CBI Climate
Underfloor Air System

UFAD

Underfloor air distribution system

Design guide

Version 1.0

Index

Introduction

Today an access floor responds to the need for flexibility and speed of implementation, indeed, once placed above the standard structural floor of the building it provide a service and utility space to run cabling (for voice, data and power) and piping. Consequently the underfloor space can also be used as supply plenum for air distribution, provided that the floor heights are normally between 30 cm and 45 cm, although lower height are possible. The air is diffused in the environments through diffusers placed on the floor, with different shapes (circular, rectangular or square) and with different finishes (aluminum, steel or plastic). Flow rate and head for air flow are ensured by air handling units that are also able to provide the necessary air replace. A system thus composed is called underfloor air distribution system (UFAD). The air handling units are provided of coils that allow heat exchange for both heating and cooling. The advantage of this type of conditioning system is that the thermal comfort increase because the air is diffused at a reasonable temperature and velocity in closer proximity to the building occupants. In any case, the great advantage of the Ufad system is its flexibility and re-configurability that allow at the system to be readjusted quickly and easily when change the needs for space use. For this reason the UFAD system is particularly suitable for offices, open spaces, meeting rooms, waiting rooms, libraries and other similar.

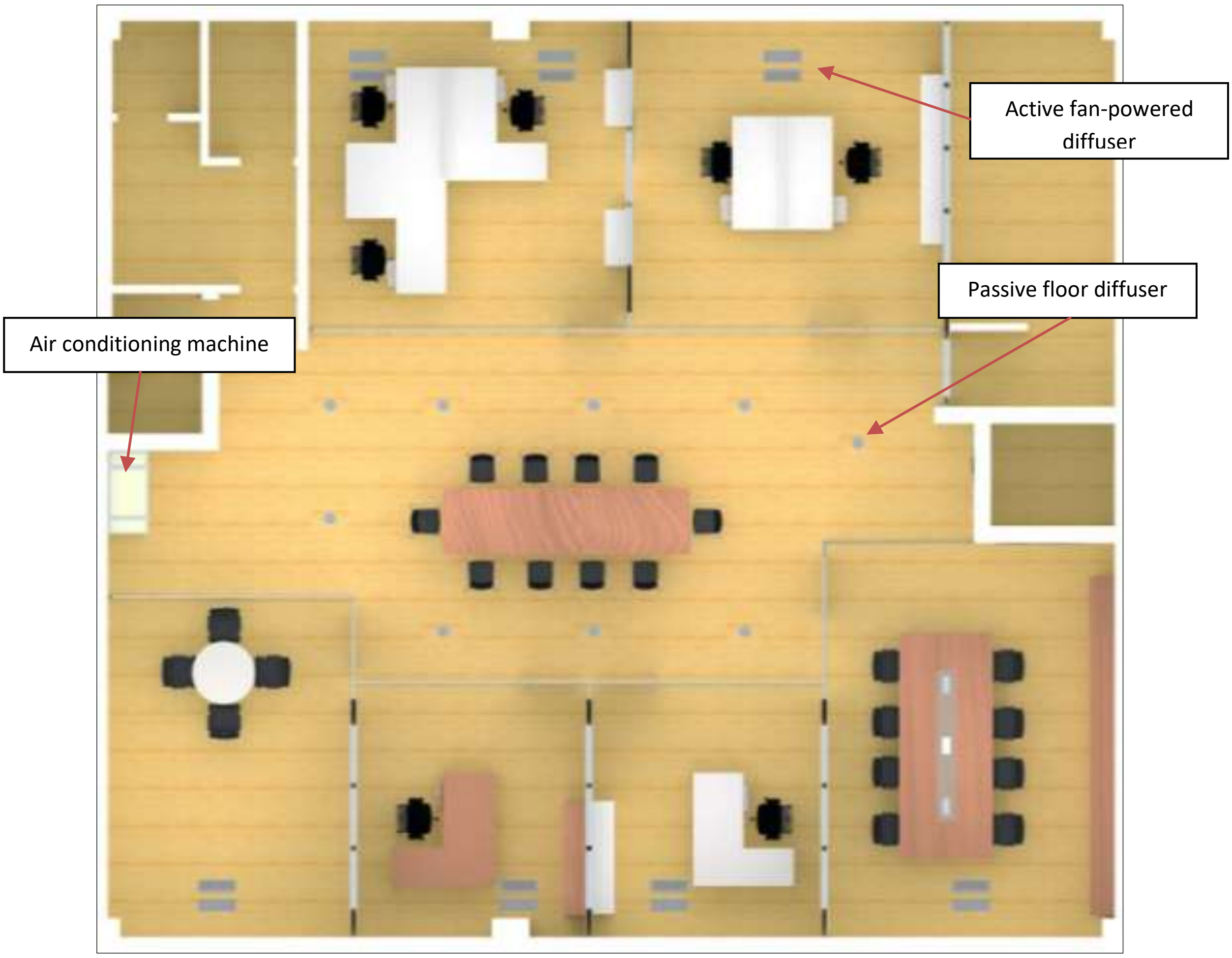

Figure 1 - Example of office with UFAD system. In the interior zone are placed passive floor diffusers, while into the office active fan-powered diffusers are placed to control the temperature singularly.

System description

The raised access floor

An access floor is a flooring system that is installed above the standard structural floor of the building. The system is composed by a steel structure and tiles, which can be made with a wooden or calcium sulphate core and various types of surface finishes (such as ceramic, solid wood, linoleum, antistatic pvc, static-dissipative, conductive pvc). We will reference CBI Europe S.p.a. access floor systems (www.cbi-europe.com). The steel structure consist of adjustable pedestals and stringers that links the pedestals among them. The adjustable pedestals must be placed according of a matrix 0,6 m x 0,6 m which support the weight of the access floor panels and the loads on the floor above. The floor panels are laid into this grid system. The structural floor is normally sealed to provide a moisture and dust barrier. The primary usage of the access floor systems is to provide a service and utility space to run cabling for voice, data and power. In some cases the access floor systems is used to run piping. In these cases the height of the access floor can be minimum 45 mm up to greater heights. When the underfloor space is to be used as supply plenum for air distribution floor heights are normally from 30 cm to 45 cm, although lower height are possible.

Figure 2 – Raised access floor

The raised access floors can be successfully applied to many type of buildings both new constructions and renovation. Particularly suitable for new construction, it allows to obtain an excellent result of integrated architectural design, where aesthetic finishes and plants are in perfect harmony to reduce the cost of the building, both during construction and maintenance. Very important to said is that using an access floor system such as plenum for air distribution the ceiling space could be reduced allowing a floor-to-floor height 0,3 m less than standard. This can be accomplished by either the use of open ceiling space with only lighting and sprinklers in the space, or by reducing the ceiling plenum space since large supply ducts are not required. The reduction in height would result in a reduction of overall building cost. Instead, when the access floor systems is used in retrofit situations a few special consideration are required, because the stairways, the elevator lobbies and the bathrooms which are built on the original structure floor need to be raised to the new floor level.

