INTRODUCTION

Underfloor air distribution (UFAD) is an air distribution strategy for providing ventilation and space conditioning in buildings as part of the design of an HVAC system. UFAD systems use the underfloor plenum beneath a raised floor to provide conditioned air through floor diffusers directly to the occupied zone.

Aim: To achieve thermal stratification and to reduce the energy use

Scope: Under floor air distribution is frequently used in office buildings, particularly highly-reconfigurable and open plan offices where raised floors .UFAD is also common in command centers, IT data centers and Server rooms that have large cooling loads from electronic equipment and requirements for routing power and data cables. The ASHRAE Under floor Air Distribution Design Guide suggests that any building considering a raised floor for cable distribution should consider UFAD. (Airports, Industries, public complexes, recreation, laboratories, etc...).

Objectives:

1. Improved ventilation efficiency and indoor air quality
2. Improved occupant comfort, productivity and health
3. Reduced energy use

A brief note on UFAD SYSTEM

An extensive literature review about Underfloor Air Distribution (UFAD) systems is presented. For the review, various sources and search engines were used to find the technical research and literature by using specific keywords to search for the relevant reports or browsing through the list of documents. Sources and search engines include ASHRAE abstract archives (1980-1997), Elsevier Literature Search Engine, the Center for the Built Environment (CBE), the Building Diagnostics Research Institute.

An UFAD system is an HVAC system that uses the open space (i.e., the underfloor plenum) between the structural slab and the underside of a raised floor to deliver conditioned air to supply outlets located at or near floor level within the occupied zone.

Three Basic Approaches of UFAD Systems (Bauman and Webster, 2001)

Currently, three types of UFAD systems are available. Bauman and Webster (2001) summarized these types in their paper. These are: **1) supply air delivered via passive floor registers and/or fan-powered terminal boxes supplied by a pressurized underfloor plenum and central air handler**, **2) supply air delivered via active, locally-controlled, fan-powered registers (in the floor or workstations), supplied by a very low-pressure underfloor plenum and central air handler,** and 3) **supply air delivered via under floor ducts to terminal devices or supply outlets.**

Applications

Underfloor air distribution is frequently used in office buildings, particularly highly-reconfigurable and open plan offices where raised floors are desirable for cable management. UFAD is also common in command centers, IT data centers and Server rooms that have large cooling loads from electronic equipment and requirements for routing power and data cables.

The ASHRAE Underfloor Air Distribution Design Guide suggests that any building considering a raised floor for cable distribution should consider UFAD.

Title:

Under floor air distribution**(UFAD)** systems—an alternative air destitution systems

Sources:-

- ASHRAE abstract archives (1980-1997)
- ASHRAE Bookstore

Center for the Built Environment (CBE):(F. Bauman and T. Webster.)

- UMI Digital Dissertations
- Wilson Abstracts

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Sources Searched and Keywords

Various sources and search engines were used to find the technical research and literature by using specific keywords to search for the relevant reports or browsing through the list of documents. First, the references from the book "Underfloor Air Distribution (UFAD) Design Guide" by Fred S. Bauman were used to start searching literature. His references include papers, articles, and web references presenting major contributions to the understanding and development of UFAD technology and design. Other literature search methods were utilized. Below is the list of sources.

ASHRAE abstract archives:

ASHRAE transactions and journal papers are main sources about the UFAD systems.

Center for the Built Environment (CBE):

The Center for the Built Environment (CBE) at the UC Berkeley is a National Science Foundation Industry/University Cooperative Research Center. UFAD, as one of the HVAC systems, is the topic of the center and published many papers. The main authors are F. Bauman and T. Webster.

Building Diagnostics Research Institute:

Dr. James Woods "What Real-World Experience Says About the UFAD Alternative"

The search engines and publication lists used are as follow:

- ASHRAE abstract archives (1980-1997)
- ASHRAE Bookstore
- Science Direct (ELSEVIER journals)
- UMI Digital Dissertations
- Wilson Abstracts

This progress report includes a general description of UFAD system, several findings, and a list of technical research and literature of the UnderFloor Air Distribution (UFAD)

FINDINGS

General Description of Under Floor Air Distribution (UFAD) Systems (Bauman, 2003) An underfloor air distribution (UFAD) system is an HVAC system that uses the open space (underfloor plenum) between the structural slab and the underside of a raised floor to deliver conditioned air to supply outlets located at or near floor level within the occupied zone (up to 6 ft). Since air is supplied in much closer proximity to the occupants than in conventional overhead systems, supply air temperatures must be higher (e.g., 60 ºF to 65 ºF). Usually, a task/ambient conditioning (TAC) system is used with the UFAD system to allow individuals to control thermal conditions in small and localized zones.

