PDHonline Course M217 (3 PDH)

HVAC - Overview of Underfloor Air-conditioning Systems

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Course Content

Introduction

Underfloor air distribution (UFAD) is a method of delivering air through supply outlets located at floor level, with the intent of maintaining comfort levels only in the occupied lower portion of space. This technology uses the open space (underfloor plenum) between the structural concrete slab and the underside of a raised access floor system to deliver conditioned air directly into the occupied zone of the building. This approach is an increasingly popular alternative to the traditional overhead, which attempt to condition the air in the whole volume of space from the top.

An underfloor air distribution system may also be referred to as “raised-access” flooring system or displacement ventilation. This innovative approach to heating, ventilating and air conditioning offers the utmost in occupant comfort, improved air quality and energy savings.

In this course we briefly describe the significant features, potential advantages, and design issues associated with underfloor air distribution.

Brief History

UFAD systems were originally introduced in the 1950s typically for the computer rooms and data control centers of the time. These systems were primarily designed for dissipating extremely high heat loads associated with the electronic equipments and were not intended for human comfort. These systems were subsequently modified with high aspiration swirl diffuser in 1970s for comfort applications. Statistical data indicates that the raised floor systems currently comprise an estimated 58% of new commercial building projects in Japan and about half of all new commercial projects in Europe and the United Kingdom. In North America, the market for raised floor systems is much smaller; including only about 10% of new commercial floor area, however, the proponents of the UFAD estimate that raised floor installation in North America will increase exponentially in coming years.

Technology Description

Buildings that use underfloor air distribution have a raised panel flooring system that is supported on vertical pedestal supports approximately 12 inches above the slab floor. The underfloor space delivers conditioned air through small, floor-mounted diffusers located in individual workspaces. High-induction swirl diffusers quickly mix the supply air as it enters the occupied zone. Air is circulated in an upward motion similar to natural convection and is exhausted through return grilles in the ceiling. The characteristics of an underfloor air distribution system include:

1) By delivering air directly to each workspace, the HVAC system eliminates “dead zones” of airflow.

2) Electrical power, telephone, data cable and other portions of the building’s infrastructure are located in the underfloor space.

3) Plug-in electrical boxes, power/data outlet boxes and air diffusers are flush-mounted in the floor panels and can easily be moved to accommodate reconfiguration of the workspace or floor plan.

4) The surface of the floor panels can be made of a variety of materials, including carpet tiles, decorative concrete, linoleum, finished metal or wood composite.

Traditionally, access floor systems have been widely used in clean rooms and in spaces with large amounts of electronic equipment, such as control rooms and computer rooms. With the arrival of the technologically laden office environment, demand for access floors is rising rapidly because it provides the flexibility to the owners to easily reconfigure the spaces in short time. Floor plenum heights for underfloor air distribution systems in office buildings are typically 12 to 18 inches, depending on the amount of cabling and ventilation requirements. Generally, a floor plenum height of 12 inches is adequate for most office situations.

UNDERFLOOR AIR DISTRIBUTION v/s CONVENTIONAL OVERHEAD SYSTEM DESIGN

Conventional overhead air distribution supply conditioned air at the ceiling level through an array of evenly spaced ceiling diffusers connected to extensive networks of ducting. The return is also taken from higher levels either using a ducted or plenum system (refer fig 1 below). Overhead systems promote complete mixing of supply air with room air, thereby maintaining the entire volume of air in the occupied space at the desired setpoint temperature and evenly distributing ventilation air. Supply air is typically introduced in space at 50 -55ºF and after mixing the room conditions achieve a uniform temperature of 72 -75ºF. Indoor air quality is maintained by diluting the contaminated air in the space with the required amount of outdoor air. However, these systems tend to suffer from dumping and short-circuiting, especially when low aspiration diffusers are used, resulting in poor temperature distribution, complaints about draughts, and low indoor air quality (IAQ) in the occupied space.

Underfloor aid distribution (UFAD) turns air supply upside down, allowing a floor plenum to deliver conditioned air to the space via floor grilles in the raised floor system. The floor plenum typically consists of pedestals and removable floor panels that can be rapidly reconfigured. Supply air is introduced through diffusers at floor level and is exhausted at the ceiling through return or relief grilles (refer fig 2 below).

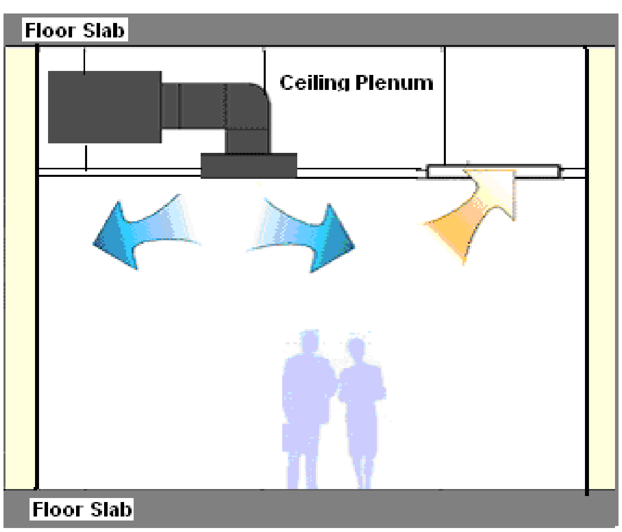


Fig -1 Conventional System

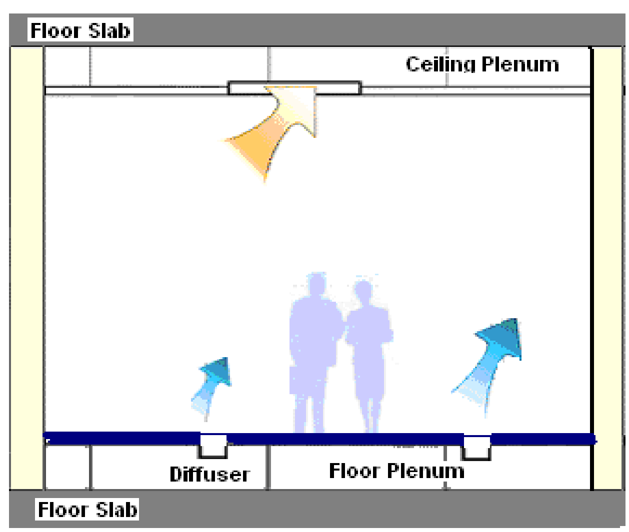


Fig - 2 Underfloor Air Distribution System

An underfloor air distribution (UFAD) system delivers air at low velocity and relatively high temperature compared to traditional overhead distribution systems. The UFAD systems use special design floor diffuser (swirl type) that provides greater mixing in the occupied zone (up to 6 ft). If the diffuser throw exceeds the stratification height (~ 6 ft), the cooler supply air will penetrate into the warmer upper layer before dropping back down into the lower region and bringing warm air down with it, thus influencing the temperature in the occupied zone.

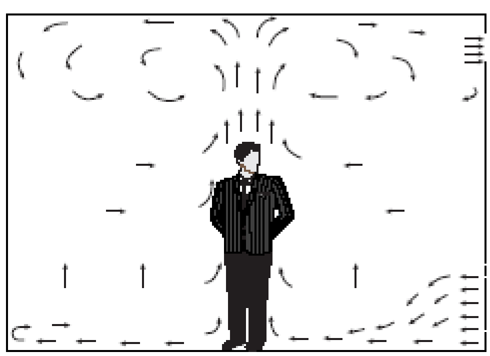
CLASSIFICATION OF UFAD SYSTEMS

Underfloor air distribution systems fall into two general categories distinguishable from one another by the temperature and velocity profiles they create in the occupied space. The first type is a displacement ventilation system; the second type is a hybrid underfloor system.

Displacement Ventilation (DV) Systems

Displacement ventilation systems deliver air at floor level into the space at very low velocity, typically less than 100 feet per minute (fpm). At this velocity, the air coming out of the diffuser can barely be felt and the fresh air "pools" onto the floor and rises slowly as it picks up heat. Heat sources create plumes that improve air circulation. Displacement ventilation systems are generally applied to spaces that require cooling, but are essentially a ventilation system with limited cooling (12 – 20 Btu/sq-ft); it does not fully meet the definition of air-conditioning. Conventional European design practice limits the use of displacement ventilation systems to spaces with peak cooling loads of 12 Btu/hr-ft^2 or less. In spaces with higher cooling loads, radiant cooling systems are used in combination with displacement ventilation. Recent U.S. research suggests that displacement ventilation systems can be applied to spaces with cooling loads up to 38 Btu/hr-ft^2.

Displacement systems have logical applications in open areas, industrial spaces or for spaces with high pollutant loads (such as smoking lounges). Draft is usually not an issue in spaces served by displacement ventilation systems, but the temperature difference between the floor and head levels (the temperature gradient) is an important design issue. Displacement systems can be installed without a raised floor, using large low-wall grilles or pedestals to let the air flow out onto the floor.) Heat sources in the conditioned space (such as people, computers, or copy machines) convect supply air upward in well-defined plumes that provide cooling where it is needed.



A comparison of system characteristics for conventional air-conditioning v/s UFAD system is tabulated below:

System Characteristics	Conventional System	Displacement System
Supply Air Flow	1,000 - 1,500 CFM	400 - 600 CFM
Diffuser Air Velocity	600 - 800 FPM	<100 FPM
Cooling Supply Air Temperature	52 - 55F	63 - 68F
Outside Air Flow	400 - 500 CFM (30%)	400 - 600 CFM (100 %)
Typical Parameters		
AC Size	3 Tons	2 to 2.5 Tons
Cooling Demand	3.3 kW	2.5 kW
Fan Demand	0.3 kW	0.2 kW
Total Demand	3.6 kW	2.7 kW

Hybrid Underfloor System:

The second general type of underfloor air distribution system can be characterized as a hybrid underfloor system, a combination of displacement ventilation and conventional mixing systems. Like the displacement ventilation system, the hybrid underfloor system attempts to condition only the occupied lower portion of space, producing two distinct zones of air, one cool and relatively fresh, the other hot and stale.