Underfloor air distribution

In a traditional underfloor air distribution system the floor space between the structural floor and the access floor is used as supply air plenum, while the return air is drawn from the plenum into the false ceilings.

The UFAD system make use of floor diffusers to discharge the air into the space with adequate velocity and air pattern to provide mixing only within the occupied zone. The system provides a more uniform temperature variation in the occupied zone to stay within the comfort envelope. Typically, in small and localized zones the occupants can control the perceived temperature of the local environment by adjusting the speed and directions, and in some cases the temperature of the incoming air supply. In this case we talk about task/ambient conditioning (TAC) system. TAC systems are distinguished from standard UFAD systems by their higher degree of personal comfort control provided by the localized supply outlets. To achieve this level of control are commonly used fan-driven (active) jet-type diffusers that are located in the space.

The plenum may be configured using one of the two approaches. The entire underfloor plenum can be pressurized to a relative low pressure of approximately 25 Pa or air discharged into the plenum at zero or neutral pressure and fans near the oulets draw he supply air from the plenum and discharge it to the space. In any case it is important to keep low the plenum pressure to avoid air leakage around floor tiles and plenum penetrations.

In the following figure are present and compare schematic diagrams of a conventional overhead system with a UFAD system, respectively, for a cooling application in an open-plan office building.

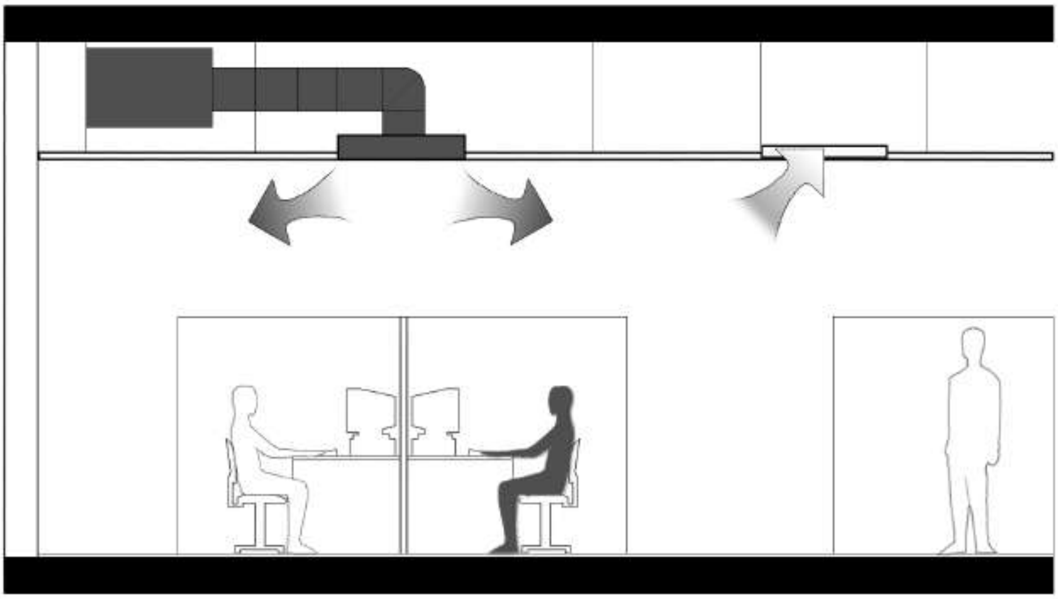

Figure 3 - Conventional overhead air distribution system

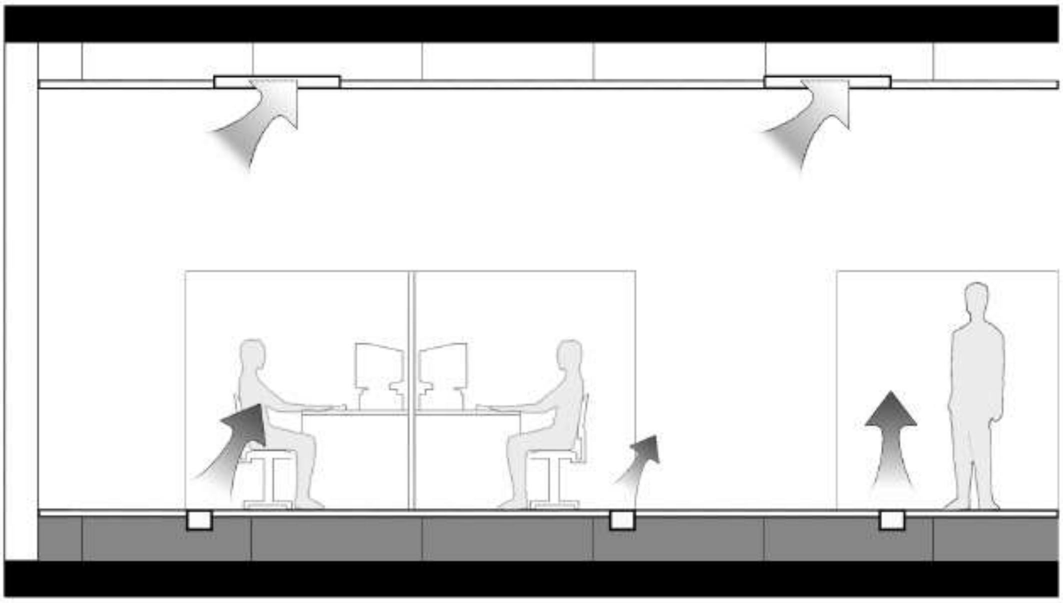

Figure 4 - Underfloor air distribution system

UFAD systems are the same as conventional overhead systems in terms of the types of equipment used at the cooling and heating plants and primary air-handling units (AHU). As show in Figure 4, all UFAD systems are configured to use an underfloor air supply plenum to deliver conditioned air directly into the occupied zone, typically through floor outlets. TAC systems use active diffusers such as floor-based diffusers. The major feature of a UFAD system, with or without TAC supply outlets, are described briefly below:

- Supply air containing at least the minimum volume of outside air is filtered and conditioned to the required temperature and humidity. It is than delivered by the air-handling unit (AHU) to an underfloor plenum, traveling through a shorter distance of ductwork than for ceiling-based systems.
- The underfloor plenum is formed by installation of a raised floor system, typically consisting of 0.6 m × 0.6 m calcium sulphate floor panels. Raised floors used with UFAD systems have typically been installed at heights 0.3–0.46 m above the concrete structural slab of the building, although lower heights are possible. The raised floor system also allows all power/voice/data cabling services to be conveniently distributed through the underfloor plenum. Savings associated with these services offset much of the initial cost of the raised floor system.
- When configuring an underfloor air supply plenum, there are three basic approaches: (1) pressurized plenum with a central air handler delivering air through the plenum and into the space through passive grilles/diffusers, modulated diffusers, and fan-powered terminal units, either used alone or in combination with one another; (2) zero-pressure plenum with air delivered into the conditioned space through local fan-powered (active) supply outlets in combination with the central air handler; and (3) in some cases, ducted air supply through the plenum to terminal devices and supply outlets. The use of pressurized underfloor plenums appears to be the focus of current practice, although zero-pressure plenums pose no risk of uncontrolled air leakage to the conditioned space, adjacent zones, or the outside.
- Within the plenum, air flows freely in direct contact with the thermally massive slab and floor panels and enters the workspace through diffusers at floor level or as part of the furniture or partitions. Because the air is supplied directly into the occupied zone, floor supply outlet temperatures should be maintained no lower than in the range of 16-18°C to avoid uncomfortably cool conditions for the nearby occupants.

- UFAD systems are generally configured to have a relatively larger number of smaller supply outlets, many in closer proximity to the building occupants, as opposed to the larger diffusers and spacing used in conventional overhead systems. Outlets that are located within workstations or otherwise near occupants at their work locations are typically adjustable or thermostatically controlled, providing an opportunity for adjacent individuals to at least have some amount of control over their perceived local thermal environment. Fan-driven TAC diffusers can more directly influence local thermal comfort by using increased air movement to provide occupant cooling.
- Air is returned from the room at ceiling level, or at the maximum allowable height above the occupied zone. This produces an overall floor-to-ceiling airflow pattern that takes advantage of the natural buoyancy produced by heat sources in the office and more efficiently removes heat loads and contaminants from the space, particularly for cooling applications. In contrast to the well-mixed room air conditions of the conventional overhead system, during cooling conditions, UFAD system operation can be optimized to promote some amount of stratification in the space, with elevated temperatures and higher levels of pollutants above head height where their effect on occupants is reduced.

Perimeter and interior zones

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 2,5 m or 3,5 m. 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.

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 envelop design is always the first stage of defense against excessive perimeter loads. 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.

Interior zones (defined as areas located further than 4,5 m 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. 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.

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.

Overview of products

According to the CBI Climate proposal for the UFAD system the following products are available.

Floor plenum

The space between the access floor and the structural floor is the floor plenum. Using this space as an air distribution plenum requires some special considerations. First the floor panel seams must provide a tight seal to prevent air leakage from the plenum into the space. In some cases ductwork is run through the space to special variable load areas and the space may need partitioning for life safety or thermal zoning. A typical underfloor plenum is between 30 cm and 45 cm in height.

Diffusers

Room air distribution is accomplished through one of two types of floor diffusers, round and rectangular. Interior spaces are controlled through a system of adjustable passive floor mounted diffusers. Each diffuser consists of an adjustable swirl plate located in a mounting basket and mounts through a hole cut in the floor panel. The basket catches any dirt or spilled liquids and prevents contamination of the space below the floor. The adjustable swirl plate allows the occupants to adjust their diffusers to a comfortable level in their space. The diffusers are design to achieve mixing of the approximately 18 °C supply air within a very tight radius of the diffuser and at very low velocity. Typical diffuser airflow is about 100 to 170 m^3/h per diffuser.

Figure 5 - Round diffuser

A second type of diffuser is used with underfloor mixing boxes and perimeter fan coil units. This rectangular grille is used to provide an air curtain washing exterior surfaces with warm or cold air. These grilles depend on much higher velocities and can be used in various lengths to match the airflow requirements of the mixing box or fan coil unit. Either a 0° or 15° deflection blade can be used to provide the required throw pattern. A version of the rectangular grilles can also be installed in a plenum that has a control damper to provide variable volume control to selected spaces. The rectangular grilles can also be used to allow return air from above the floor back down to the underfloor mixing boxes if desired. If used directly in the pressurized plenum, a standard balancing damper can be added to adjust airflow.

Figure 6 - Rectangular grille

Underfloor fan powered units

These units are designed to fit underfloor in the space between pedestals and the grids of the access floor system. CBI Climate propose two different types of products for cooling and heating, all with powered fan. Heating can be provided with either hot water coils or with electric heaters. One type is installed instead of a tile 0,6 x 0,6 m while the other type require more than one tile. In both cases the aesthetically visible part is the grid for the passage of air. They are used for perimeter spaces, conference rooms and other spaces with a highly variable load pattern. They typically use supply air from the floor plenum and increase the volume delivered to the room to meet the variable needs. There is also the possibility to have the return and the supply of the air in the same tile, with the possibility also to mix the air from the environment with the air from the plenum, in order to have a precise temperature control. The fan-coils can also be ducted to spread the air inside of linear diffuser placed at the perimeter of the building. In addition, the fan-coils can also be used with ducted primary air when that option is required to meet high thermal load requirements and to operate the necessary air changes.

Figure 7 - Fan coil for a tile 0,6 x 0,6 m with return and supply air on the top (Model ONE-IC)

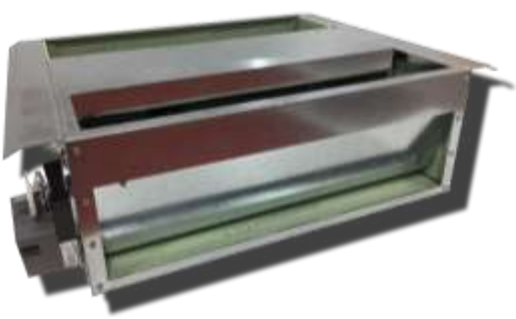

Figure 8 - Fan-coil with mixing air for the environment with the one from the underfloor plenum (Model ONE-B)

Figure 9 - Fan-coil for underfloor installation (Model VP)

Air conditioning machines

In order to diffuse high volumes of air into the underfloor plenum, CBI Climate has develop an Air Handling Unit able to treat the extract air and lead it to the desired temperature and humidity condition for the supply air. Five sizes, with air flow from 1.500 m3/h to 10.000 m3/h and thermal power from 9 kW to 55 kW, they are able to cover all system needs, from small to large spaces. Particularly suitable for the interior zone, can work in combination with fan-coils in perimeter areas and in confined offices.