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EVALUATION OF UFAD SYSTEMS

Benefits and Barriers of UFAD Systems (Bauman, 2003)

The followings are the general benefits of a UFAD system.

1) Improved thermal comfort:
   By allowing individual occupants to control their local thermal environment
2) Improved ventilation efficiency and indoor air quality:
   By delivering the fresh supply air at floor level or near the occupant
3) Reduced energy use:
   a. Cooling energy savings from economizer operation and increased chiller COP
   b. Fan energy savings
4) Significantly reduced life-cycle building costs:
   Due to reduced expenses associated with occupant "churn," remodeling or changing interior (Addison, 2001)
5) Reduced floor-to-floor height in new construction:
   By reducing the overall height of service plenum
6) Improved productivity and health

Standards and Codes- UFAD Systems

Applicable building standards and codes that have important provisions related to the design, installation, and operation of UFAD systems---

1. ASHRAE Standard 55-2004 Thermal Environmental Conditions for Human Occupancy
2. ASHRAE Standard 62-2001 Ventilation for Acceptable Indoor Air Quality
3. ASHRAE Standard 90.1-2001 Energy Standard for Buildings
   –Except Low-Rise Residential Buildings
4. ASHRAE Standard 113-1990 Method of Testing for Room Air Diffusion
5. ASHRAE Standard 129-1997 Measuring Air Change Effectiveness
6. CEC 2001 Title 24: CEC Second Generation Non-residential Standards
7. Uniform Building Code and Local Fire Codes

Notes:
#American Society of Heating, Refrigerating, and Air-Conditioning Engineers
California Energy Commission

Observations

Since UFAD technology is relatively new to the building industry, its characteristics may require consideration of unfamiliar code requirements and,
in fact, may be in conflict with the provisions of some existing standards and codes.
Applicable standards and codes should be looked at carefully; revisions and exceptions that are more compatible with UFAD technology may be forthcoming as additional research results are obtained.

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While there are many advantages of UFAD systems over traditional overhead systems, there are still some barriers in the adoption of UFAD systems. **These barriers are:**

1) New and unfamiliar technology:

Lack of familiarity can create problems throughout the entire building design, construction, and operation process, including higher cost estimates, incompatible construction methods, and incorrect building control and operation on the part of both facility managers and building occupants.

2) Lack of information and design guidelines:

There has not previously existed a set of standardized design guidelines for use by the industry.

3) Whole-building performance:

No whole-building energy simulation program capable of modeling a UFAD system. (Whole-building energy simulation program under EnergyPlus will be completed by 2006 by LBNL. The project is sponsored by California Energy Commission (CEC) and U.S. DOE).

4) Higher initial costs:

Typically, a UFAD installation requires $3 to $5 per sq. ft. premium over comparable overhead systems (Daly 2002).

5) Cold feet and draft discomfort:

Poorly designed (e.g., the close proximity of supply outlets to the occupants) and operated UFAD system can cause cold floor problem. To prevent this problem, all office floors are recommended to be carpeted.

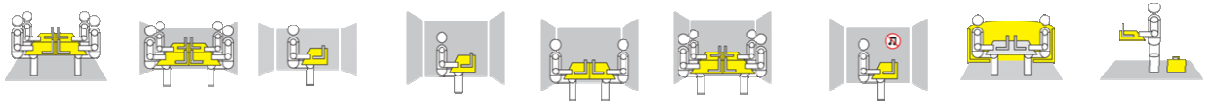
6) Condensation and dehumidification issue:

In humid climates, outside air must be properly dehumidified before delivering supply air to the underfloor plenum.

7) Spillage and dirt entering UFAD systems:

There are the probability of spillage and dirt entering directly into the underfloor supply airstream. Most floor diffusers, however, have been designed with catch-basins (e.g., to hold the liquid from a typical soft drink spill).

