakage rates shall be determined. If the results are not in compliance with Table 15.1 and Section 12.3, the causes of the leaks shall be repaired or corrected and the system retested until the rates are in compliance.
  - In Section 15.2.3, the tests conducted in 15.2.2 shall be repeated whenever an area exceeding 2,500 $ft^2$ is modified, and within 30 days prior to completion of the warranty period (See Section 14.7) for a 1,000 $ft^2$ area to be selected by GSA. If results are not in compliance with Table 15.1 and Section 12.3, the causes of the leaks shall be repaired or corrected and the system retested until the rates are in compliance, and two additional areas shall be selected by GSA and tested. If either of these areas is not in compliance with Table 15.1, all UFAD plenums within the facility shall be tested and repaired as necessary.

After air leakage testing is completed in accordance with 15.2.2 and 15.2.3, the Testing, Adjusting, and Balancing (TAB) contractor or agency shall perform the TAB work in accordance with the project specifications (see Section 15.3), and the commissioning process shall continue (see Section 15.4).

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# Introduction

The *Facilities Standards for the Public Buildings Service* (PBS P-100), published by the U.S. General Services Administration (GSA), provides design standards and criteria for new buildings, major and minor alterations, and work in historic structures. Chapter 3, Section 1 of PBS P-100 states that Raised Access Flooring (RAF) "shall be incorporated into all new construction where office functions will take place," and Chapter 9, Section 3 of PBS P-100 states that RAF "shall be used in appropriate areas in courthouses, which include courtrooms, chambers, offices, conference rooms, etc." These applications are primarily to realize space flexibility and cable management benefits.

PBS P-100 recognizes that, as the RAF approach to cable management is required in certain areas, the opportunity to combine the access flooring system with underfloor air distribution (UFAD) could be beneficial in many situations. Therefore, Chapter 6, Section 4 of PBS P-100 includes UFAD as one of the four allowable *Perimeter and Interior Heating and Cooling Systems* to be considered in the HVAC Baseline System.

Use of UFAD systems for heating, ventilating, and air-conditioning of general building spaces is a reasonably new concept when compared to the more "conventional air distribution" (CAD) methods of overhead distribution, fan-coil systems, etc. Therefore, the GSA has published this Guideline to assist architects and engineers in the selection and design of these systems. This Guideline is based on lessons learned from review of actual designs and operations of GSA and private sector facilities that incorporated RAF, with or without UFAD, from published research, and from manufacturer's information on RAF and UFAD components.

Therefore, for projects where RAF, *with* or *without* UFAD, is to be incorporated into the design, this Guideline shall be used as a supplement to PBS P-100 in order to comply with the functional and performance requirements in the project's design program and to achieve a total integration of all building systems that will provide for current operations as well as future changes.

In addition to the design professionals, this Guideline is intended for guidance and use by the construction industry (e.g., construction managers, contractors, and tradesmen) and by building managers and other management personnel.

Regarding the design and construction industries, UFAD systems require the integration of numerous building systems and components into HVAC systems in a manner that requires special attention to details and issues that represent new challenges to both designers and contractors. Thus, the major objectives of this Guideline are to develop an awareness of these issues and details, and to provide guidance that will assist the practitioners in the successful execution in both the design and construction phases.

Regarding ownership responsibilities, the benefits of both RAF and UFAD systems can be realized for the many years of operating the buildings, if the management staff is attuned to the continuing maintenance of the cable management, underfloor housekeeping, and other issues addressed in this Guideline.

This Guideline consists of two Parts: Part 1 – Raised Access Flooring (RAF) Systems, and Part 2 – Underfloor Air Distribution (UFAD) Systems. Each Part is intended to stand alone, except for cross-references where applicable. An Appendix of supporting or supplemental information follows Part 2.

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*Photographer: Frank Ooms*

# Part 1:
# Raised Access Flooring (RAF) Systems

# 1.0 Features and Characteristics

Modern use of raised flooring as modular units is about fifty years old and was developed for computer main frames mostly for the ease of wire management and provision of cooling to the equipment. More recently, using raised access flooring for many kinds of work spaces, both for wire management and air distribution, has gained popularity for its flexibility and reduction of embedded systems in the building structure.

Overhead services have long been the most common horizontal distribution means, typically in space above a suspended ceiling. Raised access flooring has considerably facilitated providing services to work stations in open office planning. Having such services easily accessible potentially reduces the need for skilled labor to change them and may reduce waste and disruption during renovations.

A modern raised access flooring system consists of proprietary modular panels and understructure that vary widely in terms of construction and cost. The primary purpose of the RAF is to provide horizontal pathways that enhance the flexibility of power, data, and communication systems. The Evaluation Sheets for Section 10270 in Masterspec© provide excellent detailed information for the basis to select and specify RAF types. Some of the basic features and characteristics can be described as follows:

Floor panels:

- Manufactured in English (typically 24" x 24") and metric (typically 600 mm x 600 mm) versions.
- Constructed of die-cast aluminum or formed steel.
- Cores may be hollow or filled with lightweight concrete, cementitious material or wood.
- Coverings include high-pressure laminate, carpet, vinyl (conductive and standard) and galvanized steel.
- Panels may be solid or perforated, or slotted for air distribution.

Understructure:

- Pedestals are adjustable and designed for the loading required. They are typically placed at all panel corners.
- The heights of the pedestals vary with the need to accommodate systems under the panels. They are available for floor surface to slab as low as 2 ½ inches (60 mm). The heights vary by manufac-

turer, by the type of specified understructure, and by the clearances needed for the horizontal distribution services.

- Dependent upon the imposed loads, the pedestal pads are bolted or glued to the structural slab. The panels are either bolted directly to the pedestals or laid on a stringer system.
- Stringers are bolted to pedestals for greater stability and load-carrying capacity (especially for rolling and seismic loads) or snap-connected to the pedestals for ease of removal.
- Stringers are available in various weights for strength, and may be formed to accept pipe and conduit hangers. Stringers may nest with the panels or be independent of the panels.
- Panels may rest on stringers with gaskets or pads for cushioning and some air-tightness, or may be placed on conductive pads to provide continuity for grounding.
- Finishes of understructure include galvanized steel, aluminum and stainless steel.

Accessories vary widely by manufacturer, but some common ones are:

- Grommets to protect wiring through openings in panels.
- Sound-deadening pads.
- Service outlets.
- Floor diffusers, registers and grilles.
- Ramps, stairs and railings.
- Air strip seals (non-structural stringers).

Functionally, a raised access floor is similar to a suspended ceiling. Many of the same coordination needs apply to the former as to the latter. Both types of space must accommodate structure, cabling, ductwork and equipment and must resolve the demand each system makes for space – especially when "horizontal distribution systems" cross one another. However, suspended ceilings accommodate horizontal distribution systems not usually found under raised access floors: lighting, fire suppression systems, public address speakers, exhaust ductwork, and plumbing drain traps and offsets to risers from the floors above. Raised access floors, on the other hand, bear the weight of the contents of the office area or other functional space including people, furnishings, equipment and some partitioning. Spaces above suspended ceilings and below raised access floors have been used as plenums for air supply and return.

Both raised access floor and suspended ceilings are typically based on rectangular grids, which are more or less visually evident, but usually cannot be completely suppressed without compromising the accessibility required. It may be necessary to reconcile the grid architecturally to other building grids such as the GSA Planning Grid (See Chapter 3, Section 1 PBS P-100), structural bays and other geometries.

The space under a raised access floor, like the space over a suspended ceiling, can become cluttered, dirty and contaminated. Likewise, floor panels like lay-in ceiling panels can become worn, distorted and damaged from removal and replacement, impact or other abuse.

The areas typically most suitable for raised access include:

- Computer rooms and other information technology spaces.
- General open office areas.
- Training and conference areas.
- Exhibit spaces.
- Support spaces for offices, including electrical closets, fan rooms, etc.
- Clean rooms

Some areas suitable for RAF require special design features:

- **Elevator lobbies**: The sill of the elevator opening must ensure edge support of the RAF – especially at freight elevators – to support rolling loads as carts are rolled off the elevator onto the floor.
- **Auditorium and courtroom seating areas** where it is planned to move these seating areas into different configurations. Stepped or sloped seating may need to be built on independent units above the floor.
- **Secure spaces**: Credit unions, interview rooms, private offices, Security Control Centers, Secure Compartmented Information Facilities (SCIF), other secure areas as permitted by regulations of the governing agency. The secure construction of the surrounding walls must extend through the raised access floor to the slab below, just as it must through the ceiling to the slab above.
- **Prisoner spaces**: such as prisoner holding cells, secure corridors, etc. The U.S. Marshals (USMS Publication 64) must approve of the use of the RAF and the system's tamper-resistant capabilities.
- **Public lobbies, atria, main elevator and escalator lobbies, main public corridors, etc.**: Care must be taken to insure that water cannot enter the underfloor space from entrances where moisture is tracked in. Also, weights of maintenance equipment such as lifts or rolling scaffold in high-ceiling public areas must be determined and designed for.

Other areas are inappropriate for raised access floor:

- **Slab-on-grade locations:** Long term protection is difficult against heat, moisture, and contaminant transfer with the soil, soil gases, ground water, and vermin through joints and cracks. RAF shall not be placed directly on concrete slab-on-grade surfaces.
- **Toilets, showers, baths, janitors' closets, dishwashing and other wet areas**: These areas have plumbing fixtures which should not rest on a raised access floor. Potential leakage and high humidity are likely to cause corrosion of panels and understructure, and growth of mold and bacteria on these surfaces.
- **Kitchens and food preparation areas**: For the same reasons as for the spaces listed above, these areas should not be placed on RAF. Although some break rooms with kitchenettes have been placed on raised access floors when water supply and drains have been possible by connection to a wet column, the risk of spillage of food and liquids and seepage into the underfloor space makes these areas a potential problem.
- **Laboratories**: Similar challenges in accommodating plumbing and moisture exist as for toilets, etc., depending upon whether the laboratory has any wet processes. Moreover, the likelihood of chemical, biological or other spills must be assessed.
- **Fire stairs**: Stair landings must interface with any adjacent raised access floors as a flush condition with the edge of the access floor well supported.
- **Mechanical equipment rooms** such as boiler, chiller, and air handling equipment rooms.
- **Central storage rooms and loading areas, trash rooms, etc**.
- **UPS, emergency generator, and similar rooms**.
- **Child care centers** where playthings, equipment and mats will often cover outlets, and where floor outlets may provide tempting objects for children to play with, drop things into, etc.

Wherever raised access floor is used, core spaces must have finish floors level with the raised access floor. This can be accomplished by changing the structural slab elevation, by building up a fixed filled floor with foam insulation board, or by building a framed raised slab under such areas as stair landings, toilet rooms and elevator lobbies.

## 2.0 Economic Considerations for Raised Access Flooring

As indicated in the Introduction of this Guideline, Chapter 3, Section 1 and Chapter 9, Section 3 of PBS P-100, require the application of RAF in specific areas of new buildings where office functions will take place and in appropriate courthouse areas. However, the features and characteristics of RAF for these applications are not specified. Moreover, Section 1.0 of this Guideline identifies other areas where the application of RAF may be beneficial, and other areas where its application requires special design consideration or is generally inappropriate.

Therefore, to ensure that the value of the RAF is maximized, a benefit-cost method shall be utilized in which the life cycle costs and benefits of RAF features and characteristics are optimized for the applications specified in Chapter 3, Section 1 and Chapter 9, Section 3 of PBS P-100. For areas where RAF is not required (see Section 1.0 of this Guideline), the RAF life cycle costs and benefits shall be compared with conventional flooring and horizontal pathways for wiring and cabling distribution above suspended ceilings. In this case, RAF is economically preferred if the benefit-cost ratio of RAF exceeds that of conventional flooring and horizontal pathways for wiring and cabling distribution above the suspended ceilings

The first cost of a raised floor, including engineering, material cost, fabrication, installation, and inspection, can be significantly higher than that of a conventional floor. In addition, the maximum area that might be ultimately utilized is normally built-out with a raised floor whether or not the current, near term, or even the actual ultimate function requires the use of RAF. Extra costs associated with power and data cabling can also be incurred using RAF. These can be considerable costs, which must be assessed in those areas where RAF is optional. Stairs, elevator shafts, piping, standpipes, etc. may have to be lengthened accordingly, and shall be considered as "related costs."

RAF is only one of many elements that must be assessed in determining value of a design. RAF may increase or decrease this value. In addition to first cost impacts on cable management and flexibility, economic considerations shall include the impact that utilization of RAF may have on health, safety, security, and sustainability (see Chapter 1, Sections 2 and 6 of PBS P-100).

Appendix A-2 of this Guideline describes methods for quantitative analysis and also provides information relating to benefits and costs that can be used in qualitative assessments. It includes discussion of:

- Life-Cycle Cost and Benefit-Cost Methods
- Benefit Factors
- Risk Factors
- Cost Factors

If a quantitative analysis is not possible for a specific project, a qualitative assessment shall be performed as outlined in Appendix A-2.

## 3.0 Cable Management Technology and Planning

While accessible vertical distribution has typically been accommodated in chases and shafts, horizontal distribution that can be accessed for maintenance, repair and expansion is more difficult. Various systems have been - and still are - used. Probably the most common practice in modern buildings is to use the space above a suspended or false ceiling for horizontal distribution, and to feed the cabling and wiring down through partitions to outlets for power, communications, and controls. In older commercial buildings with masonry partitions, the drops were typically cut into chases, then finishes (usually plaster) covered the chases and wiring. Renovations in these facilities often resulted in the abandonment of the existing wiring and the cutting of new chases. With hollow partition construction, such as gypsum board on metal studs, these drops are now more easily installed and can be relatively easily changed.

Above-ceiling distribution to offices, and other occupancies consisting of private rooms, where all work furnishings adjoin a partition with its outlets, was - and remains - a viable means of providing services. Cabling and wiring for power, communications, data and other needs can be distributed over ceilings or under floors, but when modular work furnishings are used for an open office environment, supplying from the floor is visually more appealing than dropping the wiring from the ceiling in open space areas.

In some instances, such as where flat plate concrete slabs are exposed above and below, no space for concealment of wiring exists. As a result, cellular floor ducts in metal floor panel systems or embedded ducts may be built into floor systems to feed up to “tombstone” outlets. The need for ever greater flexibility of wire management and the increase in sheer quantity of wires and fiber has made a raised access floor (RAF) a more appealing choice for many applications of wire management (See *Technology Infrastructure*, Chapter 3, Section 1, PBS P-100). Conversely, the large turning radii and separation from power cables required by fiber optic cables have compromised the ability of RAF to accommodate these new requirements without increasing the floor height, resulting in overhead cable trays (used in conjunction with bus ducts for power) becoming a primary alternative to RAF (see Chapter 6, Section 11, PBS P-100). Also refer to Sections 1, 4 and 5 in this Guideline for additional information.

Vertical alignment of electrical power, voice, and data closets is a critical function in planning for RAF systems. Accessible flexible horizontal pathways must be provided from these closets (i.e., equipment rooms) on each floor to the workstation outlets. Horizontal pathways must provide at least three separate channels for separation of power and different communications systems. Moreover, the CAT 6 and fiber optic cables must be separated from power cables. Independent channels are required in horizontal pathways for normal power; emergency power; Building Automation System (BAS) Sensor and control wiring; fire alarm; security; and television and communications, the latter which must include voice and data wiring and cabling (see Chapter 6, Section 11 of PBS P-100). The relative locations of these closets/equipment rooms on each floor are critically important to minimize the horizontal cross-overs of the various cabling and wiring, and the resulting clearance heights in the floor cavities.

As one of the purposes of modular workstation furniture is its relative ease of reconfiguration, disconnection and reconnection to floor-based systems is generally preferable and can use ordinary plug-in devices.

Where raised access flooring is used, power, communications and data can be fed to the occupied space from the underfloor space through holes cut in the floor panels with hard-wiring run through grommeted holes to junction boxes or through proprietary service devices. The hard-wired connections may be necessary for certain machinery and for computer main frames, but are not usually needed for most office equipment. These service devices allow plug-in connectivity through devices that are flush with the floor or protrude into the occupied space. They often contain multiple services in a single device.

Wiring and cable under a raised access floor is vulnerable to some of the same problems as above the ceiling. Changes may result in abandoned wiring, conduit and devices. Eventually, an underfloor space can become as cluttered as a ceiling; it must be managed and kept clean. In the design phase, sufficient clearances must be provided to allow all underfloor systems to work together and to allow for maintenance, repair and replacement. With a raised access floor, an unanticipated conflict cannot be resolved during construction by the equivalent of dropping a ceiling in an area. So, providing adequate clearances from the earliest stages of design is essential, and includes the selection of the raised access floor system. Some stringer systems drop below the bottom surface of the floor panel and thus reduce clearances. At least one manufacturer offers a 120 mm x 120 mm (4 ¾ in x 4 ¾ in) under-structure stringer to span large items such as ducts and equipment under the floor, but this adds significantly to the height needed floor-to-floor.

For renovations to existing buildings, raised access flooring may provide a less intrusive way to provide horizontal distribution than by adding a suspended ceiling which may destroy ornamental ceilings and the architecture of the interior. However, there are many considerations, including interface with existing core elements such as stairs, elevators and toilets that can complicate this application.

## 4.0 Architectural Design Considerations

Lessons learned from design reviews and on-site evaluations have revealed that successful applications of RAF require an early commitment to integrated design, with members of the design, construction, and property management actively participating in decision-making beginning at the preliminary concept design phase (see Appendix A-3 of PBS P-100). This Section focuses on architectural issues and criteria that must be addressed by the design team throughout the design and construction phases.

### 4.1 Soil and Climatic Conditions and Criteria

Incursions from soil and climatic conditions shall be controlled the same in facilities that have raised access floors as in those facilities with conventional flooring systems. Therefore, the design criteria for soil and climatic conditions pertain equally to facilities with underfloor and overhead horizontal distribution systems. However, RAF systems require control of three additional conditions: 1) the structural slabs are the platforms for the RAF; 2) the slab and exterior wall surfaces in the RAF cavities are generally not visible when the floor panels are in place; and 3) the slab and wall surfaces in the RAF cavities are in continuous and proximate contact with the cabling and wiring (see Section 1.0). Thus, water and contaminant incursions into the RAF cavities from below and above-grade sources shall be minimized to protect the wire and cable management systems, and to minimize the risks of fire and adverse health effects. Criteria (i.e., parameters and values) for the following soil and climatic conditions shall be defined, measured, and controlled during design, construction and operations:

- For at-grade or below-grade floor cavities:
  - Ground water pressure and temperature at slab interface.
  - Contaminants in ground water: unusual types or concentrations.
  - Soil gases: unusual types or concentrations.
  - Microbiological contaminants: unusual types or concentrations.
  - Vermin: types.
  - Pesticides in soil at slab interface: types and concentrations.