A fan with variable speed control can be set to obtain the air flow and pressure conditions in the plenum defined by the project. Ventilation air is always provided. The low pressure ventilation allows to move large volumes of air with the use of low power. The machines are equipped with water coils which have excellent performance both in heating that in cooling. An optinal humidifier is used to increase the relative humidity in heating when required. In order to ensure correct recirculation of the air in the environment, the machines are equipped with filters (G4 or F7) to clean the air.

These machines allow to mix the air recovered with the environment with the primary air to ensure an high level of air quality. To obtain this, one or more machines can be connected through ducts to the air handling unit positioned outside the building.

Figure 10 - Air conditioning machine (Model EAM)

Heat recovery units

When closed environments are occupied by people is necessary to guarantee adequate air changes to maintain a good level of air quality. In general buildings of large sizes (such as offices, conference centers, waiting rooms, cinemas, etc.) have Air Handling Units placed outside that deal with primary air treatment and provide the necessary air changes. The air volume that must be changed is a function of the crowding of the rooms and refers to specific standards of the country of application. For the buildings of small and medium sizes CBI Climate has designed heat recovery units that are able to ensure the adequate air changes without the use of Air Handling Units placed outside the building. The unit is equipped with two fans, one for the exhaust air and one for the renewal air, which regulate the speed according to the air flow. The high efficiency air-air recuperator ensures high performance to avoid dispersing to outside the heat energy owned by exhausted air. The unit is equipped with a by-pass dumper that allow to work in free-cooling mode or in free-heating mode, particularly requested in spring and fall to decrease the consumption of thermal energy inside the building.

Figure 11 - Heat recovery unit in combination with the air conditioning unit (Model EAM-R)

Benefit of underfloor air systems

Underfloor air systems can be used both in new building that in retrofit situations but are not the answer to every building, can anyway represent significant life cycle cost saving when applied to the appropriate buildings.

Improved thermal comfort

UFAD systems allow individual occupants to control their local thermal environment, their individual comfort preferences can be accommodated. In today’s work environment, there can be significant variations in individual comfort preferences due to differences in clothing, activity level (metabolic rate), and individual preferences. The fan-driven supply outlets provide a personal control through adjustment in air speed and temperature, this allow a higher degree of perceived comfort. Passive diffusers (diffusers that do not rely on local fans), such as the commonly used swirl floor diffusers in UFAD systems, will not provide this same magnitude of control. However, by being accessible to the occupants, these diffusers can still be effective at influencing the perceived local comfort conditions.

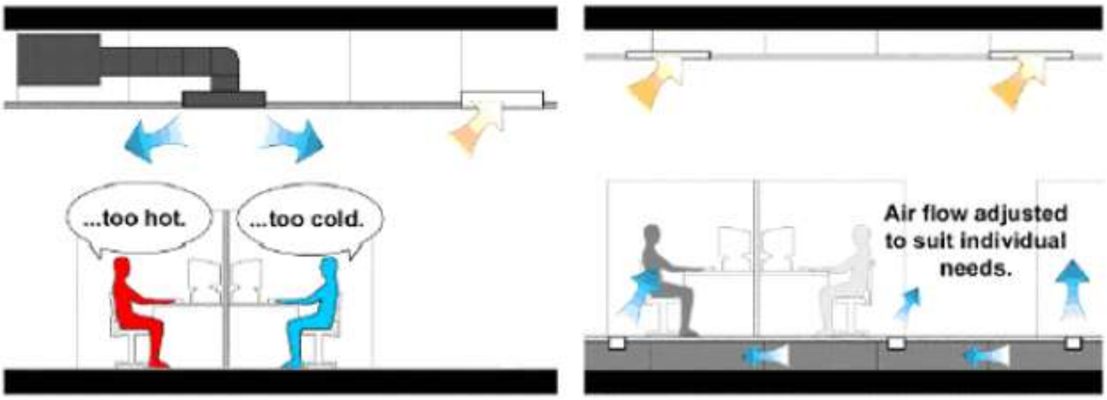

Figure 12 - Difference in thermal comfort between traditional and UFAD systems

Improved ventilation efficiency and indoor air quality

Some improvement in ventilation and indoor air quality at the breathing level can be expected by delivering the fresh supply air at floor level or near the occupant and returning at the ceiling, resulting in an upward displacement of indoor air and pollutant flow pattern. An optimized ventilation strategy is to control supply outlets to confine the mixing of supply air with room air to just below the standard respiration height (3-5 ft [0.9-1.5 m]) of the space. Above this height, stratified and more polluted air is allowed to occur. The air that the occupant breathes will have a lower concentration of contaminants compared to conventional uniformly mixed systems.

Reduced energy use

Energy savings for UFAD systems over conventional overhead systems are predominately associated with two major factors: (1) cooling energy savings from economizer operation and increased chiller COP and (2) fan energy savings. Economizer savings result from increased hours of full or partial economizer operation due to higher return air temperatures (25-30°C vs. 24°C for overhead systems) and the reduction in cooling energy required during economizer operation because of the use of higher supply air temperatures (16-18°C vs. 13°C for overhead systems). Chiller savings result from using higher chiller leaving water temperatures due to the higher supply air temperatures. Fan energy savings are associated with two factors: reduced total air volume and reduced static pressure requirements. The determination of air supply volumes required to maintain a given comfort condition are based on heat sources that enter and mix with air in the occupied zone. Static pressures are reduced due to the elimination of most branch ductwork, as the supply air flows freely through the underfloor plenum at low plenum pressures (typical pressures are 25 Pa or less). From a recent analysis of central fan energy use in UFAD systems, the average savings using a variable air-volume (VAV) control strategy over conventional VAV systems can be estimated to be about 40%. Due to the common practice of using fan-powered solutions in perimeter zones, the total fan energy savings may be significantly reduced when the energy use of these additional smaller fan units is considered.

Reduced Life-Cycle Building Costs

Based on the reduction in costs associated with office churn, UFAD systems may have better total life cycle costs. In addition, this energy efficient design will also increase the life cycle cost benefit and may make the system look more appealing.

Reduced floor-to-floor height in new construction

Buildings using UFAD have the potential to reduce floor-to-floor heights compared to projects with conventionally designed ceiling-based air distribution. This can be accomplished by reducing the overall height of service plenums and/or also possible to eliminate the ceiling plenum. However, this reduction must be evaluated based on the need for ceilings to hide light fixtures, piping for sprinklers, and to help improve room acoustics.