Office spaces and types:

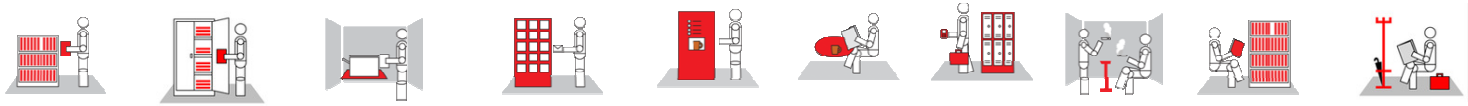


open office **team space** **cubicle** **private office** **shared office** **team room** **study booth** **work lounge** **touch down**

Meeting spaces

small meeting room **large meeting room** **Small meeting space** **large meeting space** **brainstorm room** **meeting point**

Support spaces



filing space **storage space** **print and copy area** **mail area** **pantry area** **break area** **locker area smoking room** **library** **waiting area**

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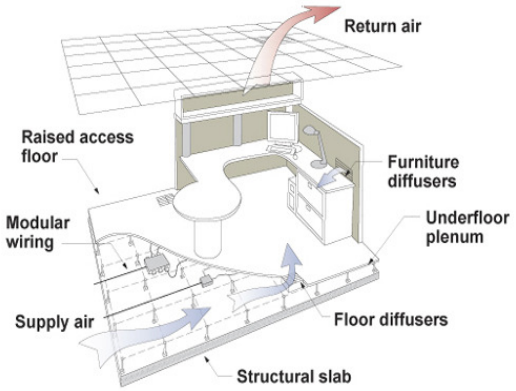
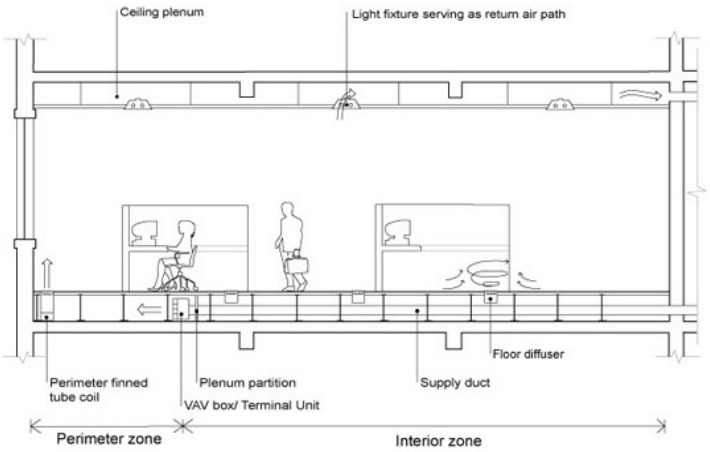
Typical Office Work Space Configuration Examples

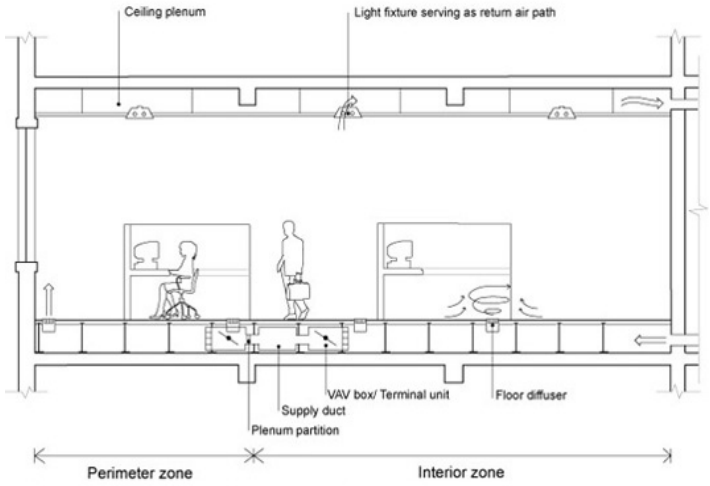


Types of plenum configurations

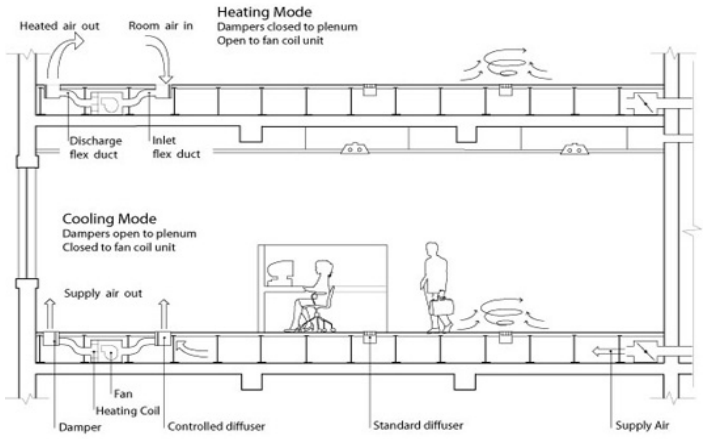
1. Multi-zoned with extensive perimeter ductwork
2. Multi-zoned with limited perimeter ductwork
3. Open-plan plenum