Hybrid systems differ from true displacement ventilation systems primarily in the way that air is delivered to the space. The primary differences are:

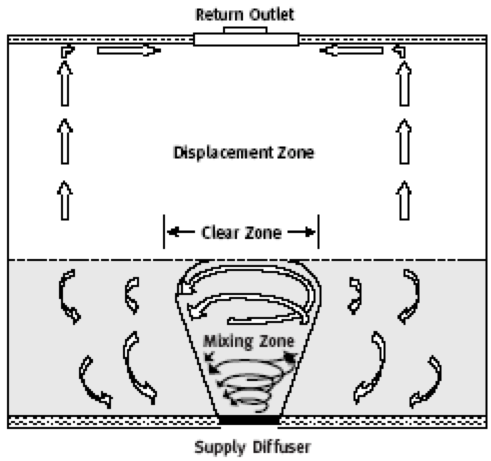
1) Air is supplied at higher velocity through smaller-sized supply outlets distributed across the floor plate. Unlike the displacement ventilation system, the hybrid underfloor system aims to reduce the stratification in the occupied lower portion by delivering air at higher velocity (200 to 400 fpm).This results in a more mixed and turbulent vertical flow profile and a smaller temperature gradient.

2) Local air supply conditions are generally under the control of a nearby occupant, allowing the possibility for some degree of personal comfort control.

3) The greater mixing (similar to overhead systems) provided by turbulent floor supply outlets used in UFAD systems increases the temperature near the floor compared to DV systems (for the same supply air temperature and volume).

4) Hybrid underfloor systems can handle higher cooling loads than displacement ventilation systems; the cooling load capacity is limited only by the number of diffusers used and the number of clear areas created.

5) At higher elevations in the room, the overall airflow performance of hybrid systems is expected to be very similar to that of DV systems.



The airflow pattern in a hybrid underfloor system is shown above. The supply diffuser entrains room air, creating a layer of mixed air in the occupied zone. This system type is attracting increasing interest because it has the potential to save energy and to provide a high degree of individual comfort control. Generally there are two types: floor void supply - ceiling return (zonal displacement systems); and floor void supply - floor void return (zonal mixing systems). This is discussed in detail in subsequent sections.

BENEFITS OF UFAD

UFAD systems have several potential advantages over traditional ceiling-based air distribution systems. The key benefits of an underfloor air distribution system are: improved occupant comfort, indoor air quality gains, energy cost savings, first cost savings, space planning flexibility and individual productivity gains.

1) **Improved Comfort & Indoor Air Quality:** The comfort and indoor air quality improvements are due to

- Underfloor-airway systems introduce fresh air directly into the occupants' breathing zone. Heat, pollutants, and stale air rise to the ceiling level, where they are exhausted. Fresh air replaces the old air rather than diluting it. The net effect is to improve the ventilation effectiveness, which improves the air quality.

- UFAD system use floor swirl diffusers, which improve indoor air quality by supplying air directly into a low-level occupancy microclimate. Air contamination produced within the office (occupants, copiers, fax machines, etc) rises upwards by convection and away from the occupied zone.

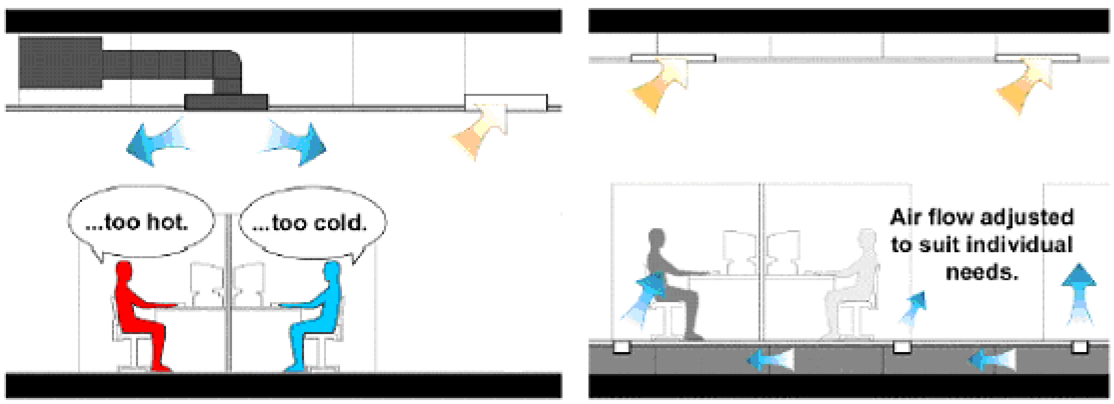
- Floor swirl diffusers also ensure high IAQ when the space is being heated, since they strongly mix the warm supply air into the occupancy microclimate.

- Floor swirl diffusers are equipped with removable baskets that capture dirt and spills before they enter the underfloor space.

- The ventilation effectiveness is greater for air supply from floor level than for air distribution from the ceiling. Studies indicate that the localized ventilation effectiveness near people for air supply from floor level is greater by 44% to 106% for seated persons and by 36% to 72% for standing persons than the ventilation effectiveness for air distribution from ceiling swirl diffusers.

- Since they operate at lower pressure and velocity, underfloor systems generally produce less noise than traditional overhead systems. However, fan-powered terminals used in neutral pressure systems may cause a small increase in noise levels.

- UFAD provides operation flexibility. Since the diffusers are housed in a modular access floor, it is easier to reposition the diffuser to another location. Each person has individual control over his or her own air supply. With the diffusers at floor level, the occupants can easily redirect or modulate the airflow into their own space and to their own liking, a benefit that is inconceivable with the conventional overhead system.



2) **Energy Impacts:** Higher energy efficiency is possible because:

- The supply air of an underfloor system is typically delivered at a higher temperature (62º F) than a conventional HVAC system (55º F). This means that the chilled-water temperature no longer will need to be distributed in the 44°F to 49ºF ranges. 50 F to 54ºF water is more than adequate to provide 62ºF supply air. With higher supply temperatures, the leaving chilled water temperature is also raised, which reduces the lift on the chiller. Higher lift means the higher coefficient of performance for the chiller typically to the tune of 3 to 15%. COP improvements, however, can be substantially reduced or eliminated if moisture control in humid climates requires the use of conventional coil leaving temperatures.

- Although underfloor systems operate at higher flow rates (5 to 20%) than conventional overhead systems, the static pressure is much lower due to minimal ductwork on the supply side of the system. Underfloor systems only need approximately 0.1 inch w.g of external static pressure for proper floor-diffuser performance; overall external fan delivery static pressure can be reduced to approximately 0.5 inch- w.g (compared to 1.5 to 2 inch w.g with overhead systems). This results in reduced fan horsepower and energy consumption, not to mention reduced first electrical and mechanical installation costs. The fan power energy savings have been estimated at 5-30%. Note that the fan energy consumption is given by equation:

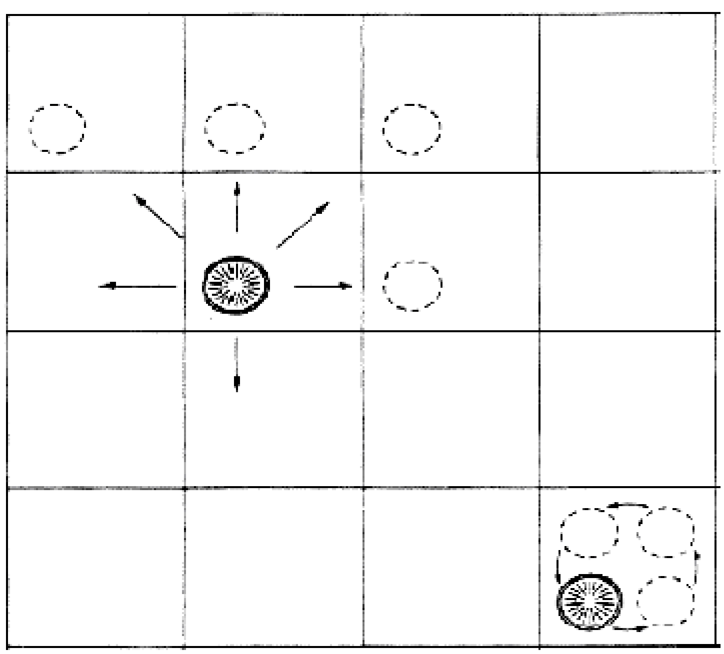
  $BHP = Q \times SP / (6356 \times Fan_{EFF})$

Where

- BHP = Break Horsepower
- Q = Air flow rate in CFM
- SP = Static pressure in-WG
- Fan $_{EFF}$ = Fan efficiency usually in 65–85% range

- The higher supply air temperature of displacement diffusers extends the free cooling capabilities of the HVAC system, significantly reducing mechanical cooling requirements in climates where this free cooling potential can be harnessed. Moreover, in arid climates, 63 to 65º F supply air may be dry enough during most hours of operation to avoid elevating the relative humidity in the space. In temperate climates, where high humidity is not a problem, the warmer supply air temperatures associated with UFAD system design increase the potential for economizer use, and allow higher cooling coil temperatures to be set, if desired. The fact that the number of hours of economizer operation is typically greater for UFAD systems also contributes to overall increased ventilation effectiveness.

3) **Increased Flexibility:** UFAD systems provide improved flexibility for building services, allowing for fast and inexpensive reconfigurations, and accommodating the high "churn" rates of the modern workplace. Churn refers to the facility management activities associated with relocating and reconfiguring of worker space. The plenum is typically used not only for UAD, but also as a conduit for cabling systems such as power cables, telephone lines and data systems, as well as a pathway for services such as sprinkler mains, drains, water piping, perimeter heater piping, central vacuum cleaning, etc. Many services, including telephone and data jacks, power outlets, and ventilation diffusers, are mounted directly in floor panels, providing "plug-and-play" adaptable workplace flexibility to tenants.



Reconfiguration of raised floor systems does not involve demolition and construction activities, reducing downtime and construction expenditures that have significant economic and environmental impacts. Since the plenum is designed to be easily accessible through removable floor plates, office spaces can be reconfigured in a matter of hours instead of days or weeks. Although the first costs of underfloor air distribution systems are typically higher than conventional overhead distribution, the incremental investment is quickly re-cooped, typically with the first reconfiguration of building services.