- For at-grade or above-grade floor cavities:
  - Summer and winter design dry-bulb temperatures, and dew-point temperatures or water vapor pressures.
  - Design wind and rain conditions: wind velocity and rainfall rates.
  - Airborne contaminants: unusual types or concentrations.

## 4.2 Architectural, Structural, Seismic, Acoustic and Vibration Design Conditions and Criteria

As stated in Section 1.0, RAF systems are proprietary designs with many variations in the specific features. Like curtain wall systems, RAF systems are engineered by manufacturers and are built from kits of parts; they are usually not interchangeable from one manufacturer to another except for the floor finishes, in some cases. The manufacturers have established patented panel, stringer and connection designs from which the architect/engineer must make a selection. Changes to the proprietary designs are possible, but at a cost premium. Moreover, these changes will not have demonstrated their functionality before being built into the project.

So, in order to meet the specific GSA requirements and criteria for a project, the RAF system shall be selected carefully from among the choices offered by the industry. As sole-source designs and specifications are generally not allowed in GSA projects, selection of a product for a feature not available from other manufacturers may not be sustainable.

### 4.2.1 Structural Conditions and Criteria

Raised access floor systems shall be selected from those that are commercially available and have been tested and rated under test methods of the Ceilings and Interior Systems Construction Association (CISCA)[1] for the following conditions:

- Ultimate Load per panel, Lbs (kN).
- Concentrated Load @ 0.10" (2.5 mm) Deflection, Lbs (kN).
- Impact Load, Lbs (kN).
- Rolling Load 10 pass, Lbs. (kN).
- Rolling Load 10,000 pass, Lbs. (kN).
- Stringer loading.
- Pedestal axial loading.
- Overturning resistance of pedestal assembly.

As a minimum, or unless otherwise stated in the building program, the selected RAF shall comply with the following structural criteria when all panels are installed:

- Uniform load: 250 Lbs/ft$^2$ (1210 kg/m$^2$).
- Point load: 2,000 Lbs (4.5 kN).
- Impact load: 1,000 Lbs (kN).
- Rolling load (1 wheel): 800 Lbs (kN) @ 10,000 passes and 1,000 Lbs @ 10 passes.

Criteria values for stringer loading, pedestal axial loading, and overturning resistance must be determined after analysis of seismic (see Section 4.2.2), acoustics and vibration (see Section 4.2.3), and other imposed live loads. Initial selection of the RAF system can then be made based on compliance with the set of criteria, as described in Section 4.2.

### 4.2.2 Seismic Conditions and Criteria

Seismic and impact testing are not included in the CISCA standard, but manufacturers assert seismic design capabilities. Generally, bolted stringer systems are used for seismic

[1] In Europe, the comparable standard is EN 128252:2001 Raised Access Floors

conditions with pedestal pads bolted rather than glued to the floor slab. For high pedestal conditions, additional seismic bracing is typically available, but the design of the system to resist a seismic force (Fp) shall be required of the manufacturer in the specification. (This is the practice used in Masterspec© guide specification for Section 10270).

RAF manufacturers generally list their products with values given for performance in the above areas, and generally have light duty and heavy duty product lines.

As a minimum, or unless otherwise stated in the building program, the selected RAF shall comply with the following seismic criteria when all panels are installed:

- For seismic zones 3 and higher, stringers and pedestals, which are rated for the zone by the manufacturer, are required and the pedestal pads shall be bolted to the slab.
- For pedestal heights of 12 in., or higher, in seismic zones 3 and higher, additional bracing shall be provided, using methods recommended by the manufacturer. Where this bracing is required, additional coordination with horizontal distribution services shall be implemented to assure adequate clearances.

### 4.2.3 Acoustics and Vibration Conditions and Criteria

Three major areas of concern relate to acoustics and vibration control in RAF systems:

- The sound of impact on the floor panels by walking and by rolling loads may require damping of the panels with cushions on the pedestals or stringers, in addition to adequate fill of the panel body. Hollow metal panels do not perform well in this respect while panels with cementitious, lightweight concrete and wood perform well. Die-cast aluminum may need damping.
- The transmission of sound under the floor from one space to another may occur. Where sound transmission attenuation is required of a partition system (i.e., see Chapter 3, Section 4: *Special Design Considerations,* and Table 3.5 in PBS P-100), the same construction shall be continued through the access floor to the slab where it shall be sealed with an acoustic sealant. Where this partition system exists below the floor panels, cable and wire management shall assure that penetrations through the partition systems have been adequately sealed, acoustically.
- Vibration transmission is typically not

addressed in RAF manufacturers' literature, nor are the criteria for design to attenuate vibration such as from machinery, transformers or other sources. Where this is a sensitive issue or concern, a specialist consultant should be engaged.

As a minimum, or unless otherwise stated in the building program, the selected RAF system shall comply with the following acoustic and vibration criteria when all panels are installed:

- The acoustic criteria in PBS P-100 apply equally to federal facilities with RAF systems and conventional flooring systems. It is the responsibility of the design team to meet these minimum standards governing the acoustic performance of various spaces and usage categories.
- The floor panels shall be concrete filled metal or concrete.
- Carpet tile shall be used where acoustics is a concern, most notably in office work areas, so that maintenance of systems under the floor can be done without destroying the carpet.
- The RAF system (i.e., panels, pedestals, and stringers) shall be designed so that resonance frequencies of the RAF and slab are avoided. The vibration of the combination of RAF system and the slab shall meet the *Floor Vibration* requirements in Chapter 4, Section 4 of the PBS P-100.

## 4.3 Fire, Smoke, Safety, and Security Zone Issues and Criteria

As indicated in the previous Sections, some features and characteristics of RAF are similar to overhead distribution systems. However, there are significant differences, including the proximity in the RAF cavities of potential fire, smoke and other hazards to the occupants. This Section specifies minimum criteria to reduce risks to occupants, first responders, and property assets.

### 4.3.1 Issues

Fire, smoke and life safety issues in facilities with RAF include:

- NFPA 75: *Protection of Electronic Computer/Data Processing Equipment* addresses a variety of requirements for raised access floors in "information technology rooms." For the purposes of Chapter 7, Section 16 in PBS P-100, "Essential Electronic Facilities" are "information technology equipment rooms" as used in Chapter 8 of NFPA 75 and related provisions.

- Detection and extinguishment systems in the cavities under RAF systems are not addressed in the model codes and are unevenly addressed by local jurisdictions except in areas covered by NFPA 75. This lack of guidance could become an issue if insulation or other materials were to ignite in these cavities. Detection by ceiling smoke or heat sensors could be delayed and extinguishment by ceiling sprinklers would be improbable. However, adding detection and extinguishment under all raised access floors would be a significant cost consideration.
- Detection and extinguishment systems, which are placed within the RAF cavity, must be coordinated with the above-floor systems and be included in the fire control center monitoring capabilities.
- If a fire were to occur in a RAF cavity, there could be a special hazard to first responders should there be failures in the floor system or if sections of the floor panels were missing at the time. In a smoke-filled, unlighted environment, the raised access floor could add another challenge to the firefighters.
- Where fire and smoke-rated partitions are required, they should pass through the raised access floor to the slab using the same construction means and methods as for such partitions above ceilings, including firestopping, fire dampers, etc. This procedure must include the RAF cavity under doorways.

Security issues in facilities with RAF include:

- Where RAF is used within a secured area, the secured wall or partition enclosure must be maintained below the floor as it is above a ceiling.
- If security includes acoustic isolation, the surrounding construction must have the same acoustic properties below the floor as above.
- Where openings occur in secured partitions below the floor, they must be protected in a similar manner as the openings above the ceiling. Where intrusion alarms are required above the ceiling, they should similarly be provided in the RAF cavity.
- The same special secure construction for SCIFs applies to RAF as to suspended ceilings.

Physical Safety issues in facilities with RAF include:

- The full load capability of a RAF is only realized when all of the floor panels are in place, as the buckling (lateral) strength of the floor depends on the presence of the panels. The safety of occupants must be assured whenever floor panels and any associated stringers are damaged or removed.

- Procedures to assure safe performance of the RAF after stringers and panels have been replaced shall be specified (See Sections 6 and 7 of this Guideline for additional discussion).

### 4.3.2 Minimum Criteria

As a minimum, the selected RAF system shall comply with the following fire-safety, smoke management, safety, and security criteria when all panels are installed:

- The RAF zone size for fire-safety, smoke management and security shall not exceed 5,000 square feet of floor area.
- Where zones are established by code or program needs for the space served by the RAF, the demising partitions shall extend into the space under the floor as well as above ceilings.
- Fire extinguishment systems as required in Chapter 8 of NFPA 75 shall be provided under RAF for "Essential Electronic Facilities", but not under RAF for other spaces unless so directed by the GSA Fire Protection Engineer through the Project Manager.
- Fire detection systems, as described in Paragraph 8.2 of NFPA 75, shall be provided under all raised access floors unless exempted by the GSA Fire Protection Engineer through the Project Manager.
- To minimize the detection time of emissions from combustion precursors in RAF cavities under Essential Electronic Facilities as provided in Chapter 7, Section 16 of PBS P-100, "early warning smoke detectors" in accordance with NFPA 75 paragraph 8.2 shall be installed under the RAF zones in these facilities (see Section 5.0 of this Guideline for additional details). In consultation with the GSA regional fire protection engineer, the following shall be determined:
  - The area of coverage and response time of the detectors.
  - The alarm function (at the Fire Command Center) and the control functions (e.g., equipment and power shutdown).
- To minimize the risk of an electrical fire beneath the RAF caused by the inadvertent release of a sprinkler head in a zone, an interlock with the Emergency Power Off (EPO) Station shall be installed (see Section 5.0 of this Guideline for additional details). The control

circuit shall be designed in consultation with the GSA Regional Fire Protection Engineer.

- Egress requirements in Chapters 7 and 8 of PBS P-100 do not address the special case of fires and toxic emissions in RAF cavities (i.e., fire, smoke, and chemicals beneath the breathing levels of the occupants). Because of the increased risk as a function of wiring and cabling density and potential security breaches beneath RAF, egress requirements for RAF zones shall be evaluated on a site-specific basis in consultation with the GSA Regional Fire Protection Engineer.
- The maximum number of contiguous panels and associated stringers that can be removed for access to the cabling, wiring or air distribution components shall be specified.
- To minimize safety risks to first responders, GSA Project Managers and design A/Es shall review with local first responders the locations and designs of areas in the building where raised access flooring is proposed, and take into consideration any recommendations to improve safety.

## 4.4 Interfaces with Architectural Materials

The following supplemental interfaces with adjacent finishes in new construction must be considered during design:

- In new construction, raised access floors should intersect partitions, columns and other vertical surfaces in the same way as conventional floor finishes, which usually consists of a top-set base of resilient wood or other material allowed by code. In the case of RAF, if the panels abutting the vertical surface must be removable to access some equipment or device there, the base must not prevent that. Panels on stringers are easily removed without tools, so the next panel can be lifted out to allow the one against the wall to be slid away without damage. Panels bolted to pedestals may be similarly removed, though tools are needed to do so, and the edge panel's fasteners to pedestals may be inaccessible under the baseboard or trim.
- Where stairs occur in raised floor areas, special detailing around the first riser, the stringers and other features will be needed to ensure an acceptable condition.

- Where raised access floor surfaces abut other floor surfaces, the detail of the joint between the two must be designed to avoid damage to the access floor panels from rolling loads as they cross the joint. Generally, this will require firm support of the panel on that edge.
- In existing construction, the interface with vertical surfaces is more complex.

Where raised access flooring is used in existing buildings, the following must be resolved:

- Ramps to the raised floor from existing floors such as stair landings, elevator lobbies, toilet rooms and other spaces: ramps must comply with accessibility requirements (See Chapter 1, Section 10 of PBS P-100).
- Existing door openings must have sufficient height to clear the raised floor unless the heads of the openings can be raised in architecturally acceptable ways. In historically and architecturally significant buildings, it may be inadvisable or impossible to raise entire doorways intact, and the raised floor may interfere with jamb plinths.
- Existing ornate wall paneling, baseboards, pilasters, etc. may not be compatible with raised access floor if the new floor level cannot be accommodated by raising the baseboard without spoiling the wall treatment.
- Existing window stools – especially those virtually at existing floor level – and under-stool radiators may not be easily interfaced with new raised access flooring.
- Existing ornate grilles such as for heating and ventilating may not be easily raised to clear the raised access floor.

Many of the above problems may be similar to those encountered when adding a suspended ceiling in an existing historically and architecturally significant buildings, which may have the added problem of obscuring ornate ceilings.

## 4.5 RAF Grids and Cavity Heights

In general, raised access floor panels used in the U.S. are 24" x 24" (600 mm x 600 mm) which is the same as the Planning Grid in PBS P-100. The panel edge should abut the finished surface of a penetrating or demising partition.

The pedestal height is determined by the need for wiring and cabling management or other systems below the floor, including anticipated expansion. If ductwork, piping and equipment must be accommodated along with wiring and cabling, the systems must be sized and laid out early in the design to ensure that adequate clearances are provided between pedestals and from slab to lowest part of the understructure, such as the stringers or service outlets.

Ceiling heights required in Chapter 3, Section 2: *Space Planning* of PBS P-100, must be measured from the top of the finished floor panel to the underside of the ceiling, whether suspended or not. The importance of determining the pedestal height very early in the design obviously affects the entire building section and overall heights. Raised access flooring in itself may or may not result in additional building height, depending on ceiling conditions.

## 5.0 Electrical Design Considerations and Criteria

Basic requirements for normal and emergency electrical power wiring distribution and for communications cabling beneath the RAF, and for grounding of the RAF, are described in Chapter 6, Sections 10 – 14 of PBS P-100. The following items highlight and supplement the PBS P-100 requirements:

- Separate panelboards shall be provided for the power circuits routed beneath RAF.
- All wiring beneath RAF shall be routed in rigid metal or flexible conduit to underfloor distribution boxes; one distribution box per bay is recommended.
- Flush-mounted access floor service boxes shall be attached to the underfloor distribution boxes by means of a modular, prewired system to facilitate easy relocation.
- Where distribution of emergency and clean power is required in areas served by RAF, special consideration shall be given to assure the availability of the power during emergency conditions (e.g., which, if any, emergency power circuits should be located beneath the RAF).
- The standard option for delivering communications services in Federal buildings is by laying cable in a tray for main runs and then branching directly on the floor slab below the RAF. Special consideration shall be given to the location of the cable trays in RAF cavities where plumbing or hydronic piping is co-located.

- All RAF shall be grounded. A grounding conductor shall be bonded to every other floor pedestal and shall be extended to a common ground bus.
- Emergency lighting systems shall not be wired through the RAF.

For protection of emergency responders and occupants in areas or zones with RAF (see Section 4.3 of this Guideline), Emergency Power Off (EPO) stations shall be located at each major point of egress at that zone. The function of the EPO stations shall be to disconnect all electrical power circuits beneath the RAF zone, before the response team enters the area. To avoid false alarms, the EPO stations shall be designed for use only by authorized personnel.

## 6.0 Requirements for Documentation

### 6.1 Specifications for Raised Access Flooring

If the Masterspec© Guide specification Section 10270 is used, careful reference to the Evaluations will provide guidance to the selection of raised access floor types in response to project-specific conditions. Special attention should be devoted to:

- Requiring a pre-installation meeting to ensure proper coordination of systems intended to be placed under the floor, with the floor installation itself, and to emphasize the need to keep the underfloor space clean.
- Requiring manufacturer certification in submittals of performance requirements specified, especially seismic.
- Clear detailing on design and shop drawings of critical areas such as edge conditions.
- Citation of all affected related sections including those in Divisions 15 and 16.
- Methods of cleaning the RAF cavities, including the installation of a central vacuum cleaning system with multiple locations to facilitate cleaning the RAF cavity.

If other guide specifications are used, attention to the same issues as above is strongly recommended. Proprietary specifications (and details) from individual manufacturers are discouraged especially since they could result in exclusions of appropriate alternative brands, eliminate meaningful competition, and result in higher costs.

## 6.2 Drawing Details for Raised Access Flooring

As proprietary products, raised access floors shall be shown on the drawings generically, with the details focusing on the project-specific interfaces with other building components and systems. Typically, details shall include:

- Edge conditions at partitions, columns, walls, and built-up adjacent floors.
- Edges and thresholds under elevator entrances, stair landings, ramps, etc.
- Partitions mounted on top of raised access floors.
- Special acoustics and acoustic seals.
- Special trim and other details for raised floors in existing buildings, especially where ornate wall, door and window conditions occur.

Where more than one type of raised access floor, pedestal height or system occurs, plans shall clearly show the extent of each type or condition.

Locations of underfloor equipment, if any, with respect to floor grid or above-floor features shall be shown.

Locations of floor service outlets, registers, grilles and diffusers, if any, with respect to modular furniture or other above-floor features shall be shown.

## 6.3 Construction Documents before Release

Because of the special details that are required for RAF systems, additional quality control of the construction documents shall be conducted. In addition to the Checklists provided in Appendix A.3 of the P-100, a Supplemental Review Checklist for RAF without UFAD is to be provided.

## 6.4 Operations and Maintenance Documents

The Property Manager shall be aware, by instructions and documentation from the raised floor manufacturer and the design team before, during and/or after installation, of the special issues involved in the operation of a building with raised access flooring, including:

- Periodic cleaning of the underfloor space, especially where panels have been removed for maintenance and repair, such as in computer rooms.
- Relocation of device outlets, floor registers, grilles and diffusers, if any, when workstation furniture, partitions or equipment are moved.

- Proper training of maintenance personnel in:
  - Safety procedures in removing and replacing panels and stringers.
  - Cleaning products to be used on panel surfaces and beneath the RAF.
  - Handling and protecting panels when removing and replacing them.
- Repair and/or replacement of floor panels with damage, such as:
  - Excessive deformation from impact so that adjacent panels do not meet tightly.
  - Loss of panel edges allowing openings between panels.
- Procedures for cutting openings in floor panels, sealing edges, etc.

## 6.5 As-Built Drawings

Along with the transfer of responsibility to the ownership team, and usually as part of the commissioning process, it is common to provide the owner with key documents and records for reference in operating the facility. Benefits of raised access floors are the ability to relocate or to provide electric power or voice/data outlets and air supply outlets as the need arises. To gain maximum benefit from the ease of these tasks mandates that the Property Manager maintain up-to-date records on the location and routing of all cables, pipes and devices.

The As-built Drawings should be maintained, preferably in electronic form, and each time a modification is undertaken, the drawings should be updated. It is highly recommended to remove abandoned cables and wires, or indicate on the As-built Drawings that they have been abandoned in place.

When replacing cables, the color coding format used in the construction phase should be adhered to. Any deviation from this format shall be indicated on the As-built Drawings.