Multi-zoned, limited perimeter ductwork



Multi-zoned, extensive perimeter ductwork



Open Plan Plenum

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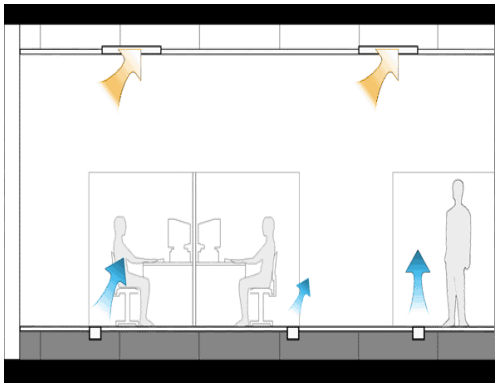
System Description



There are three basic approaches to configuring the supply-air side of an UFAD system:
•pressurized underfloor plenum with a central air handler delivering air through the plenum and into the space through passive grills/diffusers;
•zero-pressure plenum with air delivered to the space through local fan-driven supply outlets in combination with the central air handler; and
•In some arrangements the supply air is ducted through the underfloor plenum to the supply outlets, although in this last configuration certain energy and cost benefits may be reduced compared to the first two approaches.

Underfloor air distribution (UFAD) system

With UFAD systems, conditioned air from the air handling unit (AHU) is ducted into the underfloor plenum where it typically flows freely to the supply outlets. Underfloor systems are generally configured to have a relatively large number of smaller supply outlets, many in close proximity to the building occupants, as compared to a conventional overhead system.
There are three basic approaches to configuring the supply-air side of an UFAD system:

1) pressurized underfloor plenum with a central air handler delivering air through the plenum and into the space through passive grills/diffusers;
2) zero-pressure plenum with air delivered to the space through local fan-driven supply outlets in combination with the central air handler; and
3) In some arrangements the supply air is ducted through the underfloor plenum to the supply outlets, although in this last configuration certain energy and cost benefits may be reduced compared to the first two approaches.

UFAD Technology Needs

1) ***New and unfamiliar technology.*** There has been until recently a lack of quantitative performance data and systematic design guidelines on this innovative technology.
2) ***Perceived higher costs.*** The perceived higher cost of UFAD systems is one of the main reasons that UFAD technology is not used more widely by the industry today. There are several factors, however, that can make first costs very competitive with life cycle costs significantly lower than conventional overhead systems.
3) ***Problems with applicable standards and codes.*** Since underfloor technology is relatively new to the building industry, its characteristics may require consideration of unfamiliar code requirements and, in fact, may be in conflict with the provisions of some existing standards and codes.
4) ***Limited availability of UFAD products.*** Although the situation is beginning to change in recently years, in the U.S. there are only a few manufacturers offering UFAD products.
5) ***Cold feet and draft discomfort.*** Underfloor systems are perceived by some to produce a cold floor, and because of the close proximity of supply outlets to the occupants, the increased possibility of excessive draft. These conditions are primarily indicative of a poorly designed or operated underfloor system.

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Thermal Comfort in UFAD Systems

UFAD compared to other distribution systems

Overhead (mixing) – Conventional air distribution(CAD) Systems

Conventional *overhead mixing systems* usually locate both the supply and return air ducts at the ceiling level. Supply air is supplied at velocities higher than typically acceptable for human comfort and the air temperature may be lower, higher, or the same as desired room temperature depending on the cooling/heating load. High-speed turbulent air jets mix incoming supply air with the room air.

Displacement ventilation

Displacement Ventilation systems (DV) work on similar principals as UFAD systems. DV systems deliver cool air into the conditioned space at or near the floor level and return air at the ceiling level. This works by utilizing the natural buoyancy of warm air and the thermal plumes generated by heat sources as cooler air is delivered from lower elevations. While similar, UFAD tends to encourage more mixing within the occupied zone. The major practical differences are that in UFAD, air is supplied at a higher velocity through smaller-size supply outlets than in DV, and the supply outlets are usually controlled by the occupants.

UFAD and energy

The energy assessment of UFAD systems is a not fully solved issue, which has led to numerous research projects within the building science and mechanical engineering community. Proponents of UFAD point to the lower fan pressures required to deliver air in a building via the plenum as compared to through ducts. Typical plenum pressures are 25 pascals (0.0036 psi) (0.1 inch of water column) or less. The improvements in cooling-system efficiency inherent in operation at higher temperatures save energy.