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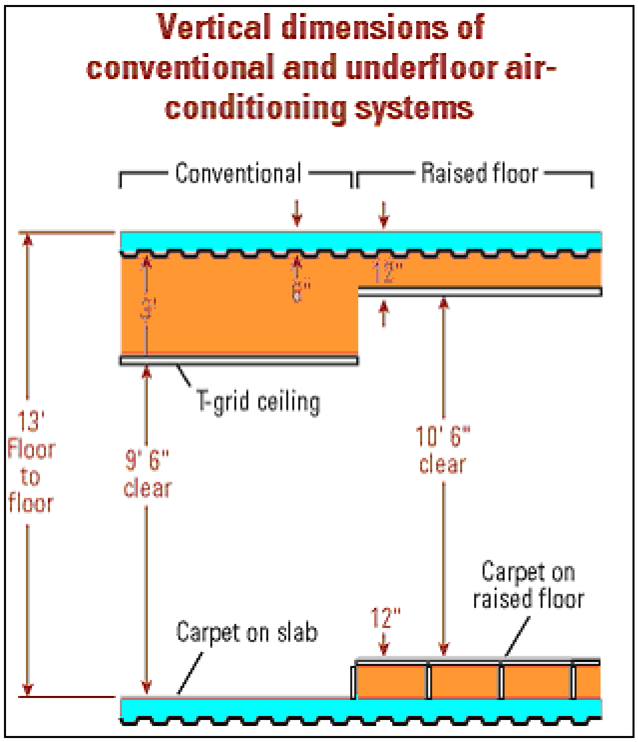
4) **Impacts on Building Design:** Underfloor air distribution permits a much more open ceiling design. It is possible to reduce floor-to-floor heights by 6 to 12 inches while maintaining the same floor-to-ceiling dimensions, especially for buildings that do not have hung ceilings. This can result in significant cost savings for multi-story buildings. The increased height also makes it easier to include indirect lighting, day lighting, light shelves and other design features in the ceiling.



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5) **Savings in Capital & Operating Costs:** In new construction, first costs of underfloor air systems are equal to or lower than ceiling HVAC systems. Once a raised floor has been cost-justified for connectivity, the introduction of underfloor air should be cost neutral or a cost savings. The full list of variables that have resulted in lower first costs for numerous underfloor air systems include:

- ✓ Reduction in HVAC construction sequencing and installation costs
- ✓ Reduction in power, data/voice networking installation costs
- ✓ Reduced ductwork, lighter duct materials
- ✓ Reduction in HVAC controls

- ✓ Lower horsepower fans
- ✓ Smaller chillers
- ✓ Building height reduction
- ✓ Construction time and materials cost savings
- ✓ Floor-to-floor height does not need to be increased in underfloor air projects, and can in fact be decreased due to the more deliberate systems integration efforts within the plenum.
- ✓ Reduction of installation costs due to all work being performed at the floor level instead of above the ceiling.
- ✓ Increased safety for construction workers (less climbing, ladders, etc.)
- ✓ VAV-box maintenance, repair, and controls are simplified.
- ✓ The system is self-balancing, since the entire system, in theory, will operate at the same pressure.

UFAD SYSTEM DESIGN PROCESS

Underfloor air distribution systems involve a considerably different process when calculating supply flow rates and temperature, along with selecting the size and number of diffusers. Since this technology is still in nascent stag in US, finding the optimal design values are mainly based on the experience of European countries and the studies carried out by CBE and ASHRAE. The design process requires expert opinion on the following:

1) Building Design Considerations
2) Identification of Zones
3) Space Cooling Loads
4) Ventilation Air Requirements
5) Supply Air Temperatures
6) System Design Air Flow Rates
7) Supply Air Layout
8) Return Air Configuration
9) Primary AC Equipment
10) Select and Locate Diffusers
11) Control Strategy

BUILDING DESIGN CONSIDERATIONS

Architectural:

1) The first item to coordinate with the architect is the location of the AC units, which will distribute the supply air to the raised-floor plenum space. Normally these AC units are ducted until the duct reaches beyond the “core” or center area of the floor or otherwise these units simply supply air directly to the raised-floor plenum, with no ductwork. Depending on the floor area and the location of the core, either the middle of the core or the end of the core is the ideal location. With this method, AC-unit quantities usually are in multiples of two.

2) Second, a raised-floor height must be established. Typical raised-floor heights are usually 12 to 18”. Published test data performed by the Center for the Built Environment (a University of California at Berkeley) recommend a minimum raised-floor height of 7” with 3” clear of any obstructions (cables, conduits, etc.) for ideal system performance and distribution.

3) The third item that must be determined is the type of secondary AC equipment and miscellaneous auxiliaries.

    - Floor grilles and plug in panels to be used must be heavy duty to withstand foot traffic. These can come with an actuator and damper that can modulate depending on space conditions and can be either ducted or non-ducted.

    - Space planning for electrical power, telephone, data cable and other elements of the building’s infrastructure.

    - Location of plug-in electrical boxes, power/data outlet boxes and air diffusers. Usually these are flush-mounted in the floor panels, which can easily be moved to accommodate reconfiguration of the workspace or floor plan.

IDENTIFYING ZONING

A zone is a space or group of spaces in a building having similar heating and cooling requirements throughout its occupied area. Large buildings include both peripheral and interior spaces. The peripheral space can extend from 8, 10 or 12 ft from the exterior wall/glazing. This space is usually reserved for offices that are occupied by the corporate elite or open for outside view. Since the wall usually has a large glass area, these zones have variable loads that are dependent on the time of year, time of day, glass construction, shading coefficients, and weather. During the winter, heating is required in these spaces; during the spring and fall, one side of the building may require heating while the other side requires cooling; and in the summer, full cooling is the norm.

Perimeter zones

The peripheral areas have varying loads and largest loads typically occur near the skin of the building. Since these areas are influenced by climatic variations, rapid fluctuations in heating and cooling demands can happen, with peak loads often occurring only for several hours per day and relatively few days of the year. Energy-efficient envelope design is always the first stage of defense against excessive perimeter loads.
While occupant control of relatively constant interior loads is reasonable, manual control for the ever-changing perimeter loads is not, and therefore underfloor plenums may need to be zoned based on building exposure, especially when using passive diffusers. Perimeter zone considerations often lead to hybrid system designs in which active, fan-powered supply units are used to increase the rate at which the system can respond to changes in load. These boxes can

be supplied with integral heating coils to provide perimeter heating as well. Displacement ventilation systems do not function well in the heating mode.

Typical perimeter zone size (occupied area): 12–15 ft deep, from the external wall.

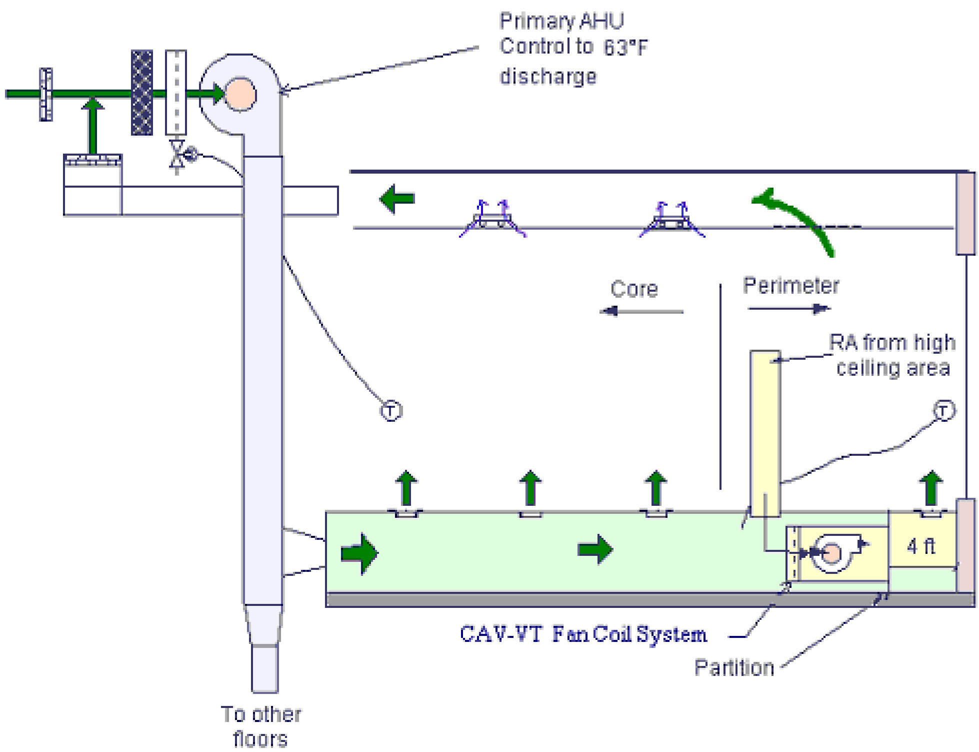
Interior zones
Interior zones (defined as areas located further than 15 ft from exterior walls) are usually exposed to relatively steady and lower (compared to perimeter zones) thermal loads with little or no variations all year round. These loads are usually due to lighting, equipment, and people. Typical values used for cooling-load calculations are 1 to 2 watts per sq ft for lighting, 3 to 5 watts per sq ft for equipment (depending on use), and a population density of one person per 100 sq ft (assuming 8-by-8- ft workstations). The sensible loads are fairly constant and therefore, these zones are well served by a constant volume or constant pressure in a pressurized system, control strategy.

The interaction between interior and perimeter systems needs careful consideration. For example, if plenum air is used to supply cooling for perimeter zones, reset of supply air temperatures for the core zones may militate against being able to satisfy perimeter load conditions.

Other special zones
Other special zones having large and rapid changes in cooling load requirements, such as conference rooms or lecture halls, should incorporate fan-powered or VAV air supply solutions. This can require underfloor partitioning for these areas. Automatic controls to these zones should be capable of meeting both peak demand and significant turndown during periods of little or no occupancy. Manual control of these zones has also been used in some installations.