The Property Manager should ensure that first responders – especially fire fighters – know of the presence of the RAF so that in event of an emergency, they are aware that they must proceed with caution in areas with the raised floor (see Section 4.3 of this Guideline).

## 6.6 Housekeeping

A visual inspection shall be made periodically to assess the cleanliness of the floor cavity. At the completion of construction, the below-floor cavity should have been sealed and thoroughly cleaned. However, over time it may become contaminated with airborne dust, insect colonies, vermin, microbial growth, moisture, or other foreign materials. It is necessary that any such inspection be planned in such a manner that all areas can be visually inspected. The cleaning of RAF cavities should be performed and documented by those who specialize in this work, as there is always the possibility of causing damage to cable layouts or connections, mechanical devices, and, anyone working in the floor cavity may be subject to personal harm because of the electric power devices.

## 7.0 Inspection, Testing and Commissioning

Sections 3 – 6 of this Guideline include considerable information concerning the coordination of the multiple trades in assuring the structural, wire-management, fire safety, and security performance of RAF systems. To achieve this required performance, diligence is required from multiple layers of responsibility in inspecting the work as the construction activities proceed.

### 7.1 Inspection

In general terms, the levels of inspection for RAF without UFAD are the same as for conventional flooring systems, and are as follows:

Level

1. Self inspection by tradesmen performing the work on a specific task.

2. Inspection of a specific task by foreman.

3. Inspection of multiple tasks in a given trade by foreman and responsible executive.

4. Inspection of given trade of interface with other trades by foreman and/or responsible executive.

5. Inspection of integrated trades and tasks comprising the whole by superintendent of construction.

6. Inspection of integrated trades and tasks comprising the whole by responsible design team representative and commissioning agent (where applicable).

7. Inspection of integrated trades and tasks comprising the whole by owner's agent or representative.

Some levels of inspection are understandably more formal than others. In general, the top three levels (5, 6 and 7) should require a formality of inspection and "approval" of some nature. This is particularly true when the successful achievement of numerous trades is necessary for the performance of the completed RAF system.

## 7.2 Testing and Commissioning

Following the completion of the construction and the various levels of inspection and approvals, the system is ready to be tested, as part of the commissioning process. Structural and seismic performance tests (see Sections 4.2.1 and 4.2.2) may be required under special conditions, otherwise inspection for compliance with specifications may be sufficient. However, performance testing for cable and wire management (see Sections 3 and 5), acoustics and vibration control (see Section 4.2.3) and fire and security control (see Section 4.3) shall be conducted as part of the commissioning process. The commissioning agent shall serve an inspection and documentation role as defined in the level 6 inspection step (see Section 7.1).

## U.S. Courthouse, Los Angeles, California

# Part 2:
# Underfloor Air Distribution (UFAD) Systems

## 8.0 Features and Characteristics

When the raised access floor (RAF) cavity serves the secondary purpose of delivering conditioned air to occupied zones (e.g., office areas and courtrooms), the floor system becomes known as an *Underfloor Air Distribution (UFAD) System*. As indicated in Section 1.0 of this Guideline, the genesis of contemporary UFAD systems was from main frame computer facilities in the mid twentieth century, in which the computer room had numerous types of computers and data processors with relatively high and constant heat dissipation rates. The major objective of the cooling system was to remove the heat from the machinery while maintaining a relatively constant dry bulb temperature and relative humidity in the computer room. These facilities generally consisted of one room conditioned as a single zone with conditioned air supplied into the floor cavity from a packaged air-conditioning unit or units. Air supply outlets were generally placed in the floor panels near the heat sources in such locations as to minimize discomfort to the individuals "operating" the computer machinery. The cooling loads were usually high density and relatively constant.

During the closing years of the century, computer, data, and communication technology had undergone extensive changes that significantly impacted the workplace environment. Area lighting was being replaced by a combination of environmental and task lighting; and convenience power outlets were required for personal computers, printers, and other electrical devices. And, there was the network of cables required for communications, data transmission, signaling, safety and environmental control systems.

As discussed in Section 1.0, a logical method of distributing and managing this multitude of wires was in an accessible underfloor cavity much like the computer rooms of fifty years earlier. Also, like the computer rooms of fifty years earlier, the presence of the underfloor cavity provided the opportunity to use it as a supply air plenum to deliver conditioned air to the vicinity of the work stations for the purpose of air conditioning for human comfort.

Thermodynamically, however, there is little similarity between the earlier process of serving single, reasonably high density and relatively constant machine cooling loads and providing air conditioning for human comfort from a single conditioning system to multiple zones of control with widely varying loads.

Functionally, UFAD systems have many similarities to the more "conventional air distribution" (CAD) systems, such as overhead or fan-coil systems. Both UFAD and CAD systems must provide the same environmental conditions for human comfort during load conditions that vary from full cooling loads, to no loads, to full heating loads. At the same time, both systems are expected to maintain the required ventilation rates at all occupied times in each room or space being conditioned, satisfy different part load requirements in adjoining zones, maintain air-pressure differences between zones and, when required, provide zone isolation for contaminant, acoustic and security control. However, the methods for achieving this control are significantly different for UFAD and CAD systems. CAD systems depend on induction of supply air (e.g., from ceiling diffusers or sidewall grilles) with room air that is not in the occupied zone to provide comfort conditions in the occupied zone while ventilating and pressuring the zone. Conversely, UFAD systems depend on mixing supply air (e.g., from the floor plenum) with room air in the occupied zone to provide thermal comfort, ventilation and pressurization. Moreover, the return air for both UFAD and CAD systems is typically through ceiling grilles into return air plenums. Thus, the psychrometrics for UFAD systems must be designed to include additional processes in order to achieve the same conditions in the occupied zones.

In addition to the psychrometric and air distribution differences between UFAD and CAD systems, there are significant physical issues that must be resolved concerning the underfloor supply air plenum, including water incursion, alarm and drainage; air leakage into the conditioned space and into building cavities; thermal inertia of plenum floor slabs and walls; interferences between mechanical and electrical components and devices; acoustical isolation; fire safety and alarms, etc.

The most fundamental step in the decision-making process of whether or not to use an underfloor air distribution (UFAD) system should always be directed toward the objective of providing an air-conditioning system that will meet all of the thermal comfort, indoor air quality, acoustic and vibration (i.e., environmental quality) criteria without compromise. As in the selection of any such system, the design study should start with analyzing the zones that are to be occupied. The two major issues to be resolved in this regard are first, room air distribution and, second, the control techniques. (Additional information is provided in Appendix A-3 of this Guideline).

All building areas to be considered for UFAD should be carefully evaluated on a case-by-case basis, but the following are some general guidelines for appropriateness. Similar to the applications for RAF discussed in Section 1.0, the areas that are most suitable for UFAD include:

- Computer rooms and other information technology or electronic equipment spaces.
- General open office areas.
- Training and conference areas.
- Exhibit spaces.

Some areas require special precautions if UFAD is used:

- **Elevator lobbies**: If necessary, UFAD may be used, though the detail of the edge of the floor with the sill of the elevator opening must ensure edge support for rolling loads as carts are rolled off an elevator onto the floor. The plenum must be sealed at the sill of the elevator to ensure that the underfloor plenum does not leak into shaft spaces.
- **Auditorium, jury box and other courtroom seating areas** with sloped or stepped floors. Special care must be taken to properly seal sloped areas and areas with steps. Scissor lifts to raised platforms for accessibility must be detailed with bulkheads around the mechanism to prevent air leakage from the plenum.
- **Secure spaces** such as secure corridors, credit unions, and the Security Control Center. If used in these areas, the secure construction of the surrounding walls must extend through the raised access floor to the slab below, and openings for UFAD airflow must be securely barred to prevent surreptitious exit.
- **Response spaces**, such as the Fire Command Center, Engineering and BAS Center: These areas must function not only at all normal periods, but also during emergency conditions.

Some areas are inappropriate for UFAD:

- **Slab-on-grade locations**: Long term protection is difficult against heat, moisture, and contaminant transfer with the soil, soil gases, ground water, and vermin through joints and cracks. UFAD shall not be placed directly on concrete slab-on-grade surfaces.

- **Slabs over garages, overhangs, and loading docks**: Long term protection is difficult against heat, moisture, and contaminant transfer through joints and cracks in concrete slabs over these locations. UFAD shall not be placed directly on concrete slabs over these locations.
- **Toilets, showers, baths, janitors' closets, dishwashing and other wet areas** have plumbing fixtures which cannot rest on a raised access floor and could not support UFAD. Potential leakage and high humidity can cause corrosion of panels and understructure and encourage growth of mold and bacteria. The risk of overflow of water from fixtures or leakage from water piping is exacerbated in UFAD because the plenum must be airtight, so the plenum could literally fill with water and cause structural failure.
- **Kitchens and food preparation areas** are unsuitable for the same reasons as for the spaces listed above. In addition to the hazards of leakage and wet operations, the amount of equipment and heavy traffic make floor diffusers undesirable. Some break rooms with kitchenettes have been placed on raised access floors with UFAD when water supply and drains have been possible by connection to a wet column. But the risk of spillage of food and liquids and seepage into the underfloor space makes this a potential problem area. The risk of leakage of water into the plenum is as discussed above for other wet spaces. The risk of vermin below the floor is high.
- **Laboratories** – similar challenges in accommodating plumbing and preventing leakage into the plenum exist as for toilets, etc., depending upon whether the laboratory has any wet processes, emergency showers, chemical spills, etc.
- **Prisoner cells or holding cells**.
- **Fire stairs.** Stair landings must interface with any adjacent raised access floors as a flush condition with the edge of the access floor well supported. UFAD extended into the stair area must be sealed to prevent flow of air into spaces within the stair, if hollow such as in steel construction, thence to other spaces;
- **Mechanical equipment rooms** such as boiler and chiller rooms, and rooms for primary air-handling units (AHU).
- **Central storage rooms and loading areas, trash rooms**, etc.

- **UPS, emergency generator, and similar rooms**.
- **Fitness centers** where equipment, mats and other items could cover floor diffusers frequently.
- **High traffic areas** such as lobbies, atria and major corridors where floor diffusers could be easily damaged, become a tripping hazard or collect dirt tracked over them.
- **Dining areas** where tables and chairs would regularly impede the diffuser air flow, and where spills of liquids and solids are common. Floor air diffusers could also be uncomfortable for diners.
- **Child care centers** where playthings, equipment and mats will often cover floor diffusers, and where floor diffusers may provide tempting objects for children to play with, drop things into, etc. Children on the floor may not be comfortable with the air distribution pattern, and could be at increased risk to exposures from contaminants in the plenum.

## 9.0 Economic Considerations for Underfloor Air Distribution

As indicated in the Introduction of this Guideline, Section 4 in Chapter 5 of PBS P-100 identifies UFAD as one of the four *Perimeter and Interior Heating and Cooling Systems* that may be considered as the HVAC Baseline System. For the basic case where the application of UFAD is being considered for an area of the facility in which RAF has previously been selected in accordance with Part 1, the application of UFAD will require modifications to the design of the RAF in accordance with Part 2. However, for the case where an UFAD application is being considered for an area in which an RAF has not been previously selected for cable management, the RAF must perform in accordance with Part 2 and the relevant sections of Part 1.

Therefore, to ensure that the value of the contemplated UFAD system is maximized, a benefit-cost method shall be utilized in which the life cycle costs and benefits of UFAD in areas with horizontal pathways for wiring and cabling distribution below the RAF, as modified for UFAD in accordance with Part 2 (see Sections 10.0, 11.1 – 11.7 and 12.1 – 12.3), are compared to the life cycle costs and benefits of a facility with a CAD system and horizontal pathways for wiring and cabling distribution below the RAF, assuming it has been selected in accordance with Part 1 but not modified in accordance with Part 2. For areas where RAF has not been previously selected, the life cycle costs and benefits of the contemplated UFAD with RAF that is in accordance with Parts 1 and 2 shall be compared with a CAD system, conventional flooring, and horizontal pathways for wiring and cabling distribution above the suspended ceiling. UFAD is economically preferred if the benefit-cost ratio of UFAD exceeds that of CAD.

UFAD is one of many options that must be assessed in determining value of a design. UFAD may increase or decrease this value. The benefit-cost analysis must include first cost, long-term operations and maintenance, and continuous testing for acceptable levels of air leakage from the UFAD plenum throughout the life of the system. Economic considerations shall also include the impact that utilization of UFAD may have on health, safety, security, and sustainability (see Chapter 1, Sections 2 and 6 of PBS P-100).

Appendix A-2 of this Guideline describes methods for quantitative analysis and also provides information relating to benefits and costs that can be used in qualitative assessments. It includes discussion of:

- Benefit-Cost and LCC Methods
- Incremental Benefit Factors
- Incremental Risk Factors
- Incremental Cost Factors

If a quantitative analysis is not possible for a specific project, a qualitative assessment shall be performed as outlined in Appendix A-2.

## 10.0 Interface between Cable Management and Air Distribution

Many of the issues of cable management for UFAD are the same as for RAF (see Section 3.0 of this Guideline). But the application of UFAD adds issues that must be addressed in cable management because the UFAD plenum must be airtight.

- All penetrations of wiring and cable entering or exiting the plenum and passing through underfloor air barriers must be made airtight. This may be accomplished in some cases by gasketing or other methods of sealing. Methods of achieving this air tightness shall be planned for and specified (see Sections 11 – 15 for additional guidance).

- Even when the most rigorous care has been taken to seal wiring and cable that enters the plenum, even greater care must be continued after occupancy to re-seal openings where cable, conduit and other wiring devices are removed and to be sure new wiring, cable and conduit are sealed when installed later on. This latter level of care may be the most difficult to achieve since the replacement of wiring will go on for the life of the building, long after the original occupants and managers have left. Methods of training contractors and Property Managers on sustaining the air tightness shall be planned for and implemented (see Section 14 for additional guidance).
- The potential hazard of fire and smoke is always present with large aggregations of electric wiring, especially as time passes and wiring is changed, flexed and reattached. Because an underfloor air plenum of UFAD is where the primary air supply is located, the propagation of smoke and other toxic emissions from an electrical fire is far greater and immediate than when the air supply is ducted. Additional methods of smoke and fire detection and protection shall be planned for and implemented (see Sections 11.5 – 11.6 for additional guidance).
- Methods of ensuring adequate clearance for wiring, cabling, air ducts, and other services in the UFAD plenum shall be planned for, detailed on drawings, and ensured during construction, operations and maintenance, and modifications (see Sections 11 – 15 for additional guidance).
- Where exiting from the UFAD plenum, power, communication and data wiring must be placed in junction boxes that are air-tight. Methods of ensuring air tightness during operations, maintenance and operations shall be planned for and implemented (see Sections 14 and 15 for additional guidance).

# 11.0 Architectural Design Considerations

The introduction of *plenum* underfloor air distribution (as differentiated from *ducted* underfloor air distribution) through raised access floors (i.e., RAF *with* UFAD) requires special design attention of the architect to bring together a variety of building products and systems to create an airtight plenum. The use of the underfloor space as an air plenum for cooling is as old as the use of raised access floors in computer rooms. Fifty years of computer room experience and more recent experience with UFAD have provided lessons that must be applied to future UFAD installations if the systems are to perform according to desired expectations, including:

- Maintenance of the plenum static pressure to allow floor diffusers to effectively supply clean and thermally treated (e.g., cooled and dehumidified, heated and humidified, and filtered) air for occupant health and comfort, and to achieve expected return air temperatures and airflow rates.
- Prevention of contamination of supply air with particulates, vapors and gases that may accumulate in the plenum.
- Coordination of the plenum space to accommodate all systems – structural, architectural, mechanical and electrical – that need to be in the space while ensuring that all will function properly.
- Operation and maintenance procedures that can ensure long-term health, safety, comfort, customer satisfaction, and economic performance.

## 11.1 Soil and Climatic Conditions and Criteria

Incursions from soil and climatic conditions into the supply air plenums of UFAD systems require special consideration and control. These plenums must remain impervious to air infiltration and water and contaminant incursions from above-grade and below-grade ambient sources throughout the life of the facility. The design criteria for soil and climatic conditions that are described in Section 4.1 of this Guideline pertain equally to facilities with RAF *with* and *without* UFAD. However, RAF *with* UFAD requires control of four additional conditions: 1) the incremental heat transfer through slabs and perimeter wall surfaces to the plenums due to the requirement to maintain the dry bulb and dew point temperatures of the supply air in the plenums at lower values than for RAF *without* UFAD; 2) the requirement to maintain positive static pressures in the UFAD plenums; 3) the incremental requirement to minimize leakage of air, water, soil gas, vermin and microbiological contaminants through the joints, connections, and subsequent cracks in the slab and perimeter wall surfaces exposed to the plenums (see Section 8.0 of this Guideline); and 4) the incremental requirement to minimize the transfer of soil or outdoor contaminants from the supply air plenums to the occupants or to the wire and cable management systems. Although the criteria are the same as those given in Section 4.1, the methods of control, which are incrementally different for RAF *with* UFAD, are described in the following Sections.

## 11.2 Air Leakage and Water Accumulation Issues and Criteria for UFAD Plenums

### 11.2.1 Plenum Air Leakage and Performance Criteria

The fundamental difference between RAF systems without UFAD and those with UFAD is the need to construct the systems essentially airtight, if they are to serve as supply air plenums. With *ducted* CAD systems, the need for less air leakage has led to improved methods of construction and the increasing use of various sealing methods as systems have been designed with less excess capacity and for better energy efficiency. Specifications for air leakage rate limitations should be the same for underfloor air plenums as for supply ductwork operating in an equivalent pressure range (ASHRAE Handbook of Fundamentals 2001 Volume 1, Chapter 34). If this were the case, the expected air leakage as a percent of supply air flow would be 1.3 % (as determined from Table 9, Chapter 34, for a duct with Leakage Class 6 , a flow rate of 3 cfm/100 $ft^2$ and static pressure of 0.5 in. w.g.). However, as discussed and categorized below (i.e., Categories 1 and 2), UFAD plenums are much more complex than a duct section, and air leakage through all pathways is expected to exceed that from a duct section.

*Therefore, as a maximum, the total air leakage from all Category 1 and Category 2 leaks shall not exceed 0.1 cfm/ft² floor area or10% of the design supply airflow rate, whichever value is smaller, when the plenum static pressure is main-*

*tained at its control value (e.g., 0.1 in. w.g.)* (See Section 15.2 for additional performance criteria and test methods).

From the standpoint of system performance and these air leakage criteria, plenum leaks fall into two distinctly different categories:

**Category 1 leaks** (i.e., General Construction Leaks) are leaks of cool conditioned supply air from the underfloor plenum into other building cavities thence either from the building or into return air passages back to the air handling units or building exhaust air system. Such leaks have several negative impacts upon the system performance, the most immediate of which is that, if the leakage rate is severe enough, there may not be enough air left to adequately cool the space under high load conditions. Under that condition or conditions of even less such leakage, where the space load can still be handled, such leaks cause an energy burden of the worst kind – waste! All of the thermodynamic energy used to condition the air and the ventilation (outdoor) air it contains is wasted through loss. Additionally, the fan energy to move the air through the conditioning units and the distribution system is wasted. If the air leaks into plenums with surface temperatures below the plenum air dew point temperature, condensation, with its consequences (e.g., mold growth, rust, deterioration), can occur.