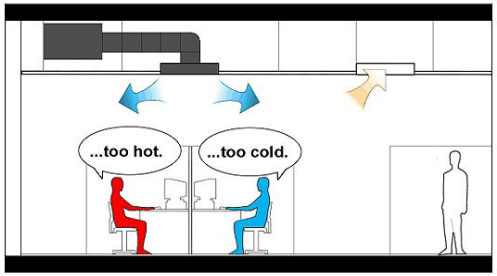


Figure 1. Conventional overhead air distribution system.

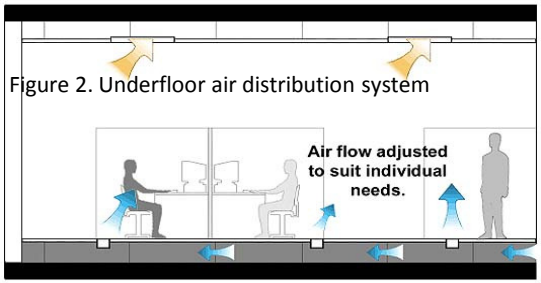
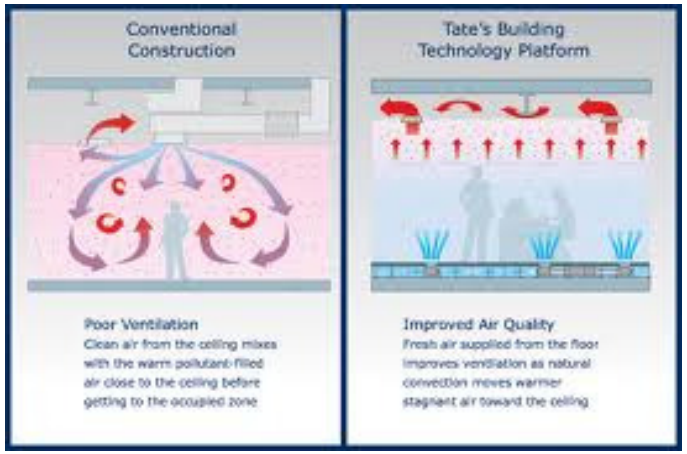


Figure 2. Underfloor air distribution system



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UFAD System Design Process:

1. Initial Building Design Considerations
2. Select System Configuration
3. Determine Space Cooling and Heating Loads
4. Zoning
5. Determine Ventilation Air Requirements
6. Determine Zone Supply Air Temperature and Flow Rate
7. Determine Return Air Configuration
8. Calculate Cooling Coil Load
9. Layout Ducts and Plenum Configuration
10. Select Primary HVAC Equipment
11. Select and Locate Diffusers
12. Develop a Control Strategy

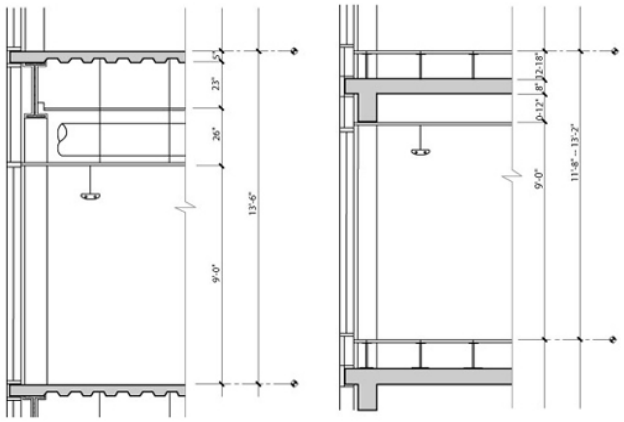

Table 1

Types and Variations of Current UFAD Systems

Supply Air	Return Air
Positive Pressure Plenum Unducted, "Push" Type ✓ Diffusers & Grilles ✓ VAV Units	**Ceiling Plenum** ➢ Ducted ➢ Partially Ducted ➢ Unducted
"Neutral" Pressure Plenum ➢ Ducted to VAV or FC Units ➢ Unducted, "Pull" Type ✓ Fan-powered VAVs ✓ Fan Coil Units ✓ Fan-powered Diffusers and Grilles	**High Sidewall Grilles** ➢ Ducted or unducted to Ceiling ➢ Ducted to VAV or FCU in Floor **Floor Plenum** ➢ Ducted from Kiosk to VAV or FCU ➢ Ducted from Grille to VAV or FCU ➢ Membrane to separate floor plenum for supply and return

Height Saving Benefit

Floor Designed with Conventional Overhead System

Floor Designed with Underfloor Air Distribution System

Plenum design

There are several approaches to address zones with significantly different thermal loads:

- ➢plenum partitioning with ducted VAV devices supplying air to each zone;
- ➢plenum partitioning with fan-powered terminal devices supplying air to each zone;
- ➢thermostatically controlled VAV diffusers may be used in both partitioned and open plenums;
- ➢local fan-driven supply outlets may be used in both partitioned and open plenums;
- ➢open plenums with mixing boxes and ducted outlets.