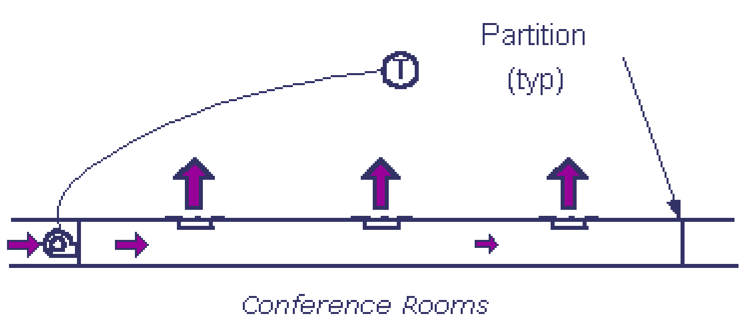
Schematic Examples

In the scheme above, interior zones are operated as a constant air volume-variable temperature (CAV-VT) system. The supply air temperature is varied in response to an average of interior temperatures measured by a series of temperature sensors linked to an energy management control system (EMCS).

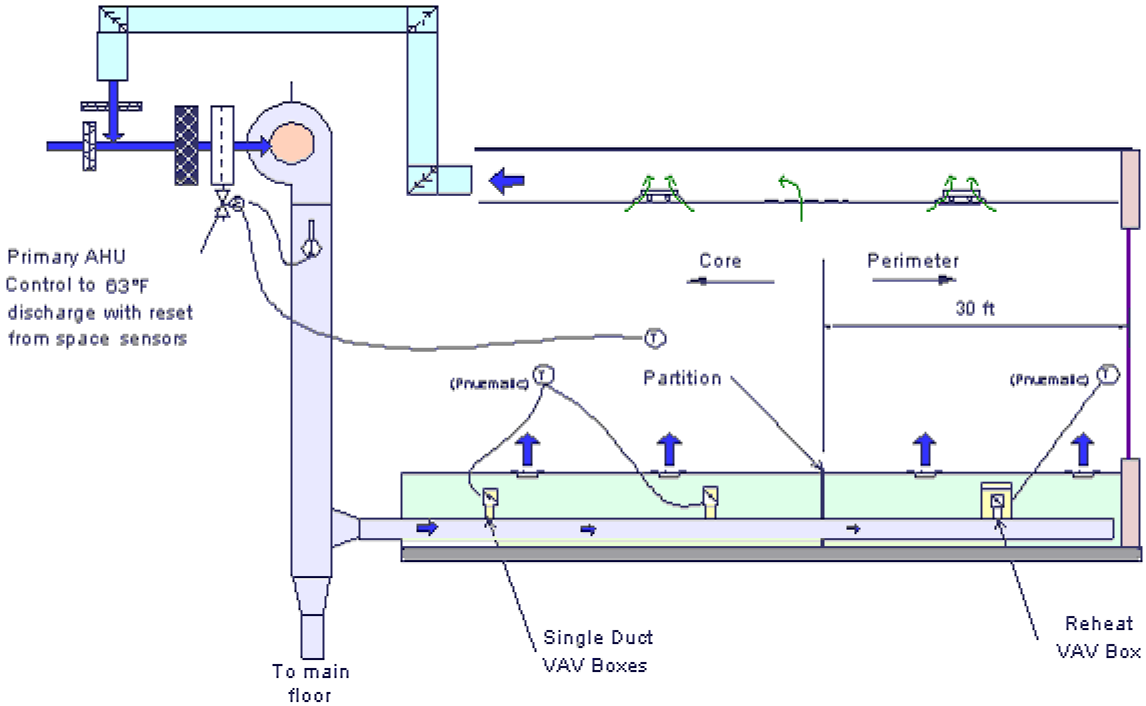


Perimeter zones are served by a CAV-VT Fan coil units draw return air through specially built duct chases located on the outer walls, allowing air to be drawn from near the ceiling. A room-air temperature sensor controls the coil water supply to fan coil unit in case of CAV – VT system. Round swirl diffusers supply variable volume air or variable temperature air to the perimeter zone. The proximity of swirl diffusers serving the interior zone augments the high demand for supply air typical of perimeter zones. Under normal operating conditions, air is returned to the AHU via return grilles and lighting fixtures located in the ceiling.

In contrast to the open plan work areas described above, the conference rooms are enclosed spaces served by a VAV system. Responding to signals from a room thermostat, supply air is drawn from within the interior plenum and supplied to a partitioned space and then through diffusers to the room using a variable speed fan, as illustrated in figure below:



This system as depicted below exemplifies one system type commonly used in early UFAD installations. It is essentially a VAV overhead system installed in the underfloor plenum space. Underfloor ducting supplies VAV boxes that deliver air into partitioned underfloor perimeter and core zones. Perimeter partitions are 30 ft from the exterior walls. Zone sizes vary from about 900 ft^2 in perimeter corner offices to about 4500 ft^2 in the interior. One or two VAV boxes typically serve a zone. Service areas in the central core are treated in a similar manner. Each zone contains swirl diffusers that are uniformly laid out; a row of diffusers is located along the exterior walls as shown in figure below:



SPACE COOLING LOADS

Cooling loads for a building with an UFAD system are calculated in much the same manner as for a conventional overhead system with few minor differences.
In UFAD system, the space is divided into two zones, an occupied zone extending from the floor to head level, and an unoccupied zone extending from the top of the occupied zone to the ceiling. The systems are designed to condition the lower occupied zone only; temperature conditions in the upper zone are allowed to float above normal comfort ranges. The fact that conditioned air is delivered at or near floor level, creates stratification which results in most convective heat gains (from sources outside the occupied zone [up to 6 ft]) to be exhausted directly at ceiling level. These loads are therefore not to be included in cooling load calculations; lighting load is one such example.

Air supply volumes therefore only consider heat sources that enter and mix with air in the occupied zone. Heat sources must be analyzed based on their convective and radiative components. Depending on the location of the heat source in the space, some amount of the convective portion can be neglected in this calculation.
Other issues that can affect load calculations include the heat exchange between the concrete slab and the supply air as it flows through the underfloor plenum. Most of this heat transferred through the floor into the supply air stream will reenter the conditioned space, although not instantaneously due to the mass of the floor panels. This adds another component to the space cooling load calculation –- estimated to be as high as 3.4 Btu/ft^2.
In most applications, reheat is primarily needed only near the building envelope where cold downdrafts from perimeter glass may cause discomfort. Heating may also be needed in some top floor interior zones and during periods of low occupancy (e.g. nights and weekends). Effective heating systems isolate the source of warm air from the thermal lag effect of the concrete slab (which is usually slightly cooler than room temperature). This can be done, for example, by

ducting from an underfloor fan coil unit, or by using baseboard radiation or convection units. Quick response on heating can be very important during morning startup.

VENTILATION AIR REQUIREMENTS

Standard 62-99 provides guidelines for the determination of ventilation rates for acceptable indoor air quality. Standard 62 sets minimum ventilation rates for office space and conference rooms at 20cfm per person and reception areas at 15cfm per person.

In the design and operation of a UFAD system containing a large number of occupant-controlled supply modules, some means must be provided to ensure that minimum ventilation rates are maintained, even when people choose to turn off their local air supply. An optimized strategy is to control supply outlets to allow mixing of supply air with room air up to a height no higher than head level (6 ft). Above this height, stratified and more polluted air is allowed to occur. The air that the occupant breathes will have a lower percentage of pollutants compared to conventional uniformly mixed systems.

SUPPLY AIR TEMPERATURES

The supply air temperatures for UFAD are higher than that that used for conventional overhead system design. Because the air is supplied directly into the occupied zone, warmer supply air temperatures prevent overcooling to nearby occupants. For cooling applications, supply air temperatures at the diffusers should be maintained no lower than in the range of 63 – 68°F with a recommended minimum ceiling height of 8 feet. This supply temperature can be reset even higher under partial load conditions.
The supply air must be introduced to the occupied lower space at a high enough flow rate to prevent an uncomfortable temperature gradient between head and foot, but at a low enough velocity to prevent the sensation of draft and prevent mixing in the upper stratified zone. *A temperature gradient between head and foot greater than 5°F is considered excessive. A gradient of 3.5°F is considered to be a good design criterion, not too large by most people's standards.*

System Type	Supply Air Temperature	Return Air Temperature
UFAD Systems	63-68°F	77-86°F
Overhead Systems	55°F	75°F

SYSTEM DESIGN AIR FLOW RATE

The calculation of cooling air supply flow rates for UFAD systems requires different considerations. This is primarily due to the fact that overhead systems assume a single well-mixed temperature throughout the space (floor-to-ceiling), while UFAD system assumes that some amount of stratification occurs. The stratified air flow pattern in UFAD systems allows most convective heat gains from sources outside the occupied zone (up to 6 ft) to be exhausted directly at ceiling level, and therefore to not be included in the air-side load.

How much airflow is needed?

Cooling air quantities for UFAD systems should be carefully determined. Many engineers assume that UFAD systems, with warmer supply air temperatures (63 to 65º F), will automatically require higher cooling air quantities in comparison to overhead mixing systems (55°F supply-air temperature) for the equivalent cooling loads. Their assumption is based on the standard room-energy-balance equation:

$H = 1.08 \times Q \times \Delta T$

Or

$Q = H / (1.08 \times \Delta T)$

Where:

- H = the heat loads in a room, in Btu per hour
- Q = the airflow moving through a room in cubic feet per minute (CFM)
- ΔT = the temperature difference between the room set point (usually 75º F for comfort applications) and supply-air temperatures in degrees F.

If this energy-balance equation were also true for UFAD systems, it would require airflow of nearly twice that for overhead systems. If the set point temperature is 75º F; for overhead system ΔT is 75 – 55 = 20°F whereas for UFAD system ΔT is 75 – 63 = 12°F. Substituting the values in the equation above will yield higher flow rates for the UFAD system.

However, the above equation is valid only for steady-state and fully mixed room conditions (i.e. set point temperature equals return-air temperature). Studies indicate that stratification for UFAD systems can result in overall delta T's (return-supply temperature difference) in the range of 15-20°F, for properly designed systems. Since the comfort conditions in an underfloor system are maintained in the lower occupied zone only, the higher return temperatures are created by stratification. The heat gain to the occupied zone and the air flow required to maintain a given comfort condition in that zone is what determines the actual air flow requirements, and consequently the overall delta T that will be developed. Typically this results in air flow rates that can be equal to or higher by fairly modest amount in order of 5 to 20%. These results have been corroborated by field tests in which the UFAD design airflow rate in perimeter zones was estimated to be in the range of 15 percent greater than an equivalent overhead system.