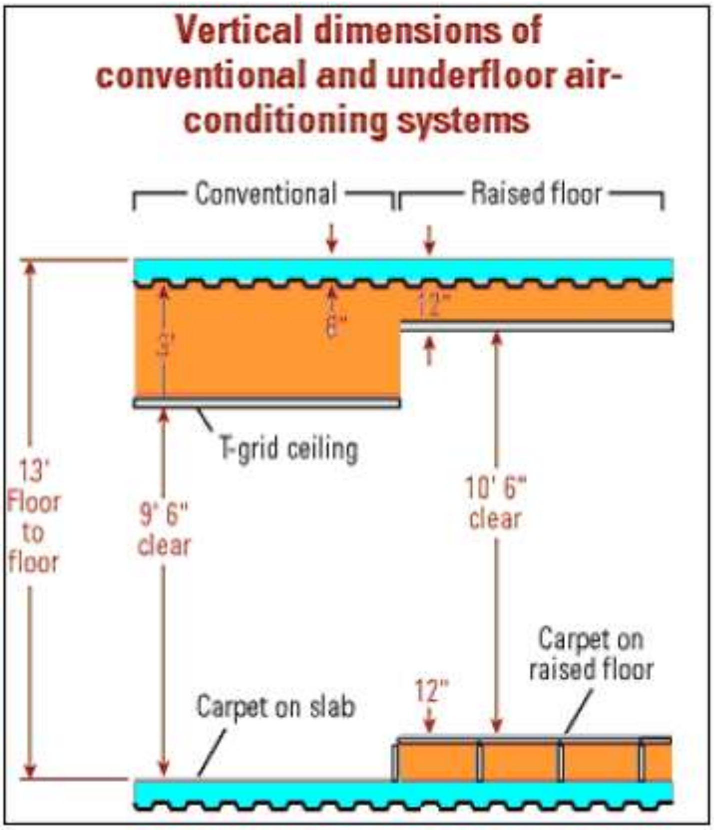

Figure 13 - Reduction floor-to-floor height

Increase 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. Reconfiguration of raised access 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 panels, office spaces can be reconfigured in a matter of hours instead of days or weeks.

Improved productivity and health

Research evidence suggests that occupant satisfaction and productivity can be increased by giving individuals greater control over their local environment and by improving the quality of indoor environments (thermal, acoustical, ventilation, and lighting). A review of relevant research has concluded that improvements in productivity in the range of 0.5% to 5% may be possible when the thermal and lighting indoor environmental quality is enhanced. These percentages, though small, have a life-cycle value approximating that of the capital and operating costs of an entire building!.

Problems of underfloor systems

Despite the advantage of UFAD systems, there exist some barriers (both real and perceived) to widespread adoption of this technology. Resistance to wider use has been driven by the perceived higher risk to designers and building owners primarily due to a lack of objective information and standardized design guidelines, perceived higher costs, limited applicability to retrofit construction, problems with applicable standards and codes, and a lack of well-documented case studies with whole-building performance and cost-savings data.

New and unfamiliar technology

For the majority of building owners, developers, facility managers, architects, engineers, and equipment manufacturers, UFAD systems still represent a relatively 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. As UFAD technology continues to grow, these problems should become less prevalent.

Perceived higher costs

The perceived higher cost is one of the main reasons why UFAD technology has been slow to be adopted by the U.S. building industry. As discussed above, this situation is now changing due to significant savings in life-cycle costs. In general, the added first cost of the access floor may be offset by cost reductions associated with decreased ductwork and cable and wire installation. Projects are frequently “sold” on the basis that UFAD is an add-on after the choice is already made to install access flooring for its cable management and reconfiguring benefits for high churn businesses. Considered in this light, the first cost of a UFAD system is commonly less than a conventional system. This technology is still in the early stages of adoption and certainly will see cost reductions as volumes increase and more UFAD-specific products become available.

Cold feet and draft discomfort

UFAD 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. Typical underfloor supply air temperatures are no lower than 16°C and usually higher except under peak load conditions. Nearly all office installations are carpeted so that cold floors should not be a problem. Individually controlled supply diffusers allow occupants to adjust the local airflow to match their personal preferences and avoid undesirable drafts.

Condensation problems and dehumidification in UFAD systems

In humid climates, outside air must be properly dehumidified before delivering supply air to the underfloor plenum where condensation may occur on cool structural slab surfaces. While humidity control of this sort is not difficult, given the large surface area of the structural slab in the underfloor plenum, it is important that it be done correctly. If a higher cooling coil temperature is used (allowing an increased chiller efficiency) to produce the warmer supply air temperatures needed in UFAD systems, the cooling coil's capacity to dehumidify will be reduced. In humid climates, 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 (16-18°C). In this situation other system design considerations will dictate whether a conventional cooling coil temperature (producing a coil leaving temperature of 12.8°C) or a colder one (e.g., from ice storage) is used.

Perception of dusty system

When it comes to the UFAD system, it is thought that this brings a lot of dust into motion, but this is only a belief that has not been reflected in practice. First of all the structural floor must be treated with anti-dust paints to avoid that an excessive quantity of dust is formed. Then the air speed is low, and this prevents the dust from entering the environment. The dust that falls from the floor inside the diffusers remains on the bottom of the diffuser basket. A simple periodic suction of the dust deposited on the bottom of the diffusers allows to avoid any problem related to the diffusion of dust.

Design consideration

General layout

When beginning the layout of a UFAD system it is best to think of it as an upside down conventional overhead system, with the following similarities and differences:

- Central cooling and heating equipment, as well as ductwork mains and branches to zone mixing terminals, can be nearly identical to traditional overhead systems;
- UFAD systems use diffusers in the access floor, much closer to the occupants, so special care needs to be exercised in their layout. Since it is a non-ducted system, simply swapping floor panels can make relocations easy;
- UFAD systems work best with uniformly loaded thermal areas. In high-load and variable-loaded zones, it can be strengthened by using active diffusers with a fan and a water or electric battery. This creates an overall hybrid system which allows you to get the best performance

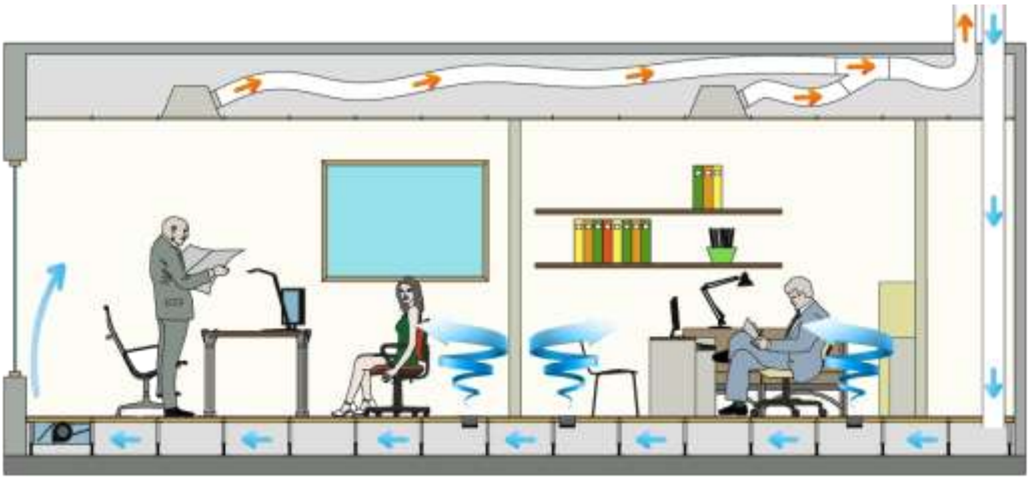

Figure 14 - UFAD system with treated air from a central Air Handling Unit, floor diffusers in the internal zone and fan-coil in the perimeter