Floor to floor heights in practice

In practice floor to floor height driven by:

1. Ceiling height in finished space (fixed)
2. Utility space above ceiling (flexible)
3. Structural system (fixed)

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Interior Zones
Partition construction: Vertical sheet metal dividers
Perimeter zone dimensions: Typically extending 4 – 5 m (12 – 15 ft) from external wall.

Supply air temperature and flow rate
Because the air is supplied directly into the occupied zone, supply air temperatures must be warmer than that used for conventional overhead system design. For cooling applications, supply air temperatures at the diffusers should be maintained no lower than in the range of 17 – 20°C (63 – 68°F) to avoid overcooling nearby occupants. This supply temperature can be reset even higher under partial load conditions.

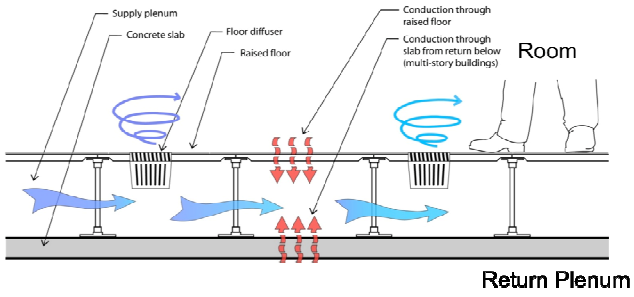
Mixed air temperature after the cooling coil, or plenum inlet temperature, must be determined by taking into account temperature increase (or decrease, depending on the slab temperature) as the air flows through the underfloor plenum. Current estimates for typical air flow rates in an underfloor plenum with a slab that is 3°C (5°F) warmer than the plenum inlet air temperature call for a 1°C (2°F) increase for every 10 m (33 ft) of distance traveled through the plenum.

In temperate climates, where high humidity is not a problem, these warmer supply air temperatures increase the potential for economizer use, and allow higher cooling coil temperatures to be set, if desired.

Cooling air quantities for UFAD systems should be carefully determined. Higher supply air temperatures would suggest that higher supply air volumes are required, but the higher return temperatures created by stratification reduce the required increase in volume. Finally, as previously described, a calculation of the portion of heat sources that bypass the occupied zone in the space allows cooling air quantities to be further reduced. The net effect is that for most designs, controlled stratification in the space allows cooling air quantities for UFAD systems to be equal to or less than those required under the same conditions using overhead air distribution.

As discussed further below under controls, control strategies for temperature and flow rate will vary depending on the magnitude and variability of loads in each control zone, as well as other system design issues.

	Supply air temperature	**- Return air temperature**
UFAD Systems	17-20°C (63-68°F)	- 25-30°C (77-86°F)
Overhead Systems	13°C (55°F)	- 24°C (75°F)



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Diffusers

The flexibility of mounting supply diffusers in movable raised access floor panels is a major advantage for UFAD systems. The inherent ability to easily move diffusers to more closely match the distribution of loads in the space makes the placement of diffusers a much easier task. In fact, initial layout can be done quite crudely. Final placement can take place after the location of furniture and loads, as well as the preferences of individual occupants, are more accurately determined.

11A. Passive Diffusers

Passive diffusers are defined as air supply outlets that rely on a pressurized underfloor plenum to deliver air from the plenum through the diffuser into the conditioned space of the building. Swirl floor diffusers, constant velocity floor diffusers, and linear floor grills are the primary types of floor diffusers

Diffuser Types:

1.**Swirl**

Airflow pattern - Swirling upwards, rapid mixing.
Adjustability - Rotate grill or bucket to adjust air flow volume.
Ideal Location - Interior and perimeter zones.