Also with this reason, the thermostats in UFAD systems are always placed in supply air path as the indoor set point temperature and return air temperatures shall be influenced by stratification.

SUPPLY AIR LAYOUT

Underfloor ducts serving specific zones should be sized to accommodate peak cooling loads. The design and layout of main ducts from the central plant to plenum inlet locations is similar to that of conventional overhead systems except that access must be provided for the ducts to reach the underfloor plenum. The amount of main ductwork can be reduced in designs using medium to small-sized air handlers (floor-by-floor units) that are located closer to the point of use. However, ductwork for ventilation air is still required and must be sized accordingly, if the use of an outside-air economizer will be an important operating strategy.

The height of underfloor plenums is generally determined by the largest HVAC components located under the floor. These components can typically be distribution ductwork, fire dampers at plenum inlets, fan coil units, and terminal boxes. Commercially available HVAC products allow plenum configurations as low as 8 inches although heights in the range of 12-18 inches are more common.

There are two 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

In some arrangements the supply air is ducted through the underfloor plenum to the supply outlets. In this approach configuration certain energy and cost benefits may be reduced compared to the above two approaches.

Pressurized Underfloor Plenum

Pressurized plenums have been the most commonly installed UFAD configuration. In this approach, the system design is controlled to maintain a small positive pressure (0.05 to 0.1 inches w.g) in the underfloor plenum relative to the conditioned space. The characteristics of the system are:

1) Pressurized floors operate with a small positive static pressure in the floor plenum - about one-tenth of an inch water gauge (0.10 inches w.g). This pressure drives the supply air through simple diffusers placed as necessary in the floor - typically, one for each 100 square feet.

2) Even with so little static pressure, air can be moved to diffusers at least 30 feet from a supply riser or duct without creating temperature inconsistencies in the space. Even longer "throw" distances are possible with deep floor plenums.

3) Pressurized plenums are designed to deliver supply air at constant temperature and volume to all outlets of the same size and control setting within the conditioned space.

4) The system uses a minimum amount of ductwork and typically maximum floor area served by each free-discharge supply air duct is 3,200 ft^2. The number of plenum inlet locations is a function of the size of control zones, access points available in the building, amount of distribution ductwork used under the floor, and other design issues. Within the underfloor plenum, it is always desirable to the extent possible to have the supply air flow freely to the supply outlets.

5) Almost all available floor diffusers allow some amount of individual control (usually volume and in some cases direction) by nearby occupants.

6) Because the supply air in the underfloor plenum is in direct contact with the concrete structural slab, the underfloor thermal mass has the effect of providing a consistent cool air temperature reservoir (for cooling applications), making UFAD systems extremely stable in their operation.

In some system designs, using multiple medium or small-sized (floor-by-floor) air-handling units (AHUs) can minimize or totally eliminate ductwork; and improve zone control when AHU capacities correspond to the specific requirements of each plenum zone.

7) Where differences between interior loads and perimeters are not significant, a common pressurized plenum with a greater number of floor diffusers along the perimeter may be used to deal with the increased load density along the building façade. This is often combined with perimeter radiant or convective heating coils. Alternatively, the plenum can be partitioned with separate perimeter air supply as needed or perimeter zones can be equipped with fan-powered terminal boxes (usually VAV) with reheat in the underfloor plenum or as fan coil units located in the space against the perimeter walls beneath glazing.

The concerns

1) The airflow performance can be impacted by uncontrolled air leakage and when floor panels are removed for access to the underfloor plenum. The two primary types of uncontrolled air leakage from pressurized plenums include: a) Leakage due to poor sealing or construction quality of the plenum and b) Leakage between floor panels. Although due to the relatively low pressure (0.05 - 0.2 inches w.g.) used in pressurized plenums, the leakage into adjacent zones is minimal and much of the leakage will be into the same conditioned zone of the building. The amount of expected leakage can be calculated from the following:

$Lv = 4005 \times (R_p)^{½}$

$L = 4005 \times A \times (R_p)^{½}$

Where

- Lv = Leakage velocity in FPM
- L = Air leakage in CFM
- R_p = Room pressure in in-WG
- A = Opening area

Assuming 0.05 inches –w.g plenum pressures the leakage velocity is

= 0.223 x 4005 = 895 feet per minute

With a total of 1 sq-inch opening size

Leakage air volume = 1 x 895/144 = 6.2 CFM per sq-inch

These amounts can be a substantial fraction of the total required cooling, especially in the interior zones. If access panels are removed for long periods of time or the distance between primary air inlets and supply diffusers is too great, control of air flow will be diminished. A higher plenum pressure of the order of (0.5 inches w.g) could result in problems with over-conditioning, lifting of carpets, and problems with diffusers. It is therefore important that proper attention be given to the sealing of junctions between plenum partitions, slab, access floor panels, and exterior or interior permanent walls during the construction phase of the project.

2) Zoning and partitioning of the underfloor plenum should be kept to the minimum necessary to optimize UFAD performance and efficiency. This ensures the system's ability to avoid

unacceptable variations in supply air temperature (due to heat gain from or loss to the concrete slab and raised floor structure) and quantity (due to pressure loss, obstructions, or friction) within the zone. 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

Zero Pressure Plenum

Primary air supply to the underfloor plenum is similar to the above; however each plenum is maintained at very nearly the same pressure as the conditioned space. Local fan air terminals under local thermostatic control draw air from the plenum and supply it into the occupied space. By relying on both a primary air handler and local fan-powered outlets to draw air from the plenum into the space, zero-pressure configurations can more reliably maintain some amount of cooling effect even if the chillers are off due to the thermal inertia of the concrete slab. Localized manual fan speed control also improves individual control of occupant thermal comfort. The characteristics of zero pressure plenum are:

1) Zero-pressure floors rely on small fan-powered distribution boxes to push air up into the conditioned space. Some designs with fan-powered boxes in the floor keep the plenum at negative pressure relative to the space, to draw return air back into the supply air and moderate its temperature.

2) The plenum is maintained at very nearly the same pressure as the conditioned space, meaning that zero-pressure plenums pose no risk of uncontrolled air leakage through any crack or opening to the conditioned space, adjacent zones, or outside. While fan-powered outlets provide improved control of the supply airflow rate compared to passive diffusers, potential first cost and energy use premiums must be carefully considered. The removal of floor panels does not disrupt overall supply-air flow.

3) Local fan-powered outlets under thermostatic or individual control allow supply air conditions to be controlled over a wide range as necessary. This controllability can be used to handle zones with significantly different thermal loads without underfloor partitioning. The use of partitioning for zone control can also be applied in a similar way as for pressurized plenums. The greater ability of zero-pressure systems to provide localized cooling suggests their suitability in projects involving high and diversified heat loads.

General Design Guidelines

1) Effective plenum heights for underfloor air are pervasively set at 12 to 18 inches, with no penalty for even higher plenums.

2) Distances from the vertical riser to air supply zone can be as long as 80 feet; however, 30–40 feet are preferable to ensure no thermal decay and controllable pressure conditions.

3) For delivering combined cooling and ventilation in office environments 0.1 inch-w.g (25 Pa) static pressure for plenum is usually satisfactory. Given this low pressure and limited distances from risers, air tightness is not a major issue; however carpet tiles could be offset 50% over access floor tiles to support air tightness of the plenum.

4) Perimeter air-conditioning is typically ducted and plenum subdivisions are common to service different tenants or high demand spaces such as conference rooms. The internal zones typically use un-ducted air supply.

RETURN AIR CONFIGURATION

For optimal cooling, it is important to locate return grills above the occupied zone, which is around 6 ft above floor level. The recirculation air must return at higher elevations through grilles located in a suspended ceiling or through high sidewall grilles if no ceiling plenum is present. This supports an overall floor-to-ceiling airflow pattern and takes advantage of efficient removal of heat load & contaminants through the natural buoyancy produced by heat sources in the space. Two schemes are generally used:

Return air mixed with primary air in AHU: A certain portion of return air could be mixed with primary air from the AHU to achieve desired air temperatures and humidity and enable reduced energy costs. In many climates to achieve proper humidity control, conventional cooling coil temperatures must be selected (producing a coil leaving temperature of 55°F). In this situation, a return air bypass control strategy can be employed in which a portion of the return air is bypassed around the cooling coil and then mixed with the air leaving the coil to produce the desired warmer supply air temperature (63-68°F).

Return air is routed directly to the underground plenum: When the return air is routed directly back into the underfloor plenum, the amount of re-circulation ductwork can be significantly reduced. The return air is not taken back to the air handler and is brought down through the induction shafts formed with furring spaces along structural columns. It is important that the supply and return air streams must be well mixed within the underfloor plenum before delivery to the conditioned space. This can usually be achieved by distributing the primary air at regularly spaced intervals throughout the plenum, and/or employing fan-powered local supply units to aid mixing of primary supply air with the return air.

DESIGN OPTIONS

Option # 1 Floor Void Supply – Ceiling Return

Zonal displacement systems: Zonal displacement systems use the floor void as a supply channel and the ceiling void as a return channel. Zones may be 1000-2500 sq-ft. They usually work with minimum fresh air rates offering savings in fan power and seasonal peak energy demand. The supply air velocity under the floor may be low and designers should take care to check temperature pick up. Simulation shows that lengths of paths under the floor should be less than 45 feet.

Underfloor requirements: Such systems can make use of swirl grilles when the cooling load is small (20 – 25 Btu/sq-ft) and the supply temperature is limited to 65°F, but with higher loads, swirl grilles should be replaced by fan-assisted terminals with vertical distribution. The vertical distribution avoids draughts as warmer room air is entrained into the air stream instead of cooler air being blown across the floor at a low level as in the case of swirl.

Good for high load areas: These systems are suitable for machine rooms where air can be introduced directly into the base of the equipment at a low temperature. Such systems are used for data centers, server rooms and other high load areas where cooling loads can exceed 380-475 Btu/sq-ft. Fresh air is usually ducted to the top inlet of the zonal unit. This system has a more complicated ventilation distribution and exhaust system than zonal mixing systems.