Figure 15 – UFAD system with treated air from an Air Handling Unit with partial renew of the air, floor diffusers in the internal zone and fan-coil in the perimeter

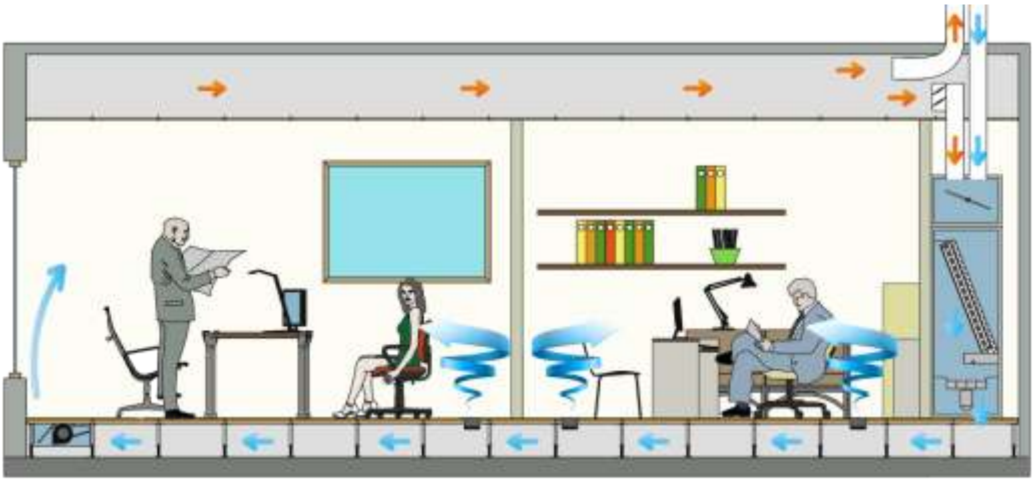

Figure 16 - UFAD system with treated air from an Air Handling Unit with partial renew of air and ceiling plenum no-ducted, floor diffusers in the internal zone and fan-coil in the perimeter

Figure 17 - UFAD system with treated air from an Air Handling Unit with ducted air recovery, floor diffusers in the internal zone and fan-coil in the perimeter

Supply air temperature

The supply air temperature for UFAD system are higher than that used for conventional overhead system design. Because the air is supplied directly into the occupied zone, warmer supply air temperature prevent overcooling to nearby occupants. For cooling applications, supply air temperature at the diffusers should be maintained no lower than in the range of 17 °C – 20 °C with a recommended minimum ceiling height of 2,5 m. 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 3 °C is considered excessive. A gradient of 2 °C is considered to be a good design criterion, not too large by most people's standards.

Table 1 – Supply air temperature

System Type	Supply Air Temperature	Return Air Temperature
UFAD System	17 – 20 °C	25 – 30 °C
Overhead Systems	13 °C	24 °C

Type diffusers

In UFAD system there are two basic types of diffusers to choose from: passive and active. Passive diffusers are used in pressurized plenum systems while active diffusers are used in neutral pressure or fan-powered pressurized plenum systems. There are three basic styles of diffusers, swirl, VAV floor grille and linear bar grille. Passive diffusers are able to move required air quantities at low plenum pressures (12,5 to 25 Pa) and have very low noise generation values, usually under NC20. In fact, a white noise generation system within the plenum is often recommended for proper acoustic privacy in open office situations.

Table 2 - Type diffusers

Diffuser Type	Diffuser Style	Uniform loading	Variable loading
Passive	Swirl	Core – open areas & offices Perimeter – open areas	Base loading
	Floor grilles	Large equip. loads, few people	Base loading
Active (fan-powered)	Swirl	Not recommended	Not recommended
	Linear Bar or Floor grilles	Spaces with tighter temperature tolerances	Conference rooms, Perimeter

Passive type diffusers can be easily rearranged by just moving floor panels; active types require moving fan units, power and control wiring and potentially ductwork. Active diffusers are found more often in TAC designs and as part of hybrid solutions to satisfy heavy and/or widely variable loaded spaces. UFAD diffusers should not be used where liquid spillage potential is high, even though they have a catch basin for incidental spills, and they should not be placed in traffic areas where high rolling loads are expected.

Room air distribution

When a UFAD system is used, room air distribution occurs within the occupied zone (up to 1,8 m above finished floor), making this area a critical design element. Designs can be either CAV (constant air volume) or VAV (variable air volume), or as is more often the case, a hybrid using some of both to satisfy the varying room requirements. CAV systems usually vary the temperature of the supply air to meet the space temperature set point, while VAV systems provide constant temperature and vary the quantity of air supplied to the zone. These concepts are not as clear-cut as with overhead systems because UFAD allows the occupants to easily adjust the diffusers of either system to affect airflow volume and even pattern or direction in some instances.

Dimensional constraints of the plenum

Experimental tests have shown that the minimum height possible for an air distribution plenum is 100 mm, but the air speed must be kept very low, not more than 0.005 m/s. For homogeneous distributions of the air in the plenum it is necessary that the height varies between 30 and 45 cm. Lower heights are possible but the limits in the air flow must be evaluated and the distribution surface reduced.

The maximum practical distance between the point where conditioned air is injected into the open underfloor plenum and its point of discharge into the space is generally determined by:

1. The degree of thermal decay experienced by the air as it moves to the supply outlet.
2. The residence time of the conditioned air within the open floor cavity.

While resident within the underfloor plenum, the conditioned air is subject to heat transfer from the building slab, as well as the room (by means of the raised floor panels). This thermal transfer rate generally limits the distance through which the conditioned air may travel according to its maximum allowable temperature rise. Designers familiar with underfloor system design typically employ as a guideline a 0.1-0.3 °C temperature gain per linear meter of travel, resulting in a maximum practical distance of 15-18 m between the plenum inlet and point of discharge into the space.

Horizontal ductwork and air highways may be used to bridge the distance between the point of injection into the plenum and the farthest supply outlet. If employed, the velocities in these conduits should be limited to a maximum of 6-7.5 m/s. Outlets can be located along the length of the duct (or air highway) to optimally allocate the air within the plenum.