**Category 2 leaks** (i.e., Product Leaks) are those that leak air through raised floor system components into the space to be conditioned. The major cause of troublesome Category 2 leaks is specifying the wrong type products. The components through which such leaks occur include:

- Floor panel seams and edge closures.
- Electric power connection and outlet devices.
- Communications & data cable outlet devices.
- Air diffuser devices that do not close tightly.

When specifying these devices, care shall be taken to specify ones that are designed to be airtight when subjected to pressure values that will be experienced with the respective floor system. There has been extensive discussion in the industry regarding the effects of the plenum air leakage into the occupied space and only the mechanical systems designer can determine the leakage rate that would be detrimental to the system performance. It depends upon the load analysis for each individual space. For example, consider an interior room, say, a private office. When no one is occupying the office and the lights are out there is no load. If even a small quantity of air leakage provides a constant flow of, say, 63º F air into the room, the room air and its furnishings will ultimately reach 63ºF. Designers of early VAV systems called this phenomenon the "ice box effect" which they solved with tight shutoff boxes, fan powered mixing or reheat – none of which are available to apply to air leakage from the floor. Thus Category 2 air leakage should either be avoided or understood, and assurances taken to offset the detrimental effects.

Another design option relating to Category 2 leaks would be to provide zone baffles around each controlled zone and to duct supply air into the zone through a VAV control terminal – thus supplying the amount of air into the plenum that is required by the thermostat to handle the room load. Under this scenario, the floor leakage would not be a thermal comfort factor. The main disadvantage would be the negative impact the duct and zone partitions would have on cable routing and the location of machinery below the floor.

*Because of the detrimental effect that leakage can have on performance, the underfloor plenums shall be thoroughly leak tested and approved by the general contractor, commissioning agent, architect/engineer of record and the owner's agent* (see Section 15 for additional guidance).

Except for computer room applications, few manufacturers offer products specifically designed for UFAD in non-computer room environments, where leakage from the plenum and loss of static pressure is specifically addressed. Section 15.2 provides additional guidance and criteria that shall be used to minimizing air leakage, and Section 11.6 provides additional guidance and criteria that shall be used to ensure water detection and control.

Air leakage in RAF products and general construction can occur through:

- Joints or cracks between panels:
    - In order that panels be readily removed and replaced for access

purposes, the joints are usually not gasketed, so air can leak through these joints or cracks between the panels. Even if gaskets are provided, removal of panels over time can damage the gaskets and edge trim. These cracks not only allow air to escape from the plenum, they also allow contaminants to enter the plenum by gravity or induction – especially during cleaning of the floor surface.

  - Where carpet tiles are staggered to cover the panel joints, leakage can be reduced, though field data on the effectiveness under actual operations are not available.
  - At least one manufacturer offers a non-structural air-seal strip for use at panel joints where no stringers are used, though data on the effectiveness is not available.
  - Stringer understructures may reduce the leakage between panels, though data on the effectiveness is not available.
- Panel accessories:
  - The recessed units for plug-in of power, data and communications are typically not designed to be airtight (i.e., they have been designed for RAF without UFAD). Experience has shown these units to be a significant source of air leakage (i.e., approximately 10 – 15 cfm/device at 0.1 in. w.g.). Control of this air leakage is a matter of product design that the designer must resolve with proposed manufacturers by requiring maximum acceptable leakage rates in the specifications.
  - Floor diffusers may leak significantly when supposedly closed. Experience also has shown these diffusers to be a significant source of air leakage (i.e., approximately 10 – 15 cfm/device at 0.1 in. w.g.). Control of this air leakage is a matter of product design that the designer must resolve with proposed manufacturers by requiring maximum acceptable leakage rates in the specifications (see Sections 14.1 and 15.2).
- Intersection of the RAF with other construction:
  - Most building trades are not accustomed to rigorous procedures to ensure an airtight assembly, so detailing must be very clear on the need to seal the many potential points where leakage might occur (see Sections 11.3 and 14 for additional guidance):
  - At all walls, partitions and columns,

the floor panels must fit tightly against all vertical surfaces surrounding or penetrating the plenum. These joints must be sealed with sealant or gaskets.

- All wall finishes, such as gypsum board, must extend to the slab of the plenum floor, be provided with a j-bead or other edge trim and be sealed with sealant to prevent leakage of plenum air into voids such as partition framing, furring and the like.
- At exterior walls where the plenum slab ends, airtight firestopping material must be used to prevent leakage to the space below.
- At abutting built-up floor construction, such as at toilet rooms, stair landings and elevator shafts, solid air *barriers* must be installed to prevent leakage into shafts or voids in the adjacent floor construction.
- At expansion joints, the expansion joint resilient filler construction must be airtight to prevent leakage from the plenum to the space below or through the raised access floor itself.
- Where other equipment or construction penetrates the plenum, such as platform lifts, sliding fire doors, stairs, etc., the penetrations must be isolated with airtight bulkheads.
- Wherever pipes, conduit, ducts or other items penetrate the wall of the plenum, they must be sealed fully around the perimeter.

Therefore, in order to minimize air leakage through joint and cracks between panels, through the interfaces with other construction, and through the panels, themselves, raised access floors for UFAD applications shall be provided with stringers or other demonstrably equivalent air-sealing devices, staggered carpet tiles shall be provided, and floor panel accessories with minimum leakage values shall be specified and installed.

### 11.2.2 Water Accumulation and Performance Criteria

Having sealed all joints of the air plenum to make it airtight, it will then be effectively watertight as well, and vulnerable to indoor flooding. Should sprinklers discharge, hydronic or other devices leak, or condensation build up on cold perimeter surfaces, water can accumulate:

- In the event of a major leak such as a sprinkler discharge, water could fill the plenum and, unless the structure is designed for the load, failure could occur. To prevent water accumulation in the plenum, the following methods shall be considered:

- Moisture detectors in the plenum alarmed to a 24/7 monitoring location such as the security control center would provide early warning so systems could be shut down. Some sensors are not very robust when accidentally stepped on or otherwise damaged.
- Floor drains designed to be airtight when inactive or self-priming floor drains may be more reliable (see Sections 11.6 for additional guidance and criteria).
- Design of the structure to support a water-filled plenum is possible, but may be cost-prohibitive.

- Other leaks or moisture accumulation may not pose a flooding risk, but can cause significant damage to the wiring and cabling, corrode the RAF panels and understructure, and result in growth of mold and bacteria on these surfaces. To minimize the risk of water accumulation from other leaks or condensation, the following methods must be considered:
  - Cold surfaces such as overhangs of the slab under the UFAD or contact of the slab with the outdoor temperatures through spandrels should be insulated and a vapor retarder should be installed on the warm side of the surface (see Section 8.0 for additional guidance on areas where UFAD is not appropriate).
  - Plumbing, sanitary, and hydronic piping should not be installed in UFAD plenums.
  - Provide supply air to the plenums at dew point temperatures at values not to exceed 50°F (10°C).

## 11.3 Structural and Seismic Considerations

The structural factors influencing the RAF design (see Sections 4.2.1 and 4.2.2) may be affected by the UFAD requirements. RAF *without* UFAD may only require pedestal heights for wire management and be most easily built using stringerless construction (i.e., attachment of panels directly to pedestals). UFAD may require greater pedestal heights to allow for air transport, and for various system components to clear each other.

- Increased pedestal heights are more vulnerable to lateral instability, especially in seismic events, as has been seen in computer rooms subjected to these forces. The importance of bracing increases with pedestal heights and the need to coordinate lateral bracing with under floor obstructions such as ductwork is essential.

- Use of stringer understructure (bolted where appropriate for seismic conditions) improves the lateral stability of the floor system, especially when multiple panels must be removed, as may be the case to maintain items under the floor. However, as stringer systems make access to underfloor systems more difficult and cost more than stringerless installations, the temptation to compromise the system selection must be resisted.

## 11.4 Acoustics and Vibrations Considerations

UFAD introduces to the RAF acoustics considerations (see Section 4.2.3) the need, in certain instances, to move air through an acoustical barrier under the floor. This may be related to security if there is an eavesdropping concern, so the means employed to maintain acoustical attenuation may require approval of security authorities. The types and locations of sound attenuators are likely to have significant effects on the control of pressurization and airflow in the UFAD plenums. However, the issues related to sound attenuation in the return air systems are likely to be the same as in return air plenums and ducts for other (e.g., overhead) air distribution systems (see Sections 11.7, and 12.1 for additional guidance).

UFAD also introduces additional vibration issues. The location of the AHUs, terminal devices in the plenum, and methods of connecting ductwork (i.e., perimeter reheat units) to the floor diffusers can exacerbate the vibration conditions (e.g., resonance) considered in Section 4.2.3. UFAD is not expected to require a change in vibration criteria from 4.2.3, but additional methods to achieve compliance may be required.

## 11.5 Fire, Smoke, Safety, and Security Zone Issues and Criteria

The introduction of air movement through the UFAD plenum introduces additional issues and criteria to those in Section 4.3 that must be addressed with regard to fire, smoke transmission, security, and egress.

### 11.5.1 Issues

The fire, smoke, and safety considerations are generally the same as those described for RAF *without* UFAD (Section 4.3), except:

- With primary air supply moving through the UFAD plenum, the propagation of smoke, toxic fumes and fire into the occupied zones may be accelerated.
- Fire extinguishment systems, where required, will add to the demand for space under the floor and will require still more coordination through the GSA Fire Protection Engineer and Project Manager.
- Any sprinkler extinguishment system can further complicate the management of the under floor plenum and potentially increase the needed pedestal heights.
- If sprinkler extinguishment systems are added below the floor, the risk of undetected accidental discharge reinforces the need for moisture detection and/or drainage of the plenum.
- Gaseous total flooding extinguishment systems as described in NFPA 75, paragraph 8.4 may avoid water damage and potential risk of overloading the building structure from flooding the plenum.

UFAD introduces to the RAF security considerations (see Section 4.3) the need to move air through a secure barrier under the floor. This additional concern can be avoided if the secured area is supplied by an independent HVAC system. But if cost or other design factors dictate placement of transfer openings for air through the secure partitions, adequate forced and surreptitious passage barriers, such as bars or grates (as would be required for similar conditions above a ceiling), must be designed and approved by security officials.

### 11.5.2 Minimum Criteria

In addition to the minimum criteria defined in Section 4.3.2, or unless otherwise specifically excluded in the building program, the selected UFAD system shall comply with the following fire-safety, smoke management, safety, and security criteria, evaluated with all RAF panels installed:

- Fire extinguishment systems shall be provided in plenums serving Essential Electronic Facilities as provided in Chapter 7, Section 16 of PBS P-100, and may be necessary elsewhere as directed by the GSA Fire Protection Engineer through the Project Manager.
- To minimize the risk of an electrical fire in a UFAD plenum caused by the

inadvertent release of a sprinkler head in a zone, an interlock with the EPO Station shall be installed (see Section 5.0). The control circuit shall be designed in consultation with the GSA Regional Fire Protection Engineer.

- For physical and fire safety, the floor mounted supply air diffusers and grilles shall be cast aluminum or steel, and the openings shall be designed to prevent penetration by small heels (see Section 11.7 for additional requirements).
- Egress requirements in Chapters 7 and 8 of PBS P-100 do not address the special case of fires and toxic emissions in UFAD plenums (i.e., fire, smoke, and chemicals beneath the breathing levels of the occupants). Because of the increased risk as a function of wiring and cabling density, supply air transport through the UFAD plenum, and potential air leakage and security breaches in the UFAD plenums, egress requirements for RAF zones shall be evaluated on a site-specific basis in consultation with the GSA Regional Fire Protection Engineer.

## 11.6 Detection and Drainage of Water and Moisture in UFAD Plenums

Protection from three major pathways of water accumulation shall be provided in UFAD plenums: 1) leaks from joints and cracks in slab and perimeter walls; 2) inadvertent floods from sprinkler discharges or other accidents; and 3) condensation on cold surfaces in the plenum. Methods of sealing and insulating surfaces in UFAD plenums are described in Section 11.2 of this Guideline. However, to provide additional protection, in case of water accumulation in the plenum, the following controls shall be designed, specified and installed:

- A moisture detection system for the slab surfaces of the plenums with sufficient detector sensitivity to provide warning through the Building Automation System (BAS) so the area can be identified and the source of moisture can be located and repaired to prevent damage to the wiring and cabling. The types, numbers, and locations of the moisture detectors shall be selected based on the likelihood of leaks from plumbing and hydronic piping in the plenum, and the likelihood of condensation formation. The moisture detection system shall also be interlocked with the EPO Stations so that the power in the plenum will be shut off after a specified time, if a response through the BAS has not occurred.

- A drainage system in the slab of the plenum with sufficient self-priming traps, or other comparable devices, to minimize damage to the wiring, cabling and UFAD devices in the plenum. An alarm shall be interlocked with drainage systems and the EPO stations will also be interlocked with the drainage alarm so that the power in the plenum shall be shut off after a specified time, if a response through the BAS has not occurred.

## 11.7 Room Air Distribution and Return Air Pathway Coordination

Because the effectiveness of floor grilles and diffusers in UFAD applications depends on correct vertical and horizontal throw of the air into the room, it is important to locate these devices where they will not be covered over or otherwise be impeded, or where they are likely to cause occupant discomfort (see Section 12.1 for additional details).

Many UFAD applications are associated with open space planning and using modular furniture with compact work station configurations. However, other applications involve private offices, conference rooms, and other enclosed zones as described in Section 8.0. For both perimeter and interior UFAD zones, the most common location for grilles and diffusers is in the raised floor panels. However, other locations often include low-sidewalls or partitions in which the grilles and diffusers primarily have horizontal throws. Linear diffusers that are hard-ducted to fan-powered VAV boxes for heating and cooling are common for perimeter zones, whereas ducted and unducted diffusers and grilles in the raised floor panels are common for cooling only in interior zones. When linear diffusers are located in perimeter zones, care must be taken to assure that furniture (e.g., bookcases, file cabinets, credenzas, etc.) will not be placed on them. Similarly, care must be taken to assure that furniture, partitions, or other devices will not restrict the air distribution from interior floor diffusers:

- Ensure that diffuser and grille locations are shown on a drawing together with furniture placement, fixed and moveable partitions, and other known items to be placed on the RAF, so that physical conflicts and occupant drafts are avoided, at least in the initial occupancy. Future conflicts can only be avoided by proper management of reconfigurations of the space.

- When locating floor diffusers and grilles, conflicts with under floor features must also be avoided. Diffuser housings and associated control devices project down into the UFAD plenum and can conflict with such items as ductwork, distribution panels or air-handling units. (Additional air distribution considerations and performance criteria are provided in Section 12).

UFAD plenum air distribution for a conditioned perimeter or interior zone shall not exceed unducted distances of 50 feet from the point of supply entry into the plenum to the most distant air diffuser in that zone.

Multiple air-handling units per floor are recommended, enabling precise/economical off-hour zone control. Connections (chilled water/heating to air handling equipment) should enable "plug-n-play" change-out of air-handling equipment if space thermal loads change significantly over the life of the building.

The return air pathways from the return air grilles of UFAD systems to the air handling units shall meet the same criteria as specified for *Plenum and Ducted Return Air Distribution* of CAD systems (see Chapter 5, Section 8 of PBS P-100). The locations of the return air grilles to provide return air control (see Section 8.0 of this Guideline) shall be determined by the architect/engineer of record, and shown on the construction drawings with sufficient details so that a complete testing, adjusting and balancing procedure can be achieved (see Section 15 of this Guideline).

# 12.0 Mechanical Design Considerations

The requirements for the design of UFAD systems, from a thermodynamic perspective, and from the perspective of design engineering disciplines, are no different than those of any other subsystem. The design engineer must thoroughly understand the fundamental as well as the unique features and characteristics of the systems and components that are being integrated into the building, and then apply those features in such a way as to achieve the expected performance.

## 12.1 Thermal, Air Quality, and Acoustical Design Conditions and Criteria

Design conditions must be equally controlled in facilities that have raised UFAD systems as in those facilities with CAD systems. Therefore, the design criteria for thermal, indoor air quality (IAQ) and acoustics and vibrations that are specified in Chapter 5, Section 3: *Design Criteria* of PBS P-100 pertain equally to facilities with UFAD and CAD systems. However, with UFAD, special care is required to assure that the floor surface temperatures, and the air temperatures and air velocities near the floor, will not result in thermal discomfort or dissatisfaction with the office environment.

As a minimum, the conditions shown in Table 5-1 of PBS P-100 must be maintained at all elevations between 150 mm (6 inches) and 1800 mm (6 feet) above the finished floor in all occupied zones. However, the temperature values shown in Table 5-1 are for dry bulb temperatures in occupied zones where the air speed is less than 0.2 m/s (40 ft/min) and net thermal radiant exchange between the occupants and surrounding surfaces is negligible. Therefore, for UFAD systems, where occupied areas are in close proximity to the floor grilles or diffusers that have air velocities exceeding 0.2 m/s (40 ft/min), the acceptable values in Table 5-1 shall be in terms of Operative Temperatures as defined in ASHRAE Standard 55 (i.e., see Note 13 in Table 5.1, Chapter 5, Section 3 of PBS P-100).

To achieve these conditions, UFAD systems require control of four additional factors not associated with CAD systems: 1) the heat transfer through the structural slabs that are the platforms for the RAF (i.e., the bottom surfaces of the UFAD plenums); 2) the incremental heat, infiltration and water vapor transmission through exterior wall surfaces that interface with the UFAD plenums, which are approximately 10°F

(5°C) lower than typical occupied zones; 3) the heat transfer through the floor panels to the plenum; and 4) precise air temperature and static pressure distributions throughout the UFAD plenums. These factors are further described in the following Sections.

### 12.2 System Time Constant (Thermal Inertia)

A unique feature of UFAD systems (see Section 8.0) is that the plenum through which the supply air flows is the building structure and the floor materials. If the non-active side of the structure (that not exposed to the supply air) is well insulated such that it loses or absorbs a minimum amount of heat from the surroundings, the entire mass will approach thermal equilibrium with the supply air after several hours of operation. Thereafter, the supply air at the floor diffusers can be assumed to be essentially equal to the temperature of the air leaving the air-handling unit and entering the plenum.

If, for capacity control purposes, an effort is made to increase the supply air temperature to reduce the capacity, the control response cannot be predicted and thus an alternative approach to capacity reduction must be employed.