Option #2 Floor Void Supply – Floor Void Return

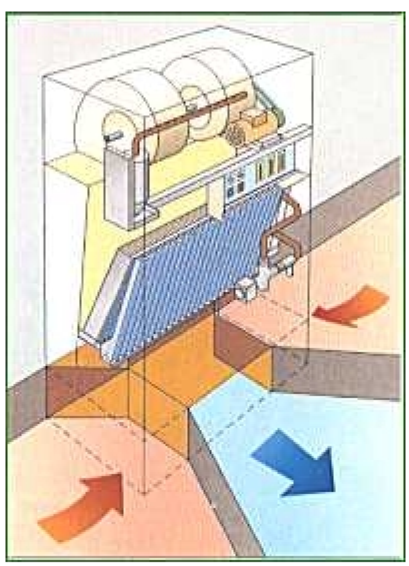
Zonal mixing systems: Zonal mixing systems make use of the floor void as both supply and return channels. Such systems typically make use of fan assisted terminals, which introduce the conditioned air into the space. Return is taken back by the negative pressure created by the terminal units and is controlled by the application of air segregation baffles/damper positioned above the return air plenum in the raised floor.

Users have freedom to adjust both the temperature set point and fan speed on the unit. The space temperature is controlled by the flow rate of air introduced, which in turn is usually controlled by a damper, operating under the dictates of onboard sensors. The need for wall-mounted thermostats is eliminated. Metal ducts are generally not used for return ducts. Zones may range up to 3000 sq-ft.

Fresh air may be introduced into the return plenum or directly to the unit and exhaust air may be extracted through toilets, kitchens and additionally through exhaust air grilles at high level if required.

PRIMARY HVAC EQUIPMENT

The air conditioning units for UFAD system should preferably be down blast configuration; come packaged with their own controls, and can be chilled water, water cooled, or split-system air cooled. The standard unit will discharge within a ducted system below the raised floor. Regarding the control package the critical applications such as data center or computer room may require precision air-conditioning unit (for tight control over temperature and humidity control), specifying a high end control option may not be necessary for general purpose applications such as open office spaces.



Plenum systems can be either pressurized or operated at neutral pressure. Pressurized plenums generally use passive diffusers; neutral-pressure plenums use fan-powered diffusers. Fan-powered diffusers provide better local control of airflow rate at the expense of additional fan power, noise and cost. (See below for further information on diffusers).

AIR DISTRIBUTION TERMINALS - 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. Final placement can take place after the location of furniture and loads, as well as the preferences of individual occupants, are more accurately determined.

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

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 examples of primary types of floor diffusers.

- **Swirl floor diffuser:** This is the most commonly installed type of diffuser in UFAD systems; the swirling air flow pattern of air discharged from this round floor diffuser provides rapid mixing of supply air with the room air in the occupied zone. Swirl diffusers are generally installed as passive diffusers, requiring a pressurized underfloor plenum, although fan-driven models are available. Occupants have limited control of the amount of air being delivered by rotating the face of the diffuser, or by opening the diffuser and adjusting a volume control damper.

- **Constant velocity floor diffuser:** This recently introduced diffuser is designed for variable-air-volume operation. It uses an automatic internal damper to maintain a constant discharge velocity, even at reduced supply air volumes. This is a passive diffuser (power is needed for the damper motor only), requiring a pressurized plenum, but fan-driven configurations are also available. Air is supplied through a slotted square floor grill in a jet-type air flow pattern. Occupants can adjust the direction of the supply jets by changing the orientation of the grill. Supply volume is controlled by a thermostat on a zone basis, or if available, as adjusted by an individual user.

- **Linear floor grill:** Linear grills have been used for many years, particularly in computer room applications. Air is supplied in a jet-type planar sheet making them well matched for placement in perimeter zones adjacent to exterior windows. Although linear grills often have multi-blade dampers, they are not designed for frequent adjustment by individuals, and are therefore not typically used in densely occupied office space.

Check with the manufacturers for the most up-to-date product information on passive diffusers. A general comparison is tabulated below:

Parameters	**Diffuser Types**

	Swirl	**Constant Velocity**	**Linear**
Figure			
Air Flow Pattern	Swirling upwards, rapid mixing	Multi directional, air jet	Planar sheet, air jet
Adjustability	Rotate grill or bucket to adjust air flow volume	Adjust grill for changes to air flow direction, thermostat for air flow volume	Multi-blade damper is used to adjust air flow volume
Ideal Location	Interior and perimeter zones	Interior and perimeter zones	Perimeter zones
Installation	Require minimum 8-inch high raised floor plenum	Require minimum 12-inch high raised floor plenum	Require minimum 12-inch high raised floor plenum

While floor swirl diffusers and constant velocity diffusers are usually used for internal zones and in occupied spaces, linear floor grilles are often used along perimeter glazing to create an upward air curtain that shields the occupancy microclimate from outdoor transmitted loads, though such grilles should not be located near occupants due to the threat of draughts. 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.

In addition to the three types of diffusers described above, several different designs for active diffusers are available which include Floor supply module, Desktop air supply pedestals, underdesk diffuser, partition-based diffuser etc. Active diffusers are less susceptible to pressure variations (such as when access floor panels are removed) and other flow restrictions. Check with the manufacturers for the most up-to-date product information on special purpose active diffusers.

General Design Considerations

1) Diffuser density should be no less 1 per 100 ft^2 with diffusers to be at least 2.5 feet from the occupants.

2) Swirl diffusers ensure effective thermal mixing and maintain stratification for energy conservation. These are preferable to jet diffusers.

3) With induction diffusers and swirl distribution, up to 100cfm can be supplied per diffuser, especially with the larger 8” diffuser. Otherwise, between 25-75cfm would be maximum allowable and greater diffuser densities would be required.

4) Diffuser slots should be inclined to effectively diffuse the air and generate a swirl for induction, with an industry preference between 36-38º incline from the vertical.

5) As a rule of thumb, floor diffusers selection is based on air delivery rate of 50-150cfm at 0.05-0.25 inch w.g with velocities of 50-150 fpm.

6) As a rule of thumb of limit the maximum distance from the plenum inlet to the farthest diffuser to about 50 to 60 ft in pressurized plenum designs.

7) Fan-powered floor air diffusers must be designed to ensure effective room air mixing and horizontal distribution patterns to eliminate drafts and thermal discomfort. Fan-powered floor boxes are valuable for high thermal load areas such as conference rooms; however, the combination of passive and fan-powered diffusers must be studied in relation to short-circuiting.

CONTROL STRATEGIES

Control strategies for UFAD system are similar to the overhead system except that controlling the humidity while maintaining high supply air temperatures in UFAD system require special focus. Conventional supply air system cools the air close to its dew point. The moisture in air starts condensing, when the air is cooled to an apparatus dew point of ~50 to 52°F. This corresponds to supply air temperatures of ~55°F.

Humidity Control

In UFAD system, to achieve the required higher supply air temperatures while still maintaining humidity control, three common strategies often used are: 1) mixing upstream of the primary AHU cooling coil, 2) Mixing downstream of the primary AHU cooling coil (also known as side stream bypass control) and 3) using separate thermal conditioning and ventilation systems for interior and perimeter zones.

1) Traditional Approach: The supply air is first cooled to 50 to 55°F, if dehumidification is necessary, and is then heated through a heating coil to the desired supply air temperature of 63 to 68°F. This is a very energy inefficient scheme and is not recommended.

2) If the return air is mixed into the supply air stream after the outdoor air has been cooled / dehumidified then reheat of the air is unnecessary since the desired supply air temperature is achieved by mixing the supply air with recirculated air. Such mixing typically occurs in the floor plenum, producing the desired supply air temperature in the floor void. It is best to draw the return air from a high level (for example from a ceiling plenum) to benefit from stratification, though some systems draw the air from the occupancy zone (for example from floor level). An alternate to above approach for large complexes may be to introduce a secondary 100% outdoor air cooling coil to dehumidify and pre cool the outdoor air to 55°F, distributed to primary AC units located at various zones and then mixed with warmer bypassed return air to produce the desired plenum inlet air temperature. It is important that these systems use enthalpy based economizer control to ensure proper supply air humidity control.

For each of the above two systems, the primary AHU may provide either constant air volume (CAV) or variable air volume (VAV) and may supply air to a "pressurized underfloor plenum" or to a "zero-pressure underfloor plenum".

Temperature Control:

1) A preferred method for interior zones is constant air volume, variable temperature (CAV-VT). Supply temperature is controlled based on zone thermostats. Occupants can make minor changes to local comfort conditions by adjusting a diffuser.

2) Perimeter zone operation can be either variable air volume (VAV) or CAV-VT, but in either case must be able to respond to the special cooling and heating demands of these zones. Because of varying loads found in perimeter, use a separate dedicated system or at least a hybrid solution in which fan-powered outlets and/or additional equipment are used to address the extra heating and cooling requirements of these zones.

Individual Control Strategies

1) The ability to easily relocate diffusers is critical to churn/ reconfiguration cost savings and all systems should be coordinated to make this possible (carpet, outlets, diffusers, tethers). Changing the density and location of diffusers is the central strategy of underfloor air systems to effectively deliver breathing air and cooling to the range of functions and layouts that occur in the dynamic workplace environment.

2) Fan controls are required for conference rooms, and possibly additional water based cooling (e.g. fan-coil) controls.

3) Directional control is a benefit for higher velocity and non-swirl diffusers where supply air streams of 65ºF could be uncomfortable on the lower body.

4) Replacing pressurized buildings with the natural stratification distribution of conditioned air, (rising from an underfloor air system to a ceiling return) allows for local opening of windows without compromising ventilation effectiveness. Due to temperature stratification that naturally occurs with UFAD systems, thermostats should be carefully placed and their readings correlated with acceptable comfort conditions in the occupied zone. For example, if stratification is large, an acceptable temperature at the five-foot level may in fact coincide with uncomfortably cool temperatures at the ankle level.

5) Since supply air flowing through the underfloor plenum is in direct contact with the concrete floor slab of the building, control strategies must consider thermal storage in the slab as well as other mass in the plenum (e.g., floor panels). In temperate climates, cool nighttime air can be brought into the underfloor plenum where it effectively cools the slab overnight. During the following day's cooling operation, higher supply air temperatures can be used to meet the cooling demand, thereby reducing refrigeration loads for at least part of the day. This 24-hour thermal storage strategy benefits from lower off-peak utility rates and extends the hours of economizer operation.