The discharge velocity through these smaller outlets should, however, be limited to 4-5 m/s. The placement of balancing dampers in these discharge outlets should also be considered to avoid variances in the plenum distribution.

Return air configuration

For optimal cooling, it is important to locate return grills above the occupied zone, which is around 1,8 m 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:

- <u>Return air mixed with primary air in AHU</u>: 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 coil leaving temperature of 12 °C). 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 (17 – 20 °C).

- Return air is routed directly to the underfloor 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 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 conditioning 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 return air.

Air leakage

While air leakage is not an issue for zero-pressure plenum designs, evidence from completed projects using pressurized plenums indicates that uncontrolled air leakage from the plenum can impair system performance. If this leakage occurs across the building envelope it will directly impact energy use. If the leakage occurs within the building it may or may not impact energy use depending on where the leakage takes place. In any case, it is highly recommended to minimize leakage from the plenum and, when it is unavoidable, to account for the leakage airflow rate in the operation of the system.

There are two primary types of uncontrolled air leakage from a pressurized underfloor plenum: (1) leakage due to poor sealing or construction quality of the plenum and (2) leakage between floor panels. A third type of leakage occurs when floor panels are removed for access to the plenum, but this is usually temporary.

Leakage Due to Construction Quality

It is important that proper attention be given to the sealing of edge details all around the underfloor plenum, including window-wall connections to the slab, interior walls, along pipe chases, stair landings, elevators, and HVAC shaft walls during the construction phase of the project. Even if this is done, the integrity of a "well-sealed" underfloor plenum must be preserved over the lifetime of the building, as subsequent work can easily lead to new penetrations. If this is not done carefully, these types of leaks will be the most difficult to locate and fix later in the project. In most cases, designers can expect to encounter leakage losses of 10% to 30%, depending on quality of construction.

Leakage Between Floor Panels

Leakage between floor panels, as depicted in Figure 18, is a function of the raised floor panel type and installation, carpet tile installation, and pressure difference across the plenum. Despite the relatively low pressures (12.5 - 25 Pa) used in pressurized plenums, the large floor surface area makes this leakage an important consideration for design and operation.

Table 3 lists air leakage data from recent tests conducted on a typical raised floor installation. Results represent the leakage through gaps between floor panels only, as all other gaps in the plenum were sealed during the tests. Measured data are shown for a plenum pressure of 12.5 Pa and for three different modes of floor covering: none (bare floor panels), aligned carpet tiles, and offset carpet tiles. No adhesive was used to install the carpet tiles during these tests so reported leakage values will be slightly conservative. As shown in Figure 19, aligned carpet tiles occur when the size and edges of the carpet tile match those of the floor panel (0.6 m × 0.6 m). Offset carpet tiles occur when the carpet tile is shifted over so that the edges are not aligned. The floor panels tested represent a design that is known to have the lowest leakage of most commercially available models. Experiments have shown that air leakage will vary approximately as the square root of plenum pressure. Based on this relationship, the air leakage values for a plenum pressure of 25 Pa can be estimated and are listed in Table 3.

Table 3 - Air Leakage Through Gaps Between Floor Panels [L/(s*m^2)

Plenum Pressure [Pa]	Carpet Tile Configuration		
	None	Aligned	Offset
12,5	3,5	1,5	0,7
25	4,9	2,1	1,0

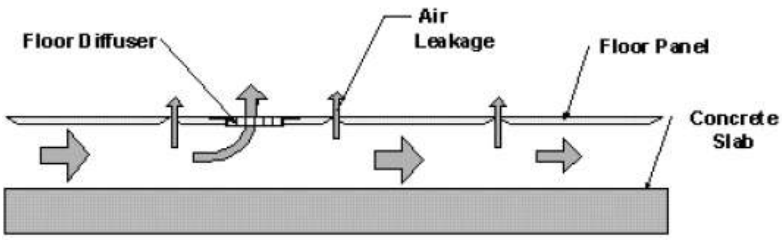

Figure 18 - Airflow and leakage in a pressurized underfloor air supply plenum

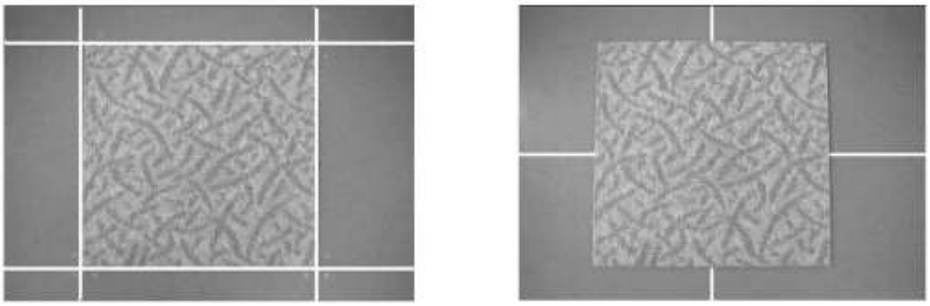

Figure 19 - Two different modes of carpet tile installation on raised floor panels: aligned (left) and offset (right). White lines indicate the floor panel edges.

The magnitude of air leakage from a pressurized plenum shown in Table 3 is surprisingly high. The results indicate that the layer of carpeting plays an important role by significantly reducing air leakage rates between floor panels. The performance of a UFAD system with bare floor panels would be severely compromised if no additional means of sealing between panels were installed. Placing carpet tiles across the gaps between floor panels (offset mode) reduces the air leakage rate by 50% compared to aligned carpet tiles. Even with carpeting in place, the results suggest that minimizing leakage from other parts of the underfloor plenum should have a high priority.

Control systems

UFAD systems rely on proper design and operation of the controls like any other system. Listed below are concepts and concerns that, if incorporated into the design, will result in maintaining the stratification layer and its many benefits:

- Most UFAD systems use pressurized plenums and CAV passive diffusers, requiring some type of pressurization control on either the zone mixing box or central equipment.
- Zone control with CAV diffusers requires adjustment of the supply air temperature at the air terminal. This is best accomplished using fan-coil connected to the zone ceiling plenum return air that mixes with the primary air.

- Resetting Supply Air Temperature up under light loads allows additional hours of outdoor air economizer cooling, especially in drier climates.
- Nighttime pre-cooling, done correctly to avoid potential condensation on the plenum surfaces, can offset or delay thermal decay of the zone SAT.
- Thermostat mounting heights are often being set lower because of ADA (Americans with Disabilities Act), from 1,2 to 1,4 m the access floor. This is actually a benefit because if mounted too high the thermostat would be sensing the higher temperatures near the stratification layer, requiring adjusting the set point upwards to compensate.
- Systems, which use fan-coil to control the zone primary airflow for ventilation requirements, can use a control on the fan speed to reduce primary airflow in lower occupancy periods resulting in additional energy savings.
- Control requirements of ASHRAE Standard 90.1 should be adhered to. Including setback requirements and optimum start requirements.