Another design option that is not available as a result of the thermal inertia phenomenon is unoccupied cycle shutdown. Experience reveals that it is very difficult, if not impossible, with most UFAD systems to exercise an option of "night" or unoccupied cycle shutdown for energy reduction. The issue is, if a UFAD system is operating at, say, 63°F supply air temperature and the cooling system is turned off overnight or on weekends, the building and its structure will increase in temperature, possibly even exceeding the "occupied" indoor air temperature. Then, upon turning the system back on, the supply air would gain heat, possibly even exceeding the room temperatures for several hours following startup. Thus, this Guideline does not encourage the practice of unoccupied cycle shutdown

An alternative to unoccupied shutdown might be an unoccupied control cycle that would make no effort to "pick up" the space load, but that would simply hold the structure enclosing the air paths at the supply air temperature.

- Supply Air Reset Temperature:
  In VAV system design, if the room humidity is controlled by some means other than the space cooling supply air, it is quite common to raise the tempera-

ture of the air from an air-handling unit to that temperature required to serve the cooling need of the zone requiring the most cooling. This control option is difficult to utilize successfully with a UFAD plenum because of the thermal lag phenomenon. For systems in which this feature is otherwise deemed necessary, some engineers have installed ducted systems in the floor cavity or insulated the inside of the cavities with rigid thermal insulation. (Note: if this insulation option is being considered, refer to Chapter 5, Section 13: *Thermal Insulation* of PBS P-100 for additional requirements.)

- Space Heating with UFAD:
  In areas of the country in which outdoor temperatures are such that buildings have both heating and cooling loads, the heating loads cannot be served with warm air through the air-handling units via UFAD systems. Again, this is because of the inherent unpredictability of control when switching from cooling to heating and visa versa. When it is desired to provide the heat from the floor diffusers as is sometimes recommended for the floor outlets placed along the outer or perimeter walls, this can be done by installing terminal reheat coils working in conjunction with the floor diffusers (see Section 11.7 in this Guideline for related issues).

- Heat Gain/Loss From Plenum
  In most buildings, the UFAD plenum structures are not in thermal equilibrium with their surroundings. Such cases are: 1) where a spandrel beam forms one wall of the plenum and is subjected to solar and transmission heat exchange with the outdoors; 2) the lower face (e.g., floor slab) of the plenum is exposed to the "warm" return air plenum of the space below; 3) the face of the plenum is exposed to outdoor temperatures in the space below (such as an outdoor soffit, unheated garage, or slab-on-grade); or 4) an interior vertical closure is exposed to a non-conditioned space. These situations can usually be analyzed through well-accepted transient heat transfer analyses and the impact predicted. Once the dynamics and magnitude of the heat transfer characteristics have been determined, control algorithms can be developed to prevent these heat exchanges from detrimentally impacting the performance.

# 13.0 Electrical Design Considerations

Cable management and planning for systems with underfloor air require the same fundamental considerations as for RAF systems without underfloor air as described in Section 5.0, with some additional considerations resulting from the fact that 1) the horizontal pathway serves as an air distribution path, and 2) the cables share the space with mechanical ducting, possibly piping, and other devices.

## 13.1 Cables in Air Distribution Pathways (Plenums)

The National Electrical Code (NEC) addresses the requirements of power and voice/data cables installed in air distribution pathways ("plenums"). These requirements include:

- Power wiring shall be protected in metallic conduits or raceways.
- Voice/data cabling shall be insulated with "plenum rated" insulation.
- All cabling shall be routed for the minimum length possible and voice/data cable length shall not exceed 90 meters.
- All cables shall be color coded by service (phone, data, etc.) and clearly marked for plenum use.

## 13.2 Sharing Space with Mechanical Devices

Whenever power wiring or cabling pierces the enclosure of a UFAD plenum, or an HVAC zone or an acoustical partition within the plenum, it shall be done so in such a way as to maintain an airtight seal. When the cable or wire is in a conduit, both the annular space between the conduit and the closure material shall be sealed and the conduit end shall be plugged to prevent air from leaking through the conduit. The specific methods of achieving such seals are the responsibility of the design professionals.

Where ducts or mechanical devices are located such that they create potential obstructions to the routing of cabling, a minimum of 4 inches (100 mm) of vertical clearance shall be provided to allow the cables to cross above the ducts. Where ductwork is run, care should also be taken to allow space for air diffuser extensions, and electric power and voice/data termination boxes that extend downward into the UFAD plenum.

A fundamental caution when planning a RAF with UFAD was stated in Section 3.0 of this Guideline, to wit: "*With a raised access floor, an unanticipated conflict cannot be resolved during construction by the equivalent of dropping a ceiling in an area.*" Thus, all possible interferences *must* be anticipated and resolved during the planning and design process. Additionally, since future technology is unknown at this time, spaces, clearances, routing and other geometrics that may be required in the future will need to be accommodated by the underfloor air system design.

## 14.0 Requirements for Documentation

### 14.1 Specifications for UFAD, including a "Mockup"

If Masterspec© Guide specification Section 10270 is used, careful reference to the Evaluations will provide guidance to selection of raised access floor types in response to project-specific conditions. However, Section 10270 is not specifically directed at UFAD, and will require appropriate modification. Related sections will also require coordination and modification to ensure all trades involved in providing airtight plenums are alerted to the importance of this requirement.

In addition to the items specified in Section 6.1 of this Guideline, special attention should be devoted to:

- Requiring a pre-installation meeting to:
    - Emphasize the importance of sealing the plenum.
    - Ensure proper coordination of systems intended to be placed under the floor with the floor installation itself.
    - Emphasize the need to keep the underfloor space clean.
- Requiring manufacturer's certification in submittals of performance requirements specified, especially seismic.
- Clear detailing on design and shop drawings of critical areas such as edge conditions.
- Requiring that a full-size mockup be constructed, on-site or off-site, of a large enough segment of the UFAD to provide a basis of standard of workmanship. The performance of the mockup shall be tested in accordance with the procedure in Section 15.2.1. As stated in Section 15.1, "It is highly recommended that the same craftsmen (or at a minimum the same foremen) who are to execute

the work on the building participate in building, inspecting and pressure testing the mockup. The mockup may be a part of the actual installation or it may be a separate structure, the size of which should be no less than 1,000 square feet, if off-site, or two structural bays of the building if a part of the actual construction. As a minimum, the mockup shall contain a representative quantity of the building and system elements that are reasonably expected to impact the UFAD plenum performance including but not limited to:

- Structural concrete work and details.
- Structural concrete sealants, sealer coats and finishes.
- Exterior walls.
- Elevator shafts, stairwells, escalator areaways.
- Partition and solid walls finished to floor.
- Partition and walls extended to structure.
- Floor panels.
- Access floor penetrations.
- Electrical power and communications outlets with connections, wire and conduit.
- Supply air diffusers, grilles, VAV boxes and controllers with thermostats.
- Other temperature control devices with thermostats such as underfloor fan-powered VAV boxes with terminal reheat.
- Underfloor plenum dividers.
- Electrical and piping penetrations, conduits and cables.
- Structural column and shear wall penetrations.
- Thermostat wiring details.
- Floor finish applications.

- Specifying spare panels, stringers, pedestals and accessories for replacements.
- Citing all related sections of the specifications that will be affected by creating an airtight, clean plenum with appropriate moisture handling provisions. These should all refer to the Raised Access Floor/UFAD section as a "Related Section". These may include, but not be limited to:
    - *Division 3 – Concrete* – Cast-in-place concrete and Floor topping sections shall include treatment of all cracks and joints, and the application of a sealer coat on the slab under the floor system as appropriate. This sealer coat must not be confused with the sealer that may be applied as part of the concrete curing process. A separate sealer coat shall

be applied prior to the installation of the UFAD system, including the RAF framework, cables and wiring, and ductwork.

- *Division 5 – Metals* – Architectural joint systems section with expansion joints must include need for floor joints to be air tight.
- *Division 7 – Thermal and Moisture Protection* - Sealants must specifically be designated for the plenum spaces and be selected accordingly; EIFS, if any and if in any way connected to the plenum, should refer to the construction needed to seal the EFIS framing space from the plenum; fire-resistive joint systems (fire stops) must refer to the air-tightness requirements of such joints occurring in plenum slabs.
- *Division 8 – Doors and Windows* – Any door systems such as sliding, folding, etc. that must penetrate the plenum should reference to the need for maintaining an air tight condition with a barrier or bulkhead, if those are provided in these sections.
- *Division 9 – Finishes*
  - Gypsum board assemblies and shaft wall; other similar partition, furring and similar assemblies must specify that these finishes must seal to the slab. Gypsum board must also be taped at the joints within the plenum. Acoustic, security, fire and smoke resistance characteristics must also be specified to be continuous under the floor in the plenum, including under door openings.
  - Carpet tile should be specified to have joints occur over panels rather than at panel joints. Carpet type should be selected to generate minimal lint and other contaminants that could potentially fall or be induced into the plenum. Adhesive must be used and applied that will not gum up panel screws.
  - Ample replacement tiles must be specified to provide for changes in floor service unit and diffuser locations.
- *Division 10 – Specialties* - Various types of operable partitions, if penetrating the plenum, must be isolated with barriers or bulkheads to prevent leakage. If resting on the raised access floor, adequate support of their weight must be shown and specified. A central vacuum cleaning system shall be installed with

multiple locations to facilitate cleaning of the UFAD plenum.

- *Division 11 – Equipment* – Any equipment specified in this division that may penetrate the plenum and/ or rest on the slab under the plenum must be provided with barriers around the equipment in the plenum or other measures to seal and prevent leakage. If equipment is supported on the RAF, adequate support must be shown and specified, and equipment locations must be coordinated with floor diffusers, grilles, service units, etc.
- *Division 12 – Furnishings* - Any furnishings specified in this division must be coordinated with floor diffusers, grilles, service units, etc.
- *Division 13 – Special Construction* - Security and fire detection and suppression sections must reflect the requirements for the underfloor plenum, including coordination with other systems designed for the plenum penetrations of the plenum by wire, conduit or other devices for these systems must be sealed and airtight;
- *Division 14 – Conveying Systems* – Any system that penetrates the plenum such as wheelchair lifts, escalators, moving walks, etc. must be specified and shown to be isolated from the plenum by barriers or bulkheads to prevent air leakage. Elevator shafts must be detailed to show separation from plenum by air-tight construction, including at the entrance sills.
- *Divisions 15 – Mechanical* - Floor diffusers and grilles should be in this division rather than in the Raised Access Floor section of Division 10. Emphasis is needed on providing coordination drawings of underfloor ductwork and locating floor diffusers coordinated with furnishings, equipment, etc.
- *Division 16 – Electrical* – Floor service units for power, data and communications should be in this division rather than in the Raised Access Floor section of Division 10. The allowable air leakage of these units must also be addressed. Coordination drawings may be needed for underfloor cable trays, if any, locations of floor service units and coordination with furnishings, equipment, etc.

If other guide specifications are used, attention to the same issues as above is necessary. Proprietary specifications (and details) from individual manufacturers is not in compliance with federal acquisition regulations and thus prohibited, since it could exclude appropriate alternative brands and eliminate meaningful competition and perhaps result in higher costs.

### 14.2 Drawing Details for UFAD

RAF *with* or *without* UFAD shall be shown on the drawings generically with the details focusing on the project-specific interfaces with other building components and systems. Typically, details shall include:

- Edge conditions with air seals at partitions, columns, walls, and built-up adjacent floors.
- Seals of partition finishes as they abut the plenum slab. J-bead and sealant shall be shown and called out wherever an air seal is needed.
- Seals at plenum slab perimeter, including at firestopping.
- Seals of expansion joints and other penetrations.
- Air barriers or bulkheads around penetrations of plenum such as sliding fire doors, rolling doors, stairs, lifts, equipment, etc.
- Edges and air seals and thresholds under elevator entrances, stair landings, ramps, etc.
- Partitions mounted on top of raised access floors.
- Special acoustic properties and acoustic seals.
- Special trim and other details for raised floors in existing buildings, especially where ornate wall, door and window conditions occur.

Where more than one type of raised access floor, pedestal height or system occurs, plans shall clearly show the extent of each type or condition.

Locations of underfloor equipment, if any, with respect to floor grid or above-floor features shall be shown.

Locations of floor service outlets, registers, grilles and diffusers, if any, with respect to modular furniture or other above-floor features shall be shown.

### 14.3 Evaluate Construction Documents before Release

Because of the special details that are required for RAF with UFAD, additional quality control of the construction documents shall be conducted. In addition to the Checklists provided in Appendix A.3 of the P-100, a Supplemental Review Checklist for RAF with UFAD is to be provided.

## 14.4 Operations and Maintenance Documents

The Property Manager shall be aware, by instructions and documentation from the raised floor manufacturer and the Contract Documents before, during and/or after installation, of the special issues involved in the operation of a building with RAF *with* UFAD, including:

- Monitoring and supervision of changes to systems under the floor.
  - Abandoned electrical circuits shall be removed completely, and any openings left in the walls or floor of the plenum must be sealed.
  - When new wiring, conduit or cabling is run, penetrations of the plenum shall be sealed as the original installation.
- Periodic cleaning of the underfloor space is essential, especially where panels have been removed for maintenance and repair.
- Training and supervision of O&M personnel in relocation of device outlets, floor registers, grilles and diffusers, when workstation furniture, partitions or equipment are moved, and replacement of panels previously pieced with floor diffusers and service units with solid panels, and restoration of carpet tile keeping the joint pattern intact. These measures are necessary to preserve the original integrity of the plenum.
- Every time panels are removed for service or replacement, they and adjacent panels should be checked for damage, especially to edges.
- Proper training of maintenance personnel in cleaning products and in handling and protecting panels when removing and replacing them is required.
- Repair and/or replacement of floor panels with damage such as:
  - Excessive deformation from impact so that adjacent panels do not meet tightly.
  - Loss of panel edges allowing openings between panels.
- Procedures for cutting openings in floor panels, sealing edges, etc. shall be specified.
- To ensure plenum pressure, air leakage tests should be conducted in any area being modified that is 2,500 sf or greater (see Section 15.2.3 for additional details).

## 14.5 As-Built Drawings

Along with the transfer of responsibility to the ownership team, and usually as part of the commissioning process, it is common to provide the owner with key documents and records for reference in operating the facility. Benefits of UFAD systems include the ability to relocate or to provide electric power or voice/data outlets and air supply outlets as the need arises. To gain maximum benefit from the ease of these tasks mandates that the owner maintain up-to-date records on the location and routing of all cables, pipes and devices.

The As-built Drawings should be maintained, preferably in electronic form, and each time a modification is undertaken, the drawings should be updated. It is highly recommended to remove abandoned cables, wires, or ductwork or indicate on the As-built Drawings that they have been abandoned in-place.

When replacing cables, the color coding format used in the construction phase should be adhered to. Any deviation from this format shall be indicated on the As-built Drawings.

The air tightness of the underfloor plenum must be maintained at all times. When removing a conduit or cable that passes through the plenum wall, slab floor or the raised floor, the opening must be sealed with an approved fire rated material. When new cables or conduits are being installed, the annular openings through which they pass must be sealed tightly (see Sections 11.2, 13.2 and 15.2.2). All modifications shall be indicated on the As-built Drawings.

Another advantage of a UFAD system is that as the spaces are reconfigured, the air outlets can be relocated by simply relocating the raised floor panel that contains the outlet. Although it may seem unnecessary to record the types and locations of the outlets on the As-built Drawings, as they can be "seen," it is quite possible that they could be covered with a carpet tile or piece of furniture. Thus, all outlets locations and types should be recorded on the drawings.

Care should be taken if outlets are added so as not to upset the air balance or overload the fan motor.

If supply outlets are thermostatically controlled, the location of the thermostat that controls each outlet should be clearly marked on the As-built Drawings.

The Property Manager shall be sure that first responders – especially fire fighters – know of the presence of the RAF with UFAD so that in the event of an emergency, they are aware that they must proceed with caution in areas with the raised floor (see Section 11.5).

### 14.6 Housekeeping

A visual inspection shall be made periodically to assess the cleanliness of the UFAD plenum. At the completion of construction, the UFAD plenum surfaces are sealed and thoroughly cleaned. However, over time they may become contaminated with airborne dust, insect colonies, vermin, microbial growth, moisture, or other foreign materials. It is necessary that any such inspection be planned in such a manner that all areas can be visually inspected. The cleaning of UFAD plenums should only be done by those who specialize in this work, since there is always the possibility of causing damage to cable layouts or connections, mechanical devices, and inherent danger to individuals working in the plenum due to the presence of electric power devices.

### 14.7 Warranty Period

As the integrity of the UFAD plenum can be compromised by contractors and operating personnel during and after initial occupancy (see Sections 14.4 – 14.6), an extended warranty that covers the UFAD plenum and specifies acceptable air leakage rates from the plenum shall be coordinated with the Contracting Officer to ensure continuous performance after Substantial Completion. It is recommended that the warranty be extended for a minimum of five (5) years.

## 15.0 Inspection, Testing and Commissioning

Sections 11 – 14 include considerable information concerning the coordination of the multiple trades in assuring the air tightness of the underfloor air plenums. Also, Sections 11.2 and 15.2 provide detailed information and performance criteria on plenum air leaks. To achieve the required performance, diligence is required from multiple layers of responsibility in inspecting the work as the construction activities proceed.

### 15.1 Inspection

In general terms, the seven levels of inspection for RAF with UFAD are the same as identified in Section 7.1. Some such levels of inspection are understandably more formal than others. In general, the top three levels (5, 6 and 7) should require a formality of inspection and "approval" of some nature. This is particularly true when the successful achievement among numerous trades is necessary for the optimal performance of the completed UFAD system.

It is highly recommended that the same craftsmen (or at minimum the same foremen) who are to execute the work on the building, participate in building, inspecting and pressure testing the mockup (see Section 14.1).

## 15.2 Testing

Following the completion of the construction and the various levels of inspection and approvals, the system is ready to be tested. The mockup (see Section 14.1) shall be tested prior to the actual construction of the UFAD plenum.

### 15.2.1 Test Procedure for Mockup

The mockup shall be tested prior to the construction of any of the permanent building UFAD systems by the following procedure.

1. A test fan shall be provided which shall have the capability of supplying various airflow quantities from shutoff to 120% of design airflow quantity required for the mock-up test and shall be driven by a variable speed inverter. The test fan shall be installed with an airflow test station and the supply duct connected into the plenum with an adhesive sealed pressure tight connection.
2. A static pressure sensor-controller shall be inserted into the plenum and calibrated against a calibrated static pressure sensor immediately adjoining it. The controller shall be arranged to control the speed of the test fan.

3. The UFAD plenum shall be installed complete with a representative number of supply diffusers, electrical power outlets, and voice/data outlets. The supply diffusers, whether automatically or manually controlled, shall be in the fully closed design position.