STANDARDS AND CODES

Listed below are few applicable building standards and codes that have important provisions related to the design, installation, and operation of UFAD systems.

1) ASHRAE Standard 55-1992: This standard provides the thermal environmental conditions for human occupancy

2) ASHRAE Standard 62-1999: This standard provides guidelines to the ventilation for acceptable Indoor Air Quality

3) ASHRAE Standard 90.1-1999: This standard provides guidelines to the energy efficient design of new buildings intended for human occupancy.

4) ASHRAE Standard 113-1990: This standard provides guidelines to the method for evaluating the air diffusion performance of an air distribution system.

5) ASHRAE Standard 129-1997: This standard describes a test method for evaluating an air distribution system's ability to provide required levels of ventilation air to the building occupants.

DESIGN ISSUES

The following are the key design issues to the success of underfloor air delivery systems.

Issue #1 CONTROLLING DEWPOINT

Objective: Maintenance of a comfortable dew point (55ºF) in the space while delivering supply air at a drybulb temperature significantly above that point (> 60ºF, 16ºC)

Condensation can be a concern in underfloor systems, if the cool plenum is suddenly exposed to warm, moist air. *The dewpoint of the air entering the plenum must always be lower than the lowest temperature of any exposed surface within the plenum, otherwise condensation will occur.* This phenomenon can be avoided, if the plenum is well sealed against outside air infiltration, and if sudden step-changes in supply air conditions are avoided. For example, when the fan shuts down at the end of the day, warm and moist air should be blocked from rushing into the cool plenum. Similarly, during occupied hours, if the mechanical cooling abruptly shuts down and the dewpoint of the supply air suddenly rises, the fan may need to be shut off, or the outside air dampers adjusted.

Air handling units for underfloor air delivery must utilize two air streams that will be mixed to provide the supply stream to the space. The first stream includes all of the ventilation air volume and some portion of the return air. It is chilled to a temperature such that when mixed with a second stream, bypassed return air only, provides a dewpoint suitable for comfort (< 53ºF, 11.5ºC). The dual stream approach may be accomplished within the air handler itself, or by separately dehumidifying the outside air supply. With low supply temperature conditions it is advisable to run the computer calculation for condensation and possibly apply insulation and a vapor seal to the underside of the slab. Maximum supply air to room temperature differentials should not usually exceed 50°F. The velocity of the air should be less than 200 feet per minute to minimize temperature pick-up. Paths can be extended under the floor to 100 to 125 feet. Space humidity should be monitored through the BMS. To satisfy IAQ and as recommended by ASHRAE, an upper RH limit of 60 percent in summer should not be exceeded.

Issue # 2 SEALING THE FLOOR PLENUM

Objective: Adequate sealing of the floor air plenum at core and window walls and at column covers to prevent bypassing of air to return the plenum

Among the underfloor design issues, sealing of the floor plenum may seem to be least within the computational domain of analysis, yet because of the potential loss to system performance and due to the challenge in achieving it (consider the number of trades involved in building the plenum), it is important to consider. Coordination between the architectural and engineering design disciplines, along with sufficient construction oversight, is required to insure a sufficiently tight plenum.

Issue #3 ENSURING CORRECT SUPPLY AIR TEMPERATURES

Objective: Design of underfloor plenum supply to prevent unacceptable temperature rises (<5ºF) between plenum supply point and floor registers.

One of the most challenging design problems associated with underfloor air systems is assuring correct supply air leaving the floor diffuser. Because the diffusers are scattered over a large area of the access floor, it is not possible to maintain a uniform temperature. The primary source of heat gain to the plenum supply air is through the structural slab from the return plenum below. The main variable determining the supply temperature at a particular diffuser is the length of time the air leaving that diffuser has spent in the plenum. That duration is a function of the flow path from the supply plenum inlet to the diffuser. Due to architectural constraints, the open area available for charging the supply plenum is likely to be limited. As a result, air velocity through this inlet opening is likely to be as high as 1000 fpm. This momentum admitted to the floor must be dissipated within the plenum because exit velocities from the floor diffusers are so much less (400 fpm). As a result, large scale vortices tend to form within the floor plenum, extending the time the supply air spends in the plenum which increases the heat gain to the supply air that results in excessive supply air temperatures at some of the diffusers (i.e., those whose supply was most affected by the vortices).

With a properly stratified room, temperatures in the return plenum will reach 82ºF or higher. The thermal resistance of a 5-inch conventional concrete slab is comparable to that of insulated glass, resulting in significant potential heat gain to the 60ºF supply air.

Issue #4 ENSURING TURBULENT MIXING OF SUPPLY & ROOM AIR AT DISCHARGE

Objective: Immediate mixing of the supply air at discharge of the floor diffuser to achieve comfortable air temperatures (> 70ºF) within close proximity to the supply diffusers (< 15 inch, 0.4 m.)

Currently the most successful methodology for addressing air mixing at the diffuser discharge is the "swirl" diffuser. This diffuser discharges the air into the space in a swirling pattern at a medium face velocity (400fpm). Because of the swirling pattern, the diffuser does not form a persistent jet; rather the turbulence at the discharge causes rapid mixing with the room air and sheds momentum through smaller scale transient vortices. Typical air velocities measured 3 feet above the diffuser are less than 80 fpm (0.4 m/s). These jets do not persist into the occupied torso zone to disrupt the incipient thermal plumes rising from occupants and equipment, so that the desired thermal stratification is not disrupted.

Issue #5 DISTRIBUTION & DESIGN OF AIR DELIVERY SCHEME

Objective: Provision of a terminal and air delivery scheme throughout the occupied space, including near window walls that will maintain thermostat settings without disrupting naturally occurring temperature stratification.

The design issue discussed here is the provision of an effective perimeter terminal system to achieve temperature control and load tracking without disrupting stratification in the occupied region of a zone. In several projects, variable temperature airflow terminals with updraft slot diffusers at the base of the window wall have provided the requisite control and stratification. For example, New Dubai Airport use series flow fan-powered terminals at the perimeter zones that provide a constant volume variable temperature flow stream that responds to space mounted thermostats to control space temperature.

Issue #6 PREVENTING DIRT PROBLEMS

Objective: Prevent dirt being blown into indoor spaces

A common concern among occupants of buildings with UFAD systems is that dirt and spillage will more easily enter the underfloor plenum where it will mix with the air supply stream and be blown around the occupied space. Off-gassing from cabling, cement dust shed from the slab, debris and spills sifted down through the floor, and biological growth due to moisture are all other possible sources of pollution that could degrade the quality of the ventilation air before it even enters the space. Allowances for these ill effects need to be considered during design of the system. Few important design considerations must be noted:

1) The UFAD diffuser design must include catch basin design with traps that capture spills (for example from a typical soft drink spill) and can be easily cleaned as part of the regular maintenance schedule.

2) Slabs can be sealed to reduce dust and inhibit bacterial growth.

3) Floor panels can be manufactured and installed to close tolerances.

4) Except near the plenum inlets, air speeds within the underfloor plenum are so low that they do not entrain any dirt or other contaminants from the plenum surfaces into the supply air. Tests have shown that floor diffusers do not blow more dirt into the space than other air distribution systems.

Issue #7 FIRE PREVENTION & CONTROL

Objective: Prevent fire outbreak

The combustibility of access panels, floor coverings and cabling (power, data, and communication) contained in supply air plenums in UFAD systems is an important consideration. Fire-rated material will be required in almost all jurisdictions. Wires and cables in an air supply plenum should be non-combustible and/or contained in fire rated conduit.

The plenum size may also be limited by the fire code, so it may be necessary to partition the plenum into smaller subzones. Some fire codes limit the total area less than 3,000 ft^2 and horizontal dimension in one direction less than 30 ft of an unobstructed underfloor air supply plenum. It may also be necessary to install smoke detectors in the plenum.

Issue #8 CONTROLLING COSTS

Objective: UFAD must ensure higher rate of return on the life cycle basis

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.

It is a myth that the UFAD systems initial cost is more than the conventional HVAC system. Increases in first costs are almost completely attributable to the cost of the raised floor that is often charged to the underfloor air system despite the fact that the plenum also serves networking installation and modification cost savings. The fact is that the higher installation costs associated with the access floor can be offset by lower first costs in wiring and HVAC system costs, lower operations and maintenance costs, and higher occupant satisfaction. Finally, with flexibility and accessibility come the advantages of adaptability.

Compared to a building with a conventional HVAC system, a building with an underfloor air distribution system can be constructed at a competitive first cost and can operate at a considerably lower life cycle cost. The following parameters need to be noted while carrying out life cycle analysis:

- The structural components of the underfloor system typically cost about $6 to $8 per square foot. However, significant labor and capital savings result from the reduced cost of installing ductwork, supply fans, electrical service and data/communication services. These savings bring the net increase in first cost down to approximately $2 per square foot (based on 1999 costs).

- The elimination of hard-wired furniture and partitions, if these were being considered, can reduce the unit cost of a work station by as much as $1,500, further decreasing the building's first cost and possibly delivering first-cost net savings.*

- Access floors inherently reduce ongoing operating costs in spaces with a high churn rate, where people, furniture, and equipment are frequently moved to accommodate changing project or team requirements. Facilities managers can spend less time and money on renovations, since changes in wiring and HVAC services are simple and uncompromising. If cable or HVAC outlets are out of reach or inconveniently located, they are simply moved. Churn savings can range from $3 to $5 per square foot – a substantial amount considering the U.S. churn rate now averages 33 percent annually. Savings in space remodeling costs over the life of the system can easily pay for the incremental cost.

In retrofit projects however, the 5-20% increase in first costs for underfloor air systems are typically due to modifications required to ramp or rebuild elevator cores, fire stairs and bathrooms to the raised floor height. At present, there are only a few manufacturers offering UFAD products. With higher adoption of UFAD technology, the production volumes shall go up, further justifying the cost economics.

KEY CONSTRUCTION ISSUES

Underfloor air distribution (UFAD) systems require good coordination between all building trades throughout the design and construction process. Shown below are few recommendations for design and construction.

Access Floor Design

Access floor panels are available in four different materials: all steel; concrete; aluminum; or wood.