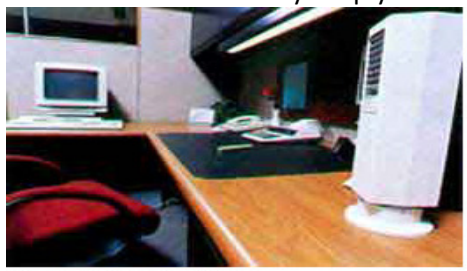
2.**Constant Velocity**
Airflow pattern - Multi directional, air jet.
Adjustability - Adjust grill for changes to air flow direction, thermostat for air flow volume.
Ideal Location - Interior and perimeter zones.

3.**Linear**

Airflow pattern - Planar sheet, air jet.
Adjustability - Multi-blade damper is used to adjust air flow volume.
Ideal Location - Perimeter zones.

4.Active Diffusers

Active diffusers are defined as air supply outlets that rely on a local fan to deliver air from the plenum through the diffuser into the conditioned space of the building. Passive diffusers can generally be converted to an active diffuser by simply attaching a fan-powered outlet box to the underside of the diffuser or grill.



Desktop air supply pedestals

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Construction Phase Guidelines

- ▪It is essential that the implications of the raised access floor be considered early in the design process.
- ▪The concrete slab surface must be sealed to reduce dust, and the underfloor plenum and floor panels must be thoroughly cleaned both during installation of the access floor and again before occupancy.
- ▪The height of the access floor and the placement of the 0.6 m x 0.6 m (2 ft x 2 ft) raised floor pedestal grid is critical with respect to locating all underfloor service installations.
- ▪It is important to lay out underfloor equipment requiring regular maintenance to be located in accessible areas, such as corridors, not underneath furniture and partitions.
- ▪In partitioned office spaces, offset the partition grid from the floor grid so that partitions do not cover joints between floor panels, thereby preventing access to the underfloor plenum on both sides of the partition.
- ▪Consider dead load allowance and seismic bracing of the access floor.
- ▪Determine areas in the building with no access floor and allow for transitions to areas with access flooring.
- ▪In pressurized underfloor air distribution systems, greater care must be taken during construction to seal the underfloor plenum to prevent uncontrolled air leakage.
- ▪Designers must consider that fan rooms or access for HVAC distribution will be required at more frequent intervals than with conventional air distribution systems.
- ▪If called for, return air shafts must be designed between the ceiling and the underfloor plenum, usually around columns or other permanent building elements.
- ▪The main structural slab, the traditional working platform, will not be available continuously during construction, and therefore a well coordinated construction sequence is necessary.

Applications

What are the different applications of a UFAD?

Application	Restrictions / Additional Comments	Examples
Industrial	Should not be used where pollutants are heavier than air unless they are directly removed by local extraction	Production/assembly halls, stores, factories.
Offices	Likely to need additional cooling devices. Works best when •ceiling heights are greater than 2.5m •casual loads are moderate •occupants are mainly sedentary •buildings are airtight	Open plan or cellular.
Recreation	Can achieve very low noise levels compared to mixing systems. Underseat air supplies should be used with particular attention to local draught conditions	Theatres, cinemas, auditoria, sports halls, fitness rooms and restaurants.
Laboratories	Should not be used where pollutants are heavier than air unless they are directly removed by local extraction.	All types.

UFAD ventilation efficiency

•Field research found that UFAD system had lower airborne particle concentrations than OH system (Japan, 1995)

•Sensation of air movement gives perception of better IAQ, important for occupant satisfaction

Title:
Under floor air distribution**(UFAD)** systems—an alternative air destitution systems

Sources:-
- ASHRAE abstract archives (1980-1997)
- ASHRAE Bookstore
Center for the Built Environment (CBE):(F. Bauman and T. Webster.)
- UMI Digital Dissertations
- Wilson Abstracts

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How does it work?

Once the air enters through the floor diffusers, it spreads across the floor forming a reservoir of fresh cool air. Any sources of heat (e.g. people computers etc.) will generate a thermal plume rising upward entraining the surrounding air, as shown in the Figure. The fresh cool air at floor level will flow to replace that which is warmed and lifted into the convective plumes. By this means the fresh air continuously replaces the air as it is used and contaminated air is lifted to high level for removal from the space.

The energy conservation aspects

UFAD is a more energy efficient system than the 'mixing flow' ceiling based distribution system, due to the following reasons:

• Air is provided at low flow rates, as buoyancy is utilized to distribute air through the space. Low flow rates result in the reduction of energy usage of the fans used to distribute air through the under floor ducts.

•The supply air is at a relatively high air temperature (i.e. 19°C), as the air is supplied closer to the source of heat gains. Relatively high air temperature means lower chilled water temperatures, resulting in an effective reduction of the heat load / tonnage of the chillers installed.