4. The fan shall be operated to hold the test pressure in the plenum. The test pressure shall be the design operating static pressure for the system.

5. The system shall be operated for 24 hours, with the measured static pressure

(in. w.g.) and airflow rate (CFM) recorded 24 times (nominally each hour). The sum of the 24 flow rates (CFM) shall be divided by 24. This average value will be considered the sum of the Category 1 and Category 2 leakage (see Section 11.2.1) and called the å leakage.

6. With the test fan off, the floor panel and edge joints, the supply air diffusers and the cable floor connectors shall be tightly sealed with mastic and sealant taping, and the test repeated for 24 hours with hourly readings, and the method of averaging repeated. This value will represent the Category 1 leakage.

7. Subtracting the Category 1 leakage rate from the å leakage rate will represent the Category 2 leakage rate.

8. The leakage rates shall be compared to the allowable rates from the Table 15-1. If the rates are found to exceed the table values in either category, steps shall be taken to re-inspect, utilizing test smoke if necessary, determine sources or causes of the leakage, repair or correct and retest - repeating this process until the rates are within the Table 15-1 limits.

9. The systemic corrections that are required for the mockup to bring it into compliance with the test limits shall be incorporated into the construction process and procedures for the remaining UFAD plenums in the building.

| Test | ∑ Air Leakage (CATEGORY 1 + CATEGORY 2) | Category 1 |
|---|---|---|
| Mock-up | 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 the design supply air flow rate, whichever value is smaller | 0.03 cfm/ft$^2$ floor area or 3% of the design supply air flow rate, whichever value is smaller |

Table 15-1. Maximum allowable UFAD plenum air leakage rates in mock-up and building floor plenums, when measured at design operating static pressure.

### 15.2.2 Building Floor Plenum Tests during Construction

The lessons learned in step 9 in Section 15.2.1 shall be disseminated to all the trades involved in the construction of the plenums as supplemental information, not to be a basis for a change in the contract price. They should also be distributed to all inspection and approval authorities on the project.

The permanent building floor plenums shall then be tested by the following procedures. These test results shall be professionally certified by a nationally recognized Testing, Adjusting, and Balancing Contractor or agency (i.e., NEBB, AABC, or TABB):

1. The testing shall be performed after the concrete surfaces of the plenum have been sealed, and all mechanical and electrical devices, equipment, cables, racks, diffusers, power connectors and voice/data connectors and floor finishes have been installed.

2. The permanent air-handling system shall have been installed, inspected and successfully tested.

3. The static pressure sensing component of the BAS shall have been installed and calibrated before the test. An independent, calibrated static pressure gauge shall be installed adjacent to each permanent sensor.

4. All supply air diffusers, of both automatically or manually controlled types, shall be closed to their minimum design positions and the fan shall be operated on pressure control - controlling at the design static pressure in the plenum for 24 hours.

5. During the test, the supply air quantity (CFM) and the static pressure shall be read and recorded approximately once each hour (time noted) for 24 hours and recorded. The flows for each hour shall then be added and the sum divided by 24 to obtain the total å leakage.

6. If the total å leakage exceeds the allowable maximum in Table 15-1, the construction shall be inspected, tested with test smoke if necessary, causes repaired or corrected, and the system retested until the rates are within the Table values.

### 15.2.3 Floor Plenum Tests during Warranty

All penetrations, modifications and repairs to the UFAD plenum are to be documented on the As-built drawings (see Sections 14.4 – 14.6). To ensure long-term performance of the UFAD plenum, the following additional air-leakage testing shall be conducted whenever an area exceeding 2,500 $ft^2$ is modified, and during a period within thirty (30) days prior to completion of the warranty period (see Section 14.7). These test results shall be professionally certified by a nationally recognized Testing, Adjusting, and Balancing Contractor or agency (i.e., NEBB, AABC, or TABB):

1. Steps 3 – 5 in Section 15.2.2 shall be repeated for a contiguous floor area of at least 1,000 $ft^2$, which shall be selected by the owner.

2. If the total å leakage exceeds the allowable maximum in Table 15-1:
   2.1 The plenum of the selected area shall be inspected, tested with test smoke if necessary, causes repaired or corrected, and the system retested until the rates are within the Table values.
   2.2 Steps 3 – 5 in Section 15.2.2 shall be repeated for two additional contiguous floor areas of at least 1,000 $ft^2$, which shall be selected by GSA.

3 If the total å leakage exceeds the allowable maximum in Table 15-1 for either of the areas selected in 2.2, all of the UFAD plenums in the facility shall be inspected, tested with test smoke if necessary, causes repaired or corrected, and the system retested until the rates are within the Table values.

## 15.3 Testing, Adjusting and Balancing Air System

After the leak testing is completed in accordance with 15.2.2 or 15.2.3, the Air and Water System Testing, Adjusting and Balancing (TAB) Contractor or agency shall perform the TAB work in accordance with the Project Specifications.

## 15.4 Commissioning

The UFAD system requires no special or unusual steps in the commissioning process. The commissioning agent shall serve an inspection and documentation role as defined in the level 6 inspection step (see Section 7.1).

## Federal Building, Oklahoma City, Oklahoma

*Photographer: Timothy Hursley*

## Appendices:

A-1: Definitions

A-2: Economic Considerations

A-3: UFAD Systems

# Appendix

## Appendix A-1: Definitions

**Air Handling Unit (AHU):** A fan assembly, which is located in a mechanical equipment room and may include heating and cooling coils and filters. The AHU provides supply air through conventional or underfloor air distribution (See Chapter 5, Section 4 of PBS P-100).

**Building Automation System (BAS):** A direct digital control (DDC) system for providing lower operating costs and ease of operation. The BAS shall adjust building systems to optimize their performance and the performance with other systems in order to minimize overall electric and fuel consumption of the facility (See § Chapter 5, Section 16 of PBS P-100).

**Benefit-Cost Analysis:** A systematic quantitative method of assessing the desirability of investments, projects, or policies when it is important to take a long view of future effects and a broad view of possible side-effects. The benefit-cost analysis provides a ratio of the life cycle benefits of the alternative to the life cycle costs of the alternative.

**Building Life-Cycle Cost (BLCC) Model:** A computer program developed by the National Institute of Standards and Technology to provide economic analysis of proposed capital investments that are expected to reduce long-term operating costs of buildings. It is especially useful in evaluating the costs and benefits of energy conservation projects in buildings.

**Conventional Air Distribution (CAD):** Transportation of supply air from air-handling units to occupied zones by ductwork in ceiling spaces, wall cavities, or floor cavities (See Chapter 5 Section 4 of P-100).

**Category 1 Leaks:** Leaks of cool conditioned supply air from the underfloor plenum into other building cavities, and then either from the building or into return air passages back to the air- handling units or building exhaust air system.

**Category 2 Leaks:** Leaks of air through raised floor system components into the space to be conditioned.

**Cavity:** An opening or hollow volume beneath the raised access flooring.

**Conventional Flooring (CF):** A finished flooring assembly without underfloor cavities or air plenums for cable management.

**Cost-Effectiveness:** A systematic quantitative method for comparing the costs of alternative means of achieving the same stream of benefits or a given objective.

**Diffuser:** A circular, square, or rectangular air distribution outlet located in the ceiling, wall, or floor, and comprised of deflecting members to discharge supply air in various directions and planes, and arranged to promote mixing of primary air with secondary room air (SMACNA HVAC Testing, Adjusting, and Balancing, 2002).

**Emergency Power Off (EPO) Station:** A secured panel located at each major point of egress in a zone and used by emergency personnel to disengage electrical circuits.

**Equipment-Centric:** Refers to concentration of electronic equipment such as computers, telecommunications equipment, etc.

**Energy Efficiency:** Building energy efficiency is defined as the ratio of energy required to provide the specified exposure criteria to the energy consumed for this purpose. Energy efficiency focuses on minimizing energy waste rather than minimizing energy consumption.

**Grille:** A louvered or perforated covering for an air passage opening which can be located on a wall, ceiling or floor (SMACNA HVAC Testing, Adjusting, and Balancing, 2002).

**Leadership in Energy and Environmental Design (LEED™):** A national consensus-based, market-driven building rating system designed by the U.S. Green Building Council to encourage the development and implementation of green building practices.

**Life Cycle Benefits:** The overall estimated benefits for a particular alternative over the time period corresponding to the life of the program, including direct and indirect initial benefits plus any periodic or continuing benefits resulting from operation and maintenance.

**Life-Cycle Cost (LCC):** LCC applies to both equipment and projects, and includes all costs from project inception to disposal of equipment. Life cycle costs are determined by an analytical study of total costs experienced during the life of equipment or projects. The objective of LCC analysis is to choose the most cost-effective approach from a series of alternatives so that the least long-term cost of ownership is achieved. LCC analysis helps justify equipment and process selection based on total costs rather than the initial purchase price of equipment or projects.

**Occupied Zone:** The region normally occupied by people within a space, generally considered to be between the floor and 1.8 m (6 ft) above the floor and more than 1.0 m (3.3 ft) from outside walls/windows or fixed heating, ventilating, or air-conditioning equipment and 0.3 m (1 ft) from internal walls. (ASHRAE Standard 55-2004, also see Chapter 5, Section 3 of P-100).

**Optimize:** To select the solution that minimizes or maximizes an objective function over a range of options.

**Outlet Flow Rate (CFM):** The volumetric airflow rate (cubic feet per minute) delivered by the device at the design static pressure (in. w.g.).

**Pedestal:** Vertical support members for raised access flooring panels.

**Plenum:** An air compartment connected to one or more distributing ducts (SMACNA HVAC Systems Testing, Adjusting and Balancing, 2002).

**Pressure, Static:** The normal force per unit area that would be exerted by a moving fluid on a small body immersed in it if the body were carried along with the fluid. Practically, it is the normal force per unit area at a small hole in a wall of the duct or plenum through which the fluid flows (piezometer) or on the surface of a stationary tube at a point where the disturbances, created by inserting the tube, cancel. It is supposed that the thermodynamic properties of a moving fluid depend on static pressure in exactly the same manner as those of the same fluid at rest depend upon its uniform hydrostatic pressure (SMACNA HVAC Systems Testing, Adjusting and Balancing, 2002).

**Psychrometrics:** The subscience of the thermodynamic properties of moist air. It is used to show how changes in heating, cooling, humidification, and dehumidification can affect the properties of moist air, and provides data necessary to analyze processes relating to air distribution.

**Raised Access Flooring (RAF):** A finished flooring assembly that also provides accessible horizontal pathways for cable management through cavities underneath modular floor panels, which are supported above the sub-flooring by an understructure.

**Secure Compartmented Information Facility (SCIF):** An accredited area, room, group of rooms, building, or installation where secure and/or classified information may be stored, used, discussed, and/or processed.

**Sound Attenuator:** A device or equipment that prevents, reduces, or absorbs sound.

**Stringers:** Horizontal support members for raised access flooring panels.

**Sunk Cost:** A cost incurred in the past that will not be affected by any present or future decision. Sunk costs should be ignored in determining whether a new investment is worthwhile.

**Supply Air:** Air leaving an air handling unit that has been cleaned and thermally treated to achieve the indoor design criteria for the occupied zones (See Chapter 5, Section 3 of PBS P-100).

**Temperature, Dew Point:** The temperature at which moist air becomes saturated (100% relative humidity) with water vapor when cooled at constant pressure (ASHRAE Standard 55-2004).

**Temperature, Dry Bulb:** The temperature of a gas or mixture of gases (e.g., air) indicated by an accurate thermometer after correction for radiation (SMACNA HVAC Systems Testing, Adjusting and Balancing, 2002).

**Temperature, Operative:** The uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment (ASHRAE Standard 55-2004). A practical procedure to calculate the Operative Temperature is provided in Appendix C of ASHRAE Standard 55-2004 for air velocities up to 1 m/s (200 fpm).

**Testing, Adjusting and Balancing (TAB):** A process to verify that all heating, ventilating and air-conditioning (HVAC) water and air flows and pressures meet the design intent and equipment manufacturer's operating requirements (SMACNA HVAC Systems Testing, Adjusting and Balancing, 2002).

**Throw:** The horizontal or vertical axial distance an airstream travels after leaving an air outlet before the maximum stream velocity is reduced to a specific terminal value; e.g., 200, 150, 100 or 50 fpm (1.0, 0.75, 0.5 or 0.25 m/s) (SMACNA HVAC Systems Testing, Adjusting and Balancing, 2002).

**Underfloor Air Distribution (UFAD)**: Transportation of supply air from air-handling units to occupied zones through plenums under raised access flooring (RAF) (See Chapter 5, Section 4 of PBS P-100).

## Appendix A-2: Economic Considerations

Economic considerations are paramount to assure maximum value to the federal government. To ensure that this value is maximized, a benefit-cost method shall be utilized in which the life cycle costs and benefits of RAF are compared to the life cycle costs and benefits of a facility with conventional flooring and horizontal pathways for wiring and cabling distribution above suspended ceilings. The RAF is economically preferred if the benefit-cost ratio of the RAF exceeds that of the conventional floor.

Analogous considerations are required for UFAD. As with the case of RAF, a benefit-cost method shall be utilized in which the life cycle costs and benefits of UFAD in appropriate areas with horizontal pathways for wiring and cabling distribution below the RAF, and as modified for UFAD, are compared to the life cycle costs and benefits of a facility with overhead or sidewall supply air (i.e., conventional) air distribution (CAD) and horizontal pathways for wiring and cabling distribution below the RAF, assuming RAF has been selected. UFAD is economically preferred if the benefit-cost ratio of UFAD exceeds that of CAD.

RAF for office areas is only one element that must be assessed in determining value, and RAF may increase or decrease this value. UFAD is one of the four optional *Perimeter* *and Interior Heating and Cooling Systems* to be considered in defining the HVAC Baseline System (see Chapter 5, Section 4 of PBS P-100), and is one of several options that must be assessed in determining value. UFAD may increase or decrease this value. In addition to first cost impacts on HVAC, cable management, and flexibility concerns, economic considerations shall include the impact that utilization of RAF/UFAD may have on health, safety, security, and sustainability (PBS P-100).

Assessing RAF and UFAD economic and related factors can be difficult as relatively little reliable, objective information is available in the published literature. Further, much of what is available is imprecise with respect to the differences between RAF with and without UFAD.

This Appendix describes methods for quantitative analysis and also provides information relating to benefits and costs that can be used in qualitative assessments. If quantitative analysis is not possible for a specific project, the qualitative methods shall be used.

### A-2.1 Life-Cycle Cost and Benefit-Cost Methods

Life-cycle cost (LCC) is an analytical method that is required by GSA as it is mandated by law (PBS P-100). LCC analysis sums, over a designated study period, all costs related to the owning and operating of a building or building system, adjusted for the time-value of money. These costs include those related to initial capital investment, operating, maintenance, and repair costs, energy costs, and other costs. LCC estimates are calculated in present-value dollars; that is, all future costs are discounted to present value and summed. Thus, LCC provides a systematic method for comparing project alternatives with different streams of costs *that provide the same benefits* in a time-equivalent manner.

Many established guidelines and computer-based tools effectively support LCC analysis. The National Institute of Standards and Technology (NIST) has prepared the *Life Cycle Costing Manual for the Federal Energy Management Program* (NIST Handbook 135), and annually issues discount factors for LCC analysis. NIST has also established the Building Life Cycle Cost (BLCC) computer program to perform LCC analyses – see *The NIST "Building Life-Cycle Cost" Program, Version 4.3: User's Guide and Reference Manual*, National Institute of Standards, October 1995. The NIST materials define all required LCC methodologies used in GSA design applications (PBS P-100). LCC information can also be obtained from the Center for the Built Environment (CBE) UFAD Cost Analysis Model, which is documented in *CBE UFAD Cost Analysis Model: UFAD First Cost Model, Issues and Assumptions*, Center for the Built Environment, University of California, Berkeley, May 2004; and from *Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems*, American Society for Testing and Materials (ASTM) E917. LCC is defined in the Code of Federal Regulations (CFR), Title 10, Part 436, Subpart A: *Program Rules of the Federal Energy Management Program* (PBS P-100).

Life-Cycle Cost without Benefit-Cost analysis is incomplete as it assumes no difference in benefits between options under consideration. Benefit-Cost methods utilize the results of the LCC to permit a decision to be made as to the alternative preferred on economic grounds.

For Raised Access Flooring:

- The ratio of the total life cycle RAF benefits to the LCC of the RAF is computed, and the ratio of the total life cycle benefits of the conventional system (i.e., conventional flooring with horizontal distribution above suspended ceilings) to the LCC of the conventional system is computed. The two ratios are then compared, and the alternative with the highest ratio – the largest economic benefits relative to costs – is preferred on economic grounds.
- At the Final Concept Phase (see Appendix A-3 of PBS P-100), the benefits and costs of using RAF over the life of the project shall be compared to the benefits and costs of the conventional system, including overhead cabling, and the system with the most favorable benefit-cost ratio shall be used. Note that RAF with underfloor cable management may involve higher first costs than a conventional floor with overhead cable management, but may reduce LCC.

For Underfloor Air Distribution

- Two ratios are computed: 1) the ratio of the total life-cycle benefits of UFAD to the life-cycle costs of UFAD; and 2) the ratio of the total life cycle benefits of CAD to the LCC of CAD. The two ratios are then compared, and the alternative with the highest ratio – the largest economic benefits relative to costs – is preferred on economic grounds.

- At the Final Concept Phase (see Appendix A-3 of PBS P-100), the incremental benefits and costs of using UFAD over the life of the project shall be compared to the benefits and costs of CAD, assuming RAF has been selected, and the system with the most favorable benefit-cost ratio shall be used. UFAD with underfloor cable management may involve higher first costs than CAD, but may reduce LCC.

Guidance for selecting economic methods to evaluate investments in building systems and to measuring net economic benefits can be obtained from *Standard Practice for Measuring Net Benefits for Investments in Buildings and Building Systems*, ASTM E 1074 and *Standard Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems*, ASTM E1185. Additional information on applying benefit-cost methods can be obtained from *Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems*, ASTM E964; *Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems*, ASTM E1057; *Practice for Measuring Payback for Investments in Buildings and Building Systems*, ASTM El121; and "Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs," OMB Circular A-94 Revised, October 29, 1992.

As described above, benefit-cost methods are applied subsequent to the LCC analysis, but this benefit-cost calculation is complicated by two factors. First, while potential RAF and UFAD benefits relating to productivity, workplace flexibility, energy consumption, churn cost savings, etc. are well publicized, the potential risks and costs are neither well known nor quantified.

Second, RAF cannot readily be analyzed within the structure of the currently available, mandated NIST LCC model and BLCC computer program. RAF is not explicitly included in currently available state-of-the-art LCC methods, including the NIST BLCC method that is required to be used in GSA design applications. However, RAF considerations can be included in LCC parameters relating to annually recurring, escalating costs (such as service or maintenance which involves increasing amounts of work, and frequent replacements that escalate at a rate different than inflation) and operating, maintenance, and repair costs.