1) All-steel floor panels have a number of benefits. They are lightweight, which allows for ease of handling; they have a high load performance; and they are noncombustible.

2) Concrete floor panels are used in offices and equipment rooms. They have an excellent rolling load performance and the panels are solid and free from any floor- or plenum-generated noise. They also have excellent grounding and electrical continuity.

3) Aluminum panels, also known as “floating floors,” are used in clean rooms and other high-tech locations. These panels are unique in that they are perforated and have grates to provide optimum laminar airflow patterns in a downflow configuration, thus preventing particles from contaminating sensitive machinery and equipment in clean rooms. Floating floors contain no ferrous material to interfere with magnetic fields and are available in a wide selection of conductive, static-dissipative coverings or coatings.

4) Wood panels are available as a lower-cost option for offices and equipment rooms. They are durable, quiet, and economical, but building codes do not allow them to be used with underfloor supply systems because they are combustible.

Access floors can be finished in a number of different materials. In office environments, panels can be covered in carpet, conductive and static-dissipative vinyl, wood, or high pressure laminate (HPL). Recycled carpet and cork-finished tiles are also available as an environmentally responsible alternative to conventional materials. In clean rooms with floating floors, panels are finished in a variety of conductive and nonconductive coatings.

Maintenance of an access floor system is straightforward. Due to the modular nature of the system, carpet can be replaced as needed in high-wear areas simply by replacing the carpet on the affected sections. HVAC diffusers have a removable bucket trap that captures dirt and spills before they enter the underfloor space. These traps are emptied during normal janitorial service.

Pedestals are located under the corner of each panel. A pedestal consists of a base, tube, and head. The height of the pedestal determines the height of the floor and the depth of the underfloor space. The base is attached to the underlying concrete slab or steel deck by either mastic or mechanical fasteners. The head is attached to the corner of the panel using screws or a proprietary engineered fastening system. The pedestal heights are adjustable, allowing the installation of a laser-leveled floor system over a concrete slab that may contain irregularities or not be level. Once the access floor is installed and leveled, subsequent leveling of furniture, bookcases, and file cabinets is generally not required.

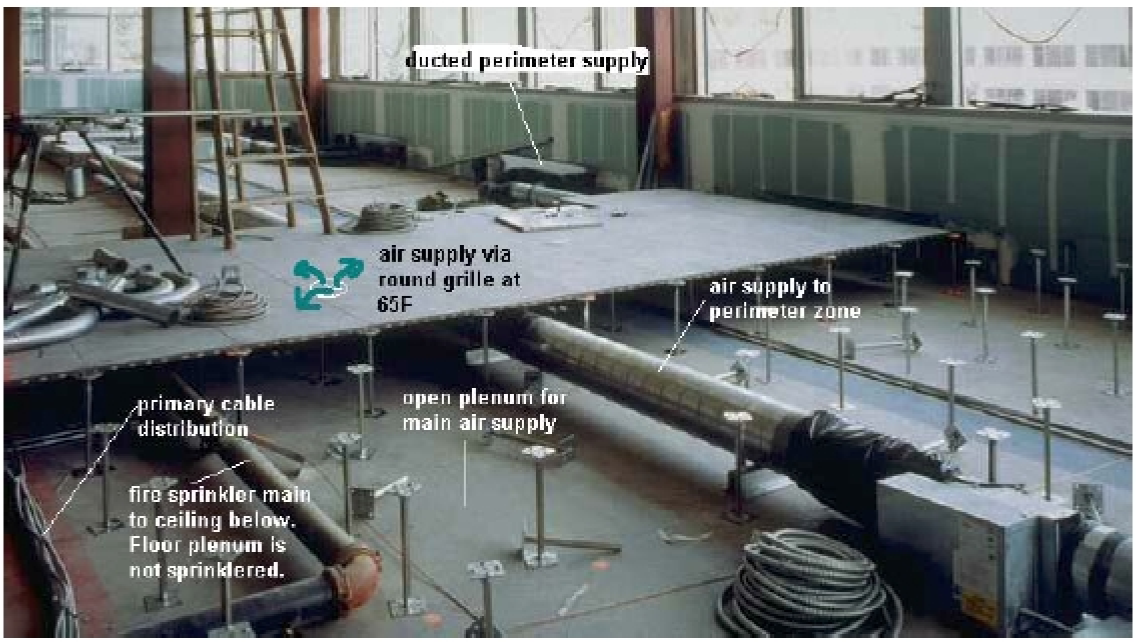
Wiring Systems

An access floor simplifies the installation of power, network, video, and phone wiring. The wiring systems run at floor level where they are needed, eliminating the necessity for power poles to bring cables from the ceiling down to floor level. Wire trays and cable support systems used above suspended ceiling systems are not required. Systems furniture and demountable walls are no longer required to carry electricity down from the ceiling, so they can be moved without bringing in an electrician. Access to the cabling systems and connection points is accomplished by simply lifting the appropriate floor panels.

A recent advance in cabling technology is the structured cabling system. This system integrates the various cabling needs—data, telephone, power, and building controls—into a set of packaged multifunction cables, complete with junction boxes and snap-in connectors. Data, telecom, standard and isolated ground power is brought to each workstation in a single, multifunction panel.

The systems can be extended while under load, maintaining productivity of adjacent workstations during office reconfiguration.

Locations of equipment should be coordinated with space plan for maintenance access



Other Standard Recommendations

1) To accommodate all underfloor service installation, determine the critical height of the access floor, which is typically 12 inches minimum for unducted plenum. Designers must consider additional spaces if fan powered units are required. The placement of the 2 ft x 2 ft raised floor pedestal grid is critical.

2) Use 18” x 18” size carpet tiles, which should be offset 50% over access floor tiles to support air tightness of the plenum.

3) Consider dead load allowance and seismic bracing of the access floor. For most office spaces, underfloor systems rated at 1000 or 1250 psi are sufficient. In areas with heavier traffic loads, such as loading docks, elevator entrances and corridors, underfloor strengths of 1500 psi are more appropriate. In environments with heavy equipment such as printing machinery and data centers, floor panels up to 2500 psi can be specified.

4) Lay out underfloor equipment requiring regular maintenance in accessible areas, such as corridors, not underneath furniture and partitions.

5) Seal all the surfaces (concrete slab) to reduce dust particularly in pressurized underfloor air distribution systems to prevent uncontrolled air leakage.

6) 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.

7) Determine areas in the building with no access floor and allow for transitions to areas with access flooring.

8) Make use of return airshafts usually around columns or other permanent building elements.

9) The floor panels should be screwed down or otherwise uses a stringer system, which is common in computer room applications. Typically, the panels with corner screws were designed for use without stringers in office applications (i.e., post support system). Structural integrity is provided by diagonal seismic bracing at regular intervals.

10) Use hard conduit for wiring from the central core to various distribution junction boxes (J-box); flexible conduit is used between the junction box and a similar one screwed to the floor panels in a workstation.

11) Telecom cables can be free run in the plenum and then pass through small holes drilled through the floor panels.

12) The largest dimension of system components (e.g., ducts) that can reasonably fit between underfloor pedestals is 22 inches. Where structural members/ducts cross the pedestal grid, metal bridging can be installed, spanning from one panel to another in place of a pedestal.

13) Consider the compatibility of anticipated building plan geometries with the following typical system component dimensions.

    - Raised access floor panel dimensions: 24 inch square
    - Underfloor plenum pedestal spacing: as for floor panels, e.g. 24 inch
    - Typical perimeter zone size (occupied area): 12–15 ft deep, from the external wall.

APPLICATION OF UFAD SYSTEMS

Buildings with high "churning rate": Any spaces that are designed with the "open office plan" are good candidates for underfloor air. As occupant loads are frequently added, subtracted, shuffled, and moved, the flexibility and accessibility of the underfloor system serve as a great financial benefit to the building owners and operators, saving time and money with each renovation.

Spaces with high ceilings: Spaces with high ceilings provide good energy-savings opportunities for designers of underfloor systems. Although 8 feet is considered to be the minimum ceiling height, a higher ceiling promotes the formation of a large vertical temperature gradient, producing the stratification layers that naturally induce warmer stale air to rise above the cooler fresh air.

Examples of high ceiling spaces where underfloor supply and displacement ventilation systems may be successfully implemented are theaters, courtrooms, lobbies, and industrial and manufacturing facilities.

Spaces with low sensible loads: Spaces with low sensible loads in the occupied zone also provide good opportunities for designers of underfloor systems because they inherently require less airflow and therefore pose less risk of a draft.

Energy efficient day-lit spaces: Energy-efficient day-lit spaces represent a good opportunity for underfloor supply systems since they often extend to the designer the advantages associated with both higher ceilings and lower loads. Light shelves and interior shading devices are generally located above the occupied zone. Solar heat gains intercepted by these features do not contribute to the occupied zone-cooling load. Energy-efficient buildings with well-insulated walls and high-performance glass have reduced cooling and heating requirements at the perimeter.

High heat density industrial and manufacturing facilities: Other good candidates for underfloor air systems are industrial and manufacturing facilities where heat-producing processes like soldering, brazing, welding, grinding, and machining can be served very effectively by a displacement system. Applications that may not work well with displacement ventilation are those in which the pollutant sources are heavier than air and not accompanied by heat. Some chemical and biological manufacturing or laboratory spaces, for example, may not lend themselves to successful implementation of displacement ventilation systems.

Flexibility with efficiency: In offices where cooling loads are high, the zonal mixing solution becomes more attractive than the zonal displacement system as it can achieve cooling loads up to and in excess of 100 Btu/sq-ft without undue draught, while offering the possibility for effective warm air heating in perimeter zones in winter and cooling in summer.

In summary, UFAD systems offer potential for initial capital savings, which may be achieved by lowering slab-to-slab heights, reducing cooling capacity requirements due to stratification, thermal inertia improvements, minimized ducting, and reduced construction schedules. The additional costs of the access floor system are partially offset by savings in wiring and HVAC installation costs. In buildings where frequent remodeling is required, savings in remodeling costs alone can easily pay for the system. Additionally an access floor system provides synergistic combination of routing building services such as power, voice and data wiring in the access floor peeving way for easy maintenance and better management of communication and data infrastructure. This integrated design solution provides the building owner a substantial return on investment over the life of the building.