Temperature Control Strategy

In UFAD systems control strategies are similar to the overhead system, in particular for the Temperature Control strategy:

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.

Constant Pressure Control Strategy

A common control method for interior zones maintains constant static pressure in the underfloor plenum to ensure constant volume airflow from each diffuser (similar model and setting). Plenum pressure is maintained by adjusting fan capacity at the air handler. Occupants can make minor changes to local comfort conditions by manually adjusting a diffuser, but such adjustments are viewed as setup adjustments, not operating adjustments. As long as load variations in the zone due to diversity and other occupancy changes are small, and the net impact on plenum pressure by occupant diffuser adjustments is minimal, this strategy results in very nearly a constant-air-volume (CAV) operation and can maintain acceptably comfortable space conditions. In this configuration, one strategy for controlling supply air temperature that has been applied successfully in practice is to use measured return air temperature as a means of maintaining stratification at the desired level.

However, even with proper design that promotes stratification at peak conditions, CAV operation can result in a changing environment in the occupied region as load changes. In CAV spaces, constant supply air temperature with decreasing load causes the space temperature profile to shift toward cooler temperatures and become less stratified. In this case, the average occupied zone temperature tends to be a few degrees cooler than the peak load thermostat temperature. Thus, supply air temperature (SAT) reset is recommended. However, the system response time during SAT reset can be significant due to the important impact of the temperature of the thermally massive concrete slab on supply air temperatures. CAV systems become progressively more over-aired as loads decrease from peak conditions, eventually virtually eliminating stratification. If the system is over-designed in the first place, stratification is likely never to be experienced in actual operation, which may explain why many projects in operation today report lack of stratification.

Many projects use CAV systems for large interior zones where the perimeter zones are served by supply air passing through the plenum of the interior zone. If these interior systems were conservatively sized compared to actual loads and zone airflow is not properly adjusted during system balancing, then the zone will be over-aired. Air leakage from pressurized plenums plus the additional heat loss through the floor surface can provide a substantial portion of the required cooling under part-load conditions. If part-load conditions or over-airing in the interior lead to a significant increase in the SAT, this may compromise the system's ability to accommodate peak perimeter cooling loads, if they occur simultaneously. In CAV systems, interior zone airflows should be well matched to actual loads; active and robust control of SAT should be employed without starving the perimeter.

Individual Control Strategy

A very important aspect for an UFAD system is the personal comfort that can be assured to the occupants of the environment. In particular, Individual Control Strategy:

- The ability to easily relocate diffusers is critical to churn/reconfiguration cost saving and all systems should be coordinated to make this possible (carpet, outlets, diffusers…). 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.
- Fan controls are required for conference rooms, and possibility additional water based cooling (fan-coil) controls.
- Directional control is a benefit for higher velocity and non-swirl diffusers where supply air streams of 18 °C could be uncomfortable on the lower body.
- Replacing pressurized buildings with the natural stratification of conditioned air, (rising from an underfloor air system to a ceiling return) allows for local opening for windows without compromising ventilation effectiveness. Due to temperature stratification that naturally occurs with acceptable comfort conditions in the occupied zone.
- 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 temperature 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 extend the hours of economizer operation.

LEED points

There is a nationwide trend toward constructing buildings that are more environmentally friendly to meet green building or sustainable design construction standards. The LEED (Leadership in Energy and Environmental Design) standards are a voluntary rating system that rates the building design on its environmental impact on the community, the site, the water efficiency, the energy efficiency and the indoor environmental quality for the occupants. This standard sets green building objectives in 5 categories that offer a total of 32 credits, from which a design can accumulate up to 69 points. The rating system is based on the number of points awarded and goes from a certified level at 29 to platinum level at 52. Some prerequisite requirements are required, but other than that, the points may come from any of the 5 categories. HVAC related systems account for 40% of the possible points. The points are based on the entire building as a system. No particular product or system is certified by the program but rather the building in which they are used. Underfloor air systems have potential in at least seven areas, primarily within the environmental and indoor air quality areas. The largest points area in the program is optimizing energy performance. This credit varies from 1 point for exceeding ASHRAE 90.1 energy cost budget (ECB) model by 15%, up to 10 points for a 60% reduction. In most UFAD projects the analysis would involve using the ASHRAE energy cost budget to compare the underfloor system to the energy costs of a VAV reheat system.

UFAD systems may have a distinct advantage in this area since they incorporate many potential energy saving features. Lower fan static requirements as the result of low plenum pressure distribution will reduce required fan energy. Mechanical cooling requirements and hence equipment size and part load efficiency may be improved due to the use of higher discharge temperatures. Economizer usage may be extended to get more free cooling hours and help reduce part load energy requirements. In general, UFAD systems have the potential to show significant energy savings over the required base system used in the energy budget model. The UFAD system may also qualify for points under the material and resources category. Within this category 3 points can be earned for building reuse. If the project involves an existing building, the percentage of building shell reuse would help obtain these credits. UFAD systems lend themselves very well to certain retrofit situations where the building is being renovated to meet the requirements of new technology without destroying the current building structure. UFAD gives the architect a range of options to achieve these goals.

Looking at the Indoor Environmental Quality category, UFAD systems have the potential to qualify for points in 3 areas. This is the area where many of the existing certified projects have relied on points from UFAD systems. The first is the area of ventilation effectiveness. UFAD systems are not rated by ASHRAE as having any advantage in ventilation effectiveness as we noted earlier. However, in the current LEED documentation, it is implied to have ventilation effectiveness greater than one. As a result, the use of UFAD systems may be a qualifying point. The second area addresses system controllability, where the LEED requirement is for interior zones to provide individual control to at least 50% of the occupants. Since UFAD diffuser provides individual control inherently, the system again is nearly an automatic qualification for this point. The third area relates to thermal comfort. Since UFAD systems have been shown to provide a high degree of personal comfort with space control parameters that fall within the guidelines of the ASHRAE standard 55 comfort envelope, the system can qualify for this credit as well.

UFAD has shown itself to be an excellent system to consider on projects seeking LEED certification. Remember, however, that certification is based on the total building system and the points and overall rating for a specific project are dependent on the design of that project.

Conclusion

In summary, UFAD systems offer potential for initial capital saving, 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 saving in wiring and HVAC installation costs. In building where frequent remodeling is required, saving in remodeling cost 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.

CBI Climate Underfloor Air System

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