BLCC can be used to evaluate UFAD, which may have higher initial costs but lower operating-related costs over the project life than the lower-initial-cost CAD option, while providing comparative levels of service (reliability, safety, occupant comfort, conformance with building codes, noise levels, useable space, etc.). With BLCC, the life-cycle costs of UFAD and CAD are computed and compared to determine which has the lowest life-cycle cost, and UFAD can be analyzed within the structure of the currently available, mandated NIST LCC model and BLCC computer program (PBS P-100).

To perform the required LCC analysis and the subsequent benefit-cost comparison for RAF and the conventional floor alternative and for UFAD and CAD, the following parameters and associated quantitative or (at a minimum) qualitative values shall be considered:

- Life cycle benefits, including IAQ effects, occupant comfort, productivity, workflow and workplace configuration flexibility, churn savings, wiring/cable management, waste reduction, tenant rollover, and space rental value.
- Life cycle costs, including installation costs, energy costs, health risks and costs, fire safety risks and costs (including fire protection costs and risks to occupants and first responders), seismic loading risks and costs, risks and costs of accidents, security risks and costs, operating costs, maintenance and cleaning costs, and added space costs.

GSA must approve the set of parameters and related values prior to use in a specific project. Once the LCC analysis has been conducted, the costs of RAF and of conventional flooring and the costs of UFAD and of CAD must be compared to the benefits of each alterative, and the alternative with the most favorable benefit-cost ratio shall be used (PBS P-100).

In certain cases, application of objective benefit-cost methods may indicate that RAF and/or UFAD is not the preferred alternative. In these cases, the results of the benefit-cost comparison must be weighed with quality assurance and validation methods when making design decisions, professional judgment must be applied, and recommendations shall be submitted to GSA for approval (PBS P-100). Guidance can be obtained from *Standard Practice for Applying Analytical Hierarchy Process to Multiattribute Decision Analysis of Investments Related to Buildings and Building Systems*, ASTM 1765.

### A-2.2 Benefit Factors

GSA is committed to providing physical work environments that have acceptable IAQ, contribute to occupant comfort, and enhance work flow. GSA further recognizes that productivity is greatly affected by the working environment (PBS P-100). RAF and UFAD systems may increase productivity by reducing churn time and by enhancing configuration flexibility. Flexibility may be improved if RAF/UFAD makes it easier to relocate or add power/data/voice outlets to the work environment. This enhanced flexibility may increase productivity by making it easier to reconfigure workflow-oriented workspaces. The workflow may require a team-centric furniture layout, individual work stations, or a combination of the two. RAF/UFAD may also enhance productivity in applications where requirements are likely to change during the life cycle of the core building and in cable intensive installations where cables need to be accessed for change, reconfiguration, monitoring, etc. In addition, UFAD may increase productivity by facilitating thermal comfort and IAQ improvements.

The workflow process is likely to change many times over the life of a federal facility, and many office and work areas are constantly changing: Agency missions and priorities change, new staff are hired, new work space is required, work areas are expanded and reconfigured, moves are made to new space, and equipment is added – see the 1999 GSA report *The Integrated Workplace: A Comprehensive Approach to Developing Workspace*. Computer equipment for each work area, as well as other office equipment, increases the need for wiring. It should be determined whether RAF/UFAD is likely to reduce major disruptions in creating new workspace and getting all required equipment wired in. It should also be determined whether making these changes is easier with RAF/UFAD or with conventional flooring using overhead cabling.

While productivity gains with RAF/UFAD are possible, they are not assured. For example, equipment turnover in many modern equipment centric areas is around two years and creates the situation where data and power cabling is subject to nearly continuous change. The difficulty of access to cabling when it is under the raised floor or in the UFAD plenum can result in delay, costs, and reduced productivity associated with changing needs. Further, if the cabling is in the UFAD plenum, the air tightness integrity of the plenum must be assured.

Many claims have been made for UFAD benefits, but few have been validated. The following is a critical review of the some of the claimed benefits. It should be noted in the following review that UFAD might increase or decrease benefits with respect to *CAD, with or without RAF*.

In new construction, UFAD first costs may be equal to or lower than CAD first costs *if a raised floor has been selected.* The factors that affect UFAD first costs include: HVAC construction sequencing and installation costs; power, data/voice networking installation costs; ductwork and duct materials costs; HVAC controls costs; power for fans; sizes of chillers; building height impacts; and construction time and materials costs. It has also been reported that floor-to-floor height may not need to be increased in UFAD projects.

UFAD may influence thermal comfort and IAQ. Thermal comfort may be greater with UFAD systems if air velocities are low and diffusers are designed for effective mixing without drafts. Indoor air quality may be impacted by a number of factors, including the ability to relocate and add diffusers to match use patterns and the proximity of the diffusers to the individual's breathing zone. The upward direction of air flow from UFAD air theoretically removes equipment contaminants and heat directly through ceiling return air systems.

Flexibility may be improved if UFAD supports a greater level of spatial change. This enhanced flexibility may increase productivity if it makes it easier to reconfigure workflow-oriented workspaces. The workflow may require a team-centric furniture layout, individual work stations, or a combination of the two. UFAD may also enhance productivity in applications where requirements are likely to change during the life cycle of the core building. Flexible and adaptive UFAD systems may reduce material and component waste that is often necessary in mechanical and electrical system modifications.

It shall be determined whether UFAD or CAD can be better designed to allow for a continuous reconfiguration of thermal zones and controllers, or with micro-zoning (one zone per workstation) that can be dynamically grouped and regrouped with control. User controls improve user satisfaction with thermal comfort. UFAD may enhance the ability to relocate diffusers, which is critical to churn/reconfiguration cost savings, and all systems can be coordinated to make this possible (carpet, outlets, diffusers, tethers).

Compared to CAD, UFAD has more supply air diffusers and they are located closer to the occupants. It shall be determined if this may help to support the use of task/ambient conditioning, which provides occupants with individual comfort control through the use of fan-powered, directional air outlets that increase local air movement. It shall be determined if UFAD may also have lower ambient noise levels due to low face velocity at the floor diffuser. Additional discussion of potential UFAD benefits can be obtained from *Energy Savings Potential of Flexible and Adaptive HVAC distribution Systems for Office Buildings*, Air-conditioning and Refrigeration Technology Institute, March 2002.

There are several available reports on assessing and measuring productivity in federal workplaces. These include the 1999 GSA report *Workplace Evaluation Study*, which describes the GSA cost per person model; the 2001 GSA report *Productivity and the Workplace*, which presents the workplace performance model and the GSA productivity payback model; and the 2001 GSA report *People and the Workplace*, which discusses productivity measurement.

GSA is committed to incorporating principles of sustainable design and energy efficiency into all of its building projects, but sustainable design shall not adversely affect the health and comfort of building occupants (PBS P-100). It shall be determined whether RAF/UFAD contributes to the sustainability of the building and to energy efficiency by reducing energy requirements and by reducing the total amount of waste generated over the building's lifetime (PBS P-100). Waste may be reduced due to the ease of reconfiguring office spaces with minimal structural perturbations – see the current version of the *Whole Building Design Guide* at www.wbdg.org for additional guidance on estimating this waste reduction.

GSA is committed to minimizing use of nonrenewable energy, and Executive Order 13123 establishes a national program to reduce building annual energy consumption by 35 percent from the 1985 baseline – see *Greening the Government Through Efficient*

*Energy Management*, Executive Order 13123, June 3, 1999 (PBS P-100). GSA also supports the federal government's Energy Star Buildings Program for achieving metered consumption with the top 25 percent of involved building categories (PBS P-100). Guidance on the Energy Star Buildings Program can be obtained from the Energy Star web site at www.energystar.gov. However, little empirical evidence exists that RAF (as distinct from UFAD) is likely to have a measurable effect on energy costs.

All GSA projects must be certified through the Leadership in Energy and Environmental Design (LEED™) Green Building Rating System of the U.S. Green Building Council, and GSA's sustainability objective for LEED™ certification involves exceeding ASHRAE 90.1 (P-100, 2005: Section 1.7). RAF may contribute to increased LEED™ points (PBS P-100). UFAD may impact LEED™ categories such as Ventilation Effectiveness, Thermal Comfort, and Optimized Energy Performance, and may contribute to LEED™ points (PBS P-100). Additional guidance can be obtained from the U.S. Green Building Council's *Leadership in Energy and Environmental Design Building Rating System*, version 2.1 and the 2004 GSA report *GSA LEED™ Cost Study*.

### A-2.3 Risk Factors

Building occupant health and related health costs are major GSA concerns. Water, mold, contaminants (food, drinks, trash, etc.) and rodent infestation in RAF cavities and UFAD plenums can cause potentially serious indoor air quality and health problems. Contamination can result from lateral and/or vertical instability of the framing systems and from improper sealing of cutouts and can increase risks and costs. It is thus important to minimize sources and pathways for liquids, water, water vapor, and contaminant incursion into RAF cavities and UFAD plenums, including migration through building envelopes.

If the UFAD plenum is airtight, as it should be, the plenum will be virtually water tight. To avoid the possibility of structural failure for applications involving framed structural floors (i.e. other than slab on-grade), there must be a way to quickly/automatically remove standing water in the raised floor cavity caused by catastrophic leak, fire suppression, or other flood scenario.

Water, mold, and contaminant control, including minimizing sources and pathways for liquid water, water vapor, and contaminant incursion into RAF cavities and UFAD plenums (e.g., migration through building envelopes), is critical. In addition, care must be taken to assure the 1ong-term cleanliness of the supply air in the UFAD plenums and to ensure the effective pressurization of the UFAD plenums.

In UFAD systems, the floor surface temperatures will likely be lower than in CAD systems, resulting in increased radiant exchange with the occupants and an increased risk of thermal discomfort. Acceptable air speed in the occupied space (as defined in ASHRAE 55-2004) and the acceptable relative humidity range (as defined in ASHRAE 62.1-2004) may be more difficult to maintain with UFAD than with CAD. These values may be more difficult to achieve in occupied areas with UFAD than in comparable areas with CAD, primarily due to the need to limit the supply air temperature to not less than 63 – 65°F dry bulb temperature and the air velocities to no more than 50 feet/min (0.25 m/s) through the floor diffusers in order to create the turbulent mixing needed in UFAD. Design guidance from a thermophysiological response perspective can be obtained from the *ASHRAE Handbook of Fundamentals*. Additional guidance can be obtained from *Thermal Environmental Conditions for Human Occupancy*, ANSI/ ASHRAE 55-2004 and *Ventilation for Acceptable Indoor Air Quality*, ANSI/ ASHRAE 62.1-2004.

GSA is committed to protecting human life in federal buildings. Physical safety, life safety, and fire and smoke management are critical in RAF cavities and UFAD plenums that contain water pipes and/or electrical and IT wiring/cabling. When cabling is run within an RAF cavity or UFAD plenum, issues relating to fire protection shall be addressed. One way to address these is to enclose cabling in a fire-rated conduit, which may be metal or a special fire rated polymer.

Although protection and response criteria are available for some extraordinary incidents, the characteristics of UFAD plenums present special issues that shall be addressed. Internal floods in UFAD systems can result in additional structural loads; local seismic conditions or live (e.g., rolling) loads may require heavy duty pedestals, stringers and cross-bracing; and special transitions at the interfaces with non-raised flooring and other surfaces are required to minimize accidents, flame spread, and air leakage. For UFAD systems, criteria for isolation and containment of chemical or biological releases and fire and smoke control shall be defined, especially for pressurized plenums that maximize exposures to seated occupants. When water from floods or leaks accumulates in the UFAD supply plenum, the risk of electrical fires increases because the power wiring is typically not waterproofed. "Emergency Power Off" (EPO) stations shall be required for each fire zone in UFAD systems in order to disengage all power in "wet plenums."

In offices and other equipment-centric areas there is often extensive cabling underneath raised floors and within UFAD plenums involving large amounts of PVC insulation. This extensive cabling in the underfloor cavity or UFAD plenum increases the risk of fire. Fires in such areas requiring extensive cabling/wiring in the underfloor cavity (such as offices, data centers, laboratories, medical facilities, clean rooms, and telecommunications facilities) can arise from problems with the wiring, electrical distribution system components, and electronic equipment (computer hardware, power switchgear, overcurrent protection devices, etc). The probability of a fire occurring in such areas is estimated to be "somewhat likely" (0.0001 - 0.01/yr). This implies that, of every 10,000 equipment-centric facilities, every year a fire is "somewhat likely" in between one and 100 of them. Additional guidance can be obtained from the article "Business Interruption Risk Assessment: A Multi-Disciplinary Approach, by M.H. Long, in" *Disaster Recovery Journal*, 1997.

A fire in a raised floor area, particularly within the UFAD plenum, is serious due to the mass of cabling and the highly toxic and corrosive combustion product resulting from a PVC fire (burning plastics create extremely toxic gasses). Further, cable fires under the raised floor or in UFAD plenums can be especially dangerous because the hot toxic gasses can exit anywhere and can be more concentrated than re-circulated and diluted gasses in re-circulated air. There is also a higher probability that the gasses will exit within the breathing zone – during fires the standard procedure is to crawl to safety, a practice that could be fatal if the fire is in the raised floor or the UFAD plenum.

Fires in areas with RAF and/or UFAD can be especially dangerous for occupants and for fire fighters, police, security staff, EMT personnel, and other first responders, since fire-weakened access panels present obvious hazards that may be difficult to deal with – especially in dark, smoke filled environments. Moreover, increasing the height of the raised floor – UFAD may require plenums 18" or higher, increases the potential danger to the occupants and the first responders.

Risk control alternatives include a system tripped by cross-zoned smoke detection and pre-action sprinkler systems, which could reduce the risk of water damage from a failed head. Beneath the raised floor or within the UFAD plenum, it may be necessary to install a “very early smoke detection system” in which the smoke induction associated with such a unit reduces the activation time. Other options include a carbon dioxide system or a similar environmentally friendly gaseous extinguishing system, improved fire detection (e.g., line detectors), and/or improved passive fire protection (e.g., fire-resistant intumescent paints or fire stops).

The full load capability of an RAF or UFAD raised floor is only realized when all of the panels are in place, as the buckling (lateral) strength of the floor depends on the presence of the panels. However, panels and even rows of panels are routinely removed in areas when cabling changes or maintenance is performed. This can lead to collapse of the plenum; but even one panel left open poses a significant and unexpected risk to staff and visitors moving in the area. Moreover, the risk increases with the height of the raised floor, and UFAD typically requires plenums that are more than 12" deep. In addition, equipment is frequently moved over the course of the lifetime over many areas, and this creates the risk that the floor loading will be exceeded, leading to a floor collapse.

RAF and UFAD increase the difficulty of assuring compliance with seismic requirements for equipment-centric areas. Supporting equipment above the floor on a grid compromises the ability to anchor equipment. This is a serious problem in cases where the capability to withstand seismic shocks is required. For example, in and around Kobe, Japan during the earthquake of 1995, data centers experienced an extraordinary range of earthquake damage. Many centers which should have been operational within hours or days were down for more than a month when a large number of supposedly earthquake-rated raised floor systems buckled, sending IT equipment through the floor. Similarly, during the World Trade Center collapse of 2001, nearby data centers which should have survived the tragedy were seriously damaged and experienced extended down time when impacts to the buildings caused raised floor systems to buckle and collapse.

Safe, secure, cost-effective buildings are a major GSA priority. Therefore, the RAF or UFAD design shall not increase risks of casualties, property damage, and loss of critical functions. Electronic security is a key element of facility protection (PBS P-100). RAF and UFAD have some inherent security concerns, as electronic devices may be installed in the plenum and, since the UFAD plenum will often be 18" or higher, it may even provide physical access. Thus, in facilities with high security requirements, RAF or UFAD shall not increase the risk of a security breach.

"Zinc whisker" contamination is another potential RAF/UFAD problem that has led to loss of critical functions. Zinc whiskers are micron-sized filaments that grow on galvanized steel plates and, since zinc conducts electricity, a filament falling on a circuit board is capable of causing a short circuit. Such contamination is especially difficult to detect because the filament disintegrates, leaving little or no trace. The source of this contamination is often the galvanized coating on the underside of raised floor tiles and, while zinc whiskers have been found on a wide range of surfaces, access floor panels are of particular concern because they have large surface areas and are often moved during day-to-day operations. Tin and tin alloy whiskers can also cause problems in electronic equipment.

The whiskers are fragile and easily break off the panel. They can then get into the UFAD supply airflow and be carried to the equipment via the plenum beneath the flooring. Zinc whiskers cause failures in electronic systems and can have severe financial impact in equipment-centric areas. However, the problem is recognized in the industry and advancements have been made in the fabrication of raised floor systems which can be designed to minimize the problem of zinc whiskers.

Additional guidance on risk factors can be obtained from the following sources: *Standard Practice for Measuring Cost Risk of Buildings and Building Systems*, ASTM E 1946; *Risk Management Guidance for Health, Safety, and Environmental Security*, ASHRAE, 2003; and *Guidance for Protecting Building Environments From Airborne Chemical, Biological, or Radiological Attacks*, NIOSH, 2002.

### A-2.4 Cost Factors

It shall be determined if the first cost of RAF/UFAD, including engineering, material cost, fabrication, installation, and inspection, is significantly higher than that of a conventional floor and/or CAD. In addition, the maximum area that might be ultimately utilized is normally built-out with a raised floor whether or not the current, near term, or even the actual ultimate function requires the use of RAF. Extra costs associated with power and data cabling can also be incurred using RAF/UFAD. Stairs, elevator shafts, piping, standpipes, etc. may have to be lengthened accordingly and shall be considered "related costs."

Architecturally, RAF/UFAD can present costly challenges. As the height of the floor and plenum increases, ramps from finished floor level to access floor level increase in length. Depending on the height of the floor or plenum (which can be 12 inches or more), stairs and landings may also have to be provided to access the RAF/UFAD area. These ramps and stairs occupy valuable space, increasing the cost per usable square footage. Weight limitations on access floor loading must also be considered. For many applications the initial high cost of installing RAF/UFAD and its continuing maintenance requirements may limit its application to specialized areas. Further, advancements in optical data transmission between electronic equipment have reduced the requirements to install CAT 6 cables under floors and have made overhead cable trays (used in conjunction with bus ducts for power) an alternate solution. This overhead solution may reduce the costs of stringing new power and connectivity.

UFAD may require significant changes in architectural, structural, mechanical, and electrical loads and designs. For example, the height of the supply air plenum and choice of using return air plenums can affect the size and locations of windows, the seismic load imposed on the floor, and the external and internal thermal loads to be dissipated by the HVAC system. Nevertheless, the exposure criteria to be maintained in the occupied zones shall not be different for UFAD than for CAD.