•Since new air is kept separate from stale air, the breathed air quality is substantially uncontaminated

What is the difference in capital cost, compared to ceiling based systems?

The increase in cost for UFAD is mainly due to the requirement of false flooring or the forming of ducts (in concrete) as a part of the floor slab.

There is a reduction in cost when a UFAD system is used due to the reduction in the cost of the chillers and fans.

Therefore, the effective cost difference will vary depending on the size of the system.

Saying that if operational cost is taken into consideration any increase in cost of the UFAD will have an ROI of less than a year.

Will the ducts get dirty sooner, due to the diffusers being on the floor?

This is probably the biggest misconception people have about UFAD. The answer to it is contrary to what anyone would think. The ducts do not get dirtier as the ducts are positively pressurized. This in simple terms means that the dirt would be blown out instead of sucked into the ducts.

Will the flexibility of the interior planning be restricted due to the diffusers on the floor?

This is probably the biggest disadvantage of UFAD, unlike the ceiling distribution system where the furniture can be placed directly under the diffusers. In UFAD, furniture cannot be directly placed on the diffusers. Therefore, reducing flexibility of interior planning in a speculative office space. However, if UFAD is considered during the initial architectural planning, the area & dimensions of the floor plate can be designed to get a relatively higher flexibility in planning.

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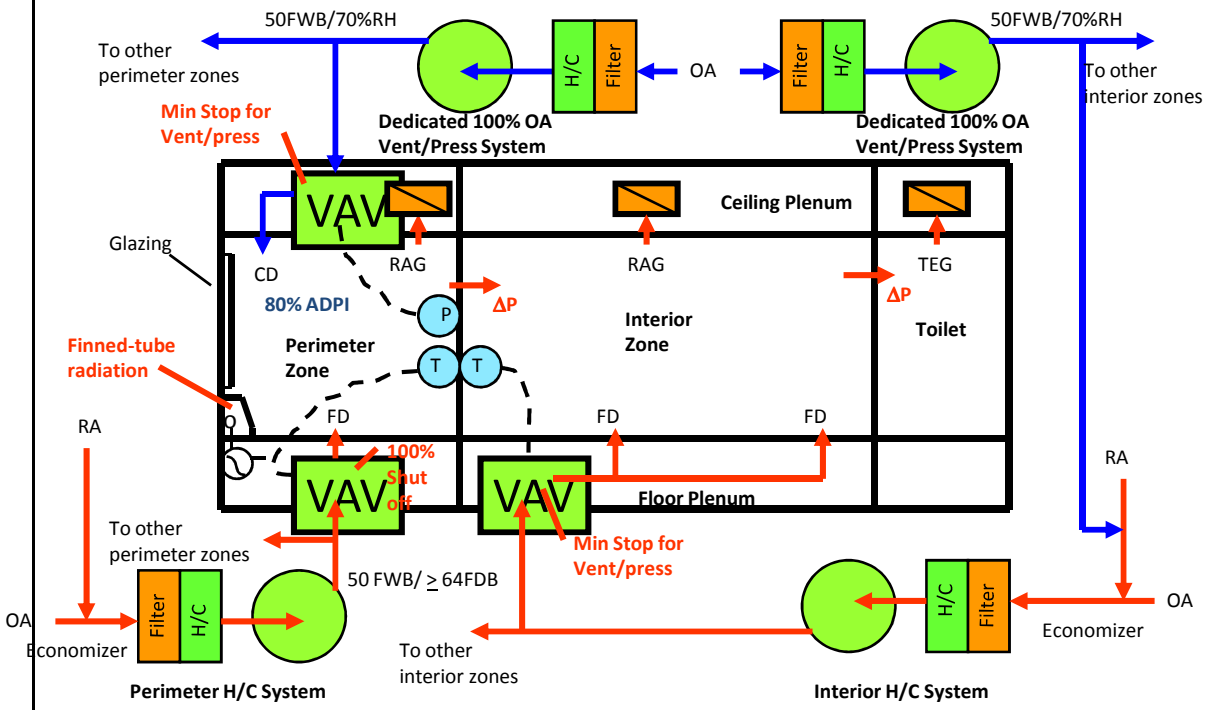
Schematic of UFAD Systems Specified by GSA



Conclusions

- *Both UFAD and CAD systems will require more care in design,* installation *and operation as consequences become more apparent*
- *commissioning, and building diagnostic techniques continue to improve and provide greater assurance of system performance*
- *UFADs are attractive alternatives to CADs, but more limited than marketing suggests.*

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