Positive pressure within UFAD plenums can force air movement into space perimeter partitions, and costs may be incurred in sealing the plenums. Effective perimeter air barriers shall be treated the same as ductwork. To assure effective ventilation air distribution, dedicated ventilation systems shall be used to provide dehumidified positive air pressure to the building, avoiding possible failure of large main air-handling equipment to control minimum outside air intake, to distribute that ventilation air precisely, to dehumidify the building, and to operate efficiently/stably at low-air volume conditions. These treatments may involve additional costs.

With UFAD, exposure criteria may be more difficult to control during occupancy than with CAD (i.e., uniformly mixed air in room), as UFAD systems will incorporate either vertical displacement or turbulent mixing strategies. These require additional data to assess system performance. Therefore, additional costs may have to be incurred in UFAD design to ensure that the specified exposure values are achieved during occupancy (i.e., effects of occupant disturbance of airflow patterns).

Adequate sizes and locations of mechanical equipment rooms, locations and accessibility of equipment, and components in UFAD plenums shall be assured to minimize disruption of occupied space during maintenance (PBS P-100). Access to UFAD equipment shall be facilitated by its placement in positions that will not be covered by furniture/partitions. Equipment access above 10 feet from the service floor shall be avoided. Proper air-handling unit mechanical space shall be provided to enable equipment servicing, and adequate mechanical space (approximately 4 percent of the floor area) shall be provided. This may involve significant additional costs.

Locating UFAD air-handling units within interior core areas can cause distribution path problems in that corridors are often not intended to have raised floor treatments. To provide an air path from core-located air-handling equipment, either the RAF must be extended to include corridors (with attended concerns for rolling load specifications), or overhead distribution to space drop-downs must be considered. An alternative is to place air-handling equipment within the space being served, i.e. not in core locations. This may involve significant additional costs.

Selection of UFAD may not alleviate the use of suspended ceilings. Rather, UFAD facilities may require two plenums, the ceiling plenum that contains plumbing, sprinkler systems, lighting, power wiring and return and exhaust air ductwork, and the raised floor plenum that contains power wiring, hydronics, IT cabling, and supply air. Thus, UFAD heights may be 18" or higher and the height of the occupied zone varies considerably in UFAD. The methods of maintaining stratification shall be accordingly adapted. This may involve significant additional costs.

Due to the higher supply air temperatures in UFAD than in CAD, the maximum cooling capacitance of the UFAD system may be lower than CAD. The need to provide greater levels of cooling in certain areas, such as conference rooms, may require adding fan-powered diffusers, dedicated ducting to create conference room zones, and additional water-based cooling components, all of which may impact the cost of the system.

RAF cavities and UFAD plenums are not convenient to clean, as dust, grit, trash, and various items normally accumulate under the floor and within the plenum, and cleaning of access floor space used as an air plenum is difficult. The complexity, difficulty, and accidental risk potential associated with cleaning this area can be costly problems which will continue through the life of the facility.

The building flooring under the RAF/ UFAD, which will usually be concrete, shall be sealed to prevent the accumulation of concrete dust in the cavity. The cavity shall also be sealed to prevent rodent infestation.

Additional guidance on cost factors can be obtained from the following sources: *Standards on Building Economics* (Fifth Edition), ASTM; *Green Buildings Costs and Financial Benefits*, Massachusetts Technology Corporation, 2003; *Good HVAC Practices for Residential and Commercial Buildings*, ACCA, 2003; *Standard Guide for General Principles of Sustainability Relative to Buildings*, ASTM WK5566, 2004; and *The Costs and Benefits of Green Buildings: A Report to California's Sustainable Building Task Force*, 2003.

# Appendix A-3: UFAD Systems

## A-3.1 Functions and Characteristics of UFAD Systems

When the RAF cavity serves the secondary purpose of delivering conditioning air to the space, the floor system is then called an *Underfloor Air Distribution (UFAD) System*. The genesis of contemporary UFAD systems was in main frame computer facilities in the mid twentieth century, in which the computer room had numerous types of computers and data processors with relatively high and constant heat dissipation rates. The major objective of the cooling system was to remove the heat from the machinery while maintaining a relatively constant dry bulb temperature and relative humidity in the computer room. These facilities generally consisted of one room conditioned as a single zone with conditioned air supplied into the floor cavity from a packaged air-conditioning unit or units. Air supply outlets were generally placed in the floor panels near the heat sources in such locations as to minimize discomfort to the individuals "operating" the computer machinery. The cooling loads were usually high density and relatively constant.

During the closing years of the century, computer, data, and communication technology had undergone extensive changes, and significantly impacted the workplace environment. Area lighting was being replaced by a combination of environmental and task lighting, convenience power was required for personal computers, printers, charging cords for portable electronics. And, there was the network of cables required for communications, data transmission, signaling, safety and environmental control systems.

A logical method of distributing and managing this multitude of wires was in an accessible underfloor cavity much like the computer rooms of fifty years earlier. Also, like the computer rooms of fifty years earlier, the presence of the underfloor cavity provided the opportunity to use it as a supply air plenum to deliver conditioned air to the vicinity of the work stations for the purpose of air- conditioning for human comfort.

However, it is important to recognize at the outset that, thermodynamically, there is little similarity between the earlier process of serving single, reasonably high density and relatively constant machine cooling loads and providing air conditioning for human comfort from a single conditioning system to multiple zones of control with widely varying loads.

Thus, when planning the design of a UFAD system to provide air-conditioning for human comfort, a designer must decide on the method to be employed to satisfy all varying load conditions from full cooling loads, to no load, to full heating load. The system must, at the same time, maintain the required minimum ventilation rate at all occupied times in each room or space to be conditioned while satisfying different part load requirements in adjoining spaces. The design options and pitfalls relating to this objective are discussed in some detail in Section 12 of this Guideline.

An advantage of utilizing a UFAD system is its compatibility with displacement ventilation design in those climactic locations where this type of distribution can satisfy thermal comfort and ventilation requirements. Displacement ventilation systems have been employed successfully in dry climates and in those spaces in which there is a space cooling load imposed primarily by the occupants and appliances (i.e., not by other internal cooling loads or by heat gain through the building envelope). The assumption is that room air velocity is not necessary to stimulate moisture evaporation or convective velocity to achieve sensible heat removal for human comfort. With these systems, ventilation and conditioning air is introduced at or near the floor at relatively low velocities and at no more than about 5 – 10°F cooler than the "comfort" temperature at the breathing level (say, 5 feet above the finished floor). As the air is heated by heat dissipation from the occupants and the appliances, the warming air rises, picking up heat, odors and contaminants and is expelled through a return air system at the ceiling. The concept is that there is little or no vertical mixing and that the temperature rises as the air mass rises, continually increasing in temperature. Ideally, then, the warmer temperatures above the occupancy height do not have to be controlled within the conditioned air temperature rise of the delta T (i.e., difference between room and supply air temperatures) that is needed in the room for the cooling and ventilation.

When heat gain through the envelope is significant or the indoor air relative humidity exceeds about 40% and some air velocity is necessary (e.g., 0.15 m/s or 30 feet per minute) to assist in the cooling process of the human body, displacement ventilation type air distribution systems are normally not utilized. Rather, other air distribution products and designs are available (i.e., turbulent mixing) that are claimed to enhance the performance of displacement ventilation systems by creating horizontal turbulent layers in the space while maintaining upper layer stratification by preventing vertical mixing.

Section 12 in Part 2 of this guideline includes a discussion of the engineering concepts, both fluid and thermal, relating to the design of the UFAD systems. In addition to the space conditioning there are two unique challenges in the design. One is the psychrometric need to cool the air to a 52°F dewpoint temperature and then to provide a secondary conditioning process to raise the dry bulb temperature to about 63°F for the underfloor supply plenum. The other is the immense thermal mass of the building structure that essentially forms part of the air passage. If this latter challenge is not addressed in the system design, it will result in a control time constant not normally encountered in air systems.

In addition to the air-conditioning principles relating to UFAD systems there are significant physical issues that must be addressed concerning the underfloor supply air plenum. These issues, which are also discussed in some detail in Part 2, include such concerns as water incursion, alarm and drainage; air leakage into the conditioned space and into building cavities; interferences between mechanical and electrical system's components and devices; acoustical isolation; fire safety and alarms, etc.

The most fundamental step in the decision-making process of whether or not to use an underfloor air distribution (UFAD) system should always be directed toward the objective of providing an air-conditioning system that will meet all of the thermal comfort, indoor air quality, acoustic and vibration (i.e., environmental quality) criteria without compromise. As in the selection of any such system, the design study should start with analyzing the spaces that are to be occupied. The two major concerns in this regard include, first, room air distribution system and, second, the control techniques.

## A-3.2 Room Air Distribution System

In order to analyze the capability of achieving an acceptable air distribution system for space cooling, one must recognize that the theory of underflow air distribution is significantly different from the overhead or sidewall techniques with which most engineers (and space occupants) are familiar. With overhead or sidewall supply diffusers or grilles, the concept is to use the device to mix the colder supply air with the room air while absorbing the heat and then extracting the return air from the space at the room temperature. The ambient air velocity needed for comfort is generated by the introduction velocity of the supply air, and the system is ideally designed so that the lower supply air temperature never impacts the occupant. The ideal performance is to have a homogeneous temperature throughout the occupied zone of the space and the supply diffuser is designed to supply at a reasonably high velocity (300 to 500 ft/min, 1.5 – 2.5 m/s or higher).

With the underfloor distribution system, cold air is supplied through floor grilles or diffusers at reasonably low velocities designed to achieve vertical stratification in temperature instead of mixing. The theory is that the air then moves vertically up through the space absorbing heat and contaminants as it flows upward to return air inlets in the ceiling. In this model (i.e., vertical displacement), the temperature of the air leaving the grille is at approximately the supply air temperature of 63°F and, dependent on the amount of horizontal mixing at the floor caused by the grille or diffuser (i.e., turbulent mixing), the floor surface temperatures may vary from 63 – 72°F. Ideally, as the air moves upward by buoyant effects, the air increases in temperature such that it reaches the desired space temperature of, say 75°F, at about the breathing level (5 feet), and continues to increase to about 77 - 83°F as it enters the ceiling return plenum. To prevent vertical mixing, which would negate the stratification, the outlet velocities must be kept reasonably low which limits the capacity of commercially available floor grilles and diffusers to approximately 50 – 100 CFM (25 – 50 l/s).

## A-3.3 Capacity Control Options

Control techniques must also be resolved in the schematic design phase (i.e., Final Concept, Appendix A.3, PBS P-100). Following the determination of space usages and a preliminary load analysis, the thermostatic control zones and thermostat locations must be established. Next, the method of changing (i.e. reducing) the capacity as the load reduces in any given zone must be determined. The two methods available are to either reduce the flow rate (CFM) or to reduce the temperature differential between the room air and the supply air from the plenum (delta-T).

A benefit in UFAD system air distribution that is not available in ceiling or high sidewall Variable Air Volume (VAV) systems is the compatibility with displacement ventilation. Since displacement ventilation theory does not require a high outlet velocity to create mixing, the outlet flow rate (CFM) from a UFAD outlet that utilizes displacement ventilation can be reduced without concern of "dumping" which results from such a reduction with overhead or high sidewall systems. The minimum flow to which a UFAD outlet can be "turned down" then is set by the minimum required to maintain adequate ventilation air at the breathing level. Below that minimum flow, the only option is some form of reheat which must be justified from an energy consumption perspective. (This is a method of reducing the delta-T.) With an overhead VAV system, the fan powered terminal achieves this by mixing warm air from the ceiling plenum with cold supply air, but this option is not available in a UFAD system, since the plenum air and that immediately above the floor is essentially at the supply air temperature.

Another option available with overhead ducted systems that is not available with UFAD systems is the re-setting of the supply air temperature. With the UFAD system, if all of the zones on a given air-handling unit are at less than design load, the supply air temperature cannot be changed (raised) to satisfy the flow requirements. The reason for this is that the air pathways are massive (see Section 12.2) and will require long periods of time following a change in air temperature to return to thermal equilibrium, during which time lack of space temperature control will be realized.

There are design options available for addressing these issues, some of which require the routing of ducting from the outlet of the AHU to or near the floor outlet(s). If one or more of these solutions are elected, care must then be taken to coordinate the design and routing of the ductwork with the cable management.

When UFAD is utilized with RAF, an additional benefit is that there is usually more than ample space for all of the cable requirements. However, the designers must be careful not to block cable access routes with ductwork or with air flow control partitioning below the floor.

As all HAVC designers are aware, the heat capacity equation is used in a first law balance to relate the cooling capacity of conditioned air to the space sensible cooling or heating load at any given time. This equation, expressed for an air system (where q is the load in BTU/hr, CFM is the supply air quantity in cubic feet per minute, tr is the room temperature, °F and ts is the supply air temperature), is:

$$q \quad = \quad CFM\ (1.1)\ (tr - ts) \qquad \text{Equation [1]}$$

or

$$q \quad = \quad CFM\ (1.1)\ (Dt) \qquad \text{Equation [2]}$$

Then, at design load, the value thereof is inserted into the equation, the desired room air temperature and supply air temperatures are inserted and the equation is solved for the needed air circulation quantity. This is a straightforward calculation for a "conventional" air distribution (CAD) system, which maintains a homogeneous mix of room air at the room air temperature. However, for a UFAD system, which utilizes displacement ventilation or turbulent mixing, proponents of the technique maintain that all of the heat that is "captured" above the "occupied" height of, say, 6 feet, does not have to be accounted for in the calculation of the space load, if indeed vertical mixing does not occur. It has also been published that this non-accounted for heat generally represents about 40% of the cooling load in the normal office environment. The recommendation by manufacturers of UFAD diffusers and related products is that 60% of the normally calculated cooling load be used in Equation [1] and that this would provide adequate cooling with the same air at 63° F supply temperature as a conventional (mixing) system would require at 55° F – considering a 75° F room.

The stratifying air would continue to heat above the 6-foot level and the cooling coil would, of course, "see" the same sensible load in either case.

Once the system parameters have been established at full load conditions, the only two options available for changing the system cooling capacity with load variations is to design the control system to effect changes in either the (CFM) or the (Dt) as the loads vary. Methods that have been used in conventional or homogeneous temperature, air mixing systems historically are shown in Table 1.

| Generic | Examples |
| --- | --- |
| **Group 1 Variable $\Delta t$** | |
| Heat-Cool-Off | Single Zone Air Handling Unit |
| | Fan Coil Units |
| | Residential HVAC Units |
| Dual Stream | Double Duct |
| | Multi Zone |
| Reheat | Single Zone Reheat |
| | Terminal Reheat |
| **Group 2 Variable CFM** | |
| Variable Volume | VAV Shutoff |
| **Group 3 Combination** | |
| Variable Volume & Reheat | VAV Reheat (Sequence) |
| Variable Volume & Dual Stream | Series Fan Powered VAV |
| | Parallel Fan Powered VAV |
| Variable Volume, Dual Stream, And Reheat | Series Fan Powered VAV/Reheat |
| | Parallel Fan Powered VAV/Reheat |

Table A-4.1. Types of Capacity Control Systems.

There are hybrid systems that function thermodynamically as one of the four generic systems (i.e., heat-cool-off, dual stream, reheat or variable volume). An example would be, say, in a perimeter zone, combining a variable volume unit with minimum position terminal units and finned tube radiation in the space. The finned tube heat would be controlled such to always assure enough cooling load to satisfy the minimum flow (thermodynamically, a VAV reheat system).

When considering options for space temperature control with UFAD systems, the system options are limited by physical (dimensional) limitations, thermodynamic opportunities, and products. The options available which can be used independently or in combination are variable air volume and reheat and numerous manufactures provide products specifically to be installed in the surface of the floor system and in the floor cavity.

Additionally, there are various hybrid systems that have been designed and employed successfully including displacement ventilation or turbulent mixing VAV with perimeter radiation in the conditioned space and ceiling mounted fan powered VAV terminals that supplied the discharge air into the underfloor supply air plenum.

A third hybrid system utilizes underfloor supply ducts to a partitioned zone plenum provided with a VAV terminal where the air enters the partitioned zone. With this system, air leakage from the plenum to the space would not adversely impact the performance.

### A-3.4 Ventilation and Humidity Control

The baseline system required by the GSA standard PBS P-100 consists of two very different types of air-handling systems. One is a dedicated outdoor air unit (DOA) or ventilation air conditioner (VAC) and the other is a recirculating air conditioning (RAC) unit. Both of these types of air-handling systems pertain equally to CAD and UFAD systems (see Chapter 5, Section 4 of PBS P-100).

The ventilating air-conditioning unit is required to be sized only for the ventilation air required for the zones served, as determined by ASHRAE Standard 62. It is important to note that this unit (these units) is not to be sized to handle all of the circulated air but only the ventilation component All of the ventilation air is to be introduced to the building through this unit (or these units). The VAC unit is to provide all necessary cleaning (particulate and/or chemical) preheating, cooling, dehumidifying and volume control of the ventilation air. Another important feature is, to the extent feasible, all humidity control for the **building** is to be provided with this unit (usually by simple dewpoint control).

The second unit type is a simple recirculating unit which simply recirculates air from the space or spaces, removes any space generated particulate, provides any necessary sensible cooling or heating and supplies the air back to the space.

PBS P-100 further requires that the Ventilation Air Conditioning unit be used to pressurize the building during occupied and unoccupied times. The recirculating units are required to be located in fan rooms on the floors which they serve, and since they have no requirement for outdoor air they can be located conveniently in interior equipment rooms in the core of the building.

In warm humid climates the discharge temperature of the cooling dehumidifying coils in the VAC units must be at or below the desired room dewpoint temperature (approximately 52°F) and it can be distributed at that temperature to help satisfy space sensible loads or reheated as necessary when there is no space sensible load. The air can then be distributed directly to the spaces providing constant or controlled quantity ventilation air, or it can be distributed into the return air stream of the recirculating units. The option selected is determined by the design engineer.

If the engineer elects to distribute the ventilation air directly to the spaces, the UFAD VAV controls can be tight shutoff since ventilation would no longer pose a constraint on the system design.

Another advantage of the P-100 baseline system concept, insofar as UFAD systems are concerned, is that the higher supply air temperature required (63ºF) could simply be the controlled coil discharge temperature from the recirculating air-conditioning unit since this unit is not required for building dehumidification.

If the system designer, through life cycle cost analysis (See Sections 2 and 9 and Appendix A-2 of this Guideline), can demonstrate it beneficial to provide the outdoor air through mixing damper control at all of the air handling units that serve the spaces, it will be necessary to reduce the air to the controlled dewpoint temperature of about 52°F and then increase it to the UFAD supply temperature of about 63°F. Since this cannot be done with reheat (ASHRAE Standard 90.1) it will require the use of a return air bypass system which adds both cost and complexity and the resultant decreased reliability.

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